SANITARY ENGINEERING;

SEWERAGE.

SANITARY ENGINEERING

A GUIDE

TO THE CONSTRUCTION OF

WORKS OF SEWERAGE

AND

HOUSE DRAINAGE

WITH

TABLES FOR FACILITATING THE CALCULATIONS OF THE ENGINEER.

BY

BALDWIN LATHAM, C.E., M. INST. C.E., F.G.S., F.M.S.,

PAST PRESIDENT OF THE SOCIETY OF ENGINEERS, &C.

SECOND EDITION.

LONDON:
E. & F. N. SPON, 46, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
1878.

PREFACE.

FIRST EDITION.

It should now be well known that the preservation of life and health is in a great measure dependent on the faithful prosecution of sanitary works. On this account the information contained in this volume is made public, for, important as the study of Sanitary Science may appear, nevertheless, up to the present time, no work has been published which treats entirely on subjects relating to sanitary engineering. The literature of sanitary engineers is, for the most part, spread over a vast number of Parliamentary papers. The present volume, treating entirely of works of Sewerage and House Drainage, is offered as an instalment, to be followed by other volumes, so as to complete the whole range of the works in which the Sanitary Engineer is engaged. In compiling this volume, the author has not confined himself to examples taken exclusively from his own practice, but has given examples and opinions of other professional men, who are labouring in the same field with him, in prosecuting works for the welfare of humanity. The Author is conscious that many imperfections exist in this volume, but his great anxiety has been to make the information it contains public as speedily as possible, and his excuse for not having presented it in better form must be that it has been hurriedly compiled in the moments of leisure snatched from active professional pursuits.

B. L.

7, Westminster Chambers,
London, S.W., *April*, 1873.

PREFACE.

SECOND EDITION.

It is gratifying to the Author to find that there has been so great a demand for the first edition of this work; which demand he takes to be the best evidence of the necessity which existed for a practical work devoted exclusively to the study of questions relating to the construction of sewers and their appendages.

The encouragement offered to the Author by the great demand and speedy disposal of the first edition of this work has induced him to endeavour to still further enhance the value and extend the usefulness of the present publication. The former edition has been completely revised, a large portion has been re-written, and very considerable and important additions have been made; while matters of doubtful character, which appeared in the former edition, have either been omitted or more completely elucidated in the present work.

The work now presented will bring to the attention of the reader information of the most recent date of what is known in that field devoted to the prosecution of Sanitary Engineering, so far as affects works of sewerage.

Many recent inventions relating to the construction of sewers or drains, and which merit notice, will be found described in the following pages.

The Tables, which formed an important feature in the last edition, have been very considerably extended, and a number of additional Tables have been supplied in the present work, which it is hoped will add to its intrinsic value by rendering it more useful to those who may have occasion to consult its pages.

The plates and woodcuts in the present volume have been very materially increased, and, by clearly elucidating recent improvements in the construction of sewerage works, will still further add to the value of the present book.

The Author is conscious that, even in this amended work, some imperfections may exist, and that in all probability he has omitted to notice apparatus or arrangements which may be of great value, but which have either escaped his notice or have not been brought to his attention.

It is hoped by the Author that this work will help to place the practice of the Sanitary Engineer upon a more firm and sure foundation, and that, by rightly aiding the practice of the laws of nature, it will confer lasting benefits on all who may consult and act on the advice given in its pages.

B. L.

7, Westminster Chambers,
London, S.W., *July*, 1878.

TABLE OF CONTENTS.

CHAPTER I.

INTRODUCTION. NECESSITY OF SANITARY MEASURES.

CHAPTER II.

HISTORICAL NOTES.

CHAPTER III.

VARIOUS PLANS PROPOSED IN CARRYING OUT SANITARY WORKS.

CHAPTER IV.

WORKS OF SEWERAGE.

CHAPTER V.

AREA AND PLANS OF THE DISTRICT TO BE SEWERED.

CHAPTER VI.

RAINFALL AND SEWERS.

CHAPTER VII.

GEOLOGICAL CHARACTER AND PHYSICAL OUTLINE OF DISTRICT.

CHAPTER VIII.

POPULATION.

CHAPTER IX.

WATER SUPPLY OF A DISTRICT.

CHAPTER X.

SANITARY APPLIANCES OF DISTRICT.

CHAPTER XI.

POSITION OF OUTFALL AND MODE OF DISPOSING OF THE SEWAGE.

CHAPTER XII.

SELF-CLEANSING SEWERS AND VELOCITIES OF FLOW.

CHAPTER XIII.

DISCHARGE OF SEWERS.

CHAPTER XIV.

GAUGING.

CHAPTER XV.

COURSE OF SEWERS.

CHAPTER XVI.

INTERCEPTING SEWERS.

CHAPTER XVII.

SECTIONAL FORM OF SEWERS.

CHAPTER XVIII.

MATERIALS EMPLOYED IN THE CONSTRUCTION OF SEWERS AND THEIR MODE OF APPLICATION.

CHAPTER XIX.

BRICK SEWERS.

PAGES

CHAPTER XX.

CONCRETE SEWERS.

CHAPTER XXI.

CEMENT AND MORTAR.

CHAPTER XXII.

SAND AND WATER.

CHAPTER XXIII.

TIMBER.

CHAPTER XXIV.

IRON AND OTHER METALS.

CHAPTER XXV.

FOUNDATIONS FOR SEWERS.

CHAPTER XXVI.

JUNCTIONS WITH SEWERS.

CHAPTER XXVII.

FLUSHING ARRANGEMENTS OF SEWERS.

CHAPTER XXVIII.

VENTILATION OF SEWERS AND DRAINS.

CHAPTER XXIX.

MANHOLES AND LAMPHOLES.

CHAPTER XXX.

GULLIES AND TRAPS.

CHAPTER XXXI.

SEA OUTFALLS.

CHAPTER XXXII.

TIDE VALVES.

CHAPTER XXXIII.

PENSTOCKS.

CHAPTER XXXIV.

TANK SEWERS AND SEWAGE RESERVOIRS.

CHAPTER XXXV.

INVERTED SYPHONS.

CHAPTER XXXVI.

SUBSOIL DRAINAGE OF THE SITES OF TOWNS.

CHAPTER XXXVII.

HOUSE DRAINAGE.

CHAPTER XXXVIII.

WATER-CLOSETS.

CHAPTER XXXIX.

URINALS.

CHAPTER XL.

TOOLS USED IN CLEANSING SEWERS.

CHAPTER XLI.

REPAYMENT OF LOANS.

INDEX TO THE PLATES.

INDEX TO WOODCUTS.

INDEX TO TABLES.

SANITARY ENGINEERING.

CHAPTER I.

INTRODUCTION.

Life and health are, in a great measure, dependent upon rightly understanding and practising those laws which constitute sanitary science.

Pure air, pure water, and nutritious food, are the three great agents for promoting life and health. Any one of these once used, or combining with matter of a deleterious character, loses its vital property, and becomes, as it were, poison, unfit again to fulfil its sanitary mission, until it has been exposed to those revivifying influences which will restore its vital energy.

Agents promoting life and health.

Use of agents destroys their vitality.

Atmospheric air consists of oxygen, nitrogen, carbonic anhydride, and other gaseous matters. The average composition of the air in England consists of the following proportions of gaseous matter :—

Composition of atmosphere.

	Per cent.
Oxygen	20·61
Nitrogen	77·95
Carbonic anhydride	·04
Aqueous vapour	1·40
Nitric acid	Traces.
Ammonia	
Carburetted hydrogen	

In the air of towns are also found traces of sulphuretted hydrogen and sulphurous anhydride.

Air is inspired by the adult human subject, as stated by Professor Pettenkofer, at the rate of about 360 cubic feet in twenty-four hours, and this quantity is about three thousand times greater in bulk than the average liquid and solid food taken for the sustenance of the

Professor Pettenkofer, and the quantity of air inspired.

Dr. R. Angus Smith, and quantity of inspired air.

body. Dr. Robert Angus Smith says, that if we reckon fifteen respirations per minute, and 31 cubic inches each respiration, and in the expired air 5 per cent. of carbonic anhydride, and 15 per cent. of oxygen; in twenty-four hours a man produces 19 cube feet of carbonic anhydride, and consumes 380 cube feet of air, a sufficiently large quantity to show the necessity for thorough ventilation.

It is the oxygen of the air that is alone utilized by the animal economy. The products of oxidation, arising from the combination of oxygen with the retrograde elements of the body, are expelled by the lungs and skin, and in the excretions. It is the oxygen of the atmosphere alone that has the power of oxidizing and removing the waste of animal life. The nitrogen is merely present as a diluent, which modifies the stimulating effect of the oxygen. Air once used loses its vitality, and becomes unfit to sustain life.* Air, too, that is loaded with decomposing matter will not sustain life in health, because the oxygen of the air is absorbed or used up by the organic matters which are present when undergoing decomposition. Air carrying decomposing matter and the germs of disease is also directly injurious, in the sense that it becomes the vehicle which conveys these noxious elements. The breathing of vitiated air, or air loaded with decomposing or other deleterious matter, will lower the natural vitality so as to render the human subject susceptible to disease, and in this state the subtle germs of disease hold uncontrolled sway, and produce results as certain as if the person attacked had received a dose of any well-known specific poison.

Causes of vitiation of air.

Effect of breathing bad air.

Use of water by animals.

Water is the agent used for conveying nutrition to every part of the animal system; and, after fulfilling this mission, it becomes the vehicle for conveying away

* It is considered by Professor Pettenkofer that one part by volume of carbonic anhydride in one thousand volumes of atmospheric air is the limit which defines good air from bad air.

all those soluble compounds which have subserved their purpose in the animal economy. Hence it is found that nearly all the soluble substances cast off by the animal creation are present in the urine. The necessity of pure water is as great as that of pure air. Deleterious matters present in water, as a rule, act more speedily than those present in the air, because, when conveyed in water, they pass at once by the rapid process of venous absorption into the system. In the Report of Dr. Simon, the late Medical Officer of the Privy Council for 1869, it is stated, in reference to water supply and disease, that "the doctrine, in general terms, that a vast influence is exercised over the health of communities by the quality of the water supply which they consume, is one, which as far back in literature as any reference to such questions could be expected to exist, may be seen to have universal medical consent in its favour; and during long ages of history, the common instincts of mankind were even surer and stronger than undeveloped science. Of the many invaluable additions and improvements which medical knowledge has received within the last quarter of a century, scarcely any can, in my opinion, be compared, for present practical importance, to the discoveries which have given scientific exactitude to parts of the above-stated general doctrine, and have enabled us definitely to connect the epidemic spread of bowel infections in this country with the existence of certain faults of water supply. Not only is it now certain that the faulty public water supply of a town may be the essential cause of the most terrible epidemic outbreaks of cholera, typhoid fever, dysentery, and other allied disorders, but even doubts are widely entertained whether these diseases, or some of them, can possibly attain general prevalence in a town except where the faulty water supply developes them."

All soluble substances in urine.

Speedy action of bad water.

Report of medical officer of Privy Council on influence of water supply.

The food we daily eat goes to make up for the daily loss and waste, or to replace those substances

Food and its purposes.

which have been expired, or passed away in the excretions. The process of nutrition is carried on by the blood. By means of digestion and assimilation food is converted into blood, and only those substances capable of producing blood are of real value as food; the rest are discarded and passed away in the solid excrements: consequently, in the fæces is found all undigested food,* as well as the solid matters which are excreted by the animal system. The nitrogenous compounds, all of which are soluble in water, are principally passed away in the urine. The nitrogen present in the fæces is very small, and is principally derived from the liquid which is secreted in order to assist the passage of the solid fæces through the system.

All food should be capable of making blood.

Nitrogen in urine.

Small quantity of nitrogen in fæces.

Study vegetable physiology.

If the various processes carried on in the vegetable kingdom are now considered, we shall find, when studying the physiology of vegetable life, that oxygen, which is of such vital importance to the animal creation, is, simply as oxygen, of no special service to the vegetable kingdom; but it has been arranged, in the good order of Providence, that all the agents, whether air, water, or food, that have subserved the use of animals, and have ceased to promote animal life, having certainly become converted into agents destructive to its existence, have been rendered fit agents for the support of vegetable life. The vegetable kingdom utilizes those waste elements which have been cast off by the animal kingdom, and, after utilizing them, retains only those substances which the air or water had originally taken up from the animal, and in its turn again gives up the air, water, and food, in a fit and healthful state for the use of animals.

Oxygen not required by vegetables.

Air, water, food, used by animals, purified by vegetables.

* Dr. W. B. Carpenter, C.B., F.R.S., says, in his able work on human physiology, that "the absolute quantity of solid matter discharged in the fæces in the twenty-four hours is about 460 grains, of which only ten per cent. consists of undigested matter." This was the result of an experiment made on men in Coldbath Fields Prison by Dr. Edward Smith.

The foregoing simple physiological facts should be well understood, for in rightly comprehending them lies the whole secret of successfully carrying on sanitary operations, and dealing in a scientific and proper manner with those compounds which are constantly being eliminated from the animal system, and which are destined to become the food of the vegetable kingdom.

Necessity for understanding animal physiology.

In nature it has been provided that all those matters that have once served the purpose of the animal economy, if not at once brought into contact with the vegetable kingdom, shall undergo change, so as to render them fit to be again used by the animal creation. Thus, urine and fæces are capable of undergoing change. By decomposition, portions escape as gases into the atmosphere, which being dispersed by the wind soon become food for plants. Others, again, combine with the mineral constituents of the earth. The process is not so rapid as when all these matters are taken at once to the field, but the cycle is, nevertheless, as complete; for, sooner or later, they all go to administer to the wants of the vegetable kingdom, and poor, ignorant man alone suffers for the delay; for, in the incipient stages of self-purification, the matters evolved have proved highly injurious to health and life, producing what is called an unsanitary condition, which either causes or aggravates the type of a certain class of disease. The cause of disease is external to the human body; it is not the natural effect of existence, but it is the penalty of neglect, abuse, and also of want. Every disease has its own type, its own specific germ of generation. Every germ of disease requires conditions suitable for its development. When the human body first contracts disease, every effort is made to throw it off by those channels provided for the secretions and waste products; and when diseases of a certain type become epidemic, the cause may be looked for in the rapid development or distribution of the

Effects of decomposition.

What disease is the result of.

Germs of disease.

Rapidity with which germs develop.

germs of disease under favourable conditions. It is difficult to conceive how small an amount of matter the germ may be in zymotic diseases, and how rapidly it may develop. We know with what rapidity a single microscopic cell of yeast or other ferment will develop countless multitudes of cells, with the power of bringing favourable matter into a rapid state of fermentation. So it may be that a single infected person will, under favourable conditions, become the prolific centre of infection. So easily are the seeds of disease spread, that it becomes only a matter of common prudence to strive to maintain the body in health, by removing those causes which tend to lower vital energy; and to dispose of, in an expeditious and safe way, all those matters excreted by the human body, whether in health or disease, for we know that "every imprudence carries its own punishment." If the air of heaven is vitiated, the water rendered impure, or our food improper or insufficient, the body is robbed of life-giving elements, and soon succumbs to disease and death. It is the true aim and object of the sanitary engineer to assist Nature in her great but simple operations, to facilitate the purification of the air, to prevent dangerous impurities entering our supplies of water, to supply abundance of these life-giving elements, to remove, as speedily as possible, before decomposition commences, all those matters eliminated from the animal system, together with all other decomposing refuse. Dr. Lyon Playfair, in his address in the Health Section of the Social Science Congress, held at Glasgow in 1874, stated, "Man has no control over a single natural force. He may, indeed, use the forces of nature by means of his intelligence to effect a specific end, but he cannot turn them a hairbreadth out of their course. The laws of health, like other laws of nature, are relentless in their severity. If you stand on the verge of a precipice and overbalance yourself, the law of gravity relentlessly pulls you down, and dashes you to pieces on the base.

Effects of impure air and water.

Object of sanitary engineer.

Dr. Lyon Playfair on laws of health.

Equally without mercy are you punished for the smallest infraction of the laws of health, whether you live in cities or in fields. Man, indeed, has no control over a single law of nature, but if he live in obedience to these laws he will find that they are arranged with supreme beneficence for his well-being. An intelligent submission to them produces health and longevity, while the slightest infraction of them is mercilessly punished with disease and shortness of days."

Artificial existence in towns.

Wherever masses of human beings congregate, whether in towns or villages, or in armies in the field, camp, or barrack, an artificial existence, to a certain extent, springs up. Each individual is no longer dependent upon himself; the habits of those around him influence his own position. The preservation of the health of every class in a community is equally important to the rich and to the poor. It is important to the wealthy that the poor should be kept in health, for the influence of infection, once introduced into the dwellings of the poor, often spreads far and wide, and is no respecter of persons. It is important to the poor man, as his health is his wealth.

Preservation of health, importance of, to all classes.

Intention of sanitary laws.

Sanitary laws and regulations are intended to give power to communities which single individuals cannot possess, viz. the power to promote general measures calculated to secure or improve the state of public health. In this country it so happens that the sanitary laws, to a certain extent, are permissive, so that we see some districts in which the law is rigidly enforced, while, on the other hand, community after community is still found living in the most unsanitary condition, and disease and death reign supreme. No effort is made to remedy the state of neglect which may still be found in many undrained or ill-drained places. The local authorities are not always imbued with the true spirit of humanity, money considerations are with them often of greater importance than the question of life and health, and it not unfrequently happens that

Sanitary laws permissive.

political capital is made out of sanitary agitation. The advocates of filth and dirt appeal to the breeches-pocket—too often with success—thus literally fulfilling those lines written by the poet Burns :—

> " Man's inhumanity to man
> Makes countless thousands mourn."

The authorities in many towns appear to overlook the hard fact that while they remain inactive, disease and death do not. Dr. Farr, F.R.S., in his valuable report on mortality from cholera in England in 1848 and 1849, says very truly that " wherever the human race, yielding to ignorance, indolence, or accident, is in such a situation as to be liable to lose its strength, courage, liberty, wisdom, lofty emotions—the plague, the fever, or the cholera comes; not committing havoc perpetually, but turning men to destruction, and then suddenly ceasing that they may consider. As the lost father speaks to the family, and the slight epidemic to the city, so the pestilence speaks to nations, in order that greater calamities than the untimely death of the population may be averted. For to a nation of good and noble men death is a less evil than degradation of race."

Dr. Farr, F.R.S., on places subject to pestilences.

Power of Local Government Board to compel prosecution of sanitary works.

The Local Government Board has now the power to compel communities who have neglected their sanitary duties to introduce proper measures, or the works may be performed for them; but, alas! at present in how few places requiring attention has this power been exercised.

Good results of sanitary works.

Little more than a quarter of a century has elapsed since efforts were made in this country to improve the sanitary condition of the great masses of the people. But short as the period has been, much good has been done, many lives have been saved, and much sickness and misery averted. The modern works of sewerage and water supply have been experiments made for improving the state of public health, and that they

Works of sewerage and water supply experiments to improve public health.

have accomplished the end for which they were inaugurated will be seen from Table No. 1, which contains the results in twelve towns that have been selected from the records collected by the medical officers of the Privy Council, and published in the ninth report of that department.

Records of medical officers, Privy Council.

In examining the Table it will be seen that in some cases the actual saving in health has not been great. For example, at Rugby. This may be accounted for from the fact that it is far more difficult to reduce the death rate in a healthy district and make it more healthy, than it is to reduce it in an unhealthy district and make it comparatively healthy. It will be seen that in the case of Rugby, before the prosecution of the works the rate of mortality was comparatively low. Since the completion of these works even that low rate of mortality has improved, while those particular diseases which are attributable to sanitary neglect have considerably declined.

Effect of sanitary works in comparatively healthy districts.

Rugby mortality.

TABLE No. 1.—Showing the RESULTS of SANITARY WORKS.

Table No. 1.

Name of Place.	Population in 1861.	Average Mortality per 1000 before Construction of Works.	Average Mortality per 1000 since Completion of Works.	Saving of Life per cent.	Reduction of Typhoid Fever rate per cent.	Reduction in rate of Phthisis per cent.
Banbury ..	10,238	23·4	20·5	12½	48	41
Cardiff ..	32,954	33·2	22·6	32	40	17
Croydon ..	30,229	23·7	18·6	22	63	17
Dover	23,108	22·6	20·9	7	36	20
Ely	7,847	23·9	20·5	14	56	47
Leicester ..	68,056	26·4	25·2	4½	48	32
Macclesfield	27,475	29·8	23·7	20	48	31
Merthyr ..	52,778	33·2	26·2	18	60	11
Newport ..	24,756	31·8	21·6	32	36	32
Rugby	7,818	19·1	18·6	2½	10	43
Salisbury ..	9,030	27·5	21·9	20	75	49
Warwick ..	10,570	22·7	21·0	7½	52	19

It will be seen by a glance at the above Table that the sanitary works which have been carried out in the places named have had a marked effect in staying the ravages of disease and death, and they have also had

Effect of sanitary works in staying the ravages of disease.

the effect of prolonging the average duration of life. The good that has arisen from the prosecution of sanitary works, wherever properly carried out, may be taken as the harbinger of more hopeful times, when the benefits of sanitary measures will be better understood, and more extensively adopted. As an example of the gradual improvement in the health of the country from the adoption of sanitary measures, the statistics given of London by the Right Honourable Dr. Lyon Playfair, in his address at the Social Science Congress at Glasgow in 1874, show in a very marked manner :—

Good that has arisen from sanitary operations.

Period.	Death rate per 1000.
1660–79	80·0
1681–90	42·1
1746–55	35·5
1846–55	24·9
1871	22·6

Statistics showing improved health.

How much society loses annually by preventible disease it is impossible to fully estimate, as health is so intimately connected with all the branches of everyday life. We know that the power of physical ability forms the basis of the value of all descriptions of labour, and that the full value of work cannot be got from a sickly and consequently feeble population; therefore, those communities that are in a bad sanitary state are considerable losers. The national prosperity of the country is impeded by the undue amount of sickness we have to support, and the losses of human life we have to sustain. If upon no other than economical grounds, it is true economy to spend some little of our earnings in the prosecution of sanitary works. Health is the capital of the labouring man. It is better to give health than alms, for an unsanitary state brings sickness, disease, and mortality, which are followed by pauperism, demoralization, and crime. Dr. Johnson says, "To preserve health is a moral and religious duty. For health is the basis of all social virtues. We can be useful no longer than we are well." Napoleon, from

Physical ability basis of value.

National prosperity of country impeded.

Health is capital.

Quotation from Dr. Johnson.

the result of long experience in the hygiene of armies, greatly valued sanitary measures, for he said to Autonomarchi at St. Helena: "Life is a fortress which neither you nor I know anything about. Why throw obstacles in the way of its defence? Water, air, and cleanliness are the chief articles in my pharmacopœia." In how many cases has preventible illness destroyed the prospects in life of its victims; how often has the invalid become a burden to his fellow-creatures; how often has a father of a family been stricken by preventible disease, and left his family chargeable to the rates? In how many cases has the loss of a paternal guide left families to grow up in a course of vice and crime, to become a permanent expense to their country? These are all matters that are really past calculation, but nevertheless we acknowledge the facts. The Rev. C. Girdlestone, M.A., has said: "It too often happens that a man dies and his place is taken by another without cost to his employer, and less consideration is shown to him than would have been given to a horse or a dog, which could not be replaced without pecuniary outlay."

Napoleon's Pharmacopœia.

Effect of illness and death.

Charges on rates.

Rev. C. Girdlestone, M.A., and small consideration shown to man.

It has been found in unsanitary districts that sickness bears a regular proportion to the rate of mortality, and sanitary works can be measured by the £. *s.* *d.* saved. The Right Honourable Dr. Lyon Playfair calculated some years since, that for every unnecessary death we have twenty-eight cases of sickness, but in his address delivered at Glasgow, in 1874, he stated that "Statistical investigations made by Pettenkofer show us that for every case of death in public institutions for the sick there are thirty-four cases of serious sickness, so that the unnecessary deaths must be multiplied by that number in order to give you the minimum cases of preventible sickness. These cases of sickness last on an average 18½ days." Dr. Playfair valued the labour at 2*s.* per day. The principal members of the Epidemiological Society have pointed out that "the statistics of disease are not less necessary than statistics of mortality," and they say, "taking one

Sickness bears a proportion to mortality.

Dr. Lyon Playfair's calculations.

Professor Pettenkofer.

Quotation from Dr. Rumsey's 'Fallacies of Statistics.'

disease with another, there are between twenty and thirty cases of sickness to every death; but this estimate is probably too favourable to disease, at least in large towns." "In Manchester, the proportion varies from twenty-eight to thirty cases to one death." Among Friendly Societies it is found that the yearly duration of sickness "involves an average of two weeks to each member." Dr. Farr, F.R.S., has computed the money value of the agricultural labourer at twenty-five years of age at 246*l.* 7*s.*, as being the estimate of his future wages, after deducting the necessary cost of maintenance. An estimate of the probable effect of the sanitary works can be propounded in this way: *First*, the saving in the cost of funerals, inclusive of mourning and fees, which upon an average may be set down at 5*l.* each. *Secondly*, the saving by reason of the escape from sickness, with its cost, including the value of labour which is lost. To be upon the safe side, it may be taken, for every life saved by sanitary works, twenty-five persons would escape sickness, and that 1*l.* per case would represent but a moderate value of the result, including loss of time, physic, medical and other attendance. *Thirdly*, the value of the labour saved to the country by the prevention of premature death—for every adult female, 5*s.* per week, and for every adult male, 10*s.* per week, or a mean of 7*s.* 6*d.* per week, may be taken as the value of the labour, over and above the cost of maintenance. If a town which has carried out sanitary works compares its savings under the above heads, with its expenditure, it will be found, in the course of a few years, that, in all cases in which the sanitary works have been properly carried out, the money value of the lives saved, and the sickness averted, will exceed the full estimated cost of the works executed. The author, in his "Inaugural Address" as President of the Society of Engineers in 1868, made such a calculation, taking the town of Croydon as an example, which has been corrected up to the end of the year 1875.

Dr. Farr's calculations.

Estimated value of sanitary works.

Number of cases of sickness prevented.

Value of labour.

Quotations from Inaugural Address, Society of Engineers.

Expenditure in Croydon to end of 1875. Expenditure in Croydon.

	£	s.	d.
Purchase of freehold lands	55,000	0	0
Construction of waterworks	80,000	0	0
Construction of sewers, sewage irrigation works, public baths, abattoirs, and general improvements	132,665	0	0
	£267,665	0	0

The average mortality of the town of Croydon for eight years—from 1848 to 1855 inclusive—was 24·03 per thousand, and for the twenty years since 1855 it has averaged 19·56 per thousand, showing a saving of 4·47 per thousand per annum. The mortality in the Mortality in Croydon.

Note.—Croydon has not reaped such full advantages from the prosecution of sanitary works as have been secured in some other districts which have been sewered under the author's direction, or, even, in parts of the same district, by reason of the probability that the supply of water furnished by the Local Board is at times unwholesome, as it is taken from wells sunk in permeable strata in the centre of the old town of Croydon, and which are liable to contamination from their local position. The mortality of a large portion of the district appears to be influenced, in a marked degree, by the water supply, as will be seen by the following figures taken from the published returns of the Croydon Local Board of Health :— Note on Croydon mortality. Influence of Croydon water supply on health.

Year.	General Mortality, Croydon Parish.	Norwood only.
	Per 1000 living.	Per 1000 living.
1866	19·92	15·34
1867	18·34	14·78
1868	21·85	12·04
1869	20·71	13·20
1870	20·34	11·30
1871	20·12	13·38
1872	18·45	14·80
1873	17·49	12·97
1874	17·92	14·09
1875	21·61	14·32

Norwood forms a part of Croydon, and its sewerage works were principally carried out under the direction of the author, but there is nothing special in the system of sewers which should render the district more healthy than other portions of Croydon except that the Health of Norwood.

year 1848 was 28·48 per thousand, and in the year 1875* 21·61 per thousand, in 1848 the population was 19,168, in the middle of 1875 it was 63,000, showing

supply of water is principally furnished by one of the Thames Water Companies. The evidence of the mortality of particular years, when carefully extracted, shows that the health of Croydon is materially affected by the state of the springs. Low springs, which favour the conditions necessary for impurities being passed into the water supply, and for the concentration of the poison of disease, are shown to be inimical to the health of the district using this water. So also periods of excessive rainfalls which have caused a sudden elevation of the water under the town and have carried impurities from the surface into the springs, have equally affected the health of the district. The result of this action, but not its cause, was observed by Dr. Westall, nearly twenty years ago, when he reported to the Croydon Local Board, "It would appear that a particularly dry season is not more conducive to health than an unusually wet one." These two conditions of wet and drought may affect the health of a district through its water supply, but general experience shows that they do not affect the health of districts through a system of sewers which is abundantly supplied with water, as is the case at Croydon.

Health influenced by state of springs.

Dr. Westall's opinion.

Dr. Philpot's report on cases of fever.

Dr. Philpot, the Medical Officer of Health of Croydon, reported to the Local Board that in the year 1875, 1176 cases of fever occurred in Croydon parish. Croydon water, which the author considers was the cause of the fever, is supplied only to a portion of the parish, the remaining portion being supplied by the Lambeth Water Company, and from other sources. In this year, 1159 of the cases occurred in a population of 49,250 supplied with Croydon water, or one case of fever occurred in every 42·49 persons living in this district in this particular year, and one death occurred in every 13·96 cases. In the district supplied by the Lambeth Water Company and from other sources, which was inhabited by a population of 13,750 persons, in the year 1875 17 cases of fever were reported, or one case in every 808·82 persons living in the district, and one death occurred in every 3·4 cases. With reference to the 17 cases of fever, it should be observed that most of them can be directly traced to a connection with the Croydon Water District, such, for example, as children residing outside the water district but attending school within the water district. It has been contended by some persons, in spite of the proofs to the contrary, that this epidemic of fever was due to defective sewers; but that defective sewers did not influence this disease in Croydon in this particular year is manifest from the distribution of the disease in reference to the district served with the alleged defective sewers; for, singularly enough, in the district served with these defective sewers (all of which, with an unimportant exception, are within the Croydon water area), in the year 1875, one

Number of persons attacked with fever in Croydon Water District.

Persons attacked with fever outside Croydon Water District.

Influence of defective sewers.

* The death rate this year was higher than usual, due to an epidemic outbreak of enteric fever, which the author attributes to the use of water impregnated with the poison of the disease.

the population increased 223 per cent., and the death rate reduced 18·6 per cent., between the periods before referred to. The mean population for twenty years since the year 1855, when the sanitary works may be said to have been completed, and in successful operation, has been 43,912. By taking the mean saving of life of 4·47 per thousand, and multiplying it by the

Decline in mortality, increase in population.

person out of every 45·03 persons living in these districts served with the defective sewers had fever, and but one death occurred in every 25·76 cases. From these figures it will be seen that there was less fever within the district served by the defective sewers, and also fewer deaths to cases within the same area, thus very clearly establishing the fact that the influence of the alleged defective sewers was certainly inoperative as an agent in promoting this particular outbreak of fever. That sewers had no influence whatever in this outbreak of fever was further shown from the fact that in a number of houses that had no connection whatever with any sewers, but which were supplied with Croydon water, the inmates suffered from the fever. It has been admitted by some that no doubt the fever of 1875 was due to the water, but they say the water was not at fault at its source, but that it was contaminated in the pipes by reason of an intermittent supply, and the liability of impure air being drawn into the water pipes when they were emptied of water. The supply of water in the district served by the Lambeth Company was daily intermitted, and there was a greater amount of intermitting of the water supply in the district that had the least fever than ever occurred in the Croydon Water District, and yet no evil results followed the intermitting of the Lambeth Company's water, although in many cases in the same road, using the same sewer, but having a different source of water supply, the Lambeth water consumers escaped entirely, while in almost every house taking Croydon water the inmates more or less suffered from the fever. That intermittent water supply could have little or no effect in causing fever in Croydon will be seen from the fact that the inhabitants of the Croydon Water District suffered least when there was the greatest amount of intermittency in the Croydon water supply, the intermittency being the greatest in the summer months, when the fever was the least. Before long the author hopes to lay before the public the whole of the facts in connection with the prevalent epidemics of fever that have occurred in Croydon, but which refer essentially to the subject of water supply, and do not come within the scope of this work, and he trusts that those who have heard of the severe criticisms passed on the author by some professed sanitarians, will suspend their judgment until the whole case is clearly laid before them. This much may, however, now be said, that it has taken the ratepayers of Croydon two years to turn out a hostile majority to an inquiry into the water supply of Croydon, and to place on the Local Board of Health a majority in favour of an inquiry, which was entrusted to J. F. Bateman, Esq., C.E., F.R.S., the

Defective sewers inoperative as an agent producing this outbreak of fever.

Houses not connected with sewers, inmates suffered from fever.

Fever attributed to intermittent water supply.

No evil follows intermittent water supply in Lambeth Water Company's district of Croydon.

Fever less prevalent in Croydon when there was the greatest intermittency.

Criticisms on the author.

Inquiry into Croydon water, by J. F. Bateman.

mean population in thousands, and again by the number of years, we get $43 \cdot 912 \times 4 \cdot 47 \times 20 = 3926$ lives saved. Of this number about six-tenths or 2356 would be adults, or persons above the age of twenty, but probably one-tenth of these would be infirm from age; by making this deduction we have still 2121 persons in the full vigour of life who have been saved. By using the figures before quoted in connection with the lives saved, we shall get the money value of the benefits conferred by the works.

Money savings in Croydon.

	£	s.	d.
3926 funerals, &c., saved, at 5*l*. each	19,630	0	0
3926 × 25 = 98150 cases of sickness prevented, at 1*l*. each	98,150	0	0
2121 value of labour at 19*l*. 10*s*. for 10 years	413,595	0	0
	£531,375	0	0

In this case, while 267,665*l*. had been expended on all the public works, they had affected a saving equal to 531,375*l*., so that in the short space of twenty years a sum exceeding by 95 per cent. the total expenditure for works executed and the purchase of freehold property has resulted from the prosecution of sanitary measures.

Life priceless.

Although it has here been attempted to put a money value on life, we individually feel that life is priceless, and that we may look to the 3926 persons saved from the jaws of death in this single town, as the living testimony of the great value of sanitary works.

In considering the influence of sanitary works on the health of a district like Croydon, which is inhabited by a well-to-do population, and in which con-

result of which confirms the author in the three essential points as to the causes of fever in Croydon:

1st. That the fever of 1875 was due to water.

2nd. That the water supply was contaminated at its source in the wells.

3rd. That whenever the springs of Croydon are low, the water supply, from the local position of the wells in the centre of the town, must become contaminated when the rate of abstraction exceeds the yield of the drainage area.

siderable accessions to the population are due to the immigration of persons from other districts, it is right to say that the death rates, independently of any sanitary measures, ought to be low, for the simple reason that in such a district there are always living a very considerably larger number of persons at the ages at which they are least susceptible to the inroads of disease and death, for, as Dr. Rumsey, F.R.S., has pointed out in his work on 'Some Fallacies of Statistics,' "it seems to be a law of nature—always in operation—that organic life is most liable to perish in its earlier stages, the liability decreasing in something like geometrical progression, until the plant or animal becomes full grown, and the reproductive function is established;" so in places like Croydon, the population of which is largely made up by the immigration of those least liable to death by reason of their age, the death rates will and ought to be more favourable than is the case in those districts whose increase of population is exclusively due to the increase of births over deaths. Moreover, while those districts that receive an immigrant population have apparently low death rates, the districts that lose by immigration their population least susceptible to the inroads of death, have high death rates. It is therefore absolutely necessary, in forming an opinion as to the healthiness or unhealthiness of a district, that the ages and condition of the population inhabiting the district should be fully considered, or very considerable errors will arise.

Reasons why Croydon should have low death rate.

Dr. Rumsey.

Law of nature.

Effects of immigration.

Necessary to consider condition of population.

For the authorities of any town to permit any person to perish by sanitary neglect is just the same as taking them out of their homes and forcibly putting them to death; and yet if this were done the whole nation would revolt at the crime. But in how many instances do our local authorities look calmly on while poor and innocent victims are condemned to breathe a poisoned atmosphere, or drink poisoned water.

Position taken by medical men.

The medical men of this country have, as a rule, acted like true philanthropists in generally taking the lead in all questions relating to the prevention of disease. To no body of scientific persons are the effects of an unsanitary condition made more painfully manifest. Disease in unsanitary districts sits like a vampire on its victim, which is never satiated till the last drop of life-blood is exhausted. Medical men know full well that it is almost futile to apply their healing art in unsanitary places. The removal of the patient, even in the most rapid disorders of a zymotic type, to a healthy hospital in a more salubrious neighbourhood, renders the effects of disease less fatal. The reason is obvious; if the patient remain in the region where he has contracted disease, and in which he is continually exposed to malarious influence, the case is in all respects like that of a man who is being murdered by slow and secret poisoning; the doctor may be called in, and he may prescribe for his symptoms, but the dose of subtle poison is still secretly administered, and as the cause of the diseased symptoms is not removed, the natural effects can rarely be prevented.

Effects of disease in unsanitary localities.

Effect of removal of patients.

Influence of scientific press.

The scientific press of our country has done much to spread the knowledge of sanitary principles by exposing our faults and failings, by chronicling successful examples, by showing up in its true light the sanitary condition of various localities, by warning us of the danger that surrounds us, by advising us as to the steps we should take in the elucidation of truth and eradication of error, and, finally, in the encouragement invariably given to the advancement and prosecution of sanitary science.

Alchemist of old in vain spent time in searching for the philosopher's stone.

The alchemist of old vainly expended his time in the search after the philosopher's stone, which was to convert all the baser metals into gold, or whereby he was to compound an elixir of life, that would restore to age the healthful elasticity of youth, and prolong human existence. In the prosecution of sanitary works we have discovered a real philosopher's stone, for such works have been abundantly shown to have added to the average duration of life; and in the utilization of those waste products which have hitherto been looked upon as dirt, rich and golden harvests have been, and still will be, produced.

Sanitary work a real philosopher's stone.

CHAPTER II.

HISTORICAL NOTES.

Historical notice.

If we refer to the page of history, we shall find that, in all ages of the world, wherever civilization advanced to any degree of refinement, sanitary measures were invariably adopted. Thus works of water supply, sewerage, and temples of health, were constructed in all the ancient cities of the world. Many of these works have outlived the destruction which has doomed more imposing but less useful structures. Alexandria, Carthage, Herculaneum, Jerusalem, Nineveh, Rome, and many other cities, had a complete system of sewers and waterworks. In Rome, after the lapse of twenty-five centuries, the Cloaca, constructed when she was in the meridian of her power, is still retained, and performs a similar duty for modern Rome as that intended to serve the ancient city. Many works executed in the early periods of the world's history were of so stupendous a character as to rival the largest works of the present day, and they bear the strongest evidence of the clear knowledge of the sanitary appliances required for every large and populous city. The Egyptians worshipped the Scarabæus or scavenger dung beetle, probably recognizing its utility from a sanitary point of view as well as admiring the lustre of its coat, or holding in veneration its forethought in protecting its young as well as esteeming its habits of persistent perseverance under the most trying difficulties, and also recognizing in these insects a community of interests in which individual action was made subservient to the general advantage of the species. It would, in all probability, be well for us

Works carried out in ancient cities.

Cloaca of Rome.

Worship of the Scarabæus.

Use of beetles.

if we held many members of the beetle tribe in more veneration, as it is well known that while some of these useful insects are scavengers, and dispose of much organic matter which, by accumulating and decaying, proves injurious to health, other orders live on those low forms of vegetable or fungoid growth, with which is linked, in a manner not yet fully understood, the germ theory of disease.

Persian sanitary laws.

The Persians had some very clear notions of the necessity of preserving the purity of rivers, which were held in special veneration, and were not to be defiled by any excretion of the human body. Earth and fire were also held sacred by them, so that neither burial nor cremation would meet the necessities of such a creed—hence the dead were disposed of in much the same way as the Parsees of India and the native Australians dispose of their dead, by exposing them to be carried away by birds, beasts, and insects, or dissipated in the atmosphere at some remote place.

Jewish mode of disposing of fæcal matter.

It was enjoined on the Hebrews to dispose of the excretions of the human body by burying them in the earth at a place beyond the limits of their habitations.

Burning of excrement.

We also find that from early periods the Hebrews dried their excrementitious matters and used it as fuel.

Mosaic dispensation.

Under the Mosaic dispensation sanitary laws were religiously observed; hence the discoveries made in ancient Jerusalem in modern times are full of interest. In the works here executed we see that the Jews possessed a clear knowledge of the necessity of removing all decomposing matter as expeditiously as possible, to a place outside their city, and that when so removed, they knew how to dispose of it.

Sanitary works of Jerusalem.

From Dr. Whitty's excellent work, 'On the Water Supply and Sewerage of Jerusalem,' we learn that "Eusebius, who was a native of Palestine, and died there about the year 340," thus quotes Timocrates, the Surveyor of Syria, who stated of Jerusalem, "The whole city flowed with water, so that even the gardens were irrigated by those overflowing waters out of the city."

Timocrates.

Dr. Whitty on the sanitary works of Jerusalem.

Dr. Whitty further quoting from a paper by the Rev. George Williams, B.D., Senior Fellow of King's College, Cambridge, upon recent discoveries of Dr. Pierotti, says, "The situation of the Temple appears to be fixed, beyond all possibility of doubt, by the recent discovery, by Signor Pierotti, of the complete water system connected with the Hebrew Temple, still existing as entire as when it was in daily use during the period of the Jewish Commonwealth. The perfect preservation of this complicated system of aqueducts, drains, and reservoirs, is owing to the fact that they are excavated in the solid rock, and therefore have not been affected by the demolition of the structures above, except in so far as they may have become partially blocked up by the accidental falling in of the *débris* of the ruined buildings."

Sewerage of the Temple of Jerusalem.

"Had history been silent on the subject, yet we should have been forced to conclude that there was a very complete system of sewerage connected with the Temple, introducing a large quantity of water to dilute the blood, which would otherwise have a tendency to coagulate, and carrying off the blood and offal from the sacred precincts." This history tells us was actually the case, and the supply of water was so managed as to flush the whole court, and carry off the blood of the numerous sacrifices. The drains leading from the Temple, and probably from the city, discharged themselves into a pit, which is now called the "Fountain of the Virgin," and which communicates, by means of a channel in the rock, with another pit now traditionally called the "Pool of Siloam," but which there is every evidence to show is not the true "Pool of Siloam."

Use of tanks.

"It is a necessary consequence of the Fountain of the Virgin having been originally a cesspool, if that be admitted a fact incapable of being controverted, that the Pool of Siloam (now so called) was likewise a cesspool, formed for the purpose of receiving the liquor from the upper cesspool, in order that the manure in it might become sufficiently desiccated to be in a fit state for removal by the gardeners who purchased it, and that the tunnelled conduit was that through which the moisture was drained off into the lower cesspool, or liquid-manure tank." We find from the Mishna:— "There was a certain cave beneath the altar whereby filth and uncleanness were carried down into the Valley of Kedron, and the gardeners paid so much money as would purchase a trespass offering for the privilege of fertilizing their gardens with it." The liquid matter, after leaving the traditionary Pool of Siloam, was then used, as it is at the present day, for the purpose of irrigating the king's gardens. From this description of the outfall works of the sewerage of ancient Jerusalem we learn that the sewage was collected in tanks, the solid matter was removed from it and sold, and the liquid was afterwards used for the purpose of irrigation, just as is the most approved practice of the present day. Mishna.

The Greeks had special provision in their houses for the reception of the excretions, and latrines appear to have formed one of the necessary provisions of a good Grecian house. Portable vessels were also used for the reception of the excreted matter. In the Museum of the Louvre may be seen an inscription from the Temple of Delphi which runs thus: "It is forbidden to discharge excrement on the sacred soil." Such an inscription shows that the habits of the people at that period were not dissimilar to those of our own time, for how frequently the eye now falls on a notice to the same effect, "Commit no nuisance." The Greek sanitarians. Inscription from Delphi.

In the best days of Greece and Rome, all matters relating to public health were much studied. The letters of Pliny, written nearly two thousand years ago, throw a considerable degree of light upon the state of sanitary science at that period. For example, we find him writing, when Governor of the province of Bithynia Pliny's letters.

and Pontus, to draw the attention of the Emperor Trajan to the sanitary condition of the town of Amastria, which had a remarkably fine street of great length, but by the side of which ran what was termed a river, but which was evidently an offensive open sewer, for Pliny thought it necessary to tell the Emperor that it ought to be covered up. Further, it will be seen from Pliny's letters that the modern practice of asking the assent of Government to the prosecution of sanitary works was the recognized mode of procedure in the time of the Emperor Trajan. For example, Pliny drew the attention of the Emperor to the fact that the people of Nicæa had built a theatre, upon which 80,000*l*. had been spent when it was found that the walls were cracked from top to bottom. The people of Nicomedeia had spent a large sum on an aqueduct, and left it so unfinished that it actually fell to pieces. The same fate attended a second attempt, so that the town, after a vast outlay, was still without water, and he asks the Emperor if he may use the old materials to bring in the water from a spring which he had visited, and points out "that it is really of the first importance that they should have an architect from Rome to superintend the affair, and guarantee them against a recurrence of failure." "The inhabitants of the colony of Sinope were badly off for water, and it could only be conveyed into the town from a distance of sixteen miles. Pliny consults the Emperor, and tells him that he believes the money can be raised on the spot, if he, the Emperor, is willing to concede such an indulgence to the thirsty townspeople. Trajan's reply is favourable; the work, he says, will conduce to the health and beauty of the place." A further example is given in Mr. E. Walford's translation of 'Juvenal,' which gives an insight into the condition of ancient Rome. He says, "As in modern Edinburgh, so in ancient Rome, night was the time chosen by the careful housewife for throwing the slops from the upper windows

Sanitary condition of Amastria.

Assent of Government copied from Roman procedure.

Failure of Roman works.

Opinion of Emperor Trajan.

Mr. E. Walford's 'Juvenal.'

into the open drain that runs through the street beneath. And not only slops, but other harder if more cleanly *débris* descended from the many storied pile."

> " Whence heedless garrettiers their potsherds throw,
> And crush the unwary wretch that walks below,
> Clattering, the storm descends from heights unknown,
> Ploughs up the street, and wounds the flinty stone.
> Pray then, and count your humble prayer well sped
> If pots be only—emptied on your head."

Vitruvius mentions a case which shows the attention paid to all matters relating to the health of communities. It appears that the inhabitants of the old city of Salapia were continually out of health, and at last they applied to Marcus Hostilius and obtained permission to remove the city to a more healthy locality, and the Roman Senate and people gave their assent, and the city was removed to a more healthy position, four miles from its former site.

Vitruvius.

Removal of Salapia.

In F. Liger's 'Historical Account of Sanitary Appliances,' we find it stated that "the public latrines of Rome were farmed out to Foricarii, who paid a rent into the treasury and levied a payment from those who used them," in a manner exactly similar to that now adopted at the principal railway stations in this country. "At the end of the third century, under Diocletian, there were one hundred and forty-four of these receptacles in the city of Rome, but, in the fourth century, if we may believe Panciollus, there were only forty-four." F. Liger supposes that "these latrines were quite distinct from the cloaca or drains, and were not usually connected with them, as certain writers have imagined." He also states that "the palaces and public edifices were also provided with latrines."

F. Liger.

Latrines of Rome.

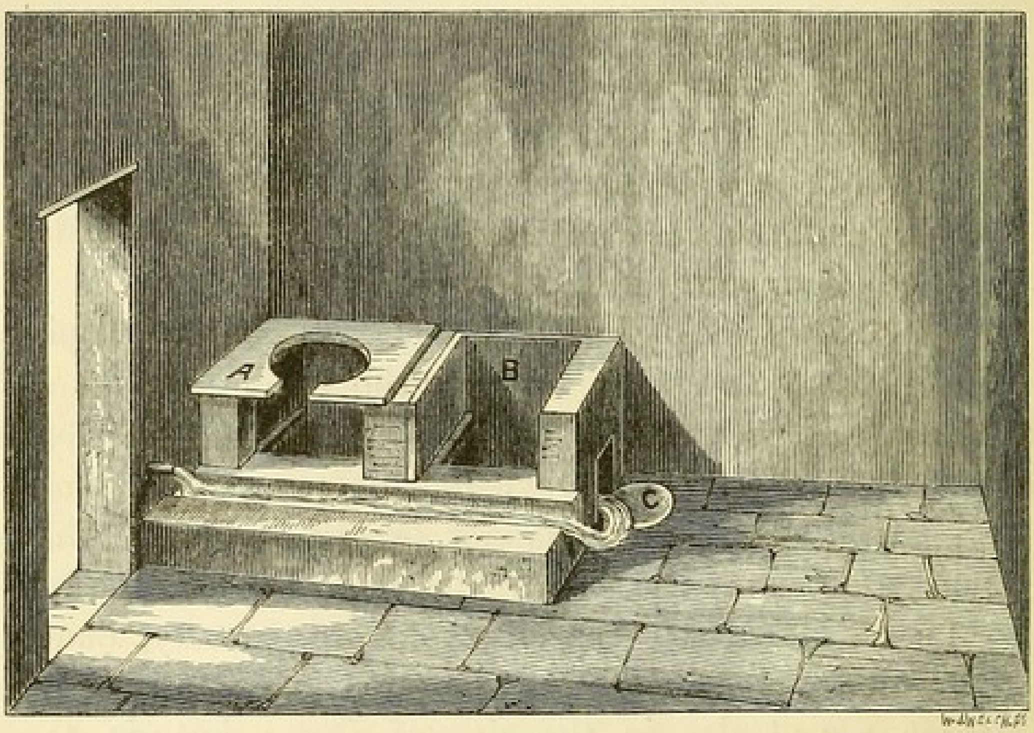
The ruins of Pompeii show very clearly that latrines existed that were supplied with water, and from which drains conveyed away the polluting matter. The large quantities of water required for many of the ancient

Pompeii.

towns was no doubt due in a measure to the fact that continuous streams of water were required in the rude sanitary appliances in use at that period for conveying away excreted, and, probably, other refuse matters. The good effects of great dilution of the polluting matter appear to have been well understood at that remote age, and the benefits of such dilution are seen from the fact that, at the outfalls of the sewers, as shown by Macrobius and Lucilius, "the fattest and most delicate fish in the Tiber were caught." In Fig. 1 is

Evidence of dilution of sewage.

Fig. 1.



Pompeian sterquilinium.

shown a perspective view of a Pompeian sterquilinium. The arrangement shows a room provided with three distinct receptacles, one having a seat, A, a second intended for the use of those that squat, B, and a third opening marked C, evidently to be used as a urinal. In front of the receptacles A and B a gutter is formed, which receives its water supply as shown. The water, after flowing through this gutter, flows through the urinal, and passes through the receptacles for the fæcal matter, and then to the sewer. Such an arrangement as here delineated was a very perfect sanitary appliance, using, no doubt, a very large quantity of water, but the water was so disposed of in this arrangement as to effectually guard against its pollution. It is well known that the Romans were adepts in the art of draining, and that they had made considerable advances in the mode of forming drains, and that for this purpose earthenware pipes were used by them in their own country, and also in the provinces under their control, which is very clearly shown by the evidence collected at Chester, recorded in the twelfth volume of the 'Transactions of the Institution of Civil Engineers,' which shows that specimens of red unglazed pipes were exhibited, which, from the inscription on them, were believed to have been laid by the Twelfth Roman Legion. It is also mentioned that the Babylonians employed unglazed ware for tubular drains.

Use of earthenware pipes by Romans.

Roman pipes at Chester.

In Figs. 2 and 3 are shown a part of a plan and

Fig. 3.

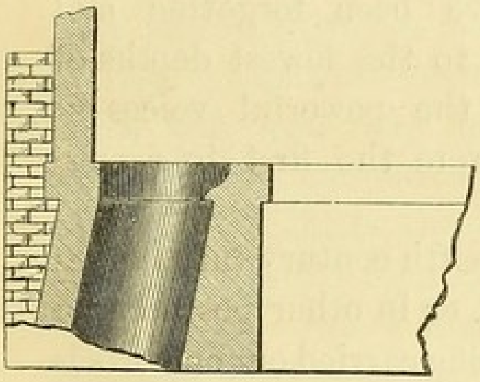
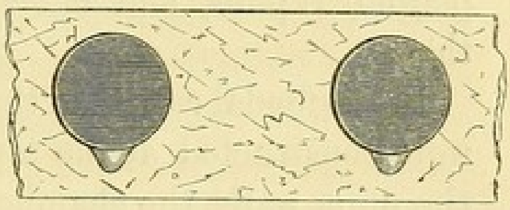


Fig. 2.



section of a latrine discovered by Messrs. Cochin and Bellicard at Pozzuoli, and described in 'Antiquités d'Herculanum.'

At one period, even in Rome, the inhabitants emptied every morning the contents of the vessels containing waste and excrementitious matter into the public streets, which were regularly scavenged. However, from the earliest period of the Republic it was forbidden to throw or place any excrementitious refuse on the public roads.

Disposal of excrement in Rome.

It is by no means clear if cesspools were ever in use in ancient Rome. Vitruvius does not mention them, and no remains of such receptacles have been found; in fact, the cesspool appears to be an institution dating from about the ninth century, for it is certain that about this period the monasteries were provided with latrines, which were placed in special detached buildings—such an arrangement as clearly to imply the use of one or more cesspools. In the eleventh century, it is mentioned by Liger that excavations made in the Abbey of Paris reveal the fact that there existed at this period "pits without any bottom," doubtless intended to receive fæcal matters. Although these ancient examples of sanitary works were executed when art and science had reached a high degree of excellence, we come to a period in history when both art and science declined, and with them the prosecution of those sanitary works which were of so beneficial and useful a character; in fact, the benefits derivable from sanitary science seem to have been forgotten and ignored, and the people sunk to the lowest depths of sanitary neglect, from which the powerful voices of plague, typhus, and cholera were the first to arouse them.

Cesspools date from ninth century.

Period in history when sanitary science declined.

Voice of disease awakened people.

In the feudal castles of the twelfth century the latrines were constructed at the top of, or in other positions in the outer walls, the chamber being carried out on corbels so as to overhang, in order to secure a clear fall for the fæcal and other matters into the fosse of the castle. A century later special towers were constructed, containing the latrines tier above tier, so constructed as to provide accommodation on every floor of the building, and usually communicating with a cesspool within the basement of the tower. These towers were called "garderobe towers." Mr. Robert Rawlinson, C.E., C.B., when reporting on the drainage of Windsor Castle, mentions the fact that "in the earliest days of Windsor Castle, sanitary appliances were of the rudest form. Within

Sanitary arrangements in feudal castles.

Garderobe towers.

Windsor Castle.

the walls there were floors of mud, covered with rushes and litter; and externally, heaps of ordure and refuse, but no sewers nor cesspools. When chamber floors were first added to Windsor Castle, square 'stacks,' or vertical openings like large flues, were formed in the exterior walls to serve as privies." With regard to the more modern arrangements of Windsor Castle, in 1862 Mr. Rawlinson reported that during the previous sixteen years fifty-one cesspools, varying in size from 12 feet by 8 feet and 9 feet deep to 3 feet diameter and 6 feet deep, had been abolished.

Mr. R. Rawlinson's report.

Cesspools in use at Windsor Castle.

Dr. Lyon Playfair stated in his address at Glasgow in 1874 that "when the civilization of the Egyptians, the Jews, the Greeks, and the Romans faded, the world passed through dark ages of mental and physical barbarism. For a thousand years there was not a man or woman in Europe that ever took a bath. How different that time was from the times which preceded it when daily baths were common among the poor, you may gather from the praises of personal ablution which abound in ancient authors." "No wonder that there came the wondrous epidemics of the middle ages, which cut off one-fourth of the population of Europe—the spotted plague, the black death, sweating sickness, and the terrible mental epidemics which followed in their train—the dancing mania, the mewing mania, and the biting mania. But even when the middle ages had passed away, and the sun of civilization was again rising over the gloomy darkness of these centuries, what a heritage of filth-produced disease still remained! Look at Defoe's or Montaigne's descriptions of the plagues of their day. Montaigne gives us some statistics which Defoe does not. The plague at Bordeaux, from which Montaigne fled to his country house, killed 18,000 out of 40,000 people. It followed him and destroyed whole villages. The harvest was not reaped, the grapes were ungathered, and men's minds were occupied, not with the thought of life, but

Evidence of Dr. Lyon Playfair of sanitary neglect in Dark Ages.

Plagues of the Middle Ages.

Montaigne and Defoe.

how to protect their bodies from wild beasts after their death. He gives a terrible picture of one of his own workmen, whose last act of life was to draw the earth over his own expiring body. It is not a pleasing task to dwell on the habits of the population, even in our country, in past times. Go back only to the time previous to the Reformation, and you can have no difficulty in understanding why luxury and squalor produced the plagues of the times of the Tudors and the Stuarts. High above all other dwellings were the castles and the monasteries, but the cabin of the peasant was worse than any to be now found in the farthest isles of Scotland. It was made of reeds and sticks, plastered over with mud. In these wigwams lived an ague-stricken population. In the towns, the mechanics lived in rooms without glass windows, slept on straw beds, and worked in workshops unheated by coal fires. Even in well-to-do houses rushes covered the earthen floors, and got saturated with scraps of food, which remained to putrify under a new layer of rushes scattered over it, so that the 'petremen' came to dig saltpetre out of the floors. Filth, instead of being abhorred, was almost sanctified. The monks imitated the filthy habits of the hermits and saints of early Christian times, for the early Fathers commended them. Even St. Jerome used to praise the filthy habits of hermits. He especially commends an Egyptian hermit, who only combed his hair on Easter Sunday, and never washed his clothes at all, but let them fall to pieces by rottenness. St. Antony never washed his feet. St. Thomas-à-Becket, when martyred, had under-garments in a state which makes one shudder in the remembrance. And so the monks, up to the time of the Reformation, and, indeed, in part up to the present day, thought, or professed to think, that by antithesis, pollution of the body indicated cleanliness of the soul. Practically, indeed, it helped to it. Because the odour of sanctity, which infested these old

Times of Tudors and Stuarts.

Description of habitation.

Filth almost sanctified.

Filthy habits of hermits.

St. Antony.

St. Thomas-à-Becket.

Odour of sanctity.

monks and hermits, helped to keep them apart from the temptations of the world; for the world scarcely cared to come into too close contact with these odoriferous saints. But this association of filth with religion was unhappy in its consequences, for men ceased to connect disease with uncleanliness, and resorted to shrines and winking virgins for cures of maladies which were produced by their own physical and moral impurities." For twenty years after the Restoration there was an exceptionally high mortality, even for that epoch, in the metropolis, and, no doubt, throughout the kingdom. Macaulay describes it as a time "when men died faster in the purest country air than they now die in the most pestilential lanes of our towns, and when men died faster in the lanes of our towns than they now die on the coast of Guiana." Dr. Edward Bascome states, in his 'History of Epidemics,' that up to the year 1760, "extraordinary as it may appear, there was not any such thing as a privy in Madrid; it was customary to throw the ordure out of the windows at night, and it was removed by scavengers the next day. An ordinance having been issued by the king that every householder should build a privy, the people violently opposed it as an arbitrary proceeding, and the physicians remonstrated against it, alleging that the filth absorbed the unwholesome particles of the air, which otherwise would be taken into the human body. His Majesty, however, persisted, but many of the citizens, in order to keep their food wholesome, erected privies close to their kitchen fireplaces." This latter arrangement was evidently copied from more ancient times, for the Romans invariably constructed their latrines in chambers adjoining their kitchens.

Lord Macaulay.

Dr. Bascome.

Sanitary arrangements in Madrid.

CHAPTER III.

VARIOUS PLANS PROPOSED IN CARRYING OUT SANITARY WORKS.

Success of sanitary works. On what it depends.

THE success of the prosecution of sanitary works is more dependent upon the character of the works executed than upon any salubrity or insalubrity of climate. This is seen from an examination of the rates of mortality in some continental towns. For example, we find that both Brussels and Paris, which have climates far more salubrious than that of London, have, nevertheless, a higher rate of mortality than London, proving conclusively that the sanitary works of London are of a more effectual, and, therefore, more perfect character, and that they better fulfil their mission than those adopted either in Brussels or Paris. The health of the inhabitants of London, when compared with that of some of the provincial towns of England, shows, in the same marked degree, the superiority of the sanitary works of the metropolis.

Various modes for effecting the removal of decomposing matters.

Various modes have been proposed from time to time for effecting, or perfecting, the appliances within our towns for the removal of all decomposing matter, and various agents have been suggested for use in connection with the removal of those accumulations of filth and dirt which have been found to be so prejudicial to health and life. All the elements known to the ancients have been laid under tribute for this purpose; fire, air, earth, and water have all been proposed and adopted, in their turn, as sanitary agents to be used in connection with the removal of such matter, and for securing the great objects sought by the sanitary engineer.

The advocates of fire recommend that all the waste products of our towns and populous places should be committed to the flames. Use of fire as a sanitary agent.

A second set of advocates would have us believe that air is the best agent for removing those matters, and that the pneumatic is the proper system to be adopted. Use of air as a sanitary agent.

A third set of advocates recommend mother-earth as by far the best agent that can be used in connection with the removal of all fæcal and decomposing matter from the habitations of the people. Use of earth as a sanitary agent.

A fourth set of advocates maintain that the water-carriage system is the best, and the only feasible plan that can be adopted under the varied requirements of a town population. Use of water as a sanitary agent.

Upon careful consideration it must be seen that none of those agents which have been proposed fulfil all our requirements, when we have to deal with the question of removing, not only the fæcal matter, but other refuse from the houses and manufactories of our towns. For example, fire, air, and earth are of little use for removing and disposing of liquid filth; whereas water and air are incapable of being applied so as to deal with a very large mass of the accumulating matter of our towns, namely, the sweepings from streets, ashes and solid garbage from houses, all of which are now required to be removed by manual and horse labour. None of agents proposed entirely effectual.

Air and water have been proposed as the medium by which decomposing matter shall be conveyed through a properly constructed system of pipes, or tubes, out of our towns, and then used for agricultural purposes. Purpose for which air and water proposed to be used.

Fire has been recommended simply as a means whereby decomposing matter may be destroyed, or rather converted, by rapid oxidization into harmless elements. Purpose for which fire proposed to be used.

Earth and other materials of this character have from time to time been recommended and used, more with a view to deodorize and fix the elements of decomposition, so as to render the matter to be dealt with less baneful Purpose for which earth is used.

in its effects on health when accumulating in towns, and also as a means of preserving its manurial value.

Water-carriage preferred.

Of all the systems that have been proposed, the water-carriage system, properly carried out, is, in the opinion of the author, the best adapted to the varied requirements of a town population for effecting the speedy removal of the principal matter liable to decomposition, and the storage of which, even for a brief period, near our dwellings, may be attended with dangerous consequences. It will also be found equal to any other system in securing the manurial elements that have to be utilized; but it should not be overlooked that other systems are applicable, and may be adopted with manifold advantage in conjunction with water-carriage when the circumstances are such as to debar the entire use of that system.

Systems applicable under certain conditions.

CHAPTER IV.

WORKS OF SEWERAGE.

In carrying into effect the works necessary for the sewerage of a town, three distinct operations have to be performed :—

Objects to be secured in works of sewerage.

1st. The drainage of the surface.
2nd. The drainage of the subsoil.
3rd. The removal of fæcal and liquid refuse.

Work performed by ancient sewers.

The sewers of ancient cities were intended to combine two of these objects, or the removal of all surface water and fæcal refuse. The early sewer works of this country were designed for conveying away surface drainage only, which, as a rule, was passed by short lines of sewers to the nearest natural outlet. It was illegal, prior to the year 1815, to pass fæcal matter into sewers. Such matter was generally allowed to accumulate in cesspools, either under the habitations of the people, or in close proximity thereto; but the growing evils of this system were so great that, about the year mentioned, the laws which guarded sewers were by the tacit consent of the various authorities allowed to lapse. But it was not until the year 1847 that the first Act of Parliament was passed, which made it compulsory to pass fæcal and other matters of this character into sewers. Much difference of opinion has been expressed as to the mode in which the objects sought to be fulfilled by sewers ought to be carried out in practice. It may be taken as an ascertained fact that no abstract rule universally applicable can be laid down for the guidance of the engineer in the prosecution of works of sewerage, although there are some general principles

Illegal to drain into sewers.

Compulsory powers to drain into sewers.

Differences as to work to be performed by sewers.

No abstract rule can be laid down for guidance of engineer.

which are common, and applicable to every town. Naturally there are conditions and circumstances which arise during the prosecution of sanitary works, and which differ in different places, which must guide the engineer as to the plan of sewerage he should adopt.

Sanitary works to be capable of fulfilling their mission.

In all sanitary works it should be laid down as a first requirement that the works shall be capable of fulfilling their sanitary mission. All questions relating to the pecuniary results that may arise from the profitable disposal of the matters to be dealt with, must be taken to be of secondary importance, although this question must not be entirely lost sight of.

Definition of words "sewer" and "drain."

The definition of the words "sewer" and "drain" in the present day simply means that drains become sewers in name when they are used for the conveyance of the sullage or liquid refuse from more than one house. So long as the liquid refuse of any one house is confined within a system of ducts that serve only the one particular house, notwithstanding its size and the ramification of the ducts, all these ducts are drains; but from the point where one house-drain joins with another house-drain, or with a duct conveying the sewage from a number of houses, from that point the drain becomes a sewer.

Callis on sewers.

Callis, on the law of sewers, delivered at Gray's Inn in August, 1622, speaking of the origin of the word, says, "Some mincing the word, compound it of two words, *sea* and *were*, saying, that *nomina sunt consonantia rebus;* and there is some coherence between the name and the nature of the thing;" and he further said that, "the sewer is a fresh-water trench compassed in on both sides with a bank, and is a small current or little river." A gutter was also defined by Callis as "of a less size, and of a narrower passage and current than a sewer is; and, as I take it, a gutter is the diminutive of a sewer." Speaking of the law, Callis said, "The use of a sewer is common, and of a gutter peculiar;" and so it is in modern times, the right of user of sewers is common to all, but the right to the use of a drain is particular. Mr. Robert Rawlinson, C.E., C.B., in a paper read at the Society of Arts in March, 1862, says, in reference to the origin of the word "sewer," that, "according to Lord Coke, a place where water 'issues,' or vulgarly 'sues.'"

Mr. Robert Rawlinson, quotation from Lord Coke.

The preliminary inquiry in a district will naturally embrace—

Matters for consideration in designing works of sewerage.

1st. The area of the district to be sewered.

2nd. The rainfall of the district, and the proportion it is intended or desirable to admit into the sewers.

3rd. The geological character and physical outline of the district.

4th. The present and prospective number of its inhabitants.

5th. The supply of water in the district.

6th. The sanitary appliances at present in operation, or to be adopted.

7th. The position of the outfall, and the mode of disposing of the sewage.

CHAPTER V.

AREA AND PLANS OF THE DISTRICT TO BE SEWERED.

Survey of district.

In order to arrive at correct conclusions as to what is necessary to be done in the way of sewerage within a district, a careful survey with levels should be made. Such survey should include not only the area of the district which may be under the jurisdiction of the local authority by whom the engineer may be engaged, but the area which is fixed by the natural configuration of the country around.

Survey in some cases to embrace adjoining district.

It often happens that there are portions of other districts which naturally drain into the district to be dealt with; therefore it may be advisable to take into consideration the volume of sewage or rainfall which may be contributed from such areas. Where several districts governed by different local authorities lie in close proximity, and within the same natural drainage area, it will be desirable for the engineer to take cognizance of the fact, and to make such recommendation, when it is advisable, as may lead the several authorities to combine either for the purpose of sewerage or for the purpose of disposing of the sewage of their respective districts.

Mode of dealing with rainfall of high districts.

In many cases where a large amount of rain falls upon the higher lands above the district to be dealt with, the natural outlet for which is through the district, it will be well to conduct such rainfall by its natural channels, or, in some cases, it may be requisite to construct special artificial channels for its passage, so as not to unduly burden the sewers with a large and intermittent volume of water. It is indispensable that the drainage area above the district to be dealt with should be taken into account in every case when artificial channels are required to be provided for the conveyance of upland waters through the district under consideration.

It not unfrequently occurs that the engineer is called upon to define a district for the purposes of adopting the Local Government or other Drainage Acts; and in doing this he should take into consideration the natural drainage area, and to make the district selected "compact and practicable." As to surveys, in districts in which it is proposed to carry out works of sewerage, the engineer will find that the Ordnance Department have published accurate geometrical plans and surveys of many places, which will often be found of great service to him when designing works of sewerage. In districts in which no accurate plans exist, special surveys will have to be undertaken, and it is desirable, when such surveys are made, that they should be conducted on trigonometrical principles, in order that they may be as accurate as possible. In the suggestions which were issued by Mr. Robert Rawlinson, C.B., from the Local Government Act Office, the following instructions are given as to the preparation of plans and sections of any proposed works of sewerage:—"A general plan, exhibiting the area which will be affected by the proposed works, should be laid down to a scale of not less than two feet to a mile. It should have figured upon it the levels of the centres of all streets and roads at their intersections and angles, and at every change of inclination. Where a district is near the sea it should show the high and low tide level of the sea, and where there is a river the summer and flood water levels should be recorded. Permanent bench-marks, having reference to the surface levels, should be cut on public buildings, &c., throughout the district, and also be marked on the plan. Sections should accompany this plan, upon which the levels of the cellars should be shown. Such a plan might be used for showing lines of main sewers and drains, lines of water pipes and gas-mains. The lines of main sewers and drains should

Drainage district to be defined.

Surveys.

Ordnance maps.

General plan.

What should be shown on plan.

have the cross-sectional dimensions and gradients distinctly marked upon them. The dimensions of water and gas pipes should also be shown in figures or by writing." "A detailed plan for the purposes of house drainage, paving, the sale and purchase of property, &c., should be constructed to a scale of not less than 10 feet to a mile. Upon this plan should be exhibited all houses and other buildings, bench-marks, the levels of streets and roads, of cellars, of the sea at high and low tide level, and the summer and flood level of rivers. Three feet by 2 feet will be a convenient size for the sheets of this plan, and by representing the marginal lines of the sheets upon the general plan, the general plan will become a very useful index." In districts in which it is deemed desirable to carry out works of sewerage as speedily as possible, the Local Government Board do not place any unnecessary obstacle in the way of carrying out such works; and in cases where no plans exist, they will, as a preliminary step, be satisfied, on certain conditions, with less carefully prepared plans, as before suggested, for they state:—"As, however, it may occasionally be desired to carry out works piecemeal, with a view to save the time which would be occupied in the preparation of a complete plan from actual survey, it will be sufficient, in the first instance, to furnish a general plan of streets and roads only, with the surface levels, and those of the deepest cellars, and the proposed scheme of works shown thereon, after which the works can proceed in sections; but with each separate application for sanction to a loan a correct plan and section or sections should be submitted, accompanied by detailed estimates and specifications. It should be understood, however, that the complete plan of the entire district must be proceeded with, so that when the works are finished the Local Board and this office may possess a proper record."

Detail plan.

Index to general plan.

Plans that may be used under urgent circumstances.

Compulsory powers to carry out works.

When carrying out sewerage or sewage utilization works, when it is necessary to put in force the compulsory powers, authority is conferred either by provisional order issued by the Local Government Board, which requires to be confirmed by Parliament, or by the direct sanction of Parliament. In either case it is now necessary to deposit plans, and the Standing Orders of Parliament require that such plans shall be drawn to a scale of not less than four inches to the mile. They are to show the line or situation of the whole work, or any lateral deviation which may be proposed, and if upon the line of the proposed work, or within the limits of deviation, unless the plan shall be drawn to a scale of not less than a quarter of an inch to every 100 feet, an enlarged plan of any "building, yard, court-yard, or land within the curtilage of any building, or of any ground cultivated as a garden," is to be added, and is to be drawn to a scale of not less than a quarter of an inch to every 100 feet. Sections of the work require to be prepared, which shall be of the same horizontal scale as the plan, and have a vertical scale of not less than one inch to every 100 feet; and should it be intended to make any alteration "in the water level of any canal, or in the level or rate of inclination of any turnpike road, public carriage road, or railway," cross-sections must be provided having a horizontal scale of not less than one inch to every 330 feet, and a vertical scale of not less than one inch to every 40 feet.

Parliamentary plans.

Scale of plans.

In addition to the plans required for Parliamentary purposes, or for deposit at the Local Government Board, the engineer should, in every case, prepare detail drawings of the works he is about to execute, for the guidance of those who may have to carry them out. Such details should be drawn to as large a scale as compatible.

Necessity of detail drawings.

In the case of towns having an outfall into the sea, or into a tidal river, careful observations should be made both as regards the direction of the flow of the currents and the rise and fall of the tide. In the case of works extending into the sea-way, the assent of the Admiralty will be required for their construction.

Sea outfalls.

CHAPTER VI.

RAINFALL AND SEWERS.

Use of rain-gauge.

THE amount of rain that falls in a district is computed from the amount collected in the rain-gauge. There are few towns or districts at the present day in which some person or other does not keep a rain-gauge, and register the rainfall. Numerous observations of the amount of rain falling in various districts are annually compiled and published by Mr. G. J. Symons, F.R.S., F.M.S., and such tables are of great importance and inestimable value to the engineer in designing works of sewerage. In a system of sewerage, the works for dealing with the rainfall must be constructed with reference to the maximum falls of rain which will require to be conveyed away without causing inconvenience to the inhabitants of the district. The quantity of rain to be carried, either by sewers, surface-water drains, storm overflows, or any special work provided for this purpose, should be calculated upon the largest amount of rain which falls in the shortest period of time.

Mr. Symons' Rainfall Tables.

Maximum amount of rain should be ascertained.

Difference of opinion as to admitting rainfall into sewers.

Much difference of opinion has been expressed with regard to the advisability or not of admitting rainfall into sewers. Some persons propose that in every district the rainfall should be entirely separated from the sewers; but unfortunately the persons who make this proposition have had, as a rule, a very limited experience as to the effects of rainfall on sewers and sewage. In proposing the separation of the rainfall from the sewers, the fulfilment of three objects is sought: 1st, to increase the manurial value of the sewage; 2nd, to obviate the inconvenience attending the purification of a large and uncertain volume of sewage in times of rainfall; and 3rd, to give to the

Objects sought to be attained by exclusion of rainfall.

streams of the country the natural volume of water due to the rainfall within their collecting area; or, in the words of Mr. F. O. Ward, "to convey the rainfall to the rivers and the sewage to the land." In some districts it may be important to keep the rainfall as far as possible out of the sewers; but there are other districts in which no material advantage would arise from excluding rainfall from sewers; but, on the other hand, positive injury may accrue to the fresh-water streams, by reason of the polluted matters brought down in time of storm. For example, in urban districts, which are closely inhabited, or in which there is a great traffic, experience clearly shows that the rainfall in such districts becomes as impure as the most impure sewage found in sewers. The analysis made by Professor Way of surface-drainage water, flowing from the principal streets of London, shows beyond doubt that the water contributed to sewers, in time of rainfall, is quite as impure as that of any sewage. The Tables Nos. 2 and 3 on the following page give the analysis of street water, and the analysis of the matters found in such water.

Rainfall in urban districts.

Professor Way, analysis of street water.

From Tables No. 2 and No. 3 it will be seen that in districts in which there is great traffic, or which are closely built upon, if a system of sewers is to be carried out which shall intercept all impurities from the fresh-water courses of the country, it will be absolutely necessary to admit a large proportion of the rainfall into the sewers, in order that it may be dealt with so that it may be purified and rendered fit to be passed into the natural streams of the country. In districts where the rainfall is of small amount, it is generally loaded with impurities; while with a heavy rainfall the water last contributed may flow off comparatively pure. Taking this fact into consideration, it is easy, in many districts, to design a system of sewerage combining the admission of small amounts of rainfall into the intercepting sewers of a town, while in time of heavy rainfall the comparatively pure water should not pass into the inter-

Effect of traffic, &c., on rainfall.

Small rainfalls give impure water; large rainfalls pure water.

Scheme for intercepting impure rainfalls from rivers.

TABLE No. 2.—Showing the ANALYSIS of STREET WATER.
By PROFESSOR WAY.
The water was intercepted in its passage to the sewers.

Number of Bottle.	Name of Street.	Quality of Paving.	Quality of Traffic.	Residue in an Imperial Gallon.		
				Soluble.	Insoluble.	Both.
				grains.	grains.	grains.
1	Duke Street, Manchester Square	Macadamized	Middling	92·80	105·95	198·75
7	Foley Street (upper part)	"	Little ..	95·30	116·30	211·43
5	Gower Street	Granite ..	Middling	126·00	168·30	294·30
12	Norton Street	" ..	Little ..	123·87	3·00	126·87
3	Hampstead Road (above the canal)	Ballasted ..	Great ..	96·00	84·00	180·00
4	Ferdinand Street	" ..	Middling	44·00	48·30	92·30
2	Ferdinand Place	" ..	Little ..	50·80	34·30	85·10
10	Oxford Street	Granite ..	Great ..	276·23	537·10	813·33
6	" "	Macadamized	" ..	194·62	390·30	584·92
11	" "	Wood	" ..	34·00	5·00	39·00

TABLE No. 3.—Showing the ANALYSIS of the SOLUBLE MATTER in DIFFERENT SPECIMENS of STREET-DRAINAGE WATER.
By PROFESSOR WAY.

	Grains in an Imperial Gallon.			
	Great Traffic.		Little Traffic.	
	Granite, No. 10.	Macadam, No. 6.	Granite, No. 12.	Macadam, No. 7.
Water of combination and some soluble organic matter	77·56	29·07	22·72	13·73
Silica	0·51	2·81	..	..
Carbonic acid	15·84	12·23	None.	None.
Sulphuric acid	36·49	38·23	46·48	34·08
Lime	6·65	13·38	25·90	16·10
Magnesia	None.	23·51	Trace.	3·50
Oxide of iron and alumina, with a little phosphate of lime	2·58	1·25	..	..
Chloride of potassium	None.	10·99	None.	2·79
" sodium	53·84	44·88	18·44	19·70
Potash	82·76	18·27	8·75	5·23
Soda	..	..	1·58	..
	276·23	194·62	123·87	95·13

cepting sewers, but should flow on to its natural outlet. The arrangement by which this may be accomplished is the reverse of the principlé already put in practice by Mr. J. F. Bateman, C.E., F.R.S., in the Manchester Waterworks, for separating pure and impure water, and is so very simple, and not liable to derangement, that it may easily be introduced in practice, when it will commend itself. It is constructed in accordance with the well-known laws, that the combined effect of horizontal projection and of gravity on a stream of water issuing from an orifice, causes the liquid to assume the form of a parabolic curve; therefore, when it is desired to project a stream a certain distance horizontally, it follows, as a natural sequence, that when the velocity of projection is small (owing to the longer interval of exposure to effect of gravity), comparatively the vertical space fallen through in reaching the desired point will be great; while, when the velocity is great, the vertical space fallen through will be small. Plate XVII., Fig. 9, shows the arrangement. In this case, the sewer for conveying rainfall is assumed to be 2 feet diameter, and has a rate of inclination of 1 in 550, and it is supposed to cross over the intercepting sewer on its course to a river. At the point the sewers cross, an opening is made in both sewers, or in the bed of the rainfall sewer, and in the crown of the intercepting sewer. In this case, the opening is supposed to be 1 foot wide, and at the point of opening, a sudden fall is given to the rainfall sewer, making a step of 2 feet in the sewer. When 3 inches in depth of rainfall flows through the rainfall sewer, the velocity of the current will be 1·6 foot per second, and, in order to pass the opening, 1 foot wide, the step forming a weir should be 6·29 feet; but as it is only 2 feet, all the water flowing down the sewer would pass into the intercepting sewer. When 6 inches in depth of water is running through the 2-feet rainfall sewer, the velocity of current will be 2·25 feet per second, and, in order to pass the opening, the step

Effect of gravity and projection.

Arrangement for intercepting rainfall.

should be 3·25 feet, so that this quantity will also pass into the intercepting sewer. When the rainfall sewer runs half full, the velocity will be 3 feet per second, and, in order to pass the opening, the step or fall should be 1·70 foot; but as in this case it is stated to be 2 feet, all the water brought down by the rainfall sewer will pass over the opening, and would be discharged direct into the river, instead of passing into the intercepting sewer; and so, by adjusting the width of the opening into the intercepting sewer, or the amount of fall at the weir, any given amount of rainfall may be made to pass into the sewers, or be discharged into the streams of the district, as may be required; thus, when the rainfall is small and very impure it will pass into the intercepting sewers; but when the rainfall is great and pure, the velocity is such that it will leap over the opening provided for the interception of the impure rainfall, and pass on to its natural outlet.

Plate I.

Description of intercepters used by author at Longton.

Plate I. illustrates the rain-water intercepters designed by the author for the district of the Corporation of Longton. In this district the sanitary authority made arrangements with his Grace the Duke of Sutherland, whose property is contiguous to the borough, whereby the sewage is taken on to his Grace's land for the purpose of being purified and utilized. One of the conditions insisted upon by the Duke of Sutherland in taking the sewage was that the rainfall, as far as practicable, should be diverted from the sewers, and passed into the natural channels of the district. An inspection of this district would convince even the most casual observer that if the rainfall from the streets were entirely intercepted from the sewers, with it the principal portion of the sewage would pass into streams; as such are the habits of many of the people that they make use of the street gutters for the deposition of nearly all liquid refuse. In this district it is clear that unless some means were adopted by which, at ordinary times, the water from the streets could be carried to the sewers, the authorities would still have a

Necessity of intercepting impure surface water.

liability for polluting the streams hanging over them after having made arrangements for the purification of the sewage. So an arrangement of self-acting rain-water intercepters has been adopted, by the instrumentality of which, when there is a small amount of rain, or when there is nothing but sewage running down the street gutters, it is intercepted, and flows into the sewers proper; but so soon as the rainfall increases, and the contents of the surface-water drains become comparatively pure, this water will not pass into the sewers, but will leap over the opening provided between the two sets of sewers and pass to the natural channels of the district. The openings between the two systems of sewers are also arranged so as to be capable of being opened at pleasure, to admit a smaller or greater amount of liquid to the sewer proper, or at any time may be shut so as to exclude it altogether from passing into the sewer.

Intercepters are adjustable.

It was found desirable in the case of Longton, and it may occur in many other places, to introduce rain-water intercepters where the streams or channels into which the storm-water is to be discharged are liable to considerable changes of level in times of rainfall. Now, unless provision were made against the contingency, there would be a liability of the flood-water passing back into the sewer through the opening provided for the interception of the impure water of the district. To obviate this, an arrangement has been adopted by the author at Longton, which is shown in Fig. 4.

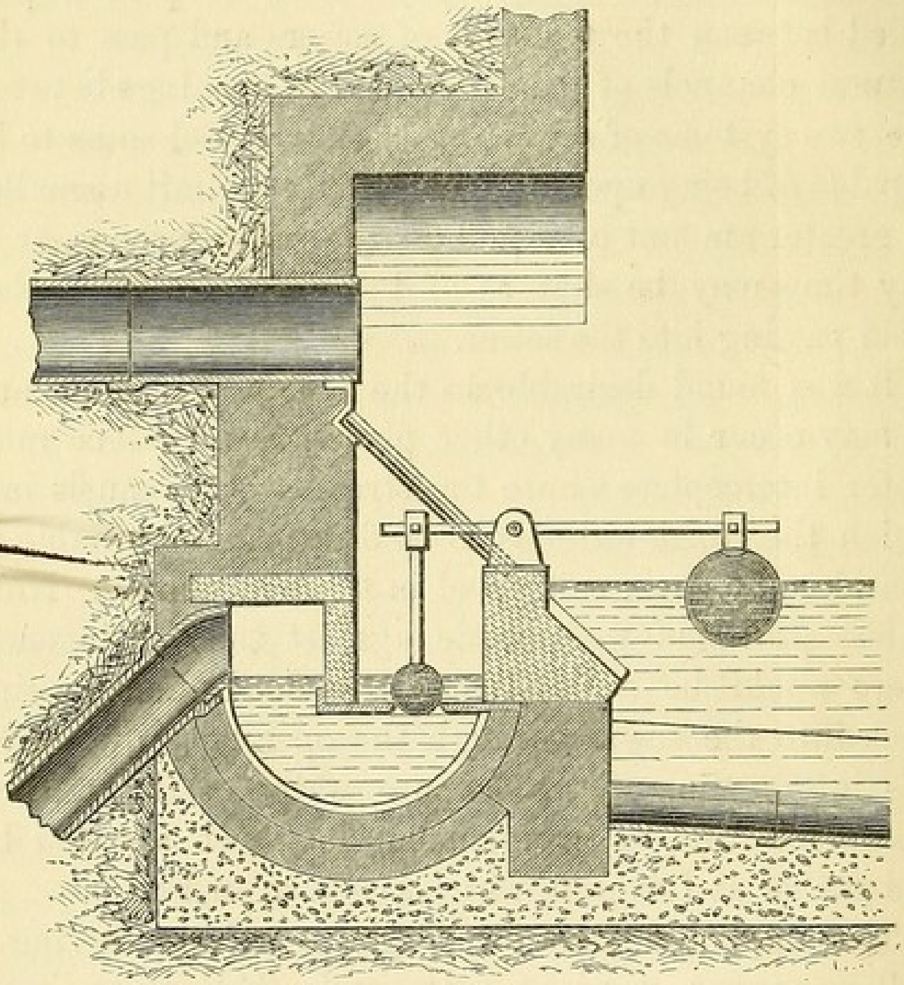
Exclusion of flood-water from sewer.

The apparatus consists simply of a lever having a hollow copper, wood, or guttapercha ball at one end, which in time of flood is made to close a circular opening in a cast-iron plate, through which opening the impure waters have ordinarily to pass to the sewer, and a copper float at the other end of the lever. The apparatus is fixed on one side of the adjustable opening provided for the admittance of the impure waters into the sewers, and in dry weather the superior weight of the float at the end of the longer arm of the lever lifts up the ball out of its seating, and so there is a free passage into the sewer; but in time of flood, should the water rise to such a height as would admit it into the sewers, the float acting at the longer end of the lever rises and pushes down the ball into its seating, so as to effectually shut the opening into the sewer. The whole apparatus is extremely simple and self-acting.

Rainfall in rural districts.

There are some districts of a rural character in which

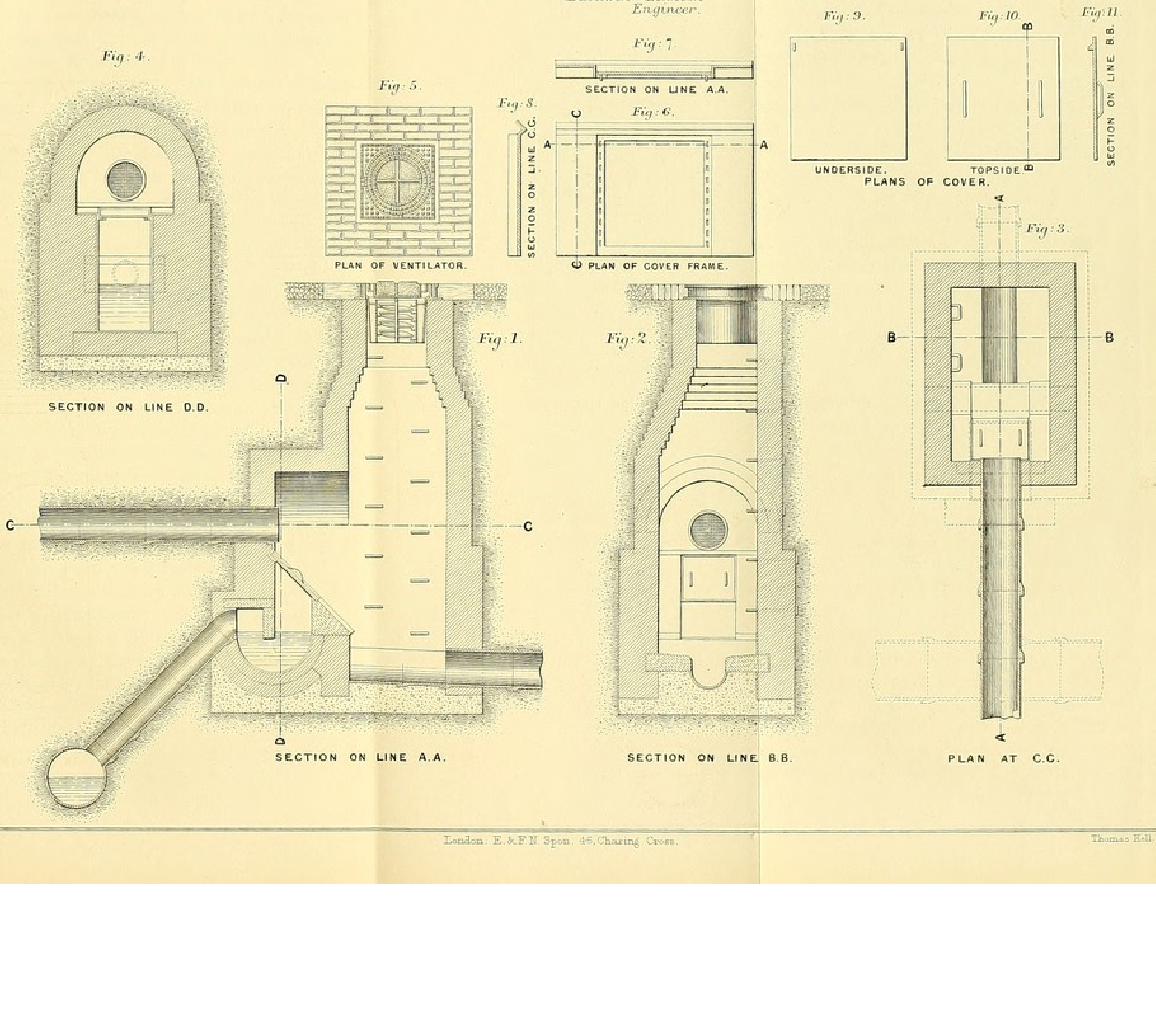
Fig. 4.



the surface drainage is generally comparatively pure, and consequently it could therefore be conveyed to the ordinary water-courses of the district without detriment. On the question of the admittance of rainfall into sewers, Professor Way, speaking of the analysis of the surface water of London, states that, "so far as London is concerned, and considering only the composition of

SURFACE WATER INTERCEPTOR. LONGTON SEWERAGE WORKS.

Baldwin Latham
Engineer.



London: E. & F. N. Spon. 46, Charing Cross. Thomas Kell, Lith.

the liquid which reaches the sewers in the time of rain from the streets, it seems pretty certain that it would be as valuable in a manurial point of view as the ordinary contents of the sewers. There would seem no reason, therefore, to exclude such waters on the ground of the dilution and deterioration of the sewage, to which they might be supposed to lead."

Rain acts as a scavenger.

In considering the question of the amount of rainfall to be admitted into sewers, it should always be borne in mind that rain acts as a scavenger in washing the air and the surface of the streets, courts, yards, roofs, &c., and conveys away an immense amount of impurity. In some foreign countries in which there are distinct periods of wet and drought, it may always be desirable to convey away the excessive storm-water by a distinct set of sewers, while the sewage proper may be conveyed away by another set of sewers, the reason for which is obvious, as, owing to the large amount of rainfall compared with the comparatively limited quantity of sewage, the channels for conveying away the combined rainfall and sewage would have to be constructed so much out of proportion to the ordinary work the sewers would have to perform in periods of drought, that a sufficient velocity of current would not be maintained in the sewers to keep them clear, and consequently they would become sewers of deposit, and might prove highly injurious to health, as the deposit would naturally accumulate at those periods of the year when decomposition was most active.

Experience in foreign countries.

Desirable to intercept rainfall when pumping has to be resorted to.

In some districts, owing to the natural position of their outfall, artificial power may be required to lift the sewage to a considerable height, in order to dispose of it. In this case it would be prudent for the engineer to consider how much rainfall he can exclude without polluting the natural streams of the district. Recent experience at Harrogate shows that a sanitary authority may be made liable for the results of pollution arising from the conveyance of the surface drainage

Experience of effects of surface water at Harrogate.

from streets into the natural water-courses of the country.

Dilution does not always injure sewage.

In studying the question of rainfall it would be well always to bear in mind that experience has shown that dilution of the sewage by rainfall does not materially diminish its total collective value, although it may add considerably to the expense of its application to agricultural purposes; and, consequently, in order to secure the best possible return, it may be desirable to exclude as much rainfall from the sewers as possible in every scheme in which pumping has to be resorted to, in order to reduce the expenses of sewage disposal to a minimum. When sewage is intended to be treated chemically, rainfall should be excluded as far as possible from the sewers.

Seaside towns.

In many seaside places, or in districts in which the low-lying sewers are tide-locked, it will be well to convey away the rainfall by sewers distinct from those which collect the ordinary sewage. To what extent this may be necessary, the engineer will consider after fully taking into account the principle of interception, which is hereafter referred to.

Provision to be made for percentage only of rainfall.

In all cases in which rainfall is admitted into sewers it is found by experience that only a certain percentage of the actual rain finds its way to the sewers, the other portion being either evaporated or absorbed, and it generally occurs that when we have the largest rainfalls, as in thunder-storms, evaporation and absorption are usually most active. In experiments made some years since by Mr. Dickenson, on the rainfall in the district of the Colne, he found on an average of seven years, that from April to September inclusive, 93 per cent. of rainfall was evaporated, and 7 per cent. absorbed, equal to 1192 tons of water per acre evaporated; while but 91 tons per acre were absorbed or filtered into the ground; and from October to March inclusive, 25½ per cent. of water was evaporated, equal to 360 tons of water per acre, and 1052 tons per acre were absorbed.

Mr. Dickenson's experiments.

Mr. Charles Greaves, M. Inst. C.E., has shown by experiments he conducted at Lea Bridge, and recorded in volume xlv. of the 'Transactions of the Institution of Civil Engineers,' that the amount of water passing through a Dalton's gauge filled with earth, on an average of twenty-two years, the average annual rainfall of the period being 25·837, was 6·866 inches, and the amount evaporated 18·970 inches. Experiments with sand show that when the average rainfall of fourteen years was 25·721 inches, the amount percolating through sand was 21·406 inches, and the amount evaporated from sand 4·313 inches, and at the same time the amount evaporated from a water surface was 20·613 inches. Mr. John Evans, F.R.S., who has continued the experiments of Mr. Dickenson, shows that during the twenty years from 1855 to 1875, in the winter months, out of an average rainfall of 13·028 inches, 5·200 filtered through the soil gauge, and 7·792 through a chalk gauge; and in the summer months, out of an average rainfall of 13·352 inches, ·625 inch filtered through the soil gauge, and 1·719 through the chalk gauge; or on an average of the whole period of twenty years, the average yearly rainfall was 26·492 inches, the filtration through the soil gauge 5·852 inches, and through the chalk gauge 9·511.

Mr. C. Greaves, C.E. Percolation experiments.

Mr. J. Evans, F.R.S. Percolation experiments.

The intercepting sewers of London have been constructed to convey rainfall at the rate of a quarter of an inch in depth from the whole area drained every twenty-four hours, at the time the maximum flow of sewage is being discharged. Provision is made to deal with a larger amount of rainfall than this by means of storm-water overflows, communicating with outfalls into the Thames which have been retained or specially provided in the natural drainage valleys of the district. No provision, however, seems to have been made in the intercepting sewers for leakage of subsoil water into the sewers; this quantity is included in the $\frac{1}{4}''$ of rainfall; leakage therefore reduces the actual capacity of the sewers for the reception of rainfall.

Amount of rain admitted into the sewers of London.

Although the sewers of London are calculated to carry away rain at the rate of a quarter of an inch in twenty-four hours, and it is stated in Sir J. Bazalgette's paper on the "Main Drainage of London," that there are not more than twenty-five days per annum when the rainfall in twenty-four hours exceeds this quantity, it must be apparent that the sewers of London are only calculated to convey away one-hundredth of an inch of rainfall and subsoil water per hour, in addition to the sewage, and whenever the rainfall exceeds this rate of fall, although the total fall in twenty-four hours may not equal a quarter of an inch, great inconvenience must naturally be occasioned in the low-level districts, especially if the rain occurs at periods when the sewers are tide-locked, and cannot consequently get relief by the storm-water overflows. Experience in connection with the metropolitan sewers has shown that the allowance made for rainfall and subsoil water in the low-level districts is not sufficient, and consequently some of the low-lying districts which are below high-water mark get flooded, the reason being that, in the low-level districts, when there is a rainfall exceeding the quantity the sewers are constructed to contain, and at the same time the storm-water outlets are tide-locked, the low-lying districts cannot get relief, and are consequently flooded. To obviate this inconvenience, the Metropolitan Board of Works have determined that, when the low-level sewers are filled to excess, and no relief can be afforded by the storm-water outlets by reason of the state of the tide, the excess, or what would under similar circumstances in a high-level sewer flow direct to the Thames, shall, in the case of the low-level sewers, be pumped into the river. From the discussion which took place at the Institution of Civil Engineers, after papers had been read on the drainage of London and Paris, it appears that in 1857 Messrs. Bidder and Hawksley found, in the case of London, that with a rainfall of 2·90″ in

In London, sewers carry ·01 inch rain and subsoil water per hour.

Low-level districts of London get flooded.

Sufficient allowance not made for rainfall in low-level districts of London.

Determination of Metropolitan Board to pump sewage into river Thames.

Messrs. Bidder and Hawksley.

twenty-six hours, Savoy Street sewer delivered 64·5 per cent., Ratcliffe Highway sewer 52 per cent., while Lieut.-Colonel Haywood found in the same storm that London Bridge sewer discharged 53 per cent. Lieut.-Colonel Haywood, in April, 1858, had gaugings taken of the same sewer, "when ·24 of an inch of rain fell in an hour and a half, he then found that 74 per cent. of the total quantity ran off, leaving 26 per cent. to be absorbed or evaporated. Of a rain-storm of ·54 of an inch, in five hours, in June, 1858, there was delivered into the Irongate sewer, which drained an area entirely paved and built over, as much as 94·5 per cent. of the total rainfall; and of all the storm-gaugings he had made, that was the greatest percentage he ever knew discharged by a sewer. In August, 1858, with a rainfall of ·48 inch in one hour and two-thirds of an hour he found only 78 per cent. of the total quantity discharged into the Irongate sewer." The author has found that the amount of water contributed in various districts depends very much upon the character of the surface which receives the rainfall. In districts in which the geological character is porous, the rain contributed to the sewers is very small. For example, in the case of Croydon, where the geological formation principally consists of gravel overlying chalk, the amount of rain contributed by a storm of ·72 of an inch, in twelve hours, in October, 1865, did not yield more than one-tenth of it to the sewers. In a district in Warwickshire, on the new red marl formation, the surface of which is almost entirely impervious, provision was made by the author to lead off a rainfall of 1 inch in twenty-four hours, together with one-half the maximum quantity of sewage in six hours, taken at 5 cube feet per head in twenty-four hours, and the sewers were found to be by no means too large.

Lieut.-Colonel Haywood.

Amount of water depends on character of district.

Experience on gravel and chalk at Croydon.

Experience on red marl of Warwickshire.

Table No. 4 shows the number of days during seventeen years, on which rain fell, the total amount of rain, and when the rainfall at Croydon was equal to or

TABLE No. 4.—Showing the NUMBER of DAYS when RAIN FELL at CROYDON, the AMOUNT of FALL, and the DAYS when the RAINFALL was EQUAL TO, or EXCEEDED in any ONE DAY, the respective QUANTITIES of 1″, ½″, ¼″, and ⅕″ in a PERIOD of SEVENTEEN YEARS.

Compiled from observations by Mr. George Corden, of Croydon.

Rain-gauge 154·6 feet above Ordnance Datum.

Year.	January.						February.					
	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.
1861	2	·49	..	..	1	1	8	2·37	1	1	4	4
1862	8	2·10	..	2	3	5	2	·48	..	..	2	2
1863	16	2·87	..	1	6	7	7	·61	..	..	..	2
1864	8	1·34	..	..	1	2	9	1·32	..	..	2	3
1865*	9	3·45	..	4	5	5	8	1·82	..	1	2	3
1866*	14	4·51	1	2	7	8	17	5·11	1	2	10	11
1867	14	3·12	1	1	5	8	9	1·24	..	..	1	3
1868	19	4·31	..	2	6	8	7	1·22	..	1	1	2
1869	16	2·91	..	1	4	7	15	2·46	..	1	3	4
1870	17	1·43	..	..	..	1	13	1·72	..	1	2	2
1871	16	2·87	..	1	5	5	11	1·19	..	..	1	1
1872	21	5·54	..	4	9	10	14	1·07	..	..	..	..
1873	18	4·08	1	3	5	5	11	1·69	..	1	2	3
1874	11	1·15	..	..	1	2	9	1·83	1	1	1	1
1875	19	3·49	..	1	7	7	11	1·04	..	..	2	2
1876	10	1·04	..	..	1	1	18	2·05	..	..	3	4
1877	27	5·53	1	4	7	9	18	1·70	..	..	1	2
Averages	14·4	2·89	·23	1·52	4·29	5·35	11·0	1·70	·17	·53	2·17	2·88

Year.	March.						April.					
	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.
1861	13	2·72	..	1	5	5	3	·61	..	..	2	2
1862	15	3·26	..	2	5	5	15	2·27	..	..	3	5
1863	8	·79	..	..	..	1	11	·61	..	..	..	1
1864	9	2·95	..	3	5	5	3	·64	..	..	1	1
1865*	9	1·05	..	..	1	2	3	·27	..	..	..	..
1866*	14	2·08	..	1	1	1	13	2·04	..	1	2	3
1867	14	2·58	..	..	4	6	16	1·75	..	1	1	2
1868	14	1·08	..	..	1	1	12	1·92	..	1	3	3
1869	18	1·52	..	..	1	2	8	1·16	..	..	2	2
1870	11	1·84	..	..	2	4	6	·42	..	..	..	..
1871	10	1·50	..	1	2	2	14	3·23	1	1	3	5
1872	13	2·13	..	2	2	4	12	1·23	..	..	2	2
1873	17	1·55	..	..	..	2	11	·63	..	..	..	1
1874	8	·55	..	..	1	1	11	1·87	..	..	4	5
1875	7	·65	..	..	1	1	8	1·74	..	1	2	2
1876	17	2·57	..	..	4	5	15	1·67	..	..	2	2
1877	18	2·15	..	..	4	5	17	4·10	..	3	4	4
Averages	12·6	1·82	..	·58	2·29	3·05	10·4	1·53	·05	·47	1·82	2·35

Year.	May.						June.					
	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.	No. of days on which rain fell.	Rainfall in month. Inches.	1″ or over.	½″ or over.	¼″ or over.	⅕″ or over.
1861	5	·93	..	1	1	1	14	1·90	..	..	3	4
1862	16	3·45	..	3	5	5	6	3·06	1	2	4	4
1863	7	1·50	..	1	3	3	14	3·59	..	3	4	7
1864	10	2·69	..	..	1	2	5	·80	..	..	..	1
1865*	11	3·40	2	3	3	4	5	1·99	..	2	3	3
1866*	9	2·17	..	1	3	3	12	3·05	..	3	4	4
1867	10	1·52	..	..	2	3	7	1·85	..	1	3	3
1868	7	·76	..	..	..	1	5	·35	..	..	..	1
1869	16	3·20	..	3	5	5	9	1·34	..	1	1	1
1870	6	·86	..	..	2	2	3	·20	..	..	..	..
1871	6	1·00	..	..	1	2	13	2·68	..	1	6	7
1872	12	3·05	..	2	5	6	15	1·96	..	..	2	4
1873	13	1·21	..	..	1	1	10	3·41	..	4	4	6
1874	6	·86	..	..	1	1	10	2·54	..	2	4	6
1875	8	·95	..	..	2	3	14	2·26	..	..	3	4
1876	7	·93	..	1	1	1	13	·99	..	..	1	1
1877	13	2·38	..	..	3	7	5	·87	..	..	1	1
Averages	9·52	1·81	·11	·88	2·29	2·94	9·41	1·93	·05	1·11	2·52	3·35

TABLE No. 4—*continued.*

Year.	July. No. of days on which rain fell.	July. Rainfall in month. Inches.	July. 1" or over.	July. ½" or over.	July. ¼" or over.	July. ⅛" or over.	August. No. of days on which rain fell.	August. Rainfall in month. Inches.	August. 1" or over.	August. ½" or over.	August. ¼" or over.	August. ⅛" or over.	September. No. of days on which rain fell.	September. Rainfall in month. Inches.	September. 1" or over.	September. ½" or over.	September. ¼" or over.	September. ⅛" or over.
1861	15	2·78	..	1	2	5	9	·54	..	..	..	..	..	2·16	No detail record			
1862	15	2·09	..	..	4	5	9	3·36	1	1	4	6	11	1·96	..	1	4	4
1863	3	1·16	..	1	2	3	14	2·10	..	..	2	3	19	5·16	..	4	8	10
1864	3	·99	..	1	2	2	4	1·19	..	..	2	4	10	3·09	..	3	6	8
1865*	10	3·33	..	3	4	5	15	3·69	1	2	4	5	1	·27	..	..	1	1
1866*	8	1·48	..	..	3	3	16	3·16	1	1	4	7	19	4·07	..	2	7	7
1867	14	4·21	1	2	4	5	8	2·08	..	1	3	3	11	2·57	..	2	4	4
1868	5	2·23	1	1	2	2	12	2·98	..	1	5	5	7	1·71	..	1	2	2
1869	4	·66	..	..	1	1	10	1·24	..	..	2	2	15	3·32	..	3	4	4
1870	9	2·24	1	2	3	3	8	1·86	..	2	2	3	8	2·44	..	2	4	5
1871	18	2·89	..	1	4	6	6	·81	..	1	1	1	12	5·00	1	4	7	7
1872	13	3·29	1	2	4	6	13	2·24	..	1	3	4	11	1·63	..	1	1	3
1873	8	2·27	1	2	2	2	13	2·53	..	1	3	6	9	2·30	..	1	4	4
1874	7	1·18	..	1	1	1	13	2·41	..	1	3	5	14	2·49	..	1	3	4
1875	17	4·50	..	1	6	6	8	·90	..	..	1	1	11	2·90	1	2	4	4
1876	7	·34	..	..	..	..	12	2·75	..	1	6	7	18	3·07	..	2	5	6
1877	11	2·58	..	2	4	5	13	2·70	..	1	5	6	12	1·65	..	1	2	2
Averages	9·82	2·24	·29	1·17	2·82	3·52	10·7	2·14	·17	·82	2·94	4·00	11·7	2·69	·12	1·87	4·12	4·68

Year.	October. No. of days on which rain fell.	October. Rainfall in month. Inches.	October. 1" or over.	October. ½" or over.	October. ¼" or over.	October. ⅛" or over.	November. No. of days on which rain fell.	November. Rainfall in month. Inches.	November. 1" or over.	November. ½" or over.	November. ¼" or over.	November. ⅛" or over.	December. No. of days on which rain fell.	December. Rainfall in month. Inches.	December. 1" or over.	December. ½" or over.	December. ¼" or over.	December. ⅛" or over.	Rainfall per annum. Inches.
1861	7	1·03	..	..	2	2	..	5·41	No detail record				4	1·29	..	1	1	2	22·18
1862	17	4·92	..	3	6	7	7	1·37	..	..	4	4	9	2·02	..	..	4	5	30·34
1863	13	2·22	..	1	3	3	10	2·08	..	1	2	2	8	2·88	..	2	3	3	25·57
1864	4	1·26	..	2	2	2	11	3·46	1	2	5	6	5	·53	..	..	1	1	20·26
1865*	22	7·20	1	6	10	10	18	3·14	..	..	5	6	9	1·80	..	..	3	3	31·41
1866*	10	1·33	..	1	1	2	11	1·38	..	..	2	3	16	2·00	..	..	3	3	32·38
1867	14	1·89	..	1	3	3	4	·62	..	..	1	1	11	1·61	..	1	1	1	25·04
1868	9	2·37	..	3	3	4	9	1·15	..	..	2	2	24	4·50	..	1	8	11	24·58
1869	9	1·66	..	1	2	2	12	2·53	..	2	3	3	12	3·38	..	2	6	6	25·38
1870	17	4·24	..	2	6	8	10	1·89	..	1	3	4	14	3·03	..	2	3	6	22·19
1871	11	1·17	..	..	1	2	10	·55	..	..	..	..	13	1·65	..	..	1	4	24·54
1872	24	5·24	..	4	8	8	21	3·50	..	..	5	6	20	4·39	..	3	6	8	35·27
1873	14	3·14	1	2	3	3	14	2·54	..	1	4	5	6	·36	..	..	..	..	25·71
1874	17	4·83	..	5	8	9	12	2·59	..	2	3	3	13	1·80	..	1	2	3	24·10
1875	18	4·07	..	2	10	11	19	3·15	..	2	6	6	12	1·22	..	..	1	2	26·87
1876	11	1·31	..	..	1	2	19	2·67	..	..	5	6	24	7·43	..	8	11	15	26·82
1877	14	1·97	..	..	4	5	22	4·94	1	2	5	8	17	1·61	..	..	2	3	32·18
Averages	13·59	2·93	·11	1·94	4·29	4·88	13·06	2·52	·12	·81	3·43	4·06	12·76	2·44	..	1·23	3·29	4·47	26·75

* The figures for these years have been supplied by J. G. Symons, Esq., F.R.S., F.M.S.

exceeded in any one day the respective quantities of 1 inch, half an inch, quarter of an inch, and one-fifth of an inch. The Table also shows the distribution of the falls throughout the year.

From Table No. 4 it will be seen that out of an annual average of 139 days on which rain fell there is but 1·42 day in the year when 1 inch or more rain fell. On 12·93 days half an inch or more rain fell. On 36·27 days a quarter of an inch or more rain fell; and on 45·53 days one-fifth of an inch or more rain fell.

In sewers we have to deal with rain as it falls.

In Table No. 4 the total quantity of rain falling in twenty-four hours alone is given, but in a sewer we have to deal with the rain as it falls, although there are but a few days in the year when any large quantity of rain falls. It should be observed that some very small falls, as measured in the twenty-four hours, occur in a very limited period, and that if the rain continued at the rate of the fall, it would greatly increase the number of days in the year when heavy falls of rain occur. If a sewer is over-charged for a limited period, which may be the case with a very small rainfall as at present measured, very great injury is likely to arise in some districts, and hence the necessity of making separate provision, independently of the sewers, for the rainfall in all cases where it can be accomplished.

A necessity for separate provision for rainfalls.

Calculations for town of Dantzic.

In the strongly fortified town of Dantzic, the geological formation of which is principally sand, and the district very flat, the author made provision for carrying off a quarter of an inch of rainfall in twenty-four hours, together with 2 cube feet per head of sewage in eight hours.* The volume of water supply in this district is about 3 cube feet per head in twenty-four hours, and the sewage was calculated at 4 cube feet in twenty-four hours. The rainfall in this district is about 20 inches annually, but is distributed on an average of years over

Volume of water supply, Dantzic.

Distribution of rainfall of Dantzic.

* It is the practice of some engineers to calculate the volume of sewage to be dealt with as equal to one-half flowing off in six hours, or two-thirds in eight hours.

270 days per annum, and there are only fourteen days per annum when the rainfall equals or exceeds a quarter of an inch in twenty-four hours; only six days per annum when it equals or exceeds half an inch in twenty-four hours; and only about one day per annum when the rainfall reaches or exceeds 1 inch in twenty-four hours. In order to deal with any excess of rainfall beyond the quarter of an inch in twenty-four hours, rain-water outlets have been provided, so that when the sewers become overfilled they discharge their contents at various places into the natural outfalls. In cases in which it is intended to admit rainfall into sewers, the proportionate amount to be contributed by storms will differ in different districts, and the engineer will have to use a considerable degree of discretion in the matter; but correct results can only be arrived at after considerable experience and long observation. The following Table, No. 5, will be found convenient for use in making calculations as to the amount of rain falling upon the site of a drainage area:

Rain-water outlets.

Contribution of storm-water to sewers.

Table No. 5.

TABLE No. 5.—Showing the QUANTITY of RAINFALL per ACRE.

Inches in Depth of Rain.	Cube Feet per Acre.	Gallons per Acre.	Inches in Depth of Rain.	Cube Feet per Acre.	Gallons per Acre.
·1	363	2,262	·6	2178	13,573
·15	544·5	3,393	·65	2359·5	14,704
·2	726	4,524	·7	2541	15,836
·25	907·5	5,656	·75	2722·5	16,967
·3	1089	6,787	·8	2904	18,098
·35	1270·5	7,918	·85	3085·5	19,309
·4	1452	9,049	·9	3267	20,360
·45	1633·5	10,180	·95	3448·5	21,491
·5	1815	11,311	1·0	3630	22,622
·55	1996·5	12,442			

CHAPTER VII.

GEOLOGICAL CHARACTER AND PHYSICAL OUTLINE OF THE DISTRICT.

Influence of geological strata on health.

THE influence of geological strata upon health has from time immemorial received a certain amount of consideration, but until a very recent period the actual result of such influences was based upon very crude and uncertain opinions. Of late, very precise results of the effect of geological strata on health have been compiled by Dr. Buchanan, of the Medical Department of the Privy Council. The last column of Table No. 1, page 9, shows the reduction in the death rate from phthisis in the case of twelve towns. This saving of life is ascribed to the effect of drainage works in drying the subsoil of those places. The effects of a dry subsoil in influencing health were pointed out by Dr. Bowditch, of Massachusetts, in a pamphlet in 1862, wherein he showed that a greater number of deaths took place from phthisis when the inhabitants of a district are located upon a retentive geological formation than takes place when they are disposed on a pervious formation. Dr. Buchanan, in his researches in reference to the influence of the works of sewerage of this country on the public health, and also as to the influence of the geological character of the soil on phthisical diseases, confirms these views; moreover, he found that districts having rapidly inclined retentive geological formations, have a less death rate from phthisis than those in which the same formation is comparatively flat. He also shows that a pervious formation, saturated with fresh water, is favourable to the development of phthisical complaints, while a pervious formation, saturated with sea

Dr. Buchanan.

Reference to Table No. 1, page 9.

Effects of dry subsoil. Dr. Bowditch.

Difference between saturation with fresh and sea water.

water, has, as in the case of some of our sea-coast towns, little or no effect in influencing phthisical disorders. This may be due to the circulation of the water in the soil, caused by the rise and fall of the tide, which prevents stagnation, the great enemy of life. The marked condition of good health in most sea-coast towns which have a porous and saturated subsoil is, in all probability, in a great measure due to the undeviating level of the subterranean water-line. The sea is the natural vent for subterranean water. The conditions of level under which the water is discharged at the sea-coast are such that but a slight amount of deviation in the level can arise, for subterranean water may be assumed to stand at its outfall into the sea at or near the same level as the mean level of the sea into which the water is discharged, and which point is an unvarying or fixed level. When we move into the country from the sea we find the water level of the subterranean water rises as we leave the shore, and the farther we move from the point of natural vent of the subterranean water great changes throughout the year are observable in the water level. It has been shown by Professor Pettenkofer that epidemic outbreaks of both enteric fever and cholera are coincident with changes in the water level of the soil. This is especially the case in gravel soil, and when well water is used which has been taken from wells sunk into the gravel soil, and which soil is also polluted with excremental matter. Low water under such conditions, or a rapid rise in the water line after being low, or any great or sudden change in the water level is sure to be followed by an epidemic of enteric fever. It appears that a process of development of matters excreted from the human body is necessary in order to secure the evil results arising from excrementitious pollution of water, and this development in part takes place in contact with the soil, or certain organic changes occur in the soil which could only be secured by a change in

Good health of seaside towns.

Influence of undeviating water line on health.

Professor Pettenkofer shows the influence of low water in producing diseases.

Use of well water.

the water level. The fluctuating water line simply acts mechanically in furthering the processes of nature. The author has observed, in a number of instances brought to his attention, that without the fluctuation in the water level excremental pollution appears to be inoperative in producing epidemic disease. In India cholera produces the greatest mortality at a time coincident with the lowest levels of the subsoil water. A fluctuating water line is not the cause of disease, as we can well understand that water may fluctuate and produce the most healthful results by promoting an aeration and purification of the soil. Disease is the result of excremental pollution of the soil, favoured by certain descriptions of soil and variation in the subsoil water level within that soil. Those who design systems of sewers or drains will do well to remember when water is met with in the soil, that this water may become a destructive agent to health and life by reason of its contamination by leaky sewers, the evil effects of which may be carried to considerable distances. All subterranean water must be looked upon not as so much inert matter, but as always on the move ready to carry the influences of pollution in the direction of its flow. It has often been observed that on sloping ground disease due to excremental pollution occurs only on the lower side of a street, under the houses of which the underground current of water is poisoned by a leaky sewer or other receptacle of fæcal matter, while the houses located above the source of pollution are healthy. The healthiness or unhealthiness of our houses is, in a great measure, influenced by the condition of the ground atmosphere on which they are built, and this ground atmosphere is materially affected by ground pollution, for germinal matter deposited in contact with the soil receives that development necessary to run its destructive career, and the conditions of temperature and structure of our houses render them favourable ducts for drawing up out of a

Without change in water level no disease.

Cholera coincident with low water in soil.

Disease result of excremental pollution of soil.

Influence of subterraneous currents in carrying impurities.

Ground atmosphere.

polluted soil those miasms which have proved, and still will prove, destructive to human health and life. It is imperatively necessary, therefore, that all sewers and drains should, throughout their entire length, be constructed so as to be perfectly impermeable, and thus prevent those certain results which will inevitably arise when the ground or water beneath our habitations is polluted by excremental matter. The influence of sewerage works in draining the subsoil of a town, and thereby beneficially influencing public health, was understood by some engineers at an early period after the revival of sanitary science; for in the report upon the "City Sewers," by Messrs. Walker, Brunel, and Cubitt, dated August, 1848, we find it stated that "the first and perhaps not least important purpose of sewers, as respects health, is the underdrainage of the surrounding earth. They answer this purpose effectually and quietly, and have done it so long that their importance in this respect is apt to be overlooked." In all works of sewerage, in order to get their full benefit, it is requisite that provision should be made for the drainage of the subsoil. The mere fact of carrying out a system of sewerage, and being obliged to cut through various strata of a more or less retentive character, is naturally a means of securing to a great extent subsoil drainage; but it is not well to depend entirely upon the intersection of various geological formations, as it has been shown, from the results compiled by Dr. Buchanan, that drainage works when first brought into operation, or during their construction, have had greater effect in drying the subsoil and in reducing the rate of death arising from phthisical disorders than has been secured in after years. This may be accounted for from the fact that the drainage of the subsoil was more perfect prior to the complete consolidation of the sewer trenches than it has been subsequently. In designing a system of sewers, therefore, the engineer should

Sewers should be impermeable.

Benefits of sub-drainage understood by engineers.

Report of Walker, Brunel, Cubitt.

Provision should be made for sub-drainage.

Effects of drainage works in reducing subsoil water.

Provision should be made for subsoil

drainage in such a way as not to allow sewage to escape.

make provision—more especially in retentive geological formations—for the effectual drainage of the subsoil, the works for which purpose should be constructed and carried out so as to prevent any chance of sewer water percolating into the surrounding ground. The mode in which this operation can be accomplished will be considered hereafter.* The geological character of the district in which sewerage works are executed will also materially affect the quantity of water which may be collected from the surface of the district. In districts in which an impermeable stratum covers the surface, the volume of water contributed to the sewers will be large, and be discharged more rapidly than in districts in which the geological formation is of a pervious description. On the other hand, it not unfrequently happens in districts which are covered with a pervious geological formation, that a short distance below the surface subsoil water in large quantities is met with, supplying the sewers with a constant quantity of spring water, and not unfrequently leading to difficulty in the construction of the works. The geological character of the district must also be studied with a view to the stability of the works which are to be executed. If it is found that the character of the strata is not sufficiently stable to receive the sewers, provision will have to be made whereby a good foundation for the works to be executed may be secured.

Districts in which impermeable stratum covers surface.

Districts in which pervious stratum covers surface.

Subsoil water yielded to sewers.

Example of Redhill.

As a not unfrequent example of the results of sewerage works, carried out in a district of a permeable geological formation, the small town of Redhill, in Surrey, may be taken. The works of sewerage were designed by the author. The town is located on the lower greensand formation, and its population is under 5000. In carrying on the work of excavation for the sewers in all parts of the district, more or less subsoil water had to be contended with. In the lower portions of the district especially, the saturation of the

* Vide page 476.

subsoil was so considerable that great difficulty arose in the prosecution of the works, for so unstable was the subsoil that special artificial foundations for the sewers had to be adopted.* The completion of the works in a great measure removed the subsoil water; but even now, in the driest season, the springs yield not less than 25 cube feet of water per minute to the sewers.

Influence of physical outline on surface discharge.

The physical outline of the district will also have a material influence upon the volume of the water which has to be conveyed by the sewers. In districts in which the gradients are steep, the discharge of surface water takes place more rapidly than in those districts in which the same description of geological strata is comparatively flat, and in a district with steep gradients a larger percentage of rainfall will be contributed to the sewers than is found to be the case in districts in which the gradients are flat. The consideration of the outline of a district is of great importance when studying the question of the ventilation of sewers; the same provisions that are effectual for the ventilation of sewers in flat districts are totally inadmissible when the gradients are great, for wherever the gradients are steep, the sewers will act as chimneys for drawing off the foul gas from the lower parts of a district, and disperse it in the higher parts, so, when the gradients are steep, special provision should be made in order to prevent sewer air travelling from the lower to the higher portions of a district. The mode in which this may be effected is hereafter considered at page 372.

Influence of physical outline on ventilation of sewers.

* See Fig. 54, page 277.

CHAPTER VIII.

POPULATION.

Present population.

In this country, where great attention has been paid to tabulating the population of various districts, it is no difficult task for the engineer to calculate the present population of a district for which the works of sewerage are to be constructed. It may, however,

Prospective population.

become difficult to calculate the prospective population of the district, which is a point of importance, as in all works of sewerage the money expended on the works should be distributed over a term of years for repayment, and it is only just to those of the ratepayers who may hereafter occupy the district, that the works towards which they will have to contribute should be of equal service to them as to those who called them into existence. The mode usually adopted in approximating the future population, is to ascertain what has been the prospective rate of increase for a number of years back, and by making the same, or, in some cases, a greater allowance for increase in the future, so to calculate what is likely to be the probable population in years to come. In some districts this mode of estimating the population has been shown to be liable to error, as there are districts, such as manufacturing or suburban districts, located near large centres of population, which are liable to rapid rates of increase, and in some cases the population of particular manufacturing and mining districts has been found to decline. The

How population ascertained.

present population of a district can always be pretty correctly ascertained by taking the number of inhabited houses, which may be got from the rate-books, and multiplying the number by the average number of inhabitants which were found at the previous census to occupy a house. As a rough and ready rule, it may be computed that five persons inhabit each separate dwelling. Population affects works of sewerage, inasmuch as each individual member of the community uses a certain quantity of water for ablution and general cleansing purposes, and each individual also contributes a certain amount of manurial matter to the sewers, which forms the basis of the value of the sewage of a town, so that it is absolutely necessary that the number of the population contributing to the sewers should be ascertained, and taken into consideration by the engineer, when designing works of sewerage, or sewage disposal.

How population affects works of sewerage.

CHAPTER IX.

WATER SUPPLY OF A DISTRICT.*

How water supply affects works of sewerage.

THE works appertaining to the water supply of a district are specially treated hereafter. Water supply affects a system of sewerage to be carried out in any town, by reason of the volume of water that has to be conveyed away. The sources of supply to be taken into consideration are:—

1st. The volume of water distributed by specially constructed waterworks.

2nd. The amount raised or taken from tanks and wells on private property.

3rd. The quantity contributed by manufactories.

Average quantity of water supply.

Taking an average of 120 towns in this country, the author found that the volume of water supplied daily for all purposes averaged 25 gallons per head. In some cases the quantity was greatly in excess of this average, for as much as 56 gallons per head was supplied, while in some towns it did not exceed 10 gallons per head. The quantity of water used in a district in a great manner depends upon the facilities afforded to the public in procuring the supply, also upon the sanitary appliances in operation within the district, and to some extent upon the character of the population supplied with water. Districts in which water-closets are universally used, or in which the use of private baths is general, have a somewhat higher rate of water consumption than districts in which the only supply of water is from isolated stand pipes, and in which the

Quantity depends upon facility of procuring it.

Water-closets and baths increase quantity.

* It is the intention of the author to treat the subject of Water Supply in a separate volume, and he has now such a work in preparation, but it will be some time before it is ready for publication.

TABLE No. 6.—Showing the VOLUME of SEWAGE of some TOWNS.

Name of Town.	Area of District in Acres Sewered.	Population of Sewered District.	Average Quantity of Sewage daily discharged by Sewers. Gallons.	Quantity of Sewage discharged per head per day in Gallons.	Proportionate Number of Houses supplied with Water-closets.	Remarks.
Alnwick and Canongate	600	6,000	300,000	50	Nearly all	
Bangor	600	10,500	630,000	50	$\frac{4}{5}$ths	
Birmingham ..	8000	300,000	15,000,000	50	Very few	
Bishop Auckland	290	5,000	30,000	6	Very few	
Bury St. Edmunds ..	350	13,000	50,000	4	1 per cent.	Imperfectly sewered.
Cardiff	344	30,000	2,000,000	66	Nearly all	
Carlisle	2000	30,000	843,000	28	$\frac{3}{5}$ths	
Cheltenham ..	2000	36,000	600,000	$16\frac{2}{3}$	Nearly all	
Coventry ..	..	42,000	750,000	18	420	
Crewe	..	16,000	613,000	$38\frac{1}{3}$	$1\frac{1}{4}$ per cent.	With exception of about 50 water-closets, all ash-pits.
*Croydon ..	1260	45,000	3,345,000	$76\frac{1}{2}$	All	Dry weather flow 56 gallons per head, due to water supply.
Haverfordwest	1760	7,000	150,000	$21\frac{1}{2}$	$\frac{1}{2}$	
Kelso	100	4,300	60,000	14	10 per cent.	
Leek	1280	10,500	400,000	38	1 in 30	
Leicester ..	1300	93,000	3,000,000	$32\frac{1}{4}$	6,900	6 per cent., privy cesspools.
Liverpool ..	7014	500,000	16,000,000	32	Nearly all	The volume of sewage is the minimum dry weather flow.
London	59,010	3,000,000	88,000,000	29	w.c. general	
Loughborough	380	10,800	200,000	$18\frac{1}{2}$	1 in 80	
Luton	..	17,000	640,000	36·4	1 in 30	
Merthyr Tydvil	..	50,000	850,000	17	But few	Dry weather flow.
Nottingham ..	1800	120,000	1,900,000	16	$\frac{1}{4}$	
Plymouth ..	600	75,000	5,000,000	66	Nearly all	
Preston	2418	83,000	2,000,000	24	1 in 20	Dry weather flow.
Redhill	..	3,200	286,000	89	50 per cent.	200,000 gallons is spring water.
Rugby	200	8,000	382,000	$47\frac{3}{4}$	$\frac{6}{7}$ths	Dry weather flow.
Scarborough ..	884	23,000	256,000	11	$\frac{2}{3}$rds	
Selby	2620	6,000	160,000	26	Nearly all	
Sheerness ..	150	13 000	310,000	23	1 per cent.	
Skipton	130	6,000	116,000	20	314	Dry weather flow.
Southampton	800	45,000	2,000,000	44	Nearly all	
Southport ..	400	12,000	290,000	24	About $\frac{1}{2}$	
St. Helens ..	700	25,000	850,000	34	1 in 30	
Taunton ..	560	15,000	250,000	17	90 per cent.	
Wakefield ..	1500	26,000	1,000,000	38	6 per cent.	
Warwick ..	..	10,000	700,000	70	..	Gelatine manufactory at Warwick uses about 300,000 gallons of water per day.
Waterloo ..	214	4,500	225,000	50	..	
Weston-super-Mare	480	10,000	480,000	48	$\frac{9}{10}$ths	

* This only includes Croydon proper, which does not embrace the whole parish. Adequate measures are not adopted by the Local Authority for the prevention of the waste of water, which is excessive in this district, and spring water enters the old sewers from the imperfect manner in which they were jointed.

ash-pit or some other dry system is in operation. The quantity of water supplied by pumps or other appliances procured locally from wells or tanks is generally small, for where the labour of procuring supplies of water is great, the quantity used is small; on the other hand, where facilities for procuring water are great, the consumption is found to be large.

Quantity used by manufacturers.

The quantity of water used by manufacturers must be considered, as provision will generally have to be made for receiving such water in the sewers. In some processes of manufacture large quantities of water are used, which subsequently find their way to the sewers. For example, in the town of Warwick there is a single gelatine manufactory which uses as much water in the process of manufacture as is used by the whole population of the town, which contains upwards of 10,000 persons, so that in this district provision had to be made for a much larger volume to pass into the sewers than would have been due under ordinary circumstances.

Volume of sewage for which provision should be made.

As a general rule, 5 cubic feet per head per day, half flowing off in six hours, is the quantity of sewage the engineer must make provision for, in addition to such an amount of rainfall and subsoil water as he may be disposed to admit into the sewers. Table No. 6 gives the volume of sewage in some towns, and will be of interest and value as a guide for future works.

CHAPTER X.

SANITARY APPLIANCES OF DISTRICT.

Complete system of sewerage.

WHEN a complete system of sewerage is intended to be carried out, and water-carriage is to be used for the removal of all the refuse and fæcal matter usually transported by sewers, the engineer will have no great difficulty in arriving at the probable volume of sewage he will have to deal with. In some places there exist differences of opinion amongst the Sewer Authorities as to the benefits derivable from the universal application of the water-carriage system. It might be supposed that when carrying out a system of sewerage in a district in which the water-closet system is intended only to be partially adopted, as is now the case in many manufacturing towns in the North of England, it would be necessary to make some abatement in the sizes of the sewers on account of the volume of sewage to be excluded. In many northern towns of this country the authorities oppose the introduction of water-closets on the ground of the increased volume of water it would be necessary to procure if their use became general. Many persons also oppose the introduction of water-closets on the ground that they are the sole cause of the pollution of the streams of the country. A very slight amount of investigation will show that the sewage of the northern towns in which midden-steads are generally adopted, is, as a rule, quite as impure, and nearly as great in volume, as in districts in which water-closets are universally used, while at the same time the sewage contains nearly as large an amount of putrescent organic matter as in a water-closet town. The Rivers Pollution Commissioners

Differences of opinion on water-closets.

Northern towns of England, opposition to water-closets.

Midden-stead towns' sewage impure.

Analysis of sewage of towns.

have given the figures recorded in Table No. 7, these being the result of the examination of the sewage of a large number of midden-stead and water-closet towns.

TABLE No. 7.—Showing the COMPOSITION of the SEWAGE of TOWNS in PARTS per 100,000.

Description.	Total Solid Matter in Solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Total combined Nitrogen.	Chlorine.	Suspended Matters. Mineral.	Organic.	Total.
Average midden towns	82·4	4·181	1·975	5·435	6·451	11·54	17·81	21·30	39·11
Average water-closet towns ..	72·2	4·696	2·205	6·703	7·728	10·66	24·18	20·51	44·69

The excess of chlorine in the sewage of a midden-stead town shows that there is a larger proportion of urine present in a given volume of sewage than is found in a water-closet town. The Rivers Commissioners also found that the case is not substantially altered where earth-closets are used: they said, "The sewage from Broadmoor Lunatic Asylum, in which these closets are partially used, exhibits no exceptional degree of weakness," and they conclude by saying, "It seems hopeless, therefore, to anticipate any substantial reduction of sewage pollution by dealing with solid excrementitious matters only." The great consumption of water in many towns is due rather to imperfect fittings, &c., than to the introduction of water-closets. At Croydon the author made numerous experiments, and found that for all domestic purposes, inclusive of water-closets, the average consumption of water in houses in which the fittings were perfect did not exceed five gallons per head per day, and this result was arrived at in the case of houses* which were above the average rateable value. Various devices have been proposed at different times in order to separate fæcal matter from the sewers or in some cases to separate the urine from the solid fæces. All these devices have

Broadmoor sewage and earth-closets.

Consumption of water due to imperfect fittings.

Consumption of water with perfect fittings.

Separation of fæcal matter from sewers.

Separation of urine from fæces.

* These houses were not fitted with baths.

been propounded with a view to get some money return for the agricultural constituents of the material to be dealt with, and not by any means with the view of introducing such appliances as a sanitary necessity. Table No. 6, page 67, shows the volume of sewage in various towns, the proportionate number of water-closets in use is also given, and consequently the Table in question may be taken as a guide by the engineer in carrying out similar works. To what has already been stated it is only necessary to add that the introduction of the water-closet, with perfect water-waste preventing fittings, will not materially increase the volume of sewage, for which provision will require to be made, as the water used for this purpose forms but a small part of the whole of the water used for domestic and general purposes; therefore, in districts in which ash-pits, earth-closets, or other devices of this character are used for collecting fæcal matter, it will be well that the same provision should be made in the size of the sewers as is made in those districts in which water-closets are universally adopted.

Agricultural not sanitary expedients.

Volume of sewage of towns.

Water-closets not materially increase water supply.

CHAPTER XI.

POSITION OF OUTFALL AND MODE OF DISPOSING OF THE SEWAGE.

Position of outfall must be first considered.

THE position of the outfall of the district is one of the first points that will require the consideration of the engineer, and so soon as the outfall has been arranged the rest of the scheme may be proceeded with without hesitation. In no case is it now advisable to proceed with works of internal sewerage until an outfall has been secured. In a great measure the success of the scheme will depend both upon the position and the number of outfalls to be brought into operation in a district.

Sewers follow natural falls.

As a rule it is usual, in constructing sewers, to lay them in the direction of the natural falls of the district, consequently the outfalls of sewers are almost invariably found to be located in the valley of a river or stream which naturally provides for the drainage.

Sewage must not be passed into rivers.

But as it is advisable that the sewage in no case should be allowed to intermix with the pure natural water of the country, so as to lead to its pollution, provision must be made for either purifying the sewage before passing it into the fresh-water streams, or, as in the case of sea-coast towns, to lead it to such a point as not to become the cause of offence.

Purification of sewage.

In inland towns it will be found that there are chemical or mechanical systems which will greatly palliate the evils of pollution by precipitating or deodorizing the sewage, but the nuisance arising from sewage pollution may not always be removed in this way; consequently such works are generally supplemented by intermittent filtration, or irrigation works.

Sewage irrigation.

The plan that has hitherto proved most successful in purifying the sewage of an inland town is that of utilizing it in its fresh state on properly prepared land. In sea-coast towns it will generally be found most economical to carry the sewage directly out to sea; but in some cases, as a matter of precaution, the sewage may be required to be filtered, or otherwise treated, before being discharged into the sea, as prevailing winds may blow floating matter on to the shore. Where sewage has to be raised artificially, in order to be applied to land, as will be the case in many towns, the point of outfall will be one of material importance. In some towns, a system of interception hereafter referred to, with two or more outfalls, may be advantageously introduced in order to diminish the cost of the system of sewers, and establish the economic disposal of the sewage. All outfalls should be protected by proper arrangements so as to exclude reverse currents of either water or air from entering the sewers.

Sewage, sea-coast towns.

Intercepting sewers.

Outfall must be protected.

CHAPTER XII.

SELF-CLEANSING SEWERS AND VELOCITIES OF FLOW.

Construction of sewers left to unskilful workmen.

THE early sewer works in this country were generally put into the hands of the most unskilful workmen. Little or no attention was paid to the proper construction of drains or sewers; in fact, it appears that the fastidious generations of the past looked upon constructions that had to do with the removal of those waste matters which have to be dealt with in every house and in every town, as too disgusting in their nature to be mentioned in the ears of refined society. The frightful consequences arising from this utter disregard of these very necessary matters became the means, in a great measure, of awakening attention and scientific inquiry into the principles which should regulate the construction of sewers. So well is the importance of securing perfect works of sewerage now understood, that it has become a proverbial saying that "a man should look to his drains before he furnishes his drawing room." The early sewers executed in this country have been called "sewers of deposit;" in fact, at one period it seems to have been a recognized feature that all sewers must sooner or later choke from the accumulation of deposit, therefore certain rules and regulations were laid down for their construction, with a view to make the sewers of such a size as should be convenient for the purpose of sending men into them to cleanse them when they became choked. Figs. 5, 6, and 7, represent three sizes of sewers. Those of 2 feet diameter (Fig. 5) were considered sufficient for men to crawl into in order to cleanse them; when they were from

Causes which led to improvement in construction of sewers.

Proverbial saying.

Sewers of deposit.

Rules for constructing sewers for men to enter.

Description of woodcuts.

3 feet to 3 feet 6 in vertical dimensions (Fig. 6) men could crouch in them, and when they were from 4 feet to 4 feet 6 in vertical dimensions (Fig. 7) men could move in a stooping position, and they were required to be made at least 6 feet in height, in order that men could stand in an upright position; when constructing sewers on these principles, it was conceded that the larger sewers were made the better they were, for it was shown that if sewers were made sufficiently high for men

Argument in favour of large sewers.

Fig. 5.

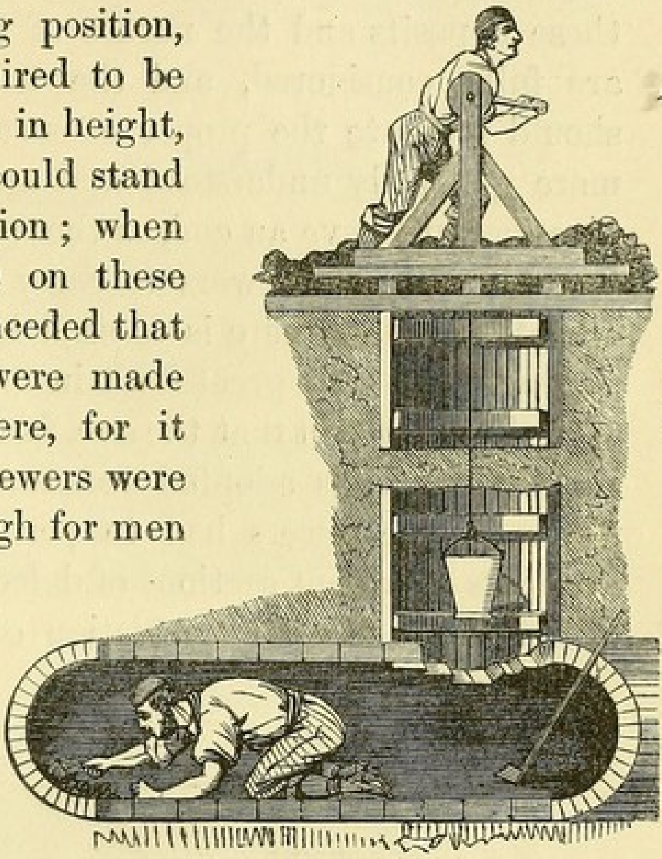


Fig. 6.

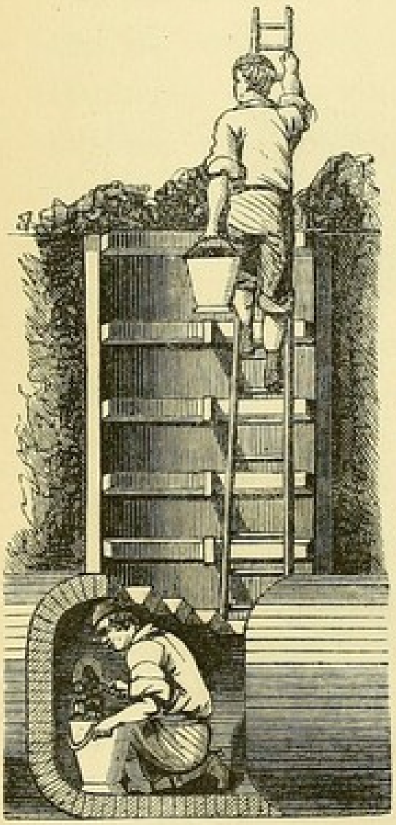
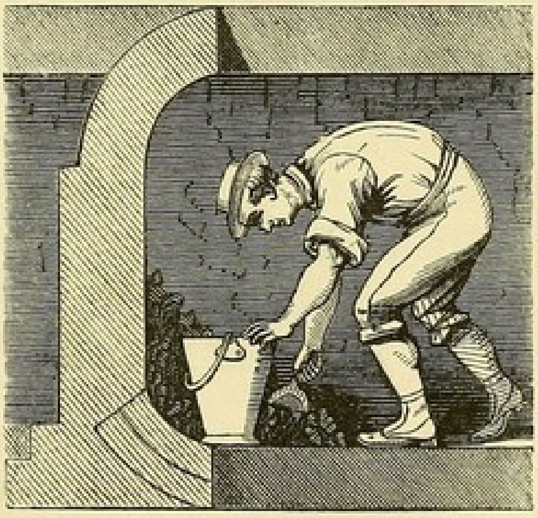


Fig. 7.



to walk through them, a man was able to remove in the course of a few hours, from a choked sewer, as much matter as he would in as many days from a sewer of smaller dimensions. The author in the course of his

Vile character of cleansing operation.

experiences has often seen men pass into old sewers of no larger diameter than 2 feet (Fig. 5), which had become completely choked with decomposing fæcal and other vile matter. When the noxious character of these deposits and the nature of the work performed are fully considered, and the true principles which should regulate the proper construction of sewers are more generally understood and appreciated, these vile practices will have an end, as there is no more necessity to send men into sewers to carry out such disgusting operations, than there is to send boys up chimneys to sweep them. The great fault in the early sewer works arose from the fact that the size, form, mode of construction, or materials adopted were not in accordance with the work the sewers had to perform. The following woodcuts represent sections of defective forms of drains and sewers. Fig. 8 is a section of a house-drain the

Fault of early sewers.

Description of woodcuts.

Fig. 8.

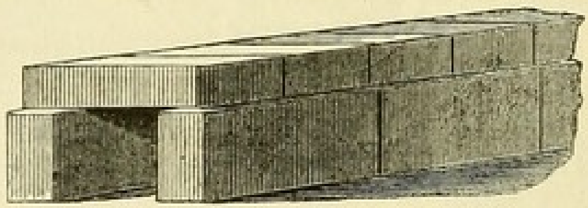
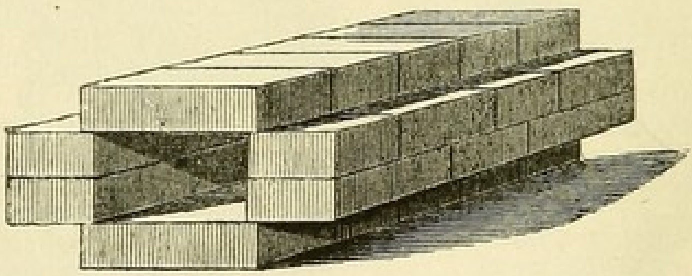


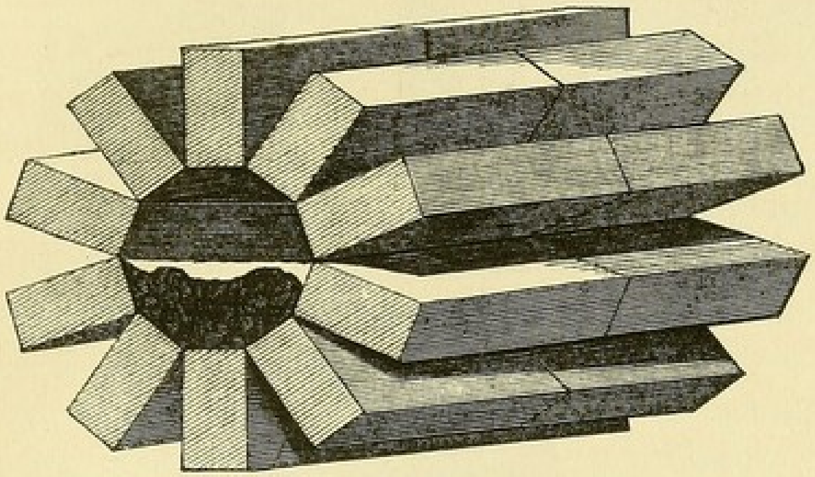
Fig. 9.



sides of which are constructed of bricks laid on edge on the floor of the trench, covered again with bricks lengthways, so as to give a sectional area of 6 inches by 4½ inches; such drain having nothing but a rough and often pervious soil, for its floor soon stopped up. Fig. 9 is an improvement on Fig. 8, inasmuch as bricks are also used to form the invert of the sewer.

Fig. 10 represents an attempt to construct a circular sewer of small dimensions with the ordinary bricks. The effect of using such bricks in constructing so small a sewer is shown in the wide gaping joints at the back,

Fig. 10.



and as such sewers were generally put together with improper materials, in course of time the ordinary mortar in the joints disappeared, and the liquid escaped through the joints and left the solid matter to choke the sewer.* The earlier sewers were generally made with flat inverts, in fact this was the plan adopted by the Romans, and was probably copied from them. The stream of sewage flowing through the sewers was often very small in proportion to the size of the sewer, and, when spread over a large flat surface, its velocity was so much impeded by the frictional resistance of the bed, and the angles of the channel, that the matters in suspension in the water were deposited, until at length the sewers became completely choked, and then commenced those disgusting operations of sending men into them to remove the obstructions. The following Figures, 11, 12, and 13, show the way in which matters accumulate in sewers.

Early sewers had flat inverts.

These examples are taken from well-authenticated

* Many of the houses in the west-end of London still remain drained in this manner.

Examples compiled, General Board of Health.

records compiled by the General Board of Health. The materials used in the construction of sewer works have

Fig. 11.

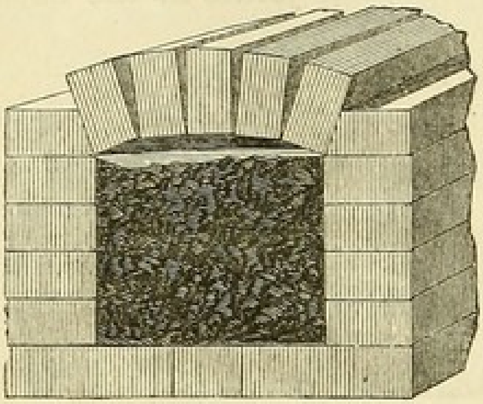


Fig. 12.

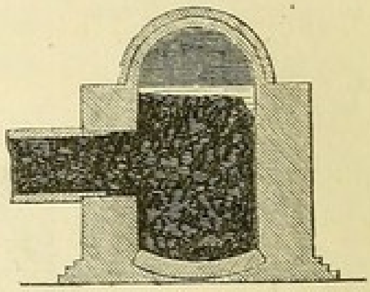


Fig. 13.

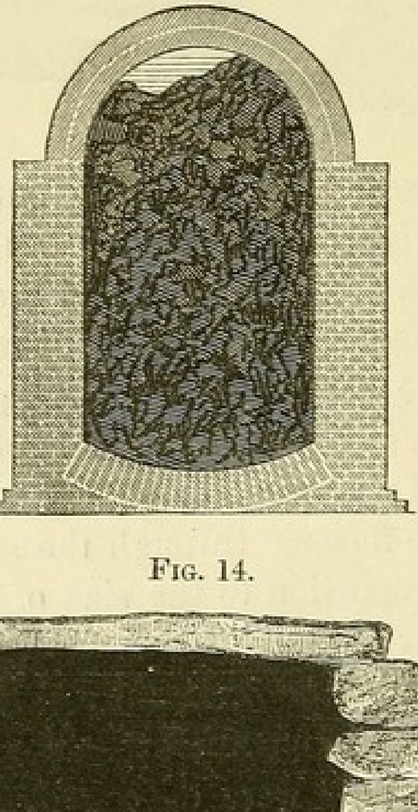
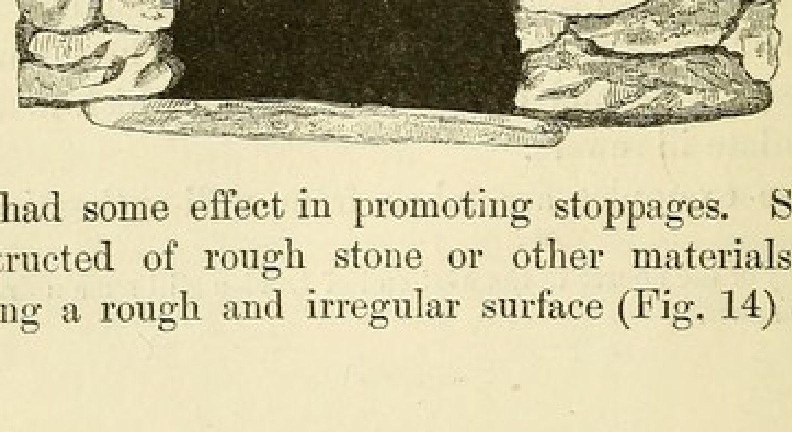


Fig. 14.



Materials used in sewers.

also had some effect in promoting stoppages. Sewers constructed of rough stone or other materials presenting a rough and irregular surface (Fig. 14) cause an obstruction to the flow of the sewage by retarding the stream, which leads to deposit. Other sewers were constructed of such an impervious character that they really became absorbing sewers (vide Figs. 5 to 10), that is, the solid and liquid matters passed into the sewers, the liquid flowed away through the crevices and joints of the sewer itself into the subsoil, and left the solid matter to choke the sewers. It has been amply demonstrated, from the results gained by experience in the management and working of sewers, that by so proportioning the size, form, and inclination of a sewer to the volume of sewage it has to convey, it may be made self-cleansing. It was a generally received opinion at one time that all brick sewers were sewers of deposit, and that pipe sewers were self-cleansing, but upon this point there can be no greater mistake. Pipe sewers may become sewers of deposit, and brick sewers may be made self-cleansing. In order to prevent deposit in sewers, it is necessary to provide a certain velocity in the flow of sewage, which must be secured throughout the whole system of sewers, and such velocity must be sufficient to prevent the subsidence from the liquid of any matters in suspension, and also to move along the bed of the channel any solid deposit. Numerous experiments have been made, at various times, by different individuals, as to the effect of currents of water in moving matter along variously formed channels, and from these experiments certain rules have been laid down for the guidance of the engineer when constructing works of sewerage. Mr. Wicksteed ascertained, on the Leicester sewerage works, that if a bottom velocity of 16 inches per second, equal to $\frac{9}{10}$ths of a mile per hour, could be maintained, such velocity would prevent the deposit of small pieces of brick and stone, and with a velocity of $21\frac{3}{4}$ inches per second, or 1·24 mile per hour, iron borings or heavy slag would be removed by the current. Experience in the working of sewers, since the date of

Absorbing sewers.

How sewers are to be made self-cleansing.

Velocity of flow to be maintained.

Experiments.

Mr. Wicksteed's experiments.

these experiments, has amply demonstrated that the velocity of flow must be considerably greater than shown by Mr. Wicksteed's experiments, if sewers are to be kept free from deposit. In no case should the velocity be less than 2 feet per second, but in the generality of cases it should be much greater. It is surprising to hear some persons, who really ought to know better, at the present day contending that fall for a sewer is not of any material importance, and who state, no doubt what they think is true, that sewers without fall work well, and are self-cleansing. Careful inquiry into all these alleged examples shows how utterly mistaken the persons are who make these statements, and that the inevitable result of constructing sewers without fall has invariably led to failure of the work.

Velocity must not be less than 2 ft. per second.

M. Dubuat gives the velocity necessary to remove certain solid substances as under:—

	ft.	in.	
River mud, semi-fluid	0	3	per second.
Brown pottery clay	0	3¼	„
Common clay	0	6	„
Yellow sand, loamy	0	8½	„
Common river sand	1	0	„
Gravel, size small seeds	0	4¼	„
„ of peas	0	7⅛	„
„ of beans	1	0½	„
Coarse ballast	2	0	„
Sea shingle, about 1 in. diameter	2	2	„
Large shingle	3	0	„
Angular shingle, size of hen's eggs	3	3	„
Broken stones	4	0	„
„ agglomerated, or schistous rocks	4	4	„
Rocks with distinct layers	6	0	„
Hard rocks	10	0	„

Mr. Beardmore.

The late Mr. Nathaniel Beardmore, C.E., in his extremely valuable Hydraulic Tables, gave 150 feet per minute as the velocity which should be maintained in sewers. Mr. J. Phillips, C.E., who has had considerable experience in the working of sewers in London, states that a velocity of 2½ feet per second, equal to 1¾ mile per hour, will prevent deposit. Professor Rankine says that the velocity in sewers should not

Mr. Phillips.

Professor Rankine.

be less than 1 foot per second or more than $4\frac{1}{2}$ feet per second. House-drains, he says, should have a velocity of $4\frac{1}{2}$ feet per second. The velocity necessary to remove obstructions from sewers in a great measure depends on the specific gravity of the deposit. All matters submerged in water lose weight in proportion to the volume of water they displace, consequently comparatively small currents have great effect in carrying forward solid matter. Experiments made by Mr. T. E. Blackwell, C.E., for the Government referees in the plan of the main drainage of the metropolis, show, very clearly, the effect of currents in removing substances of different specific gravity. For example, coal of a specific gravity of 1·26 commenced to move in a current of from 1·25 to 1·50 foot per second, a second sample of coal of specific gravity 1·33 did not commence to move until the velocity was 1·50 to 1·75 foot per second, a brickbat of specific gravity 2·0, and chalk of specific gravity 2·05, required a velocity of 1·75 to 2 feet per second to start them. Oolite stone specific gravity 2·17, brickbat 2·12, chalk specific gravity 2·0, broken granite specific gravity 2·66, required a velocity of 2·0 to 2·25 feet per second to start them. Chalk specific gravity 2·17, brickbats specific gravity 2·18, limestone specific gravity 1·46, required a velocity of from 2·25 to 2·50 feet per second to start them. Oolite stone, specific gravity 2·32, flints specific gravity 2·66, limestone specific gravity 3·00, required a velocity of 2·50 to 2·75 to start them. It was shown in these experiments that after the start of the materials with the current, in no case did the materials to be transported travel at the same rate as the stream, but in every case their progress was considerably less, as a rule often more than 50 per cent. less than the velocity of the current. The author in the course of his experience has found that in order to prevent deposit in small sewers or drains, such as those of 6 inches and 9 inches diameter, a velocity of not less than 3 feet per second should be produced.

Velocity to remove obstructions depends on their specific gravity.

Mr. T. E. Blackwell's experiments.

Materials transported do not move with same velocity as the current.

Author's experience.

Sewers from 12 to 24 inches diameter should have a velocity of not less than $2\frac{1}{2}$ feet per second, and in sewers of larger dimensions in no case should the velocity be less than 2 feet per second. Recently the author has been called upon to reconstruct the sewers of several towns in which they have ceased to work by reason of the inattention paid to matters relating to fall, and practical experience now clearly demonstrates that no sewers ought to be constructed with less falls than to give the velocities above mentioned. In order to maintain these velocities in sewers, it is absolutely requisite that a certain rate of inclination should be secured; thus small sewers will require a greater rate of fall than large sewers, and large sewers, on the other hand, must have provided a much larger volume of fluid, so that the proper velocity through them may be maintained. It is not sufficient to design a large sewer in a district of small fall, unless, to prevent its becoming a sewer of deposit (which it would undoubtedly become even when its rate of inclination when running full or half full would give the required velocity to make it self-cleansing), we are sure of a volume of sewage which will fill the sewer to the proper extent so as to maintain the velocity required, either naturally, or artificially by flushing arrangements. Sewers of various sizes, having different rates of inclination, will have the same velocity: for example, a sewer 10 feet diameter having a fall of 2 feet per mile, a sewer 5 feet diameter a fall of 4 feet per mile, a sewer 2 feet diameter a fall of 10 feet per mile, and a sewer 1 foot diameter a fall of 20 feet per mile; but in order to maintain the same velocity the 10-feet sewer will require to convey one hundred times, the 5-feet twenty-five times, and the 2-feet four times as much sewage as the 1-foot sewer. The adjustment of the various sizes of sewers is a matter which will always require the careful consideration of the engineer.

Sufficient volume of sewage is necessary to render sewers self-cleansing.

Sewers of various sizes have same velocity.

Hitherto, in speaking of velocities, we have been dealing with the mean velocity of streams, but in practice it is found that velocity increases in a current as the fluid particles of the stream are removed from its sides or bed, consequently the velocity at the bottom of a channel, or over the invert of a sewer, is the velocity which is really effective in scouring it, and such velocity is always less than the mean velocity. The mean velocity of the stream, according to M. Prony's formula, is as follows:— Bottom velocity in sewers. M. Prony's formula.

$$v = V \frac{V + 7 \cdot 776}{V + 10 \cdot 335}.$$

V = surface velocity.
v = mean ,,

Experiments made by Messrs. A. A. Humphrey and H. L. Abbot show that the velocity of a stream varies at different depths, and that the variation is represented by a parabolic curve, the axis of which is parallel to the surface of the stream, and at the place of the greatest velocity "the ordinates are the depths and the abscissæ the corresponding velocities," and they state in their report on the Mississippi river that "a mathematically exact expression for the mean velocity of the whole curve at once results from what has already been established and from the well-known property of the parabola, that the area of the segment included between the co-ordinates of any point is equal to two-thirds of the rectangle constructed upon those co-ordinates," and they gave the following formula for computing the mean velocity:— Experiments, A. A. Humphrey and H. L. Abbot.

$$Vm = \tfrac{2}{3} V d_1 + \tfrac{1}{3} V D + \frac{d_1}{D} (\tfrac{1}{3} V o - \tfrac{1}{3} V D).$$

Vm = mean velocity.
Vd_1 = maximum velocity.
Vo = surface velocity.
VD = bottom velocity.
d_1 = depth below surface of fillet, moving at maximum velocity.
D = depth of stream.

Practical rule for sewers.

For all practical purposes in the case of sewers the velocity along the invert of the sewer will be 76 per cent. of the mean velocity given in the Tables, so that the velocities given therein ought not to be departed from. The velocity in a sewer is proportionate to the square root of the section when divided by the wetted perimeter, therefore velocity diminishes greatly with the depth of the stream flowing through the sewers, and, as a rule, when we have the smallest quantity of sewage and the least depth flowing through the sewers, the sewage is carrying its maximum load of suspended matter, consequently there is a greater inclination for matter to subside at such times, on account of the velocity being at its minimum.

Sewers in upper district.

In every system of sewers the upper portions should naturally have a greater rate of inclination than the lower portions of the system, as in those parts there is a smaller quantity of sewage to deal with, and consequently a greater fall is required to produce the necessary velocity to render the sewer self-cleansing.

Necessity for flushing sewers.

In cases in which the ordinary flow of sewage would not give the requisite velocity to render the sewers of a district self-cleansing, artificial means are used for flushing the sewers by temporarily increasing the volume passed through them in a given time. The various modes which are adopted for flushing sewers, are hereafter specially considered.

Muddiness and cleanness of water affect velocity of flow.

Observations made by the author on a stream flowing in a brick culvert show that the muddiness or cleanness of the water has a most important influence on the velocity of flow, for he has repeatedly observed when the same depth of water is flowing in the same channel there is always a considerable retardation in the velocity whenever the water is turbid. What amount of material or what character of material has the greatest effect in retarding the flow of water is not at present known. Observation, however, goes so far to show that we may reasonably conclude that water holding in suspension solid matters, or in solution large quantities of salts, is not so mobile as water which is comparatively free from such matters. The great discrepancy in hydraulic formulæ, founded on practical results, may in a great measure be due to the differences in the qualities of the water used or observed by the different persons. Further experimental research is necessary in order to collect data, showing to what extent the quality or impurities held by water affect its flow.

Mobility of water influenced by foreign matters.

Further experiments on flow of impure water necessary.

Description of Tables relating to the Velocities in Sewers Nos. 8 to 28 inclusive.

These Tables are worked out from the formulæ of Weisbach, given at page 130.

Table No. 8.

Table No. 8 shows the proper inclination of various sized circular sewers from 3 inches to 10 feet diameter for velocities varying from 2 feet to 6 feet per second. It is equally applicable to sewers running full or half full. In this Table it is calculated that the head of water is equal to the velocity in feet, therefore the velocity in feet multiplied by the inclination equals the length of sewer in feet, to which the calculation correctly applies. For example, a drain 4 inches diameter is required to be laid at such inclination as to give a velocity of 3 feet per second. On examination of the Table it will be seen, under the column of velocity for 3 feet, that a 4-inch drain must have an inclination of 1 in 92, therefore to make the calculation strictly correct, $3 \times 92 = 276$ feet, is the length of the drain to which the calculation applies. If the velocity is 6 feet per second, the rate of inclination given by the Table for a 4-inch drain would be 1 in 24, and $6 \times 24 = 144$ feet, the length to which this calculation correctly applies.

Table No. 9.

Table No. 9 shows the proper inclination of oval sewers for velocities varying from 2 feet to 6 feet per second when flowing full. This Table is applicable only to the old form of oval sewer, in which the transverse diameter is two-thirds of the vertical diameter, the invert having a radius equal to one-fourth the transverse diameter, and the radius of the sides being one and a half times the transverse diameter. In this Table it is calculated that the head of water is taken the same as in the previous Table, or equal to the velocity; consequently the length of sewer to which the Table is applicable equals the velocity multiplied by the rate of inclination. For example, a sewer 3 feet × 4 feet 6 inches, having a velocity of 2 feet per second, would require to be laid at an inclination of 1 in 2028, and the length of sewer to which the calculation is applicable $= 2 \times 2028$, or 4056 feet.

Table No. 10.

Table 10 shows the proper inclination of oval sewers (old form) for velocities varying from 2 feet to 6 feet when flowing two-thirds full.

Table No. 11.

Table No. 11 shows the proper inclination of oval sewers (old form) for velocities varying from 2 feet to 6 feet when the sewers are running one-third full. It will be seen by comparing Table No. 10 with Tables Nos. 9 or 11 that when a sewer is running two-thirds full, with a given rate of inclination, a greater velocity is produced than when the same sewer is running full or one-third full, or, in other words, it requires less inclination to produce the same velocity in a sewer when running two-thirds full, than is required to produce the same velocity in the same sewer when running full or one-third full.

Note to Tables Nos. 9, 10, and 11.

New form of oval sewer. Table No. 12.

Table No. 12 shows the proper inclination of oval sewers for velocities varying from 2 feet to 6 feet per second when running full. This Table is only applicable to the new form of oval sewer or sewers in which the transverse diameter is two-thirds of the vertical diameter, the invert having a radius equal to one-eighth of the transverse diameter, the radius of the sides being one and a third times the transverse diameter. In this Table it is calculated that the head of water is equal to the velocity in feet, therefore the velocity in feet multiplied by the inclination equals the length of sewer in feet, to which the calculation correctly applies, consequently the length of sewer to which the Table is applicable equals the velocity multiplied by the rate of inclination. For example, a sewer 3 feet × 4 feet 6 inches, having a velocity of 2 feet per second, would require to be laid at an inclination of 1 in 1991, and the length of sewer to which the calculation is applicable equals 2 × 1991 or 3982 feet.

Table No. 13 shows the proper inclination of oval sewers of the new form (the proportions of which are given in the description of Table No. 12) for velocities varying from 2 feet to 6 feet per second when running two-thirds full. Table No. 13.

Table No. 14 shows the proper inclination of oval sewers of the new form (the proportions of which are given in Table No. 12) for velocities varying from 2 feet to 6 feet when running two-thirds full. Table No. 14.

Table No. 15 shows the proper inclination for a defined velocity in circular sewers of 1 foot diameter when running full or half full, and working under various heads. The proper inclination of any other sized circular sewer may be found by multiplying the inclination given in this Table by the diameter of the sewer in feet or decimal parts of feet. Therefore, as we have already laid down the rule that in no sewers should the velocity be less than 2 feet per second, the least inclination of any sewer may be approximately arrived at by multiplying the number 583 by the diameter in feet, or decimal parts in feet, of the proposed sewer. So with any other velocity, if the figures given in this Table are kept in mind, the rate of inclination for any other sized sewer may be easily ascertained. For example, take a sewer 6 inches diameter with a velocity of 2 feet, we shall find that $\cdot 5 \times 583 = 291 \cdot 5$, gives the least rate of inclination at which a sewer of that diameter should be laid down, or 1 in 291. If we take Table No. 15.

a sewer 10 feet diameter, with a velocity of 2 feet, 10×583 gives 5830, representing the least inclination of a sewer of that size, or 1 in 5830, and so on in regard to any other size. This Table is applicable to any length of sewer. In using it, all that is required to be determined is the total fall in the sewer we propose to construct. For example, say that it is 10 feet, under column h we find 10 feet, and under the column of velocity, say 2 feet, we find 606·3, which represents the least inclination of a sewer of 1 foot diameter. If the sewer was 3 feet diameter, the proper rate of inclination to give a velocity of 2 feet per second, would be $3 \times 606{\cdot}3 = 1$ in 1819, or if the sewer was 18 inches diameter, and the velocity required 3 feet per second, we shall find opposite the 10-feet fall in the column of 3-feet velocities, 289·4, which multiplied by $1{\cdot}5$ foot $= 1$ in 434.

Table No. 16. Table No. 16 shows the proper inclination for a defined velocity in oval sewers (old form) 1 foot $\times$ 1 foot 6 inches when running full and working under various heads. The proper inclination of any other sized oval sewer may be easily ascertained from this Table, for it will be found that if the least or transverse diameter in feet or decimal parts of feet is multiplied by the inclination given under the several velocities in this Table, the result will express the proper inclination for any other sized sewer having the usual proportions, that is, in cases in which the transverse diameter equals two-thirds that of the vertical diameter, the invert being struck with a radius of one-fourth the transverse diameter of the sewer, the side being struck with a radius equal to the vertical dimensions of the sewer.* For example, if we take a sewer 3 feet $\times$ 4 feet 6 inches, the total fall in the length of sewer taken into consideration being 10 feet, the velocity requisite to be maintained in the sewer when running full being 2 feet per second, we shall find under column of 2-feet

* The proportion is shown in Fig. 20, page 178.

velocities opposite 10 feet, 702·6; if we multiply this by 3 feet, or the transverse diameter of the sewer in question, it will correctly express the inclination of the required sewer, or $3 \times 702 \cdot 6 = 1$ in 2107·8.

Table No. 17 is similar to No. 16, except that it is calculated to give the inclination and velocity in oval sewers (old form) when running two-thirds full. Table No. 17.

Table No. 18 is similar to No. 16, except that it is calculated to give the inclination and velocity in oval sewers (old form) when running one-third full. Table No. 18.

Table No. 19 shows the proper inclination for a defined velocity in oval sewers 1 foot × 1 foot 6 inches of the new form,* or sewers in which the transverse diameter is equal to two-thirds of the vertical diameter. The invert is struck with a radius of one-eighth of the transverse diameter, the radius of the sides being one and a third times the transverse diameter when running full and working under various heads. The proper inclination of any other sized oval sewer of the same proportions can easily be ascertained from this Table. It will be found that if the least or the transverse diameter in feet or decimal parts of feet is multiplied by the inclination giving the several velocities in this Table, the result will express the proper inclination of any other sized sewer having the same proportions. Table No. 19.

Table No. 20 is similar to Table No. 19, except that it is calculated to give the inclinations for velocities in oval sewers of the new form when running two-thirds full. Table No. 20.

Table No. 21 is similar to Table No. 19, except that it is calculated to give the inclination for velocities in oval sewers of the new form when running one-third full. Table No. 21.

Table No. 22 gives the velocity in feet per minute in circular sewers of sizes varying from 3 inches to 10 feet diameter when constructed at inclinations varying from Table No. 22.

* The proportion is shown in Fig. 21, page 180.

1 in 5 to 1 in 6000. In preparing this Table, the length of sewer taken into consideration is the same as in Table No. 8, or the head of water is taken as being equal to the velocity. For all practical purposes it may be considered correct, but in cases in which greater accuracy is required, the proper inclinations may be worked out from Table No. 15.

Table No. 23. Table No. 23 gives the velocity in feet per minute in oval sewers of the old form of section when running full. It is calculated for sewers varying in size from 1 foot × 1 foot 6 inches to 6 feet × 9 feet, when constructed at inclinations varying from 1 in 100 to 1 in 4000.

Table No. 24. Table No. 24 is similar to Table No. 23, except that the calculations are made for sewers when running two-thirds full.

Table No. 25. Table 25 is similar to Table No. 23, except that the calculations are made for sewers when running one-third full.

Table No. 26. Table No. 26 gives the velocity in feet per minute in oval sewers of the new form, and is calculated for sewers varying in size from 1 foot × 1 foot 6 inches to 6 feet × 9 feet, constructed at inclinations varying from 1 in 100 to 1 in 4000.

Table No. 27. Table No. 27 is similar to Table No. 26, except that it is calculated for oval sewers of the new form when running two-thirds full.

Table No. 28. Table No. 28 is similar to Table No. 26, except that it is calculated for oval sewers of the new form running one-third full.

TABLE No. 8.—Showing the PROPER INCLINATION of CIRCULAR SEWERS, for Velocities varying from 2 feet to 6 feet per second, when RUNNING FULL or HALF FULL.

Diameter in Inches.	Rate of Inclination for								
	$v = 2.$	$v = 2·5.$	$v = 3.$	$v = 3·5.$	$v = 4.$	$v = 4·5.$	$v = 5.$	$v = 5·5.$	$v = 6.$
3	1 in 146	1 in 97	1 in 69	1 in 51	1 in 40	1 in 32	1 in 26	1 in 22	1 in 18
4	„ 194	„ 129	„ 92	„ 68	„ 53	„ 42	„ 34	„ 29	„ 24
6	„ 292	„ 193	„ 137	„ 102	„ 80	„ 63	„ 51	„ 43	„ 36
8	„ 389	„ 257	„ 183	„ 137	„ 106	„ 85	„ 69	„ 57	„ 48
9	„ 437	„ 290	„ 206	„ 154	„ 119	„ 95	„ 77	„ 65	„ 54
10	„ 486	„ 322	„ 229	„ 171	„ 133	„ 106	„ 86	„ 72	„ 60
12	„ 583	„ 386	„ 275	„ 205	„ 159	„ 127	„ 103	„ 86	„ 72
14	„ 681	„ 450	„ 321	„ 239	„ 186	„ 148	„ 121	„ 100	„ 84
15	„ 729	„ 482	„ 344	„ 256	„ 199	„ 159	„ 129	„ 107	„ 90
16	„ 778	„ 515	„ 367	„ 273	„ 212	„ 169	„ 138	„ 115	„ 96
18	„ 875	„ 579	„ 412	„ 307	„ 239	„ 190	„ 154	„ 129	„ 108
20	„ 972	„ 643	„ 458	„ 342	„ 265	„ 212	„ 172	„ 143	„ 120
21	„ 1021	„ 676	„ 481	„ 359	„ 278	„ 223	„ 181	„ 150	„ 126
22	„ 1069	„ 708	„ 504	„ 376	„ 292	„ 233	„ 189	„ 158	„ 132
24	„ 1166	„ 772	„ 550	„ 410	„ 318	„ 254	„ 206	„ 172	„ 144
27	„ 1312	„ 869	„ 619	„ 461	„ 358	„ 286	„ 232	„ 193	„ 162
30	„ 1458	„ 965	„ 687	„ 512	„ 398	„ 317	„ 257	„ 215	„ 180
33	„ 1604	„ 1062	„ 756	„ 564	„ 438	„ 349	„ 283	„ 236	„ 198
36	„ 1749	„ 1158	„ 825	„ 615	„ 477	„ 381	„ 309	„ 258	„ 216
40	„ 1944	„ 1286	„ 917	„ 683	„ 530	„ 423	„ 343	„ 287	„ 240
42	„ 2041	„ 1351	„ 962	„ 718	„ 557	„ 445	„ 362	„ 301	„ 252
45	„ 2186	„ 1448	„ 1031	„ 769	„ 596	„ 476	„ 386	„ 323	„ 270
48	„ 2332	„ 1544	„ 1100	„ 820	„ 636	„ 508	„ 412	„ 344	„ 288
54	„ 2624	„ 1737	„ 1237	„ 922	„ 716	„ 571	„ 463	„ 387	„ 324
60	„ 2915	„ 1930	„ 1375	„ 1025	„ 795	„ 635	„ 515	„ 430	„ 360
66	„ 3207	„ 2123	„ 1512	„ 1127	„ 875	„ 698	„ 566	„ 473	„ 396
72	„ 3498	„ 2316	„ 1650	„ 1230	„ 954	„ 762	„ 618	„ 516	„ 432
78	„ 3790	„ 2509	„ 1787	„ 1332	„ 1034	„ 825	„ 669	„ 559	„ 468
84	„ 4081	„ 2702	„ 1925	„ 1435	„ 1113	„ 889	„ 721	„ 602	„ 504
90	„ 4373	„ 2895	„ 2062	„ 1537	„ 1193	„ 952	„ 772	„ 645	„ 540
96	„ 4664	„ 3088	„ 2200	„ 1640	„ 1272	„ 1016	„ 824	„ 688	„ 576
102	„ 4956	„ 3281	„ 2337	„ 1742	„ 1352	„ 1079	„ 875	„ 731	„ 612
108	„ 5247	„ 3474	„ 2475	„ 1845	„ 1431	„ 1143	„ 927	„ 774	„ 648
114	„ 5539	„ 3667	„ 2612	„ 1947	„ 1511	„ 1206	„ 978	„ 817	„ 684
120	„ 5830	„ 3860	„ 2750	„ 2050	„ 1590	„ 1270	„ 1030	„ 860	„ 720

TABLE No. 9.—Showing the PROPER INCLINATION of OVAL SEWERS (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-fourth of the transverse diameter, the radius of the sides being 1½ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING FULL.

Size of Sewer.	$v = 2$.	$v = 2·5$.	$v = 3$.	$v = 3·5$.	$v = 4$.	$v = 4·5$.	$v = 5$.	$v = 5·5$.	$v = 6$.
' " ' "									
1 0 × 1 6	1 in 676	1 in 448	1 in 318	1 in 238	1 in 185	1 in 147	1 in 120	1 in 100	1 in 84
1 2 × 1 9	,, 789	,, 523	,, 371	,, 277	,, 216	,, 171	,, 140	,, 117	,, 98
1 4 × 2 0	,, 902	,, 597	,, 424	,, 317	,, 247	,, 196	,, 160	,, 133	,, 112
1 6 × 2 3	,, 1014	,, 672	,, 477	,, 357	,, 278	,, 220	,, 180	,, 150	,, 126
1 8 × 2 6	,, 1127	,, 747	,, 530	,, 397	,, 308	,, 245	,, 200	,, 167	,, 140
1 10 × 2 9	,, 1239	,, 821	,, 583	,, 436	,, 339	,, 269	,, 220	,, 183	,, 154
2 0 × 3 0	,, 1352	,, 896	,, 636	,, 476	,, 370	,, 294	,, 240	,, 200	,, 168
2 2 × 3 3	,, 1465	,, 971	,, 689	,, 515	,, 401	,, 318	,, 260	,, 217	,, 182
2 4 × 3 6	,, 1578	,, 1045	,, 742	,, 555	,, 432	,, 343	,, 280	,, 233	,, 196
2 6 × 3 9	,, 1690	,, 1120	,, 795	,, 595	,, 463	,, 367	,, 300	,, 250	,, 210
2 8 × 4 0	,, 1803	,, 1195	,, 848	,, 635	,, 493	,, 392	,, 320	,, 267	,, 224
2 10 × 4 3	,, 1915	,, 1269	,, 901	,, 674	,, 524	,, 416	,, 340	,, 283	,, 238
3 0 × 4 6	,, 2028	,, 1344	,, 954	,, 714	,, 555	,, 441	,, 360	,, 300	,, 252
3 2 × 4 9	,, 2141	,, 1419	,, 1007	,, 753	,, 586	,, 465	,, 380	,, 317	,, 266
3 4 × 5 0	,, 2254	,, 1493	,, 1060	,, 793	,, 617	,, 490	,, 400	,, 333	,, 280
3 6 × 5 3	,, 2366	,, 1568	,, 1113	,, 833	,, 648	,, 514	,, 420	,, 350	,, 294
3 8 × 5 6	,, 2479	,, 1643	,, 1166	,, 873	,, 678	,, 539	,, 440	,, 367	,, 308
3 10 × 5 9	,, 2591	,, 1717	,, 1219	,, 912	,, 709	,, 563	,, 460	,, 383	,, 322
4 0 × 6 0	,, 2704	,, 1792	,, 1272	,, 952	,, 740	,, 588	,, 480	,, 400	,, 336
4 2 × 6 3	,, 2817	,, 1867	,, 1325	,, 991	,, 771	,, 612	,, 500	,, 417	,, 350
4 4 × 6 6	,, 2930	,, 1941	,, 1378	,, 1031	,, 802	,, 637	,, 520	,, 433	,, 364
4 6 × 6 9	,, 3042	,, 2016	,, 1431	,, 1071	,, 833	,, 661	,, 540	,, 450	,, 378
4 8 × 7 0	,, 3155	,, 2091	,, 1484	,, 1111	,, 863	,, 686	,, 560	,, 467	,, 392
4 10 × 7 3	,, 3267	,, 2165	,, 1537	,, 1150	,, 894	,, 710	,, 580	,, 483	,, 406
5 0 × 7 6	,, 3380	,, 2240	,, 1590	,, 1190	,, 925	,, 735	,, 600	,, 500	,, 420
5 2 × 7 9	,, 3493	,, 2315	,, 1643	,, 1229	,, 956	,, 759	,, 620	,, 517	,, 434
5 4 × 8 0	,, 3606	,, 2389	,, 1696	,, 1269	,, 987	,, 784	,, 640	,, 533	,, 448
5 6 × 8 3	,, 3718	,, 2464	,, 1749	,, 1309	,, 1018	,, 808	,, 660	,, 550	,, 462
5 8 × 8 6	,, 3831	,, 2539	,, 1802	,, 1349	,, 1048	,, 833	,, 680	,, 567	,, 476
5 10 × 8 9	,, 3943	,, 2613	,, 1855	,, 1388	,, 1079	,, 857	,, 700	,, 583	,, 490
6 0 × 9 0	,, 4056	,, 2688	,, 1908	,, 1428	,, 1110	,, 882	,, 720	,, 600	,, 504

TABLE No. 10.—Showing the PROPER INCLINATION of OVAL SEWERS (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-fourth of the transverse diameter, the radius of the sides being 1½ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING TWO-THIRDS FULL.

Size of Sewer.	$v=2$.	$v=2\cdot5$.	$v=3$.	$v=3\cdot5$.	$v=4$.	$v=4\cdot5$.	$v=5$.	$v=5\cdot5$.	$v=6$.
′ ″ ′ ″									
1 0 × 1 6	1 in 737	1 in 488	1 in 347	1 in 259	1 in 201	1 in 160	1 in 131	1 in 108	1 in 91
1 2 × 1 9	,, 860	,, 569	,, 405	,, 302	,, 234	,, 187	,, 153	,, 126	,, 106
1 4 × 2 0	,, 983	,, 651	,, 463	,, 345	,, 268	,, 213	,, 175	,, 144	,, 121
1 6 × 2 3	,, 1105	,, 732	,, 520	,, 388	,, 301	,, 240	,, 196	,, 162	,, 137
1 8 × 2 6	,, 1228	,, 813	,, 578	,, 432	,, 335	,, 267	,, 218	,, 180	,, 152
1 10 × 2 9	,, 1351	,, 895	,, 636	,, 475	,, 368	,, 293	,, 240	,, 198	,, 167
2 0 × 3 0	,, 1474	,, 976	,, 694	,, 518	,, 402	,, 320	,, 262	,, 216	,, 182
2 2 × 3 3	,, 1597	,, 1057	,, 752	,, 561	,, 435	,, 347	,, 284	,, 234	,, 197
2 4 × 3 6	,, 1720	,, 1139	,, 810	,, 604	,, 469	,, 373	,, 306	,, 252	,, 212
2 6 × 3 9	,, 1842	,, 1220	,, 867	,, 647	,, 502	,, 400	,, 327	,, 270	,, 228
2 8 × 4 0	,, 1965	,, 1301	,, 925	,, 691	,, 536	,, 427	,, 349	,, 288	,, 243
2 10 × 4 3	,, 2088	,, 1382	,, 983	,, 734	,, 569	,, 453	,, 371	,, 306	,, 258
3 0 × 4 6	,, 2211	,, 1464	,, 1041	,, 777	,, 603	,, 480	,, 393	,, 324	,, 273
3 2 × 4 9	,, 2334	,, 1545	,, 1099	,, 820	,, 636	,, 507	,, 415	,, 342	,, 288
3 4 × 5 0	,, 2457	,, 1627	,, 1157	,, 863	,, 670	,, 533	,, 437	,, 360	,, 303
3 6 × 5 3	,, 2579	,, 1708	,, 1214	,, 906	,, 703	,, 560	,, 458	,, 378	,, 319
3 8 × 5 6	,, 2702	,, 1789	,, 1272	,, 950	,, 737	,, 587	,, 480	,, 396	,, 334
3 10 × 5 9	,, 2825	,, 1871	,, 1330	,, 993	,, 770	,, 613	,, 502	,, 414	,, 349
4 0 × 6 0	,, 2948	,, 1952	,, 1388	,, 1036	,, 804	,, 640	,, 524	,, 432	,, 364
4 2 × 6 3	,, 3071	,, 2033	,, 1446	,, 1079	,, 837	,, 667	,, 546	,, 450	,, 379
4 4 × 6 6	,, 3194	,, 2115	,, 1504	,, 1122	,, 871	,, 693	,, 568	,, 468	,, 394
4 6 × 6 9	,, 3316	,, 2196	,, 1561	,, 1165	,, 904	,, 720	,, 589	,, 486	,, 410
4 8 × 7 0	,, 3439	,, 2277	,, 1619	,, 1209	,, 938	,, 747	,, 611	,, 504	,, 425
4 10 × 7 3	,, 3562	,, 2359	,, 1677	,, 1252	,, 971	,, 773	,, 633	,, 522	,, 440
5 0 × 7 6	,, 3685	,, 2440	,, 1735	,, 1295	,, 1005	,, 800	,, 655	,, 540	,, 455
5 2 × 7 9	,, 3808	,, 2521	,, 1793	,, 1338	,, 1038	,, 827	,, 677	,, 558	,, 470
5 4 × 8 0	,, 3931	,, 2603	,, 1851	,, 1381	,, 1072	,, 853	,, 699	,, 576	,, 485
5 6 × 8 3	,, 4053	,, 2684	,, 1908	,, 1424	,, 1105	,, 880	,, 720	,, 594	,, 501
5 8 × 8 6	,, 4176	,, 2765	,, 1966	,, 1468	,, 1139	,, 907	,, 742	,, 612	,, 516
5 10 × 8 9	,, 4299	,, 2847	,, 2024	,, 1511	,, 1172	,, 933	,, 764	,, 630	,, 531
6 0 × 9 0	,, 4422	,, 2928	,, 2082	,, 1554	,, 1206	,, 960	,, 786	,, 648	,, 546

TABLE No. 11.—Showing the PROPER INCLINATION of OVAL SEWERS (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-fourth of the transverse diameter, the radius of the sides being $1\frac{1}{2}$ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING ONE-THIRD FULL.

Size of Sewer. ′ ″ ′ ″	$v=2.$	$v=2\cdot5.$	$v=3.$	$v=3\cdot5.$	$v=4.$	$v=4\cdot5.$	$v=5.$	$v=5\cdot5.$	$v=6.$
1 0 × 1 6	1 in 482	1 in 319	1 in 227	1 in 170	1 in 132	1 in 105	1 in 85	1 in 71	1 in 60
1 2 × 1 9	,, 562	,, 372	,, 265	,, 198	,, 154	,, 122	,, 99	,, 83	,, 70
1 4 × 2 0	,, 643	,, 425	,, 303	,, 227	,, 176	,, 140	,, 113	,, 95	,, 80
1 6 × 2 3	,, 723	,, 478	,, 340	,, 255	,, 198	,, 157	,, 127	,, 106	,, 90
1 8 × 2 6	,, 803	,, 532	,, 378	,, 283	,, 220	,, 175	,, 142	,, 118	,, 100
1 10 × 2 9	,, 884	,, 585	,, 416	,, 312	,, 242	,, 192	,, 156	,, 130	,, 110
2 0 × 3 0	,, 964	,, 638	,, 454	,, 340	,, 264	,, 210	,, 170	,, 142	,, 120
2 2 × 3 3	,, 1044	,, 691	,, 492	,, 368	,, 286	,, 227	,, 184	,, 154	,, 130
2 4 × 3 6	,, 1125	,, 744	,, 530	,, 397	,, 308	,, 245	,, 198	,, 166	,, 140
2 6 × 3 9	,, 1205	,, 797	,, 567	,, 425	,, 330	,, 262	,, 212	,, 177	,, 150
2 8 × 4 0	,, 1285	,, 851	,, 605	,, 453	,, 352	,, 280	,, 227	,, 189	,, 160
2 10 × 4 3	,, 1366	,, 904	,, 643	,, 482	,, 374	,, 297	,, 241	,, 201	,, 170
3 0 × 4 6	,, 1446	,, 957	,, 681	,, 510	,, 396	,, 315	,, 255	,, 213	,, 180
3 2 × 4 9	,, 1526	,, 1010	,, 719	,, 538	,, 418	,, 332	,, 269	,, 225	,, 190
3 4 × 5 0	,, 1607	,, 1063	,, 757	,, 567	,, 440	,, 350	,, 283	,, 237	,, 200
3 6 × 5 3	,, 1687	,, 1116	,, 794	,, 595	,, 462	,, 367	,, 297	,, 248	,, 210
3 8 × 5 6	,, 1767	,, 1170	,, 832	,, 623	,, 484	,, 385	,, 312	,, 260	,, 220
3 10 × 5 9	,, 1848	,, 1223	,, 870	,, 652	,, 506	,, 402	,, 326	,, 272	,, 230
4 0 × 6 0	,, 1928	,, 1276	,, 908	,, 680	,, 528	,, 420	,, 340	,, 284	,, 240
4 2 × 6 3	,, 2008	,, 1329	,, 946	,, 708	,, 550	,, 437	,, 354	,, 296	,, 250
4 4 × 6 6	,, 2089	,, 1382	,, 984	,, 737	,, 572	,, 455	,, 368	,, 308	,, 260
4 6 × 6 9	,, 2169	,, 1435	,, 1021	,, 765	,, 594	,, 472	,, 382	,, 319	,, 270
4 8 × 7 0	,, 2249	,, 1489	,, 1059	,, 793	,, 616	,, 490	,, 397	,, 331	,, 280
4 10 × 7 3	,, 2330	,, 1542	,, 1097	,, 822	,, 638	,, 507	,, 411	,, 343	,, 290
5 0 × 7 6	,, 2410	,, 1595	,, 1135	,, 850	,, 660	,, 525	,, 425	,, 355	,, 300
5 2 × 7 9	,, 2490	,, 1648	,, 1173	,, 878	,, 682	,, 542	,, 439	,, 367	,, 310
5 4 × 8 0	,, 2571	,, 1701	,, 1211	,, 907	,, 704	,, 560	,, 453	,, 379	,, 320
5 6 × 8 3	,, 2651	,, 1754	,, 1248	,, 935	,, 726	,, 577	,, 467	,, 390	,, 330
5 8 × 8 6	,, 2731	,, 1808	,, 1286	,, 963	,, 748	,, 595	,, 482	,, 402	,, 340
5 10 × 8 9	,, 2812	,, 1861	,, 1324	,, 992	,, 770	,, 612	,, 496	,, 414	,, 350
6 0 × 9 0	,, 2892	,, 1914	,, 1362	,, 1020	,, 792	,, 630	,, 510	,, 426	,, 360

TABLE No. 12.—Showing the PROPER INCLINATION of OVAL SEWERS (New Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-eighth of the transverse diameter, the radius of the sides being $1\frac{1}{3}$ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING FULL.

Size of Sewer. ′ ″ ′ ″	v = 2.	v = 2·5.	v = 3.	v = 3·5.	v = 4.	v = 4·5.	v = 5.	v = 5·5.	v = 6.
1 0 × 1 6	1 in 664	1 in 440	1 in 312	1 in 234	1 in 181	1 in 144	1 in 118	1 in 98	1 in 82
1 2 × 1 9	„ 775	„ 513	„ 364	„ 272	„ 212	„ 168	„ 137	„ 115	„ 96
1 4 × 2 0	„ 885	„ 586	„ 416	„ 311	„ 242	„ 192	„ 157	„ 131	„ 110
1 6 × 2 3	„ 995	„ 660	„ 468	„ 350	„ 272	„ 216	„ 177	„ 147	„ 124
1 8 × 2 6	„ 1106	„ 733	„ 520	„ 389	„ 302	„ 240	„ 196	„ 164	„ 137
1 10 × 2 9	„ 1216	„ 806	„ 572	„ 428	„ 333	„ 264	„ 216	„ 180	„ 151
2 0 × 3 0	„ 1327	„ 879	„ 624	„ 467	„ 363	„ 288	„ 236	„ 196	„ 165
2 2 × 3 3	„ 1438	„ 953	„ 676	„ 506	„ 393	„ 312	„ 255	„ 213	„ 179
2 4 × 3 6	„ 1549	„ 1026	„ 728	„ 545	„ 424	„ 336	„ 275	„ 229	„ 192
2 6 × 3 9	„ 1659	„ 1099	„ 780	„ 584	„ 454	„ 360	„ 295	„ 245	„ 206
2 8 × 4 0	„ 1770	„ 1173	„ 833	„ 623	„ 484	„ 384	„ 314	„ 262	„ 220
2 10 × 4 3	„ 1880	„ 1246	„ 885	„ 662	„ 514	„ 408	„ 334	„ 278	„ 234
3 0 × 4 6	„ 1991	„ 1319	„ 937	„ 701	„ 545	„ 433	„ 353	„ 294	„ 247
3 2 × 4 9	„ 2102	„ 1393	„ 989	„ 740	„ 575	„ 457	„ 373	„ 311	„ 261
3 4 × 5 0	„ 2213	„ 1466	„ 1041	„ 779	„ 605	„ 481	„ 393	„ 327	„ 275
3 6 × 5 3	„ 2323	„ 1539	„ 1093	„ 818	„ 636	„ 505	„ 412	„ 343	„ 289
3 8 × 5 6	„ 2434	„ 1613	„ 1145	„ 857	„ 666	„ 529	„ 432	„ 360	„ 302
3 10 × 5 9	„ 2544	„ 1686	„ 1197	„ 896	„ 696	„ 553	„ 452	„ 376	„ 316
4 0 × 6 0	„ 2655	„ 1759	„ 1249	„ 935	„ 726	„ 577	„ 471	„ 393	„ 330
4 2 × 6 3	„ 2766	„ 1833	„ 1301	„ 973	„ 757	„ 601	„ 491	„ 409	„ 344
4 4 × 6 6	„ 2876	„ 1906	„ 1353	„ 1012	„ 787	„ 625	„ 511	„ 425	„ 357
4 6 × 6 9	„ 2986	„ 1979	„ 1405	„ 1051	„ 817	„ 649	„ 530	„ 442	„ 371
4 8 × 7 0	„ 3097	„ 2053	„ 1457	„ 1090	„ 847	„ 673	„ 550	„ 458	„ 385
4 10 × 7 3	„ 3207	„ 2126	„ 1509	„ 1129	„ 878	„ 697	„ 569	„ 474	„ 399
5 0 × 7 6	„ 3318	„ 2199	„ 1561	„ 1168	„ 908	„ 721	„ 589	„ 491	„ 412
5 2 × 7 9	„ 3429	„ 2273	„ 1613	„ 1207	„ 938	„ 745	„ 609	„ 507	„ 426
5 4 × 8 0	„ 3540	„ 2346	„ 1665	„ 1246	„ 969	„ 770	„ 628	„ 523	„ 440
5 6 × 8 3	„ 3650	„ 2419	„ 1717	„ 1285	„ 999	„ 794	„ 648	„ 540	„ 454
5 8 × 8 6	„ 3761	„ 2493	„ 1769	„ 1324	„ 1029	„ 818	„ 668	„ 556	„ 467
5 10 × 8 9	„ 3871	„ 2566	„ 1821	„ 1363	„ 1059	„ 842	„ 687	„ 572	„ 481
6 0 × 9 0	„ 3982	„ 2639	„ 1873	„ 1402	„ 1090	„ 866	„ 707	„ 589	„ 495

TABLE No. 13.—Showing the PROPER INCLINATION of OVAL SEWERS (New Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-eighth of the transverse diameter, the radius of the sides being $1\frac{1}{3}$ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING TWO-THIRDS FULL.

Size of Sewer.	$v = 2$.	$v = 2·5$.	$v = 3$.	$v = 3·5$.	$v = 4$.	$v = 4·5$	$v = 5$.	$v = 5·5$.	$v = 6$.
′ ″ ′ ″									
1 0 × 1 6	1 in 717	1 in 475	1 in 338	1 in 252	1 in 196	1 in 156	1 in 127	1 in 105	1 in 89
1 2 × 1 9	,, 837	,, 554	,, 394	,, 294	,, 228	,, 182	,, 149	,, 123	,, 103
1 4 × 2 0	,, 957	,, 634	,, 451	,, 336	,, 261	,, 208	,, 170	,, 140	,, 118
1 6 × 2 3	,, 1076	,, 713	,, 507	,, 378	,, 293	,, 234	,, 191	,, 158	,, 133
1 8 × 2 6	,, 1196	,, 792	,, 563	,, 420	,, 326	,, 260	,, 213	,, 175	,, 148
1 10 × 2 9	,, 1315	,, 871	,, 619	,, 462	,, 358	,, 286	,, 234	,, 193	,, 163
2 0 × 3 0	,, 1435	,, 950	,, 676	,, 504	,, 391	,, 312	,, 255	,, 210	,, 177
2 2 × 3 3	,, 1555	,, 1029	,, 732	,, 546	,, 424	,, 338	,, 276	,, 228	,, 192
2 4 × 3 6	,, 1674	,, 1109	,, 788	,, 588	,, 457	,, 363	,, 298	,, 245	,, 207
2 6 × 3 9	,, 1794	,, 1188	,, 844	,, 630	,, 489	,, 389	,, 319	,, 263	,, 222
2 8 × 4 0	,, 1913	,, 1267	,, 901	,, 672	,, 522	,, 415	,, 340	,, 280	,, 236
2 10 × 4 3	,, 2033	,, 1346	,, 957	,, 714	,, 554	,, 441	,, 361	,, 298	,, 251
3 0 × 4 6	,, 2153	,, 1425	,, 1013	,, 756	,, 587	,, 467	,, 383	,, 315	,, 266
3 2 × 4 9	,, 2272	,, 1504	,, 1070	,, 798	,, 619	,, 493	,, 404	,, 333	,, 281
3 4 × 5 0	,, 2392	,, 1584	,, 1126	,, 840	,, 652	,, 519	,, 425	,, 350	,, 296
3 6 × 5 3	,, 2511	,, 1663	,, 1182	,, 882	,, 685	,, 545	,, 446	,, 368	,, 310
3 8 × 5 6	,, 2631	,, 1742	,, 1239	,, 925	,, 718	,, 571	,, 468	,, 386	,, 325
3 10 × 5 9	,, 2751	,, 1821	,, 1295	,, 967	,, 750	,, 597	,, 489	,, 403	,, 340
4 0 × 6 0	,, 2870	,, 1900	,, 1351	,, 1009	,, 783	,, 623	,, 510	,, 421	,, 355
4 2 × 6 3	,, 2990	,, 1979	,, 1408	,, 1051	,, 815	,, 649	,, 531	,, 438	,, 369
4 4 × 6 6	,, 3110	,, 2059	,, 1464	,, 1093	,, 848	,, 675	,, 553	,, 456	,, 384
4 6 × 6 9	,, 3229	,, 2138	,, 1520	,, 1135	,, 880	,, 701	,, 574	,, 473	,, 399
4 8 × 7 0	,, 3349	,, 2217	,, 1577	,, 1177	,, 913	,, 727	,, 595	,, 491	,, 414
4 10 × 7 3	,, 3468	,, 2297	,, 1633	,, 1219	,, 946	,, 753	,, 616	,, 508	,, 428
5 0 × 7 6	,, 3588	,, 2376	,, 1689	,, 1261	,, 978	,, 779	,, 638	,, 526	,, 443
5 2 × 7 9	,, 3708	,, 2455	,, 1746	,, 1303	,, 1011	,, 805	,, 659	,, 543	,, 458
5 4 × 8 0	,, 3827	,, 2534	,, 1802	,, 1345	,, 1043	,, 831	,, 680	,, 561	,, 473
5 6 × 8 3	,, 3947	,, 2613	,, 1858	,, 1387	,, 1076	,, 857	,, 701	,, 578	,, 488
5 8 × 8 6	,, 4066	,, 2692	,, 1914	,, 1429	,, 1109	,, 883	,, 723	,, 596	,, 502
5 10 × 8 9	,, 4186	,, 2772	,, 1971	,, 1471	,, 1141	,, 909	,, 744	,, 613	,, 517
6 0 × 9 0	,, 4306	,, 2851	,, 2027	,, 1513	,, 1174	,, 935	,, 765	,, 631	,, 532

TABLE NO. **14.**—Showing the PROPER INCLINATION of OVAL SEWERS (New Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-eighth of the transverse diameter, the radius of the sides being $1\frac{1}{3}$ the transverse diameter, Velocities varying from 2 feet to 6 feet per second, when RUNNING ONE-THIRD FULL.

Size of Sewer.	$v=2$.	$v=2\cdot5$.	$v=3$.	$v=3\cdot5$.	$v=4$.	$v=4\cdot5$.	$v=5$.	$v=5\cdot5$.	$v=6$.
′ ″ ′ ″									
1 0 × 1 6	1 in 448	1 in 297	1 in 211	1 in 158	1 in 122	1 in 97	1 in 79	1 in 66	1 in 56
1 2 × 1 9	,, 522	,, 346	,, 246	,, 184	,, 143	,, 114	,, 92	,, 77	,, 65
1 4 × 2 0	,, 597	,, 395	,, 281	,, 211	,, 163	,, 130	,, 105	,, 88	,, 74
1 6 × 2 3	,, 672	,, 445	,, 316	,, 237	,, 184	,, 146	,, 118	,, 99	,, 84
1 8 × 2 6	,, 746	,, 494	,, 351	,, 263	,, 204	,, 162	,, 132	,, 110	,, 93
1 10 × 2 9	,, 821	,, 543	,, 386	,, 290	,, 225	,, 179	,, 145	,, 121	,, 102
2 0 × 3 0	,, 896	,, 593	,, 422	,, 316	,, 245	,, 195	,, 158	,, 132	,, 112
2 2 × 3 3	,, 970	,, 642	,, 457	,, 342	,, 266	,, 211	,, 171	,, 143	,, 121
2 4 × 3 6	,, 1045	,, 691	,, 492	,, 369	,, 286	,, 227	,, 184	,, 154	,, 130
2 6 × 3 9	,, 1120	,, 741	,, 527	,, 395	,, 307	,, 244	,, 197	,, 165	,, 139
2 8 × 4 0	,, 1194	,, 790	,, 562	,, 421	,, 327	,, 260	,, 211	,, 176	,, 149
2 10 × 4 3	,, 1269	,, 840	,, 597	,, 448	,, 348	,, 276	,, 224	,, 187	,, 158
3 0 × 4 6	,, 1344	,, 889	,, 633	,, 474	,, 368	,, 293	,, 237	,, 198	,, 167
3 2 × 4 9	,, 1418	,, 939	,, 668	,, 500	,, 389	,, 309	,, 250	,, 209	,, 177
3 4 × 5 0	,, 1493	,, 988	,, 703	,, 527	,, 409	,, 325	,, 263	,, 220	,, 186
3 6 × 5 3	,, 1568	,, 1037	,, 738	,, 553	,, 429	,, 341	,, 276	,, 231	,, 195
3 8 × 5 6	,, 1642	,, 1087	,, 773	,, 579	,, 450	,, 358	,, 290	,, 242	,, 204
3 10 × 5 9	,, 1717	,, 1136	,, 808	,, 606	,, 470	,, 374	,, 303	,, 253	,, 214
4 0 × 6 0	,, 1792	,, 1186	,, 844	,, 632	,, 491	,, 390	,, 316	,, 264	,, 223
4 2 × 6 3	,, 1866	,, 1235	,, 879	,, 658	,, 511	,, 406	,, 329	,, 275	,, 232
4 4 × 6 6	,, 1941	,, 1284	,, 914	,, 685	,, 532	,, 423	,, 342	,, 286	,, 242
4 6 × 6 9	,, 2016	,, 1334	,, 949	,, 711	,, 552	,, 439	,, 355	,, 297	,, 251
4 8 × 7 0	,, 2090	,, 1383	,, 984	,, 737	,, 573	,, 455	,, 369	,, 308	,, 260
4 10 × 7 3	,, 2165	,, 1433	,, 1019	,, 764	,, 593	,, 471	,, 382	,, 319	,, 270
5 0 × 7 6	,, 2240	,, 1482	,, 1055	,, 790	,, 613	,, 488	,, 395	,, 330	,, 279
5 2 × 7 9	,, 2314	,, 1531	,, 1090	,, 816	,, 634	,, 504	,, 408	,, 341	,, 288
5 4 × 8 0	,, 2389	,, 1581	,, 1125	,, 843	,, 654	,, 520	,, 421	,, 352	,, 297
5 6 × 8 3	,, 2464	,, 1630	,, 1160	,, 869	,, 675	,, 536	,, 434	,, 363	,, 307
5 8 × 8 6	,, 2538	,, 1680	,, 1195	,, 895	,, 695	,, 553	,, 448	,, 374	,, 316
5 10 × 8 9	,, 2613	,, 1729	,, 1230	,, 922	,, 716	,, 569	,, 461	,, 385	,, 325
6 0 × 9 0	,, 2688	,, 1778	,, 1266	,, 948	,, 736	,, 585	,, 474	,, 396	,, 334

TABLE No. 15.—Showing the PROPER INCLINATION of CIRCULAR SEWERS, 1 foot diameter, when RUNNING FULL, or HALF FULL, for Velocities varying from 2 feet to 10 feet per second, and working under various heads.

The proper inclination of any other sized circular sewer for the same velocity may be found by multiplying the inclination given in this Table by the diameter of the sewer in feet and decimal parts of feet.

$h =$	$v = 2·0.$	$v = 2·25.$	$v = 2·5.$	$v = 2·75.$	$v = 3·0.$	$v = 3·25.$	$v = 3·5.$	$v = 3·75.$	$v = 4·0.$	$v = 4·25.$	$v = 4·5.$	$v = 4·75.$	$v = 5·0.$	$v = 5·25.$	$v = 5·5.$	$v = 5·75.$
·5	1 in 497·6	1 in 377·8	1 in 290·1	1 in 223·2	1 in 171·2	1 in 129·5	1 in 95·6	1 in 67·7	1 in 44·3	1 in 24·4	1 in 7·6					
1·0	„ 554·8	„ 436·4	„ 350·1	„ 284·4	„ 233·4	„ 192·7	„ 159·7	„ 132·6	„ 110·0	„ 90·9	„ 74·8	1 in 61·0	1 in 49·0	1 in 38·4	1 in 29·0	1 in 20·7
1·5	„ 573·9	„ 455·9	„ 370·1	„ 304·8	„ 254·1	„ 213·8	„ 181·1	„ 154·2	„ 131·9	„ 113·1	„ 97·2	„ 83·6	„ 71·8	„ 61·4	„ 52·2	„ 44·1
2·0	„ 583·4	„ 465·7	„ 380·1	„ 315·0	„ 264·5	„ 224·3	„ 191·8	„ 165·0	„ 142·9	„ 124·2	„ 108·4	„ 94·9	„ 83·2	„ 72·9	„ 63·8	„ 55·8
2·5	„ 589·1	„ 471·6	„ 386·1	„ 321·1	„ 270·7	„ 230·6	„ 198·2	„ 171·5	„ 149·4	„ 130·8	„ 115·1	„ 101·6	„ 90·0	„ 79·8	„ 70·8	„ 62·8
3·0	„ 592·9	„ 475·5	„ 390·1	„ 325·2	„ 274·9	„ 234·8	„ 202·4	„ 175·9	„ 153·8	„ 135·3	„ 119·6	„ 106·2	„ 94·6	„ 84·4	„ 75·4	„ 67·5
3·5	„ 595·6	„ 478·3	„ 393·0	„ 328·1	„ 277·8	„ 237·8	„ 205·5	„ 179·0	„ 156·9	„ 138·4	„ 122·8	„ 109·4	„ 97·9	„ 87·7	„ 78·7	„ 70·8
4·0	„ 597·7	„ 480·4	„ 395·1	„ 330·3	„ 280·0	„ 240·1	„ 207·8	„ 181·3	„ 159·3	„ 140·8	„ 125·2	„ 111·8	„ 100·3	„ 90·2	„ 81·2	„ 73·3
4·5	„ 599·3	„ 482·0	„ 396·8	„ 332·0	„ 281·8	„ 241·9	„ 209·6	„ 183·1	„ 161·1	„ 142·6	„ 127·1	„ 113·7	„ 102·2	„ 92·1	„ 83·1	„ 75·3
5·0	„ 600·6	„ 483·3	„ 398·1	„ 333·4	„ 283·2	„ 243·3	„ 211·0	„ 184·5	„ 162·6	„ 144·1	„ 128·6	„ 115·2	„ 103·7	„ 93·6	„ 84·7	„ 76·9
5·5	„ 601·6	„ 484·4	„ 399·2	„ 334·5	„ 284·3	„ 244·4	„ 212·1	„ 185·7	„ 163·8	„ 145·3	„ 129·8	„ 116·5	„ 105·0	„ 94·9	„ 86·0	„ 78·2
6·0	„ 602·4	„ 485·3	„ 400·1	„ 335·4	„ 285·2	„ 245·4	„ 213·1	„ 186·7	„ 164·8	„ 146·3	„ 130·8	„ 117·5	„ 106·0	„ 95·9	„ 87·0	„ 79·2
7·0	„ 603·8	„ 486·7	„ 401·5	„ 336·9	„ 286·7	„ 246·9	„ 214·6	„ 188·2	„ 166·3	„ 147·9	„ 132·4	„ 119·1	„ 107·6	„ 97·5	„ 88·7	„ 80·9
8·0	„ 604·8	„ 487·7	„ 402·6	„ 338·0	„ 287·8	„ 248·0	„ 215·8	„ 189·4	„ 167·5	„ 149·1	„ 133·6	„ 120·3	„ 108·8	„ 98·7	„ 89·9	„ 82·1
9·0	„ 605·6	„ 488·5	„ 403·4	„ 338·8	„ 288·7	„ 248·9	„ 216·7	„ 190·3	„ 168·4	„ 150·0	„ 134·5	„ 121·3	„ 109·8	„ 99·7	„ 90·9	„ 83·1
10·0	„ 606·3	„ 489·2	„ 404·1	„ 339·5	„ 289·4	„ 249·6	„ 217·4	„ 191·0	„ 169·1	„ 150·8	„ 135·3	„ 122·0	„ 110·6	„ 100·5	„ 91·7	„ 83·9
20·0	„ 609·1	„ 492·1	„ 407·1	„ 342·5	„ 292·5	„ 252·7	„ 220·6	„ 194·3	„ 172·4	„ 154·1	„ 138·6	„ 125·4	„ 114·0	„ 103·9	„ 95·1	„ 87·4
50·0	„ 610·9	„ 493·9	„ 408·9	„ 344·4	„ 294·4	„ 254·6	„ 222·5	„ 196·2	„ 174·4	„ 156·1	„ 140·7	„ 127·4	„ 116·0	„ 106·0	„ 97·2	„ 89·5
Infinite	„ 612·0	„ 495·0	„ 410·1	„ 345·6	„ 295·6	„ 255·9	„ 223·8	„ 197·5	„ 175·7	„ 157·4	„ 142·0	„ 128·8	„ 117·4	„ 107·4	„ 98·6	„ 90·9

$h =$	$v = 6·0.$	$v = 6·25.$	$v = 6·5.$	$v = 6·75.$	$v = 7·0.$	$v = 7·25.$	$v = 7·5.$	$v = 7·75.$	$v = 8·0.$	$v = 8·25.$	$v = 8·5.$	$v = 8·75.$	$v = 9·0.$	$v = 9·25.$	$v = 9·5.$	$v = 9·75.$	$v = 10·0.$
·5																	
1·0	1 in 13·3	1 in 6·7	1 in ·9														
1·5	„ 36·9	„ 30·4	„ 24·8	1 in 19·6	1 in 14·9	1 in 10·7	1 in 6·9	1 in 3·4									
2·0	„ 48·7	„ 42·3	„ 36·7	„ 31·6	„ 27·0	„ 22·9	„ 19·1	„ 15·6	1 in 12·4	1 in 9·6	1 in 6·9	1 in 4·4	1 in 2·1				
2·5	„ 55·7	„ 49·4	„ 43·8	„ 38·8	„ 34·2	„ 30·1	„ 26·4	„ 22·9	„ 19·8	„ 17·0	„ 14·3	„ 11·9	„ 9·6	1 in 7·5	1 in 5·6	1 in 3·8	1 in 2·1
3·0	„ 60·4	„ 54·2	„ 48·6	„ 43·6	„ 39·1	„ 35·0	„ 31·3	„ 27·8	„ 24·7	„ 21·9	„ 19·3	„ 16·9	„ 14·6	„ 12·5	„ 10·6	„ 8·9	„ 7·2
3·5	„ 63·8	„ 57·6	„ 52·0	„ 47·0	„ 42·5	„ 38·4	„ 34·7	„ 31·3	„ 28·2	„ 25·4	„ 22·8	„ 20·4	„ 18·2	„ 16·1	„ 14·3	„ 12·5	„ 10·8
4·0	„ 66·3	„ 60·1	„ 54·6	„ 49·6	„ 45·1	„ 41·0	„ 37·4	„ 34·0	„ 30·9	„ 28·1	„ 25·5	„ 23·1	„ 20·9	„ 18·8	„ 17·0	„ 15·2	„ 13·5
4·5	„ 68·3	„ 62·1	„ 56·6	„ 51·6	„ 47·1	„ 43·0	„ 39·4	„ 36·0	„ 32·9	„ 30·1	„ 27·5	„ 25·2	„ 23·0	„ 20·9	„ 19·1	„ 17·3	„ 15·7
5·0	„ 69·9	„ 63·7	„ 58·2	„ 53·2	„ 48·7	„ 44·7	„ 41·0	„ 37·6	„ 34·5	„ 31·8	„ 29·2	„ 26·8	„ 24·7	„ 22·6	„ 20·7	„ 19·0	„ 17·4
5·5	„ 71·2	„ 65·0	„ 59·5	„ 54·5	„ 50·0	„ 46·0	„ 42·3	„ 39·0	„ 35·9	„ 33·2	„ 30·6	„ 28·2	„ 26·1	„ 24·0	„ 22·1	„ 20·4	„ 18·8
6·0	„ 72·2	„ 66·0	„ 60·6	„ 55·6	„ 51·1	„ 47·1	„ 43·4	„ 40·1	„ 37·0	„ 34·3	„ 31·7	„ 29·3	„ 27·2	„ 25·1	„ 23·3	„ 21·5	„ 19·9
7·0	„ 73·9	„ 67·7	„ 62·3	„ 57·3	„ 52·8	„ 48·8	„ 45·2	„ 41·8	„ 38·8	„ 36·0	„ 33·5	„ 31·1	„ 29·0	„ 26·9	„ 25·1	„ 23·3	„ 21·7
8·0	„ 75·2	„ 69·0	„ 63·6	„ 58·6	„ 54·1	„ 50·1	„ 46·5	„ 43·1	„ 40·1	„ 37·4	„ 34·8	„ 32·4	„ 30·3	„ 28·3	„ 26·4	„ 24·7	„ 23·1
9·0	„ 76·2	„ 70·0	„ 64·6	„ 59·6	„ 55·1	„ 51·1	„ 47·5	„ 44·1	„ 41·1	„ 38·4	„ 35·8	„ 33·5	„ 31·4	„ 29·3	„ 27·5	„ 25·8	„ 24·1
10·0	„ 76·9	„ 70·8	„ 65·3	„ 60·4	„ 55·9	„ 51·9	„ 48·3	„ 45·0	„ 41·9	„ 39·2	„ 36·7	„ 34·3	„ 32·2	„ 30·2	„ 28·3	„ 26·6	„ 25·0
20·0	„ 80·5	„ 74·3	„ 68·9	„ 64·0	„ 59·6	„ 55·6	„ 52·0	„ 48·6	„ 45·6	„ 42·9	„ 40·4	„ 38·1	„ 35·9	„ 33·9	„ 32·1	„ 30·4	„ 28·8
50·0	„ 82·6	„ 76·5	„ 71·1	„ 66·2	„ 61·8	„ 57·7	„ 54·1	„ 50·8	„ 47·8	„ 45·1	„ 42·6	„ 40·3	„ 38·2	„ 36·2	„ 34·4	„ 32·7	„ 31·1
Infinite	„ 84·0	„ 77·9	„ 72·5	„ 67·6	„ 63·2	„ 59·2	„ 55·6	„ 52·3	„ 49·3	„ 46·6	„ 44·1	„ 41·8	„ 39·7	„ 37·7	„ 35·9	„ 34·2	„ 32·6

h in the Table represents the total fall in a length of sewer. The length of sewer taken into calculation is found by multiplying h by the rate of inclination of the sewer. Example: a sewer 1 foot diameter with a velocity of 3 feet per second, the total fall from head to outlet being 6 feet, the length of the sewer is $6 \times 285·2 = 1711·2$ feet. If the sewer is 6 feet diameter and the velocity required 3 feet, the total fall being 10 feet, the proper inclination $= 6 \times 289·4 = 1$ in 1736, and the length of sewer to which the calculation correctly applies $= 10 \times 1736 = 17360$ feet. The figures underlined are the points where the head $h =$ the velocity, and correspond with the inclination given in Table No. 8.

TABLE No. 16.—Showing the PROPER INCLINATION for OVAL SEWERS, 1′ 0″ × 1′ 6″ (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius equal to one-fourth the transverse diameter, and the radius of the sides being one and a half times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when RUNNING FULL, and working under various heads.

The proper inclination for the same velocity of any other sized oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet or decimal parts of feet.

h =	$v = 2·0$.	$v = 2·25$.	$v = 2·5$.	$v = 2·75$.	$v = 3·0$.	$v = 3·25$.	$v = 3·5$.	$v = 3·75$.	$v = 4·0$.	$v = 4·25$.	$v = 4·5$.	$v = 4·75$.	$v = 5·0$.	$v = 5·25$.	$v = 5·5$.	$v = 5·75$.
′																
·5	1 in 576·6	1 in 437·8	1 in 336·2	1 in 258·6	1 in 198·4	1 in 150·1	1 in 110·8	1 in 78·4	1 in 51·3	1 in 28·3	1 in 8·8					
1·0	,, 642·9	,, 505·7	,, 405·7	,, 329·6	,, 270·5	,, 223·3	,, 185·1	,, 153·6	,, 127·4	,, 105·3	,, 86·6	1 in 70·7	1 in 56·8	1 in 44·5	1 in 33·6	1 in 24·0
1·5	,, 665·0	,, 528·3	,, 428·9	,, 353·2	,, 294·5	,, 247·7	,, 209·9	,, 178·7	,, 152·8	,, 131·0	,, 112·6	,, 96·9	,, 83·2	,, 71·2	,, 60·5	,, 55·1
2·0	,, 676·0	,, 539·6	,, 440·5	,, 365·0	,, 306·5	,, 259·9	,, 222·3	,, 191·2	,, 165·5	,, 143·9	,, 125·6	,, 110·0	,, 96·4	,, 84·5	,, 73·9	,, 64·7
2·5	,, 682·6	,, 546·5	,, 447·4	,, 372·1	,, 313·7	,, 267·2	,, 229·7	,, 198·7	,, 173·1	,, 151·6	,, 133·4	,, 117·8	,, 104·3	,, 92·5	,, 82·0	,, 72·8
3·0	,, 687·0	,, 551·0	,, 452·0	,, 376·8	,, 318·5	,, 272·1	,, 234·6	,, 203·7	,, 178·2	,, 156·8	,, 138·6	,, 123·0	,, 109·6	,, 97·8	,, 87·4	,, 78·2
3·5	,, 690·1	,, 554·2	,, 455·3	,, 380·2	,, 321·9	,, 275·6	,, 238·1	,, 207·3	,, 181·8	,, 160·4	,, 142·3	,, 126·8	,, 113·4	,, 101·6	,, 91·2	,, 82·0
4·0	,, 692·6	,, 556·7	,, 457·8	,, 382·7	,, 324·5	,, 278·2	,, 240·8	,, 210·1	,, 184·6	,, 163·2	,, 145·1	,, 129·6	,, 116·2	,, 104·5	,, 94·1	,, 84·9
4·5	,, 694·4	,, 558·5	,, 459·8	,, 384·7	,, 326·5	,, 280·3	,, 242·9	,, 212·2	,, 186·7	,, 165·3	,, 147·3	,, 131·8	,, 118·4	,, 106·7	,, 96·3	,, 87·2
5·0	,, 695·9	,, 560·0	,, 461·3	,, 386·3	,, 328·1	,, 281·9	,, 244·5	,, 213·8	,, 188·4	,, 167·0	,, 149·0	,, 133·5	,, 120·2	,, 108·5	,, 98·1	,, 89·1
5·5	,, 697·1	,, 561·3	,, 462·6	,, 387·6	,, 329·4	,, 283·2	,, 245·8	,, 215·2	,, 189·8	,, 168·4	,, 150·4	,, 135·0	,, 121·7	,, 110·0	,, 99·6	,, 90·6
6·0	,, 698·0	,, 562·3	,, 463·6	,, 388·7	,, 330·5	,, 284·3	,, 246·9	,, 216·3	,, 190·9	,, 169·5	,, 151·5	,, 136·1	,, 122·8	,, 111·1	,, 100·8	,, 91·8
7·0	,, 699·7	,, 564·0	,, 465·3	,, 390·4	,, 332·2	,, 286·1	,, 248·7	,, 218·1	,, 192·7	,, 171·4	,, 153·4	,, 138·0	,, 124·7	,, 113·0	,, 102·8	,, 93·8
8·0	,, 700·9	,, 565·2	,, 466·5	,, 391·6	,, 333·5	,, 287·4	,, 250·1	,, 219·5	,, 194·1	,, 172·8	,, 154·8	,, 139·4	,, 126·1	,, 114·4	,, 104·2	,, 95·2
9·0	,, 701·8	,, 566·1	,, 467·5	,, 392·6	,, 334·5	,, 288·4	,, 251·1	,, 220·5	,, 195·1	,, 173·8	,, 155·9	,, 140·5	,, 127·2	,, 115·5	,, 105·3	,, 96·3
10.0	,, 702·6	,, 566·9	,, 468·3	,, 393·4	,, 335·3	,, 289·2	,, 251·9	,, 221·3	,, 195·9	,, 174·7	,, 156·8	,, 141·4	,, 128·1	,, 116·4	,, 106·2	,, 97·2
20·0	,, 705·8	,, 570·2	,, 471·7	,, 396·9	,, 338·9	,, 292·8	,, 255·6	,, 225·1	,, 199·8	,, 178·6	,, 160·7	,, 145·3	,, 132·1	,, 120·4	,, 110·2	,, 101·3
50·0	,, 707·9	,, 572·3	,, 473·8	,, 399·1	,, 341·1	,, 295·0	,, 257·8	,, 227·4	,, 202·1	,, 180·9	,, 163·0	,, 147·6	,, 134·4	,, 122·8	,, 112·6	,, 103·7
Infinite	,, 709·2	,, 573·6	,, 475·2	,, 400·5	,, 342·6	,, 296·5	,, 259·3	,, 228·9	,, 203·6	,, 182·4	,, 164·5	,, 149·2	,, 136·0	,, 124·4	,, 114·2	,, 105·3

h =	v = 6·0.	v=6·25.	v = 6·5.	v=6·75.	v = 7·0.	v=7·25.	v = 7·5.	v=7·75.	v = 8·0.	v=8·25.	v = 8·5.	v=8·75.	v = 9·0.	v=9·25.	v = 9·5.	v=9·75.	v = 10·0.
·5																	
1·0	1 in 15·4	1 in 7·8	1 in 1·0														
1·5	,, 42·8	,, 35·3	,, 28·7	1 in 22·7	1 in 17.3	1 in 12·4	1 in 8·0	1 in 3·9									
2·0	,, 56·4	,, 49·0	,, 42·5	,, 36·6	,, 31·3	,, 26·5	,, 22·2	,, 18·1	1 in 14·4	1 in 11·1	1 in 8·0	1 in 5·1	1 in 2·4				
2·5	,, 64·5	,, 57·2	,, 50·7	,, 44·9	,, 39·7	,, 34·9	,, 30·6	,, 26·5	,, 22·9	,, 19·7	,, 16·6	,, 13·8	,, 11·1	1 in 8·7	1 in 6·5	1 in 4·4	1 in 2·4
3·0	,, 70·0	,, 62·8	,, 56·3	,, 50·5	,, 45·3	,, 40·5	,, 36·2	,, 32·2	,, 28·6	,, 25·4	,, 22·3	,, 19·6	,, 16·9	,, 14·5	,, 12·4	,, 10·3	,, 8·3
3·5	,, 73·9	,, 66·7	,, 60·3	,, 54·5	,, 49·3	,, 44·5	,, 40·2	,, 36·3	,, 32·7	,, 29·5	,, 26·4	,, 23·7	,, 21·1	,, 18·7	,, 16·6	,, 14·5	,, 12·5
4·0	,, 76·8	,, 69·6	,, 63·3	,, 57·5	,, 52·3	,, 47·5	,, 43·3	,, 39·4	,, 35·8	,, 32·6	,, 29·5	,, 26·8	,, 24·2	,, 21·8	,, 19·7	,, 17·6	,, 15·7
4·5	,, 79·1	,, 71·9	,, 65·6	,, 59·8	,, 54·6	,, 49·8	,, 45·6	,, 41·7	,, 38·1	,, 34·9	,, 31·8	,, 29·2	,, 26·6	,, 24·2	,, 22·1	,, 20·0	,, 18·2
5·0	,, 81·0	,, 73·8	,, 67·5	,, 61·7	,, 56·5	,, 51·8	,, 47·5	,, 43·6	,, 40·0	,, 36·9	,, 33·8	,, 31·1	,, 28·6	,, 26·2	,, 24·0	,, 22·0	,, 20·2
5·5	,, 82·5	,, 75·3	,, 69·0	,, 63·2	,, 58·0	,, 53·3	,, 49·0	,, 45·2	,, 41·6	,, 38·5	,, 35·4	,, 32·7	,, 30·2	,, 27·8	,, 25·6	,, 23·6	,, 21·8
6·0	,, 83·7	,, 76·5	,, 70·2	,, 64·4	,, 59·2	,, 54·6	,, 50·3	,, 46·5	,, 42·9	,, 39·8	,, 36·7	,, 34·0	,, 31·5	,, 29·1	,, 27·0	,, 24·9	,, 23·1
7·0	,, 85·7	,, 78·5	,, 72·2	,, 66·4	,, 61·2	,, 56·6	,, 52·3	,, 48·5	,, 44·9	,, 41·8	,, 38·7	,, 36·0	,, 33·6	,, 31·2	,, 29·1	,, 27·0	,, 25·2
8·0	,, 87·1	,, 80·0	,, 73·7	,, 67·9	,, 62·7	,, 58·1	,, 53·8	,, 50·0	,, 46·4	,, 43·3	,, 40·3	,, 37·6	,, 35·2	,, 32·8	,, 30·6	,, 28·6	,, 26·8
9·0	,, 88·2	,, 81·1	,, 74·8	,, 69·1	,, 63·9	,, 59·2	,, 55·0	,, 51·1	,, 47·6	,, 44·5	,, 41·5	,, 38·8	,, 36·4	,, 34·0	,, 31·8	,, 29·9	,, 28·0
10·0	,, 89·1	,, 82·0	,, 75·7	,, 70·0	,, 64·8	,, 60·1	,, 56·0	,, 52·1	,, 48·6	,, 45·4	,, 42·5	,, 39·8	,, 37·3	,, 35·0	,, 32·8	,, 30·8	,, 29·0
20·0	,, 93·2	,, 86·1	,, 79·9	,, 74·2	,, 69·1	,, 64·4	,, 60·2	,, 56·3	,, 52·8	,, 49·7	,, 46·8	,, 44·1	,, 41·6	,, 39·3	,, 37·2	,, 35·2	,, 33·4
50·0	,, 95·7	,, 88·6	,, 82·4	,, 76·7	,, 71·6	,, 66·9	,, 62·7	,, 58·9	,, 55·4	,, 52·3	,, 49·4	,, 46·7	,, 44·2	,, 41·9	,, 39·9	,, 37·9	,, 36·0
Infinite	,, 97·3	,, 90·2	,, 84·0	,, 78·3	,, 73·2	,, 68·6	,, 64·4	,, 60·6	,, 57·1	,, 54·0	,, 51·1	,, 48·4	,, 46·0	,, 43·7	,, 41·6	,, 39·6	,, 37·8

Example: Required to know the proper inclination for an oval sewer, of the old form and proportions, 2 feet by 3 feet, in which the velocity when flowing full is 3·25 feet per second, and the observed or available fall is 6 feet, then 2 × 284·3 = 568·6, or 1 in 568·6 is the proper rate of inclination.

TABLE No. 17.—Showing the PROPER INCLINATION for OVAL SEWERS, 1′ 0″ × 1′ 6″ (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius equal to one-fourth the transverse diameter, and the radius of the sides being one and a half times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when RUNNING TWO-THIRDS FULL, and working under various heads.

The proper inclination for the same velocity of any other sized oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet or decimal parts of feet.

h =	v = 2·0.	v = 2·25.	v = 2·5.	v = 2·75.	v = 3·0.	v = 3·25.	v = 3·5.	v = 3·75.	v = 4·0.	v=4·25.	v = 4·5.	v=4·75.	v = 5·0.	v=5·25.	v = 5·5.	v=5·75.
·5	1 in 628·4	1 in 477·1	1 in 366·3	1 in 281·9	1 in 216·2	1 in 163·5	1 in 120·7	1 in 85·5	1 in 55·9	1 in 30·8	1 in 9·6					
1·0	,, 700·6	,, 551·1	,, 442·1	,, 359·1	,, 294·7	,, 213·3	,, 201·7	,, 167·4	,, 138·9	,, 114·8	,, 94·5	1 in 77·0	1 in 61·9	1 in 48·5	1 in 36·6	2 in 26·1
1·5	,, 724·7	,, 575·7	,, 467·4	,, 384·9	,, 320·9	,, 270·0	,, 228·7	,, 194·7	,, 166·6	,, 142·8	,, 122·8	,, 105·6	,, 90·7	,, 77·5	,, 65·9	,, 55·7
2·0	,, 736·7	,, 588·1	,, 480·0	,, 397·8	,, 334·0	,, 283·3	,, 242·2	,, 208·4	,, 180·5	,, 156·8	,, 136·9	,, 119·8	,, 105·1	,, 92·1	,, 80·6	,, 70·5
2·5	,, 743·9	,, 595·5	,, 487·6	,, 405·5	,, 341·8	,, 291·2	,, 250·3	,, 216·6	,, 188·7	,, 165·2	,, 145·3	,, 128·3	,, 113·7	,, 100·8	,, 89·4	,, 79·3
3·0	,, 748·7	,, 600·5	,, 492·7	,, 410·7	,, 347·1	,, 296·5	,, 255·6	,, 222·0	,, 194·2	,, 170·8	,, 151·0	,, 134·1	,, 119·5	,, 106·6	,, 95·2	,, 85·2
3·5	,, 752·1	,, 604·0	,, 496·3	,, 414·3	,, 350·8	,, 300·3	,, 259·5	,, 225·9	,, 198·1	,, 174·8	,, 155·1	,, 138·2	,, 123·6	,, 110·8	,, 99·4	,, 89·4
4·0	,, 754·7	,, 606·6	,, 498·9	,, 417·1	,, 353·6	,, 303·2	,, 262·4	,, 228·9	,, 201·1	,, 177·8	,, 158·1	,, 141·2	,, 126·7	,, 113·9	,, 102·5	,, 92·6
4·5	,, 756·8	,, 608·7	,, 501·1	,, 419·3	,, 355·9	,, 305·5	,, 264·7	,, 231·2	,, 203·4	,, 180·1	,, 160·5	,, 143·6	,, 129·1	,, 116·3	,, 105·0	,, 95·1
5·0	,, 758·4	,, 610·3	,, 502·7	,, 421·0	,, 357·6	,, 307·2	,, 266·4	,, 233·0	,, 205·3	,, 182·0	,, 162·4	,, 145·5	,, 131·0	,, 118·2	,, 107·0	,, 97·1
5·5	,, 759·7	,, 611·7	,, 504·1	,, 422·4	,, 359·0	,, 308·6	,, 267·8	,, 234·5	,, 206·8	,, 183·5	,, 163·9	,, 147·1	,, 132·6	,, 119·8	,, 108·6	,, 98·7
6·0	,, 760·7	,, 612·8	,, 505·2	,, 423·5	,, 360·1	,, 309·8	,, 269·1	,, 235·8	,, 208·1	,, 184·8	,, 165·2	,, 148·4	,, 133·9	,, 121·1	,, 109·9	,, 100·0
7·0	,, 762·5	,, 614·6	,, 507·0	,, 425·4	,, 362·0	,, 311·7	,, 271·0	,, 237·7	,, 210·0	,, 186·8	,, 167·2	,, 150·4	,, 135·9	,, 123·1	,, 112·0	,, 102·1
8·0	,, 763·7	,, 615·9	,, 508·4	,, 426·8	,, 363·4	,, 313·2	,, 272·5	,, 239·2	,, 211·5	,, 188·3	,, 168·7	,, 151·9	,, 137·4	,, 124·6	,, 113·5	,, 103·7
9·0	,, 764·7	,, 616·9	,, 509·4	,, 427·8	,, 364·5	,, 314·3	,, 273·6	,, 240·3	,, 212·6	,, 189·4	,, 169·8	,, 153·1	,, 138·7	,, 125·9	,, 114·8	,, 105·0
10·0	,, 765·6	,, 617·8	,, 510·3	,, 428·7	,, 365·4	,, 315·2	,, 274·5	,, 241·2	,, 213·5	,, 190·4	,, 170·8	,, 154·1	,, 139·7	,, 126·9	,, 115·8	,, 106·0
20·0	,, 769·1	,, 621·4	,, 514·1	,, 432·5	,, 369·3	,, 319·1	,, 278·5	,, 245·3	,, 217·7	,, 194·6	,, 175·0	,, 158·3	,, 143·9	,, 131·2	,, 120·1	,, 110·4
50·0	,, 771·4	,, 623·7	,, 516·4	,, 434·9	,, 371·8	,, 321·6	,, 281·0	,, 247·8	,, 220·2	,, 197·1	,, 177·6	,, 160·9	,, 146·5	,, 133·9	,, 122·8	,, 113·1
Infinite	,, 772·8	,, 625·1	,, 517·9	,, 436·4	,, 373·3	,, 323·1	,, 282·6	,, 249·4	,, 221·9	,, 198·8	,, 179·3	,, 162·6	,, 148·2	,, 135·6	,, 124·5	,, 114·8

$h =$	$v = 6·0.$	$v=6·25.$	$v = 6·5.$	$v=6·75.$	$v = 7·0.$	$v=7·25.$	$v = 7·5.$	$v=7·75.$	$v = 8·0.$	$v=8·25.$	$v = 8·5.$	$v=8·75.$	$v = 9·0.$	$v=9·25.$	$v = 9·5.$	$v=9·75.$	$v = 10·0.$
·5																	
1.0	1 in 16·8	1 in 8·5	1 in 1·1														
1·5	,, 46·6	,, 38·4	,, 31·3	1 in 24·8	1 in 18·8	1 in 13·5	1 in 8·7	1 in 4·3									
2·0	,, 61·5	,, 53·4	,, 46·3	,, 39·9	,, 34·1	,, 28·9	,, 24·1	,, 19·7	1 in 15·7	1 in 12·1	1 in 8·7	1 in 5·6	1 in 2·7				
2·5	,, 70·3	,, 62·4	,, 55·3	,, 49·0	,, 43·2	,, 38·0	,, 33·3	,, 28·9	,, 25·0	,, 21·5	,, 18·1	,, 15·0	,, 12·1	1 in 9·5	1 in 7·1	1 in 4·8	1 in 2·7
3·0	,, 76·3	,, 68·4	,, 61·4	,, 55·1	,, 49·4	,, 44·2	,, 39·5	,, 35·1	,, 31·2	,, 27·7	,, 24·4	,, 21·3	,, 18·4	,, 15·8	,, 13·4	,, 11·2	,, 9·1
3·5	,, 80·5	,, 72·7	,, 65·7	,, 59·4	,, 53·7	,, 48·5	,, 43·8	,, 39·5	,, 35·6	,, 32·1	,, 28·8	,, 25·8	,, 23·0	,, 20·4	,, 18·0	,, 15·8	,, 13·7
4·0	,, 83·7	,, 75·9	,, 68·9	,, 62·6	,, 57·0	,, 51·8	,, 47·2	,, 42·9	,, 39·0	,, 35·5	,, 32·2	,, 29·2	,, 26·4	,, 23·8	,, 21·4	,, 19·2	,, 17·1
4·5	,, 86·2	,, 78·4	,, 71·5	,, 65·2	,, 59·5	,, 54·3	,, 49·8	,, 45·5	,, 41·6	,, 38·0	,, 34·7	,, 31·8	,, 29·1	,, 26·4	,, 24·1	,, 21·9	,, 19·8
5·0	,, 88·3	,, 80·5	,, 73·5	,, 67·2	,, 61·5	,, 56·4	,, 51·8	,, 47·5	,, 43·6	,, 40·1	,, 36·8	,, 33·9	,, 31·2	,, 28·5	,, 26·2	,, 24·0	,, 22·0
5·5	,, 89·9	,, 82·1	,, 75·1	,, 68·8	,, 63·1	,, 58·1	,, 53·4	,, 49·2	,, 45·3	,, 41·9	,, 38·6	,, 35·6	,, 32·9	,, 30·3	,, 27·9	,, 25·7	,, 23·7
6·0	,, 91·2	,, 83·4	,, 76·5	,, 70·2	,, 64·5	,, 59·5	,, 54·8	,, 50·6	,, 46·7	,, 43·3	,, 40·0	,, 37·0	,, 34·3	,, 31·7	,, 29·4	,, 27·1	,, 25·1
7·0	,, 93·3	,, 85·5	,, 78·7	,, 72·4	,, 66·7	,, 61·7	,, 57·0	,, 52·8	,, 49·0	,, 45·5	,, 42·3	,, 39·3	,, 36·6	,, 34·0	,, 31·7	,, 29·4	,, 27·4
8·0	,, 94·9	,, 87·1	,, 80·3	,, 74·0	,, 68·3	,, 63·3	,, 58·7	,, 54·4	,, 50·6	,, 47·2	,, 43·9	,, 40·9	,, 38·2	,, 35·7	,, 33·4	,, 31·2	,, 29·2
9·0	,, 96·2	,, 88·4	,, 81·6	,, 75·3	,, 69·6	,, 64·6	,, 60·0	,, 55·7	,, 51·9	,, 48·5	,, 45·2	,, 42·3	,, 39·6	,, 37·0	,, 34·7	,, 32·6	,, 30·5
10·0	,, 97·2	,, 89·4	,, 82·6	,, 76·3	,, 70·6	,, 65·6	,, 61·0	,, 58·7	,, 52·9	,, 49·5	,, 46·2	,, 43·3	,, 40·6	,, 38·1	,, 35·7	,, 33·6	,, 31·6
20·0	,, 101·6	,, 93·8	,, 87·0	,, 80·8	,, 75·2	,, 70·2	,, 65·6	,, 61·4	,, 57·6	,, 54·2	,, 51·0	,, 48·1	,, 45·4	,, 42·9	,, 40·5	,, 38·4	,, 36·4
50·0	,, 104·3	,, 96·6	,, 89·8	,, 83·6	,, 78·0	,, 73·0	,, 68·4	,, 64·2	,, 60·4	,, 57·0	,, 53·8	,, 50·9	,, 48·2	,, 45·7	,, 43·4	,, 41·3	,, 39·3
Infinite	,, 106·1	,, 98·4	,, 91·6	,, 85·4	,, 79·8	,, 74·8	,, 70·2	,, 66·0	,, 62·2	,, 58·9	,, 55·7	,, 52·8	,, 50·1	,, 47·6	,, 45·3	,, 43·2	,, 41·2

Example: Required to know the proper inclination for an oval sewer, of the old form and proportion, 4 feet by 6 feet, in which the velocity when running two-thirds full is to be 3 feet per second, and the observed or available fall is 4 feet, then $4 \times 353·6 = 1414·4$, or 1 in 1414·4.

TABLE No. 18.—Showing the PROPER INCLINATION for OVAL SEWERS, 1′ 0″ × 1′ 6″ (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius equal to one-fourth the transverse diameter, and the radius of the sides being one and a half times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when RUNNING ONE-THIRD FULL, and working under various heads.

The proper inclination for the same velocity of any other sized oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet or decimal parts of feet.

h =	v = 2·0.	v = 2·25.	v = 2·5.	v = 2·75.	v = 3·0.	v = 3·25.	v = 3·5.	v = 3·75.	v = 4·0.	v=4·25.	v = 4·5.	v=4·75.	v = 5·0.	v=5·25.	v = 5·5.	v=5·75.
′ ·5	1 in 411·2	1 in 312·2	1 in 239·7	1 in 184·5	1 in 141·5	1 in 107·0	1 in 79·0	1 in 55·9	1 in 36·6	1 in 20·2	1 in 6·3					
1·0	„ 458·5	„ 360·6	„ 289·3	„ 235·1	„ 192·9	„ 159·2	„ 132·0	„ 109·6	„ 90·9	„ 75·1	„ 61·8	1 in 50·4	1 in 40·5	1 in 31·7	1 in 24·0	1 in 17·1
1·5	„ 474·3	„ 376·8	„ 305·9	„ 251·9	„ 210·0	„ 176·7	„ 149·7	„ 127·4	„ 109·0	„ 93·5	„ 80·3	„ 69·1	„ 59·3	„ 50·7	„ 43·1	„ 36·4
2·0	„ 482·1	„ 384·8	„ 314·1	„ 260·3	„ 218·6	„ 185·4	„ 158·5	„ 136·4	„ 118·1	„ 102·6	„ 89·6	„ 78·4	„ 68·8	„ 60·2	„ 52·7	„ 46·1
2·5	„ 486·8	„ 389·7	„ 319·1	„ 265·4	„ 223·7	„ 190·6	„ 163·8	„ 141·7	„ 123·5	„ 108·1	„ 95·1	„ 84·0	„ 74·4	„ 65·9	„ 58·5	„ 51·9
3·0	„ 490·0	„ 393·0	„ 322·4	„ 268·8	„ 227·2	„ 194·1	„ 167·3	„ 145·3	„ 127·1	„ 111·8	„ 98·8	„ 87·7	„ 78·1	„ 69·7	„ 62·3	„ 55·7
3·5	„ 492·2	„ 395·3	„ 324·8	„ 271·2	„ 229·6	„ 196·5	„ 169·8	„ 147·9	„ 129·7	„ 114·4	„ 101·5	„ 90·4	„ 80·9	„ 72·5	„ 65·1	„ 58·5
4·0	„ 493·9	„ 397·0	„ 326·5	„ 273·0	„ 231·4	„ 198·4	„ 171·7	„ 149·8	„ 131·6	„ 116·3	„ 103·5	„ 92·4	„ 82·9	„ 74·5	„ 67·1	„ 60·6
4·5	„ 495·3	„ 398·4	„ 327·9	„ 274·4	„ 232·9	„ 199·9	„ 173·2	„ 151·3	„ 133·1	„ 117·8	„ 105·0	„ 93·9	„ 84·4	„ 76·0	„ 68·7	„ 62·2
5·0	„ 496·3	„ 399·4	„ 329·0	„ 275·5	„ 234·0	„ 201·1	„ 174·4	„ 152·5	„ 134·4	„ 119·1	„ 106·3	„ 95·2	„ 85·7	„ 77·3	„ 70·0	„ 63·5
5·5	„ 497·2	„ 400·3	„ 329·9	„ 276·4	„ 234·9	„ 202·0	„ 175·3	„ 153·5	„ 135·4	„ 120·1	„ 107·3	„ 96·3	„ 86·8	„ 78·4	„ 71·1	„ 64·6
6·0	„ 497·9	„ 401·1	„ 330·7	„ 277·2	„ 235·7	„ 202·8	„ 176·1	„ 154·3	„ 136·2	„ 120·9	„ 108·1	„ 97·1	„ 87·6	„ 79·2	„ 71·9	„ 65·4
7·0	„ 499·0	„ 402·2	„ 331·8	„ 278·4	„ 236·9	„ 204·0	„ 177·3	„ 155·5	„ 137·4	„ 122·2	„ 109·4	„ 98·4	„ 88·9	„ 80·6	„ 73·3	„ 66·8
8·0	„ 499·8	„ 403·0	„ 332·7	„ 279·3	„ 237·8	„ 204·9	„ 178·3	„ 156·5	„ 138·4	„ 123·2	„ 110·4	„ 99·4	„ 89·9	„ 81·6	„ 74·3	„ 67·8
9·0	„ 500·5	„ 403·7	„ 333·4	„ 280·0	„ 238·6	„ 205·7	„ 179·1	„ 157·3	„ 139·2	„ 124·0	„ 111·2	„ 100·2	„ 90·7	„ 82·4	„ 75·1	„ 68·6
10·0	„ 501·0	„ 404·3	„ 334·0	„ 280·6	„ 239·2	„ 206·3	„ 179·7	„ 157·9	„ 139·8	„ 124·6	„ 111·8	„ 100·8	„ 91·4	„ 83·1	„ 75·8	„ 69·3
20·0	„ 503·3	„ 406·7	„ 336·4	„ 283·0	„ 241·7	„ 208·8	„ 182·3	„ 160·5	„ 142·5	„ 127·4	„ 114·6	„ 103·6	„ 94·2	„ 85·9	„ 78·6	„ 72·2
50·0	„ 504·8	„ 408·2	„ 337·9	„ 284·6	„ 243·3	„ 210·4	„ 183·9	„ 162·1	„ 144·1	„ 129·0	„ 116·3	„ 105·3	„ 95·9	„ 87·6	„ 80·4	„ 74·0
Infinite	„ 505·7	„ 409·1	„ 338·9	„ 285·6	„ 244·3	„ 211·5	„ 185·0	„ 163·2	„ 145·2	„ 130·1	„ 117·4	„ 106·4	„ 97·0	„ 88·7	„ 81·5	„ 75·1

$h =$	$v = 6·0$.	$v = 6·25$.	$v = 6·5$.	$v = 6·75$.	$v = 7·0$.	$v = 7·25$.	$v = 7·5$.	$v = 7·75$.	$v = 8·0$.	$v = 8·25$.	$v = 8·5$.	$v = 8·75$.	$v = 9·0$.	$v = 9·25$.	$v = 9·5$.	$v = 9·75$.	$v = 10·0$.
·5																	
1·0	1 in 11·0	1 in 5·5	1 in ·7														
1·5	,, 30·5	,, 25·1	,, 20·5	1 in 16·2	1 in 12·3	1 in 8·8	1 in 5·7	1 in 2·8									
2·0	,, 40·2	,, 34·9	,, 30·3	,, 26·1	,, 22·3	,, 18·9	,, 15·8	,, 12·9	1 in 10·2	1 in 7·9	1 in 5·7	1 in 3·6	1 in 1·7				
2·5	,, 46·0	,, 40·8	,, 36·2	,, 32·0	,, 28·3	,, 24·9	,, 21·8	,, 18·9	,, 16·3	,, 14·0	,, 11·8	,, 9·8	,, 7·9	1 in 6·2	1 in 4·6	1 in 3·1	1 in 1·7
3·0	,, 49·9	,, 44·8	,, 40·2	,, 36·0	,, 32·3	,, 28·9	,, 25·9	,, 23·0	,, 20·4	,, 18·1	,, 15·9	,, 14·0	,, 12·1	,, 10·4	,, 8·8	,, 7·3	,, 5·9
3·5	,, 52·7	,, 47·6	,, 43·0	,, 38·8	,, 35·1	,, 31·7	,, 28·7	,, 25·9	,, 23·3	,, 21·0	,, 18·8	,, 16·9	,, 15·0	,, 13·3	,, 11·8	,, 10·3	,, 8·9
4·0	,, 54·8	,, 49·7	,, 45·1	,, 41·0	,, 37·3	,, 33·9	,, 30·9	,, 28·1	,, 25·5	,, 23·2	,, 21·0	,, 19·1	,, 17·3	,, 15·5	,, 14·0	,, 12·5	,, 11·2
4·5	,, 56·4	,, 51·3	,, 46·8	,, 42·7	,, 38·9	,, 35·5	,, 32·6	,, 29·8	,, 27·2	,, 24·9	,, 22·7	,, 20·8	,, 19·0	,, 17·3	,, 15·8	,, 14·3	,, 13·0
5·0	,, 57·8	,, 52·6	,, 48·1	,, 44·0	,, 40·2	,, 36·9	,, 33·9	,, 31·1	,, 28·5	,, 26·3	,, 24·1	,, 22·2	,, 20·4	,, 18·7	,, 17·1	,, 15·7	,, 14·4
5·5	,, 58·9	,, 53·7	,, 49·2	,, 45·1	,, 41·3	,, 38·0	,, 35·0	,, 32·2	,, 29·7	,, 27·4	,, 25·3	,, 23·3	,, 21·6	,, 19·8	,, 18·3	,, 16·9	,, 15·5
6·0	,, 59·7	,, 54·5	,, 50·1	,, 46·0	,, 42·2	,, 38·9	,, 35·9	,, 33·1	,, 30·6	,, 28·3	,, 26·2	,, 24·2	,, 22·5	,, 20·7	,, 19·2	,, 17·8	,, 16·4
7·0	,, 61·1	,, 55·9	,, 51·5	,, 47·3	,, 43·6	,, 40·3	,, 37·3	,, 34·5	,, 32·0	,, 29·8	,, 27·7	,, 25·7	,, 24·0	,, 22·2	,, 20·7	,, 19·3	,, 17·9
8·0	,, 62·2	,, 57·0	,, 52·6	,, 48·4	,, 44·7	,, 41·4	,, 38·4	,, 35·6	,, 33·1	,, 30·9	,, 28·8	,, 26·8	,, 25·1	,, 23·3	,, 21·8	,, 20·4	,, 19·0
9·0	,, 63·0	,, 57·8	,, 53·4	,, 49·2	,, 45·5	,, 42·2	,, 39·2	,, 36·5	,, 34·0	,, 31·7	,, 29·6	,, 27·7	,, 25·9	,, 24·2	,, 22·7	,, 21·3	,, 19·9
10·0	,, 63·6	,, 58·5	,, 54·0	,, 49·9	,, 46·2	,, 42·9	,, 39·9	,, 37·2	,, 34·7	,, 32·4	,, 30·3	,, 28·4	,, 26·6	,, 24·9	,, 23·4	,, 22·0	,, 20·6
20·0	,, 66·5	,, 61·4	,, 56·9	,, 52·9	,, 49·2	,, 45·9	,, 42·9	,, 40·2	,, 37·7	,, 35·5	,, 33·4	,, 31·5	,, 29·7	,, 28·0	,, 26·5	,, 25·1	,, 23·8
50·0	,, 68·3	,, 63·2	,, 58·7	,, 54·7	,, 51·0	,, 47·7	,, 44·7	,, 42·0	,, 39·5	,, 37·3	,, 35·2	,, 33·3	,, 31·6	,, 29·9	,, 28·4	,, 27·0	,, 25·7
Infinite	,, 69·4	,, 64·4	,, 59·9	,, 55·9	,, 52·2	,, 48·9	,, 45·9	,, 43·2	,, 40·7	,, 38·5	,, 36·4	,, 34·5	,, 32·8	,, 31·1	,, 29·7	,, 28·3	,, 27·0

Example: Required to know the proper inclination for an oval sewer, of the old form and proportions, 2·5 feet × 3·75 feet, in which the velocity when running one-third full is to be 2 feet per second, and the observed or available fall is 10 feet, then 2·5 × 501 = 1252·5, or 1 in 1252·5.

Table No. 19.—Showing the Proper Inclination of Oval Sewers, 1′ 0″ × 1′ 6″ (New Form), in which the transverse diameter is equal to two-thirds the vertical diameter, the invert having a radius equal to one-eighth the transverse diameter, and the radius of the sides being one and a third times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when Running Full, and working under various heads.

The proper inclination for the same velocity of any other sized oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

$h =$	$v = 2·0.$	$v = 2·25.$	$v = 2·5.$	$v = 2·75.$	$v = 3·0.$	$v = 3·25.$	$v = 3·5.$	$v = 3·75.$	$v = 4·0.$	$v = 4·25.$	$v = 4·5.$	$v = 4·75.$	$v = 5·0.$	$v = 5·25.$	$v = 5·5.$	$v = 5·75.$
·5	1 in 566·0	1 in 429·8	1 in 330·1	1 in 254·1	1 in 194·7	1 in 147·3	1 in 108·8	1 in 77·1	1 in 50·4	1 in 27·7	1 in 8·7					
1·0	,, 631·1	,, 496·5	,, 398·3	,, 323·7	,, 265·5	,, 219·2	,, 181·7	,, 150·9	,, 125·1	,, 103·4	,, 85·2	1 in 69·5	1 in 55·7	1 in 43·6	1 in 33·0	1 in 23·6
1·5	,, 652·8	,, 518·7	,, 421·0	,, 346·9	,, 289·1	,, 243·2	,, 206·0	,, 175·5	,, 150·0	,, 128·6	,, 110·7	,, 95·2	,, 81·6	,, 69·8	,, 59·4	,, 50·2
2·0	,, 663·6	,, 529·8	,, 432·4	,, 358·5	,, 300·9	,, 255·1	,, 218·1	,, 187·8	,, 162·5	,, 141·2	,, 123·4	,, 108·0	,, 94·6	,, 82·9	,, 72·6	,, 63·5
2·5	,, 670·2	,, 536·5	,, 439·2	,, 365·5	,, 308·0	,, 262·3	,, 225·4	,, 195·2	,, 170·0	,, 148·8	,, 131·0	,, 115·7	,, 102·4	,, 90·7	,, 80·5	,, 71·4
3·0	,, 674·5	,, 541·0	,, 443·8	,, 370·1	,, 312·7	,, 267·1	,, 230·3	,, 200·1	,, 175·0	,, 153·9	,, 136·1	,, 120·9	,, 107·6	,, 95·9	,, 85·8	,, 76·7
3·5	,, 677·6	,, 544·2	,, 447·0	,, 373·4	,, 316·1	,, 270·6	,, 233·8	,, 203·6	,, 178·5	,, 157·5	,, 139·8	,, 124·6	,, 111·3	,, 99·7	,, 89·6	,, 80·5
4·0	,, 679·9	,, 546·5	,, 449·4	,, 375·9	,, 318·6	,, 273·1	,, 236·4	,, 206·2	,, 181·2	,, 160·2	,, 142·5	,, 127·3	,, 114·0	,, 102·5	,, 92·4	,, 83·4
4·5	,, 681·7	,, 548·4	,, 451·3	,, 377·8	,, 320·6	,, 275·1	,, 238·4	,, 208·3	,, 183·3	,, 162·3	,, 144·6	,, 129·5	,, 116·2	,, 104·7	,, 94·6	,, 85·6
5·0	,, 683·2	,, 549·9	,, 452·9	,, 379·4	,, 322·2	,, 276·7	,, 240·0	,, 209·9	,, 184·9	,, 163·9	,, 146·3	,, 131·2	,, 117·9	,, 106·4	,, 96·4	,, 87·4
5·5	,, 684·4	,, 551·1	,, 454·1	,, 380·6	,, 323·4	,, 278·0	,, 241·3	,, 211·3	,, 186·3	,, 165·3	,, 147·7	,, 132·6	,, 119·3	,, 107·8	,, 97·8	,, 88·9
6·0	,, 685·4	,, 552·1	,, 455·1	,, 381·7	,, 324·5	,, 279·1	,, 242·4	,, 212·4	,, 187·4	,, 166·5	,, 148·9	,, 133·8	,, 120·5	,, 109·0	,, 99·0	,, 90·1
7·0	,, 686·9	,, 553·7	,, 456·8	,, 383·4	,, 326·2	,, 280·8	,, 244·2	,, 214·2	,, 189·2	,, 168·3	,, 150·7	,, 135·6	,, 122·4	,, 110·9	,, 100·9	,, 92·0
8·0	,, 688·1	,, 554·9	,, 458·0	,, 384·6	,, 327·5	,, 282·1	,, 245·5	,, 215·5	,, 190·5	,, 169·6	,, 152·0	,, 136·9	,, 123·8	,, 112·3	,, 102·3	,, 93·4
9·0	,, 689·0	,, 555·8	,, 458·9	,, 385·6	,, 328·5	,, 283·1	,, 246·5	,, 216·5	,, 191·6	,, 170·7	,, 153·1	,, 138·0	,, 124·9	,, 113·4	,, 103·4	,, 94·5
10·0	,, 689·7	,, 556·5	,, 459·7	,, 386·4	,, 329·3	,, 283·9	,, 247·3	,, 217·3	,, 192·4	,, 171·5	,, 154·0	,, 138·9	,, 125·7	,, 114·3	,, 104·3	,, 95·4
20·0	,, 692·9	,, 559·9	,, 463·1	,, 389·8	,, 332·8	,, 287·5	,, 251·0	,, 221·0	,, 196·2	,, 175·3	,, 157·8	,, 142·7	,, 129·6	,, 118·2	,, 108·2	,, 99·4
50·0	,, 694·9	,, 561·9	,, 465·1	,, 391·9	,, 334·9	,, 289·7	,, 253·1	,, 223·2	,, 198·4	,, 177·6	,, 160·1	,, 145·1	,, 131·9	,, 120·5	,, 110·6	,, 101·8
Infinite	,, 696·2	,, 563·2	,, 466·5	,, 393·3	,, 336·3	,, 291·1	,, 254·6	,, 224·7	,, 199·9	,, 179·1	,, 161·6	,, 146·6	,, 133·5	,, 122·1	,, 112·2	,, 103·4

h =	v = 6·0.	v = 6·25.	v = 6·5.	v = 6·75.	v = 7·0.	v = 7·25.	v = 7·5.	v = 7·75.	v = 8·0.	v = 8·25.	v = 8·5.	v = 8·75.	v = 9·0.	v = 9·25.	v = 9·5.	v = 9·75.	v = 10·0.
·5																	
1·0	1 in 15·2	1 in 7·6	1 in ·9														
1·5	„ 42·0	„ 34·6	„ 28·1	1 in 22·3	1 in 17·0	1 in 12·3	1 in 7·9	1 in 3·9	1 in ·3								
2·0	„ 55·4	„ 48·1	„ 47·1	„ 35·9	„ 30·7	„ 26·0	„ 21·7	„ 17·8	„ 14·2	1 in 10·9	1 in 7·8	1 in 5·0	1 in 2·4				
2·5	„ 63·4	„ 56·2	„ 49·8	„ 44·1	„ 39·0	„ 34.3	„ 30·1	„ 26·2	„ 22·6	„ 19·4	„ 16·3	„ 13·5	„ 11·0	1 in 8·6	1 in 6·3	1 in 4·3	1 in 2·4
3·0	„ 68·8	„ 61·6	„ 55·2	„ 49·6	„ 44·5	„ 39·8	„ 35·6	„ 31·7	„ 28·2	„ 25·0	„ 22·0	„ 19·2	„ 16·7	„ 14·3	„ 12·1	„ 10·1	„ 8·2
3·5	„ 72·6	„ 65·5	„ 59·1	„ 53·5	„ 48·4	„ 43·8	„ 39·6	„ 35·7	„ 32·2	„ 29·0	„ 26·0	„ 23·3	„ 20·8	„ 18·4	„ 16·2	„ 14·2	„ 12·3
4·0	„ 75·5	„ 68·4	„ 62·0	„ 56·4	„ 51 3	„ 46·7	„ 42·5	„ 38·7	„ 35·2	„ 32·0	„ 29·0	„ 26·3	„ 23·8	„ 21·4	„ 19·3	„ 17·3	„ 15·4
4·5	„ 77·7	„ 70·6	„ 64·3	„ 58·7	„ 53·6	„ 49·0	„ 44·8	„ 41·0	„ 37·5	„ 34·3	„ 31·4	„ 28·7	„ 26·2	„ 23·8	„ 21·7	„ 19·7	„ 17·8
5·0	„ 79·5	„ 72·4	„ 66·1	„ 60·5	„ 55·4	„ 50·9	„ 46·7	„ 42·9	„ 39·4	„ 36·2	„ 33·3	„ 30·6	„ 28·1	„ 25·7	„ 23·6	„ 21·6	„ 19·7
5·5	„ 81·0	„ 73·9	„ 67·6	„ 62·0	„ 56·9	„ 52·4	„ 48·2	„ 44·4	„ 40·9	„ 37·8	„ 34·8	„ 32·1	„ 29·6	„ 27·3	„ 25·1	„ 23·2	„ 21·3
6·0	„ 82·2	„ 75·1	„ 68·8	„ 63·2	„ 58·2	„ 53·6	„ 49·4	„ 45·7	„ 42·2	„ 39·1	„ 36·1	„ 33·4	„ 30·9	„ 28·6	„ 26·4	„ 24·5	„ 22·6
7·0	„ 84·1	„ 77·0	„ 70·8	„ 65·2	„ 60·1	„ 55·6	„ 51·4	„ 47·7	„ 44·2	„ 41·1	„ 38·1	„ 35·4	„ 33·0	„ 30·6	„ 28·5	„ 26·6	„ 24·7
8·0	„ 85·5	„ 78·5	„ 72·2	„ 66·7	„ 61·6	„ 57·1	„ 52·9	„ 49·2	„ 45·7	„ 42·6	„ 39·6	„ 36·9	„ 34·5	„ 32·2	„ 30·0	„ 28·1	„ 26·3
9·0	„ 86·7	„ 79·6	„ 73·3	„ 67·8	„ 62·8	„ 58·2	„ 54·1	„ 50·3	„ 46·9	„ 43·7	„ 40·8	„ 38·1	„ 35·7	„ 33·4	„ 31·2	„ 29·3	„ 27·5
10·0	„ 87·6	„ 80·5	„ 74·2	„ 68·7	„ 63·7	„ 59·1	„ 55·0	„ 51·2	„ 47·8	„ 44·7	„ 41·7	„ 39·1	„ 36·6	„ 34·3	„ 32·2	„ 30·3	„ 28·5
20·0	„ 91·6	„ 84·6	„ 78·3	„ 72·8	„ 67·8	„ 63·3	„ 59·1	„ 55·4	„ 52·0	„ 48·9	„ 46·0	„ 43·3	„ 40·9	„ 38·6	„ 36·5	„ 34·6	„ 32·8
50·0	„ 94·0	„ 87·0	„ 80·8	„ 75·3	„ 70·3	„ 65·7	„ 61·6	„ 57·9	„ 54·5	„ 51·4	„ 48·5	„ 45·9	„ 43·5	„ 41·2	„ 39·1	„ 37·2	„ 35·4
Infinite	„ 95·6	„ 88·6	„ 82·4	„ 76·9	„ 71·9	„ 67·4	„ 63·3	„ 59·6	„ 56·2	„ 53·1	„ 50·2	„ 47·6	„ 45·2	„ 42·9	„ 40·8	„ 38·9	„ 37·1

Example: Required the proper inclination for an oval sewer of the New Form, 3′ 0″ × 4′ 6″, the total fall in the length taken into consideration = 9 feet, the velocity required when running full being 2 feet per second, then 3 feet × 689·0 = 2067·0 = 1 in 2067.

TABLE No. 20.—Showing the PROPER INCLINATION of OVAL SEWERS, 1′ 0″ × 1′ 6″ (New Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-eighth of the transverse diameter, and the radius of the sides being one and a third times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when RUNNING TWO-THIRDS FULL, and working under various heads.

The proper inclination for the same velocity of any other oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

$h =$	$v = 2·0$.	$v = 2·25$	$v = 2·5$.	$v = 2·75$.	$v = 3·0$.	$v = 3·25$.	$v = 3·5$.	$v = 3·75$.	$v = 4·0$.	$v = 4·25$.	$v = 4·5$.	$v = 4·75$.	$v = 5·0$.	$v = 5·25$.	$v = 5·5$.	$v = 5·75$.
·5	1 in 611·7	1 in 464·7	1 in 357·0	1 in 275·0	1 in 210·5	1 in 159·2	1 in 117·6	1 in 83·3	1 in 54·5	1 in 30·1	1 in 9·5					
1·0	,, 682·1	,, 536·7	,, 430·6	,, 350·1	,, 287·0	,, 236·9	,, 196·4	,, 163·1	,, 135·3	,, 111·9	,, 92·1	1 in 75·0	1 in 60·1	1 in 47·1	1 in 35·5	1 in 25·3
1·5	,, 705·6	,, 560·7	,, 455·1	,, 375·1	,, 312·5	,, 262·8	,, 222·7	,, 189·7	,, 162·2	,, 139·2	,, 119·6	,, 102·8	,, 88·2	,, 75·4	,, 64·1	,, 54·1
2·0	,, 717·3	,, 572·7	,, 467·4	,, 387·6	,, 325·2	,, 275·7	,, 235·8	,, 203·0	,, 175·7	,, 152·8	,, 133·4	,, 116·7	,, 102·2	,, 89·5	,, 78·4	,, 68·5
2·5	,, 724·3	,, 579·9	,, 474·8	,, 395·2	,, 332·9	,, 283·5	,, 243·7	,, 211·0	,, 183·8	,, 161·0	,, 141·7	,, 125·0	,, 110·6	,, 98·0	,, 86·9	,, 77·1
3·0	,, 729·0	,, 584·7	,, 479·7	,, 400·2	,, 338·0	,, 288·7	,, 248·9	,, 216·3	,, 189·2	,, 166·4	,, 147·2	,, 130·6	,, 116·2	,, 103·7	,, 92·6	,, 82·9
3·5	,, 732·4	,, 588·1	,, 483·2	,, 403·7	,, 341·6	,, 292·4	,, 252·7	,, 220·1	,, 193·0	,, 170·3	,, 151·1	,, 134·6	,, 120·2	,, 107·7	,, 96·7	,, 87·0
4·0	,, 734·9	,, 590·7	,, 485·8	,, 406·4	,, 344·4	,, 295·2	,, 255·5	,, 223·0	,, 195·9	,, 173·3	,, 154·1	,, 137·6	,, 123·3	,, 110·8	,, 99·8	,, 90·1
4·5	,, 736·8	,, 592·7	,, 487·8	,, 408·5	,, 346·5	,, 297·3	,, 257·6	,, 225·1	,, 198·1	,, 175·5	,, 156·3	,, 139·9	,, 125·6	,, 113·1	,, 102·2	,, 92·5
5·0	,, 738·4	,, 594·3	,, 489·5	,, 410·2	,, 348·2	,, 299·1	,, 259·4	,, 226·9	,, 199·9	,, 177·3	,, 158·2	,, 141·7	,, 127·5	,, 115·0	,, 104·1	,, 94·4
5·5	,, 739·7	,, 595·6	,, 490·8	,, 411·5	,, 349·6	,, 300·5	,, 260·9	,, 228·4	,, 201·4	,, 178·8	,, 159·7	,, 143·2	,, 129·0	,, 116·6	,, 105·6	,, 96·0
6·0	,, 740·8	,, 596·7	,, 491·9	,, 412·7	,, 350·8	,, 301·7	,, 262·1	,, 229·6	,, 202·6	,, 180·1	,, 161·0	,, 144·5	,, 130·3	,, 117·9	,, 106·9	,, 97·3
7·0	,, 742·4	,, 598·4	,, 493·7	,, 414·5	,, 352·6	,, 303·5	,, 263·9	,, 231·5	,, 204·5	,, 182·0	,, 162·9	,, 146·5	,, 132·3	,, 119·9	,, 109·0	,, 99·4
8·0	,, 743·7	,, 599·7	,, 495·0	,, 415·8	,, 353·9	,, 304·8	,, 265·3	,, 232·9	,, 206·0	,, 183·5	,, 164·4	,, 148·0	,, 133·8	,, 121·4	,, 110·5	,, 100·9
9·0	,, 744·7	,, 600·7	,, 496·0	,, 416·8	,, 355·0	,, 305·9	,, 266·4	,, 234·0	,, 207·1	,, 184·6	,, 165·5	,, 149·1	,, 134·9	,, 122·6	,, 111·7	,, 102·1
10·0	,, 745·5	,, 601·5	,, 496·8	,, 417·7	,, 355·9	,, 306·8	,, 267·3	,, 234·9	,, 208·0	,, 185·5	,, 166·4	,, 150·0	,, 135·9	,, 123·5	,, 112·6	,, 103·1
20·0	,, 749·0	,, 605·1	,, 500·5	,, 421·4	,, 359·7	,, 310·7	,, 271·3	,, 238·9	,, 212·1	,, 189·6	,, 170·6	,, 154·2	,, 140·1	,, 127·8	,, 116·9	,, 107·4
50·0	,, 751·1	,, 607·3	,, 502·7	,, 423·7	,, 362·0	,, 313·0	,, 273·6	,, 241·3	,, 214·5	,, 192·1	,, 173·1	,, 156·7	,, 142·6	,, 130·3	,, 119·5	,, 110·0
Infinite	,, 752·5	,, 608·7	,, 504·2	,, 425·2	,, 363·5	,, 314·6	,, 275·2	,, 242·9	,, 216·1	,, 193·7	,, 174·7	,, 158·4	,, 144·3	,, 132·0	,, 121·2	,, 111·7

$h=$	$v=6·0.$	$v=6·25.$	$v=6·5.$	$v=6·75.$	$v=7·0.$	$v=7·25.$	$v=7·5.$	$v=7·75.$	$v=8·0.$	$v=8·25.$	$v=8·5.$	$v=8·75.$	$v=9·0.$	$v=9·25.$	$v=9·5.$	$v=9·75.$	$v=10·0.$
·5																	
1·0	1 in 16·3	1 in 8·3	1 in 1·1														
1·5	„ 45·3	„ 37·5	„ 30·4	1 in 24·1	1 in 18·4	1 in 13·2	1 in 8·5	1 in 4·2	1 in ·2								
2·0	„ 59·8	„ 52·1	„ 45·1	„ 38·9	„ 33·2	„ 28·1	„ 23·5	„ 19·3	„ 15·4	1 in 11·8	1 in 8·5	1 in 5·4	1 in 2·6				
2·5	„ 68·5	„ 60·8	„ 53·9	„ 47·7	„ 42·1	„ 37·0	„ 32·5	„ 28·3	„ 24·4	„ 20·9	„ 17·7	„ 14·6	„ 11·9	1 in 9·3	1 in 6·9	1 in 4·6	1 in 2·6
3·0	„ 74·3	„ 66·6	„ 59·8	„ 53·6	„ 48·0	„ 43·0	„ 38·5	„ 34·3	„ 30·5	„ 27·0	„ 23·8	„ 20·7	„ 18·0	„ 15·5	„ 13·1	„ 10·9	„ 8·9
3·5	„ 78·4	„ 70·8	„ 64·0	„ 57·8	„ 52·3	„ 47·3	„ 42·8	„ 38·6	„ 34·8	„ 31·3	„ 28·1	„ 25·1	„ 22·4	„ 19·9	„ 17·5	„ 15·3	„ 13·3
4·0	„ 81·5	„ 73·9	„ 67·1	„ 61·0	„ 55·4	„ 50·4	„ 46·0	„ 41·8	„ 38·0	„ 34·6	„ 31·4	„ 28·4	„ 25·7	„ 23·2	„ 20·8	„ 18·6	„ 16·7
4·5	„ 84·0	„ 76·4	„ 69·6	„ 63·5	„ 57·9	„ 52·9	„ 48·5	„ 44·3	„ 40·5	„ 37·1	„ 33·9	„ 30·9	„ 28·3	„ 25·8	„ 23·4	„ 21·2	„ 19·3
5·0	„ 85·9	„ 78·3	„ 71·5	„ 65·4	„ 59·9	„ 54·9	„ 50·5	„ 46·3	„ 42·5	„ 39·2	„ 36·0	„ 33·0	„ 30·3	„ 27·8	„ 25·5	„ 23·3	„ 21·4
5·5	„ 87·5	„ 79·9	„ 73·1	„ 67·0	„ 61·5	„ 56·5	„ 52·1	„ 48·0	„ 44·2	„ 40·8	„ 37·6	„ 34·7	„ 32·0	„ 29·5	„ 27·2	„ 25·0	„ 23·1
6·0	„ 88·8	„ 81·2	„ 74·4	„ 68·4	„ 62·9	„ 57·9	„ 53·5	„ 49·4	„ 45·6	„ 42·2	„ 39·0	„ 36·1	„ 33·4	„ 30·9	„ 28·6	„ 26·4	„ 24·5
7·0	„ 90·9	„ 83·3	„ 76·5	„ 70·5	„ 65·0	„ 60·0	„ 55·6	„ 51·5	„ 47·7	„ 44·4	„ 41·2	„ 38·3	„ 35·6	„ 33·1	„ 30·8	„ 28·7	„ 26·7
8·0	„ 92·4	„ 84·9	„ 78·1	„ 72·1	„ 66·6	„ 61·6	„ 57·2	„ 53·1	„ 49·3	„ 46·0	„ 42·8	„ 39·9	„ 37·3	„ 34·8	„ 32·5	„ 30·3	„ 28·4
9·0	„ 93·6	„ 86·1	„ 79·3	„ 73·3	„ 67·8	„ 62·9	„ 58·5	„ 54·4	„ 50·6	„ 47·3	„ 44·1	„ 41·2	„ 38·6	„ 36·1	„ 33·8	„ 31·6	„ 29·7
10·0	„ 94·6	„ 87·1	„ 80·3	„ 74·3	„ 68·8	„ 63·9	„ 59·5	„ 55·4	„ 51·6	„ 48·3	„ 45·1	„ 42·2	„ 39·6	„ 37·1	„ 34·8	„ 32·7	„ 30·7
20·0	„ 99·0	„ 91·4	„ 84·7	„ 78·7	„ 73·2	„ 68·3	„ 63·9	„ 59·9	„ 56·2	„ 52·9	„ 49·7	„ 46·8	„ 44·2	„ 41·8	„ 39·4	„ 37·3	„ 35·4
50·0	„ 101·6	„ 94·0	„ 87·3	„ 81·3	„ 75·9	„ 71·0	„ 66·6	„ 62·6	„ 58·9	„ 55·6	„ 52·5	„ 49·6	„ 47·0	„ 44·5	„ 42·2	„ 40·1	„ 38·2
Infinite	„ 103·3	„ 95·8	„ 89·1	„ 83·1	„ 77·7	„ 72·8	„ 68·4	„ 64·4	„ 60·7	„ 57·4	„ 54·3	„ 51·4	„ 48·8	„ 46·4	„ 44·1	„ 42·0	„ 40·1

Example: Required to know what should be the proper inclination for an oval sewer of the New Form, 3 feet 4 inches × 5 feet, in which the velocity of flow when flowing two-thirds full is to be $2\frac{1}{4}$ feet per second, the observed fall from end to end of the sewer being 7 feet. From the Table we take out of the column of 2·25 for velocities, and opposite 7 feet we find 598·4, which being multiplied by 3·33, the transverse diameter of the proposed sewer, we get the proper inclination of the proposed sewer = 598·4 × 3·33 = 1 in 1992·6.

TABLE No. 21.—Showing the PROPER INCLINATION of OVAL SEWERS, 1′ 0″ × 1′ 6″ (New Form), in which the transverse diameter is equal to two-thirds the vertical diameter, the invert having a radius equal to one-eighth the transverse diameter, and the radius of the sides being one and a third times the transverse diameter, for Velocities varying from 2 feet to 10 feet per second, when RUNNING ONE-THIRD FULL, and working under various heads.

The proper inclination for the same velocity of any other sized oval sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

$h =$	$v = 2·0$.	$v = 2·25$.	$v = 2·5$.	$v = 2·75$.	$v = 3·0$.	$v = 3·25$.	$v = 3·5$.	$v = 3·75$.	$v = 4·0$.	$v = 4·25$.	$v = 4·5$.	$v = 4·75$.	$v = 5·0$.	$v = 5·25$.	$v = 5·5$.	$v = 5·75$.
′																
·5	1 in 382·0	1 in 290·2	1 in 222·9	1 in 171·5	1 in 131·4	1 in 99·4	1 in 73·5	1 in 52·1	1 in 33·9	1 in 18·7	1 in 5·9					
1·0	,, 426·0	,, 335·2	,, 268·9	,, 218·5	,, 179·2	,, 147·9	,, 122·7	,, 101·9	,, 84·4	,, 69·8	,, 57·5	1 in 46·8	1 in 37·5	1 in 29·5	1 in 22·3	6 in 15·8
1·5	,, 440·7	,, 350·2	,, 284·2	,, 234·2	,, 195·1	,, 164·1	,, 139·1	,, 118·5	,, 101·2	,, 86·8	,, 74·7	,, 64·2	,, 55·0	,, 47·2	,, 40·1	,, 33·8
2·0	,, 448·0	,, 357·7	,, 291·9	,, 242·0	,, 203·1	,, 172·2	,, 147·3	,, 126·8	,, 109·6	,, 95·3	,, 83·3	,, 72·9	,, 63·8	,, 56·0	,, 49·0	,, 42·8
2·5	,, 452·4	,, 362·2	,, 296·5	,, 246·7	,, 207·9	,, 177·1	,, 152·2	,, 131·8	,, 114·7	,, 100·5	,, 88·5	,, 78·1	,, 69·1	,, 61·3	,, 54·4	,, 42·8
3·0	,, 455·3	,, 365·2	,, 299·6	,, 249·8	,, 211·1	,, 180·3	,, 155·5	,, 135·1	,, 118·1	,, 103·9	,, 91·9	,, 81·5	,, 72·6	,, 64·8	,, 58·0	,, 51·8
3·5	,, 457·4	,, 367·3	,, 301·8	,, 252·1	,, 213·4	,, 182·6	,, 157·9	,, 137·5	,, 120·5	,, 106·3	,, 94·4	,, 84·0	,, 75·1	,, 67·4	,, 60·5	,, 54·4
4·0	,, 459·0	,, 368·9	,, 303·4	,, 253·8	,, 215·1	,, 184·3	,, 159·6	,, 139·2	,, 122·3	,, 108·1	,, 96·2	,, 85·9	,, 77·0	,, 69·3	,, 62·4	,, 56·3
4·5	,, 460·2	,, 370·2	,, 304·7	,, 255·1	,, 216·4	,, 185·7	,, 161·0	,, 140·6	,, 123·7	,, 109·5	,, 97·6	,, 87·3	,, 78·4	,, 70·7	,, 63·9	,, 57·8
5·0	,, 461·2	,, 371·2	,, 305·7	,, 256·1	,, 217·4	,, 186·8	,, 162·1	,, 141·7	,, 124·8	,, 110·7	,, 98·8	,, 88·5	,, 79·6	,, 71·9	,, 65·1	,, 59·0
5·5	,, 462·0	,, 372·0	,, 306·5	,, 257·0	,, 218·3	,, 187·7	,, 163·0	,, 142·6	,, 125·7	,, 111·6	,, 99·7	,, 89·4	,, 80·5	,, 72·9	,, 66·1	,, 60·0
6·0	,, 462·7	,, 372·7	,, 307·2	,, 257·7	,, 219·0	,, 188·4	,, 163·7	,, 143·4	,, 126·5	,, 112·4	,, 100·5	,, 90·2	,, 81·3	,, 73·7	,, 66·9	,, 60·8
7·0	,, 463·7	,, 373·8	,, 308·3	,, 258·8	,, 220·2	,, 189·6	,, 164·9	,, 144·6	,, 127·7	,, 113·6	,, 101·7	,, 91·5	,, 82·6	,, 74·9	,, 68·2	,, 62·1
8·0	,, 464·5	,, 374·6	,, 309·1	,, 259·6	,, 221·0	,, 190·4	,, 165·7	,, 145·5	,, 128·6	,, 114·5	,, 102·7	,, 92·4	,, 83·5	,, 75·9	,, 69·1	,, 63·0
9·0	,, 465·1	,, 375·2	,, 309·8	,, 260·3	,, 221·7	,, 191·1	,, 166·4	,, 146·2	,, 129·3	,, 115·2	,, 103·4	,, 93·1	,, 84·2	,, 76·6	,, 69·9	,, 63·8
10·0	,, 465·6	,, 375·7	,, 310·3	,, 260·8	,, 222·2	,, 191·7	,, 167·0	,, 146·7	,, 129·9	,, 115·8	,, 104·0	,, 93·7	,, 84·8	,, 77·2	,, 70·5	,, 64·4
20·0	,, 467·8	,, 378·0	,, 312·6	,, 263·2	,, 224·6	,, 194·1	,, 169·4	,, 149·2	,, 132·4	,, 118·3	,, 106·5	,, 96·3	,, 87·5	,, 79·9	,, 73·1	,, 67·1
50·0	,, 469·1	,, 379·3	,, 314·0	,, 264·6	,, 226·0	,, 195·5	,, 170·9	,, 150·7	,, 133·9	,, 119·9	,, 108·1	,, 97·9	,, 89·0	,, 81·4	,, 74·7	,, 68·7
Infinite	,, 470·0	,, 380·2	,, 314·9	,, 265·5	,, 227·0	,, 196·5	,, 171·9	,, 151·7	,, 134·9	,, 120·9	,, 109·1	,, 98·9	,, 90·1	,, 82·5	,, 75·8	,, 69·8

$h =$	$v = 6·0$.	$v = 6·25$.	$v = 6·5$.	$v = 6·75$.	$v = 7·0$.	$v = 7·25$.	$v = 7·5$.	$v = 7·75$.	$v = 8·0$.	$v = 8·25$.	$v = 8·5$.	$v = 8·75$.	$v = 9·0$.	$v = 9·25$.	$v = 9·5$.	$v = 9·75$.	$v = 10·0$.
·5																	
1·0	1 in 10·2	1 in 5·1	1 in ·6														
1·5	,, 28·3	,, 23·3	,, 18·9	1 in 15·0	1 in 11·5	1 in 8·3	1 in 5·3	1 in 2·6	1 in ·1								
2·0	,, 37·4	,, 32·4	,, 28·1	,, 24·3	,, 20·8	,, 17·6	,, 14·7	,, 12·0	,, 9·6	1 in 7·3	1 in 5·3	1 in 3·4	1 in 1·6				
2·5	,, 42·8	,, 37·9	,, 33·6	,, 29·8	,, 26·4	,, 23·2	,, 20·3	,, 17·6	,, 15·2	,, 13·0	,, 11·0	,, 9·1	,, 7·4	1 in 5·8	1 in 4·3	1 in 2·9	1 in 1·6
3·0	,, 46·4	,, 41·6	,, 37·3	,, 33·5	,, 30·1	,, 26·9	,, 24·0	,, 21·4	,, 19·0	,, 16·8	,, 14·8	,, 12·9	,, 11·2	,, 9·7	,, 8·2	,, 6·8	,, 5·5
3·5	,, 49·0	,, 44·2	,, 39·9	,, 36·1	,, 32·7	,, 29·6	,, 26·7	,, 24·1	,, 21·7	,, 19·5	,, 17·6	,, 15·7	,, 14·0	,, 12·4	,, 11·0	,, 9·6	,, 8·3
4·0	,, 50·9	,, 46·1	,, 41·9	,, 38·1	,, 34·7	,, 31·6	,, 28·7	,, 26·1	,, 23·7	,, 21·5	,, 19·6	,, 17·7	,, 16·1	,, 14·5	,, 13·1	,, 11·7	,, 10·4
4·5	,, 52·4	,, 47·6	,, 43·4	,, 39·6	,, 36·2	,, 33·1	,, 30·2	,, 27·7	,, 25·3	,, 23·1	,, 21·2	,, 19·3	,, 17·7	,, 16·1	,, 14·7	,, 13·3	,, 12·0
5·0	,, 53·6	,, 48·9	,, 44·6	,, 40·8	,, 37·5	,, 34·3	,, 31·5	,, 28·9	,, 26·6	,, 24·4	,, 22·5	,, 20·6	,, 19·0	,, 17·4	,, 16·0	,, 14·6	,, 13·3
5·5	,, 54·6	,, 49·9	,, 45·6	,, 41·8	,, 38·5	,, 35·3	,, 32·5	,, 29·9	,, 27·6	,, 25·4	,, 23·5	,, 21·6	,, 20·0	,, 18·4	,, 17·0	,, 15·7	,, 14·3
6·0	,, 55·4	,, 50·7	,, 46·4	,, 42·7	,, 39·3	,, 36·2	,, 33·4	,, 30·8	,, 28·5	,, 26·3	,, 24·4	,, 22·5	,, 20·9	,, 19·3	,, 17·9	,, 16·6	,, 15·2
7·0	,, 56·7	,, 52·0	,, 47·7	,, 44·0	,, 40·6	,, 37·5	,, 34·7	,, 32·1	,, 29·8	,, 27·7	,, 25·7	,, 23·9	,, 22·3	,, 20·7	,, 19·3	,, 18·0	,, 16·6
8·0	,, 57·7	,, 53·0	,, 48·7	,, 45·0	,, 41·6	,, 38·5	,, 35·7	,, 33·1	,, 30·8	,, 28·7	,, 26·7	,, 24·9	,, 23·3	,, 21·8	,, 20·3	,, 19·0	,, 17·7
9·0	,, 58·5	,, 53·7	,, 49·5	,, 45·8	,, 42·4	,, 39·3	,, 36·5	,, 33·9	,, 31·6	,, 29·5	,, 27·5	,, 25·7	,, 24·1	,, 22·6	,, 21·1	,, 19·8	,, 18·5
10·0	,, 59·1	,, 54·3	,, 50·1	,, 46·4	,, 43·0	,, 39·9	,, 37·1	,, 34·6	,, 32·2	,, 30·1	,, 28·2	,, 26·4	,, 24·7	,, 23·2	,, 21·8	,, 20·5	,, 19·1
20·0	,, 61·8	,, 57·1	,, 52·9	,, 49·1	,, 45·8	,, 42·7	,, 39·9	,, 37·4	,, 35·1	,, 33·0	,, 31·0	,, 29·2	,, 27·6	,, 26·1	,, 24·7	,, 23·4	,, 22·1
50·0	,, 63·4	,, 58·7	,, 54·5	,, 50·8	,, 47·5	,, 44·4	,, 41·6	,, 39·1	,, 36·8	,, 34·7	,, 32·8	,, 31·0	,, 29·3	,, 27·8	,, 26·4	,, 25·1	,, 23·8
Infinite	,, 64·5	,, 59·8	,, 55·6	,, 51·9	,, 48·6	,, 45·5	,, 42·7	,, 40·2	,, 37·9	,, 35·8	,, 33·9	,, 32·1	,, 30·5	,, 29·0	,, 27·6	,, 26·3	,, 25·0

Example: Required to know what should be the proper inclination for an oval sewer of the New Form, 1 foot 6 inches × 2 feet 3 inches, in which the velocity of flow, when running one-third full, shall be 4 feet per second, the observed fall from end to end of the sewer being 3 feet. From the Table we take out of the column for velocities 4·0, and opposite 3 feet 118·1, which being multiplied by 1·5 foot, the transverse diameter of the sewer, we get the proper inclination of the proposed sewer = 118·1 × 1·5 = 1 in 177·15.

Table No. 22.—Velocities in feet per minute in Circular Sewers, when

Rate of Inclination.	Size, $d = 3''$.	Size, $d = 4''$.	Size, $d = 6''$.	Size, $d = 8''$.	Size, $d = 9''$.	Size, $d = 10''$.	Size, $d = 12''$.	Size, $d = 14''$.	Size, $d = 15''$.	Size, $d = 16''$.	Size, $d = 18''$.	Size, $d = 20''$.	Size, $d = 21''$.	Size, $d = 22''$.	Size, $d = 24''$.	Size, $d = 27''$.	Size, $d = 30''$.	Size, $d = 33''$.
1 in 5	664	755	896	1007	1054	1097	1174	1242	1272	1300	1353	1401	1423	1445	1484			
" 6	611	696	831	936	981	1023	1097	1162	1192	1220	1272	1319	1341	1363	1401			
" 7	569	649	778	878	922	962	1034	1097	1126	1153	1205	1251	1272	1294	1332			
" 8	535	611	734	831	873	912	981	1043	1071	1097	1147	1192	1213	1234	1272			
" 9	506	579	696	789	831	869	936	996	1023	1049	1097	1141	1162	1183	1220			
" 10	481	551	664	755	794	831	896	955	981	1007	1054	1097	1118	1138	1174			
" 15	395	454	551	630	664	696	755	807	831	854	896	936	955	973	1007			
" 20	342	395	481	551	582	611	664	711	734	755	794	831	848	865	896			
" 25	306	353	432	496	525	551	600	644	664	684	720	755	771	787	816			
" 30	278	322	395	454	481	506	551	592	611	630	664	696	711	726	755			
" 35	257	298	366	421	446	470	513	551	569	586	619	649	664	678	705			
" 40	240	278	342	395	418	440	481	517	535	551	582	611	625	638	664			
" 45	225	261	322	372	395	415	454	489	506	521	551	579	592	605	630			
" 50	213	246	307	354	375	394	432	465	481	496	525	551	564	576	600			
" 60	193	226	279	323	343	361	395	426	440	454	481	506	517	528	551			
" 70	178	209	257	298	317	334	366	395	408	421	446	470	481	491	513			
" 80	166	194	239	278	296	312	342	369	382	395	418	440	451	461	481			
" 90	156	182	225	262	279	294	322	348	360	372	394	415	426	435	454			
" 100	147	172	213	248	264	279	306	330	342	353	374	394	404	413	432	457	481	503
" 110	140	163	202	236	251	265	291	315	326	336	357	376	386	395	413	436	459	481
" 120	133	155	193	225	240	253	278	301	312	322	342	360	369	378	395	418	440	461
" 130	128	149	186	216	230	243	267	289	299	309	328	346	355	363	379	401	423	443
" 140	123	143	178	208	221	233	257	278	288	298	316	334	342	350	365	387	408	427
" 150	118	138	172	201	213	225	248	268	278	288	306	322	330	338	353	374	395	414
" 160	..	133	166	194	206	218	240	259	269	278	296	312	320	327	342	362	382	401
" 170	..	129	160	188	199	211	232	251	261	269	287	303	310	317	332	352	371	389
" 180	..	125	155	182	193	205	225	244	253	261	278	294	301	308	322	342	361	378
" 190	..	121	151	177	188	199	219	237	246	254	270	286	293	300	313	333	351	368
" 200	..	118	147	172	183	194	213	231	239	248	263	278	285	292	305	324	342	359
" 250	..	..	131	153	163	172	189	205	213	221	234	247	254	260	272	290	305	321
" 300	..	..	118	138	147	156	172	187	193	200	213	225	231	237	248	264	278	292
" 350	..	..	..	127	135	143	158	172	178	184	196	207	213	218	228	243	256	270
" 400	..	..	..	118	126	133	147	160	166	172	183	193	199	203	213	226	239	251
" 450	..	..	..	..	118	125	138	150	156	162	172	182	187	191	200	213	225	236
" 500	..	..	..	..	..	118	130	142	147	153	162	172	177	181	189	202	213	224
" 550	..	..	..	..	..	..	124	135	140	145	154	163	168	172	180	192	203	213
" 600	..	..	..	..	..	..	118	129	134	139	147	156	160	164	172	183	194	203
" 650	..	..	..	..	..	..	..	123	128	133	141	149	153	157	165	175	186	195
" 700	..	..	..	..	..	..	..	118	123	127	135	143	147	151	158	168	179	188
" 750	..	..	..	..	..	..	..	..	118	122	130	138	142	145	152	162	172	181
" 800	..	..	..	..	..	..	..	..	..	118	126	133	137	140	147	157	166	175
" 850	..	..	..	..	..	..	..	..	..	..	122	129	133	136	142	152	161	169
" 900	..	..	..	..	..	..	..	..	..	..	118	125	129	132	138	147	156	164
" 950	..	..	..	..	..	..	.	..	..	..	..	121	125	128	134	143	151	159
" 1000	..	..	..	..	..	..	..	..	..	..	..	118	121	124	130	139	147	155

In this Table the length of sewer taken into consideration = the

Example: A sewer 12″ diameter having an inclination of 1 in 160, the velocity in feet per minute as given by this Table = 240, the velocity per second = 4 feet, and the length of sewer to which this Table applies = 4 × 160 = 640 feet.

unning Full, or Half Full, and at various rates of inclination.

Size, d = 36″.	Size, d = 40″.	Size, d = 42″.	Size, d = 45″.	Size, d = 48″.	Size, d = 54″.	Size, d = 60″.	Size, d = 66″.	Size, d = 72″.	Size, d = 78″.	Size, d = 84″.	Size, d = 90″.	Size, d = 96″.	Size, d = 102″.	Size, d = 108″.	Size, d = 114″.	Size, d = 120″.	Rate of Inclination.
																	1 in 5
																	,, 6
																	,, 7
																	,, 8
																	,, 9
																	,, 10
																	,, 15
																	,, 20
																	,, 25
																	,, 30
																	,, 35
																	,, 40
																	,, 45
																	,, 50
																	,, 60
																	,, 70
																	,, 80
																	,, 90
525	551	564	582	600	633	664	693	720	746	771	794	817	839	859	878	896	,, 100
501	527	539	557	574	606	636	664	691	715	739	762	784	805	825	844	862	,, 110
481	506	517	535	551	582	611	638	664	688	711	733	755	775	794	813	831	,, 120
463	487	498	515	531	561	589	615	640	664	686	707	728	748	767	785	803	,, 130
446	470	481	497	513	542	569	595	619	642	664	685	705	724	743	761	778	,, 140
432	454	465	481	496	525	551	576	600	622	644	664	684	703	721	739	755	,, 150
418	440	451	466	481	509	535	559	582	604	625	645	664	682	700	718	734	,, 160
406	427	438	453	467	494	520	543	566	587	608	627	646	664	681	698	714	,, 170
395	415	426	440	454	481	506	529	551	572	592	611	630	648	664	680	696	,, 180
384	404	415	429	442	468	493	516	537	558	577	596	614	632	648	664	680	,, 190
375	395	404	418	431	457	481	503	524	545	564	582	600	617	633	649	664	,, 200
335	353	362	375	387	411	433	453	472	490	507	524	541	557	572	586	600	,, 250
305	322	330	342	353	375	395	414	431	448	465	481	496	511	525	538	551	,, 300
282	298	306	316	327	347	366	384	400	416	432	447	461	475	488	501	513	,, 350
263	278	285	295	306	325	342	359	375	390	404	418	432	445	457	469	481	,, 400
247	261	268	278	289	307	323	339	354	368	381	395	408	420	432	443	454	,, 450
234	247	254	263	273	290	306	321	335	349	362	375	387	399	410	421	432	,, 500
223	235	242	250	260	276	291	305	319	332	344	356	368	379	390	401	412	,, 550
213	225	231	239	248	263	278	292	305	318	330	342	353	364	375	385	395	,, 600
204	216	222	230	238	252	267	280	293	305	317	329	340	350	360	370	380	,, 650
196	208	213	221	229	243	257	270	282	294	305	316	327	337	347	357	366	,, 700
189	201	205	213	221	235	248	260	272	284	295	305	315	325	335	345	354	,, 750
183	194	199	206	213	226	239	251	263	274	285	295	305	315	324	333	342	,, 800
177	188	193	199	206	219	231	243	255	266	276	286	296	305	314	323	331	,, 850
172	182	187	193	200	213	225	236	247	258	268	278	287	296	305	314	322	,, 900
167	177	181	188	195	207	219	230	240	251	261	270	279	288	297	305	313	,, 950
162	172	176	183	190	202	213	224	234	244	254	263	272	281	289	297	305	,, 1000

te of inclination multiplied by the velocity in feet per second.

For all practical purposes the velocities given in this Table may be taken as correct; in cases in which great accuracy required the proper inclination will be found from Table No. 15.

TABLE No. 22.—VELOCITIES in feet per minute

Rate of Inclination.	Size, $d = 3''$.	Size, $d = 4''$.	Size, $d = 6''$.	Size, $d = 8''$.	Size, $d = 9''$.	Size, $d = 10''$.	Size, $d = 12''$.	Size, $d = 14''$.	Size, $d = 15''$.	Size, $d = 16''$.	Size, $d = 18''$.	Size, $d = 20''$.	Size, $d = 21''$.	Size, $d = 22''$.	Size, $d = 24''$.	Size, $d = 27''$.	Size, $d = 30''$.	Size, $d = 33''$.
1 in 1100	..	..	..	..	..	..	..	..	..	..	..	..	..	118	124	132	140	147
" 1200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	118	126	133	140
" 1300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	127	134
" 1400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	122	129
" 1500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	118	124
" 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120
" 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 4900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 5000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 5100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 5400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 5700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
" 6000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

In this Table the length of sewer taken into consideration = the

Example: A sewer 102″ diameter, having an inclination of 1 in 4900, the velocity in feet per minute as given by this Table = 120, the velocity per second = 2 feet, and the length of sewer to which this Table applies = 2 × 4900 = 9800 feet.

Circular Sewers—*continued.*

ize, d = 36".	Size, d = 40".	Size, d = 42".	Size, d = 45".	Size, d = 48".	Size, d = 54".	Size, d = 60".	Size, d = 66".	Size, d = 72".	Size, d = 78".	Size, d = 84".	Size, d = 90".	Size, d = 96".	Size, d = 102".	Size, d = 108".	Size, d = 114".	Size, d = 120".	Rate of Inclination.
154	163	168	174	181	192	203	213	223	232	241	250	259	268	276	283	290	1 in 1100
147	156	160	166	172	183	193	203	213	222	231	240	248	256	264	271	278	„ 1200
141	149	153	159	165	175	185	195	204	213	222	230	238	245	253	260	267	„ 1300
135	143	147	153	158	168	178	187	196	205	213	221	229	236	243	250	257	„ 1400
130	138	142	147	152	162	172	181	189	197	205	213	221	228	235	241	248	„ 1500
126	133	137	142	147	157	166	175	183	191	199	206	213	220	227	233	239	„ 1600
122	129	133	137	142	152	161	169	177	185	193	200	206	213	220	226	232	„ 1700
118	125	129	133	138	147	156	164	172	180	187	194	200	207	213	219	225	„ 1800
..	121	125	129	134	143	151	159	167	174	181	188	194	201	207	213	219	„ 1900
..	118	121	126	130	139	147	155	162	169	176	183	189	195	201	207	213	„ 2000
..	..	..	123	127	135	143	151	158	165	172	178	184	190	196	202	208	„ 2100
..	..	..	120	124	132	140	147	154	161	168	174	180	186	192	198	203	„ 2200
..	..	..	..	121	129	136	143	150	157	164	170	176	182	187	193	198	„ 2300
..	..	..	..	118	126	133	140	147	154	160	166	172	178	183	188	193	„ 2400
..	..	..	..	..	123	130	137	144	150	156	162	168	174	179	184	189	„ 2500
..	..	..	..	..	120	128	135	141	147	153	159	165	170	175	180	185	„ 2600
..	..	..	..	..	118	125	132	138	144	150	156	161	166	171	176	181	„ 2700
..	..	..	..	..	..	123	129	135	141	147	153	158	163	168	173	178	„ 2800
..	..	..	..	..	..	120	126	132	138	144	150	155	160	165	170	175	„ 2900
..	..	..	..	..	..	118	124	130	136	142	148	153	158	163	168	172	„ 3000
..	..	..	..	..	..	..	122	128	134	139	145	150	155	160	165	169	„ 3100
..	..	..	..	..	..	..	120	126	132	137	142	147	152	157	162	166	„ 3200
..	..	..	..	..	..	..	118	124	130	135	140	145	150	155	159	163	„ 3300
..	..	..	..	..	..	..	..	122	128	133	138	143	148	153	157	161	„ 3400
..	..	..	..	..	..	..	..	120	126	131	136	141	146	150	154	158	„ 3500
..	..	..	..	..	..	..	..	118	124	129	134	139	144	148	152	156	„ 3600
..	..	..	..	..	..	..	..	..	122	127	132	137	141	145	149	153	„ 3700
..	..	..	..	..	..	..	..	..	120	125	130	135	139	143	147	151	„ 3800
..	..	..	..	..	..	..	..	..	118	123	128	133	137	141	145	149	„ 3900
..	..	..	..	..	..	..	..	..	..	121	126	131	135	139	143	147	„ 4000
..	..	..	..	..	..	..	..	..	..	119	124	129	133	137	141	145	„ 4100
..	..	..	..	..	..	..	..	..	..	118	123	127	131	135	139	143	„ 4200
..	..	..	..	..	..	..	..	..	..	..	121	125	129	133	137	141	„ 4300
..	..	..	..	..	..	..	..	..	..	..	120	124	128	132	136	140	„ 4400
..	..	..	..	..	..	..	..	..	..	..	118	122	126	130	134	138	„ 4500
..	..	..	..	..	..	..	..	..	..	..	..	121	125	129	133	136	„ 4600
..	..	..	..	..	..	..	..	..	..	..	..	119	123	127	131	134	„ 4700
..	..	..	..	..	..	..	..	..	..	..	..	118	122	126	130	133	„ 4800
..	..	..	..	..	..	..	..	..	..	..	..	..	120	124	128	131	„ 4900
..	..	..	..	..	..	..	..	..	..	..	..	..	119	123	127	130	„ 5000
..	..	..	..	..	..	..	..	..	..	..	..	..	118	122	126	129	„ 5100
..	..	..	..	..	..	..	..	..	..	..	..	..	..	118	122	125	„ 5400
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	118	121	„ 5700
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	118	„ 6000

te of inclination multiplied by the velocity in feet per second.

For all practical purposes the velocities given in this Table may be taken as correct; in cases in which great accuracy required the proper inclination will be found from Table No. 15.

Table No. 23.—Table of Velocities in feet per minute in Oval Sewers (Old Form), invert having a radius of one-quarter of the transverse

Rate of Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	329	356	381	404	425	444	463								
„ 110	314	339	363	385	405	424	442								
„ 120	300	324	347	368	388	407	424								
„ 130	288	312	334	354	373	391	403								
„ 140	277	300	321	341	359	377	393								
„ 150	267	289	310	329	347	364	380								
„ 160	258	280	300	319	336	353	368								
„ 170	250	271	291	309	326	342	357								
„ 180	243	263	282	300	317	332	347								
„ 190	236	256	275	292	308	323	338								
„ 200	230	249	267	284	300	315	329	343	356	368	380	392	403	414	425
„ 250	205	222	238	253	267	281	294	306	318	329	340	351	361	371	381
„ 300	186	202	216	230	243	256	268	279	290	300	310	320	330	339	348
„ 350	171	186	199	212	224	236	247	258	268	277	286	295	304	313	321
„ 400	159	173	186	198	209	220	230	240	250	259	268	276	284	292	300
„ 450	149	162	174	186	197	207	217	226	235	244	252	260	268	276	283
„ 500	141	153	165	176	186	196	205	214	222	230	238	246	253	260	267
„ 550	134	146	157	167	177	186	195	203	211	219	226	233	240	247	254
„ 600	128	139	149	159	169	178	186	194	202	209	216	223	230	237	243
„ 650	123	133	143	152	161	170	178	186	193	200	207	214	221	227	233
„ 700	118	128	137	146	155	163	171	179	186	193	200	206	212	218	224
„ 750	..	123	132	141	149	157	165	172	179	186	193	199	205	211	216
„ 800	..	119	128	136	144	152	159	166	173	180	186	192	198	204	209
„ 850	..	..	124	132	140	147	154	161	168	174	180	186	192	197	202
„ 900	..	..	120	128	136	143	150	156	162	168	174	180	186	191	196
„ 950	..	..	..	124	132	139	145	151	157	163	169	175	180	185	190
„ 1000	..	..	..	121	128	135	141	147	153	159	165	170	175	180	185
„ 1100	..	..	..	..	121	128	134	140	146	152	157	162	167	172	177
„ 1200	..	..	..	..	..	122	128	134	140	145	150	154	159	164	168
„ 1300	..	..	..	..	..	..	122	128	134	139	143	148	152	157	161
„ 1400	..	..	..	..	..	..	..	123	128	133	137	142	146	151	155
„ 1500	..	..	..	..	..	..	..	118	123	128	133	137	141	145	149
„ 1600	..	..	..	..	..	..	..	..	118	123	128	132	136	140	144
„ 1700	..	..	..	..	..	..	..	..	..	119	124	128	132	136	140
„ 1800	..	..	..	..	..	..	..	..	..	..	120	124	128	132	136
„ 1900	..	..	..	..	..	..	..	..	..	..	..	120	124	128	132
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	121	125	128
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	122	125
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	119	122
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	119
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

which the transverse diameter is equal to two-thirds of the vertical diameter, the
ımeter, when RUNNING FULL and at various rates of inclination.

ze, 6″ × 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Rate of Inclination.
																1 in 100
																„ 110
																„ 120
																„ 130
																„ 140
																„ 150
																„ 160
																„ 170
																„ 180
																„ 190
35	445	454	463	472	481	490	499	508	516	524	532	540	548	556	563	„ 200
90	399	408	416	424	432	440	448	456	464	471	479	486	493	500	507	„ 250
56	364	372	380	388	395	403	410	417	424	431	438	445	451	457	463	„ 300
29	337	344	352	359	366	373	380	387	393	400	406	412	418	424	430	„ 350
08	315	322	329	336	343	350	356	362	368	374	380	386	392	398	403	„ 400
90	297	304	311	317	323	329	335	341	347	353	358	364	369	375	380	„ 450
74	281	288	294	300	306	312	318	324	329	335	340	346	351	356	361	„ 500
61	267	274	280	286	292	298	303	309	314	319	324	329	334	339	344	„ 550
49	255	261	267	273	279	284	289	295	300	305	310	315	320	325	329	„ 600
39	245	251	257	262	267	272	277	282	287	292	297	302	307	312	316	„ 650
30	236	242	247	252	257	262	267	272	277	282	287	291	296	300	304	„ 700
22	228	233	238	243	248	253	258	263	268	272	277	281	286	290	294	„ 750
15	220	225	230	235	240	245	250	255	259	263	268	272	276	280	284	„ 800
08	213	218	223	228	233	237	242	247	251	255	259	263	267	271	275	„ 850
01	206	211	216	221	226	230	235	239	243	247	251	255	259	263	267	„ 900
95	200	205	210	215	219	223	228	232	236	240	244	248	252	256	260	„ 950
90	195	200	205	209	213	217	222	226	230	234	238	242	246	250	253	„ 1000
81	186	191	195	199	203	207	211	215	219	223	227	230	234	238	241	„ 1100
73	178	182	186	190	194	198	202	206	209	213	216	219	223	227	230	„ 1200
66	170	174	178	182	186	190	193	197	200	204	207	210	214	217	220	„ 1300
59	163	167	171	175	178	182	185	189	192	196	199	202	206	209	212	„ 1400
53	157	161	165	169	172	176	179	183	186	189	192	195	198	201	204	„ 1500
48	152	156	159	163	166	170	173	177	180	183	186	189	192	195	198	„ 1600
44	147	151	154	158	161	164	167	171	174	177	180	183	186	189	192	„ 1700
39	142	146	149	153	156	159	162	166	169	172	175	177	180	183	186	„ 1800
35	138	142	145	148	151	154	157	161	164	167	170	172	175	178	181	„ 1900
31	134	138	141	144	147	150	153	156	159	162	165	167	170	173	176	„ 2000
28	131	134	137	140	143	146	149	152	155	158	161	163	166	169	171	„ 2100
25	128	131	134	137	140	143	146	149	151	154	157	159	162	165	167	„ 2200
22	125	128	131	134	137	140	142	145	148	150	153	155	158	161	163	„ 2300
19	122	125	128	131	134	137	139	142	145	147	150	152	155	157	159	„ 2400
.	119	122	125	128	131	134	136	139	141	144	147	149	151	154	156	„ 2500
.	..	120	122	125	128	131	133	136	138	141	143	146	148	151	153	„ 2600
.	..	..	120	122	125	128	130	133	135	138	140	143	145	147	150	„ 2700
.	..	..	..	120	123	125	128	130	133	135	138	140	142	144	147	„ 2800
.	..	..	..	..	120	123	125	128	130	133	135	137	139	142	144	„ 2900
.	..	..	..	..	..	121	123	126	128	130	133	135	137	139	141	„ 3000
.	..	..	..	..	..	118	120	123	126	128	130	132	134	137	139	„ 3100
.	..	..	..	..	..	..	118	121	123	126	128	130	132	134	136	„ 3200
.	..	..	..	..	..	..	..	119	121	124	126	128	130	132	134	„ 3300
.	..	..	..	..	..	..	..	..	119	122	124	126	128	130	132	„ 3400
.	..	..	..	..	..	..	..	..	..	120	122	124	126	128	130	„ 3500
.	..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	„ 3600
.	..	..	..	..	..	..	..	..	..	..	..	120	122	124	126	„ 3700
.	..	..	..	..	..	..	..	..	..	..	..	..	120	122	124	„ 3800
.	..	..	..	..	..	..	..	..	..	..	..	..	..	120	122	„ 3900
.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	„ 4000

TABLE No. 24.—TABLE of VELOCITIES in feet per minute in OVAL SEWERS (Old Form), having a radius of one-fourth of the transverse diameter,

Rate of Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	344	371	396	420	441	462	483								
,, 110	328	354	378	401	421	441	462								
,, 120	314	339	362	384	404	423	442								
,, 130	301	325	348	369	388	407	425								
,, 140	290	314	336	356	374	392	410								
,, 150	280	303	324	344	362	379	396								
,, 160	271	293	314	333	351	368	384								
,, 170	262	284	304	323	340	357	373								
,, 180	254	275	295	314	330	347	363								
,, 190	247	268	287	305	321	337	353								
,, 200	241	261	280	298	314	329	344	358	371	384	396	408	420	431	442
,, 250	214	232	249	265	280	294	307	320	332	344	355	366	377	387	397
,, 300	194	211	226	241	255	268	280	292	303	314	324	334	344	353	362
,, 350	179	194	208	222	235	247	258	269	280	290	300	309	318	327	336
,, 400	167	181	194	207	219	230	241	251	261	271	280	289	297	305	313
,, 450	157	170	183	195	206	216	226	236	245	254	263	272	280	288	296
,, 500	148	161	173	184	195	205	214	223	232	241	249	257	265	273	280
,, 550	141	153	164	175	185	195	204	212	221	229	237	245	252	259	266
,, 600	134	146	157	167	176	186	195	203	211	219	226	233	240	247	254
,, 650	128	139	150	160	169	178	187	195	203	210	217	224	231	237	243
,, 700	123	134	144	153	162	171	179	187	195	202	209	216	222	228	234
,, 750	119	129	139	148	156	165	173	181	188	195	201	208	214	220	226
,, 800	..	125	134	143	151	159	167	175	182	188	194	201	207	213	219
,, 850	..	121	130	138	146	154	162	169	176	182	188	194	200	206	212
,, 900	..	..	126	134	142	149	157	164	170	176	182	188	194	200	206
,, 950	..	..	122	130	138	145	152	159	165	171	177	183	189	194	200
,, 1000	..	..	119	127	134	141	148	155	161	167	173	179	184	189	195
,, 1100	..	..	..	120	127	134	141	147	153	159	164	170	175	180	185
,, 1200	..	..	..	..	122	128	134	140	146	152	157	162	167	172	177
,, 1300	..	..	..	..	..	123	129	134	140	145	150	155	160	165	169
,, 1400	..	..	..	..	..	119	124	129	134	139	144	149	153	158	162
,, 1500	..	..	..	..	..	..	120	124	129	134	139	144	148	153	157
,, 1600	..	..	..	..	..	..	..	120	124	129	134	139	143	147	151
,, 1700	..	..	..	..	..	..	..	..	120	125	129	134	138	142	146
,, 1800	..	..	..	..	..	..	..	..	..	121	125	130	134	138	142
,, 1900	..	..	..	..	..	..	..	..	..	..	122	126	130	134	138
,, 2000	..	..	..	..	..	..	..	..	..	..	119	123	126	130	134
,, 2100	..	..	..	..	..	..	..	..	..	..	..	120	123	127	130
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	120	124	127
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	121	124
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	121
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	119
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

n which the transverse diameter is equal to two-thirds of the vertical diameter, the invert
vhen Running Two-thirds Full, and at various rates of inclination.

Size, 3' 6" × 5' 3".	Size, 3' 8" × 5' 6".	Size, 3' 10" × 5' 9".	Size, 4' 0" × 6' 0".	Size, 4' 2" × 6' 3".	Size, 4' 4" × 6' 6".	Size, 4' 6" × 6' 9".	Size, 4' 8" × 7' 0".	Size, 4' 10" × 7' 3".	Size, 5' 0" × 7' 6".	Size, 5' 2" × 7' 9".	Size, 5' 4" × 8' 0".	Size, 5' 6" × 8' 3".	Size, 5' 8" × 8' 6".	Size, 5' 10" × 8' 9".	Size, 6' 0" × 9' 0".	Rate of Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
453	463	473	483	493	503	512	521	530	538	546	554	562	570	578	585	,, 200
407	416	425	434	443	452	460	468	476	484	491	498	506	513	520	527	,, 250
371	380	389	397	405	413	421	428	435	442	449	456	463	470	477	483	,, 300
344	352	360	368	376	383	390	397	404	411	417	423	429	436	442	448	,, 350
321	329	337	344	351	358	365	372	378	384	390	396	402	408	414	420	,, 400
303	310	317	324	331	338	345	351	357	363	369	374	380	385	391	396	,, 450
287	294	300	307	314	321	327	333	339	344	350	355	361	366	371	376	,, 500
273	280	286	293	299	305	311	317	323	328	333	338	344	349	354	359	,, 550
261	268	274	280	286	292	298	304	309	314	319	324	329	334	339	344	,, 600
250	256	262	268	274	280	286	292	297	302	307	312	316	321	326	331	,, 650
240	246	252	258	264	270	275	280	285	290	295	300	304	309	313	318	,, 700
232	238	243	249	255	260	265	270	275	279	284	289	293	298	302	307	,, 750
224	230	235	241	246	251	256	261	266	270	275	280	284	289	293	297	,, 800
217	223	228	233	238	243	248	253	258	262	267	271	275	280	284	288	,, 850
211	216	221	226	231	236	241	246	250	254	259	263	267	272	276	280	,, 900
205	210	215	220	225	230	234	239	243	247	252	256	260	264	268	272	,, 950
200	205	210	214	219	224	228	232	236	240	245	249	253	257	261	265	,, 1000
190	195	199	203	208	213	217	221	225	229	233	237	241	244	248	252	,, 1100
181	186	190	194	199	203	207	211	215	219	222	226	230	233	237	240	,, 1200
173	178	182	186	191	195	199	202	206	210	213	216	220	223	227	230	,, 1300
167	171	175	179	183	187	191	194	198	202	205	208	212	215	219	222	,, 1400
161	165	169	173	177	181	185	188	191	195	198	201	205	208	211	214	,, 1500
155	159	163	167	171	175	178	182	185	188	191	194	198	201	204	207	,, 1600
150	154	158	162	165	169	172	176	179	182	185	188	191	194	197	200	,, 1700
146	149	153	157	160	164	167	171	174	177	179	182	186	189	191	194	,, 1800
142	145	149	152	156	159	162	166	169	172	174	177	180	183	186	189	,, 1900
138	141	145	148	152	155	158	161	164	167	170	173	176	178	181	184	,, 2000
134	137	141	144	148	151	154	157	160	163	166	168	171	174	176	179	,, 2100
131	134	137	140	144	147	150	153	156	159	162	164	167	170	172	175	,, 2200
128	131	134	137	140	143	146	149	152	155	158	160	163	166	168	171	,, 2300
125	128	131	134	137	140	143	146	148	151	154	156	159	162	164	167	,, 2400
122	125	128	131	134	137	140	143	145	147	150	153	156	158	160	163	,, 2500
120	122	125	128	131	134	137	140	142	144	147	150	153	155	157	159	,, 2600
..	120	123	126	129	132	134	137	139	141	144	147	150	152	154	156	,, 2700
..	..	121	124	126	129	132	134	136	139	142	144	147	149	151	153	,, 2800
..	..	..	121	124	126	129	131	134	136	139	141	144	146	148	150	,, 2900
..	..	..	119	122	124	127	129	132	134	136	139	141	144	146	148	,, 3000
..	..	..	..	120	122	125	127	129	131	134	136	138	141	143	145	,, 3100
..	..	..	..	..	120	123	125	127	129	132	134	136	139	141	143	,, 3200
..	..	..	..	..	..	121	123	125	127	130	132	134	137	139	141	,, 3300
..	..	..	..	..	..	119	121	123	125	128	130	132	134	136	138	,, 3400
..	..	..	..	..	..	..	119	121	123	126	128	130	132	134	136	,, 3500
..	..	..	..	..	..	..	..	119	121	124	126	128	130	132	134	,, 3600
..	..	..	..	..	..	..	..	..	120	122	124	126	128	130	132	,, 3700
..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	130	,, 3800
..	..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	121	122	124	126	,, 4000
..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	,, 4100
..	..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	,, 4200
..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	122	,, 4300
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	,, 4400

TABLE No. 25.—VELOCITIES in feet per minute in OVAL SEWERS (Old Form), in which a radius of one-fourth of the transverse diameter, when

Rate of Incli-nation.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	277	300	321	341	359	377	394								
„ 110	264	286	306	325	342	359	376								
„ 120	252	273	292	311	328	344	360								
„ 130	241	262	280	298	314	330	345								
„ 140	232	252	270	287	303	318	333								
„ 150	224	243	260	277	292	307	321								
„ 160	217	235	252	268	283	297	311								
„ 170	210	227	244	260	274	288	302								
„ 180	204	221	237	252	266	280	293								
„ 190	198	215	230	245	258	272	285								
„ 200	193	209	224	238	251	264	277	289	300	311	321	331	341	350	359
„ 250	171	186	199	212	224	236	247	257	267	277	286	295	304	313	321
„ 300	155	169	181	193	204	214	224	234	243	252	261	269	277	285	293
„ 350	143	155	166	177	187	197	207	216	224	232	240	248	256	263	270
„ 400	133	144	155	165	175	184	193	201	209	216	224	231	238	245	252
„ 450	125	135	145	155	164	173	181	189	196	203	210	217	224	230	237
„ 500	118	128	137	146	155	163	171	179	186	193	199	206	212	218	224
„ 550	..	122	130	139	147	155	162	170	177	184	190	196	202	208	213
„ 600	..	..	125	133	140	148	155	162	169	175	181	187	193	199	204
„ 650	..	..	119	127	134	141	148	155	161	167	173	179	185	190	195
„ 700	..	..	..	122	129	136	143	149	155	161	167	172	177	182	187
„ 750	..	..	..	118	124	131	138	144	149	155	161	166	171	176	181
„ 800	..	..	..	..	120	127	133	139	144	150	155	160	165	170	175
„ 850	..	..	..	..	..	123	129	135	140	145	150	155	160	165	169
„ 900	..	..	..	..	..	119	125	131	136	141	145	150	155	160	164
„ 950	..	..	..	..	..	..	121	127	132	137	141	146	151	155	159
„ 1000	..	..	..	..	..	..	..	123	128	133	137	142	146	150	155
„ 1100	..	..	..	..	..	..	..	..	121	126	130	135	139	143	147
„ 1200	..	..	..	..	..	..	..	..	..	120	124	129	133	137	141
„ 1300	..	..	..	..	..	..	..	..	..	..	119	123	127	131	135
„ 1400	..	..	..	..	..	..	..	..	..	..	..	118	122	126	130
„ 1500	..	..	..	..	..	..	..	..	..	..	..	..	118	122	125
„ 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	118	120
„ 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3000															

the transverse diameter is equal to two-thirds of the vertical diameter, the invert having RUNNING ONE-THIRD FULL, and at various rates of inclination.

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Rate of Incli-nation.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
368	377	385	393	401	409	417	424	431	438	445	452	459	466	473	479	,, 200
329	337	345	352	359	366	373	380	387	393	399	406	412	418	424	430	,, 250
300	307	314	321	328	334	341	347	353	359	365	371	377	382	388	393	,, 300
277	284	291	297	303	309	315	321	326	332	338	343	349	354	359	364	,, 350
258	265	271	277	283	289	294	300	305	311	316	321	326	331	336	341	,, 400
243	249	255	261	266	272	277	282	287	293	298	303	307	312	316	321	,, 450
230	236	242	247	252	257	262	267	272	277	282	287	291	296	300	304	,, 500
219	224	230	235	240	245	249	254	259	264	269	273	277	282	286	290	,, 550
209	214	219	224	229	234	238	243	248	252	257	261	265	269	273	277	,, 600
200	205	210	215	220	224	228	233	238	242	246	250	254	258	262	266	,, 650
192	197	202	207	212	216	220	224	228	232	236	240	244	248	252	256	,, 700
186	190	195	199	204	208	212	216	220	224	228	232	236	240	244	247	,, 750
180	184	188	192	197	201	205	209	213	217	221	225	228	232	235	238	,, 800
174	178	182	186	191	195	199	203	206	210	214	218	221	225	228	231	,, 850
168	172	176	180	185	189	193	197	200	204	208	211	214	218	221	224	,, 900
163	167	171	175	179	183	187	191	194	198	202	205	208	212	215	218	,, 950
159	163	167	171	175	179	182	186	189	193	197	200	203	206	209	212	,, 1000
151	155	159	162	166	170	173	177	180	183	187	190	193	196	199	202	,, 1100
144	148	152	155	159	162	165	169	172	175	178	181	184	187	190	193	,, 1200
138	142	146	149	152	155	158	161	164	167	170	173	176	179	182	185	,, 1300
133	136	140	143	146	149	152	155	158	161	164	167	169	172	175	177	,, 1400
128	131	134	137	140	143	146	149	152	155	158	161	163	166	169	171	,, 1500
123	126	129	132	135	138	141	144	147	150	153	155	157	160	163	165	,, 1600
119	122	125	128	131	134	137	140	142	145	148	150	152	155	158	160	,, 1700
..	119	122	124	127	130	133	136	138	140	143	145	148	150	153	155	,, 1800
..	..	119	121	124	126	129	132	134	136	139	141	144	146	148	150	,, 1900
..	..	..	118	121	123	125	128	130	133	135	138	140	142	144	146	,, 2000
..	..	..	..	..	120	122	125	127	129	132	134	136	138	140	142	,, 2100
..	..	..	..	..	..	119	122	124	126	129	131	133	135	137	139	,, 2200
..	..	..	..	..	..	..	119	121	123	125	127	129	132	134	136	,, 2300
..	..	..	..	..	..	..	..	..	120	122	124	126	129	131	133	,, 2400
..	..	..	..	..	..	..	..	..	..	119	121	123	126	128	130	,, 2500
..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	127	,, 2600
..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	124	,, 2700
..	..	..	..	..	..	..	..	..	..	..	..	..	119	120	122	,, 2800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	,, 2900
																,, 3000

Table No. 26.—Table of Velocities in feet per minute in Oval Sewers (New Form), having a radius of one-eighth of the transverse diameter, and the radius of the sides rates of inclination.

Rate of Incli-nation.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	326	353	377	399	420	440	460								
„ 110	311	336	359	381	401	420	439								
„ 120	297	322	344	365	384	403	420								
„ 130	285	309	331	351	370	387	404	420							
„ 140	275	297	318	338	356	373	390	405	420						
„ 150	265	287	307	326	344	361	377	392	406	420					
„ 160	256	277	297	316	333	349	365	380	394	407	420				
„ 170	248	269	288	306	323	339	354	368	382	395	408	420			
„ 180	241	261	280	297	314	329	344	358	371	384	397	409	420		
„ 190	234	254	272	289	305	320	335	349	362	374	386	398	409	420	
„ 200	228	247	265	282	297	312	326	340	353	365	377	388	399	410	420
„ 250	203	220	236	251	265	278	291	303	315	326	337	348	358	368	377
„ 300	184	200	214	228	241	253	265	276	287	297	307	317	326	335	344
„ 350	169	184	198	210	222	234	244	255	265	275	284	293	302	310	318
„ 400	158	171	184	196	207	218	228	238	247	256	265	274	282	290	298
„ 450	148	161	173	184	195	205	214	224	232	241	249	257	265	273	280
„ 500	140	152	163	174	184	194	203	211	220	228	236	243	251	258	265
„ 550	133	144	155	165	175	184	193	201	209	217	224	231	238	245	252
„ 600	127	138	148	158	167	176	184	192	200	207	214	221	228	235	241
„ 650	121	132	142	151	160	168	176	184	191	199	205	212	219	225	231
„ 700	..	127	136	145	154	162	169	177	184	191	198	204	210	216	222
„ 750	..	122	131	140	148	156	163	170	177	184	191	197	203	209	214
„ 800	..	..	127	135	143	151	158	165	171	178	184	190	196	202	207
„ 850	..	..	123	131	138	146	153	159	166	172	178	184	190	195	201
„ 900	..	..	119	127	134	141	148	154	161	167	173	178	184	189	195
„ 950	..	..	..	123	130	137	144	150	156	162	168	173	179	184	189
„ 1000	..	..	..	120	127	133	140	146	152	158	163	169	174	179	184
„ 1100	..	..	..	..	120	127	133	139	144	150	155	160	165	170	175
„ 1200	..	..	..	..	..	121	127	132	138	143	148	153	158	162	167
„ 1300	..	..	..	..	..	..	121	127	132	137	142	147	151	156	160
„ 1400	..	..	..	..	..	..	..	122	127	132	136	141	145	150	154
„ 1500	..	..	..	..	..	..	..	..	122	127	131	136	140	144	148
„ 1600	..	..	..	..	..	..	..	..	..	122	127	131	135	139	143
„ 1700	..	..	..	..	..	..	..	..	..	..	123	127	131	135	138
„ 1800	..	..	..	..	..	..	..	..	..	..	119	123	127	131	134
„ 1900	..	..	..	..	..	..	..	..	..	..	..	119	123	127	130
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	120	123	127
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	120	123
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert being one and a third times the transverse diameter, when RUNNING FULL, and at various

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Rate of Incli-nation.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
430	440	450	460	469	478	487	496	504	512	520	528	536	543	550	557	,, 200
386	395	404	412	420	428	436	444	452	460	468	475	482	489	496	502	,, 250
353	361	369	377	385	392	399	406	413	420	427	434	441	447	453	459	,, 300
326	334	342	349	356	363	370	377	384	390	396	402	408	414	420	426	,, 350
305	312	319	326	333	340	346	353	359	365	371	377	383	388	394	399	,, 400
287	294	301	307	314	320	326	332	338	344	350	355	361	366	372	377	,, 450
272	278	285	291	297	303	309	315	321	326	332	337	342	347	353	358	,, 500
259	265	271	277	283	289	295	300	306	311	316	321	326	331	336	341	,, 550
247	253	259	265	271	276	282	287	292	297	302	307	312	317	322	326	,, 600
237	243	249	254	260	265	270	275	280	285	290	295	300	304	309	313	,, 650
228	234	239	244	250	255	260	265	270	275	279	284	289	293	297	302	,, 700
220	225	231	236	241	246	251	256	260	265	269	274	278	283	287	291	,, 750
213	218	223	228	233	238	242	247	252	256	261	265	269	274	278	282	,, 800
206	211	216	221	226	230	235	239	244	248	253	257	261	265	269	273	,, 850
200	205	210	214	219	224	228	232	237	241	245	249	253	257	261	265	,, 900
194	199	204	208	213	217	222	226	230	234	238	242	246	250	254	258	,, 950
189	194	198	203	207	212	216	220	224	228	232	236	240	243	247	251	,, 1000
180	184	189	193	197	201	205	209	213	217	221	224	228	231	235	238	,, 1100
171	176	180	184	188	192	196	200	203	207	211	214	218	221	225	228	,, 1200
164	168	172	176	180	184	188	191	195	199	202	205	209	212	215	219	,, 1300
158	162	166	169	173	177	180	184	187	191	195	198	201	204	207	210	,, 1400
152	156	160	163	167	170	174	177	181	184	187	191	194	197	200	203	,, 1500
147	151	154	158	161	165	168	171	175	178	181	184	187	190	193	196	,, 1600
142	146	149	153	156	159	163	166	169	172	175	178	181	184	187	190	,, 1700
138	142	145	148	151	154	158	161	164	167	170	173	176	178	181	184	,, 1800
134	137	141	144	147	150	153	156	159	162	165	168	171	173	176	179	,, 1900
130	133	137	140	143	146	149	152	155	158	160	163	166	169	171	174	,, 2000
127	130	133	136	139	142	145	148	151	154	156	159	162	164	167	169	,, 2100
124	127	130	133	136	139	142	144	147	150	153	155	158	160	163	165	,, 2200
121	124	127	130	133	136	138	141	144	146	149	152	154	156	159	161	,, 2300
..	121	124	127	130	132	135	138	140	143	146	148	151	153	155	158	,, 2400
..	..	121	124	127	129	132	135	137	140	142	145	147	150	152	154	,, 2500
..	..	..	121	124	127	129	132	135	137	139	142	144	147	149	151	,, 2600
..	..	..	..	122	124	127	129	132	134	137	139	141	144	146	148	,, 2700
..	..	..	..	119	122	124	127	129	132	134	136	138	141	143	145	,, 2800
..	..	..	..	..	119	122	124	127	129	131	134	136	138	140	142	,, 2900
..	..	..	..	..	..	120	122	124	127	129	131	133	136	138	140	,, 3000
..	..	..	..	..	..	..	120	122	124	127	129	131	133	135	137	,, 3100
..	..	..	..	..	..	..	..	120	122	125	127	129	131	133	135	,, 3200
..	..	..	..	..	..	..	..	..	120	122	125	127	129	131	133	,, 3300
..	..	..	..	..	..	..	..	..	..	120	123	125	127	129	131	,, 3400
..	..	..	..	..	..	..	..	..	..	..	121	123	125	127	129	,, 3500
..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	127	,, 3600
..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	,, 3700
..	..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	,, 3800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	119	121	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	,, 4000

TABLE No. 27.—TABLE of VELOCITIES in feet per minute in OVAL SEWERS (New Form), having a radius of one-eighth of the transverse diameter, and the radius of the sides at various rates of inclination.

Rate of Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	339	367	391	415	437	457	477								
,, 110	323	350	374	396	417	437	456								
,, 120	309	335	358	379	399	419	437								
,, 130	297	321	343	364	384	402	420	437							
,, 140	286	309	331	351	370	388	405	421	437						
,, 150	276	299	320	339	358	375	391	407	422	437					
,, 160	267	289	309	328	346	363	379	394	409	423	437				
,, 170	259	280	300	318	336	352	368	383	397	411	424	437			
,, 180	251	272	291	309	326	342	358	372	386	399	412	425	437		
,, 190	244	264	283	301	317	333	348	362	376	389	401	413	425	437	
,, 200	237	257	276	293	309	325	339	353	367	379	391	403	415	426	437
,, 250	211	229	245	261	276	290	303	315	327	339	350	361	372	382	391
,, 300	192	208	223	237	251	264	276	288	299	309	320	330	339	349	358
,, 350	177	192	206	219	231	243	255	266	276	286	296	305	314	323	331
,, 400	164	179	192	204	216	227	237	247	257	267	276	285	293	301	309
,, 450	154	168	180	192	203	213	223	233	242	251	259	268	276	284	291
,, 500	146	158	170	181	192	202	211	220	229	237	245	253	261	269	276
,, 550	139	151	162	172	182	192	201	209	218	226	234	241	248	256	263
,, 600	132	144	154	164	174	183	192	200	208	216	223	230	237	244	251
,, 650	127	138	148	157	167	175	184	192	200	207	214	221	228	234	240
,, 700	122	132	142	151	160	169	177	184	192	199	206	213	219	225	231
,, 750	..	127	137	146	154	162	170	178	185	192	199	205	211	217	223
,, 800	..	123	132	141	149	157	164	172	179	185	192	198	204	210	216
,, 850	..	119	128	136	144	152	159	166	173	179	186	192	198	203	209
,, 900	..	..	124	132	140	147	154	161	168	174	180	186	192	197	203
,, 950	..	..	120	128	136	143	150	156	163	169	175	181	186	192	197
,, 1000	..	..	..	125	132	139	146	152	158	164	170	176	181	187	192
,, 1100	..	..	..	119	126	132	139	145	151	156	162	167	172	177	182
,, 1200	..	..	..	..	120	126	132	138	144	149	154	159	164	169	174
,, 1300	..	..	..	..	..	121	127	132	138	143	148	153	157	162	167
,, 1400	..	..	..	..	..	..	122	127	132	137	142	147	151	156	160
,, 1500	..	..	..	..	..	..	..	122	127	132	137	142	146	150	154
,, 1600	..	..	..	..	..	..	..	..	123	128	132	137	141	145	149
,, 1700	..	..	..	..	..	..	..	..	119	124	128	132	136	140	144
,, 1800	..	..	..	..	..	..	..	..	..	120	124	128	132	136	140
,, 1900	..	..	..	..	..	..	..	..	..	..	120	124	128	132	136
,, 2000	..	..	..	..	..	..	..	..	..	..	..	121	125	129	132
,, 2100	..	..	..	..	..	..	..	..	..	..	..	..	122	125	129
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	119	122	126
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	119	123
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert being one and a third times the transverse diameter, when RUNNING TWO-THIRDS FULL, and

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Rate of Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
447	457	467	477	487	496	505	514	522	531	539	547	555	563	571	578	,, 200
401	410	419	428	437	445	453	461	469	477	485	492	500	507	514	520	,, 250
367	375	383	391	399	407	415	422	430	437	444	451	457	464	471	477	,, 300
339	347	355	363	370	377	384	391	398	405	412	418	424	431	437	443	,, 350
317	325	332	339	346	353	360	367	373	379	385	391	397	403	409	415	,, 400
299	306	313	320	326	333	339	346	352	358	364	369	375	381	386	391	,, 450
283	290	297	303	309	315	321	327	333	339	345	350	356	361	367	372	,, 500
269	276	282	289	295	301	306	312	318	323	329	334	339	345	350	355	,, 550
257	264	270	276	282	288	293	299	304	309	315	320	325	330	335	339	,, 600
247	253	259	265	270	276	281	287	292	297	302	307	312	317	321	326	,, 650
237	243	249	255	260	266	271	276	281	286	291	296	300	305	309	314	,, 700
229	235	240	245	251	256	261	266	271	276	281	285	290	294	299	303	,, 750
221	227	232	237	242	247	252	257	262	267	271	276	280	285	289	293	,, 800
214	220	225	230	235	240	244	249	254	259	263	267	272	276	280	284	,, 850
208	213	218	223	228	233	237	242	246	251	255	259	264	268	272	276	,, 900
202	207	212	217	222	226	231	235	239	244	248	252	256	260	264	268	,, 950
197	202	206	211	216	220	225	229	233	237	241	245	249	253	257	261	,, 1000
187	192	196	201	205	209	214	218	222	226	230	234	237	241	245	248	,, 1100
179	183	188	192	196	200	204	208	212	216	219	223	226	230	234	237	,, 1200
171	175	180	184	188	192	196	200	203	207	210	214	217	221	224	228	,, 1300
164	169	173	177	181	184	188	192	196	199	203	206	209	213	216	219	,, 1400
158	162	166	170	174	178	181	185	188	192	195	199	202	205	208	211	,, 1500
153	157	161	164	168	172	175	179	182	185	189	192	195	198	201	204	,, 1600
148	152	156	159	163	166	170	173	176	179	183	186	189	192	195	198	,, 1700
144	147	151	154	158	161	164	168	171	174	177	180	183	186	189	192	,, 1800
140	143	147	150	153	156	160	163	166	169	172	175	178	181	184	186	,, 1900
136	139	143	146	149	152	155	158	161	164	167	170	173	176	179	181	,, 2000
132	136	139	142	145	148	151	154	157	160	163	166	169	171	174	177	,, 2100
129	132	135	139	142	145	148	151	153	156	159	162	164	167	170	172	,, 2200
126	129	132	135	138	141	144	147	150	153	155	158	160	163	166	168	,, 2300
123	126	129	132	135	138	141	144	146	149	152	154	157	159	162	164	,, 2400
120	123	126	129	132	135	138	141	143	146	148	151	154	156	158	160	,, 2500
..	121	124	127	129	132	135	138	140	143	145	148	150	153	155	157	,, 2600
..	..	121	124	127	129	132	135	137	140	142	145	147	150	152	154	,, 2700
..	..	119	122	124	127	130	132	135	137	140	142	144	147	149	151	,, 2800
..	..	..	119	122	125	127	130	132	135	137	139	142	144	146	148	,, 2900
..	..	..	..	120	122	125	127	130	132	135	137	139	142	144	146	,, 3000
..	..	..	..	..	120	123	125	127	130	132	134	137	139	141	144	,, 3100
..	..	..	..	..	..	121	123	125	128	130	132	134	137	139	141	,, 3200
..	..	..	..	..	..	..	121	123	126	128	130	132	134	136	139	,, 3300
..	..	..	..	..	..	..	..	121	124	126	128	130	132	134	136	,, 3400
..	..	..	..	..	..	..	..	119	122	124	126	128	130	132	134	,, 3500
..	..	..	..	..	..	..	..	..	120	122	124	126	128	130	132	,, 3600
..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	130	,, 3700
..	..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	,, 3800
..	..	..	..	..	..	..	..	..	..	..	..	121	123	125	127	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	,, 4000
..	..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	,, 4100
..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	122	,, 4200
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	,, 4300

Table No. 28.—Velocities in feet per minute in Oval Sewers (New Form), in which a radius of one-eighth of the transverse diameter, and the radius of the sides being various rates of inclination.

Rate of Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	267	289	309	328	346	363	379								
„ 110	254	275	295	313	330	346	361								
„ 120	242	263	282	299	316	331	346								
„ 130	232	252	270	287	303	318	333	346							
„ 140	224	242	260	276	292	306	320	334	346						
„ 150	216	234	251	267	282	296	309	322	334	346					
„ 160	209	226	242	258	273	286	299	312	324	335	346				
„ 170	202	219	235	250	264	277	290	302	314	325	336	346			
„ 180	196	213	228	242	256	269	282	294	305	316	326	336	346		
„ 190	190	207	222	236	249	262	274	286	297	307	317	327	337	346	
„ 200	185	201	216	229	242	255	267	278	289	299	309	319	328	337	346
„ 250	164	179	192	204	216	227	237	247	257	267	276	285	293	301	309
„ 300	149	162	174	185	196	206	216	225	234	242	251	259	267	274	282
„ 350	137	149	160	171	181	190	199	208	216	224	231	239	246	253	260
„ 400	128	139	149	159	168	177	185	193	201	209	216	223	229	236	242
„ 450	120	130	140	149	158	166	174	182	189	196	203	209	216	222	228
„ 500	..	123	132	141	149	157	164	172	179	185	192	198	204	210	216
„ 550	..	..	126	134	142	149	156	163	170	176	182	188	194	200	205
„ 600	..	..	120	128	135	142	149	156	162	168	174	180	185	191	196
„ 650	..	..	..	122	129	136	143	149	155	161	167	172	178	183	188
„ 700	..	..	..	..	124	131	137	143	149	155	160	165	171	176	181
„ 750	..	..	..	..	120	126	132	138	144	149	154	159	164	169	174
„ 800	..	..	..	..	..	122	128	133	139	144	149	154	159	163	168
„ 850	..	..	..	..	..	118	124	129	134	139	144	149	154	158	163
„ 900	..	..	..	..	..	..	120	125	130	135	140	144	149	153	158
„ 950	..	..	..	..	..	..	..	121	126	131	136	140	145	149	153
„ 1000	..	..	..	..	..	..	..	..	123	128	132	137	141	145	149
„ 1100	..	..	..	..	..	..	..	..	..	121	126	130	134	138	142
„ 1200	..	..	..	..	..	..	..	..	..	..	120	124	128	131	135
„ 1300	..	..	..	..	..	..	..	..	..	..	..	118	122	126	129
„ 1400	..	..	..	..	..	..	..	..	..	..	..	..	..	121	124
„ 1500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120
„ 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

the transverse diameter is equal to two-thirds of the vertical diameter, the invert having one and a third times the transverse diameter, when RUNNING ONE-THIRD FULL, and at

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Rate of Incli-nation.
355	363	371	379	387	394	402	409	416	423	430	437	443	449	456	462	1 in 200
317	325	332	339	346	353	360	366	373	379	385	391	397	403	409	415	„ 250
289	296	303	309	316	322	328	334	340	346	352	358	363	368	374	379	„ 300
267	273	280	286	292	298	304	309	315	320	326	331	336	341	346	351	„ 350
249	255	261	267	273	278	284	289	294	299	304	309	314	319	324	328	„ 400
234	239	245	251	256	262	267	272	277	282	287	291	296	300	305	309	„ 450
221	227	232	237	242	247	252	257	262	267	271	276	280	285	289	293	„ 500
210	216	221	226	231	235	240	245	249	254	258	263	267	271	275	279	„ 550
201	206	211	216	220	225	229	234	238	242	247	251	255	259	263	267	„ 600
193	198	202	207	211	216	220	224	228	232	236	240	244	248	252	256	„ 650
185	190	194	199	203	208	212	216	220	224	227	231	235	239	242	246	„ 700
179	183	187	192	196	200	204	208	212	216	219	223	227	230	234	237	„ 750
173	177	181	185	189	193	197	201	205	209	212	216	219	223	226	229	„ 800
167	171	175	179	183	187	191	195	198	202	206	209	212	216	219	222	„ 850
162	166	170	174	178	182	185	189	192	196	199	203	206	209	213	216	„ 900
157	161	165	169	173	177	180	184	187	190	194	197	200	203	207	210	„ 950
153	157	161	164	168	172	175	179	182	185	189	192	195	198	201	204	„ 1000
145	149	153	156	160	163	166	170	173	176	179	182	185	188	191	194	„ 1100
139	142	146	149	152	156	159	162	165	168	171	174	177	180	183	185	„ 1200
133	136	139	143	146	149	152	155	158	161	164	167	169	172	175	178	„ 1300
128	131	134	137	140	143	146	149	152	155	157	160	163	165	168	171	„ 1400
123	126	129	132	135	138	141	144	146	149	152	154	157	159	162	164	„ 1500
119	122	125	128	130	133	136	139	141	144	147	149	152	154	156	159	„ 1600
..	118	121	124	126	129	132	134	137	139	142	144	147	149	151	154	„ 1700
..	..	..	120	122	125	128	130	133	135	138	140	142	144	147	149	„ 1800
..	..	..	..	..	121	124	126	129	131	134	136	138	140	143	145	„ 1900
..	..	..	..	..	..	121	123	125	128	130	132	134	137	139	141	„ 2000
..	..	..	..	..	..	..	120	122	124	127	129	131	133	135	137	„ 2100
..	..	..	..	..	..	..	..	..	121	123	126	128	130	132	134	„ 2200
..	..	..	..	..	..	..	..	..	..	120	123	125	127	129	131	„ 2300
..	..	..	..	..	..	..	..	..	..	..	120	122	124	126	128	„ 2400
..	..	..	..	..	..	..	..	..	..	..	..	119	121	123	125	„ 2500
..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	122	„ 2600
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	„ 2700

CHAPTER XIII.

DISCHARGE OF SEWERS.

Historical notice of hydraulics.

The science of hydraulics, like many kindred sciences, has gradually advanced in improvement until it has reached a high degree of perfection. It had its origin in the days of antiquity; although it is not certain that the ancient Romans and others had any formulæ, similar to those now generally used by engineers to guide them in the construction of their hydraulic works, it is quite clear that the Romans were practically masters of the laws which govern the flow and discharge of water, as the regulations existing in ancient Rome for the distribution of water within the city bear conclusive testimony that they possessed a clear knowledge of these laws, and also were acquainted with expedients which might be used for fraudulently obtaining a supply of water greater than was contemplated by their regulations. No record has been handed down to posterity of any formulæ that may have been employed in designing those stupendous works for bringing a supply of water into those ancient cities, or for calculating the discharge of the sewers flowing from those cities, and if any such were used they have been lost. After the revival of scientific research, it was not until the fourteenth century that hydraulics came to be considered a branch of science. In the seventeenth century this science received a considerable amount of attention, and from that period it has progressed rapidly towards perfection. Castelli and Torricelli, pupils of Galileo, both contributed largely to the development of this science. The former published a work on rivers in 1628, the latter discovered that by abstracting all resistances the velocity of an escaping fluid from an orifice was equal to that which a heavy body would acquire when falling in vacuo, and he argued that the acceleration in the velocity of streams was due to the slope of the surface of the water. From that period to the middle of the eighteenth century, the science of hydraulics was treated almost entirely as a theoretical deduction; but then commenced the era of experimental investigation. Professor Michelotti of Turin, and Abbé Bossut of Paris, ably represented this new era, but it was left to M. Chezy, in 1775, to reduce the laws of water in motion to simple algebraic formula. The Chezy formula, introduced nearly a century ago, was presented in a form to which most of the subsequent formulæ may be reduced. The formula is here given:—

Era of experimental research.

M. Chezy's Formula.

Chezy's formula.

$$V = \sqrt{\frac{g\,h\,a}{A\,l\,p}} = B\sqrt{r\,s.}$$

V = velocity in feet per second.
g = 32·2.
h = difference in level in whole distance l.
l = length of limited portion of channel.
a = area of cross-section.
p = length of wetted perimeter.
A = coefficient or measure of resistance.
B = determined by experiment.
$r = \frac{a}{p}$ = hydraulic mean depth.
$s = \frac{h}{l}$ = sine of slope.

This formula has been adopted by a large number of authorities, the value of B differing somewhat. As for example:—

Value of coefficients by different authorities.

Beardmore, 94·2.
D'Aubisson, 95·6 for velocities over 2 feet.
Downing and Taylor, 100 for large and rapid rivers.
Eytelwein, 93·4.
Leslie, 68 for small rivers; 100 for large.
Neville, 92·3 for velocities under 1·5 foot per second, and 93·3 for greater velocities.
Stevenson, 69 for small streams; 96 for large streams.

The formula most generally used at the present day is that ascribed to Eytelwein, introduced in the early part of the present century. It is as follows:—

Eytelwein's formula.

$$V = \cdot 9091\sqrt{2Hr}.$$

which by reduction can be put

$$V = 93\cdot 4\sqrt{rs.}$$
$$V^1 = 55\sqrt{2Hr.}$$

H = fall in feet per mile.
V = velocity per second.
V^1 = velocity per minute.
r = mean radius or hydraulic mean depth.
s = sine of slope.

Eytelwein found that the velocity per second nearly equals a mean proportional between the hydraulic mean depth and twice the fall in feet per mile. The formula used in preparing the several calculations in the Tables in this book is that of Weisbach, which is here given:—

Weisbach's formula.

$$h = \left(1 + e + c \times \frac{l}{d}\right)\frac{v^2}{2g}.$$

$$v = \frac{\sqrt{2gh}}{\sqrt{1 + e + c \times \frac{l}{d}}}.$$

h = head of water in feet
l = length of pipe in feet.
d = diameter of pipe in feet.
v = velocity in feet per second.
c = coefficient for friction in pipe.
e = coefficient of resistance for entrance of water into pipe.
$g = 32 \cdot 2$

$$c = \cdot 01439 + \frac{\cdot 016921}{\sqrt{v}}.$$

The following Table gives the different values of c for varying velocities:—

v	c	v	c	v	c
·1	·0679	·7	·0346	3	·0242
·2	·0522	·8	·0333	4	·0229
·3	·0453	·9	·0322	6	·0213
·4	·0411	1·0	·0313	8	·0204
·5	·0383	1·5	·0282	12	·0192
·6	·0362	2·0	·0263	20	·0182

e is at an average = ·505, but may be reduced to ·08 by rounding off the inlet.

For $h = v$, and $1 : i$ = rate of inclination.

$$v = \frac{64 \cdot 4}{1 \cdot 505 + \frac{c v i}{d}}.$$

It will be seen from this formula that different coefficients are used for varying velocities. Weisbach considered that the "coefficient of the resistances" increases for small velocities, and is less for great velocities. The proposition that the resistances diminish with the velocity applies to cases in which increase of velocity is due to increased capacity of the channels, but it is doubtful if it is correct in channels of diminishing size, but of increased fall. It should be fully borne in mind by those carrying out works of sewerage that gravity is the sole cause of motion. The motion of the particles of water in a sewer is wholly due to the inclination of the surface. When a fluid is brought to rest its surface will be horizontal, and when the surface is in that position the action of gravity ceases and the fluid ceases to flow. But so soon as the surface becomes inclined motion recommences, although the bottom of the channel may be horizontal, or even have an inclination opposed to that of the flow of the water. Water flowing through a sewer is subject to certain accelerating forces, so that, if it did not encounter any resistance, it would descend with an accelerating speed, just the same as any heavy body falling through air or running down an inclined plane. But in a sewer, or channel used for the conveyance of water, certain retarding forces are at work which are equal to and destroy the accelerating force at every moment. Resistance in the case of a sewer is that offered by the bed and sides of the channels. It is assumed by many authorities on hydraulics that the velocity is retarded, owing to the attraction of the particles of fluid in motion, by those particles of the fluid which adhere to the walls of the channel. If this is true the resistance of the flow of water depends, not so much upon the nature of the material composing the channel, as all materials have more or less an attraction for water, and in a channel a lamina of water is consequently spread over their surface. The experiments of Dubuat failed to show that there was any variation in the friction of water in channels of glass, lead, iron, or wood. The experiments of D'Arcy and Bazin, however, show that the nature of the materials composing the channel exercise a considerable effect on the flow, especially when the section of discharge is small, and even in channels of large size the influence of rough-

Application of coefficients of resistance.

Gravity sole cause of motion.

Retarding force.

Resistance of different materials.

Experiments of D'Arcy and Bazin.

ness or smoothness of the walls of the channel should not be ignored. According to the experiments, smooth surfaces, such as cement or good planking, offered the least resistance; then brickwork, rubble, and last, as offering the greatest resistance to the flow, we have earthen channels. For all practical purposes the nature of the materials of which a sewer is constructed need not be taken into consideration, as experience has amply demonstrated that the several quantities given in the Tables of Discharge are absolutely equal to the observed quantities flowing through ordinarily constructed sewers.

Nature of materials need not be taken into account.

Quantities given in Tables are practically correct.

Wetted perimeter.

That portion of the channel in a sewer or watercourse which is touched by the water is termed the wetted perimeter, and the greater the proportion of the wetted perimeter to the volume to be discharged the greater will be the resistance. Resistance is therefore in the inverse ratio to the section, and increases directly as the velocity. In all calculations of the discharge of water through sewers or channels, it is requisite to determine, with accuracy, the extent of the wetted perimeter, and also the sectional area of the water-way.

Hydraulic mean depth of sewers.

By dividing the sectional area of the channel by the wetted perimeter, or the contour of the wetted channel, we get what is called "the mean hydraulic depth," or often, "the mean radius."

Hydraulic mean depth of circular sewers.

In all circular sewers it is easy to determine the hydraulic mean depth, or mean radius, as the proportion between the wetted perimeter and the area, when the sewer is running full or half full, is the same, and invariably equals one-fourth the diameter of the sewer.

Hydraulic mean depth of old form of oval sewer.

The hydraulic mean depth of oval sewers varies with the volume of sewage flowing through them, but where such sewers are of the old form and proportions (Fig. 20, page 178), that is, the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius equal to one-fourth the transverse diameter, the radius of the sides being one and a half times the transverse diameter, the hydraulic mean depth when running full is found by multiplying the transverse diameter by 0·2897, when running two-thirds full by 0·3157, and when running one-third full by 0·2066. The perimeter of an oval sewer of the above proportions when running full equals 3·9649 times the transverse diameter, when running two-thirds full it is equal to 2·3941 times the transverse diameter, and when running one-third full it is equal to 1·3747 times the transverse diameter of the sewer. The hydraulic mean depth of the new form of oval sewers, or sewers in which the vertical diameter is equal to one and a half times the transverse diameter, the invert having a radius of one-eighth of the transverse diameter, the radius of the sides of the sewer being one and a third times the transverse diameter, when running full is found by multiplying the transverse diameter by 0·2844, when flowing two-thirds full by 0·3074, and when flowing one-third full by 0·1920. The perimeter of the oval sewer of the new proportions when running full equals 3·9205 times the transverse diameter, when running two-thirds full it equals 2·3497 times the transverse diameter, and when running one-third full it equals 1·3247 times the transverse diameter of the sewer. It may be observed that if the area of a 3-feet by 2-feet oval sewer, or any part of the area of the sewer the radius of the upper arch of which is unity, is multiplied by the square of the radius of the top arch of any other sewer of the same proportions, it will give the area or any part of the area, as may be required, of the sewer. In the same way, the hydraulic mean depth of any oval sewer, or any part of an oval sewer, may be found by simply multiplying the hydraulic mean depth of a sewer the radius of whose upper arch is unity by the radius of the upper arch of any other oval sewer of the same relative proportions, the hydraulic mean depth of which it is required to find.

Perimeter of old form of oval sewer.

Hydraulic mean depth of new form of oval sewer.

Perimeter of new form of oval sewer.

Rule for area and hydraulic mean depth of oval sewers.

Description of Tables relating to the Discharge of Sewers numbering from 29 to 38 inclusive.

Table No. 29 gives the area, the circumference or perimeter, and the hydraulic mean depth of circular

Table No. 29.

sewers varying in size from 3 inches to 10 feet in diameter. The discharge of any circular sewer may be arrived at by ascertaining the velocity as given in the explanation of Table No. 15, page 87, and multiplying it by the area in square feet, as given by this Table.

TABLE No. 29.—AREA and HYDRAULIC MEAN DEPTH of CIRCULAR SEWERS.

Diameter.	Area.	Circumference.	Hydraulic Mean Depth when running full.	Diameter.	Area.	Circumference.	Hydraulic Mean Depth when running full.
inches.	sq. ft.	feet	feet.	inches.	sq. ft.	feet.	feet.
3	0·0491	0·7854	·0625	36	7·069	9·425	·750
4	0·0872	1·0471	·0825	40	8·727	10·472	·833
6	0·1963	1·5708	·125	42	9·621	10·995	·875
8	0·3490	2·0942	·165	45	11·045	11·781	·9375
9	0·4418	2·3562	·1875	48	12·566	12·566	1·00
10	0·5454	2·6180	·2083	54	15·904	14·137	1·125
12	0·7854	3·1416	·250	60	19·635	15·708	1·25
14	1·069	3·665	·2917	66	23·758	17·279	1·375
15	1·227	3·927	·3125	72	28·274	18·850	1·50
16	1·396	4·188	·3333	78	33·183	20·420	1·625
18	1·767	4·712	·375	84	38·485	21·991	1·75
20	2·182	5·236	·4166	90	44·179	23·562	1·875
21	2·405	5·498	·4375	96	50·265	25·133	2·00
22	2·640	5·762	·4583	102	56·745	26·704	2·125
24	3·142	6·283	·500	108	63·617	28·274	2·25
27	3·976	7·069	·5625	114	70·882	29·845	2·375
30	4·909	7·854	·625				
33	5·940	8·640	·6875	120	78·540	31·416	2·500

Table No. 30. Table No. 30 gives the area and hydraulic mean depth of oval sewers (old form) constructed of the usual proportions, or for sewers in which the transverse diameter is equal to two-thirds the vertical diameter, and in which the invert is struck with a radius of one-fourth that of the transverse diameter, the sides being struck with a radius equal to that of the vertical diameter, or one and a half times the transverse diameter of the sewer. The discharge of any sewer may be arrived at by multiplying the sectional area of the sewer, as given in this Table, by the velocity, which may be arrived at from the explanation of Tables Nos. 16, 17, or 18, given at pages 88 and 89.

Table No. 31. Table No. 31 gives the area and hydraulic mean depth of oval sewers constructed of the new propor-

TABLE No. 30.—AREA and HYDRAULIC MEAN DEPTH of OVAL SEWERS (Old Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of ¼ of the transverse diameter.

Size of Sewer.	Sectional Area when running full.	Sectional Area when flowing ⅔rds vertical height.	Sectional Area when flowing ⅓rd vertical height.	Hydraulic Mean Depth flowing full.	Hydraulic Mean Depth flowing ⅔rds vertical height.	Hydraulic Mean Depth flowing ⅓rd vertical height.
′ ″ ′ ″	feet.	feet.	feet.	feet.	feet.	feet.
1 0 × 1 6	1·1485	0·7558	0·2840	0·2897	0·3157	0·2066
1 2 × 1 9	1·5632	1·0287	0·3865	0·3380	0·3683	0·2410
1 4 × 2 0	2·0418	1·3436	0·5049	0·3863	0·4209	0·2755
1 6 × 2 3	2·5841	1·7005	0·6390	0·4345	0·4735	0·3099
1 8 × 2 6	3·1903	2·0994	0·7889	0·4828	0·5262	0·3443
1 10 × 2 9	3·8602	2·5402	0·9545	0·5311	0·5788	0·3786
2 0 × 3 0	*4·5940	3·0232	1·1360	0·5794	0·6314	0·4132
2 2 × 3 3	5·3916	3·5480	1·3332	0·6277	0·6840	0·4476
2 4 × 3 6	6·2529	4·1149	1·5462	0·6760	0·7366	0·4820
2 6 × 3 9	7·1781	4·7237	1·7750	0·7242	0·7892	0·5165
2 8 × 4 0	8·1671	5·3746	2·0195	0·7725	0·8418	0·5409
2 10 × 4 3	9·2199	6·0674	2·2799	0·8208	0·8944	0·5852
3 0 × 4 6	10·3365	6·8022	2·5560	0·8691	0·9471	0·6198
3 2 × 4 9	11·5169	7·5790	2·8479	0·9174	0·9997	0·6542
3 4 × 5 0	12·7611	8·3978	3·1556	0·9657	1·0523	0·6887
3 6 × 5 3	14·0691	9·2585	3·4790	1·0139	1·1049	0·7231
3 8 × 5 6	15·4099	10·1613	3·8182	1·0622	1·1576	0·7575
3 10 × 5 9	16·8766	11·1061	4·1732	1·1105	1·2102	0·7920
4 0 × 6 0	18·3760	12·0928	4·5440	1·1588	1·2628	0·8264
4 2 × 6 3	19·9392	13·1215	4·9306	1·2071	1·3154	0·8608
4 4 × 6 6	21·5663	14·1922	5·3329	1·2554	1·3680	0·8952
4 6 × 6 9	23·2571	15·3049	5·7510	1·3036	1·4206	0·9297
4 8 × 7 0	25·0117	16·4596	6·1849	1·3519	1·4733	0·9641
4 10 × 7 3	26·8302	17·6563	6·6346	1·4002	1·5258	0·9986
5 0 × 7 6	28·7125	18·8950	7·1000	1·4485	1·5785	1·0330
5 2 × 7 9	30·6649	20·1757	7·5812	1·4968	1·6311	1·0675
5 4 × 8 0	32·6684	21·4983	8·0782	1·5451	1·6836	1·1019
5 6 × 8 3	34·7421	22·8629	8·5910	1·5933	1·7363	1·1363
5 8 × 8 6	36·8796	24·2696	9·1196	1·6416	1·7890	1·1707
5 10 × 8 9	39·0809	25·7182	9·6639	1·6899	1·8415	1·2052
6 0 × 9 0	41·3460	27·2088	10·2240	1·7382	1·8942	1·2396

tions, or for sewers of which the transverse diameter is equal to two-thirds the vertical diameter, the invert having a radius equal to one-eighth the transverse diameter, the radius of the sides being one and a third times the transverse diameter. The discharge of any sewer may be arrived at by multiplying the sectional area of the sewer as given in this Table by the velocity, which may be arrived at from the explanation given of Tables Nos. 19, 20, and 21, page 89.

* If this number (4·5940) is multiplied by the square of the radius of the top arch of an oval sewer of similar proportions, it will give the area of the sewer.

TABLE No. **31.**—AREA and HYDRAULIC MEAN DEPTH of OVAL SEWERS (New Form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-eighth of the transverse diameter, and the radius of the sides being one and a third times the transverse diameter.

Size of Sewer.	Sectional Area when running full.	Sectional Area when flowing ⅔ vertical height.	Sectional Area when flowing ⅓ vertical height.	Hydraulic Mean Depth flowing full.	Hydraulic Mean Depth flowing ⅔ vertical height.	Hydraulic Mean Depth flowing ⅓ vertical height.
′ ″ ′ ″	feet.	feet.	feet.	feet.	feet.	feet.
1 0 × 1 6	1·1150	·7223	·2543	·2844	·3074	·1920
1 2 × 1 9	1·5176	·9831	·3461	·3318	·3586	·2240
1 4 × 2 0	1·9822	1·2841	·4521	·3792	·4099	·2560
1 6 × 2 3	2·5087	1·6252	·5722	·4266	·4611	·2880
1 8 × 2 6	3·0972	2·0064	·7064	·4740	·5123	·3200
1 10 × 2 9	3·7476	2·4277	·8547	·5214	·5636	·3520
2 0 × 3 0	*4·4600	2·8892	1·0172	·5688	·6148	·3840
2 2 × 3 3	5·2343	3·3908	1·1938	·6162	·6660	·4160
2 4 × 3 6	6·0705	3·9325	1·3845	·6636	·7173	·4480
2 6 × 3 9	6·9687	4·5144	1·5894	·7110	·7685	·4800
2 8 × 4 0	7·9288	5·1364	1·8084	·7584	·8197	·5120
2 10 × 4 3	8·9509	5·7985	2·0415	·8058	·8710	·5440
3 0 × 4 6	10·0349	6·5007	2·2887	·8532	·9222	·5760
3 2 × 4 9	11·1809	7·2431	2·5501	·9006	·9734	·6080
3 4 × 5 0	12·3888	8·0256	2·8256	·9480	1·0247	·6400
3 6 × 5 3	13·6586	8·8482	3·1152	·9954	1·0759	·6720
3 8 × 5 6	14·9904	9·7110	3·4190	1·0428	1·1271	·7040
3 10 × 5 9	16·3842	10·6139	3·7369	1·0902	1·1784	·7360
4 0 × 6 0	17·8399	11·5569	4·0689	1·1376	1·2296	·7680
4 2 × 6 3	19·3575	12·5400	4·4150	1·1850	1·2808	·8000
4 4 × 6 6	20·9371	13·5633	4·7753	1·2324	1·3321	·8320
4 6 × 6 9	22·5786	14·6267	5·1497	1·2798	1·3833	·8640
4 8 × 7 0	24·2820	15·7302	5·5382	1·3272	1·4345	·8960
4 10 × 7 3	26·0474	16·8738	5·9408	1·3746	1·4858	·9280
5 0 × 7 6	27·8748	18·0576	6·3576	1·4220	1·5370	·9600
5 2 × 7 9	29·7641	19·2815	6·7885	1·4694	1·5882	·9920
5 4 × 8 0	31·7153	20·5455	7·2335	1·5168	1·6395	1·0240
5 6 × 8 3	33·7285	21·8497	7·6927	1·5642	1·6907	1·0560
5 8 × 8 6	35·8036	23·1940	8·1660	1·6116	1·7419	1·0880
5 10 × 8 9	37·9407	24·5784	8·6534	1·6590	1·7932	1·1200
6 0 × 9 0	40·1397	26·0029	9·1549	1·7064	1·8444	1·1520

Table No. 32.

Table No. 32 gives the discharge in cube feet per minute of circular sewers, varying in size from 3 inches to 10 feet in diameter, when laid at inclinations varying from 1 in 5 to 1 in 6000. In preparing this Table the length of sewer taken into consideration is the same as given in the description of Table No. 8, page 85. For all practical purposes this Table may be taken as correct, but in cases in which extreme accuracy is

* If this number (4·46) is multipled by the square of the radius in feet of the arched covering of an oval sewer of this particular sectional proportion, it will give the sectional area of the sewer.

required, the actual discharge may be arrived at in the way pointed out in the description of Tables Nos. 15 and 29. It may be noted that the point at which the discharge terminates in this Table represents the least inclination (giving a velocity of 120 feet per minute), which should be adopted for any sewer intended to be self-cleansing, consequently it will be seen at a glance that when a sewer of a certain size is laid at the greatest inclination that circumstances allow, to make it self-cleansing, and the discharge required is not sufficient, then a larger sewer must be adopted.

Table No. 33 gives the discharge when running full in cube feet per minute for oval sewers (old form), in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert having a radius of one-fourth of the transverse diameter. The discharge is calculated for sewers varying in size from 1 ft. × 1 ft. 6 in. to 6 ft. × 9 ft., when laid at inclinations varying from 1 in 100 to 1 in 4000. Table No. 33.

Table No. 34 is similar to Table No. 33, only that it is calculated for oval sewers (old form) when running two-thirds full. Table No. 34.

Table No. 35 is similar to Table No. 33, except that the calculations are made for oval sewers (old form) when running one-third full. Table No. 35.

Table No. 36 gives the discharge in cube feet per minute, when running full, of oval sewers (new form), or sewers in which the transverse diameter is two-thirds the vertical diameter, the invert having a radius equal to one-eighth of the transverse diameter, the radius of the sides being one and a third times the transverse diameter. The discharge is calculated for any size of sewer from 1 ft. × 1 ft. 6 in. to 6 ft. × 9 ft., and varying in inclination from 1 in 100 to 1 in 4000. Table No. 36.

Table No. 37 is similar to Table No. 36, except that it is calculated for oval sewers (new form) running two-thirds full. Table No. 37.

Table No. 38 is similar to Table No. 36, except that it is calculated for oval sewers (new form) running one-third full. Table No. 38.

TABLE No. 32.—DISCHARGE in cube feet per minute for CIRCULAR SEWERS,

Inclination.	Size, 3″.	Size, 4″.	Size, 6″.	Size, 8″.	Size, 9″.	Size, 10″.	Size, 12″.	Size, 14″.	Size, 15″.	Size, 16″.	Size, 18″.	Size, 20″.	Size, 21″.	Size, 22″.	Size, 24″.	Size, 27″.
1 in 5	32·60	65·84	175·9	351·5	465·7	598·3	922·1	1328	1561	1815	2391	3057	3422	3815	4663	
,, 6	30·00	60·69	163·1	326·7	433·4	558·0	861·6	1242	1463	1703	2248	2878	3225	3598	4402	
,, 7	27·93	56·59	152·7	306·4	407·3	524·7	812·1	1173	1382	1610	2129	2730	3059	3416	4185	
,, 8	26·26	53·28	144·1	290·0	385·7	497·4	770·5	1115	1314	1531	2027	2601	2917	3258	3997	
,, 9	24·84	50·49	136·6	275·4	367·1	474·0	735·1	1065	1255	1464	1938	2490	2794	3123	3833	
,, 10	23·61	48·05	130·3	263·5	350·8	453·2	703·7	1021	1204	1406	1862	2394	2689	3004	3689	
,, 15	19·39	39·59	108·2	219·8	293·4	379·6	593·0	862·7	1020	1192	1583	2042	2297	2569	3164	
,, 20	16·79	34·44	94·42	192·3	257·1	333·2	521·5	760·1	900·6	1054	1403	1813	2039	2284	2815	
,, 25	15·02	30·78	84·80	173·1	232·0	300·5	471·2	688·5	814·7	954·9	1272	1647	1854	2078	2564	
,, 30	13·65	28·08	77·54	158·5	212·5	276·0	432·8	632·9	749·7	879·5	1173	1519	1710	1917	2372	
,, 35	12·62	25·99	71·85	146·9	197·0	256·3	402·9	589·1	698·2	818·1	1094	1416	1597	1790	2215	
,, 40	11·78	24·24	67·14	137·8	184·7	240·0	377·8	552·7	656·4	769·2	1028	1333	1503	1684	2086	
,, 45	11·05	22·76	63·21	129·8	174·5	226·3	356·6	522·8	620·9	727·3	973·6	1263	1424	1597	1980	
,, 50	10·46	21·48	60·17	123·5	165·7	214·7	339·1	497·1	590·2	692·4	927·7	1202	1356	1521	1885	
,, 60	9·48	19·73	54·68	112·7	151·6	196·7	310·1	455·4	539·9	633·8	849·9	1104	1243	1394	1731	
,, 70	8·74	18·25	50·37	104·0	140·1	182·0	287·3	422·3	500·6	587·7	788·1	1025	1157	1296	1612	
,, 80	8·15	16·94	46·84	97·02	130·8	170·0	268·5	394·5	468·7	551·4	738·6	960·1	1085	1217	1511	
,, 90	7·66	15·89	44·10	91·44	123·3	160·2	252·8	372·1	441·7	519·3	696·2	905·6	1025	1148	1427	
,, 100	7·22	15·02	41·75	86·55	116·7	152·1	240·2	352·8	419·6	492·8	660·9	859·7	971·6	1090	1357	1817
,, 110	6·87	14·23	39·59	82·36	110·9	144·4	228·4	336·8	400·0	469·0	630·8	820·4	928·3	1043	1298	1734
,, 120	6·53	13·53	37·83	78·52	106·1	137·9	218·2	321·8	382·8	449·5	604·3	785·5	887·4	997·9	1241	1662
,, 130	6·28	13·01	36·46	75·38	101·7	132·4	209·6	309·0	366·9	431·4	579·6	755·0	853·8	958·3	1191	1594
,, 140	6·04	12·48	34·89	72·59	97·68	127·0	201·7	297·2	353·4	416·0	558·4	728·8	822·5	924·0	1147	1539
,, 150	5·79	12·05	33·71	70·15	94·15	122·6	194·7	286·5	341·1	402·0	540·7	702·6	793·6	892·3	1109	1487
,, 160	..	11·61	32·54	67·71	91·05	118·8	188·4	276·9	330·1	388·1	523·0	680·8	769·6	863·3	1075	1439
,, 170	..	11·26	31·36	65·61	87·96	115·0	182·1	268·3	320·2	375·5	507·1	661·1	745·5	836·9	1043	1399
,, 180	..	10·91	30·38	63·52	85·31	111·7	176·6	260·8	310·4	364·3	491·2	641·5	723·9	813·1	1012	1360
,, 190	..	10·56	29·60	61·77	83·10	108·5	171·9	253·3	301·8	354·6	477·1	624·1	704·6	792·0	983·4	1324
,, 200	..	10·36	28·81	60·03	80·89	105·7	167·2	246·9	293·3	346·2	464·7	606·6	685·4	770·9	958·3	1288
,, 250	..	..	25·68	53·40	72·05	93·74	148·4	219·1	261·4	308·5	413·5	539·0	610·9	686·4	854·6	1153
,, 300	..	..	23·13	48·16	64·97	85·03	135·0	199·9	236·8	279·2	376·4	491·0	555·5	625·7	779·2	1050
,, 350	..	..	..	44·32	59·67	77·93	124·0	183·9	218·4	256·9	346·3	451·7	512·3	575·5	716·4	966·
,, 400	..	..	..	41·18	55·69	72·49	115·4	171·0	203·7	240·1	323·4	421·1	478·6	535·9	669·2	898·
,, 450	..	..	..	..	52·16	68·13	108·3	160·3	191·4	226·1	303·9	397·1	449·7	504·2	628·4	846·
,, 500	..	..	..	..	..	64·31	102·05	151·8	180·4	213·6	286·3	375·3	425·7	477·8	593·8	803·
,, 550	..	..	..	..	..	..	97·34	144·3	171·8	202·4	272·1	355·7	404·0	454·1	565·6	763·
,, 600	..	..	..	..	..	..	92·63	137·9	164·4	194·0	259·7	340·4	384·8	433·0	540·4	727·
,, 650	..	..	..	..	..	..	..	131·5	157·1	185·7	249·1	325·1	368·0	414·5	518·4	695·
,, 700	..	..	..	..	..	..	..	126·1	150·9	177·3	238·5	312·0	353·5	398·6	496·4	668·
,, 750	..	..	..	..	..	..	..	..	144·8	170·3	229·7	301·1	341·5	382·8	477·6	644·
,, 800	..	..	..	..	..	..	..	..	..	164·7	222·6	290·2	329·5	369·6	461·9	624·
, 850	..	..	..	..	..	..	..	..	..	..	215·6	281·5	319·9	359·0	446·2	604·
,, 900	..	..	..	..	..	..	..	..	..	..	208·5	272·7	310·2	348·5	433·6	584·
,, 950	..	..	..	..	..	..	..	..	..	..	..	264·0	300·6	337·9	421·0	568·

…hen RUNNING FULL, and constructed at various rates of inclination.

…ize, …0″.	Size, 33″.	Size, 36″.	Size, 40″.	Size, 42″.	Size, 45″.	Size, 48″.	Size, 54″.	Size, 60″.	Size, 66″.	Size, 72″.	Size, 78″.	Size, 84″.	Size, 90″.	Size, 96″.	Size, 102″.	Size, 108″.	Size, 114″.	Size, 120″.	Inclination.
																			1 in 5
																			„ 6
																			„ 7
																			„ 8
																			„ 9
																			„ 10
																			„ 15
																			„ 20
																			„ 25
																			„ 30
																			„ 35
																			„ 40
																			„ 45
																			„ 50
																			„ 60
																			„ 70
																			„ 80
																			„ 90
61	2988	3711	4809	5426	6428	7540	10067	13038	16464	20357	24754	29672	35078	41066	47609	54646	62233	70378	„ 100
53	2857	3542	4599	5186	6152	7213	9638	12488	15775	19538	23726	28440	33665	39408	45680	52484	59824	67707	„ 110
60	2738	3400	4416	4974	5909	6924	9256	11997	15158	18774	22830	27363	32383	37950	43977	50512	57627	65271	„ 120
77	2631	3273	4250	4791	5688	6673	8924	11565	14611	18095	22034	26401	31235	36593	42445	48795	55642	63073	„ 130
03	2563	3153	4102	4628	5489	6446	8620	11172	14136	17502	21304	25554	30263	35437	41084	47268	53942	61109	„ 140
39	2459	3054	3962	4474	5313	6223	8350	10819	13685	16964	20640	24785	29335	34381	39892	45868	52381	59303	„ 150
75	2382	2955	3840	4339	5147	6044	8095	10505	13281	16456	20043	24053	28496	33376	38700	44532	50893	57653	„ 160
21	2311	2870	3726	4214	5003	5868	7857	10210	12901	16003	19478	23399	27700	32471	37679	43324	49476	56082	„ 170
72	2245	2792	3622	4099	4860	5705	7650	9935	12568	15579	18981	22783	26993	31667	36771	42242	48200	54668	„ 180
23	2186	2715	3526	3993	4738	5554	7443	9680	12259	15183	18517	22206	26331	30863	35863	41224	47066	53411	„ 190
79	2132	2651	3448	3887	4617	5416	7268	9444	11950	14816	18085	21706	25712	30159	35012	40269	46012	52155	„ 200
97	1907	2368	3082	3483	4142	4863	6537	8503	10762	13345	16260	19512	23150	27193	31608	36389	41537	47128	„ 250
55	1734	2156	2811	3175	3777	4436	5964	7756	9836	12186	14866	17895	21250	24931	28997	33399	38134	43279	„ 300
57	1604	1993	2602	2944	3490	4109	5519	7186	9123	11310	13804	16625	19748	23172	26954	31045	35512	40294	„ 350
73	1491	1859	2427	2742	3258	3845	5169	6715	8529	10603	12941	15548	18467	21714	25252	29073	33243	37781	„ 400
05	1402	1746	2278	2578	3070	3632	4883	6342	8054	10009	12211	14663	17451	20508	23833	27482	31400	35660	„ 450
46	1331	1654	2156	2444	2905	3431	4612	6008	7626	9472	11581	13932	16567	19452	22641	26083	29841	33929	„ 500
06·5	1265	1576	2052	2328	2761	3267	4390	5714	7246	9019	11017	13239	15728	18497	21506	24811	28424	32358	„ 550
2·3	1206	1506	1964	2222	2640	3116	4183	5458	6937	8624	10552	12700	15109	17744	20655	23856	27290	31023	„ 600
3·1	1158	1442	1886	2136	2540	2991	4008	5243	6652	8284	10121	12200	14535	17090	19861	22902	26226	29845	„ 650
8·7	1117	1385	1816	2049	2441	2878	3865	5046	6415	7973	9756	11738	13691	16437	19123	22075	25305	28746	„ 700
4·3	1075	1336	1755	1972	2353	2777	3737	4869	6177	7691	9424	11353	13475	15834	18442	21312	24454	27803	„ 750
4·9	1039	1294	1694	1915	2275	2677	3594	4693	5963	7436	9092	10968	13033	15331	17875	20612	23604	26861	„ 800
0·3	1004	1251	1641	1857	2198	2589	3483	4536	5773	7210	8827	10622	12635	14878	17307	19976	22895	25997	„ 850
5·8	974·2	1216	1589	1799	2132	2513	3388	4418	5607	6984	8561	10314	12282	14426	16796	19403	22257	25290	„ 900
1·3	944·5	1181	1545	1741	2076	2450	3292	4300	5464	6786	8329	10045	11928	14024	16342	18894	21619	24583	„ 950

TABLE No. 32.—DISCHARGE in cube feet per minute for CIRCULAR SEWERS,

Inclination.	Size, 3″.	Size, 4″.	Size, 6″.	Size, 8″.	Size, 9″.	Size, 10″.	Size, 12″	Size, 14″.	Size, 15″.	Size, 16″.	Size, 18″.	Size, 20″.	Size, 21″.	Size, 22″.	Size, 24″.	Size, 27″.
1 in 1000	..	..	..	..	..	..	..	..	..	..	..	257·5	291·0	327·4	408·5	552·6
,, 1100	..	..	..	..	..	..	..	..	..	..	..	..	..	311·5	389·6	524·8
,, 1200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	370·8	501·0
,, 1300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	477·1
,, 1400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 5000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 5100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 5400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 5700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 6000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

when Running Full, and constructed at various rates of inclination—*continued.*

Size, 30″.	Size, 33″.	Size, 36″.	Size, 40″.	Size, 42″.	Size, 45″.	Size, 48″.	Size, 54″.	Size, 60″.	Size, 66″.	Size, 72″.	Size, 78″.	Size, 84″.	Size, 90″.	Size, 96″.	Size, 102″.	Size, 108″.	Size, 114″.	Size, 120″.	Inclination.
721·6	920·7	1145	1502	1693	2021	2388	3213	4182	5322	6616	8097	9775	11619	13672	15945	18385	21052	23955	1 in 1000
687·3	873·2	1089	1423	1616	1922	2274	3054	3986	5060	6305	7698	9275	11045	13019	15208	17558	20060	22777	„ 1100
652·9	831·6	1039	1362	1539	1833	2161	2910	3790	4823	6022	7367	8890	10603	12466	14527	16795	19209	21834	„ 1200
623·4	796·0	996·7	1301	1472	1756	2073	2783	3632	4633	5768	7068	8544	10161	11963	13903	16095	18429	20970	„ 1300
598·9	766·3	954·3	1248	1414	1690	1985	2672	3495	4443	5542	6803	8197	9764	11511	13392	15459	17720	20185	„ 1400
579·3	736·6	919·0	1205	1366	1624	1910	2576	3377	4300	5344	6537	7890	9410	11109	12938	14950	17083	19478	„ 1500
..	712·8	890·7	1161	1318	1568	1847	2497	3259	4158	5174	6338	7659	9101	10706	12484	14441	16515	18771	„ 1600
..	..	862·4	1126	1280	1513	1784	2417	3161	4015	5004	6139	7428	8836	10355	12087	13996	16019	18221	„ 1700
..	..	834·1	1091	1241	1469	1734	2338	3063	3896	4863	5973	7197	8571	10053	11746	13550	15523	17671	„ 1800
..	..	..	1056	1203	1425	1684	2274	2965	3777	4722	5774	6966	8306	9751	11406	13169	15098	17200	„ 1900
..	..	..	1030	1164	1392	1634	2211	2886	3682	4580	5608	6773	8085	9500	11065	12787	14673	16729	„ 2000
..	..	..	..	..	1358	1596	2147	2808	3587	4467	5475	6619	7864	9249	10782	12469	14318	16336	„ 2100
..	..	..	..	..	1325	1558	2099	2749	3492	4354	5342	6465	7687	9048	10554	12214	14035	15944	„ 2200
..	..	..	..	..	..	1520	2052	2670	3397	4241	5210	6312	7510	8847	10328	11896	13680	15551	„ 2300
..	..	..	..	..	..	1483	2004	2611	3326	4156	5110	6158	7334	8646	10101	11642	13326	15158	„ 2400
..	..	..	..	..	..	..	1956	2553	3255	4071	4977	6004	7157	8444	9874	11377	13042	14844	„ 2500
..	..	..	..	..	..	..	1908	2513	3207	3987	4878	5888	7024	8294	9647	11133	12759	14530	„ 2600
..	..	..	..	..	..	..	1877	2454	3136	3902	4778	5773	6892	8093	9420	10878	12475	14216	„ 2700
..	..	..	..	..	..	..	..	2415	3065	3817	4679	5657	6759	7942	9249	10688	12263	13980	„ 2800
..	..	..	..	..	..	..	..	2356	2994	3732	4579	5542	6627	7791	9079	10497	12050	13744	„ 2900
..	..	..	..	..	..	..	..	2317	2946	3676	4513	5465	6538	7691	8966	10370	11908	13509	„ 3000
..	..	..	..	..	..	..	..	..	2898	3619	4447	5349	6406	7540	8795	10179	11696	13273	„ 3100
..	..	..	..	..	..	..	..	..	2851	3563	4380	5272	6273	7389	8625	9988	11483	13038	„ 3200
..	..	..	..	..	..	..	..	..	2803	3506	4314	5195	6185	7288	8512	9861	11270	12802	„ 3300
..	..	..	..	..	..	..	..	..	..	3449	4247	5119	6097	7188	8398	9733	11128	12645	„ 3400
..	..	..	..	..	..	..	..	..	..	3393	4181	5042	6008	7087	8285	9543	10916	12409	„ 3500
..	..	..	..	..	..	..	..	..	..	3336	4115	4965	5920	6987	8171	9415	10774	12252	„ 3600
..	..	..	..	..	..	..	..	..	..	..	4048	4888	5832	6886	8001	9224	10561	12017	„ 3700
..	..	..	..	..	..	..	..	..	..	..	3982	4811	5743	6786	7888	9097	10420	11860	„ 3800
..	..	..	..	..	..	..	..	..	..	..	3916	4734	5655	6685	7774	8970	10278	11702	„ 3900
..	..	..	..	..	..	..	..	..	..	..	..	4657	5567	6585	7661	8843	10136	11545	„ 4000
..	..	..	..	..	..	..	..	..	..	..	..	4580	5478	6484	7547	8716	9994	11388	„ 4100
..	..	..	..	..	..	..	..	..	..	..	..	4541	5434	6384	7434	8588	9853	11231	„ 4200
..	..	..	..	..	..	..	..	..	..	..	..	..	5346	6283	7330	8461	9711	11074	„ 4300
..	..	..	..	..	..	..	..	..	..	..	..	..	5301	6233	7263	8397	9640	10966	„ 4400
..	..	..	..	..	..	..	..	..	..	..	..	..	5213	6132	7150	8270	9498	10838	„ 4500
..	..	..	..	..	..	..	..	..	..	..	..	..	..	6082	7093	8207	9427	10681	„ 4600
..	..	..	..	..	..	..	..	..	..	..	..	..	..	5982	6980	8079	9286	10524	„ 4700
..	..	..	..	..	..	..	..	..	..	..	..	..	..	5931	6923	8016	9215	10446	„ 4800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6809	7889	9073	10289	„ 4900
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6753	7825	9002	10210	„ 5000
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6696	7761	8931	10132	„ 5100
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7507	8648	9818	„ 5400
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8364	9503	„ 5700
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9268	„ 6000

TABLE No. 33.—DISCHARGE in cube feet per minute for OVAL SEWERS (Old Form), in having a radius of one-fourth of the transverse diameter,

Inclination.	Size, 1' 0" × 1' 6".	Size, 1' 2" × 1' 9".	Size, 1' 4" × 2' 0".	Size, 1' 6" × 2' 3".	Size, 1' 8" × 2' 6".	Size, 1' 10" × 2' 9".	Size, 2' 0" × 3' 0".	Size, 2' 2" × 3' 3".	Size, 2' 4" × 3' 6".	Size, 2' 6" × 3' 9".	Size, 2' 8" × 4' 0".	Size, 2' 10" × 4' 3".	Size, 3' 0" × 4' 6"	Size, 3' 2" × 4' 9".	Size, 3' 4" × 5' 0".
1 in 100	378	556	778	1044	1356	1714	2127								
,, 110	361	530	741	995	1292	1637	2030								
,, 120	345	506	708	951	1238	1571	1948								
,, 130	331	488	682	915	1190	1509	1874								
,, 140	318	469	655	880	1145	1455	1805								
,, 150	307	452	633	850	1107	1405	1746								
,, 160	296	438	613	824	1072	1363	1691								
,, 170	287	424	594	798	1040	1320	1633								
,, 180	279	411	576	775	1011	1282	1588								
,, 190	271	400	562	755	982	1247	1553								
,, 200	264	389	546	734	957	1215	1511	1849	2226	2642	3103	3614	4165	4768	5423
,, 250	235	347	486	654	852	1085	1351	1650	1988	2362	2777	3236	3731	4273	4862
,, 300	213	316	442	595	775	988	1231	1504	1813	2153	2532	2950	3411	3904	4441
,, 350	196	291	406	548	714	910	1135	1391	1676	1988	2336	2720	3142	3605	4096
,, 400	183	270	380	512	667	849	1057	1294	1563	1859	2189	2545	2935	3363	3828
,, 450	171	253	355	481	628	799	997	1219	1469	1751	2058	2397	2770	3179	3611
,, 500	162	239	337	455	593	756	942	1154	1388	1651	1944	2268	2615	2994	3407
,, 550	154	228	321	432	565	717	896	1094	1319	1572	1846	2148	2481	*2845	3241
,, 600	147	217	304	411	539	686	854	1046	1263	1500	1764	2056	2377	2729	3101
,, 650	141	208	292	393	514	656	816	1003	1207	1436	1691	1973	2284	2614	2973
,, 700	136	200	280	377	494	629	786	965	1163	1385	1633	1899	2191	2511	2858
,, 750	..	192	269	364	475	606	758	927	1119	1335	1576	1835	2119	2430	2756
,, 800	..	186	261	351	459	586	730	895	1082	1292	1519	1770	2047	2349	2667
,, 850	..	..	253	341	447	567	707	868	1050	1249	1470	1715	1985	2269	2578
,, 900	..	..	245	331	434	552	689	841	1013	1206	1421	1660	1923	2200	2501
,, 950	..	..	..	320	421	536	666	814	982	1170	1380	1613	1861	2131	2425
,, 1000	..	..	..	313	408	521	648	793	957	1141	1348	1567	1809	2073	2361
,, 1100	..	..	..	..	386	494	615	755	913	1091	1282	1494	1726	1981	2259
,, 1200	..	..	..	..	..	471	588	722	875	1041	1225	1420	1643	1889	2144
,, 1300	..	..	..	..	..	..	560	690	838	998	1168	1364	1571	1808	2055
,, 1400	..	..	..	..	..	..	..	663	800	955	1119	1309	1509	1739	1978
,, 1500	..	..	..	..	..	..	..	636	769	919	1086	1263	1457	1670	1901
,, 1600	..	..	..	..	..	..	..	..	738	883	1045	1217	1406	1612	1838
,, 1700	..	..	..	..	..	..	..	..	..	854	1013	1180	1364	1566	1787
,, 1800	..	..	..	..	..	..	..	..	..	..	980	1143	1323	1520	1736
,, 1900	..	..	..	..	..	..	..	..	..	..	..	1106	1282	1474	1684
,, 2000	..	..	..	..	..	..	..	..	..	..	..	..	1251	1440	1633
,, 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	1405	1595
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	1371	1557
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1519
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

which the transverse diameter is equal to two-thirds of the vertical diameter, the invert when RUNNING FULL, and at various rates of inclination.

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
6120	6857	7662	8508	9411	10373	11396	12481	13630	14816	16068	17380	18761	20210	21729	23278	,, 200
5487	6149	6886	7644	8454	9317	10233	11205	12235	13323	14344	15648	16885	18182	19540	20962	,, 250
5009	5609	6278	6983	7736	8519	9373	10255	11188	12174	13217	14309	15460	16633	17860	19143	,, 300
4629	5193	5806	6468	7158	7893	8675	9504	10383	11284	12266	13263	14314	15416	16570	17779	,, 350
4333	4854	5434	6046	6700	7397	8140	8904	9713	10566	11469	12414	13410	14457	15554	16662	,, 400
4080	4577	5130	5715	6321	6966	7652	8379	9149	9963	10825	11695	12646	13609	14655	15711	,, 450
3855	4330	4860	5403	5982	6599	7256	7954	8693	9446	10273	11107	12021	12945	13913	14926	,, 500
3672	4114	4624	5145	5703	6297	6931	7578	8291	9016	9782	10585	11430	12318	13248	14223	,, 550
3503	3930	4405	4906	5443	6017	6605	7228	7915	8614	9353	10127	10944	11801	12701	13603	,, 600
3363	3775	4236	4723	5224	5758	6326	6928	7566	8240	8954	9703	10492	11322	12193	13065	,, 650
3236	3637	4084	4539	5025	5543	6093	6678	7298	7953	8648	9376	10110	10916	11724	12569	,, 700
3123	3513	3932	4373	4845	5348	5884	6453	7056	7695	8341	9049	9763	10548	11333	12155	,, 750
3025	3390	3797	4226	4686	5176	5698	6253	6842	7437	8065	8755	9450	10179	10943	11742	,, 800
2926	3282	3679	4098	4546	5025	5512	6053	6627	7207	7820	8461	9137	9847	10591	11360	,, 850
2828	3174	3561	3969	4407	4874	5349	5878	6412	6977	7574	8200	8859	9552	10278	11039	,, 900
2743	3082	3460	3859	4287	4723	5186	5703	6225	6776	7360	7971	8616	9294	10005	10750	,, 950
2673	3005	3375	3767	4167	4594	5047	5553	6064	6604	7176	7775	8408	9072	9770	10461	,, 1000
2547	2866	3223	3583	3968	4378	4814	5277	5768	6288	6838	7416	7991	8630	9301	9964	,, 1100
2434	2743	3072	3418	3788	4184	4605	5052	5527	6001	6532	7056	7609	8224	8871	9510	,, 1200
2335	2620	2936	3271	3629	4011	4419	4827	5286	5743	6256	6762	7296	7892	8481	9096	,, 1300
2237	2512	2818	3142	3489	3839	4233	4627	5071	5513	6010	6501	7018	7597	8168	8765	,, 1400
2153	2419	2717	3032	3370	3709	4093	4477	4910	5341	5796	6272	6775	7302	7855	8435	,, 1500
2082	2342	2633	2922	3250	3580	3954	4327	4749	5168	5612	6076	6566	7081	7621	8186	,, 1600
2026	2265	2548	2830	3150	3472	3814	4177	4588	4996	5428	5880	6358	6860	7386	7938	,, 1700
1956	2188	2464	2738	3051	3364	3698	4052	4454	4852	5274	5717	6149	6638	7152	7690	,, 1800
1899	2127	2396	2665	2951	3257	3582	3927	4320	4709	5121	5554	5976	6454	6956	7484	,, 1900
1843	2065	2329	2591	2871	3170	3489	3827	4186	4565	4968	5390	5802	6270	6761	7277	,, 2000
1801	2019	2261	2518	2791	3084	3395	3727	4078	4450	4845	5260	5663	6122	6605	7070	,, 2100
1759	1972	2211	2462	2732	3019	3326	3652	3998	4336	4722	5129	5524	5974	6448	6905	,, 2200
1716	1926	2160	2407	2672	2955	3256	3552	3890	4249	4600	4998	5385	5827	6292	6739	,, 2300
1674	1880	2110	2352	2612	2890	3186	3477	3810	4163	4508	4900	5281	5716	6136	6574	,, 2400
..	1834	2059	2297	2552	2825	3116	3402	3729	4048	4416	4802	5177	5569	6018	6450	,, 2500
..	..	2025	2242	2492	2760	3047	3327	3649	3962	4324	4672	5072	5458	5901	6326	,, 2600
..	..	..	2205	2433	2696	2977	3252	3568	3876	4232	4574	4968	5348	5745	6202	,, 2700
..	..	..	..	2393	2653	2907	3201	3488	3819	4110	4508	4864	5237	5628	6078	,, 2800
..	..	..	..	..	2588	2861	3126	3434	3733	4078	4410	4760	5126	5549	5954	,, 2900
..	..	..	..	..	..	2814	3076	3381	3675	3986	4345	4690	5052	5432	5830	,, 3000
..	..	..	..	..	..	2744	3001	3300	3618	3925	4247	4586	4942	5354	5747	,, 3100
..	..	..	..	..	..	..	2951	3246	3532	3864	4182	4516	4868	5237	5623	,, 3200
..	..	..	..	..	..	..	..	3193	3474	3802	4116	4447	4794	5159	5540	,, 3300
..	..	..	..	..	..	..	..	..	3417	3741	4051	4377	4721	5081	5458	,, 3400
..	..	..	..	..	..	..	..	..	..	3680	3986	4308	4647	5002	5375	,, 3500
..	..	..	..	..	..	..	..	..	..	..	3920	4239	4573	4924	5292	,, 3600
..	..	..	..	..	..	..	..	..	..	..	..	4169	4499	4846	5210	,, 3700
..	..	..	..	..	..	..	..	..	..	..	..	..	4426	4768	5127	,, 3800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	4690	5044	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4962	,, 4000

Table 34.—Discharge in cube feet per minute for Oval Sewers (Old Form), having a radius of one-fourth the transverse diameter,

Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	260	382	531	714	926	1173	1460								
„ 110	248	364	507	682	884	1120	1397								
„ 120	237	349	486	653	848	1074	1336								
„ 130	227	335	467	627	815	1034	1285								
„ 140	219	323	451	605	785	996	1239								
„ 150	212	312	435	585	760	963	1197								
„ 160	205	302	422	566	737	935	1161								
„ 170	198	292	408	549	714	907	1128								
„ 180	192	283	396	534	693	881	1087								
„ 190	187	276	385	519	674	856	1057								
„ 200	182	269	376	506	659	836	1040	1270	1527	1814	2128	2475	2857	3267	3712
„ 250	162	239	334	451	588	747	928	1135	1366	1625	1908	2221	2564	2933	3334
„ 300	147	217	303	410	536	681	846	1036	1247	1483	1741	2027	2340	2675	3040
„ 350	135	200	279	378	494	627	780	954	1152	1370	1612	1875	2163	2478	2822
„ 400	126	186	260	352	460	584	729	891	1074	1280	1505	1753	2020	2312	2629
„ 450	119	175	245	332	433	549	683	837	1008	1200	1414	1650	1905	2183	2486
„ 500	112	166	232	313	410	521	647	791	955	1138	1338	1559	1803	2069	2351
„ 550	107	157	220	298	389	496	617	752	909	1082	1274	1487	1714	1963	2234
„ 600	101	150	210	284	370	473	590	720	868	1034	1215	1414	1633	1872	2133
„ 650	97	143	201	272	355	452	565	692	835	992	1166	1359	1571	1796	2041
„ 700	93	138	193	260	340	434	541	663	802	954	1123	1310	1510	1728	1965
„ 750	90	133	186	251	328	419	523	642	774	921	1080	1262	1456	1667	1898
„ 800	..	129	180	243	317	404	505	621	749	888	1043	1220	1408	1614	1839
„ 850	..	124	174	235	306	391	490	600	724	860	1010	1177	1360	1561	1780
„ 900	..	..	169	228	298	378	475	582	700	831	978	1141	1320	1516	1730
„ 950	..	..	164	221	290	368	460	564	679	808	951	1110	1286	1470	1680
„ 1000	..	..	160	216	281	358	447	550	662	789	930	1086	1252	1432	1638
„ 1100	..	..	..	204	266	340	426	522	630	751	881	1031	1190	1364	1554
„ 1200	..	..	..	..	256	325	405	497	601	718	844	983	1140	1304	1486
„ 1300	..	..	..	..	..	312	390	475	576	685	806	940	1088	1251	1419
„ 1400	..	..	..	..	..	302	375	458	551	657	774	904	1041	1197	1360
„ 1500	..	..	..	..	..	..	363	440	531	633	747	874	1007	1160	1318
„ 1600	..	..	..	..	..	..	..	426	510	609	720	843	973	1114	1268
„ 1700	..	..	..	..	..	..	..	..	494	590	693	813	939	1076	1226
„ 1800	..	..	..	..	..	..	..	..	..	572	672	789	911	1046	1192
„ 1900	..	..	..	..	..	..	..	..	..	..	656	764	844	1016	1159
„ 2000	..	..	..	..	..	..	..	..	..	..	640	746	857	985	1125
„ 2100	..	..	..	..	..	..	..	..	..	..	..	728	837	963	1092
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	816	940	1067
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	917	1041
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1016
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1000
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert when RUNNING TWO-THIRDS FULL, and at various rates of inclination.

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
4194	4705	5253	5841	6469	7139	7836	8575	9358	10166	11016	11910	12849	13834	14865	15917	,, 200
3768	4227	4720	5248	5813	6415	7040	7703	8404	9145	9906	10706	11569	12450	13373	14339	,, 250
3435	3862	4320	4801	5314	5861	6443	7045	7680	8352	9059	9803	10586	11407	12268	13142	,, 300
3185	3577	3998	4450	4934	5436	5969	6534	7133	7766	8413	9094	9808	10582	11367	12190	,, 350
2972	3343	3743	4160	4606	5081	5586	6123	6674	7256	7869	8513	9191	9902	10647	11428	,, 400
2805	3150	3521	3918	4343	4797	5280	5777	6303	6859	7445	8040	8688	9344	10056	10775	,, 450
2657	2987	3332	3712	4120	4556	5005	5481	5985	6500	7061	7632	8254	8883	9541	10231	,, 500
2528	2845	3176	3543	3923	4329	4760	5218	5703	6198	6719	7266	7865	8470	9104	9768	,, 550
2416	2723	3043	3386	3753	4144	4561	5004	5456	5933	6436	6965	7522	8106	8718	9360	,, 600
2315	2601	2910	3241	3595	3974	4377	4806	5244	5706	6194	6707	7225	7791	8384	9006	,, 650
2222	2500	2799	3120	3464	3832	4209	4609	5032	5480	5952	6449	6950	7499	8050	8652	,, 700
2148	2418	2699	3011	3346	3690	4056	4444	4855	5272	5730	6213	6699	7232	7767	8353	,, 750
2074	2337	2610	2914	3228	3562	3918	4296	4697	5102	5548	6020	6493	7014	7535	8081	,, 800
2009	2266	2532	2818	3123	3449	3796	4164	4555	4950	5387	5826	6287	6795	7304	7836	,, 850
1954	2195	2454	2733	3031	3349	3688	4049	4414	4799	5226	5654	6104	6601	7098	7618	,, 900
1898	2134	2388	2660	2952	3264	3581	3934	4290	4667	5084	5504	5944	6407	6892	7401	,, 950
1852	2083	2332	2588	2874	3179	3490	3819	4167	4535	4943	5353	5784	6237	6712	7210	,, 1000
1759	1981	2210	2455	2729	3023	3321	3638	3973	4327	4701	5095	5510	5922	6378	6857	,, 1100
1676	1890	2110	2346	2611	2881	3168	3473	3796	4138	4479	4859	5258	5655	6095	6530	,, 1200
1602	1809	2021	2249	2506	2767	3046	3325	3637	3967	4297	4644	5030	5412	5838	6258	,, 1300
1546	1738	1944	2165	2401	2654	2923	3193	3496	3817	4136	4472	4847	5218	5632	6040	,, 1400
1491	1677	1877	2092	2323	2568	2831	3094	3372	3685	3995	4321	4687	5048	5427	5823	,, 1500
1435	1616	1810	2019	2244	2484	2724	2996	3266	3552	3854	4171	4527	4878	5247	5632	,, 1600
1389	1565	1755	1959	2165	2398	2632	2897	3160	3439	3733	4042	4367	4708	5066	5442	,, 1700
1352	1514	1699	1899	2099	2328	2556	2815	3072	3344	3611	3913	4252	4587	4912	5279	,, 1800
1315	1473	1655	1838	2047	2257	2479	2732	2984	3250	3511	3805	4115	4441	4784	5142	,, 1900
1278	1433	1610	1790	1994	2200	2418	2650	2896	3155	3430	3719	4024	4320	4655	5006	,, 2000
1241	1392	1566	1741	1942	2143	2357	2584	2825	3080	3349	3612	3910	4223	4526	4870	,, 2100
1213	1362	1522	1693	1889	2086	2296	2518	2754	3004	3268	3526	3818	4126	4424	4762	,, 2200
1185	1331	1488	1657	1837	2029	2235	2452	2684	2929	3188	3440	3727	4029	4321	4653	,, 2300
1157	1301	1455	1620	1798	1987	2189	2403	2613	2853	3107	3354	3635	3932	4218	4544	,, 2400
1130	1270	1422	1584	1758	1944	2143	2354	2560	2778	3026	3289	3567	3835	4115	4435	,, 2500
1111	1240	1388	1548	1719	1902	2097	2304	2507	2721	2966	3225	3498	3762	4038	4326	,, 2600
..	1219	1366	1524	1693	1873	2051	2255	2454	2664	2905	3160	3429	3689	3961	4245	,, 2700
..	..	1344	1500	1653	1831	2020	2206	2401	2626	2865	3096	3361	3616	3883	4163	,, 2800
..	..	..	1463	1627	1788	1974	2156	2366	2570	2804	3031	3292	3543	3806	4081	,, 2900
..	..	..	1439	1601	1760	1944	2123	2331	2532	2744	2988	3224	3495	3755	4027	,, 3000
..	..	..	..	1575	1731	1913	2090	2278	2475	2704	2924	3155	3422	3678	3945	,, 3100
..	..	..	..	..	1703	1883	2057	2242	2437	2663	2881	3109	3373	3626	3891	,, 3200
..	..	..	..	..	..	1852	2025	2207	2400	2623	2838	3064	3325	3575	3836	,, 3300
..	..	..	..	..	..	1821	1992	2172	2362	2582	2795	3018	3252	3498	3755	,, 3400
..	..	..	..	..	..	..	1959	2136	2324	2542	2752	2972	3204	3446	3700	,, 3500
..	..	..	..	..	..	..	..	2101	2286	2502	2709	2926	3155	3395	3646	,, 3600
..	..	..	..	..	..	..	..	..	2267	2461	2666	2881	3107	3343	3592	,, 3700
..	..	..	..	..	..	..	..	..	..	2421	2623	2835	3058	3292	3537	,, 3800
..	..	..	..	..	..	..	..	..	..	..	2580	2789	3009	3240	3483	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	2766	2961	3189	3428	,, 4000
..	..	..	..	..	..	..	..	..	..	..	..	2721	2937	3163	3401	,, 4100
..	..	..	..	..	..	..	..	..	..	..	..	..	2888	3112	3347	,, 4200
..	..	..	..	..	..	..	..	..	..	..	..	..	..	3086	3319	,, 4300
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3265	,, 4400

TABLE No. 35.—DISCHARGE in cube feet per minute for OVAL SEWERS (Old Form), in having a radius of one-fourth the transverse diameter,

Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	78·5	116	162	218	283	360	448								
,, 110	74·9	110	154	208	270	343	427								
,, 120	71·5	105	147	199	259	328	409								
,, 130	68·4	101	141	190	248	315	392								
,, 140	65·9	97·3	136	183	239	304	378								
,, 150	63·6	93·8	131	177	230	293	365								
,, 160	61·6	90·7	127	171	223	283	353								
,, 170	59·6	87·6	123	166	216	275	343								
,, 180	57·9	85·3	120	161	210	267	333								
,, 190	56·3	83·0	116	156	204	260	324								
,, 200	54·8	80·7	113	152	198	252	315	385	464	552	648	755	872	997	1133
,, 250	48·6	71·8	100	135	177	225	281	343	413	492	578	673	777	891	1013
,, 300	44·0	65·2	91·3	123	161	204	254	312	376	448	527	613	708	812	925
,, 350	40·6	59·8	83·7	113	148	188	235	288	347	412	485	566	654	749	852
,, 400	37·7	55·6	78·2	105	138	176	219	268	323	384	453	527	609	698	795
,, 450	35·5	52·1	73·1	99·0	129	165	205	252	303	361	425	495	573	655	748
,, 500	33·5	49·4	69·1	93·2	122	156	194	238	288	343	402	470	542	621	707
,, 550	..	47·1	65·6	88·7	116	148	184	226	274	327	384	447	516	592	672
,, 600	..	..	63·0	84·9	110	141	176	216	261	311	366	427	493	567	644
,, 650	..	..	60·0	81·0	106	135	168	206	249	297	350	408	473	541	615
,, 700	..	..	..	77·8	102	130	162	198	239	286	337	392	452	518	590
,, 750	..	..	..	75·3	97·8	125	157	192	230	275	325	378	437	501	571
,, 800	..	..	..	..	94·7	121	151	185	222	266	313	365	422	484	552
,, 850	..	..	..	..	..	117	146	180	216	257	303	353	409	470	533
,, 900	..	..	..	..	..	114	142	174	210	250	293	342	396	456	518
,, 950	..	..	..	..	..	..	137	169	204	243	285	333	386	441	502
,, 1000	..	..	..	..	..	..	..	164	198	236	277	324	373	427	489
,, 1100	..	..	..	..	..	..	..	..	187	223	262	308	355	407	464
,, 1200	..	..	..	..	..	..	..	..	..	213	250	294	340	390	445
,, 1300	..	..	..	..	..	..	..	..	..	..	240	280	324	373	426
,, 1400	..	..	..	..	..	..	..	..	..	..	..	269	312	359	410
,, 1500	..	..	..	..	..	..	..	..	..	..	..	..	302	347	384
,, 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	336	379
,, 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

which the transverse diameter is equal to two-thirds of the vertical diameter, the invert when RUNNING ONE-THIRD FULL, and at various rates of inclination.

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
1280	1439	1607	1786	1977	2181	2398	2622	2860	3110	3374	3651	3943	4250	4571	4897	,, 200
1145	1287	1440	1599	1770	1952	2145	2350	2568	2790	3025	3280	3539	3812	4097	4396	,, 250
1044	1172	1310	1459	1617	1781	1961	2146	2342	2549	2767	2997	3239	3484	3750	4018	,, 300
964	1084	1214	1350	1494	1648	1812	1985	2163	2357	2562	2771	2998	3228	3469	3722	,, 350
898	1012	1131	1259	1395	1541	1691	1855	2024	2208	2396	2593	2801	3019	3247	3486	,, 400
845	951	1064	1186	1312	1451	1593	1744	1904	2080	2259	2448	2637	2845	3054	3282	,, 450
800	901	1010	1122	1243	1371	1507	1651	1805	1967	2138	2318	2500	2699	2899	3108	,, 500
762	855	960	1068	1183	1307	1432	1571	1718	1874	2039	2205	2380	2572	2764	2965	,, 550
727	817	914	1018	1129	1248	1369	1503	1645	1789	1948	2108	2277	2453	2638	2832	,, 600
696	783	876	977	1085	1195	1311	1441	1579	1718	1865	2020	2182	2353	2532	2720	,, 650
668	752	843	941	1045	1152	1265	1385	1513	1647	1789	1939	2096	2262	2435	2617	,, 700
647	725	814	904	1006	1109	1219	1336	1460	1590	1729	1874	2027	2189	2358	2525	,, 750
626	703	785	872	971	1072	1179	1293	1413	1541	1675	1818	1959	2116	2271	2433	,, 800
605	680	760	845	942	1040	1144	1256	1367	1491	1622	1761	1899	2052	2203	2362	,, 850
585	657	734	818	912	1008	1110	1218	1327	1448	1577	1705	1838	1988	2136	2290	,, 900
567	638	714	795	883	976	1075	1181	1287	1406	1531	1656	1787	1933	2078	2229	,, 950
553	622	697	777	863	955	1047	1150	1254	1370	1493	1616	1744	1879	2020	2167	,, 1000
525	592	664	736	818	907	995	1095	1194	1299	1418	1535	1658	1787	1923	2065	,, 1100
501	565	634	704	784	864	949	1045	1141	1242	1349	1462	1581	1705	1836	1973	,, 1200
480	542	609	677	749	827	909	996	1088	1186	1289	1398	1512	1632	1759	1891	,, 1300
463	519	584	650	720	795	874	959	1048	1143	1243	1349	1452	1569	1691	1810	,, 1400
445	500	559	623	690	763	840	922	1008	1100	1198	1301	1400	1514	1633	1748	,, 1500
428	481	538	600	666	736	811	891	975	1065	1160	1252	1349	1459	1575	1687	,, 1600
414	466	522	582	646	715	788	866	942	1029	1122	1212	1306	1414	1527	1636	,, 1700
..	454	509	563	626	693	765	841	916	994	1084	1171	1271	1368	1479	1585	,, 1800
..	..	496	550	611	672	742	816	889	966	1054	1139	1237	1331	1430	1534	,, 1900
..	..	..	536	597	656	719	792	862	944	1023	1115	1203	1295	1392	1493	,, 2000
..	..	..	..	..	646	702	773	843	916	1001	1082	1168	1259	1353	1452	,, 2100
..	..	..	..	..	..	684	755	823	895	978	1058	1143	1231	1324	1421	,, 2200
..	..	..	..	..	..	..	736	803	873	948	1026	1108	1204	1295	1390	,, 2300
..	..	..	..	..	..	..	..	..	852	925	1002	1082	1176	1266	1360	,, 2400
..	..	..	..	..	..	..	..	..	..	902	977	1057	1149	1237	1329	,, 2500
..	..	..	..	..	..	..	..	..	..	..	961	1040	1122	1208	1298	,, 2600
..	..	..	..	..	..	..	..	..	..	..	..	1022	1103	1189	1268	,, 2700
..	..	..	..	..	..	..	..	..	..	..	..	..	1085	1160	1247	,, 2800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1227	,, 2900

TABLE No. 36.—DISCHARGE in cube feet per minute for OVAL SEWERS (New Form), having a radius of one-eighth of the transverse diameter, and the radius of the sides rates of inclination.

Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	363	536	747	1001	1301	1649	1877								
„ 110	346	510	712	956	1242	1574	1782								
„ 120	331	489	682	916	1189	1510	1705								
„ 130	318	469	656	881	1146	1450	1640	2198							
„ 140	306	451	630	848	1103	1398	1583	2120	2550						
„ 150	295	436	608	818	1065	1353	1531	2052	2465	2927					
„ 160	285	421	589	793	1031	1308	1482	1989	2392	2836	3330				
„ 170	277	408	571	768	1000	1270	1437	1926	2319	2753	3235	3759			
„ 180	269	396	555	745	972	1233	1397	1874	2252	2676	3148	3661	4214		
„ 190	261	385	539	725	945	1199	1360	1827	2197	2606	3061	3562	4104	4695	
„ 200	254	375	525	707	920	1169	1324	1780	2143	2544	2989	3473	4004	4583	5203
„ 250	226	334	468	630	821	1042	1181	1586	1912	2272	2672	3115	3592	4114	4671
„ 300	205	304	424	572	746	948	1076	1445	1742	2070	2434	2837	3271	3745	4262
„ 350	188	279	392	527	688	877	991	1335	1609	1916	2252	2622	3030	3465	3940
„ 400	176	259	365	492	641	817	926	1246	1499	1784	2101	2452	2830	3242	3692
„ 450	165	244	343	462	604	768	869	1172	1408	1679	1974	2300	2659	3052	3469
„ 500	156	231	323	437	570	727	824	1104	1335	1589	1871	2175	2519	2884	3283
„ 550	148	219	307	414	542	690	784	1052	1269	1512	1776	2068	2388	2739	3122
„ 600	141	209	293	396	517	660	747	1005	1214	1443	1697	1978	2288	2627	2986
„ 650	135	200	281	379	496	630	715	963	1159	1387	1625	1897	2198	2515	2862
„ 700	..	193	270	364	477	607	686	926	1117	1331	1570	1826	2107	2415	2750
„ 750	..	185	260	351	458	585	662	890	1074	1282	1514	1763	2037	2336	2651
„ 800	..	..	252	339	443	566	641	864	1038	1240	1459	1701	1967	2258	2564
„ 850	..	..	244	329	428	547	621	832	1008	1199	1411	1647	1907	2180	2490
„ 900	..	..	236	319	415	528	601	806	977	1164	1372	1593	1846	2113	2416
„ 950	..	..	..	309	403	513	585	785	947	1129	1332	1548	1796	2057	2342
„ 1000	..	..	..	301	393	498	568	764	923	1101	1292	1513	1746	2001	2280
„ 1100	..	..	..	..	372	476	540	728	874	1045	1229	1432	1656	1900	2168
„ 1200	..	..	..	..	..	453	516	691	838	997	1173	1369	1585	1811	2069
„ 1300	..	..	..	..	..	..	491	665	801	955	1126	1316	1515	1744	1982
„ 1400	..	..	..	..	..	..	..	639	771	920	1078	1262	1455	1677	1908
„ 1500	..	..	..	..	..	..	..	..	741	885	1039	1217	1405	1610	1834
„ 1600	..	..	..	..	..	..	..	..	..	850	1007	1172	1355	1554	1772
„ 1700	..	..	..	..	..	..	..	..	..	..	975	1137	1315	1509	1710
„ 1800	..	..	..	..	..	..	..	..	..	..	944	1101	1274	1464	1660
„ 1900	..	..	..	..	..	..	..	..	..	..	..	1065	1234	1420	1611
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	1204	1375	1573
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	1342	1524
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1487
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert being one and a third times the transverse diameter, when RUNNING FULL, and at various

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
5873	6596	7373	8206	9079	10008	10996	12044	13128	14272	15477	16746	18078	19441	20867	22358	,, 200
5272	5921	6619	7350	8130	8961	9844	10781	11774	12822	13930	15065	16257	17508	18819	20150	,, 250
4821	5411	6046	6726	7453	8207	9609	9858	10758	11707	12709	13764	14874	16004	17187	18424	,, 300
4453	5007	5603	6226	6891	7600	8354	9154	10002	10871	11787	12749	13761	14823	15935	17099	,, 350
4166	4677	5226	5816	6446	7119	7812	8572	9351	10174	11042	11957	12918	13892	14949	16016	,, 400
3920	4407	4931	5477	6078	6700	7361	8062	8804	9589	10417	11259	12176	13104	14114	15133	,, 450
3715	4167	4669	5191	5749	6344	6977	7649	8361	9087	9882	10688	11535	12424	13393	14370	,, 500
3537	3972	4440	4942	5478	6051	6661	7285	7971	8669	9405	10180	10995	11851	12748	13688	,, 550
3374	3792	4243	4728	5246	5779	6367	6969	7606	8279	8989	9736	10523	11350	12217	13086	,, 600
3237	3643	4080	4531	5033	5548	6096	6678	7293	7944	8632	9356	10119	10884	11724	12564	,, 650
3114	3508	3916	4353	4839	5339	5870	6435	7033	7666	8304	9007	9748	10490	11268	12122	,, 700
3005	3373	3785	4210	4665	5150	5667	6216	6772	7387	8007	8690	9377	10132	10889	11681	,, 750
2909	3268	3654	4068	4510	4983	5464	5998	6564	7136	7768	8404	9073	9810	10548	11319	,, 800
2814	3163	3539	3943	4375	4815	5306	5803	6356	6913	7530	8151	8803	9488	10206	10958	,, 850
2732	3073	3441	3818	4239	4690	5148	5633	6173	6718	7292	7897	8533	9202	9903	10637	,, 900
2650	2983	3342	3711	4123	4543	5012	5488	5991	6523	7084	7675	8297	8951	9637	10356	,, 950
2581	2908	3244	3622	4007	4439	4877	5342	5835	6355	6905	7485	8095	8700	9371	10075	,, 1000
2459	2758	3097	3443	3813	4208	4629	5075	5548	6049	6578	7104	7690	8271	8916	9553	,, 1100
2336	2638	2949	3283	3639	4020	4425	4856	5288	5770	6280	6787	7353	7913	8537	9152	,, 1200
2240	2518	2818	3140	3484	3852	4245	4638	5079	5547	6012	6502	7049	7590	8157	8791	,, 1300
2158	2428	2720	3015	3349	3706	4064	4468	4871	5324	5804	6280	6779	7304	7854	8429	,, 1400
2076	2338	2621	2908	3233	3559	3929	4298	4715	5129	5566	6058	6543	7053	7588	8148	,, 1500
2008	2263	2523	2819	3117	3455	3793	4152	4558	4962	5387	5836	6307	6803	7323	7867	,, 1600
1940	2189	2441	2730	3020	3329	3680	4031	4402	4794	5209	5645	6105	6589	7095	7627	,, 1700
1885	2129	2376	2640	2923	3224	3567	3909	4272	4655	5060	5487	5936	6373	6867	7386	,, 1800
1830	2054	2310	2569	2846	3141	3454	3788	4142	4516	4911	5328	5768	6194	6678	7185	,, 1900
1776	1994	2245	2498	2768	3057	3364	3691	4037	4404	4762	5170	5599	6051	6488	6984	,, 2000
1735	1949	2179	2426	2691	2973	3274	3594	3933	4293	4643	5043	5464	5872	6336	6784	,, 2100
1694	1904	2130	2373	2633	2910	3206	3497	3829	4181	4554	4916	5329	5728	6184	6623	,, 2200
1653	1859	2081	2319	2575	2847	3116	3424	3751	4070	4435	4821	5194	5585	6033	6462	,, 2300
..	1814	2032	2266	2516	2764	3048	3351	3647	3986	4346	4694	5093	5478	5881	6342	,, 2400
..	..	1982	2212	2458	2701	2980	3278	3568	3902	4226	4599	4958	5371	5767	6182	,, 2500
..	..	..	2159	2400	2659	2913	3205	3516	3819	4137	4504	4857	5263	5653	6061	,, 2600
..	..	..	..	2361	2596	2868	3132	3438	3735	4078	4408	4756	5156	5539	5941	,, 2700
..	..	..	..	2303	2554	2800	3084	3360	3679	3988	4313	4655	5048	5426	5820	,, 2800
..	..	..	..	..	2492	2755	3011	3308	3596	3899	4250	4587	4941	5312	5700	,, 2900
..	..	..	..	..	..	2709	2962	3230	3540	3840	4155	4486	4869	5236	5620	,, 3000
..	..	..	..	..	..	..	2914	3178	3456	3780	4091	4418	4762	5122	5499	,, 3100
..	..	..	..	..	..	..	..	3126	3401	3720	4028	4351	4690	5046	5419	,, 3200
..	..	..	..	..	..	..	..	..	3345	3631	3964	4284	4619	4970	5339	,, 3300
..	..	..	..	..	..	..	..	..	..	3572	3901	4216	4547	4894	5258	,, 3400
..	..	..	..	..	..	..	..	..	..	..	3838	4149	4475	4818	5178	,, 3500
..	..	..	..	..	..	..	..	..	..	..	3774	4081	4404	4743	5098	,, 3600
..	..	..	..	..	..	..	..	..	..	..	..	4014	4332	4667	5017	,, 3700
..	..	..	..	..	..	..	..	..	..	..	..	..	4261	4591	4937	,, 3800
..	..	..	..	..	..	..	..	..	..	..	..	..	..	4515	4857	,, 3900
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4817	,, 4000

TABLE No. 37.—DISCHARGE in cube feet per minute for OVAL SEWERS (New Form), having a radius of one-eighth of the transverse diameter, and the radius of the sides at various rates of inclination.

Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	245	361	502	674	877	1109	1378								
,, 110	233	344	480	644	837	1061	1317								
,, 120	223	329	459	616	801	1017	1262								
,, 130	215	316	440	592	770	976	1213	1482							
,, 140	207	304	425	570	742	942	1170	1428	1716						
,, 150	199	294	411	551	718	910	1130	1380	1657	1973					
,, 160	193	284	397	533	694	881	1095	1336	1606	1910	2245				
,, 170	187	275	385	517	674	855	1063	1299	1559	1855	2178	2534			
,, 180	181	267	374	502	654	830	1034	1261	1516	1801	2116	2464	2841		
,, 190	176	260	363	489	636	808	1005	1227	1477	1756	2060	2395	2763	3165	
,, 200	171	253	354	476	620	789	979	1197	1441	1711	2008	2337	2698	3086	3507
,, 250	152	225	315	424	554	704	875	1068	1284	1530	1798	2093	2418	2767	3138
,, 300	139	204	286	385	504	641	797	977	1174	1395	1644	1914	2204	2528	2873
,, 350	128	189	265	356	463	590	737	902	1084	1291	1520	1769	2041	2340	2656
,, 400	118	176	247	332	433	551	685	838	1009	1205	1418	1653	1905	2180	2480
,, 450	111	165	231	312	407	517	644	790	950	1133	1330	1554	1794	2057	2335
,, 500	105	155	218	294	385	490	610	746	899	1070	1258	1467	1697	1948	2215
,, 550	100	148	208	280	365	466	581	709	856	1020	1202	1397	1612	1854	2111
,, 600	95	142	198	267	349	444	555	678	817	975	1145	1334	1541	1767	2014
,, 650	92	136	190	255	335	425	532	651	786	934	1099	1281	1482	1695	1926
,, 700	89	130	182	245	321	410	511	624	754	898	1058	1235	1424	1630	1854
,, 750	..	125	176	237	309	394	491	603	727	867	1022	1189	1372	1572	1790
,, 800	..	121	169	229	299	381	474	583	703	835	986	1148	1326	1521	1734
,, 850	..	117	164	221	289	369	459	563	680	808	955	1113	1287	1470	1677
,, 900	..	..	159	214	281	357	445	546	660	785	925	1079	1248	1427	1629
,, 950	..	..	154	208	273	347	433	529	640	763	899	1050	1209	1391	1581
,, 1000	..	..	..	203	265	338	422	515	621	740	873	1021	1177	1354	1541
,, 1100	..	..	..	193	253	321	402	492	593	704	832	968	1118	1282	1461
,, 1200	..	..	..	..	241	306	381	468	566	673	791	922	1066	1224	1396
,, 1300	..	..	..	..	..	294	367	448	542	646	760	887	1021	1173	1340
,, 1400	..	..	..	..	..	..	352	431	518	618	729	852	982	1130	1284
,, 1500	..	..	..	..	..	..	..	414	499	596	704	823	949	1086	1236
,, 1600	..	..	..	..	..	..	..	..	483	578	678	794	917	1050	1196
,, 1700	..	..	..	..	..	..	..	..	467	560	657	765	884	1014	1156
,, 1800	..	..	..	..	..	..	..	..	..	542	637	742	858	985	1124
,, 1900	..	..	..	..	..	..	..	..	..	..	616	719	832	956	1091
,, 2000	..	..	..	..	..	..	..	..	..	..	..	702	813	934	1059
,, 2100	..	..	..	..	..	..	..	..	..	..	..	..	793	905	1035
,, 2200	..	..	..	..	..	..	..	..	..	..	..	..	774	884	1011
,, 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	862	987
,, 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	963
,, 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 2900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 3900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 4300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

in which the transverse diameter is equal to two-thirds of the vertical diameter, the invert being one and a third times the transverse diameter, when RUNNING TWO-THIRDS FULL, and

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																„ 110
																„ 120
																„ 130
																„ 140
																„ 150
																„ 160
																„ 170
																„ 180
																„ 190
3955	4438	4957	5513	6107	6727	7386	8085	8808	9589	10393	11238	12127	13058	14034	15030	„ 200
3548	3982	4447	4946	5480	6036	6626	7252	7914	8614	9351	10108	10925	11759	12633	13522	„ 250
3247	3642	4065	4519	5003	5520	6070	6638	7256	7891	8561	9266	9985	10762	11576	12403	„ 300
3000	3370	3768	4195	4640	5113	5617	6150	6716	7313	7944	8588	9264	9997	10741	11519	„ 350
2805	3156	3524	3918	4339	4788	5266	5773	6294	6844	7423	8033	8674	9347	10053	10791	„ 400
2646	2972	3322	3698	4088	4517	4958	5443	5940	6465	7018	7581	8194	8837	9487	10167	„ 450
2504	2816	3152	3502	3875	4272	4695	5144	5619	6122	6652	7191	7778	8373	9020	9673	„ 500
2380	2680	2993	3340	3699	4082	4476	4908	5366	5833	6344	6862	7407	8002	8602	9231	„ 550
2274	2564	2866	3190	3536	3906	4286	4703	5130	5580	6074	6575	7101	7654	8234	8815	„ 600
2185	2457	2749	3063	3386	3743	4110	4515	4927	5363	5823	6307	6817	7352	7890	8477	„ 650
2097	2360	2643	2947	3260	3608	3964	4341	4742	5165	5611	6081	6555	7074	7595	8165	„ 700
2026	2282	2547	2831	3148	3472	3818	4184	4573	4984	5418	5855	6336	6819	7349	7879	„ 750
1956	2204	2462	2739	3035	3350	3686	4043	4421	4821	5225	5670	6118	6610	7103	7619	„ 800
1894	2136	2388	2658	2947	3255	3569	3917	4286	4677	5071	5486	5943	6402	6882	7385	„ 850
1840	2068	2314	2577	2859	3160	3467	3807	4151	4533	4917	5321	5768	6216	6685	7177	„ 900
1787	2010	2250	2508	2784	3065	3379	3697	4033	4406	4782	5177	5594	6030	6489	6969	„ 950
1743	1962	2186	2439	2709	2984	3291	3602	3932	4280	4647	5034	5441	5868	6317	6787	„ 1000
1655	1865	2080	2323	2571	2835	3130	3429	3746	4081	4435	4808	5178	5590	6022	6449	„ 1100
1584	1777	1995	2219	2458	2713	2984	3272	3577	3900	4223	4582	4938	5335	5751	6163	„ 1200
1513	1699	1910	2126	2358	2604	2867	3146	3425	3738	4049	4397	4741	5126	5506	5929	„ 1300
1451	1641	1836	2046	2270	2496	2750	3020	3307	3593	3914	4232	4567	4940	5309	5695	„ 1400
1398	1573	1762	1965	2182	2414	2647	2910	3172	3467	3760	4089	4414	4755	5112	5487	„ 1500
1354	1525	1709	1895	2107	2333	2560	2816	3071	3341	3644	3945	4261	4592	4940	5305	„ 1600
1310	1476	1656	1838	2044	2252	2487	2721	2970	3232	3528	3821	4130	4453	4793	5149	„ 1700
1274	1428	1603	1780	1981	2184	2399	2643	2885	3142	3413	3698	3998	4314	4645	4993	„ 1800
1239	1389	1560	1734	1919	2116	2340	2564	2801	3052	3316	3595	3889	4198	4522	4837	„ 1900
1203	1350	1518	1687	1868	2062	2267	2485	2717	2962	3220	3493	3780	4082	4400	4707	„ 2000
1168	1321	1475	1641	1818	2007	2209	2422	2649	2889	3143	3410	3692	3966	4277	4602	„ 2100
1141	1282	1433	1606	1780	1967	2165	2375	2582	2817	3066	3328	3583	3873	4178	4473	„ 2200
1115	1253	1401	1560	1731	1912	2106	2312	2531	2763	2989	3246	3496	3781	4080	4368	„ 2300
1088	1224	1369	1526	1693	1872	2062	2265	2464	2691	2931	3164	3430	3688	3982	4264	„ 2400
1062	1194	1337	1491	1655	1831	2018	2218	2413	2636	2854	3102	3365	3618	3883	4160	„ 2500
..	1175	1316	1468	1618	1790	1975	2171	2362	2582	2796	3041	3277	3549	3810	4082	„ 2600
..	..	1284	1433	1593	1750	1931	2124	2312	2528	2738	2979	3212	3479	3736	4004	„ 2700
..	..	1263	1410	1555	1722	1901	2076	2278	2474	2699	2917	3146	3410	3662	3926	„ 2800
..	..	..	1375	1530	1695	1858	2045	2227	2438	2642	2856	3103	3340	3588	3848	„ 2900
..	..	..	..	1505	1655	1828	1998	2194	2384	2603	2815	3037	3294	3539	3796	„ 3000
..	..	..	..	..	1628	1799	1966	2143	2347	2545	2753	2993	3224	3466	3744	„ 3100
..	..	..	..	..	..	1770	1935	2109	2311	2507	2712	2928	3178	3416	3666	„ 3200
..	..	..	..	..	..	..	1903	2075	2275	2468	2671	2884	3108	3343	3614	„ 3300
..	..	..	..	..	..	..	..	2042	2239	2429	2630	2840	3062	3293	3536	„ 3400
..	..	..	..	..	..	..	..	2008	2203	2391	2589	2797	3015	3244	3484	„ 3500
..	..	..	..	..	..	..	..	..	2167	2352	2548	2753	2969	3195	3432	„ 3600
..	..	..	..	..	..	..	..	..	..	2314	2507	2709	2922	3146	3380	„ 3700
..	..	..	..	..	..	..	..	..	..	..	2466	2666	2876	3097	3328	„ 3800
..	..	..	..	..	..	..	..	..	..	..	..	2644	2853	3072	3302	„ 3900
..	..	..	..	..	..	..	..	..	..	..	..	2600	2806	3023	3250	„ 4000
..	..	..	..	..	..	..	..	..	..	..	..	..	2760	2974	3198	„ 4100
..	..	..	..	..	..	..	..	..	..	..	..	..	..	2949	3172	„ 4200
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3120	„ 4300

Table No. 38.—Discharge in cube feet per minute for Oval Sewers (New Form), in having a radius of one-eighth of the transverse diameter, and the radius of the sides and at various rates of inclination.

Inclination.	Size, 1′ 0″ × 1′ 6″.	Size, 1′ 2″ × 1′ 9″.	Size, 1′ 4″ × 2′ 0″.	Size, 1′ 6″ × 2′ 3″.	Size, 1′ 8″ × 2′ 6″.	Size, 1′ 10″ × 2′ 9″.	Size, 2′ 0″ × 3′ 0″.	Size, 2′ 2″ × 3′ 3″.	Size, 2′ 4″ × 3′ 6″.	Size, 2′ 6″ × 3′ 9″.	Size, 2′ 8″ × 4′ 0″.	Size, 2′ 10″ × 4′ 3″.	Size, 3′ 0″ × 4′ 6″.	Size, 3′ 2″ × 4′ 9″.	Size, 3′ 4″ × 5′ 0″.
1 in 100	68	100	140	188	244	310	385								
„ 110	65	95	133	179	233	296	368								
„ 120	62	91	127	171	223	283	352								
„ 130	59	87	122	164	214	272	339	413							
„ 140	57	84	117	158	206	262	326	398	479						
„ 150	55	81	113	153	199	253	314	384	463	550					
„ 160	53	78	109	148	193	245	304	372	448	532	626				
„ 170	51	76	106	143	186	237	295	361	435	516	608	706			
„ 180	50	74	103	138	181	230	287	351	422	502	590	686	792		
„ 190	48	72	100	135	176	224	279	341	411	488	573	668	771	882	
„ 200	47	70	98	131	171	218	272	332	400	475	559	651	751	859	978
„ 250	42	62	87	117	153	194	241	295	356	424	499	582	671	768	873
„ 300	38	56	79	106	138	176	220	269	324	385	454	529	611	699	797
„ 350	35	52	72	98	128	162	202	248	299	356	418	488	563	645	735
„ 400	32	48	67	91	119	151	188	230	278	332	391	455	524	602	684
„ 450	30	45	63	85	112	142	177	217	262	312	367	427	494	566	644
„ 500	..	43	60	81	105	134	167	205	248	294	347	404	467	536	610
„ 550	..	..	57	77	100	127	159	195	235	280	329	384	444	510	579
„ 600	..	..	54	73	95	121	152	186	224	267	315	367	423	487	554
„ 650	..	..	..	70	91	116	145	178	215	256	302	351	407	467	531
„ 700	..	..	..	..	88	112	139	171	206	246	289	337	391	449	511
„ 750	..	..	..	..	85	108	134	165	199	237	278	325	375	431	492
„ 800	..	..	..	..	..	104	130	159	192	229	269	314	364	416	475
„ 850	..	..	..	..	..	101	126	154	186	221	260	304	352	403	460
„ 900	..	..	..	..	..	..	122	149	180	214	253	294	341	390	446
„ 950	..	..	..	..	..	..	..	144	174	208	246	286	332	380	432
„ 1000	..	..	..	..	..	..	..	..	170	203	239	280	323	370	421
„ 1100	..	..	..	..	..	..	..	..	..	192	228	265	307	352	401
„ 1200	..	..	..	..	..	..	..	..	..	..	217	253	293	334	381
„ 1300	..	..	..	..	..	..	..	..	..	..	..	241	279	321	364
„ 1400	..	..	..	..	..	..	..	..	..	..	..	..	..	309	350
„ 1500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	339
„ 1600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1800	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2500	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
„ 2700	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

which the transverse diameter is equal to two-thirds of the vertical diameter, the invert being one and a third times the transverse diameter, when RUNNING ONE-THIRD FULL,

Size, 3′ 6″ × 5′ 3″.	Size, 3′ 8″ × 5′ 6″.	Size, 3′ 10″ × 5′ 9″.	Size, 4′ 0″ × 6′ 0″.	Size, 4′ 2″ × 6′ 3″.	Size, 4′ 4″ × 6′ 6″.	Size, 4′ 6″ × 6′ 9″.	Size, 4′ 8″ × 7′ 0″.	Size, 4′ 10″ × 7′ 3″.	Size, 5′ 0″ × 7′ 6″.	Size, 5′ 2″ × 7′ 9″.	Size, 5′ 4″ × 8′ 0″.	Size, 5′ 6″ × 8′ 3″.	Size, 5′ 8″ × 8′ 6″.	Size, 5′ 10″ × 8′ 9″.	Size, 6′ 0″ × 9′ 0″.	Inclination.
																1 in 100
																,, 110
																,, 120
																,, 130
																,, 140
																,, 150
																,, 160
																,, 170
																,, 180
																,, 190
1106	1241	1386	1542	1709	1881	2070	2265	2471	2689	2919	3161	3408	3667	3946	4230	,, 200
987	1111	1240	1379	1528	1686	1854	2027	2215	2410	2614	2828	3054	3291	3539	3799	,, 250
900	1012	1132	1257	1395	1538	1689	1850	2019	2200	2390	2590	2792	3005	3236	3470	,, 300
832	933	1046	1164	1289	1423	1566	1711	1871	2034	2213	2394	2585	2785	2994	3214	,, 350
776	872	975	1086	1205	1327	1463	1601	1746	1901	2064	2235	2416	2605	2804	3003	,, 400
729	817	915	1021	1130	1251	1375	1506	1645	1793	1948	2105	2277	2450	2639	2829	,, 450
688	776	867	964	1068	1179	1298	1423	1556	1697	1840	1996	2154	2327	2501	2683	,, 500
654	739	826	920	1020	1122	1236	1357	1479	1615	1751	1902	2054	2213	2380	2554	,, 550
626	704	788	879	971	1074	1179	1296	1414	1539	1677	1816	1962	2115	2276	2444	,, 600
601	677	755	842	932	1031	1133	1241	1354	1475	1602	1736	1877	2025	2181	2344	,, 650
576	650	725	810	896	993	1092	1196	1306	1424	1541	1671	1808	1952	2094	2252	,, 700
558	626	699	781	865	955	1051	1152	1259	1373	1487	1613	1746	1878	2025	2170	,, 750
539	605	676	753	834	922	1015	1113	1217	1329	1439	1562	1685	1821	1956	2097	,, 800
520	585	654	728	808	893	984	1080	1176	1284	1398	1512	1631	1764	1895	2033	,, 850
505	568	635	708	786	869	953	1047	1140	1246	1351	1468	1585	1707	1843	1978	,, 900
489	551	617	688	764	845	927	1019	1110	1208	1317	1425	1539	1658	1791	1923	,, 950
477	537	602	667	742	821	901	991	1081	1176	1283	1389	1500	1617	1739	1868	,, 1000
452	510	572	635	706	778	855	941	1027	1119	1215	1316	1423	1535	1653	1776	,, 1100
433	486	546	606	671	745	819	897	980	1068	1161	1259	1362	1470	1583	1694	,, 1200
414	465	519	582	645	712	783	858	938	1024	1113	1208	1300	1405	1514	1630	,, 1300
399	448	501	558	618	683	752	825	902	985	1066	1157	1254	1347	1454	1566	,, 1400
383	431	482	537	596	659	726	797	867	947	1032	1114	1208	1298	1402	1501	,, 1500
371	417	467	521	574	635	700	770	837	915	998	1078	1169	1258	1350	1456	,, 1600
..	404	452	505	556	616	680	742	813	884	964	1042	1131	1217	1307	1410	,, 1700
..	..	..	488	539	597	659	720	790	858	937	1013	1092	1176	1272	1364	,, 1800
..	..	..	..	..	578	639	698	766	833	910	984	1062	1143	1237	1327	,, 1900
..	..	..	..	..	..	623	681	742	814	883	955	1031	1119	1203	1291	,, 2000
..	..	..	..	..	..	..	665	724	788	862	933	1008	1086	1168	1254	,, 2100
..	..	..	..	..	..	..	..	..	769	835	911	985	1062	1142	1227	,, 2200
..	..	..	..	..	..	..	..	..	..	815	890	962	1037	1116	1199	,, 2300
..	..	..	..	..	..	..	..	..	..	..	868	938	1013	1090	1172	,, 2400
..	..	..	..	..	..	..	..	..	..	..	..	915	988	1064	1144	,, 2500
..	..	..	..	..	..	..	..	..	..	..	..	..	..	1038	1117	,, 2600
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1099	,, 2700

CHAPTER XIV.

GAUGING.

It often becomes necessary for the engineer to ascertain the volume of water which may be flowing through or from a sewer. This may be done by either ascertaining the mean velocity of flow and multiplying the quantity found by the sectional area of the water-way, the velocity in this case being ascertained either by means of floats or registered with a current meter, or, in a case where the liquid flowing through a sewer of a given size has a known rate of inclination, a knowledge of the depth of water flowing through that sewer at all times will be sufficient from which to calculate the quantity discharged. In general practice, however, a dam or weir may be placed in the sewer, and the quantity discharged may be ascertained from the depth of the liquid falling over. The theory of overflows is based upon the law discovered by Torricelli, that the velocity of an escaping fluid is due to the height from which it falls, with this modification however in the case of a fluid falling over a weir, the surface of which becomes depressed as it approaches, and after it leaves the overflow or weir forming a parabolic curve, and as the area of a parabola is but two-thirds the area of a parallelogram, having the same vertical and lateral dimensions, it follows that the theoretical quantity of water flowing off by an overflow is exactly two-thirds the quantity due to the theoretical head, or if the quantity is measured in terms of velocity, then v, the velocity in feet per second, is arrived at by the formula $v = \cdot 6666 \sqrt{2\,g\,h}$, in which g = effects of gravity 32·2 feet, and h the height of the fall. It has been found by careful experiment that the theoretical

Modes of ascertaining quantity flowing through sewers.

Gauging by overfalls.

Curve of water flowing over weir.

Theoretical quantity two-thirds quantity due to fall.

quantity discharged by an overflow is considerably modified by reason of the contraction of the water as it approaches and leaves the weir or overflow. It is also modified by friction, so that in practice, when the velocity due to the head of one foot equals, theoretically, 481·4 feet per minute, two-thirds of which would be 320·9 feet, experiment gives but 214 feet, or but 66·6 per cent. of theoretical quantity. Formulæ, therefore, for the discharge of overflows are based upon this reduced quantity, and it is found that the volume varies in proportion to the square root of the cube of the depth of water flowing over the weir. The depth, or head of water flowing over a weir, is the total depth of water measured from the sill of the weir to some point in the stream above the weir, beyond the influence of the depression caused by the overflow itself. The formula for the discharge from such a weir is:—

Difference between theoretical and actual discharge.

Head is the depth falling over.

$$Q = 214 \sqrt{H^3}.$$

Formula for discharge.

Q = quantity in cube feet per minute for each foot in width of weir.
H = the total depth in feet falling over the weir.

In cases, however, in which a stream moving down a channel has a considerable velocity, as it reaches the overflow this velocity tends to increase the quantity passing over the weir, and must be taken into consideration. The velocity of the approaching stream is due to a fall in the water that is not measured at the overflow, but which is equivalent to an increased depth falling over the weir. A calculation must be made in order to ascertain what is the head of water which creates the velocity of approach; this quantity being added to the observed or measured head, will give the total head creating the discharge. The formula as given by Mr. N. Beardmore, C.E., after taking into consideration the velocity of approach, is:—

Velocity in flowing stream to be considered.

Head producing the velocity of approach.

Mr. Beardmore's formula.

$$Q = 214 \sqrt{h^3 + \cdot 035\, v^2\, h^2}.$$

Q = quantity in cube feet per minute.
h = the observed depth falling over,
v = the velocity of approach in feet per second.

Opinion of author on foregoing formula.

This formula, in the opinion of the author, gives a quantity slightly in excess of the true quantity, as the head taken into account, which produces the velocity of approach, is greater than that actually due to the theoretical velocity of the stream, as the friction of the channel has been taken into consideration, which, in a case of this kind, the author considers ought not to be taken into account, as the head expended in overcoming friction cannot also produce any velocity of approach.

True head.

The true head which ought to be considered, is simply that which creates velocity after all resistances have been abstracted, and should be the proper theoretical head, or $h^1 = \frac{v^2}{2g}$ or, making allowance for the curvature of the overflow, $h^1 = \frac{v^2}{96 \cdot 6}$. In case the discharge is taken from Table No. 39, and there is a considerable velocity of approach, it should be observed that it will

Head to be added for velocity of flow.

be necessary to add a quantity to the observed head, and to ascertain the discharge due to the head after it has been so increased. A calculation will have to be made as to what is the head due to the velocity, which should be added to the observed head, giving the total head. The head creating the velocity of approach h^1, added to h, the observed head got by direct measurement = H, the total depth falling over the weir. The

Rule for finding head for velocity of approach.

head producing the velocity of approach will be found by multiplying the square of the velocity in feet per second by ·010352. Example: h, the observed head of water falling over a weir, is 1·5 foot, the velocity of approach v = 3 feet per second; required to know the quantity flowing off from each foot in width of the

Example.

overflow? By Mr. N. Beardmore's formula we find $Q = 214 \sqrt{1 \cdot 5^3 + \cdot 035 \times 3^2 \times 1 \cdot 5^2} = 432 \cdot 8$ cube feet per minute. In this case h^1, the head producing the velocity of approach $\cdot 010352 \times v^2 = \cdot 010352 \times 9 = \cdot 093168$ foot, and this quantity, added to the observed head 1·5 foot = 1·593168 foot, and the nearest head to this quantity given in Table No. 39 is $19\frac{1}{8}''$, and the discharge from each foot of overflow = 430·57 cube feet per minute, or if worked by the formula

$$Q = 214\sqrt{H^3}, \text{ the discharge} = 430\cdot19 \text{ cube feet per minute,}$$

giving, as will be seen, a slightly smaller quantity than that given by Mr. Beardmore's formula. In ordinary practice a simple rule, often sufficiently accurate for ascertaining the full head, will be to add to the observed head a hundredth part of the square of the velocity of approach in feet per second, and take the discharge for the total head from the Table.

Simple rule for head.

In the placing of weirs for gauging, they should be placed vertically. The sills should be horizontal, and sufficiently removed both from the bottom and sides, so as not to be influenced thereby, or in other words, that the stream may have full power to exercise its property of contraction on approaching the weir, and the corners of the sills and sides should be full and sharp. If a plank is used, the part over which the water flows should be made as narrow as possible. For this purpose, it should be cut away on the down-stream side at an angle of 45° to 60°, but it is better still to affix round the opening in the dam, a thin metal plate, projecting clear of the woodwork, so that when the water falls over, the thickness of the plank shall not have an effect upon the flowing water. No rounded or bevelled edges should be permitted on the upper-stream side of the weir, as these all tend to vitiate and alter the results given by the overflow. The depth of the weir, as a rule, should be proportionate to its width. The depth should be about one-third the width of the weir. These dimensions, however, cannot always be adhered to in the case of a sewer, and experience only will enable an observer to ascertain to what extent the formula for the discharge should be modified. If the sill of the weir is not made extremely thin, air is likely to accumulate on it, as the water ascends on one side as it approaches the weir, and descends on the other side as it leaves the weir, and the effect of the flow is to enclose air on the sill, which

Mode of placing gauging weir.

Construction of weirs for gauging.

Proportion of gauging weirs.

Disturbing influences.

diminishes the depth of water flowing over. On the other hand, not unfrequently if there is not much fall from the sill to the water on the lower side, a partial vacuum is likely to be created, which tends to augment the flow. Sometimes it may be necessary to make observations when the weir is drowned, that is to say, when the water on the lower side has risen above the level of the sill of the weir. In this case, the water flowing over the bottom of the weir must be treated as distinct from that still falling over. The water flowing through the bottom must be treated as water flowing through an aperture under a head equal to the difference in the level of the water above and below the weir, and the volume still falling over must be treated as water flowing over an overflow. A drowned weir will sometimes give a slightly larger amount of discharge under the same head than a weir with a clear fall, as no deduction has to be made for the curvature the water assumes in falling over a weir for that portion of the weir which is immersed, and the flow through which takes place by reason of the difference of the head of water on each side of the weir. The formula for arriving at the discharge of the drowned portion of the weir is as follows:—

Drowned weirs.

Discharge from drowned weirs.

Formula for discharge of immersed portion of weir.

$$v = 46 \cdot 5 \sqrt{2\,g\,h}.$$

v = velocity per minute,
g = effect of gravity = 32·2 feet,
h = head of water in feet,

46·5 is a mean coefficient between 56 and 37, the larger quantity being the coefficient for perfect openings, having the form of the "vena contracta," and the smaller number is applicable to openings without side walls, and may often be applied in the formula for drowned weirs. The head is the difference in level of the water on both sides of the overflow. Example: supposing that we have an overflow 1 foot deep, required to know the discharge when the water has risen on the lower side 3 inches or ·25 foot above the sill of the overflow? The head of water producing discharge through the lower portion of the weir in this case will be

Example of discharge from a drowned weir.

9 inches, or ·75 foot. The velocity of flow for the portion to be treated as water flowing through an aperture will equal $46 \cdot 5 \sqrt{2 \times 32 \cdot 2 \times \cdot 75} =$ 323·12 feet per minute, and as the area of the opening is = ·25 foot for each foot in length, the velocity multiplied by the area will give the discharge, which will be $323 \cdot 12 \times \cdot 25 = 80 \cdot 78$ cube feet per minute. There is still 9 inches or ·75 foot falling freely over the weir, which must be treated as water flowing over an overfall. The quantity will be found from Table No. 39, or by the formula $Q = 214 \sqrt{H^3} = 214 \sqrt{\cdot 75^3} = 139$ feet. The total quantity passing this overfall = $80 \cdot 78 + 139 = 219 \cdot 78$ cube feet per minute. If the water had been falling freely over the weir, the discharge would have taken place by virtue of the full head of 1 foot, and by reference to the Tables the discharge would have been 214 cube feet per minute, or the drowned overflow, under the conditions observed, gives an excess of flow over a weir having a free fall of $5\frac{3}{4}$ cube feet per minute for each foot in length of the overflow.*

Difference of discharge in favour of a drowned weir.

The depth of water falling over a weir may be registered direct on to a diagram by means of a recording gauge, which consists of a clockwork arrangement driving a cylinder at a given rate of speed, and a float, with gearing, records the height of the water on a paper fixed on the revolving cylinder at every moment it is at work. The author has made very extensive use of instruments of this class, both in connection with gauging by overflows and for other purposes where it has been necessary to keep a correct record of the changes of level in the surface of water. It should be observed that, in case the gauge is liable to be drowned, a record must be kept of the elevation of the water both above and below the overflow. Table No. 39 shows at a glance what is the quantity discharged by an overfall, whether the depth is measured in feet or inches, and is calculated from the formula $Q = 214 \sqrt{H^3}$.

Recording gauge.

Table No. 39.

* The discharge may become less than in a weir with a free fall if the coefficient is lessened.

Table No. 39.—Gauging Weirs or Overfalls.

Discharge in cubic feet per minute for **1** foot in length.

Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.
Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.
0·01		0·214	0·24		25·16	0·48		71·16
	⅛	0·227	0·25	3	26·75		5⅞	73·30
0·02		0·605	0·26		28·37	0·49		73·40
	¼	0·643		3⅛	28·44	0·50	6	75·66
0·03		1·11	0·27		30·02	0·51		77·94
	⅜	1·18		3¼	30·16		6⅛	78·03
0·04		1·71	0·28		31·71	0·52		80·24
	½	1·82		3⅜	31·92		6¼	80·43
0·05		2·39	0·29		33·42	0·53		82·57
	⅝	2·53		3½	33·71		6⅜	82·86
0·06		3·15	0·30		35·16	0·54		84·92
	¾	3·34		3⅝	35·52		6½	85·31
0·07		3·96	0·31		36·93	0·55		87·29
	⅞	4·21		3¾	37·38		6⅝	87·78
0·08		4·84	0·32		38·74	0·56		89·68
	1	5·15		3⅞	39·27		6¾	90·27
0·09		5·78	0·33		40·57	0·57		92·09
	1⅛	6·14		4	41·18		6⅞	92·79
0·10		6·77	0·34		42·42	0·58		94·53
	1¼	7·19		4⅛	43·13		7	95·34
0·11		7·81	0·35		44·31	0·59		96·98
	1⅜	8·30		4¼	45·10		7⅛	97·90
0·12		8·90	0·36		46·22	0·60		99·46
	1½	9·46		4⅜	47·11		7¼	100·49
0·13		10·03	0·37		48·16	0·61		101·95
	1⅝	10·66		4½	49·14		7⅜	103·10
0·14		11·21	0·38		50·13	0·62		104·47
	1¾	11·92		4⅝	51·20		7½	105·73
0·15		12·43	0·39		52·12	0·63		107·01
	1⅞	13·22		4¾	53·29		7⅝	108·39
0·16		13·70	0·40		54·14	0·64		109·57
	2	14·56		4⅞	55·41		7¾	111·06
0·17		15·00	0·41		56·18	0·65		112·15
	2⅛	15·95		5	57·55		7⅞	113·76
0·18		16·34	0·42		58·25	0·66		114·74
	2¼	17·37		5⅛	59·72		8	116·48
0·19		17·72	0·43		60·34	0·67		117·36
	2⅜	18·84		5¼	61·92		8⅛	119·22
0·20		19·14	0·44		62·46	0·68		120·00
	2½	20·35		5⅜	64·15		8¼	121·98
0·21		20·59	0·45		64·60	0·69		122·66
	2⅝	21·89		5½	66·40		8⅜	124·76
0·22		22·08	0·46		66·76	0·70		125·33
	2¾	23·47		5⅝	68·67		8½	127·57
0·23		23·60	0·47		68·95	0·71		128·02
	2⅞	25·09		5¾	70·97		8⅝	130·39

TABLE No. 39.—GAUGING WEIRS, &c.—*continued.*

Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.
Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.
0·72		130·74	0·98		207·61	1·24		295·49
	8¾	133·24		11⅞	210·67	1·25	15	299·07
0·73		133·47	0·99		210·89	1·26		302·67
	8⅞	136·11	1·00	12	214·00		15⅛	302·82
0·74		136·23	1·01		217·22	1·27		306·26
0·75	9	139·00		12⅛	217·35		15¼	306·58
0·76		141·79	1·02		220·45	1·28		309·91
	9⅛	141·90		12¼	220·73		15⅜	310·36
0·77		144·59	1·03		223·70	1·29		313·54
	9¼	144·82		12⅜	224·11		15½	314·15
0·78		147·42	1·04		226·97	1·30		317·20
	9⅜	147·77		12½	227·51		15⅝	317·96
0·79		150·26	1·05		230·25	1·31		320·87
	9½	150·73		12⅝	230·93		15¾	321·78
0·80		153·13	1·06		233·54	1·32		324·55
	9⅝	153·71		12¾	234·37		15⅞	325·62
0·81		156·00	1·07		236·86	1·33		328·24
	9¾	156·72		12⅞	237·83		16	329·48
0·82		158·90	1·08		240·19	1·34		331·95
	9⅞	159·75		13	241·30		16⅛	333·35
0·83		161·82	1·09		243·53	1·35		335·67
	10	162·79		13⅛	244·79		16¼	337·24
0·84		164·75	1·10		246·89	1·36		339·41
	10⅛	165·85		13¼	248·30		16⅜	341·14
0·85		167·70	1·11		250·26	1·37		343·16
	10¼	168·93		13⅜	251·82		16½	345·05
0·86		170·67	1·12		253·65	1·38		346·92
	10⅜	172·03		13½	255·35		16⅝	348·97
0·87		173·66	1·13		257·06	1·39		350·70
	10½	175·15		13⅝	258·90		16¾	352·91
0·88		176·66	1·14		260·48	1·40		354·49
	10⅝	178·28		13¾	262·47		16⅞	356·87
0·89		179·68	1·15		263·91	1·41		358·30
	10¾	181·44		13⅞	266·06		17	360·84
0·90		182·72	1·16		267·36	1·42		362·12
	10⅞	184·61		14	269·67		17⅛	364·83
0·91		185·77	1·17		270·83	1·43		365·95
	11	187·80		14⅛	273·29		17¼	368·83
0·92		188·84	1·18		274·31	1·44		369·79
	11⅛	191·01		14¼	276·93		17⅜	372·85
0·93		191·93	1·19		277·80	1·45		373·65
	11¼	194·24		14⅜	280·58		17½	376·88
0·94		195·03	1·20		281·31	1·46		377·53
	11⅜	197·49		14½	284·25		17⅝	380·93
0·95		198·15	1·21		284·83	1·47		381·41
	11½	200·76		14⅝	287·93		17¾	384·99
0·96		201·29	1·22		288·37	1·48		385·31
	11⅝	204·04		14¾	291·63		17⅞	389·07
0·97		204·44	1·23		291·92	1·49		389·22
	11¾	207·37		14⅞	295·34	1·50	18	393·14

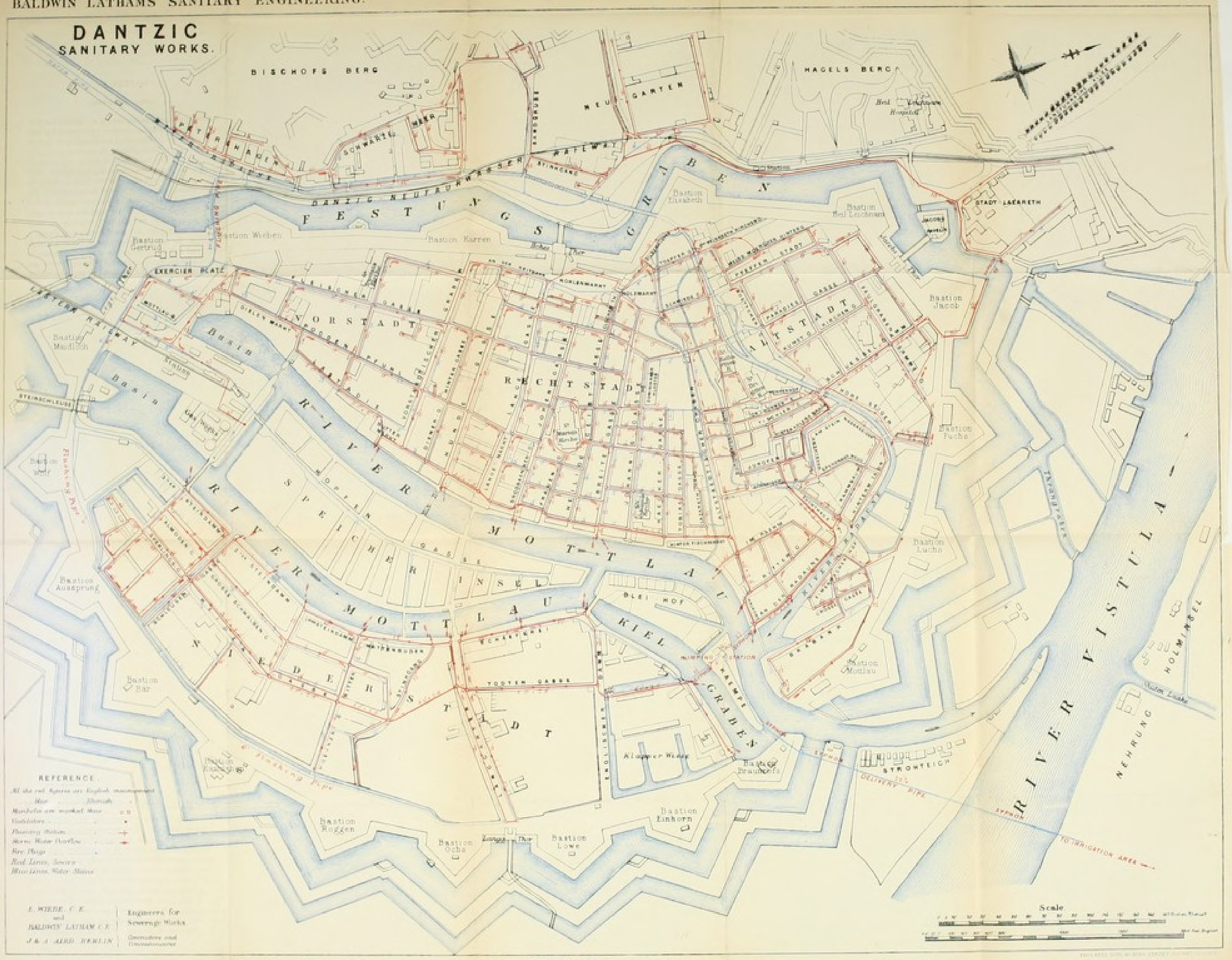
TABLE No. 39.—GAUGING WEIRS, &c.—*continued.*

Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.	Depth on Sill in		Discharge Cubic Feet.
Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.	Feet.	Inches.	Per Minute.
1·51		397·08	1·69		470·16	1·88		551·[illegible]
	18⅛	397·24		20⅜	473·47		22⅝	554·[illegible]
1·52		401·03	1·70		474·34	1·89		556·04
	18¼	401·36		20½	477·83		22¾	558·62
1·53		405·00	1·71		478·53	1·90		560·46
	18⅜	405·49		20⅝	482·21		22⅞	563·23
1·54		408·97	1·72		482·73	1·91		564·89
	18½	409·64		20¾	486·60		23	567·85
1·55		412·96	1·73		486·95	1·92		569·33
	18⅝	413·80		20⅞	491·00		23⅛	572·49
1·56		416·97	1·74		491·19	1·93		573·79
	18¾	417·97	1·75	21	495·42		23¼	577·13
1·57		420·98	1·76		499·67	1·94		578·25
	18⅞	422·16		21⅛	499·85		23⅜	581·79
1·58		425·01	1·77		503·94	1·95		582·73
	19	426·36		21¼	504·29		23½	586·46
1·59		429·05	1·78		508·21	1·96		587·22
	19⅛	430·57		21⅜	508·74		23⅝	591·15
1·60		433·11	1·79		512·50	1·97		591·72
	19¼	434·80		21½	513·21		23¾	595·85
1·61		437·17	1·80		516·80	1·98		596·23
	19⅜	439·04		21⅝	517·69		23⅞	600·56
1·62		441·25	1·81		521·11	1·99		600·75
	19½	443·30		21¾	522·19	2·00	24	605·28
1·63		445·34	1·82		525·44		25	643·50
	19⅝	447·57		21⅞	526·70		26	682·50
1·64		449·45	1·83		529·77	2·25	27	722·25
	19¾	451·85		22	531·22		28	762·75
1·65		453·56	1·84		534·12		29	803·97
	19⅞	456·15		22⅛	535·76	2·50	30	845·91
1·66		457·69	1·85		538·48		31	888·56
	20	460·46		22¼	540·31		32	931·90
1·67		461·83	1·86		542·85	2·75	33	975·92
	20⅛	464·78		22⅜	544·87		34	1020·62
1·68		465·99	1·87		547·24		35	1065·98
	20¼	469·12		22½	549·44	3·00	36	1111·98

To find discharge of weir.

To find the discharge from a weir, multiply the quantity corresponding to the depth falling over, as given in the Table, by the width of the weir in feet and parts of feet, and the result will give the discharge in cube feet per minute.

NOTE.—To bring cube feet per minute into gallons in twenty-four hours, multiply by 9000.


DANTZIC
SANITARY WORKS.
BISCHOFS BERG
HAGELS BERG
NEU GARTEN
FESTUNGS GRABEN
VORSTADT
RECHTSTADT
ALTSTADT
RIVER MOTTLAU
SPEICHER INSEL
NIEDER STADT
RIVER VISTULA
NEHRUNG
HOLMINSEL
Bastion Gertrud
Bastion Wieben
Bastion Karren
Bastion Elisabeth
Bastion Heil Leichnam
Bastion Jacob
Bastion Fuchs
Bastion Luchs
Bastion Mottlau
Bastion Braunrofs
Bastion Einhorn
Bastion Lowe
Bastion Ochs
Bastion Roggen
Bastion Bar
Bastion Aussprung
Bastion Wolf
Bastion Maidloch
EXERCIER PLATZ
STADT LAZARETH
BLEI HOF
KIELGRABEN
STROHTEICH
Klapper Wiese
TO IRRIGATION AREA
DELIVERY PIPE
REFERENCE.
Red Lines, Sewers
Blue Lines, Water Mains
E. WIEBE, C.E. and BALDWIN LATHAM, C.E. Engineers for Sewerage Works
J. & A. AIRD, BERLIN. Contractors
Scale

CHAPTER XV.

COURSE OF SEWERS.

WHEN the natural drainage area of the district has been defined, it will be well to ascertain what nature has done for the drainage, and also what has already been done by art in the way of accomplishing the work of sewerage of the district. The main lines of sewers will generally take the direction of the natural drainage valleys. Such drainage valleys will also give the lines in which the storm-water overflows will have to be constructed. The ordinary sewers of a district are now usually laid in perfectly straight lines, having manholes at every point of lateral deviation ; and manholes, lampholes, or ventilators at every point of vertical deviation or change of gradient. By constructing a system of sewers in straight lines, and with the introduction of numerous manholes and lampholes, the whole system is brought under perfect control, and can be examined at any time without having recourse to breaking open the ground ; and moreover any ordinary stoppage may be removed from the sewers with the aid of special tools applicable for the purpose, and which are applied at the manholes. The system of laying sewers in straight lines with manholes, lampholes, or ventilators at every point of change in direction, and which is so great an improvement on the old system of laying sewers in crooked lines, is due to the ingenuity and forethought of Mr. Robert Rawlinson, C.B., of the Local Government Board. The general arrangement of the sewers of a town will be seen from Plate II., which represents the sanitary works of the town of Dantzic, in Prussia. From an examination of

Natural and artificial drainage.

Direction of main lines of sewers.

Sewers to be laid in straight lines.

Use of manholes and lampholes.

Straight line system invention of R. Rawlinson, C.B.

Description of Plate II.

this plan, it will be seen that all the branch sewers are for the most part laid in straight lines, with manholes at all lateral deviations; the detail arrangement of the manholes of the minor sewers is shown in Plate X. It will be observed from these detail arrangements, that in all cases in which more than one sewer enters a manhole, the sewer forming the principal outfall is constructed at a lower level than the sewers discharging into the manhole. This arrangement is adopted for two reasons, one being to aid ventilation,* as will be hereafter explained, and the other being to aid in the discharge of the sewers. For example, take Fig. 8, Plate X., and we find three sewers, B, D, E, all meeting at about the same level, but the sewer A, which has to discharge the contents of the other sewers, is situated at a lower level in order to assist the discharge, and so every sewer is provided with a free outfall. If this arrangement were not adopted, we should find, at times, some inconvenience arise. For example, the general effect of a sudden enlargement in a sewer is to check the velocity. If the sewer D, Fig. 8, Plate X., discharged into the sewer A, both sewers being of the same size and having the same inclination, a loss of velocity would take place in passing the manhole C, and therefore if the sewer D at the time was running full bore, the sewage would head up in the manhole to such an extent as to make up for the head lost by the enlargement at the manhole, although in this case no evil would result. But supposing the sewers B and E enter the sewer at the same level, and one sewer is larger than the other, unless the manhole is of great size, the discharge of the larger sewer will interfere with the discharge of the smaller sewer. The author has seen a case in which, in time of storm, the smaller sewer could not discharge its contents, and it therefore flooded the neighbouring cellars. In the following

Description of Plate X.

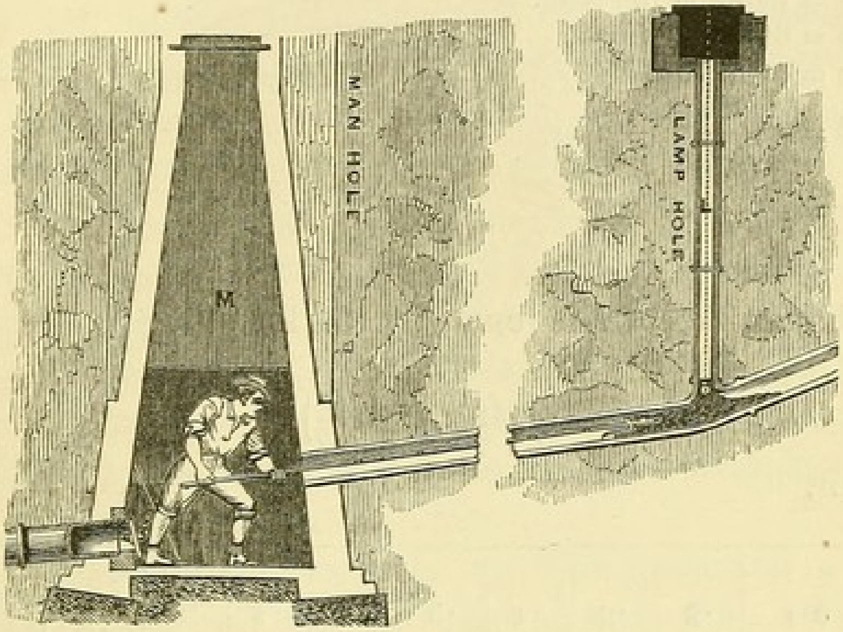
Reasons for breaking up sewers in steps.

* Vide p. 372.

woodcut, Fig. 15, is shown the mode in which stoppages are removed from modern sewers. The sewer-man has suspended a lighted lamp in the lamphole L, and has descended the manhole M, and with a series of tools

Removal of stoppages from sewers.

Fig. 15.



attached to canes, similar to those used by chimney-sweepers, he is about to remove the stoppage. The man will be able to see when the sewer is clear, as between the manhole and lamphole the sewer is laid in a perfectly straight line, and so soon as the obstruction is removed, he will be able to see the light suspended at the lamphole. Some of the tools used for the removal of stoppages are shown in Plate XXIII., and as the illustrations speak for themselves, no further description of the plate is necessary.

Tools used in removing stoppages, Plate XXIII.

The main lines of sewers are not necessarily laid in perfectly straight lines, but curves are introduced in their course; the resistance of these curves to the flow of the sewage diminishes in proportion to the smallness of the angle of divergence from straight lines, and with the greater radius of curvature. It is desirable to form in the floor of manholes, curved channels for connecting

Friction of bends.

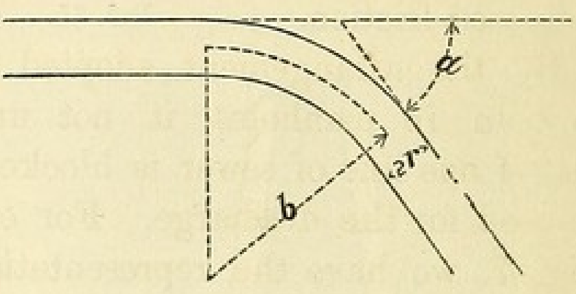
the sewers. From the following formula of Weisbach the friction of bends may be calculated :—

h = head of water necessary to overcome the angular friction.
v = velocity in feet per second.
a = angle in degrees.
r = radius of pipe.
b = radius of the bend.
$2g = 64 \cdot 38$.
c = coefficient.

$$h = c \times \frac{a}{90} \times \frac{v^2}{2g}; \text{ or,}$$

$$h = \frac{c}{579 \cdot 4} \times a \times v^2.$$

FIG. 16.



The coefficient c is found by the formula

$$c = \cdot 131 \times 1 \cdot 847 \left(\frac{r}{b}\right)^{\frac{7}{2}}$$

For,

$\frac{r}{b} = 0 \cdot 1$	·2	·3	·4	·5	·6	·7	·8	·9	1·0
$c = \cdot 131$	·138	·158	·206	·294	·440	·661	·977	1·408	1·978

In Beardmore's valuable Hydraulic Tables the formula of Robinson adapted from French experiments is used for the purpose of estimating the resistance offered by bends in pipes or channels to the flow of water, to which, however, Mr. Beardmore added a correction for the variable quantities due both to the angle and the volume flowing. The amended formula stands :—

Beardmore's formula for bends.

$$h = \frac{V^2 \times S_2 \times N \times \cdot 0003}{\sqrt{\frac{d}{4}}}.$$

h = head in inches to overcome resistance.
V = velocity in inches per second.
S = line of angle.
N = number of bends.
$\frac{d}{4}$ = hydraulic mean depth of pipe.

Loss of head caused by bends should in all calculations be deducted from the actual head, and the calculation should then be made with the reduced head.

Increased fall of bends.

When bends are used it is usual to give the sewers a little extra fall in the bend to compensate for the increased friction.

Alternate lines of sewers used for discharge.

By the arrangement adopted of allowing sewers to join in manholes, it not unfrequently happens that if one line of sewer is blocked, another line may be used for the discharge. For example, in Plate X., Fig. 7, we have the representation of a manhole in which three sewers run out, and only one runs into it. If any one of those three sewers were stopped, either of the other two would still furnish an outfall for the district above the manhole. By such an arrangement as this the area injuriously affected by a stoppage is reduced to a minimum.

Back drainage.

Much difference of opinion has been expressed as to the course in which sewers should be laid. The officers of the late General Board of Health insisted that back drainage was the proper plan to adopt; other authorities, equally eminent, have considered that less interference is caused to property, by constructing the public sewers in the public streets. The following woodcuts show the different systems. Fig. 17 is a representation of the plan of draining to the street, and Fig. 18 shows the same block of buildings draining to the back. The author in the course of his experience has found that, as a rule, it is more economical to the local authorities, and far safer, to place the public sewers in the public thoroughfares than in private land at the back of houses. The modern system of sewers laid out in straight lines, with manholes for inspection, so as to place the system of sewerage completely under control, is not applicable to back drainage, as manholes cannot be inserted on private property at the back of houses without serious inconvenience and encroachment on the rights and privileges of private citizens. To

Economical considerations.

carry sewers through private property not unfrequently leads to much ill-feeling being manifested against the local authorities, and also often entails great hardship

Back and street drainage.

Fig. 17.

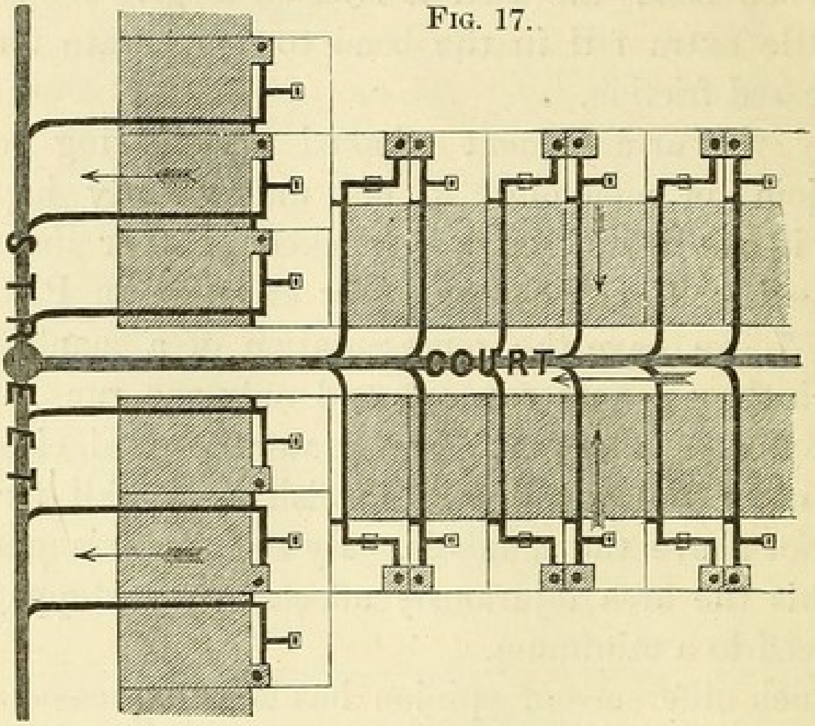
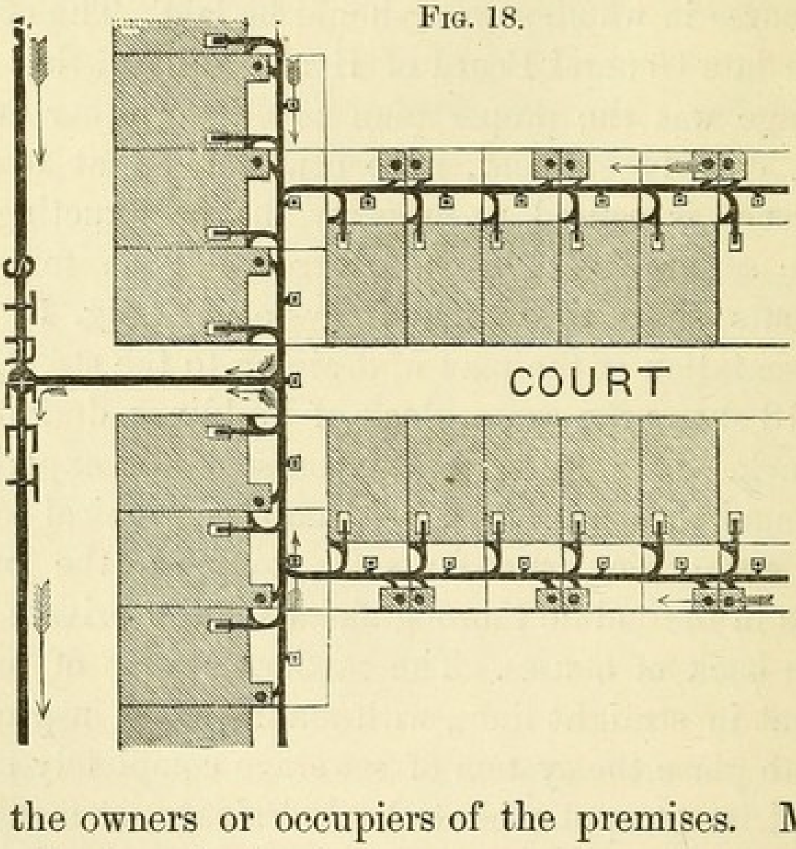


Fig. 18.



upon the owners or occupiers of the premises. Moreover, a local authority has no power to construct sewers through private grounds, except by purchasing the right of easement, which, in many cases, becomes a serious item of expense. The objection raised against the drainage to the street has arisen from having to carry house-drains through or under the houses. This is an objection when house-drains are imperfectly constructed, and would equally apply to back drainage, for unless we have sewers both at the front and back of the house, many houses would require the drains to be laid under them. To guard against the evils arising from accidents to house-drains, the local authorities in new districts have power to introduce such building regulations, so as to retain certain spaces about buildings to be erected, and where these spaces exist at the sides of the buildings the drainage can be brought from the back without traversing the house. In other cases an arrangement of passages may be left at the back of houses, in which the sewers can be constructed, so that the advantages of back drainage may be secured without the drawback of having the sewers constructed on property which it is not easy to get at. With perfectly constructed and well-ventilated house-drains, the evils of carrying them through or under houses are more imaginary than real, therefore the plea of perfecting the house drainage is no valid reason for the invasion of private property. The remarkably good health enjoyed by the inhabitants of the metropolis is very conclusive evidence that no great evils arise from carrying sewers under houses, as nearly every house in London has a drain under it. There are many cases where it is necessary to carry public sewers through private property, but such cases should form the exception, and not the rule. In considering a system of sewers in reference to the general outfall, it will sometimes be found that it may be advisable to deviate from the lines of natural drainage of the district; and in order to secure a good outfall, hills may be tunnelled, or valleys crossed by means of aqueducts or syphons. In carrying out a system of sewers, the natural streams should not be covered over and converted into sewers,

Objection against draining to the street.

Regulations in new districts.

Effects of sewers under houses in London.

Sewers carried through private property.

Outfall.

Natural streams should not be converted into sewers.

but such streams should be conveyed through the district, and be protected against pollution from sewage.

Channels for surface water to be improved.

These natural channels should receive the attention of the engineer, as they may often be improved so as to expedite the discharge of the surface water from the district.

CHAPTER XVI.

INTERCEPTING SEWERS.

THE engineer who is charged with the design of works of sewerage should pay particular attention to the principle of interception. It may often happen that the financial success of a scheme for disposing of the sewage of a district will depend upon the construction of proper intercepting sewers, that is, certain portions of the sewage should be intercepted in the higher portions of the district, and not allowed to gravitate down to the lowest level, and so the sewage of a considerable portion of such district may often be conveyed by direct gravitation to a suitable outfall, leaving only the sewage of the lowest zones to be dealt with by artificial power. Not unfrequently the intercepting sewer will form the only outfall of the district, as the sewage of the lower district may be pumped into it. In districts in which there is but a small longitudinal fall, and comparatively great lateral falls, the work of interception will form an essential feature in the scheme of sewerage. In large towns the work of interception may be carried out with advantage, and thereby often reduce the cost of the system of sewerage, as when this principle is fully carried out, a large town is divided by intercepting sewers into a number of smaller areas; and as it is well known that it is much cheaper, proportionately to the population and area, to drain a small town than a large one, so a large town divided into districts by intercepting sewers can often be drained more effectually and cheaply than if all the sewers were allowed to flow to one common level. In fact, a sewer may be compared to a cone, the base of

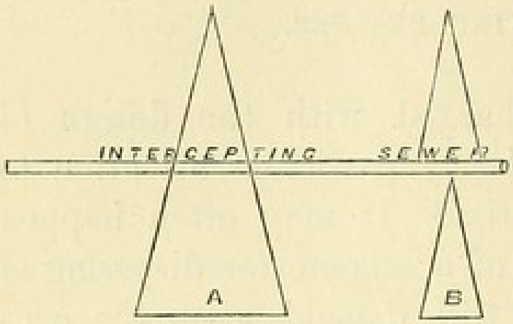
Financial success depends on intercepting sewer.

Districts in which interception should be carried out.

Saving effected by interception.

which rests in the lowest portion of the district, and the apex terminates in the highest. A system of intercepting sewers would cut this cone, and the saving in cost might be represented by the difference in cost of constructing that portion of the branch sewer represented by the frustum of the cone A (Fig. 19), below the intercepting sewer, and the construction of another smaller cone B, the apex of which would commence at the intercepting sewer, and the base rest at the lowest level of the district, due allowance of course being made for any extra sewer that may be required in carrying out the principle of interception.

Fig. 19.



Large districts.

In large districts the principle of interception forms an essential element of safety: by dividing the drainage area into smaller districts the volume of sewage or rainfall is brought more under control than in districts where the volume of sewage is large, and is allowed to fall down to the lowest level of the district.

Sea-coast towns.

In sea-coast towns the principle of interception is also of great importance. The low-level sewers in such districts are usually tide-locked, therefore it is of manifest advantage to intercept the sewage of the higher portions of the district, and to lead it away, together with the rainfall, by a distinct outfall, so as not to interfere with the tide-locked sewers of the district.

Fen districts an example.

The principle of interception is well understood in the great drainage works that have been carried out in the fen districts of this country. These large areas are entirely surrounded by intercepting drains, which catch the rainfall of the higher districts, and lead it off by gravitation to the natural outlets, leaving only the rain falling on the low lands to be dealt with by artificial means.

London sewers.

In many towns this principle of interception has formed a main feature in the scheme of sewerage, and in the case of London it has received its full development. The author has seen many cases in which towns after being sewered have increased so rapidly in size and population that the original sewers have become too small, the consequence of which has been that the lower portions of the district have been frequently inundated. By the introduction into these overgrown towns of a system of intercepting sewers, cutting the sewers already constructed, the sewage of the upper portion of the district may often be harmlessly conveyed away, leaving the sewers of the lower district ample in size to deal with the volume of sewage which is locally due to them, and so, at a comparatively small cost, the efficiency of the original sewerage works may be restored.

Districts that overgrow existing sewers.

CHAPTER XVII.

SECTIONAL FORM OF SEWERS.

Correct form of importance.

Principles on which sewers should be constructed.

External forces acting on a sewer.

Lateral movement of earth.

Splitting of pipe sewers.

GREAT variety in the shape of sewers has been adopted by various authorities at different periods. The adoption of a correct sectional form for the sewers of a district is a matter of primary importance, and when the object to be fulfilled by sewers is fully and scientifically considered, the correct shape to be adopted under varying circumstances may be easily arrived at. In practice sewers should be constructed of such a form as to convey away, with a maximum velocity, both the minimum and maximum flows, and they should also be constructed so as to ensure their stability without an unnecessary expenditure of material. The external forces acting upon a sewer are, the weight of the earth over the sewer acting in a perpendicular direction, and the weight of the earth pressing horizontally on the sides, the amount of the horizontal pressure depending on the angle of repose of the earth. The circular form is no doubt the strongest for all purposes of construction, because any pressure applied at any particular point is distributed throughout the whole structure. Theoretically, as the pressure is greatest vertically, and least horizontally, an elliptically shaped sewer would best resist the forces at work tending to crush it. There are, however, cases in which the greatest pressure is the lateral pressure, as in the case of some ground which, when cut into, has the property of what is called "creeping," or moving into the sewer trench with almost irresistible force. The author has had experience in such cases, in which lines of good pipe sewers have been completely split along the top and

SEWERS.

Fig: 1.

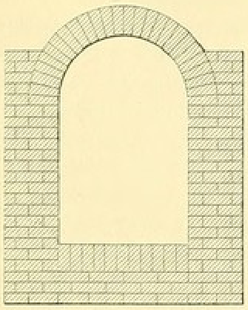


Fig: 2.

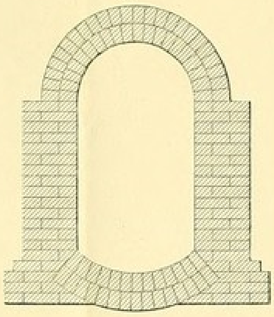


Fig: 3.

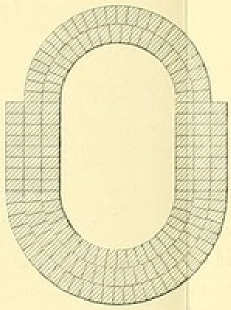


Fig: 4.

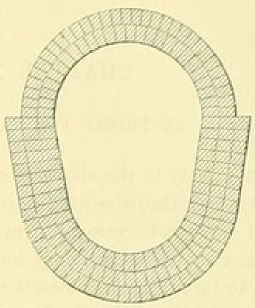


Fig: 5.

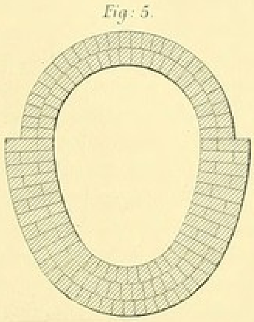


Fig: 6.

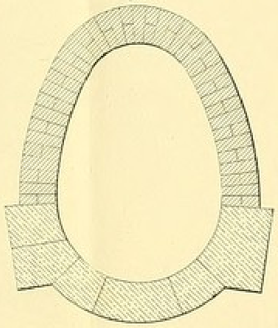


Fig: 7.

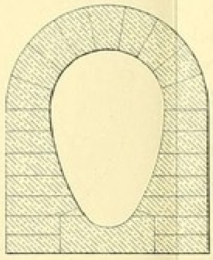


Fig: 8.

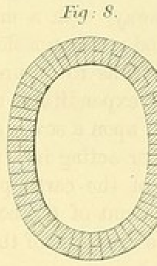


Fig: 9.

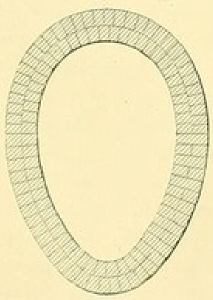


Fig: 10.

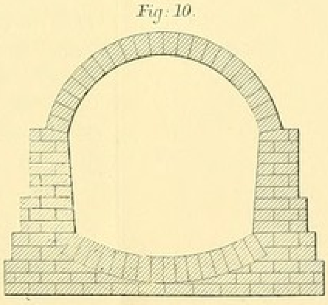


Fig: 11.

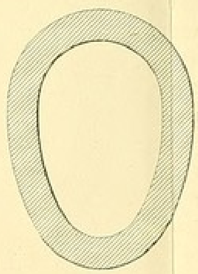
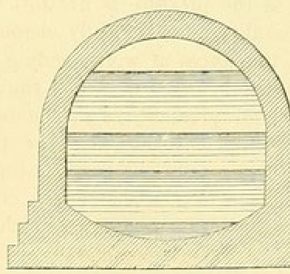


Fig: 12.



London: E. & F.N. Spon, 46, Charing Cross

Thomas Kell, lith.

bottom of the sewer, thus showing that the pressure was lateral. In the construction of sewers the external pressure the sewer has to bear is but one, and not the primary element that has to be considered, for it has already been noted that a certain minimum velocity is required in all sewers that are to be self-cleansing; and when considering the question of the flow through the sewer, the less the length of the wetted perimeter in proportion to the sectional area, by so much will the velocity of flow be increased. It is therefore advisable to adopt for sewers having an intermittent flow such a sectional form as to ensure the greatest velocity when the smallest volume is flowing through them, and for this reason in sewers that are subject to constant fluctuation of the flow, the oval form will be found to be the best. In sewers in which the volume of sewage to be conveyed is large and uniform, the circular form answers best, as it is cheaper and stronger when constructed. In Plate III. are shown a number of sewers of various sections that have from time to time been used. Fig. 1 represents the form generally adopted by the Romans; it is constructed with a flat invert, straight sides, and with a semicircular arch. Fig. 2 is an improvement on the Roman type. This form was introduced into England by special ordinance in the reign of Charles II. In this case the invert is slightly curved, the sides being straight, and the arch semicircular. Fig. 3 shows a further improvement on Fig. 2, the invert in this case being made semicircular, like the arch. Fig. 4 is another improvement, adopted in some of the London sewers, in which the curved invert is reduced to a smaller circle than that of the arch. Fig. 5 is a still further improvement, in which the invert, sides, and arch are curved. This form has been used in Westminster, Lambeth, and Finsbury. Fig. 6 represents a form of sewer similar to that of Fig. 5, except that the sewer is inverted, the larger circle forming the invert,

Sewers with intermittent flow.

Sewers with uniform flow.

Description of Plate III.

Roman sewer.

Sewer of period of Charles II.

Improved shape.

and the smaller the arch. This form was once used in Westminster, but with no very great success. Fig. 7 represents an oval sewer constructed in stonework, as used in Edinburgh. Fig. 8 represents an elliptical sewer, as used at Westminster. Fig. 9 represents an oval sewer, as used by Mr. J. Phillips, C.E., in Westminster. The mode of striking out this sewer is shown in Fig. 22, page 181. Fig. 10 represents a form which was generally used when constructing large sewers in the early London sewerage works. This form of sewer was found to be very liable to stoppage, being generally constructed of a size totally out of all proportion to the wants of the district which it was intended to drain, consequently sedimentary deposit collected in the angles, which greatly retarded the velocity. Fig. 11 represents an oval sewer used in the London districts, which is a great improvement on that of Fig. 10. Fig. 12 is a similar sewer to that of Fig. 10, the only difference being the mode in which the sewer was built up, Fig. 10 as a work of construction being preferable to that of Fig. 12, but both are inapplicable in the construction of ordinary town sewers. Fig. 1, Plate IV., represents the section of a modern egg-shaped sewer built entirely of brickwork; it is a correct representation of the outfall sewer constructed by the author at Redhill. Fig. 2 is a representation of the outfall sewer constructed by the author at Reigate. The section is taken at the point where the sewer passes under Park Hill, in tunnel. Fig. 3 is a representation of the outfall sewer of Reigate, at a point where it is carried in embankment. The two small sewers used in this case are equal in discharging capacity to the oval sewer Fig. 2. This form was adopted in order to reduce the height of the embankments, and arrangements are made at the ends of the double sewer, so that when there is a small stream flowing through the sewers, it can be diverted entirely through one or other of the sewers. Fig. 4 represents

Large London sewers.

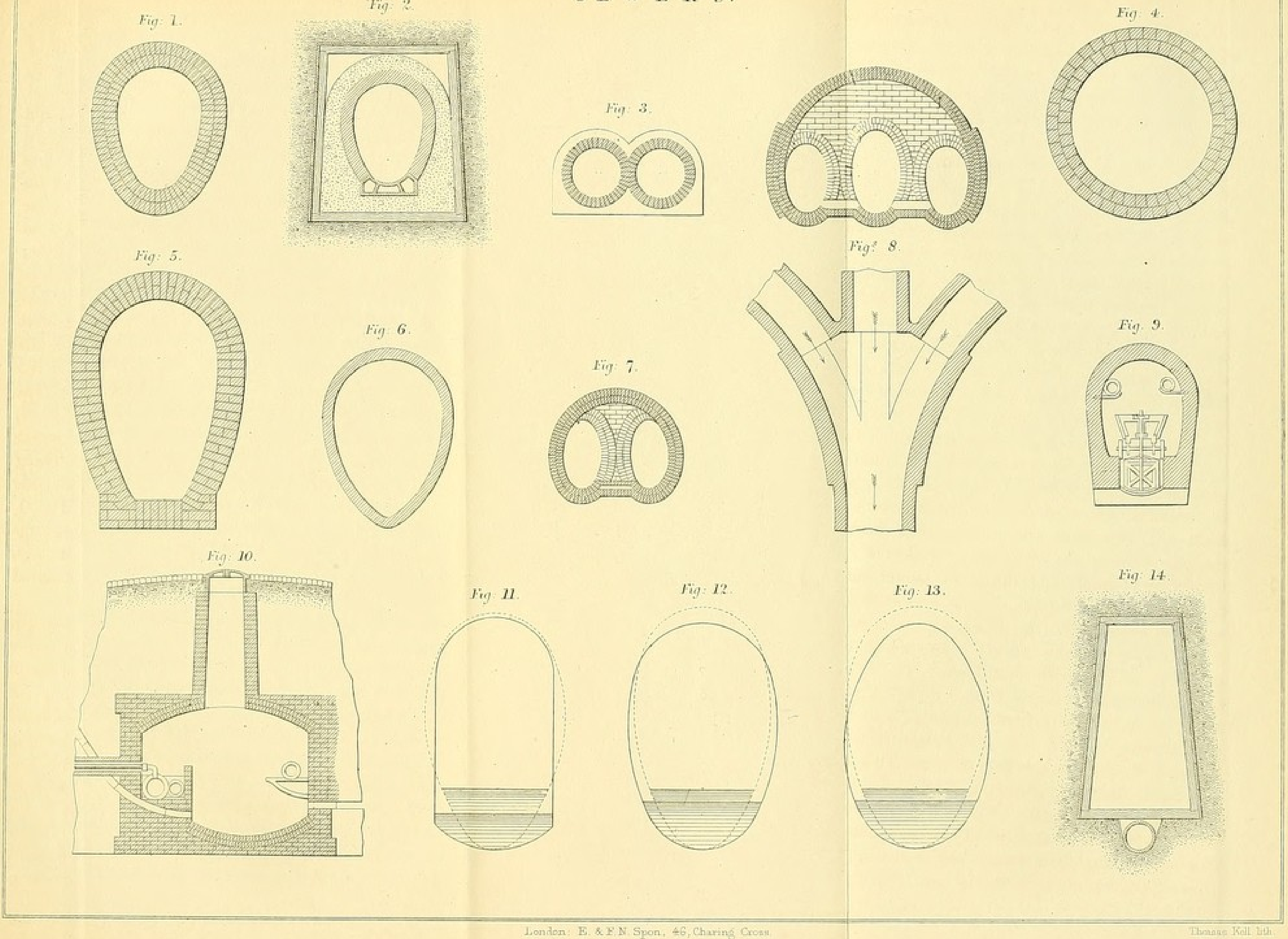
Oval London sewers.

Description of Plate IV.

Redhill sewer.

Reigate sewer.

SEWERS.



London: E. & F.N. Spon, 46, Charing Cross.
Thomas Kell lith.

a circular sewer executed in brickwork. Fig. 5 represents a section of a sewer as used at Southampton, with a flat invert; for the conveyance of small volumes of sewage this form of sewer cannot bear comparison with the ordinary oval sewer. Probably the shape was adopted for the convenience of cleansing, as the flat invert formed a better footway for the men traversing the sewer than the sharp curves of the invert of the ordinary oval sewer. Fig. 6 represents the section of an earthenware-pipe sewer used a few years ago. This form is not now generally used, as it is found that there is some difficulty in making the pipes of true section, and consequently when laid they form an imperfect sewer. Fig. 7 represents the section at a junction of two oval sewers, showing the way in which the sewers are joined. Fig. 8 represents a plan and section showing the junction of three sewers, and the way in which these communications are usually formed. Fig. 9 represents a section of a Paris sewer, the sewer proper occupying the small space shown below the truck. On each side of the sewer rails are fixed, upon which a truck, carrying a disc fitting into the sewer, is made to travel; the sewage heading up at the back of the disc propels the apparatus forward. When the sediment increases in front of the disc to such an extent as to impede its progress, the truck is drawn forward, and the solid matter is taken from before the disc and thrown into the truck. It should be observed that round the edge of this disc are numbers of small holes, and as the water heads up behind the disc it is discharged with a certain velocity through the holes, and so washes away the sediment immediately in front of the disc, and thus somewhat accelerates the progress of the apparatus. The gas and water pipes were inserted in the subway of the sewer as shown, fixed upon brackets, but it has been found by experience that the introduction of gas pipes into these combined subways and sewers is attended with some inconveni-

Southampton sewer.

Oval-pipe sewer.

Paris sewer.

ence and danger, and of late they have been removed.

Proposed Brussels sewer.

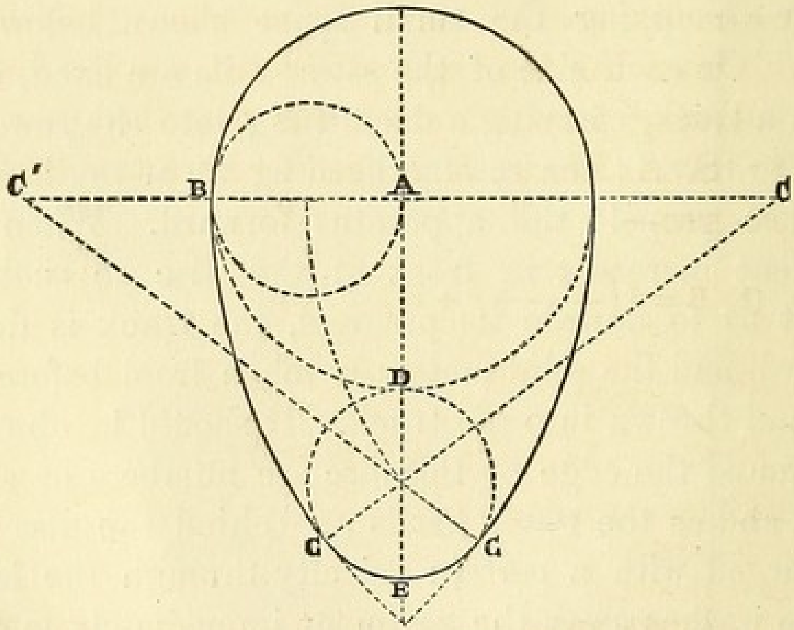
In order to obviate the difficulties which had arisen from the insertion of gas mains into sewer subways, M. Versluys, in a drainage project for Brussels, proposed to introduce another form of sewer and subway, which is shown in Fig. 10, the water pipes in this case being arranged on brackets on one side of the sewer, the gas pipes being laid in a long series of troughs of water on the other side, the idea being that the gas pipes being laid in water of greater depth than the pressure within the pipe, would check the tendency of the gas to escape; but this suggestion has not at present been acted upon, and the plan remains untried.

Advantages of oval sewers.

In studying the best form of sewer, Figs. 11, 12, and 13 show at once the advantages of the oval over other forms given in these figures. It will be seen from these figures that with the oval sewer a greater depth of sewage, with a less exposed surface, is maintained, than

Old form of oval sewer.

Fig. 20.



in any other form; therefore, in all cases in which the volume of sewage is liable to fluctuation, the oval or egg-shaped form should invariably be adopted. Fig. 14 represents an earthenware-pipe sewer constructed in tunnel. The above woodcut, Fig. 20, shows the mode adopted in striking out modern egg-shaped sewers.

This form of sewer was first introduced by Mr. John Phillips, C.E., in the year 1846. We will in future call it the old form of oval sewer to distinguish it from the new form of oval sewer. In the old form of oval sewer (Fig. 20) the following proportions are observed: vertical height equals one and a half times the transverse diameter, radius of invert equals one-fourth the transverse diameter, radius of sides equals the vertical diameter or one and a half times the transverse diameter. Tables Nos. 9, 10, 11, 16, 17, 18, 23, 24, and 25, give the velocities, and Tables Nos. 33, 34, and 35, give the discharges of sewers constructed of the proportions shown in Fig. 20.

Oval sewer introduced by Mr. J. Phillips.

Proportion of old form of oval sewer.

Tables relating to old form of oval sewer.

In some cases it may be desirable to adopt the oval shape, but with dimensions differing from the above proportions; as, for example, when carrying a sewer in an embankment, or when the shallowness of the cutting will not permit of the full vertical depth being given to the sewer, in which case the proportion of egg-shaped sewers having smaller vertical dimensions than one and a half times the transverse diameter, may be found by the following formula, which was described in a paper by Mr. S. A. Reade, M.A., read before the Society of Engineers:—

Formula for oval sewers.

$$(1)\ R = \tfrac{1}{2}\left(\frac{d^2}{r - r_1} + r + r_1\right).$$

$$(2)\ A = \frac{\pi}{180}\left\{ a(R^2 - r_1^2) + 90(r^2 + r_1^2) \right\} - d(R - r).$$

$$(3)\ C = \frac{\pi}{90}\left\{ a(R - r_1) + 90(r + r_1) \right\}.$$

R being the radius of the side;
r of the arch;
r_1 of the invert;
d the distance between the centres of the circles, or equal the depth minus $r + r_1$;
A is the area;
C the circumference;
a the angle which is subtended by the arc forming the sides, and may be found from its sine or tan.; for

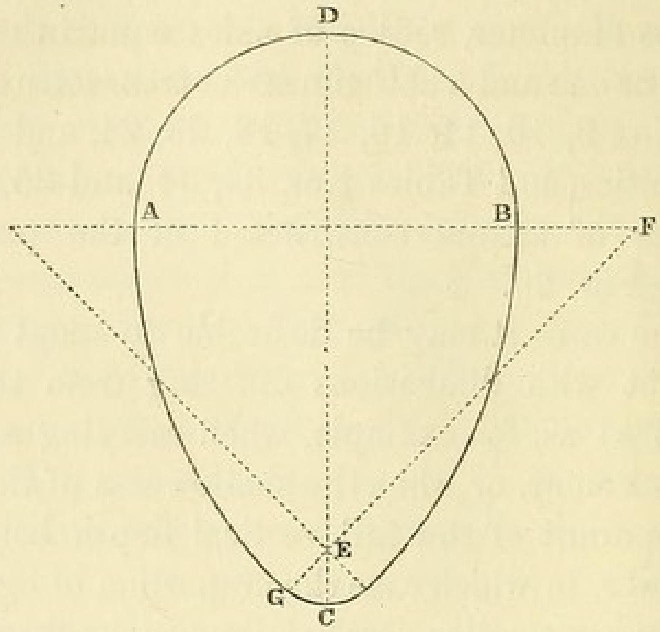
$$\text{sine } a = \frac{d}{R - r_1},\ \text{tan. } a = \frac{d}{R - r};$$

$\pi = 3{\cdot}14159.$

New form of oval sewer.

The new form of oval sewer, the idea of which is also due to Mr. John Phillips, C.E., and the particulars of which were forwarded by its inventor to the author shortly after the appearance of the first edition of this work, is illustrated in Fig. 21.

Fig. 21.



Proportion of new oval sewer.

In the new form of oval sewer (Fig. 21) the following proportions are observed: vertical height C D equals one and a half times the transverse diameter A B; the radius of invert E G equals one-eighth of the transverse diameter A B; the radius of the sides F G or F A equals one and a third times the transverse diameter. Tables Nos. 12, 13, 14, 19, 20, 21, 26, 27, and 28, give the velocities, and Tables Nos. 36, 37, and 38, give the discharge of sewers constructed of the proportions shown in Fig. 21. The new form of oval sewer has been successfully tested by the author, and it has some points that will specially recommend its adoption in many localities. The new form is stronger than the old form, and under certain conditions of small volumes of flow it is better adapted to be a self-cleansing sewer than the old form of oval sewer. It has been already mentioned that velocity is solely due to the effect of gravity, and gravity is represented by the fall

Tables relating to new form of oval sewer.

Advantages of new form of oval sewer.

of the surface of a liquid in motion. In the new form of sewer, as a given volume of sewage will fill the sewer to a greater vertical height than in the old form of sewer, it is consequently found that, with moderate quantities of sewage flowing in the sewers, there is a greater surface fall and velocity of flow in the new form of sewer than in the old form of sewer.

Other forms of oval sewers.

Other modes have been adopted for setting out oval sewers; for example, Fig. 22 represents the mode

Fig. 22.

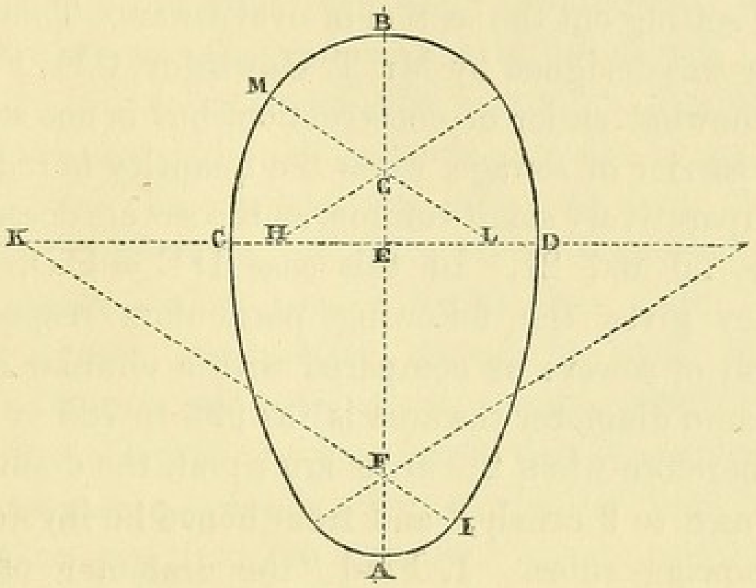
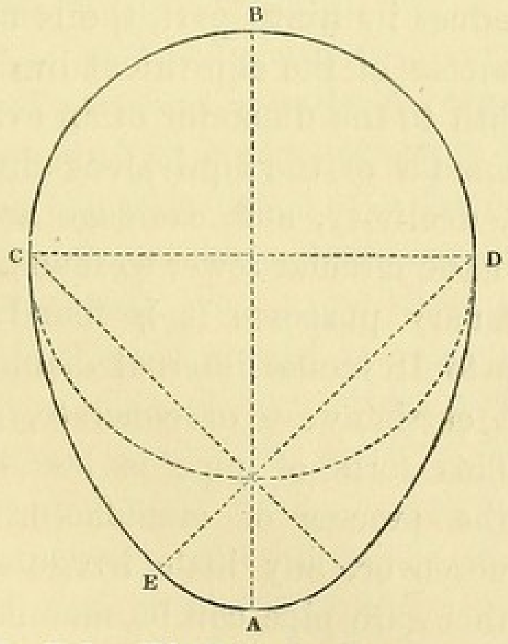


Fig. 23.



adopted by Mr. John Phillips in the construction of oval sewers, in which it is desirable to get increased height in the sewer. In this case $AB = 1\frac{2}{3}\,CD$; $AE = CD$; $AF = \frac{1}{4}$ of CD; $GE = \frac{1}{4}$ of CD; $CH = \frac{1}{6}$ of CD; and IK is parallel to LM. This form of sewer has some advantages, especially in cases where greater headway is required than is given by an oval sewer of ordinary proportions, as, for example, in a tunnel. The proportions of the head of this sewer have been made use of by the author in a tunnel sewer under the town of Longton, in conjunction with the proportions of the new oval sewer as shown in Fig. 21. Fig. 23 shows another mode of setting out the section of oval sewers. This form of sewer was designed by Mr. T. Hawksley, C.E., F.R.S. It is somewhat easier of construction, but is not such a perfect carrier of sewage, when the quantity is reduced to a comparatively small volume, as the sewers described in Figs. 20 and 21. In this case $DE = CD$. Mr. Hawksley gives the following particulars respecting this form of sewer: as compared with a circular sewer of the same diameter the area is "as 996 to 785 = 1·27 to 1; therefore when the areas are equal, the diameters will be as 8 to 9 nearly," and from hence he lays down the following rules. 1. Find "the diameter of the circular sewer capable of affording the requisite amount of drainage, deduct its ninth part, the remainder is the horizontal diameter of the equivalent oval sewer." 2. "Add one-eighth to the diameter of an oval sewer, the sum is the diameter of the equivalent circular sewer; the discharge, declivity, and drainage area," will be the same as for the circular sewer so found.

Longton tunnel sewer.

Small sewers should be circular.

For all ordinary purposes it is found in practice that sewers up to 18 inches internal diameter are best constructed in earthenware or concrete, and circular in section. This form of pipe is less liable to be distorted in the process of manufacture than oval sewers, and, moreover, any little irregularity in section in an earthenware pipe can be modified, from the fact that the circular pipes may be turned round, and if they do not fit and make a good joint one way, they may often be made to lie true on the invert by a little manipulation. Irregularly shaped pipes should not be allowed to be used for sewers, but if, from mischance, they do get into the work, the evil is less in circular-pipe than in oval-pipe sewers, as the ill effects may be modified, and moreover the percentage of distorted, pipes is far less for circular than for oval pipes, so that there is less chance of their being used in the work. In sewers of larger diameter than 18 inches it should be the rule, that when there is sufficient sewage to maintain the sewer constantly running half full, and when the same sewer flows nearly full it will be sufficient in size to carry off the maximum flow required, then the sewer should be made circular in section, as this is both the cheapest and strongest form of sewer. In all other cases, or when the fluctuation of the flow varies within greater limits than stated for circular sewers, the section should be oval, excepting only the case of very small sewers, which may be circular. Experience has shown that it is inexpedient to construct any public sewer of smaller diameter than 9 inches, not because, in some cases, smaller sized sewers would not be sufficient to convey away the full volume of the sewage produced, but in practice small sewers are very subject to accidental obstructions, and the chances of stoppage greatly increase in the case of a public sewer used by many persons in common, while the danger and inconvenience of a stoppage in a sewer used by many persons are greater than in the case of a single house drain. The experience at Croydon in reference to the size of sewers has amply demonstrated the absurdity of attempting to drain numbers of houses with small sewers, as will be observed from the following account of the early works of sewerage executed in that town. Under the direction of Mr. William Ranger, C.E., an inspector of the General Board of Health, the town of Croydon was drained on the small tubular-pipe system, and in accomplishing this work

Rule for sectional form of large sewers.

Limit to size of sewers.

Small sewers subject to accidental stoppage.

Experience in early works at Croydon.

Length of sewers constructed in Croydon.

about nineteen miles of sewers were constructed, varying in size from 4 inches to 21 inches internal diameter. The size of each length of sewer was set forth in a report of Mr. Thomas Cox, the first Surveyor of Croydon, from which it appears that the following lengths of the several sizes of sewers were constructed :—

Inches. Feet.	Inches. Feet.	Inches. Feet.
4 = 6350	10 = 2469	15 = 9518
6 = 44436	11 = 3324	18 = 1506
8 = 6435	12 = 12117	21 = 36
9 = 14100	Total length = 100,291 lineal feet.	

Number of stoppages in various sized sewers.

Between the 27th March, 1852, and 28th November, 1853, a period of twenty months, sixty stoppages took place in the 4-inch sewers, thirty-four stoppages in the 6-inch sewers, one stoppage in the 8-inch sewers, one stoppage in the 9-inch sewers, one stoppage in the 12-inch sewers, one stoppage in the 15-inch sewers, and two stoppages in the 18-inch sewers. Calculated by the length of sewers of each size in operation in Croydon at the time, the proportion of stoppages to the length of each size of sewer was as follows :—

Proportion of stoppages to length of sewers.

4-inch sewers, 1 in 106 feet.	12-inch sewers, 1 in 12117 feet.
6 ,, ,, 1 in 1307 ,,	15 ,, ,, 1 in 9518 ,,
8 ,, ,, 1 in 6435 ,,	18 ,, ,, 1 in 753 ,,
9 ,, ,, 1 in 14100 ,,	

Mr. Cox observed that the number of stoppages in the 4-inch sewers would have probably been greater, but some of these very small sewers were taken up in the period and replaced by others of larger size. All the stoppages in the 12-inch, 15-inch, and 18-inch pipe sewers occurred from the insufficiency of the strength of the pipes, and their subsequent collapse in the work. The stoppages in the smaller sewers arose from accumulations of such matters as usually enter sewers, such as paper, hair, &c. To such an extent was the small-pipe system carried in these early works at Croydon, that in one district a sewer 4 inches diameter was used for the drainage of sixteen houses, one

Stoppages due to insufficiency of strength of pipes.

Number of houses drained by small sewers.

6 inches diameter for the drainage of 137 houses. Add to this the fact that, in a part of Croydon, the sewers were laid in the subsoil water, which rose above them, and as the sewers were most imperfectly jointed with clay, it is not surprising that we have to chronicle so much failure of work. It ought also to be observed that many of these small and imperfect sewers still exist in Croydon, and continue to give trouble by reason of the stoppages that not unfrequently occur in them. To show that there was no local cause to account for the failure of the sewers at Croydon, it may be stated that between 1863 and 1873 the author constructed in Croydon upwards of forty miles of public sewers, and but a single stoppage has occurred in any of these sewers, and in this case the stoppage must have been wilfully created, as it was found to have been caused by a barrow-load of bricks, which by some means had found their way into a 9-inch sewer.

Imperfect sewers still remain in Croydon.

Sewers constructed by author in Croydon.

CHAPTER XVIII.

MATERIALS EMPLOYED IN THE CONSTRUCTION OF SEWERS AND THEIR MODE OF APPLICATION.

Different kinds of material.

THE materials that have from time to time been used in the construction of sewers are bricks of all kinds, tiles, stone, stoneware, artificial stone, asphalte, cement, concrete, glass, iron, and timber. Experience has demonstrated that, in order to secure the permanency and durability of sewer work, great care is required in the selection of a proper material, and that the best materials procurable are the cheapest in the end. The inverts of sewers are particularly liable to wear from the erosion of the water, and from the grinding action of the sand and solid matter transported over them. There are few brick sewers in London of greater age than fifty years which have not been underpinned, and provided with new inverts, and otherwise extensively repaired, on account of the destruction which has taken place from the above-named causes. In selecting materials for the construction of sewers, great care should be used in order to secure those which will be least liable to be affected, either by the chemical qualities of the sewage, the gases found in sewers, or by the mechanical action of the flowing stream and the materials transported over its bed.

Wear of sewer inverts.

Selection of materials.

Sewer pipes.

Small sewers and house-drains are now usually constructed of glazed stoneware or fire-clay pipes. It is little more than a quarter of a century since pipes of this description were first used as sewers, but in that limited space of time vast numbers have been manufactured, until the trade has become of such importance that it may be looked upon as one of the principal industries of the country. In the early days of the manufacture of sewer pipes, when little was known either of the strength or durability of the material, or its mode of application, failures resulted from the injudicious haste with which pipes were used, in large quantities, without any test being applied as to their ability to withstand the strains to which they would be subjected. As a rule, all the early sewer pipes were made too thin to withstand the pressure of the earth in deep cuttings, and were very unequally and very insufficiently burnt. As an example, the case of Croydon, already referred to at page 184, may be taken. This town was one of the first that extensively adopted the pipe system, and we find that 15-inch earthenware pipes were laid in this place in cuttings over 20 feet deep, and as the pipes were not over well burnt, and had but a thickness of $\frac{5}{8}$ of an inch, or scarcely the thickness of a modern 6-inch pipe, we are not surprised to find as soon as the pressure of the earth was brought to bear on them that the sewer collapsed, and in order to save the portions of the work not filled in it became necessary to throw a brick arch over the pipes to take the strain. At the present time pipes for the construction of sewers, both of stoneware and fire-clay, are extensively and satisfactorily used. Fire-clay pipes are not generally considered, thickness for thickness, as strong or durable as stoneware pipes. Fire-clay pipes are, however, less brittle than stoneware, and are not so liable to fracture from percussive action as stoneware pipes. There are many other descriptions of sewer pipes now in general use which alternate between the stoneware and fire-clay varieties, and it will always be a point for the engineer to consider under what class or description his pipes shall be classified.

Failure of sewer pipes.

Failure of pipes at Croydon.

Advantages and disadvantages of stoneware and fire-clay pipes.

At the present time stoneware and fire-clay pipes are made of the dimensions and thickness given in Table No. 40.

TABLE No. 40.

Stoneware. Messrs. Henry Doulton and Co., Lambeth.					Fire-clay. Messrs. Ingham and Son, Wortley.				
Internal Diameter.	Thickness.	Length in Work.	Depth of Socket.	Weight of Foot.	Internal Diameter.	Thickness.	Length in Work.	Depth of Socket.	Weight of Foot.
inches.	inches.	feet.	inches.	lbs.	inches.	inches.	ft. in.	inches.	lbs.
3	$\frac{1}{2}$	2	$1\frac{1}{2}$	6	3	$\frac{5}{8}$	2 0	$1\frac{1}{2}$	6·4
4	$\frac{5}{8}$	2	$1\frac{1}{2}$	9	4	$\frac{11}{16}$	2 0	$1\frac{1}{2}$	8·12
6	$\frac{11}{16}$	2	$1\frac{3}{4}$	$14\frac{1}{2}$	6	$\frac{3}{4}$	2 0	$1\frac{1}{2}$	13·8
9	$\frac{13}{16}$	2	2	28	9	$\frac{3}{4}$	2 0	$1\frac{5}{8}$	21·4
10	$\frac{7}{8}$	2	2	29	10	$\frac{13}{16}$	2 0	$1\frac{5}{8}$	24·4
12	1	2	2	46	12	$1\frac{1}{8}$	2 6	2	41·10
15	$1\frac{1}{4}$	2 to 3	$2\frac{1}{4}$	72	15	$1\frac{1}{4}$	2 6	2	61·2
18	$1\frac{3}{8}$	2 ,, 3	$2\frac{1}{2}$	91	18	$1\frac{3}{8}$	2 6	$2\frac{1}{4}$	83·2

Insufficiency of thickness.

In the course of his experience, the author has found, in some cases, that the thickness given in the above Table for fire-clay pipes is not sufficient. In one case especially which came under his notice, a sewer 18 inches internal diameter, constructed of fire-clay pipes having a thickness of $1\frac{1}{2}$ inch, was laid in a cutting about 16 feet deep, and filled in, in wet weather, with clay of a very unstable character, when it was found that so soon as the pipes had become thoroughly saturated with moisture, and had taken the pressure of the superincumbent earth, they altered in shape, and the vertical diameter, being no longer 18 inches, was reduced to 15 inches, when, in order to prevent a collapse of the sewer, the whole of the pipes were removed, and a brick sewer substituted. It was found in a few days after the removal of these pipes that they had returned to their circular shape, and were subsequently used in a shallower cutting. From these examples the author has also found that pipes of large diameter are not to be trusted in some soils without protection, as they get broken up. As an example, in a 27-inch sewer laid in a 16-feet trench in boulder clay which was noted for "creeping," the pipes were $2\frac{9}{16}$ inches in thickness, and, apparently perfectly laid, were split up at the top and bottom. After this

Failure of fire-clay pipes.

failure was observed the pipes were bedded in concrete, and answered every purpose. It will be seen that great care and caution are required in the selection of the pipes to be used in works of sewerage when executed in deep cuttings and in unstable ground. The best quality of earthenware pipes for sewers are those made of a vitreous imperishable material of sufficient strength to resist fracture, having toughness enough to resist shocks, being tenacious, hard, homogeneous, impervious in character, uniform in thickness, true in section, and perfectly straight, uniformly glazed both inside and outside, free from fire or other cracks, and when struck should ring clearly. Porous substances are not so good as those that are vitreous throughout, and pipes burned at a low temperature are not so good as those that have been subjected to a higher temperature. Pipes that are salt glazed are more durable and preferable to those lead or glass glazed. Salt glaze permeates the whole body of the material; other glazes form merely a surface varnish, which often hides the defects of a worthless material. The impermeability of a pipe may be taken as an element of its durability and fitness for sewer work, as the more impervious a pipe is the better will it prevent the entrance into the interstices of the material of those agents which are likely to exercise a destructive influence upon it, such as, for example, the crystallization of water in time of frost, or the formation of crystals in the presence of certain chemical compounds, or the direct chemical action of some materials found in sewers on the material itself, and which will sooner or later effectually destroy some pipes. Pipes are tested for impermeability by first drying the pipe till it ceases to lose weight, and then submerging it in water, allowing it to remain at least twenty-four hours under water, then removing it from the water, wiping dry, and re-weighing. Table No. 41 gives the results of experiments made by the author on the absorption of water by pipes. It will be seen from

Care must be exercised in selecting pipes.

Quality of good pipes.

Porous pipes objectionable.

Salt glaze.

Table No. 41.

this Table that all earthenware and fire-clay pipes absorb more or less water, and in judging of the quality of a pipe it must be considered that the best pipe is that which absorbs the least amount of water, as it will be less susceptible to the destructive influences that may arise from the permeation of the material by deleterious matter present in the sewage.

Least absorbent pipes the best.

Test of sewer pipes to resist chemical action.

As a test of sewer pipes to resist the action of certain chemicals which in some towns are allowed to enter the sewers, the method adopted is to take a piece of the pipe and pulverize it, then to boil it in hydrochloric acid, subsequently to wash on a filter, and dry, noting the loss in weight. Dr. W. A. Miller showed some years ago that stoneware pipes could be boiled in muriatic acid without suffering loss in weight—hence the repute in which utensils of this description are held by the manufacturers of chemicals. This acid test is very desirable when dealing with a material of which there is the slightest doubt. The author has found, in the course of his experience, that some pipes that appear beautiful to the eye by reason of their perfect form, uniform colour, and good glaze, and which will also ring well, are about the worst possible material that can be used for the construction of a sewer. The failure of such pipes in the ground is certain, and is due to the presence of lime in the clay of which the pipes are made, and which in the presence of the moisture of the earth renders the pipes rotten. Materials which may appear most durable, such, for example, as some pipes of the blue Staffordshire ware, which often contain lime, for it is generally present in the clays from which they are made, experience has demonstrated fail in the ground. Although blue ware containing lime, when applied as in a pipe, fails in the ground, causing the pipe to crack and break from insufficiency of strength, the same material when used in bulk, as in brickwork, is not liable to failure from this cause; hence, no doubt, if this class of pipe was made much thicker, they would stand when

Uncertain quality of pipes.

Injurious effects of lime in material.

used as sewers. The composition of the materials forming a pipe should receive the most careful consideration, and in any case of doubt the engineer should seek the

TABLE No. 41.—Showing the ABSORPTION of WATER by SEWER PIPES.

Name of Maker.	Size of Pipe as measured.	Length of Pipe as measured exclusive of Socket.	Thickness of Pipe.	Weight in lbs. when Dry.	Weight in lbs. after 24 hours immersion in Water.	Amount of Water absorbed.	Percentage of Water absorbed by Dry Pipe.
	inches.	ft. in.	inches.	lbs.	lbs.	lbs.	
Doulton and Co., London pipe	6	1 11	·75	31	31·25	·25	·806
" "	6	1 11	·72	29·5	29·75	·25	·85
S. Fisher	6	2 0	·63	28	28·75	·75	2·68
Wortley pipe	6	1 11	·74	30·5	31·75	1·25	4·10
Ingham, Wortley ..	5	1 11	·69	26·0	26·5	·50	1·92
Huddersfield pipe ..	9	2 4	·92	73	73·75	·75	1·03
Doulton and Co., London pipe	9	2 0	·87	57·75	58·75	1·00	1·73
Doulton and Co., Staffordshire pipe ..	9	1 11	·87	51·75	53·00	1·25	2·41
Cliff, Wortley	9	2 4	·81	60·5	63·25	2·75	4·54
Aylesford pipe	9	2 0	1·00	58·0	62·00	4·00	6·89
Doulton and Co., Staffordshire pipe ..	12	2 0	1·05	96·0	97·5	1·50	1·56
S. Fisher	12	1 11	1·00	84·0	88·0	4·00	4·76
Stiff and Sons	12	1 10	1·02	66·25	67·5	1·25	1·88
Wilcox and Co., Wortley	12	1 11	1·03	79·5	82·5	3·00	3·77
Doulton and Co., London pipe	15	1 11	1·06	116·5	117·0	·50	·429
Doulton and Co., Staffordshire pipe ..	15	2 6	1·26	132·0	139·0	7·00	5·30
Stiff and Sons	14	1 10	1·06	105·75	108·75	3·00	2·83
Wilcox and Co. ..	15	1 10	1·72	130·00	137·0	7·00	5·38
Ingham and Sons ..	15	2 6	1·31	165·0	174·5	9·50	5·75
Doulton and Co. ..	18	2 4	1·43	221·0	226·00	5·00	2·26
" " ..	18	2 5	1·38	210·0	217·0	7·00	3·33

advice of a competent chemist. The impermeability of a pipe may be tested by tying a piece of bladder, or other suitable substance, over one end of the pipe, then reversing it and filling it with water. If the material is not perfectly impervious it will soon be detected by the sweating of the pipe, as it is termed, or the appearance of water oozing on the outside, together with the loss of water from the interior of the pipe, which will require to be replenished if the pipe is very permeable. The tenacity of the material of which earthenware sewer pipes are manufactured is a quality that varies immensely, even in pipes manufactured at

Test of impermeability.

Tensile strength of pipes.

the same time and place. There are so many circumstances which arise during the process of manufacture that may alter the character of the finished article, that pipes of this description, when required to resist tensile strain such as would arise when they are working under pressure, cannot be recommended for use; therefore in all cases when considerable pressure has to be sustained it is better to use iron. From Table No. 42,

Table No. 42. Strength of sewer pipes.

TABLE No. 42.—Showing the BURSTING PRESSURE and TENSILE STRENGTH of SEWER PIPES.

Name of Maker.	Where made.	Size of Pipe.	Length of Pipe.	Thickness of Pipe.	Bursting Pressure in lbs. per square inch.	Tensile Strength per square inch in lbs.
		in.	ft. in.	in.		
Doulton and Co.	Staffordshire	6	1 11	·65	50	230·7
" "	London ..	6	1 11	·72	10	41·6
Ingham and Co.	Wortley ..	6	1 11	·48	4	25·0
" "	" ..	6	1 11	·69	70	304·3
S. Fisher	London ..	6	2 0	·57	15	78·9
T. H. Seacombe	Ruabon, North Wales	6	1 10½	·70	5	21·4
Aylesford ..	Aylesford ..	9	2 0	1·00	45	202·5
Doulton and Co.	London ..	9	2 0	·84	40	214·2
" "	Staffordshire	9	1 11	·79	20	113·9
Cliff	Wortley ..	9	2 4	·84	60	321·4
Brookes	Huddersfield	9	2 6	·91	55	271·9
T. H. Seacombe	Ruabon, North Wales	9	1 11	·94	30	143·6
Doulton and Co.	Staffordshire	12	2 0	1·07	7	39·2
Wilcox and Co.	Wortley ..	12	1 11	·94	7	44·6
Stiff and Sons	London ..	14	1 10	·95	30	221·0
Doulton and Co.	Staffordshire	15	1 10	1·10	20	136·3
" "	London ..	15	2 5	1·19	33	207·9
" "	" ..	15	2 5	1·25	15	90·0
Ingham and Co.	Wortley ..	15	2 5	1·15	20	130·4
T. H. Seacombe	Ruabon, North Wales	15	1 10	1·10	63	429·5

which gives the results of experiments by the author, it will be seen that the tenacity of material varies from 21·4 lbs. per square inch to 429·5 lbs. per square inch of section, a range sufficiently great to show its uncertainty and variableness.

With regard to the quality of the material used in the manufacture of sewer pipes to resist percussive action, such as, for instance, they have often to bear when earth is carelessly thrown into a trench, or the trench is rammed when there is but a thin layer of earth over the pipe, or the pipes are subjected to the jar of heavy traffic. It has been found that for all practical purposes, when the work of refilling the sewer trenches is carefully performed, the material in general use for constructing sewer pipes has sufficient toughness to resist these strains. In May, 1856, some experiments were made with sewer pipes at the works of Messrs. Burton and Waller, of Southwark, to ascertain their capability to resist shocks. For this purpose a cast-iron ball 14 lbs. in weight was allowed to fall on the pipe from the heights of 4, 5, 6, and 7 inches; the percussive force being equal to the velocity when multiplied by the weight may be taken as follows:—

Strength to resist percussion.

Percussive action.

4 inch fall	=	64·65 foot lbs.
5 „	=	72·47 „ „
6 „	=	79·38 „ „
7 „	=	85·74 „ „

Table No. 43 shows the results of the experiments.

Pipes when laid, and acting as a sewer, are always more or less exposed to the crushing action of the superincumbent earth, therefore they must be made of sufficient thickness to resist the pressure likely to be brought upon them. Sewer pipes of the thickness given in Table 40 are sufficiently strong for all practical purposes, but when laid in deep cuttings in treacherous earth the thickness should be slightly increased. Experiments have been made in order to ascertain the amount of force required to crush pipes of various kinds. Table 44 has been compiled from experiments made in the presence of Sir J. W. Bazalgette, C.E., in 1855, and before Lieut.-Colonel William Haywood, C.E., in 1856. For the purpose of experiment each pipe was placed on two flat pieces of hard wood, and a piece of hard wood was laid on the top of

Crushing of sewer pipes.

the pipes, the weight being applied by means of a lever, as shown in Fig. 24. In some of the experiments a packing of felt was placed round the pipe.

Table 43. Percussive action.

TABLE No. 43.—EXPERIMENTS on EARTHENWARE PIPES to RESIST PERCUSSIVE ACTION, made at Messrs. BURTON and WALLER'S Works, Holland Street, Blackfriars, 15th May, 1856.

Name of Maker.	Diam. of Pipe in Inches.	Thickness of Pipe in Inches.	Weight of Pipe in lbs.	Number of Pieces when Broken.	Remarks.
Doulton .	6	·75	35	2	After six blows with 4″ fall, pipe perfect; 2nd blow, 5″ fall, pipe cracked; and 7th, pipe broke.
„ ..	6	·75	35·25	..	4th blow, 5″ fall, cracked pipe; 7th pipe broke.
Aylesford	6	·75	33·5	2	4th blow, 5″ fall, made hole in pipe 3·5″×2·5″; pipe then turned over, and 2nd blow cracked and 4th pipe broke.
„ ..	6	·75	32	2	2nd blow with 5″ fall, pipe cracked; 6th blow, pipe broke.
„ ..	6	·75	32·75	2	Pipe had been soaked in water; 2nd blow with 5″ fall, pipe slightly cracked; 3rd, pipe completely cracked; 5th blow small hole; the 36th blow, hole 3·25″ × 2·5″; pipe then turned over and broke the 2nd blow.
Doulton .	9	·875	63·5	2	After six blows with 5″ and 6″ falls, pipe perfect; the 2nd blow with 7″ fall, pipe cracked; and 5th blow, pipe broke.
„ ..	9	·937	62·75	2	2nd blow with 7″ fall cracked pipe; 4th, pipe broke.
Aylesford	9	1·00	60·5	..	Pipe soaked in water, the 1st blow with 7″ fall, pipe cracked; 8th made small hole; 31st, transverse fracture; 34th, pipe broke.
„ ..	9	1·00	60·25	2	1st blow with 7″ fall, pipe slightly cracked; 6th made small hole; 36th, hole 3·75″ × 2·75″; pipe then turned and broke 1st blow.
Doulton .	12	·937	89	2	1st blow with 7″ fall cracked it; 2nd blow, pipe broke.
„ ..	12	1·00	97	..	3rd blow with 7″ fall, pipe cracked; 6th blow, piece flew out of pipe; 16th blow, large piece out of the bottom of pipe; 20th, hole in top of pipe; 29th, top shivered; 45th broken up.

Table 44. Crushing of sewer pipes.

From an examination of the Table it will be seen that the material has a pretty uniform character for resisting crushing strains, therefore can be depended upon when placed in positions liable to such strain.

The pipes most generally used in the formation of sewers are ordinary socketed pipes, and when laid in

TABLE No. 44.—EXPERIMENTS on the CRUSHING of EARTHENWARE SEWER PIPES, conducted at the WORKS of Messrs. BURTON and WALLER, Holland Street, Blackfriars.

Date of Experiment.	Maker's Name.	Diameter of Pipe in Inches.	Thickness of Pipe in Inches.	Weight of Pipe in lbs.	Breaking Weight in lbs.	Number of Pieces of broken Pipe.	Remarks.
1855. July 18	Doulton ..	$8\frac{5}{8} \times 8\frac{7}{8}$	·75	..	2713	..	Without felt pad.
,, ,,	,, ..	$8\frac{5}{8} \times 8\frac{7}{8}$	·75	..	2470	..	With felt pad.
,, ,,	Aylesford pipe ..	$8\frac{5}{8} \times 8\frac{3}{4}$	1·00	..	2106	..	Without felt pad.
,, ,,	,, ,, ..	$8\frac{7}{8} \times 8\frac{7}{8}$	1·00	..	3077	..	With felt pad.
,, ,,	Stiff ..	$8\frac{5}{8} \times 9$	·812	..	2106	..	Without felt pad.
,, ,,	,, ..	$8\frac{5}{8} \times 9$	·812	..	2228	..	With felt pad.
,, ,,	Doulton ..	$11\frac{1}{2} \times 11\frac{3}{4}$	1·00	..	3684	..	Pipes placed with largest diameter vertical.
,, ,,	,, ..	$11\frac{1}{2} \times 11\frac{3}{4}$	1·00	..	3684	..	
,, ,,	Aylesford	$12\frac{1}{4} \times 12\frac{1}{4}$	1·125	..	2936	..	Felt pad round pipe.
,, ,,	,, ..	$12\frac{1}{4} \times 12\frac{1}{4}$	1·125	..	2470	..	,, ,,
,, ,,	Stiff ..	$11\frac{3}{4} \times 12$	1·00	..	2834	..	,, ,,
,, ,,	,, ..	$11\frac{7}{8} \times 12$	·937	..	2713	..	,, ,,
1856. May 2	Boucher .	6	·75	33·5	2956	..	Pipe hard and well burnt.
,, ,,	Pilton ..	6	·75	33	1864	..	Aylesford pipe, not of true section, rather oval.
,, ,,	Boucher .	9	·875	63	2228	..	
,, ,,	Pilton ..	9	1·06	66	2775	..	Aylesford pipe.
,, ,,	Boucher .	12	·935	91	2410	..	
,, ,,	Pilton ..	12	1·125	94	2228	..	,, ,,
,, 15	Doulton ..	6	·75	35	2713	5	Transverse fractures.
,, ,,	,, ..	6	·75	35	2531	6	
,, ,,	Pilton ..	6	·75	33·5	1803	5	Longitudinal fractures in nearly parallel pieces.
,, ,,	,, ..	6	·75	32·5	1742	5	
,, ,,	,, ..	6	·75	32·75	1864	6	
,, ,,	Doulton ..	9	·937	64·5	3561	9	Pipe well made and burnt.
,, ,,	,, ..	9	·937	62·0	2956	6	
,, ,,	Pilton ..	9	1·00	62·5	2470	6	
,, ,,	,, ..	9	1·00	63·5	2470	5	
,, ,,	,, ..	9	1·00	64·0	2228	6	Badly burnt.
,, ,,	Doulton ..	12	·99	93·5	2834	9	These pipes had a fillet on spigot end.
,, ,,	,, ..	12	·937	92·0	2956	7	
,, ,,	Pilton ..	12	1·125	95·5	2470	7	Aylesford pipe, irregular in section and inferior in quality.
,, ,,	,, ..	12	1·125	98·25	2350	5	
,, ,,	,, ..	12	1·187	90·5	2228	7	

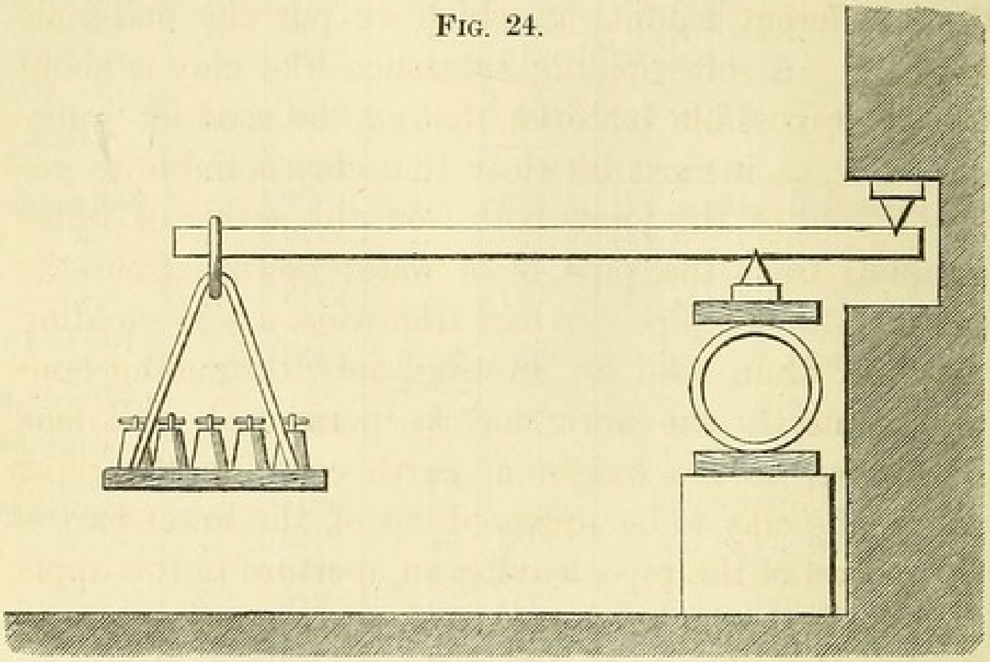
the sewer the spigot end of one pipe is inserted in the socket of another. The spigot end of the pipe should be laid down hill. In the use of socket pipes care should be taken to ascertain that the socket has been made with, and forms a component part of, the pipe.

In some cases manufacturers are in the habit of making a distinct pipe, and afterwards working the socket upon it. The consequence is that, not unfrequently, the sockets of pipes so made fail in the work, as such pipes are more fragile than pipes made in one piece.

Sewer pipes must be truly laid.

In the laying of sewer pipes it is essential that they should be laid with a perfectly true line of fall from point to point of the sewer, and that each pipe has an uniform bearing throughout its entire

Fig. 24.



length. For this latter purpose a recess may be cut in the floor of every pipe-sewer trench in order to receive the socket, or otherwise each pipe is merely supported from socket to socket.

Joint holes.

It will be found difficult to properly joint a pipe that has not a large joint hole formed in the floor of the trench, and these large joint holes become an element of weakness. Bearing this in mind and that the object to be secured is simply to get an uniform and solid bearing for the barrel of the pipe, by careful attention to the filling and packing under the pipe with concrete in cases that may require it, the object may be secured without the use of joint holes. In some of the early sewer works, failures were traced to the pipes being laid with their sockets on the floors of the trench, the pipes not having been properly packed underneath, consequently the whole load of earth was supported by the sockets and ends of the pipes, and they not unfrequently failed in the work. Great care is also required to be exercised in the jointing of pipes when laid as sewers. The material most commonly used for jointing pipes is clay, which is one of the worst materials that could be found for the purpose. We seek the most impervious materials wherewith to construct our sewers, and often spoil their effect by the indifferent manner in which we put the materials together. A soft yielding substance like clay is about the worst possible material that can be used for jointing pipes, as it must be clear that clay is liable to get washed out of the joints both from the action of water escaping from the pipe, or of water flowing from the subsoil into the pipe. Apart from this, a soft yielding material when used for jointing, notwithstanding however perfectly the work may be performed, will lead to failure, as the weight of earth covering the pipes causes the clay to be squeezed out of the lower part of the socket of the pipe, leaving an aperture in the upper part through which sewer air and sewage may escape, or water and sand be carried from the subsoil into the sewer. These serious defects in jointing not unfrequently lead to the disturbance of the line of pipes, and destroy the regularity of their bed. Portland cement used neat or sometimes mixed in the proportion of one part of cement to one of sand, is one of the best materials that can be used for jointing sewer pipes. Whenever cement is used special care must be exercised to see that it does not get into the interior of the pipe. Every pipe should be jointed as it is laid, and no fresh pipe should be laid in position until it has been ascertained that no cement has passed through the joint of the previously laid pipe, and the trench should not be filled in until the cement is set. Medina, or Roman cement may be used in cases where quickness of setting

Jointing of pipes.

Clay joints should not be permitted.

Cement joints.

is an object, and asphalte may be used with great advantage for jointing sewer pipes in some cases, especially when it is necessary to convey a sewer under a dwelling house. The author has seen cases in which drains have been completely stopped, owing to the cement used in jointing having run into the pipes when laid. One of the best modes of jointing socket pipes under all circumstances, the author has found to consist in forcing into the socket of every pipe not less than two strands of tarred gasket, of sufficient diameter to fit the socket tightly. It should be forced into the socket by hand, with a proper caulking tool, and afterwards the joint may be made with cement or asphalte in the usual way. The advantages of this mode of jointing are obvious. In ordinary sewer pipes there is an annular space between the exterior of the spigot and the interior of the socket of the pipe. When this space is filled with material like clay, and the pipes have not a solid bearing throughout their entire length, the weight of the earth on the pipe, or the effect of men walking over the line of newly laid pipes after they are jointed, causes the material to be squeezed out of the lower part of the socket, with the results that have just been referred to. Cement-jointed pipes laid in trenches filled in while the cement is soft are liable to fail like clay-jointed pipes, or when the cement is set the joints get cracked and broken from the same causes which affect clay joints, and with the same results, but when tarred gasket is used the annularity of the joint is maintained, and the material is sufficiently elastic to resile from the effects that destroy other joints; consequently pipes laid and jointed in this manner are found to preserve the uniform and straight lines of fall with which they were laid, and which is an essential feature in every properly constructed sewer. The tarred gasket also proves a most effectual agent in preventing the entrance of sand into a sewer through the sockets of the pipes.

Cement and gasket joints.

Preservation of the annularity of joint.

Failure of joints.

Prevention of sand entering sewer.

In order to preserve the concentricity of the joint of pipes when laid, Mr. Bothams, the city surveyor of Salisbury, in the year 1871, took out a patent for an improvement on the ordinary socket pipe, which is illustrated in Figs. 25, 26. On the spigot end of each

Bothams' pipe.

Fig. 25.

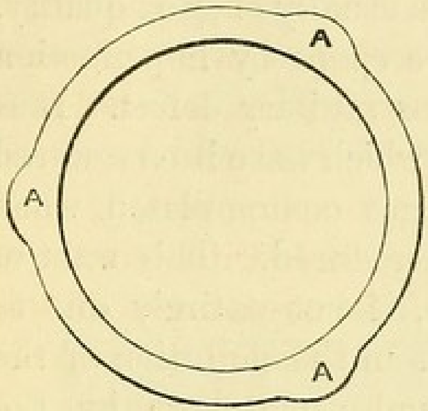
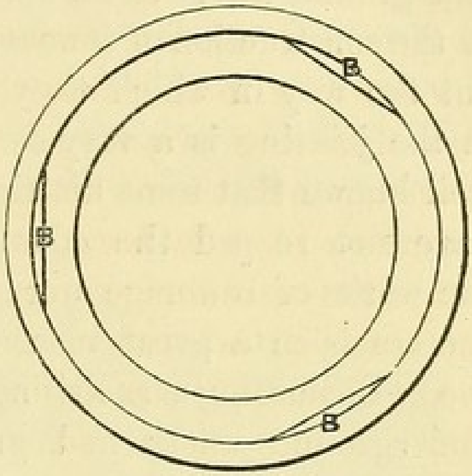


Fig. 26.



pipe projections are formed, as shown by the letter A in Fig. 25; and within the socket corresponding projections are shown, as at B in Fig. 26. The spigot end is inserted in the socket so that its projections lie within the projections in the socket, but on turning the pipe round, the projections of the spigot are brought into contact with the projections of the socket, and so concentricity of the joint is preserved. When pipes are properly bedded throughout their entire length, no precautions are required to preserve the concentricity of the joint, and if not so bedded, other causes of danger arise when the concentricity of the joint is maintained by artificial means, for if not properly bedded, every pipe becomes a girder supported at both ends, and the pipes are liable to failure from the effect of the weight of the superincumbent earth, as was found in some early sewer works to be the case. Having regard to the movements of the subterranean currents of water which may be fouled by the contents of leaky sewers, such imperfect sewers may be the means of spreading pestilence and death instead of

Importance of properly bedding pipes.

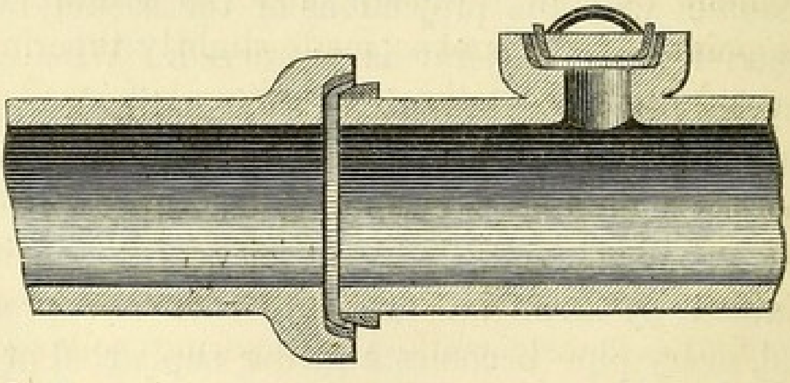
Necessity for water-tight joints.

administering to health and life. Moreover, having regard to the necessity of maintaining the purity of the ground atmosphere, which to a great extent contributes to the æration of our houses, the importance of the perfect construction of sewers and drains is a matter of no small moment, if the purity of the ground water and ground air is to be secured. The materials used in the construction of sewers are usually of good quality, but the way in which they are spoilt by imperfection in the jointing is a very serious sanitary defect. It is well known that some districts which have been sewered have not reaped the advantages contemplated when the works of sewerage were introduced. This want of success is in a great measure, if not entirely due to the evil consequences arising from the pollution of the underground water and ground atmosphere by the contents of leaky sewers. This imperfection of sewer work is an evil that has been foreseen by engineers, and to meet the necessities of the case many able men have devoted attention to the subject, none with greater success than Mr. Stanford in the introduction of his sewer joint for earthenware pipes (Fig. 27). This joint

Injurious effect of leaky joints.

Stanford's pipe joint.

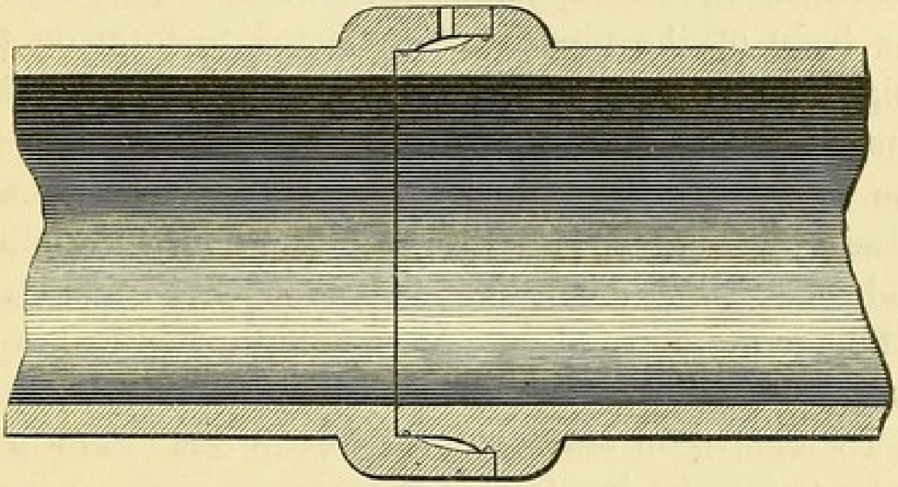
Fig. 27.



is made by casting upon the spigot and in the socket of each pipe by means of moulds carefully prepared for the purpose, rings of cheap and durable material, the composition consisting of ground earthenware pipes, sulphur, and tar, and when the pipes are put together, they fit mechanically into each other; or the joint may be first painted with ordinary tar, grease, or other material. The joints are made of a spherical form, so that a certain amount of movement or settlement may take place without destroying the joint. It should, however, be clearly borne in mind by those using these pipes, that any settlement which causes an elongation of the line of pipes will, as a natural consequence, lead to the drawing of the joints. It is therefore absolutely necessary that a good foundation should be made for these pipes, in order that the benefits to be secured by their use may be obtained. Mr. John Phillips, C.E., proposed the joint shown in Fig. 28 which is an im-

Phillips's pipe joint.

Fig. 28.



provement on the ordinary mode of jointing pipes. "The point of the spigot is made slightly tapering, and at some distance from the point there is formed on the spigot a tapering collar of larger diameter. The interior of the faucet is made with two tapering parts, so that when the spigot is inserted into the faucet, the point of the former fits, or nearly fits, the back tapering part of the faucet, while the tapering collar of the spigot fits, or nearly fits, the front tapering part of the faucet, and within the joint there is an annular cavity between the two fitting, or nearly fitting, parts. In the periphery of the faucet are provided one or more apertures by which, when the pipes have been put together, liquid cement or molten metal, or fused asphalte or other bituminous material or cementing substance, is poured or introduced so as to fill the annular cavity around the spigot. In some cases in the fitting, or nearly fitting, parts of the spigot and faucet are provided one or more annular grooves, in which is placed a ring or rings of caoutchouc, tarred hemp, spun yarn, or other yielding material, before the pipes are put together, such ring or rings having the effect of preventing the escape of the material used for filling the annular cavity, and in combination with the filling of rendering the joint tight against leakage. By this method of jointing, the pipes are rendered concentric with one another. For better supporting pipes jointed in this manner, when the socket extends beyond the body of the pipe, it is preferred to form on the spigot end a collar of a diameter equal to that of the faucet, so that both pipes may have a fair bearing on the ground on which they are laid." This joint is admirably adapted for the jointing of cement pipes, and in combination with the system of mechanically fitting joints adopted by Mr. Stanford, would form an excellent joint for earthenware pipes.

Combination of Stanford's and Phillips's joint.

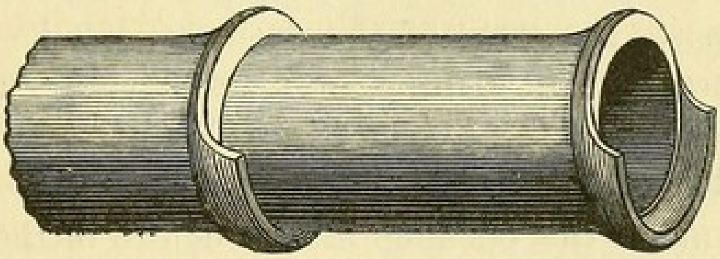
Removal of pipes from sewer.

To remove an ordinary pipe from a line of sewer in order to insert a junction, it is necessary to uncover not less than three pipes, and in large sewers a greater number, before a pipe can be raised out of the work. A pipe is usually removed by placing a lever beneath it and springing the line of pipes up, so that they assume an arched form. The pipe in this way is soon liberated from the work; the junction or another pipe may then be inserted by the reverse operation. Care should be taken after performing this work that the foundation below the line of pipes is properly restored, so as to prevent any settlement at the point where the sewer has been disturbed. When pipes have been properly jointed with cement, it is a difficult matter to remove a pipe without fracture, consequently it is desirable as far as possible, when carrying out a system of sewerage, that all the necessary junctions should be placed in the lines

Junctions should be inserted.

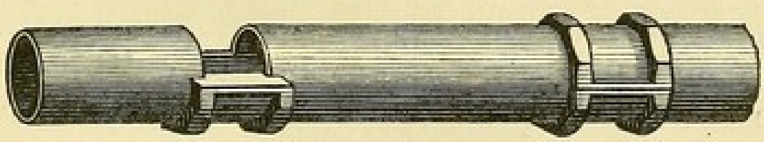
of sewers as the work proceeds, so as to avoid disturbing the sewer when laid. It should be remembered that a sewer disturbed at short distances for the purpose of inserting junctions can never be restored to as perfect a condition as a sewer that has not been disturbed. In the construction of pipe sewers a number of modifications in the detail of construction have been made by various inventors. One of the first modifications in the form of pipes, as used in the construction of sewers, was to make the pipe with half a socket, as is shown in Fig. 29, Half-socket pipes.

Fig. 29.



the object of this arrangement being to facilitate the removal of any pipe when it became necessary to insert a junction, or for other purposes. Pipes have also been made with half sockets on each end, so that when two pipes are laid together, the two half sockets form a whole socket with a joint in the centre of the socket. Pipes have also been made on the Roman type with butt joints, having a loose collar over the joint, forming as it were a double-socket joint. This form of joint is still adopted in cases where earthenware pipes are used to convey water under slight pressure, and they are usually jointed with asphalte or sulphur. Another form of sewer pipe is shown in Fig. 30. Collar joint.

Fig. 30.



This form of pipe was introduced by Mr. George Jennings some years ago. In his description of these Jennings's pipe.

pipes he states that they are "plain at both ends, are laid in chairs similar to the metals of a railway, each pipe being kept 6, 9, or 12 inches *apart*, according to their diameter. The pipes being bedded in the chairs renders the disturbance of ground under the pipes to make the joints (as at present) unnecessary, and the top part of the chair (which for distinction is called a saddle-piece) being the last fixed, enables the workman and superintendent to see that the pipes are properly laid and fairly jointed. In case of stoppage the saddle is easily removed without in any way disturbing the invert or general drain; and the pipes being some distance apart, the state of the drainage can be easily ascertained." Other forms of pipes have been used, such as capped pipes, or pipes in which holes are made in the barrel of the pipe, covered by a cap. Some makers make the opening in the centre of the pipe, others at one end, as is shown in Fig. 31; others again as in Figs. 32 and 33, which represent one of Doulton's opercular pipes.

Capped pipes.

Fig. 31.

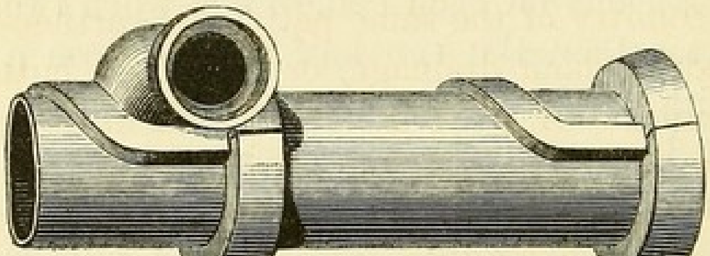


Fig. 33.

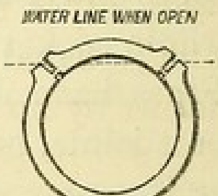
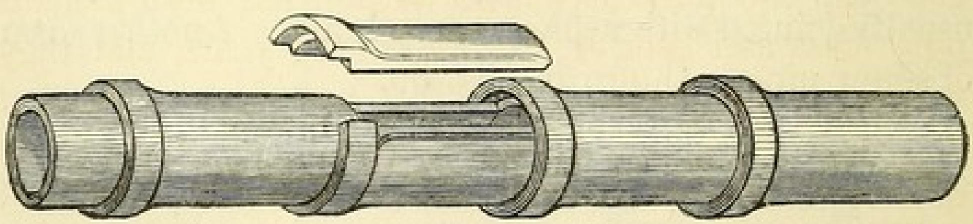


Fig. 32.



The cutting away of the barrel of every sewer pipe for the purpose of rendering it easy of inspection, or to facilitate the work of inserting junctions, to a very great extent interferes with the strength of the pipe, which under some circumstances may lead to their failure in the work. The objection to the use of half-socket pipes, and all those arrangements in which there is a joint about the centre of the pipe, is their liability to leak as soon as they begin to run more than half full. Since the introduction of the mode of laying sewers in straight lines on plan, with manholes or lampholes at changes of inclination or direction, the necessity for the most part has ceased to exist which brought out all those forms of sewer pipe which were made with a special view to facilitate the inspection of the sewers, but which, however ingenious in themselves, multiply the parts, and thereby complicate a work which should be of the simplest character.

Objections to some forms of pipe.

No necessity for certain forms of pipe.

About the period when earthenware sewer pipes were beginning to be manufactured in this country, pipes were made of Portland cement, but the enormous trade done in the manufacture of stoneware and fire-clay pipes so cheapened their cost, that the manufacturers of cement pipes could not compete with their more fortunate rivals. Pipes have been made of Portland cement in this country of the same pattern as earthenware pipes used for land drainage, or with both butt and rebated joints. A good Portland cement pipe forms by no means a bad sewer, and it will be a matter for the consideration of the engineer to ascertain if, instead of large pipe sewers, concrete pipes cannot be produced more cheaply, and are now made sufficiently good for the purpose. The author has seen cement pipes that had been in use for twenty years, and they were as sound at the end of that period as when first laid. Cement pipes of large size, with socket joints, are now extensively used in Germany, and they withstand not only the effects of a severe climate, but the chemical action of the sewage, and are produced at considerably less cost than either a brick sewer or a pipe sewer of equal calibre. Moreover, they show an extraordinary amount of endurance, and remain perfect after severe

Cement pipe.

Durability of cement pipes.

Cheapness of cement pipes.

Advantages of cement pipes.

frost, when brickwork often fails. It is a material that can be worked and moulded into any form, and maintains its form when made. It is also capable of repair, which is a point of no small importance. It is strong, as may be taken from the fact that pipes of this kind are extensively used under the embankments of the North Prussian railways. In a country like Germany, where good earthenware sewer pipes cannot be had unless imported, the use of concrete pipes for large sewers has been extensively introduced. The cement pipes now used in Germany are made with sockets, and pipes of 12 inches and upwards in diameter are made in lengths of about 5 feet each. The thickness varies with the diameter; pipes of 15 inches and 18 inches diameter have a thickness of about 2 inches. These pipes improve materially by age, and at the end of a year or two they ring, when struck, with a clear metallic sound. It is necessary to exercise great care in the choice of a cement to be used in the formation of sewer pipes, as some cements are particularly liable to fail from special causes, as will hereafter be pointed out.* The cement pipe manufacturers of Germany fully understand this, and consequently use the best Portland cement. Cement pipes of excellent quality, and fit for any sewer work, are made at the Thames Silicated Stone Works, at East Greenwich, by Messrs. Hodges and Butler. Large pipes made of this material are about the same expense as the best earthenware pipes. The smaller pipes are rather more expensive than earthenware pipes of the same size. They have, however, some advantage not possessed by pipes that have been subjected to great heat in the course of manufacture, that is, they are perfectly true in section, an advantage of no little importance if our sewers and drains are to be kept free from obstructions, which usually occur from materials being caught by the imperfect joints of the sewer. The author has care-

Use of cement pipes in Germany.

Form of cement pipe.

Choice of cement.

Pipes made at Silicated Stone Works, Greenwich.

Advantages of a cement pipe.

* *Vide* Table 49, p. 238.

fully watched the process by which these pipes are made, and has noted the care exercised in the selection of the materials, the elimination by washing of all dirt from the ballast, the mechanical perfection in which all the materials are brought together, and the careful admixture by machinery of one part of best Portland cement to three parts of prepared ballast, with only sufficient water to effect the proper admixture—a point of very considerable importance in the mixing of cement or concrete—and subsequently the mechanical means adopted for filling the wrought-iron moulds by special machinery, which secures the complete filling of the moulds without the presence of air holes, in the completed pipe. After the pipes have been thus prepared they are submerged in a bath of silicate of soda. By this means any free lime or alumina would thus form insoluble compounds of silicates of lime or alumina. The same materials combine to form a pipe made in this way as is the case in the best earthen goods. In earthenware it is the fusing action of fire that causes a combination of the materials, and in the silicated cement pipe we have the process of crystallization artificially set up, or the process which nature has adopted for the formation of some of the most enduring of rocks. In the jointing of a cement pipe with cement, there is a considerable advantage, as the crystallization in the setting of the cement is much more favourably conducted than in the case of cementing together materials of a nature differing materially from that of the cementing agent; hence a simple ogee rebated joint in a cement pipe when luted with neat cement requires a very considerable force to draw the pipes asunder. A 15-inch cement pipe jointed in this way has carried over a ton weight suspended from the lower pipe for a considerable period without failure. A stack of cement pipes of this description, 30 feet high, jointed as before described, when filled with water, are shown to be perfectly water-tight, and so impervious is the material,

Mode of manufacturing silicated cement pipes.

Treated with silicate of soda

Materials of earthenware and silicated cement pipes alike.

Advantages in jointing cement pipe.

Tests of cement pipe joint.

that no water is found to exude from the surface of the pipes under this pressure. The material of which a cement pipe is made is by no means so brittle as an ordinary earthenware pipe. A blow that would shiver in numerous pieces an ordinary earthenware pipe would simply drive a hole into a silicated concrete pipe. A concrete pipe is capable of withstanding the jars arising from heavy traffic over the streets even better than an earthenware pipe, which is a quality of no small advantage, as the author has found that in some districts earthenware pipes have been found to split in a singular fashion, the cause of failure being due to the constant tremor of heavy traffic in the streets.

Cement pipes not brittle.

Failure of earthenware pipes from tremor due to street traffic.

At the suggestion of the author, Messrs. Hodges and Butler, the makers of these silicated cement pipes, have submitted their manufacture to certain tests, which have been made by Mr. Henry Reid, C.E., of London, a gentleman who is thoroughly experienced in all matters appertaining to cements or concretes, and therefore very competent to conduct the tests. In a Report of the 11th March, 1878, Mr. Reid says:—

Tests by Mr. H. Reid, C.E.

Mr. Reid's Report.

"I have carefully tested the tensile strength of your artificial silicated stone, and find the average of the breakings to be as follows:

Tensile strength.

"No. 1 Briquette, fourteen days old, and kept in water, having a breaking section of 2·1 inches, broke at 496 lbs., being equal to 236 lbs. per square inch.

"No. 2 Briquette, seven days old, and kept in water, having a breaking section of 2·06 inches, broke at 464 lbs., being equal to 225 lbs. per square inch.

"I am of opinion that much more satisfactory results would have been obtained if the briquettes had been made of the usual shape. Owing to their being irregular in form, I was obliged to cut them to fit the clips of the testing machine, a very risky operation with such materials, which I fear has influenced these results.

"The samples of materials you sent me have been carefully analyzed, and I find the chemical value of the gravel compound to be as follows :— Analysis of materials.

" Water and loss	5·15
Oxide of iron and alumina	3·47
Lime	15·23
Soluble silica	10·80
Silica in the shape of pebbles and quartz sand	62·20
Magnesia, alkalies, carbonic acid, &c., not determined	3·15
	100·00 "

In a further Report of 20th March, 1878, Mr. Reid says :—

" These pipes are made with the best London Portland cement, weighing not less than 116 lbs. per imperial bushel. The aggregate employed is clean Thames gravel crushed by machine, and afterwards carefully washed. These two ingredients are accurately mixed in the proportions of one of cement to three of gravel. They are then moulded by a machine, and in a week's time or so, put into a bath of silicate of soda, where they remain for seven or eight days. Further Report of Mr. Reid.

" The test employed was a percussive or impact one, by dropping on the top of the pipes a cast-iron ball of 14 lbs. weight. The results were as follows :— Tests to resist impact.

Thickness and weight of cement pipes.

No.	Diameter of Pipe.	Thickness.	Weight.			Length.
	ins.	ins.	cwts.	qrs.	lbs.	ft.
1	6	$\frac{7}{8}$	0	1	13	2
2	9	1	0	2	6	2
3	12	1	0	3	1	2
4	15	$1\frac{1}{4}$	1	0	11	2
5	18	$1\frac{1}{2}$	1	2	17	2
6	24	2	2	3	14	2

" *Particulars of Tests.*

" No. 1. The ball was dropped on the centre of the top of the pipe—1st, at 1 foot high ; 2nd, at 1 foot 6 inches high, and at a height of 2 feet, when the pipe was slightly cracked across.

"The value of the impact blow is estimated at 158 lbs.

"No. 2. The ball was similarly applied as in the preceding test, and at 2 feet the pipe was fractured into several pieces.

"Impact value same as last (158 lbs.).

"No. 3. Ditto, and at 2 feet a slight crack occurred in the pipe.

"Impact value same (158 lbs.).

"No. 4. Ditto, and at 2 feet the pipe cracked right through on the upper side.

"Impact value same (158 lbs.).

"No. 5. Ditto, and at 2 feet the pipe was cracked in a straight line through the top of pipe.

"Impact value same (158 lbs.).

"No. 6. Ditto, and at 2 feet, but the pipe was not cracked until the ball was dropped from a height of 2 feet 6 inches. Crack only a fine one, and about one-half the length of the top of the pipe.

"Impact value estimated at 176 lbs."

Messrs. Sharp, Jones, and Co., rock concrete pipes.

Cement sewer pipes of excellent quality are also made by Messrs. Henry Sharp, Jones, and Co., of Bourne Valley Pottery, Poole, Dorset, who are also the manufacturers of earthenware pipes. Some doubts evidently having arisen as to the durability of pipes of this class manufactured by Messrs. Sharp, Jones, and Co., and used in the sewerage works of Bournemouth, the Improvement Commissioners sought the advice of Mr. Henry Reid, C.E., and he reported to them in reference to these pipes on the 11th March, 1878, as follows:—

Concrete pipes used at Bournemouth.

Mr. H. Reid's Report on rock concrete pipes.

"1st. The chemical analysis indicates that the concrete is good in its composition, and does not contain any ingredients likely to be prejudicially affected by sewage matter in any of its more objectionable forms.

Tensile strength of rock concrete.

"2nd. The tensile strength results were obtained by submitting to the testing machine a briquette cut out of the portion of pipe sent, and also from a briquette moulded by the manufacturers from the materials used in the fabrication of the pipe. The first briquette was unavoidably imperfect owing to the necessity of shaping it with a hammer and a chisel from the segment of pipe, and the impossibility, in consequence, of applying a true tensile strain. Notwithstanding this difficulty it sustained a tensile strain of 164 lbs. to the square inch. The second briquette, made from the same materials, and exact in form, gave much higher results, being equal to a strain of 370 lbs. per square inch.

Effects of frost on rock concrete pipes.

"3rd. The degree of cold, or its equivalent, to which I submitted a portion of the pipe far exceeded any frost likely to be experienced in an English climate, and this test resulted in the slightest perceptible appearance of degradation of the surface, indeed so slight as to be beyond the ordinary means of estimation.

Test of hydraulicity.

"4th. The test of hydraulicity is a most important one, especially where the materials are to be used in damp or wet situations, and after the most rigid test had been applied, no signs of weakness occurred either in the concrete or the fragment of stoneware pipe.

Test by impact.

"I applied the impact or percussive test by which the strength of this class of pipe is usually valued on two 2-feet concrete pipes, similar to those used by your Board. The application of this test was pursued to the point of fracture, which occurred after repeated blows by the dropping of a 7-lb. iron weight from a height of 5 feet. This result may be regarded as highly satisfactory.

"There is a peculiar advantage possessed by concrete pipes in their continuing to harden or indurate after being laid (more especially in damp positions) for years."

Sizes of pipes made.

The manufacturers of these pipes only make "rock concrete tubes," as they are called, of from 18″ to 30″ internal diameter, as the smaller sizes cannot be made at a price to effectually compete with glazed stoneware. The principal aggregate used in the manu-

Aggregate used in making rock concrete pipe.

Test of crushing concrete pipes.

facture of the concrete tubes is broken stoneware, and the materials are compressed in the moulds in the process of manufacture. Tests applied by the manufacturers in crushing 18-inch pipes, which had a thickness of $1\frac{1}{2}$ inch, are reported to have given the following results:—

	Crushing Load in lbs.
18″ stoneware pipe	3056
18″ rock concrete pipe	4977

Crushing cube of concrete.

The force required to crush a $1\frac{1}{2}$-inch cube of this material was also found to be 3·15 tons. Favourable reports have been received from places where these "rock concrete tubes" have been laid, so that there appears to be no reason why tubes of this class should not meet with a ready demand for the construction of sewers.

Cement sewers of Paris.

Silicated cement pipe sewers in America.

Some miles of sewers in Paris have been successfully constructed of "béton aggloméré́s," a concrete that will not compare with our Portland cement concrete, and in some towns in America many miles of silicated cement pipes have been laid.

Trees to be avoided.

In the construction of earthenware pipe and other sewers, where it is possible, trees should be avoided, as their roots will interfere with, and injure the action of, the sewer. The rootlets of trees will extend to considerable depths in search of nutriment or moisture.

Stoppage of sewers by roots of trees.

Measures to be adopted with trees.

The author has seen a case in which the fine rootlets of a tree entered the joints of a 15-inch pipe sewer, and, after gaining access to the interior, each of the rootlets developed to such an extent as to completely fill and choke the sewer. Where trees are unavoidable, the work should either be constructed in iron and jointed with lead, or some effectual provision must be made for excluding the roots. A mass of concrete of sufficient thickness placed round the sewer is as effectual a barrier to the roots of trees as can be artificially formed. The jointing of earthenware pipes with asphalte will probably prevent the entrance of the roots of trees, as they cannot withstand the action of the tarry compounds of asphalte. A patent was taken out in this country by Mr. E. Newton, for Mr. J. L. Graham, of New York, U.S., in 1871, for jointing pipes with asphalte. The use of asphalte for the purpose of cementing materials was known and used in ancient times, for we read that the Assyrians adopted this mode of construction in cementing burnt bricks used in building the walls of Babylon and Nineveh.

Use of asphalte for building.

CHAPTER XIX.

BRICK SEWERS.

Selection of bricks.

The selection of bricks for the construction of sewers is a matter that requires a considerable degree of attention at the hands of the engineer. The variableness of the quality of bricks throughout the country is only equalled by the diversity of kinds which are to be found. For sewer works, specially sound bricks are required, as such bricks are subjected to a variety of forces, all tending to their destruction,—such as sudden changes of temperature, chemical and mechanical action, &c. As a general rule, it may be taken for granted, that bricks of an extremely absorbent character are not well adapted for the construction of sewers. There are, however, exceptions to this rule in practice, for some very absorbent bricks are extensively used in the construction of sewers, such, for example, as gault bricks. All bricks which are not sufficiently burnt, of whatever description, should be cast aside as totally unfit for sewer work. Bricks used in sewers should have some degree of toughness, and considerable hardness. Perforated bricks are not well adapted for the construction of impermeable sewers, on account of the difficulty of rendering the work water-tight. The best bricks for the construction of sewers, more especially for those parts of the sewer liable to wear and tear from the erosion of the water, and the materials transported over the bed of the sewer, are the blue Staffordshire, or the Buckley bricks from North Wales. Excellent glazed fire-bricks are now made for sewer purposes at Wortley, near

Unburnt bricks should be rejected.

Perforated bricks.

Bricks for the inverts of sewers.

Leeds. Next in order of merit, some of the fire and terra-cotta bricks, and then follow gault bricks. In nearly all parts of the country bricks are found that are well suited for the construction of some part of a sewer, but the bricks above enumerated are undoubtedly the best for inverts and other parts liable to special wear and tear. If there should arise any doubt as to the suitability of a brick for sewer work, it may be tested by first soaking it in water and exposing it to frost; or, should this mode be unavailable, then weigh the brick and steep it for a week in a strong solution of sulphuric acid, weighing it after the test when dry. Another test, equally applicable to brick, stone, mortar, &c., is given in the 'Annales de Chimie et de Physique,' vol. 38, and is as follows:—"Prepare a cold saturated solution of sulphate of soda, then bring it to the boiling point, and suspend in it, by a string, for thirty minutes, the sample under trial; then pour the liquid, free of sediment, into a flat vessel, and suspend the stone over it in a cellar. When efflorescences appear on the specimen, it must be dipped in the solution, say two or three times a day for about a week; at the end of which time the quantity of earthy sediment in the vessel, collected on a filter and weighed, will indicate the effect to be expected from frost on the same sample." If no loss in weight occurs, and the brick in other respects is found to withstand the test, it may be safely used in the construction of sewers. Very soft bricks should on no account be used in the construction of sewers, but the roughness of the face of a brick is no material drawback to its use in the sides of a sewer, provided that there are not any real asperities on the surface that would interfere with the flow. for in all channels a lamina of water adheres to the sides, and the frictional resistance to the flow in consequence is not materially affected by the quality of the material. This, however, would not apply to the invert of a sewer,

Test for bricks.

Soft bricks should be rejected.

Rough bricks.

TABLE No. 45.—Showing the AMOUNT of ABSORPTION of WATER and the STRENGTH of BRICKS.

No.	Description of Brick.	Where Manufactured.	Name of Maker or Agent.	Size of Brick. Length in inches.	Breadth in inches.	Thickness in inches.	Weight when Dry.	Weight when Wet.	Amount of Water absorbed.	Percentage of Water absorbed.	Load at which Brick cracked.	Force required to crush Brick.	Force required to crush Brick in tons per sq. inch.	Remarks.
							lbs.	lbs.	lbs.		lbs.	lbs.		
1	Dressed blue brick	Handford, Stafford	S. Glover	8·90	4·37	3·05	9·213	9·503	0·290	3·147	48,944	216,944	2·490	
2	" "	" "	"	8·88	4·43	2·98	9·209	9·364	0·155	1·683	54,544	230,944	2·620	
3	" "	" "	Roe and Son	9·24	4·52	2·95	9·587	9·754	0·167	1·741	9,744	312,144	3·336	
4	" "	" "	"	9·25	4·57	2·90	9·518	9·777	0·259	2·721	26,544	261,968	2·766	
	Average of dressed blue brick	..	..	..	..	..	..	..	..	2·323	34,944	255,500	2·803	
5	Pressed blue brick (with frog)	Handford, Stafford	S. Glover	8·98	4·58	2·85	8·824	8·912	0·088	0·997	57,344	144,144	1·564	
6	" " "	" "	"	9·15	4·55	2·94	9·001	9·190	0·189	2·099	48,944	186,144	1·996	
7	" " "	" "	Roe and Son	9·07	4·42	2·93	8·791	8·932	0·141	1·603	62,944	129,024	1·436	
8	" " "	" "	"	8·90	4·50	2·85	8·760	9·155	0·395	4·509	60,144	145,824	1·625	
9	" " "	Longton, Stafford	Prockter and Benbow	9·30	4·55	3·00	9·288	9·888	0·600	6·459	43,344	68,544	·723	Brick not entirely crushed.
10	" " "	" "	" "	9·22	4·63	3·20	9·790	10·251	0·461	4·708	28,224	55,664	·582	
11	" " "	West Bromwich	G. Wood	8·85	4·10	2·60	7·267	7·611	0·344	4·596	70,784	406,224	4·997	Brick crushed to powder.
12	" " "	" "	"	9·00	4·34	2·65	7·683	8·061	0·378	4·919	14,224	172,144	1·967	
	Average of pressed blue brick	..	..	..	..	..	..	..	..	3·736	48,244	163,464	1·861	
13	Common blue brick	Handford	S. Glover	9·45	4·28	3·02	8·504	9·066	0·562	6·608	20,944	110,544	1·220	
14	" "	"	"	9·00	4·30	3·05	8·121	8·748	0·627	7·720	26,544	85,904	·991	" "
15	" "	Longton	Prockter and Benbow	9·70	4·50	2·98	9·647	10·117	0·470	4·871	33,824	82·544	·844	
16	" "	"	" "	9·40	4·45	3·00	9·604	10·252	0·648	6·747	34,384	71,344	·761	
	Average of common blue brick	..	..	..	..	..	..	..	..	6·486	28,924	87,584	0·954	
17	Bastard brick	Longton	LongtonHall CollieryCo.	9·17	4·55	3·10	9·156	10·236	1·080	11·795	51,744	79,744	·853	
18	"	"	" "	9·30	4·62	3·33	9·837	11·004	1·167	11·863	68,544	111,664	1·160	
	Average of bastard brick ..	..	..	..	..	..	..	..	..	11·829	60,144	95,704	1·006	
19	Wire-cut white gault brick ..	Arlsey	Gt. Northern Brick Co.	9·20	4·43	2·67	6·235	7·494	1·259	20·192	15,344	103,824	1·137	
20	" pink " ..	"	" "	9·08	4·45	2·65	6·162	7·287	1·125	18·257	15,344	132,944	1·468	" "
21	" white " ..	Sevenoaks	T. H. Crampton ..	8·97	4·27	2·73	5·875	7·100	1·225	20·851	32,144	118,944	1·386	
22	" " " ..	"	J. R. Heward	8·93	4·17	2·85	6·404	7·493	1·089	17·004	34,944	118,944	1·426	
	Average wire-cut white gault brick	..	..	..	..	..	..	..	..	19·076	24,444	118,664	1·354	
23	Pressed gault (with frog) ..	Arlsey	Gt. Northern Brick Co.	9·00	4·40	2·77	5·814	6·938	1·124	19·332	20,944	38,864	·438	
24	Perforated pressed white (with frog)	"	" "	8·66	4·10	2·63	5·172	6·089	0·917	17·730	11,984	87,584	1·101	
25	" " "	"	" "	8·76	4·13	2·60	5·277	6·259	0·982	18·609	26,544	*337,232	4·161	
26	White pressed gault (with frog)	Sevenoaks	J. R. Heward	8·97	4·44	2·64	5·973	7·081	1·108	18·550	15,344	99,344	1·113	
27	" " "	"	T. H. Crampton ..	9·00	4·40	2·65	6·201	7·372	1·171	18·884	40,544	102,144	1·151	
28	Gault machine made "	"	" " ..	8·85	4·34	2·70	5·779	7·065	1·286	22·252	16,464	90,444	1·057	" "
29	White gault "	Chilton, Suffolk	..	9·17	4·52	2·63	5·889	7·114	1·225	20·801	11,984	52,304	·563	" "
30	Pink gault "	" "	..	9·06	4·55	2·67	6·167	7·364	1·197	19·393	16,464	66,864	·724	

No.	Description	Locality	Maker											Remarks
31	White gault, machine made (with frog)	Burham	Burham Brick Co. ..	8·93	4·20	2·80	5·851	6·954	1·103	18·851	15,344	73,024	·869	Brick crushed to powder.
32	,, ,, ,,	,, ...	,, ,, ..	9·03	4·25	2·80	5·975	7·180	1·205	20·167	Under 4,000	94,864	1·103	
	Average of pressed gault brick	..	..	..	..	..	..	..	..	19·456	17,961	104,266	1·228	
33	Common red brick	Longton	T. Newbon	9·25	4·30	3·10	8·093	8·906	0·813	10·045	Under 4,000	50,624	·568	
34	,, ,, ...	,, ...	,, ...	9·08	4·28	3·05	7·945	8·759	0·814	10·204	43,344	76,944	·883	
35	,, ,, ...	,, ...	R. Steele	8·95	4·20	2·97	7·462	8·210	0·748	10·024	28,224	108,864	1·292	,, ,,
36	,, ,, ...	,, ...	,, ...	9·00	4·30	2·90	7·344	8·042	0·698	9·504	9,744	95,424	1·100	
	Average of common red brick	..	..	..	..	..	..	..	..	9·944	21,328	82,964	0·960	,, ,,
37	Common stock brick (with frog)	Croydon	Collis	8·60	3·90	2·58	5·028	5·362	0·334	6·642	23,184	*374,864	4·917	
38	Picked ,, ,,	Reigate	Thornton	9·15	4·18	2·46	4·906	5·541	0·635	12·943	24,304	135,184	1·577	,, ,,
39	,, ,, ,,	,, ...	,, ...	9·00	4·15	2·62	4·933	5·674	0·741	15·021	19,824	*349,776	4·180	
	Average common stock brick..	..	..	..	..	..	..	..	..	11·535	22,437	286,608	3·558	
40	Pressed red brick (with frog)..	Wortley (Leeds)	Ingham and Sons ..	9·48	4·62	3·18	9·781	10·623	0·842	8·608	38,864	107,744	1·908	
41	,, machine made (with frog)	,, ,,	,, ,, ..	9·34	4·45	3·44	9·823	10·747	0·924	9·406	54,544	79,744	·856	
42	,, ,, ,,	,, ,,	,, ,, ..	9·32	4·40	3·42	9·776	10·793	1·017	10·403	48,944	66,864	·727	
	Average of machine-made pressed red brick ..	..	..	..	..	..	..	..	..	9·904	51,744	73,304	·791	
43	Brown glazed brick (with frog)	Wortley (Leeds)	Ingham and Sons ..	8·95	4·38	3·40	8·552	9·315	0·763	8·920	37,744	51,744	·589	
44	,, ,, ,,	,, ,,	,, ,, ..	9·00	4·40	3·38	8·390	9·083	0·693	8·259	34,944	50,624	·570	
	Average of brown glazed brick	..	..	..	..	..	..	..	..	8·589	36,344	51,184	0·579	
45	White glazed terra-cotta (with frog)	Wortley (Leeds)	Ingham and Sons ..	8·80	4·38	3·15	7·511	8·259	0·748	9·958	29,904	17,144	·858	
46	Fire-brick, No. 1.	Stourbridge ..	A. Williams, 64, Bankside, S.E.	9·20	4·41	2·54	7·153	7·807	0·754	10·542	60,144	104,944	·1154	,, ,,
47	,, ,, ...	,, ..	,, ,,	9·18	4·30	2·46	7·178	7·837	0·659	9·180	60,144	113,344	1·281	,, ,,
48	,, ordinary	,, ..	,, ,,	9·20	4·45	2·37	7·388	8·037	0·649	8·748	71,344	127,344	1·388	,, ,,
49	,, ,, ...	,, ..	,, ,,	9·14	4·55	2·52	7·204	7·891	0·687	9·536	32,144	110,544	1·186	
	Average of fire-brick (Stourbridge)	..	..	..	..	..	..	..	..	9·510	55,944	114,044	1·252	
50	Furnace brick	Leemoor	Martin	9·15	4·38	2·51	7·539	7·961	0·422	5·597	48,944	108,304	1·206	,, ,,
51	,, ...	,, ...	,, ...	9·08	4·30	2·57	7·087	7·391	0·304	4·289	15,344	137,984	1·577	
	Average of furnace bricks (Leemoor)	..	..	..	..	..	..	..	..	4·943	32,144	123,144	1·391	
52	Fire-brick	Newcastle.. ..	A. Williams, 64, Bankside, S.E.	8·90	4·40	2·42	6·173	6·837	0·664	10·756	57,344	96,544	1·100	
53	,, ...	,, ...	,, ,,	8·93	4·40	2·45	6·120	6·675	0·555	9·068	62,944	107,744	1·222	
	Average of fire-brick (Newcastle)	..	..	..	..	..	..	..	..	9·912	60,144	102,144	1·161	
54	Fire-brick	Dinas..	..	8·92	4·25	2·50	6·353	6·953	0·600	9·444	32,144	107,744	1·268	
55	,, ...	,, ...	..	8·93	4·40	2·38	6·324	6·914	0·590	9·327	93,774	112,224	1·275	,, ,,
	Average of fire-brick (Dinas)	..	..	..	..	..	..	..	..	9·385	62,944	109,984	1·271	
56	Fire-brick, red	Welsh	..	8·65	4·28	2·65	6·586	6·990	0·404	6·134	18,704	99,344	1·197	,, ,,
57	,, ,, ...	,, ...	..	8·64	4·25	2·46	6·447	6·850	0·403	6·250	46,144	139,664	1·698	,, ,,
	Average of red fire-brick (Welsh)	..	..	..	..	..	..	..	..	6·192	32,424	119,504	1·447	

* This brick was considerably compressed before being crushed.

over which solid matters, such as stones, sand, and other things, are often rolled along. The friction of these matters on the invert of a sewer, constructed of rough bricks, would be considerable, consequently in such cases it is advisable to use glazed bricks, or invert blocks, to form the invert of the sewer. In those districts in which the quality of the bricks is such as to render them, from their character and durability, fit for the construction of certain parts of sewers, though from their roughness they would be ineligible for the invert of a sewer, special bricks or inverts should be used, making use of the local bricks for the construction of the sides and arches of the sewer, and thereby considerably decreasing the cost of the work. The forces principally at work upon a sewer are external, therefore the bricks may be said to be in a state of compression, consequently the only mechanical test to which it is necessary to subject bricks that are to be used in the construction of sewers, is the crushing test. Of course, it is well that they should also be tested for hardness and their power of absorbing moisture. Table No. 45 shows a number of experiments made by the author upon various bricks, giving their size, weight, the amount of water they are capable of absorbing, and the crushing force necessary to destroy them.

Friction on invert of sewer.

Forces at work in sewer.

Table 45.

It will be seen, on referring to the foregoing Table, that picked stock bricks are less absorbent and are capable of supporting as great a crushing load as gault bricks. This quality of stock bricks is due to the peculiar nature of the material, which is not brittle, therefore it compresses when subjected to great strain. For example, brick No. 37 in the Table had an original thickness of 2·58 inches, but was compressed in the hydraulic press to 1·08 inch in thickness before it failed, and No. 39 in the Table had an original thickness of 2·62 inches, and was compressed to 1·14 inch in thickness. The gault brick that bore the greatest strain, No. 25 in the Table, was likewise compressed

Comparison between stock and gault brick.

from 2·60 inches in thickness to 1·23 inch in thickness before it failed. This degree of compressibility of the gault brick was an exceptional circumstance, which accounts for the great load borne by it.

An instance of the evil effects of free lime in building materials is given by Mr. H. Reid, C.E., in his work on Portland Cement, which occurred in building the piers for the sewage reservoirs at the Crossness Pumping Station. Some of these piers, which were to carry the arched covering, had been built of Suffolk facing bricks, when it was found "that they became distorted and incapable of receiving the weight which they were intended to sustain; in fact, were dangerously disjointed." The cause was ascribed by Mr. Reid, who inspected them, to the fact that the bricks "had become saturated with water and thus developed a faulty process of manufacture. An excess of chalk marl had been blended with the earth from which they were made, and the free lime, imperfectly mixed, became hydrated by the rain, and produced the distortion of the piers."

Example of injurious effects of free lime in building materials. Mr. H. Reid.

Chalk marl used in brick making.

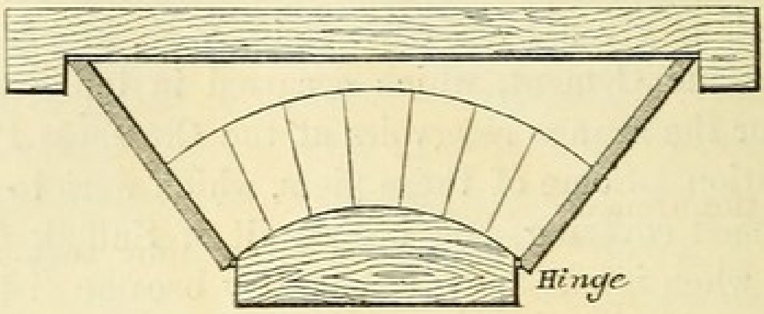
Where bricks are exclusively used in the construction of small sewers, or sewers of oval section, in which the radius of the curve of the invert is small, the sewers should be built up of bricks specially made to the proper radius. Ordinary shaped bricks are totally inadmissible for the construction of small brick sewers, on account of the wide gaping joints they leave at the back, as shown in Fig. 10, page 77. In order to secure the greatest uniformity in the sectional form of small sewers, especially their inverts when constructed in brickwork, it is customary in some cases to cast the sewer in sections in wooden moulds specially adapted for the purpose. These moulds consist of long troughs, the bottoms of which are made to the true curve of the sewer. The sides of the troughs are hinged and are kept at the proper radius by means of ties placed over the top, as shown in section, Fig. 34.

Radiating bricks.

Brick blocks.

The trough is divided by movable boards, which are placed so as to admit of a block 14 inches or 18 inches in length being made, as may be required. The bricks

FIG. 34.



are laid in the troughs, and when the trough, or any one of its divisions, is filled with bricks, cement grout is poured in and fills all the interstices and joints. After the cement has had time to set, the blocks are removed, and each one forms a perfect section of a part of the sewer. Sewers should not be entirely built up of blocks, as there is a want of bond in such work; consequently the work is not so strong as a sewer well built up of separate bricks, but brick blocks form a valuable auxiliary, especially in constructing the inverts of sewers in bad ground. Terra-cotta and enamelled bricks have been proposed for lining sewers, but neither have hitherto been brought into general use, and as equally durable and serviceable material can be procured at less cost, they are not likely to meet with any considerable demand for this purpose. Invert blocks constructed of terra-cotta, stoneware, or fire-clay, and glazed upon the invert face, are now very generally used in the construction of brick sewers of moderate size. Invert blocks greatly facilitate the construction of the sewer, and from their durability, and the smoothness of their surface, are well adapted for the formation of the invert of sewers. Invert blocks are now made both solid and hollow, the latter with both butt and lipped joints. The lipped joints are preferable, as these blocks are less liable to settle in the work than plain

Terra-cotta and enamelled bricks.

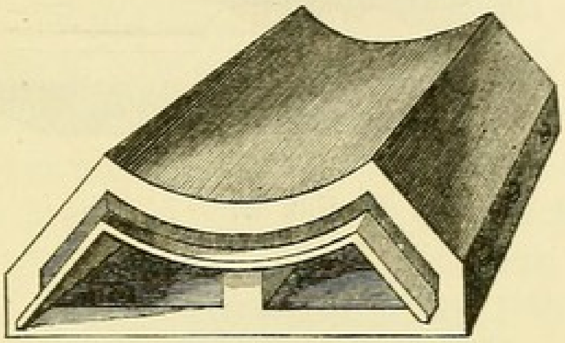
Invert blocks.

butt-jointed inverts. Fig. 35 shows a bird's-eye view of a hollow lipped invert block.

Drainage through invert blocks.

One advantage claimed for these invert blocks is that

Fig. 35.



the continuous opening through the blocks affords a ready mode of getting rid of subsoil water during the construction of the work; at the completion of the work these openings should be stopped up to prevent damage to the sewer. Experience of late years has shown that the use of hollow invert blocks is often attended with great inconvenience. These blocks have to receive the full force of the pressure of the weight of the sewer and its contents, and also the burden of the superincumbent earth. As a consequence it is not unfrequently found that they split in the work. Why invert blocks were made hollow one cannot well conceive, unless it was to save material and carriage. Many engineers who use hollow invert blocks have the hollows filled with concrete before they are laid. One of the best forms of invert block in the author's experience is that shown in Figs. 36 and 37. This form has been used in the sewers of Longton, Fig. 37 being a section of the Longton outfall sewer, the invert of which is lined with solid terro-metallic blocks grooved at each end and round the sides, as shown in detail in Fig. 36. The blocks are laid in the work so as to break joint, the cement jointing material entering the grooves of the blocks effectually keys the whole work. This mode of constructing a sewer is one of the best and

Objections to hollow invert blocks.

Solid invert blocks.

most durable it is possible to introduce. When using hollow invert blocks for the purpose of drainage, in many cases they have caused settlements to take place

Fig. 36.

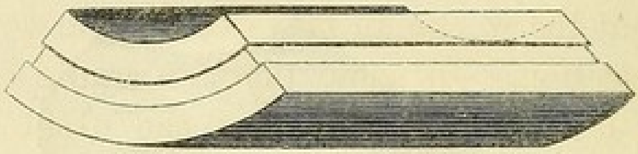
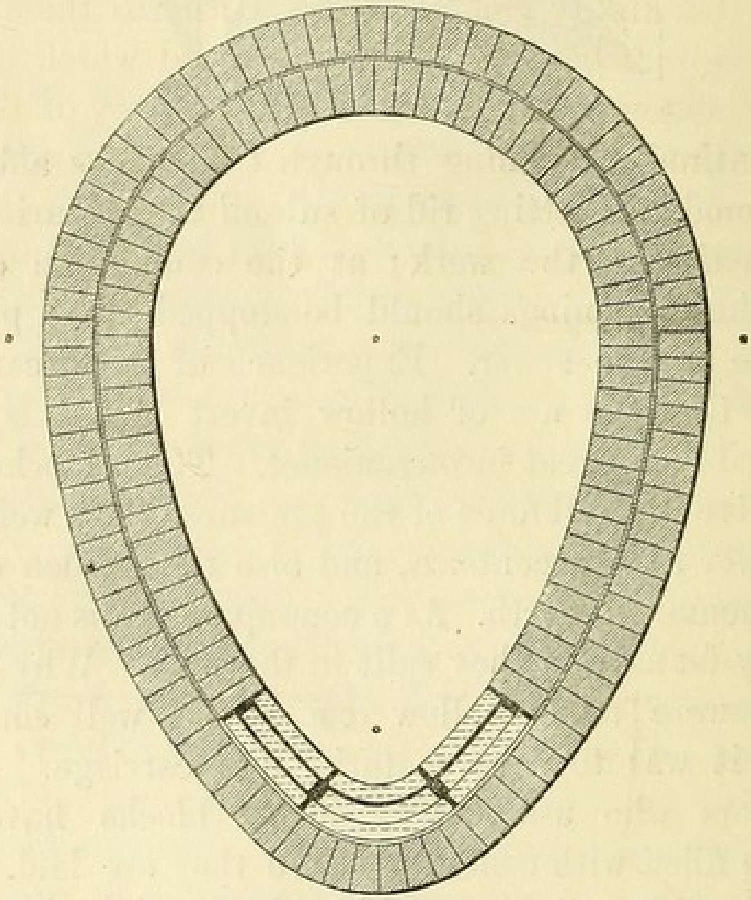


Fig. 37.



in the sewer, especially in sandy soils, as the sand gets washed into the hollow space of the invert, or through the joints (which it is almost impossible to make water-tight), into the sewer, the gradual removal of the sandy foundation of a sewer leads to settlement in the work. As a matter of practice it is almost impossible to make water-tight sewers, when constructed with hollow invert blocks. The inverts of large sewers should be lined with blue Staffordshire or glazed fire-bricks, or other

Inverts of large sewers.

bricks that are hard, smooth, and adapted for the purpose.

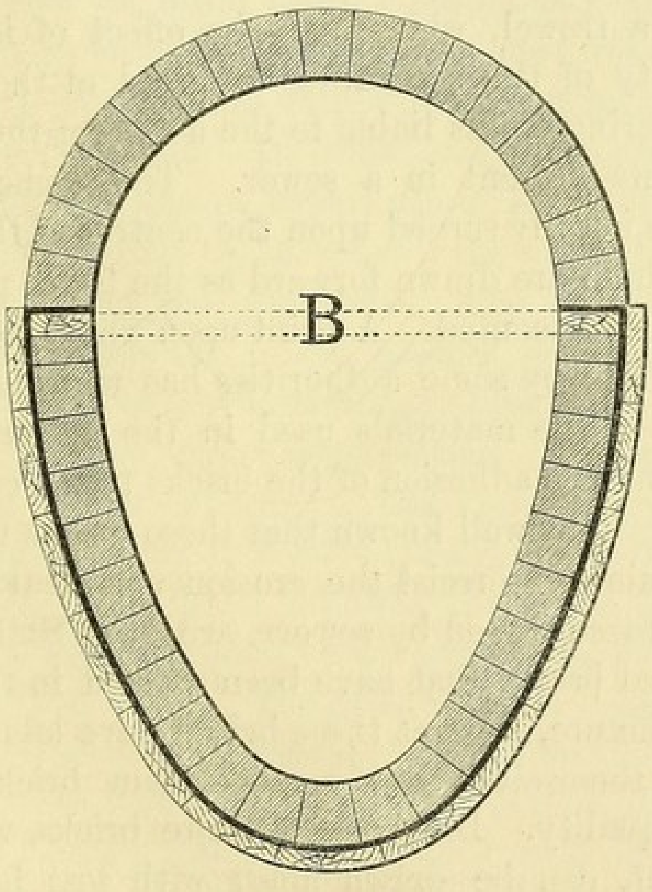
In the building of brick sewers, whether oval, circular, or otherwise shaped, templets should invariably be used, made to the true section of the sewer, in order that the workman may execute the work perfectly true in section. In some places a cradle consisting of wooden laggings is formed of the exact size of the external dimensions of the sewers, and in which the brickwork is built. The use of cradles in bad ground is to be highly commended. Hitherto these cradles have been formed with ribs of wood which are built into the sewer and interfere with the key of the work. Mr. Alfred Brittain, of Montreal, has proposed an improvement on the old form of cradle, the cradle rib in this case being formed of wrought iron, and the cradle

Use of templets.

Use of cradles for sewers.

Mr. Alfred Brittain's cradle and cradle rib.

Fig. 38.



is temporarily braced with a wooden brace B, Fig. 38. The wrought-iron rib is shown by the dark portion, the wooden lagging being placed outside the rib. Cradles of this kind, or entirely made in thin wrought iron, may be used with advantage when constructing brick or other sewers in quicksand, bog, or some other descriptions of equally bad ground. Care must be taken when building brick sewers, that a sufficient amount of cementing material is used in the work, in order to fill up every interstice and to render the work water-tight, and also that the cement or mortar used for the purpose is suited for the particular work. When a brick sewer is built up in a number of rings, it is advisable in bad ground to make a collar joint in cement 1 inch in thickness between the rings of brickwork, so as to make the sewer water-tight. The sewer Fig. 37 is shown to have a collar joint between the rings of the brickwork. The joints of the brickwork should not exceed one quarter of an inch in thickness, and they should all be stroked with the point of a trowel, which has the effect of increasing the density of the cementing material at the surface, and rendering it less liable to the action of the destructive agents present in a sewer. The arches of the sewer are usually turned upon the centres of the proper radius, which are drawn forward as the lower portion of the sewer is executed. A point upon which some stress has been laid by some authorities has reference to the selection of the materials used in the construction of sewers, and the adhesion of the bricks to the cementing material. It is well known that those bricks which are best calculated to resist the erosion and wear and tear of matters conveyed by sewers, are blue Staffordshire bricks, and bricks that have been pressed in the course of manufacture, and yet these bricks have less adhesion between themselves and cement than bricks of an inferior quality. Blue Staffordshire bricks, when laid in cement, can be drawn apart with less force than is required to separate two ordinary stock bricks, the latter bricks being totally unfit for the construction of

Cementing material.

Cement joints.

Arches of sewers.

Adhesion of cement and bricks.

the invert of a sewer. This want of adhesion between the cementing material and the best of bricks is, however, no particular objection to the use of such materials in a sewer, as it has already been mentioned that the principal strains upon a sewer, and by which it would fail, are not internal but external. In an ordinary cutting the weight of the superincumbent earth is far greater than the internal pressure; consequently, as there is no tendency for the work to be drawn asunder by tensile strains, the non-adhesion of the cement and bricks is no great drawback. There is adhesion enough in any case to maintain the shape and solidity of the work, and to render it water-tight, and the cementing material, if properly compounded, will bear as great crushing strains as the best of bricks.

Want of adhesion no objection.

In cases in which much subsoil water occurs, when constructing ordinary brick sewers, it is customary to put in a line of drain pipes continuously under the brick sewer in order to convey away the subsoil water, and to give time for the brickwork to set before being exposed to its action. In other cases sump-holes are sunk outside the line of sewer, which are continuously pumped out in order to keep down the subsoil water to a lower level than the brickwork. The engineer, however, must be on his guard against indiscriminately adopting measures for the drainage of his sewer trenches while the sewer is under construction. The author, in the course of his experience, has known very serious settlements to occur in sewers constructed with drains under them, which have led away the water, and have also carried away the sand which formed the supporting material of the sewer. The great point to bear in mind in the construction of brick sewers in ground surcharged with water, is that the water must not be allowed to come into contact with the brickwork until the mortar has set. If this is not provided for, the soluble parts of the cement will be washed out, and the cement afterwards will never properly set, or will set only in

Subsoil drains.

Drainage by sump-holes.

Damage arising from drainage of sewer trenches.

patches, leaving the sewer completely pervious. In providing proper drainage for the sewer trench the engineer must be careful not to undermine the finished work by his drainage operations. A very important point in the construction of brick sewers is to see that the bricks are perfectly saturated with water before being applied in the work. If this is not done they will rob the cementing material of the moisture necessary for its crystallization and setting, and as a natural consequence the quality of the cementing material will be greatly impaired.

Wetting of bricks.

In ordinary cuttings of 20 feet, and under, in depth, when executed in good ground, and when the greatest internal dimension of the sewer does not exceed 3 feet, it is customary to build the sewers, whether circular or oval, with a $4\frac{1}{2}$-inch ring of brickwork. Sewers from 3 feet to 6 feet in size are usually built in 9-inch brickwork, and for greater sizes the thickness is increased accordingly. Sewers with straight sides require at least 50 per cent. greater thickness of material than curved sewers of equal dimensions.

Thickness of brickwork.

The following formula will be found convenient for determining the proper thickness of the brickwork of sewers :—

Formula for determining thickness of brickwork.

$$\frac{dr}{100} = \text{thickness of brickwork in feet.}$$

d = depth of excavation.
r = external radius of sewer.

Example.

As an example, take a sewer 6 feet internal diameter executed in a 20-feet cutting. It is known from what has been previously stated, that in practice the brickwork of a sewer of this size should be 9 inches in thickness, therefore the external radius of the sewer would be $3\cdot75$ feet, and $\frac{20 \text{ feet} \times 3\cdot75}{100} = \cdot75 \text{ feet} = 9 \text{ inches.}$

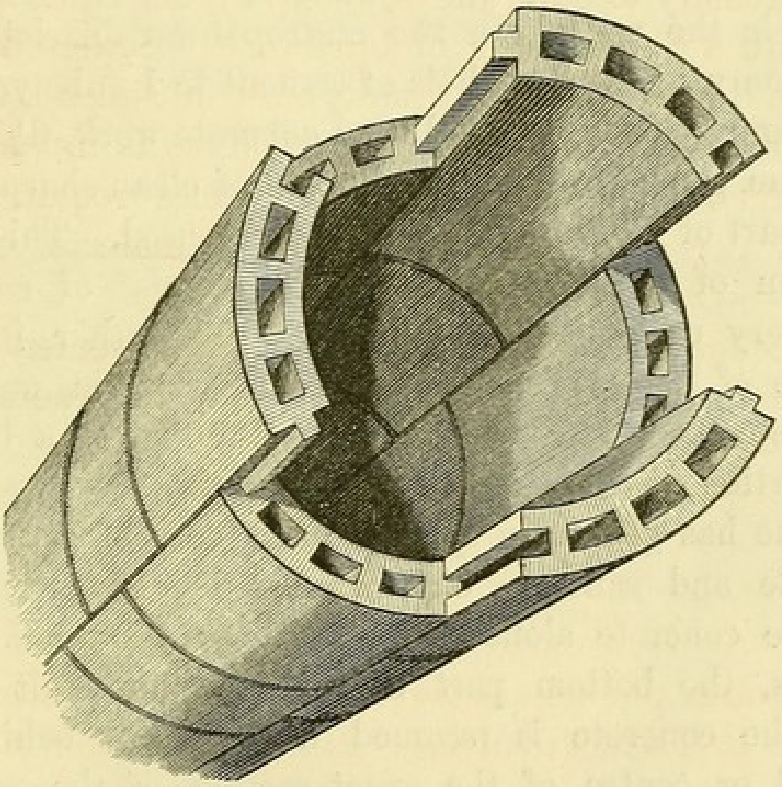
For all sizes and depths of sewer, when this formula gives a less thickness than is equally divisible by any number of half bricks of $4\frac{1}{2}$ inches, the proper thickness must be determined, so as to make it fall within and not without the last ring of the brickwork. For example, suppose the formula gave the thickness to be 1 foot, the sewer should be built in three rings of brickwork; or if the thickness given is 15 inches, then the brickwork should be four rings in thickness. The above formula is computed from the safe load that brickwork will sustain, which, in this case, after allowing for any imperfection in the nature and quality of the materials or workmanship, is taken as equal to a column of average earth 100 feet in height.

Basis on which formula is computed.

Segmental sewers.

Sewers have been made in segments of various shapes and materials. Fig. 39 represents a segmental

Fig. 39.



sewer as manufactured by Messrs. Henry Doulton and Co.

The advantages claimed for this description of sewer are that they are strong, are readily put together, pack closely for transit, and form an imperishable sewer; but it has the disadvantage that it cannot be made so watertight as a brick or concrete sewer.

CHAPTER XX.

CONCRETE SEWERS.

Recipe for making concrete.

The use of concrete in the construction of sewers may be adopted with advantage, provided the work is well executed. In constructing sewers of concrete the author has generally used a mixture of one part of Portland cement, two parts sand, and three parts of stones, broken so as to pass through a 1½-inch sieve turned over on a proper mixing platform, and used fresh in the work. In the metropolitan district it is customary to use 3 bushels of cement to 1 cube yard of sand and shingle. In ordinary concrete work, 6½ parts of clean gravel or shingle, 2½ parts of clean sharp sand to 1 part of Portland cement may be used. This proportion of mixture contains 2½ bushels* of cement in every cube yard of concrete. The author, in the course of his experience, has found that in making concrete for sewer work, it is advisable that a larger proportion of cement should be used than given above, and he has generally specified six parts of gravel or shingle and sand to one part of Portland cement.

Moulds for concrete sewer.

Where concrete alone is used for the construction of sewers, the bottom part of the sewer is built first, and the concrete is rammed into position behind a mould or centre of the exact section of the sewer; these moulds are sometimes covered with sheet zinc, and when in use are either greased over, or coated with soft soap, so as to render the face of the work as smooth as possible. The upper portion of the work is turned upon centres covered with metal in a manner analogous to that of brick sewers. The concrete ought to be

* A bushel is 1·28 cube foot.

worked immediately it is put into position with the shovel to bring the finer parts into contact with the centres, so as to secure a good face for the interior of the sewer. In some cases the sewers are pargeted with a coat of cement inside, but a good concrete sewer should require very little fettling when completed.

Examples of concrete sewers.

Fig. 40 represents an oval sewer constructed entirely in concrete. Fig. 41 represents a similar sewer, which is given as an illustration by Mr. John Grant, C.E., as a specimen of Portland cement concrete work, in his paper read before the Institution of Civil Engineers, in April, 1871. It represents a section of the Earl sewer constructed in the Deptford Lower Road. Mr. Grant states, with regard to this sewer, that it is

Fig. 40.

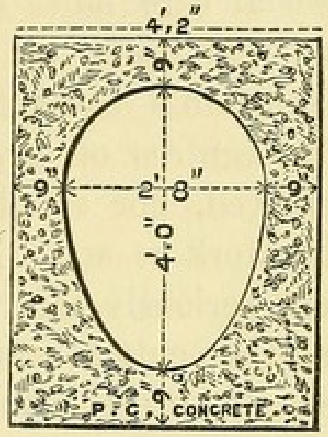
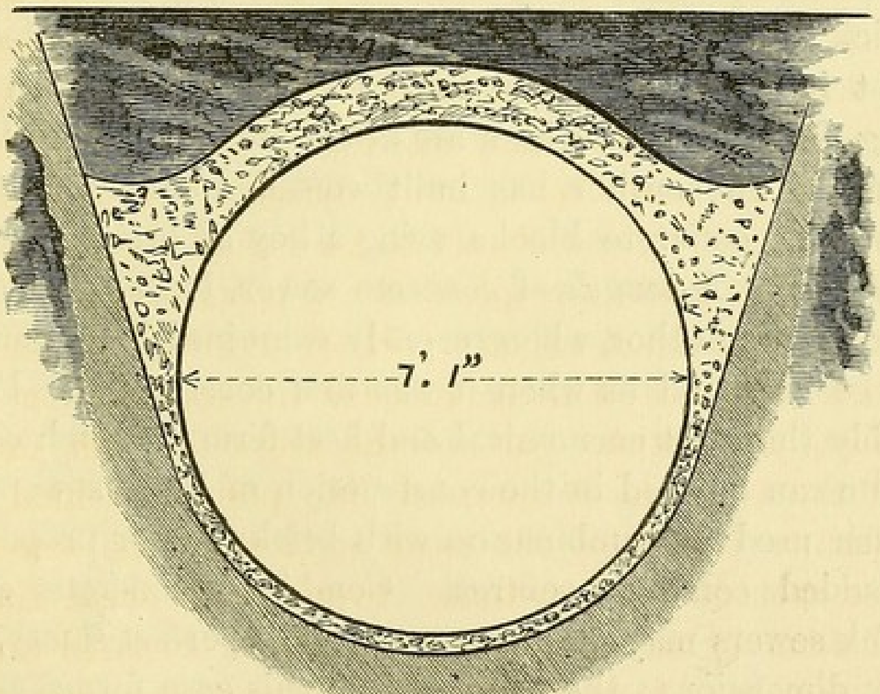


Fig. 41.



'7 feet 1 inch in diameter, cost per lineal foot, irrespective of earthwork, 16*s.*; but, inclusive of earthwork, side entrances, junctions, &c., it was about 23*s.* per lineal foot. This sewer was in some respects exceptional, inasmuch as it consisted of little more than an arch over a previously existing invert; the lower half was, however, rendered with cement and sand in equal proportions, 1 inch thick." In the construction of sewers entirely of concrete it is necessary to have a much greater length of trench opened in the streets than is customary for brick sewers, in order to allow the work to set completely before the trenches are filled in; and special care must be taken during construction of a concrete sewer to prevent its collapse from having to sustain a load before the work is perfectly hardened. The centres of any particular length should not be removed, nor should the trenches be filled in until the work is set. No doubt brick sewers are often very seriously injured by the trenches being filled in and the centres removed before the cement is properly set. Concrete sewers may be constructed of bricks made of concrete, and built up as ordinary brick sewers, but in this form they become more expensive than brick sewers. They may also be constructed of blocks cast in moulds, similar to brick blocks described in Fig. 34, page 220, which are afterwards built up into a sewer. The author has built considerable lengths of sewer in concrete blocks, using a key of brickwork in the arch. A length of concrete sewer, built ten years ago by the author, when recently examined,* was found to be as sound as when it was first constructed. Probably the most economical and best form in which concrete can be used in the construction of large sewers is when used in combination with brickwork or properly moulded concrete centres. Combined concrete and brick sewers may be constructed, with perfect safety, of any dimensions; the brickwork in this case forms, as it were, a centre for the concrete, and owing to the smaller amount of labour required, this form of construction is not so expensive as an entire concrete sewer, yet it is

Extra length of sewer trench open.

Centres: when they are to be removed.

Concrete bricks.

Concrete blocks.

Combined concrete and brick sewers.

* February, 1878.

far cheaper and stronger than an entirely brick sewer. Fig. 42 represents a section of the Croydon outfall sewer, 4 feet internal diameter, designed by the author and constructed with an inner ring of brickwork, the outer portion of the sewer being formed of concrete. This sewer was constructed above the level of

Croydon outfall sewer.

Fig. 42.

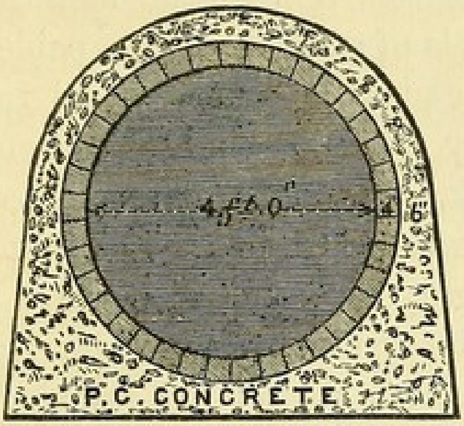
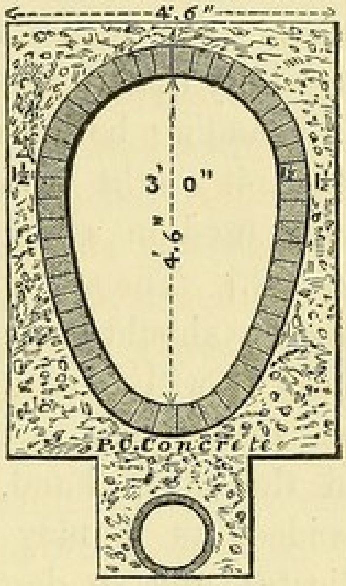


Fig. 43.



the ground, and for some months was running full bore without any earth backing at the sides, and yet, though containing such a small amount of material, not the slightest leakage took place. This was a test that no ordinary brick sewer could have borne under such circumstances, showing at once that there is a considerable degree of tenacity in the concrete covering. Fig. 43 shows a section of a sewer as constructed by the Metropolitan Board of Works, partly in brick and partly in concrete; the section also shows a pipe laid in the concrete below the level of the sewer for drainage purposes. The danger arising from the indiscriminate use of drains under sewers has been referred to at page 225.

Test of combined concrete sewer.

Sewers from 1 foot to 3 feet diameter, if required to be constructed so as to be perfectly water-tight, may, with very great advantage, be constructed partly as a concrete pipe, moulded true to shape and size, and

Sewers formed of cement pipes and concrete.

which, when provided with a proper joint luted with neat cement, and surrounded with a sufficient mass of concrete, will make one of the most perfect and water-tight forms of sewer it is possible to use. Cement pipes of large size (taking their diameter and thickness into consideration) are quite as strong, and much more certain in their quality than earthenware pipes.*

Importance of good materials.

In the making of concrete special care must be exercised with regard to the selection of the materials, especially that the cement is of good quality, capable of withstanding both the chemical and mechanical tests which it ought invariably to be subjected to before being used in sewer work, as will hereafter be considered.† The stone or gravel used in the making of concrete should be thoroughly saturated with water, for if dry it will have a tendency to abstract water from the cement, and interfere with its setting properties. On the other hand, an excess of water should be avoided, as it may wash out some of the soluble silicates, and so destroy the strength of the cement. The materials comprising concrete should be thoroughly incorporated. This work is usually performed by men turning over the materials on a wooden platform, but such work may now be better performed and more economically executed by machinery, such for example as the apparatus designed by Mr. P. J. Messent, C.E., of Tynemouth, which "consists of a closed box or chamber revolving on an axle, and of such a form as when half filled with the materials for making concrete, to cause them to be turned over sideways as well as endways four times in each revolution of the chamber, so that, after from six to twelve revolutions, the number necessary being varied according to the weight and nature of the materials, a more perfect mixture is effected than can possibly be produced by hand." The unfortunate experience of the author within the last few years, in connection with the construction of

Stone should be saturated.

Mechanical concrete mixer.

* Vide p. 212. † Vide pp. 235 to 242.

concrete sewers, shows how easily such work can be scamped by an unscrupulous contractor. It is therefore absolutely necessary in the construction of concrete sewers, that no person should be engaged who will not strictly adhere to and implicitly carry out the orders of the engineer. Moreover, as a security for good work, concrete sewers will require much more strict superintendence than brick and other sewers. The author has witnessed failures in concrete work apparently of the best description. Such work has cracked in the most mysterious manner, and it may be that at present we are not acquainted with all the circumstances concerning the qualities of this material. For example, it has not been shown that the material itself may not occasionally be in a state of unstable equilibrium arising from the crystallization commencing at the surface and terminating in the centre of the mass, the act of crystallizing, interfering as it does with the capacity of the entombed material, having the effect already mentioned, and which is identical with the results known to occur in connection with the manufacture of iron pipes, referred to at page 265, or as shown by the toy known as the "Rupert drop." It is easy to imagine that a material that may be in a state of unstable equilibrium will upon the slightest disturbance crack, as some apparently good concrete work has cracked. In a great measure the failure of these concrete works has been due to the cement drying before crystallization has been completed, or to the drying of the exterior and the crystallization of the interior of the work. In all Portland cement that is perfectly made, a slight expansion takes place in the process of crystallization, which, as a rule, is an advantage, as it causes the cementing agent to enter the pores of the material that has to be cemented, but, on the other hand, this expansion on crystallization may become an element of destruction when unequal setting takes place. The unequal setting of concrete is not so

Concrete sewers need extra careful supervision.

Failure of concrete work.

Material may be in unstable equilibrium.

Cause of good concrete works cracking.

Concrete may be used with safety below ground.

likely to take place in structures placed below the ground or in water as in those fully exposed to atmospheric influence above the ground, hence, for the purposes of foundations and for sewers, concrete forms an invaluable and secure material, for when used in this way it has long stood the test required for the confirmation of its good qualities.

The following Tables give the relative tensile and compressive strength of Portland cement concrete:—

Table showing tensile strength of concrete.

TABLE No. 46.—Showing the TENSILE STRENGTH of CONCRETE after 12 months, made with PORTLAND CEMENT weighing 112 lbs. per bushel. Compiled from experiments by J. GRANT, Esq., C.E.

Proportion of Tensile Strength.	
Ballast to Cement.	In lbs. per sq. in.
3 to 1	240·44
4 " 1	246·22
5 " 1	214·22
6 " 1	141·77*
7 " 1	163·33
8 " 1	156·42

* There appears to have been a flaw in this specimen.

Table showing compressive strength of concrete.

TABLE No. 47.—Showing the CRUSHING STRAIN on BLOCKS of CONCRETE 6 in. × 6 in. × 6 in., made with PORTLAND CEMENT weighing 110·56 lbs. per bushel, and when compressed and not compressed, and when set in AIR and WATER, after 12 months. Compiled from experiments by J. GRANT, Esq., C.E.

Proportion of Ballast to Cement.	Compressed Blocks.		Not Compressed Blocks.	
	Set in Air.	Set in Water.	Set in Air.	Set in Water.
	tons per in.	tons per in.	tons. per in.	tons per in.
1 to 1	1·055	·933	·833	1·041
2 " 1	1·194	·958	1·069	1·000
3 " 1	·833	·986	·666	·777
4 " 1	·833	·777	·777	·750
5 " 1	·680	·986	·666	·652
6 " 1	·566	·544	·505	·472
7 " 1	·458	·444	·388	·347
8 " 1	·375	·375	·347	·305
9 " 1	·333	·305	·277	·250
10 " 1	·291	·291	·222	·194

CHAPTER XXI.

CEMENT AND MORTAR.

THE selection of proper cementing material for the construction of sewers is one of vital importance to the stability of the work. In many cases in this country sewers have failed from the injudicious use of a cementing material totally unsuited for the purpose to which it was applied. The author has seen cases in which, either from the want of sufficient experience on the part of the persons employed in designing the works, or with a view of saving some trifling sum in the first cost, a cementing material has been selected for the construction of sewers totally unfit to resist the chemical action of the sewage, and the consequence has been that such sewers have failed. The cementing material used in the imperfect work here mentioned consisted of ordinary chalk lime mortar, or of chalk lime mortar mixed with a small percentage of Roman cement. The chemical action of sewage upon such mortar is due to the presence of ammonia, which, when brought into contact with ordinary lime, is converted by oxidation either into nitrous or nitric acid, which acids readily combine with the lime, and when they have so combined form nitrates or nitrites of lime, which salts are extremely soluble; the lime in this new form is soon washed out of the joints of the brickwork by the flow of the sewage through the sewer, or by subsoil water infiltrating through the work into the sewer, and every particle of lime may be thus carried away,* leaving nothing but the sand to hold the sewer together; consequently, as the work is no longer capable of bearing any strain upon it, such sewers either entirely collapse,

Failure of works from selection of unsuitable materials.

Effect of sewage on chalk lime.

* The carbonic anhydride in sewage will readily dissolve lime.

or become so distorted in shape as to be unfit for the purposes for which they were intended. The adoption therefore of a durable cementing material for the construction of sewers is a point of the first importance, and too great care cannot be exercised in the selection of proper materials. Where doubts exist as to the behaviour of cements or limes when brought into contact with sewage, it will be well to subject them both to a chemical and mechanical test, in order to ascertain if they are fit for the purposes for which they are intended. The mechanical tests for cement, which were adopted on the main drainage works of London, were devised by Mr. Henry Reid, C.E., and it was mainly through the introduction of such a system of testing, that such great improvements have been made in the process of manufacture of Portland cement. Mechanical tests for limes and cement consist in moulding the material into blocks of the shape shown in Fig. 44, which, after being set in a proper mould, is taken out and allowed to remain under water for a period of seven days, and then placed in clips shown in Fig. 44, and transferred to the breaking machine, as illustrated in Fig. 45. The machine shown

Chemical and mechanical tests should be applied.

Mr. H. Reid.

Mechanical tests.

FIG. 44.

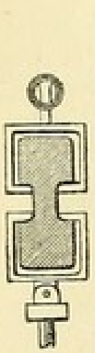
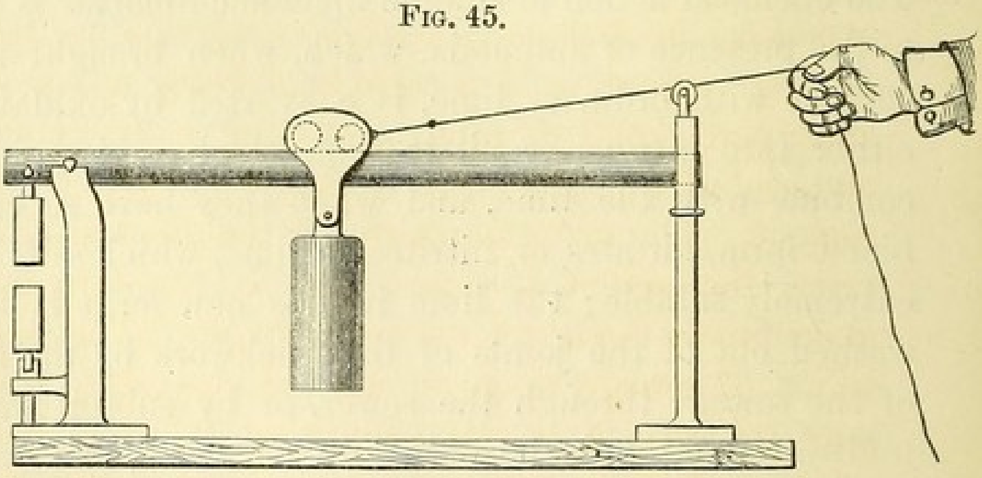


FIG. 45.



in Figs. 44 and 45 was manufactured by Adie. A machine of a similar kind is also made by Pallant. A cheap form of testing apparatus is that of Michele; this machine is not so reliable as the form shown in the illustrations, and the author has found that it can be easily tampered with. Messrs. W. H. Bailey & Co., of Salford, make a very good and efficient form of cement-testing apparatus for ascertaining the tensile or compressive strain. Cements differ materially in their power to resist tensile strains, as will be seen from the following Table, No. 48:—

TABLE No. 48.—Showing the RELATIVE TENSILE STRENGTH of PORTLAND, ROMAN, and MEDINA CEMENTS. Compiled from experiments by J. GRANT, Esq., C.E.

Age.	Portland. 123 lbs. per bushel.	White Brothers' Roman.	Medina.
	lbs. per in.	lbs. per in.	lbs. per in.
7 days	363·15	89·77	40·93
1 month	415·91	115·68	131·55
3 months	469·28	143·33	199·46
6 "	522·93	210·08	183·28
9 "	541·77	209·33	203·20
12 "	546·53	285·82	211·95
2 years	588·84	242·66	122·66
3 "	584·17	268·35	122·48
4 "	583·37	280·97	127·91
5 "	576·00	278·66	140·88
6 "	581·33	296·17	162·22
7 "	589·95	314·97	—

Strongest cement cheapest.

It should be here noted that a cement capable of bearing great tensile and crushing strains when more expensive in first cost, is often cheaper to use than an inferior cement, as it is capable of being mixed with a large percentage of sand, producing more cementing material of a quality equal to that made with a cheaper cement. The material which has the greatest power to resist the action of acids, and is the strongest, is undoubtedly the best for sewer purposes. The chemical action of sewage upon an untried cementing material may be arrived at by subjecting it to a standard solution of nitric acid. The following Table, No. 49, shows the results as arrived at by the author with regard to the resisting power of various cements to the action of nitric acid. Each of the samples tested was made in a mould of the same size, and was submerged

Chemical test for cement.

for ten days in a solution of distilled water containing 10 per cent. of nitric acid.

Nitric acid tests of cements.

TABLE No. 49.—TESTING of various kinds of LIME and CEMENT to RESIST the ACTION of NITRIC ACID. The specimens were exposed for ten days in a solution containing 10 per cent. Nitric Acid.

Description of Material.	Whether set in Air or Water.	Weight in grains before Chemical Test.	Weight in grains after Chemical Test.	Loss in grains.	Percentage of Loss.	Remarks.
Croydon chalk lime	Air	792	225	567	71·5	
Ditto	Water	..	..	..	..	Would not set in water.
Ditto and sand ..	Air	1410	68	1342	95·1	
Ditto	Water	..	..	..	..	" "
Dorking lime ..	Air	884	601	283	32·0	
Ditto	Water	957	616	341	35·6	
Ditto and sand ..	Air	1405	710	695	49·4	
Ditto	Water	1211	722	489	40·3	
Blue lias	Air	989	759	230	23·2	
Ditto	Water	1077	891	186	17·2	
Ditto and sand ..	Air	1207	795	412	34·1	
Ditto	Water	1129	856	273	24·1	
Barrow lime	Air	1091	705	386	35·3	
Ditto	Water	1044	776	268	25·6	
Ditto and sand ..	Air	1256	610	646	51·4	
Ditto	Water	1217	781	436	35·8	
Plaster of Paris ..	Air	1314	1269	45	3·4	
Ditto	Water	1402	1462	..	..	Increased in weight by contact with acid.
Ditto and sand ..	Air	1396	1272	122	8·7	
Ditto	Water	1436	1306	130	9·0	
Keene's cement ..	Air	1262	1246	16	1·2	
Ditto	Water	1269	1255	14	1·1	
Ditto and sand ..	Air	1452	1026	426	29·3	
Ditto	Water	1565	734	831	53·0	
Portland cement ..	Air	1242	1189	53	4·2	
Ditto	Water	1345	1284	61	4·5	
Ditto and sand ..	Air	1470	1400	70	4·7	
Ditto	Water	1293	1146	147	11·3	
Roman cement ..	Air	1289	1243	46	3·5	
Ditto	Water	1272	1225	47	3·6	
Ditto and sand ..	Air	1430	1286	44	3·0	
Ditto	Water	1378	1267	111	8·0	
Medina cement ..	Air	1313	1148	165	12·5	
Ditto	Water	1325	1130	195	14·7	
Ditto and sand ..	Air	1445	1252	193	13·3	
Ditto	Water	1420	1205	215	15·1	

NOTE.—When sand was used in the foregoing experiments it was mixed in equal volume with the lime or cement.

A most valuable and elaborate series of experiments on the strength of cement have been carried out by Mr. John Grant, C.E., and the results arrived at with regard to cement are recorded in two papers read before the Institution of Civil Engineers in 1866 and 1871, and may be referred to with advantage by all persons seeking information upon this very important subject. Portland cement is by far the best material that can ordinarily be used in the construction of sewers. It is an artificial cement composed of chalk and clay burnt at a high temperature, and is then ground to fine powder; the finer it is ground the better it is. The strength of Portland cement depends very much upon its weight; the heavier the cement, the stronger it is, but the heavy cements require a longer period to arrive at their ultimate strength than lighter cements, and the strongest cements are the longest in setting, showing how necessary it is that provision should be made in the construction of sewers to protect the cement from being exposed to the injuries arising from the presence of subsoil water during the construction of the work. Smeaton used plaster of Paris to protect the joints of masonry from the action of the sea, and Roman cement has been used for like purposes to protect a slower-setting but stronger cement. Good Portland cement should not weigh less than 116 lbs. per striked bushel, when filled into the measure from a hopper, or with a shovel, and is not to be beaten or the measure touched while being filled, and should be capable of bearing a tensile strain of 350 lbs. to the square inch, after seven days' immersion in water, tested on a section 2¼ inches in area. It should be ground sufficiently fine to pass through a sieve having 2500 meshes to the square inch, and not leave more than 10 per cent. of residuum in the sieve. As a further test a portion of the cement should be mixed, and after it has become stiff, it should be immersed in

Mr. J. Grant's experiments.

Portland cement.

Protection of cement from flowing water

Qualities of Portland cement.

water, and should afterwards be examined very carefully to see if there are any indications of minute cracks; and if these cracks should appear, the cement should be rejected. Excess of lime, or lime not properly combined, gives a tendency to blow; lengthened exposure to air influences will "purge" the cement of this injurious quality. Portland cement has the valuable property of not deteriorating by age, provided it be kept dry; on the contrary, a certain amount of age improves its quality. The amount of cement that should be used in making mortar, which is the material used to combine together the bricks so as to form one mass, will be a matter of judgment for the engineer; under no circumstances, however, should the amount of cement be less than the interstitial space of the sand which is to be used, if a really uniform and homogeneous compound is to be the result. The interstitial space of the sand may be arrived at by the amount of water it is capable of absorbing, which will represent the interstitial space. This space varies from about 10 to 35 per cent. of the material. It may be taken for granted that the mixture of any quantity of sand with Portland cement materially affects its strength, both tensile and compressive, as will be seen from the following Tables:—

Mixture of cement and sand.

Mode of finding interstitial space.

TABLE No. 50.—Showing the TENSILE STRENGTH of neat PORTLAND CEMENT weighing 112 lbs. the striked bushel, also when mixed with a certain proportion of Thames sand. Compiled from experiments by J. GRANT, Esq., C.E.

Tensile strength of cement and sand.

Age.	Neat. Cement.	Proportion, 1 to 1.	Proportion, 1 to 2.	Proportion, 1 to 3.	Proportion, 1 to 4.	Proportion, 1 to 5.
	lbs. per in.	lbs. per in.	lbs. per in.	lbs. per in	lbs. per in.	lbs. per in.
1 month	348·66	166·00	100·31	48·00	40·22	19·11
6 months	426·66	268·08	178·08	136·94	66·22	54·80
12 „	448·80	321·76	214·84	164·94	88·08	90·84

TABLE No. 51.—Showing the CRUSHING STRAIN of BRICKS 9 in. × 4½ in. × 3 in., made from PORTLAND CEMENT weighing 110·56 lbs. per bushel, when compressed and not compressed, and when set in AIR and WATER, after 12 months. Compiled from experiments by J. GRANT, Esq., C.E.

Compressive strength of Portland cement and sand.

Proportion of Cement and Sand.	Compressed.		Not Compressed.	
	Set in Air.	Set in Water.	Set in Air.	Set in Water.
	tons per sq. in.	tons per sq. in.	tons per sq. in.	tons per sq. in.
Neat	2·360	3·274	2·776	2·811
1 to 1	2·044	2·057	1·561	1·549
1 „ 2	1·728	1·410	1·024	·972
1 „ 3	1·328	·656	·656	·538
1 „ 4	1·076	·738	·489	·338
1 „ 5	·923	·372	·377	·212
1 „ 6	·747	·277	·271	·142
1 „ 7	·713	·260	·211	·105
1 „ 8	·475	·201	·174	·057
1 „ 9	·432	·183	·131	·057
1 „ 10	·381	·138	·118	·056

General Scott's Portland cement manufactured from sewage.

General Scott has invented a process, and brought into operation a system of manufacturing Portland cement and selenic mortar, in combination with the clarification of sewage.*

Roman cement.

Roman cement was formerly largely used in the construction of sewers, both by itself and also in combination with lime mortars. It is not more than two-thirds the price of Portland cement, but it is not more than one-third as strong, so that for all general purposes, Portland cement is the cheapest material, and is otherwise preferable.

Roman cement sets quickly.

Roman cement has the power of setting quicker than Portland cement, and on the other hand, if it is exposed to air, it absorbs moisture and carbonic acid, which form silicates and aluminates of lime, and destroy the quality of the cement. It is not capable of bearing a greater tensile strain than from 100 lbs. to 125 lbs. the square inch, after seven days' immersion. It is manufactured from septaria, found in the London clay and other geological formations. Roman cement is best when light, and should weigh about 75 lbs. per

Strength of Roman cement.

Manufactured from septaria.

Weight of Roman cement.

* This process will be explained in another volume of 'Sanitary Engineering,' under head of Lime Processes of Purifying Sewage.

striked bushel, and never should exceed in weight 80 lbs. the bushel, nor should it be used with a greater proportion of sand than one to one. It is occasionally used to protect the joints of slow-setting cements, and on account of its quickly setting is often a valuable agent in some special works.

Medina cement.

Medina cement is a variety of Roman cement containing a rather larger percentage of lime, and is made from septaria procured from Hampshire. It has the power of setting rapidly, but is inferior to Portland and Roman cements in point of strength. In some cases, hydraulic limes, such as some of the blue lias limes, may be used with advantage in sewer and water works, but, on account of their variable quality, in no case should they be adopted in the construction of a sewer until it has been shown that they are able to withstand the chemical action of the sewage, as well as that they possess the mechanical advantage of strength. Many of the lias limes are apt to cause rupture of the work if not finely ground, therefore when limes of this class are used for sewer work, they should invariably be tested by being sifted, and all samples not ground sufficiently fine to pass through a sieve having 1600 meshes to the square inch, should be rejected. Many other cements, such as Keene's Parian, plaster of Paris, and others, are not fitted for the construction of sanitary works, but are more especially adapted for the interior fittings of public and private buildings. In using all cements care should be taken that no more is mixed at one time than will be quickly used, for any cement that sets or becomes hard is unfit for use, and should be rejected. It is a singular fact that Portland cement that has been mixed some hours and is then re-mixed with fresh cement will set much more rapidly than the same cement under ordinary conditions. So also the use of hot water will set a cement more rapidly than will be the case when cold water is used. The use of hot water or the heating of the materials greatly impairs the strength of the cement.

Strength of Medina cement.

Lias limes.

Necessity for fine grinding.

Keene's Parian and plaster of Paris.

Cement that has set.

Effect of heat.

CHAPTER XXII.

SAND AND WATER.

An important point in the selection of materials is to procure a pure silicious sand for mixing with cement or lime to form mortar. The sand used should be free from all nitrogenous, and some saline matters, such as alkaline chlorides; if not, these matters are liable to undergo a chemical change, after being mixed with the lime and cement, and so cause a rupture of the work even after it has set. For cementing purposes, for mixing with cement, a sharp sand is undoubtedly the best. It would be a saving of cementing material to select sands of various degrees of fineness, so as to reduce the interstitial space as much as possible. Pure silicious sand forms, in combination with the limes, a silicate of lime which augments the strength, especially in those parts excluded from the air, as the interior of thick walls. Sand acts as a diluent for cement, so that its approximate strength, within certain limits, may be arrived at by knowing the proportions of sand used.

Influence of nitrogenous and saline matters.

Sharp sand best.

Silicious sand.

Sand a diluent.

With regard to the selection of water, either fresh or sea water may be used for mixing with Portland cement. It has been shown by Mr. J. Grant, C.E., that the use of sea-water augments the strength of Portland cement. This may be due to certain combinations taking place between some of the salts in sea-water and the cement; on the other hand, the excess of certain salts will undoubtedly injure the cement. Sewage water, for example, should on no account be used in compounding mortar. The author has seen cases in which the best materials, both as regards cement and sand, have been used, but when mixed with sewage water the cement has

Water.

Sea-water.

Excess of certain salts injurious.

never properly set, while the same cement, in the same work, compounded with pure water, has set rapidly and well. Care should also be taken in the mixing of cement that too great a proportion of water is not used. The smaller the quantity of water used in the compounding of cement the better it will be found to be, as an excess of water washes out the silicates, and so weakens the cement. The volume of water to be used, therefore, should only be sufficient to bring the mortar into a thick paste. Where more water is requisite, it is a sign that the bricks or other materials which are used in the construction of the works have not been sufficiently soaked, and that the mortar is robbed of its moisture by reason of the inattention paid to this important point.

Too much water injurious.

CHAPTER XXIII.

TIMBER.

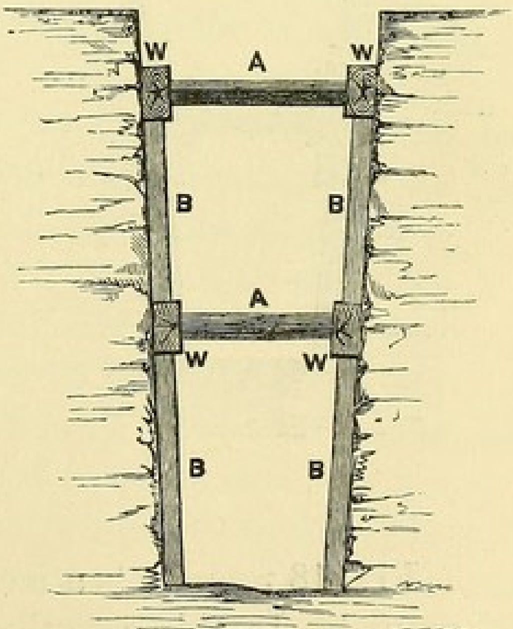
In all works of sewerage timber is extensively used in all the preliminary operations, either for shoring the trenches, shafts, or tunnels, or for constructing centres, templets, trunks, or shoots for the discharge of water. It is also occasionally used permanently in works of sewerage, as in forming foundations, or for the protection of work in exposed situations, or as a casing for a protection against frost, or to secure some outfall works from injury, such as they are liable to incur when it is necessary to pass outfall sewers along the sea-shore or into navigable channels. The point of outfall of a sewer into the sea, or into a tidal estuary, is usually marked by timber piling, which serves to protect the sewer against displacement by vessels, and also acts as a beacon to show the line of outfall, thus warning vessels from approaching too near. In all temporary works it is customary to select the cheapest timber at hand. Both English and foreign-grown timber of every variety is extensively used in shoring trenches. In some cases special timber, such as oak, is used, where great strength is required, as in some tunnel work. Fig. 46 represents one of the simplest modes

Use of timber.

Sea works.

Selection of timber.

Fig. 46.



Shoring trenches.

adopted for shoring trenches for sewer and other works. The trench is cut slightly tapering, being wider at the top than at the bottom, as there is a tendency for the timber to tighten, if it slips, or the earth contracts from drying. This system consists in providing horizontal walings, W, which are kept in position by struts, A. The walings are often supported by props, B, which are put under them, and serve to keep them in position, so that if any settlement takes place the whole framing will subside together. In other cases walings are used with short boards at the back, called poling boards, which are usually $1\frac{1}{2}$ inch in thickness, and their object is to shore a larger side area of the trench than is the case when walings alone are used. This system is illustrated in Fig. 47.

Poling boards.

Fig. 47.

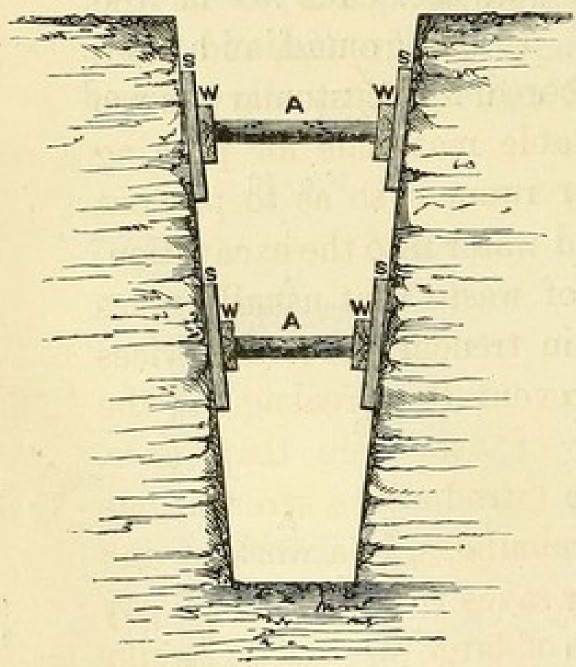
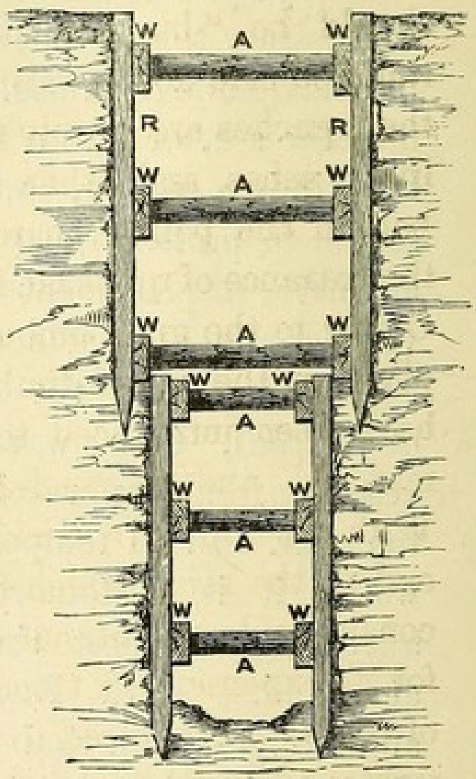


Fig. 48.



Trenches in bad ground.

Fig. 48 represents a mode of shoring trenches in bad ground. In this case the walings and struts are used as before, but instead of poling boards the runners R are used, and they are sharpened at the bottom and driven as sheet piling behind the walings. The trench in this system, in the first place, must be excavated sufficiently wide at the top to enable as many tiers of runners to be used as may be requisite to get the proper width of trench at the depth required. It should be observed, in timbering trenches, that the timber should be wedged up tightly against the sides of the trench, in order to prevent the slightest chance of movement in the surrounding earth, but not so tightly as to disturb the earth. The struts, as a rule, should be of as great a diameter as possible, for if they are small in diameter, in proportion to the width of the walings, they are apt to split the walings if any great strain is brought upon them. Where half-round timbers are used for shoring purposes, the flat sides of the timber should be placed against the side of the trench. The struts in this case should be cut to fit the walings, or, as it is termed, should be "bird's-mouthed" at the ends to fit the rounded side of the walings. In bad ground, and when the trenches are closely timbered, it is customary to use litter, ashes, and other suitable materials for packing behind the poling boards or runners, so as to prevent the entrance of quicksand and water into the excavation. Owing to the great amount of waste that usually takes place in the use of timber in trenches, several devices have been introduced to prevent the breakage of the material, and to render it of use more than once. With this view Mr. Kirkman introduced a screw at one end of the strut, which he calculates, in a work of any considerable extent, not only saves trouble, but will pay for its expense. In trenches of large size whole baulks of timber are required to be used, in which case they are tightened up by wedges, and such timbers require to be supported and braced in all directions. In tunnel work, material of good quality should be selected for timbering, and such timber should be hard and tough, as at unknown times and places considerable strains are liable to be thrown upon it. In ordinary tunnelling for sewer work the sills and posts are made of fir, and the side

Struts.

Packing against quicksand.

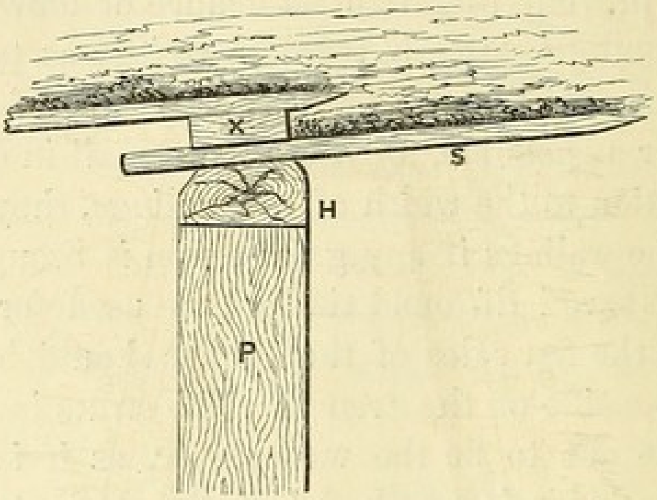
Devices to economize timber.

Large trenches.

Timber for tunnels.

posts are usually placed at an angle, and mortised or notched into the sills. The poling boards or staves are usually driven diverging outwards, so that one set overlaps the preceding set, with a wedge between the two, as shown in Fig. 49. S shows the position of the

Fig. 49.

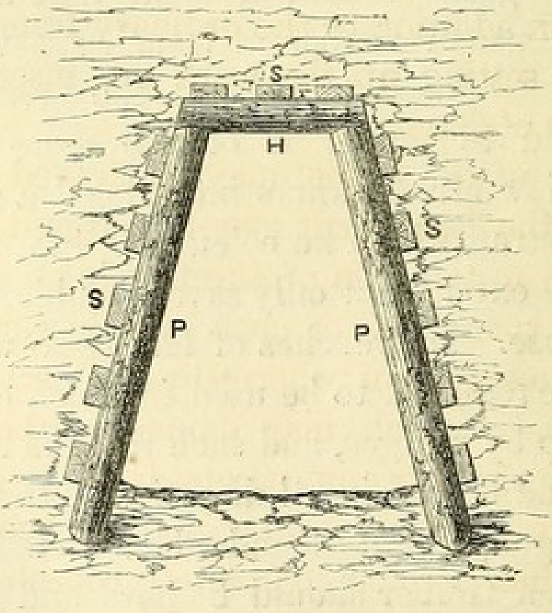


staves or poling boards, H the head of the framing, P, side post of framing, and X the wedge for keeping the staves in position.

Tunnelling in good ground.

When tunnelling in good ground, the side posts may

Fig. 50.

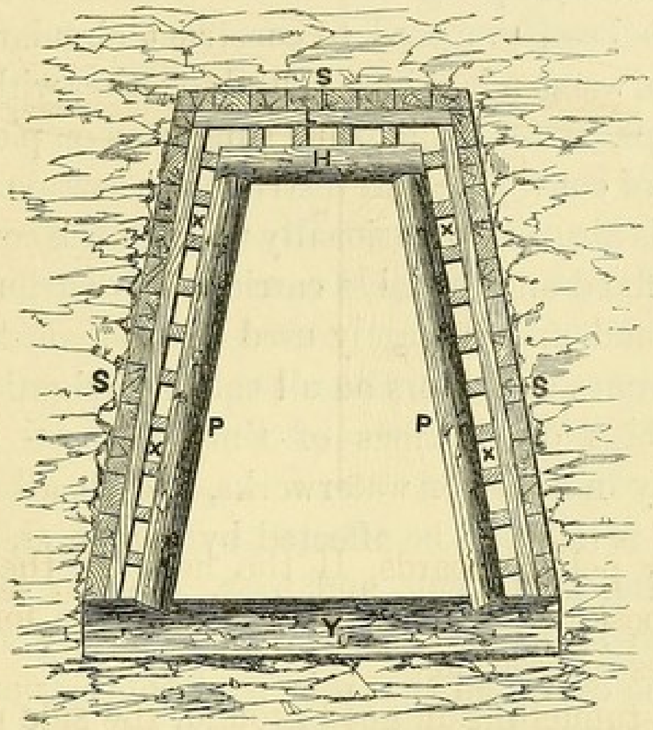


be sunk into the bottom of the excavation for a few inches, and poling boards or staves are placed at the back of the framing, as shown in Fig. 50.

When tunnelling in bad or unstable ground, a section of framing similar to that in Fig. 51 is usually adopted. Tunnelling in bad ground.

It consists in closely timbering the tunnel with the staves or poling boards S, the staves being kept in

Fig. 51.



position by the framing L, which forms a lintel and side frame in addition to the ordinary framing, and the wedges for setting up the work are inserted between the two sets of framing.

The floor of the tunnel may be treated in a similar manner to the head, or it may be covered with planks spiked down to the sills of the framing. In all cases, whether in tunnelling or open trench work, where the ground is unstable, or where slips of earth are likely to take place, which may damage either the works executed, or any adjoining property, it is customary to leave in the timber in order to take the strain until the trench has become completely consolidated, which in some cases may not occur for several years. In carrying out sewer works in narrow streets, it is advisable to shore the houses, and the stays introduced

Timber should be left in.

Shoring in narrow streets.

should be removed with caution, but not until the excavation is properly consolidated.

Timber pipes, &c.

Timber has been extensively used in past ages for the formation of aqueducts for conveying water, and for the construction of water pipes, but for these purposes it has now been generally superseded by iron. Its use for such like purposes has, however, again been revived, as it has been proposed to construct circular channels formed of wooden laggings, bound together with wrought-iron hoops, barrel fashion, and supported on piers, for the purpose of conveying and distributing sewage over land. Timber is also now occasionally used for the construction of both fixed and movable carriers for distributing sewage on land, and is largely used for the construction of sluice frames and doors on all sewage irrigation works.

Descriptions of timber best adapted.

The best descriptions of timber to be used permanently in sewer or waterworks, and in all situations where it is liable to be affected by dampness, are alder, beech, elm, larch, oak, and teak. In the selection of timber to be used permanently in sanitary works, care should be exercised that it is free from injurious shakes, large and loose knots, and sap-wood. Various processes have been adopted in order to protect timber from premature decay, and from the attacks of certain species of fungi and insects, which in some situations are liable to prey upon it, and so cause its rapid destruction. The systems are known as Kyanizing, Burnettizing, Bethell's, and Payne's processes.

Protection of timber.

Kyanizing.

Kyanizing consists in saturating the timber in a solution of corrosive sublimate (bichloride of mercury). The quantity of bichloride to be used depends more or less upon the porosity of the timber; it varies from 1 lb. to every 10 gallons of water for a strong solution, to $\frac{3}{4}$ lb. to the same quantity of water for a weak solution, the timber being exposed in tanks, so constructed that no metal is brought into contact with the solution. The period of immersion varies according to the thickness of the timber, twenty-four hours of exposure being allowed for each inch in thickness of the material.

Burnettizing.

In Burnettizing, a solution of chloride of zinc in combination with water is used, 2½ lbs. of chloride of zinc being used for every 10 gallons of water.

Bethell's process.

Bethell's process consists of impregnating the timber with creosote; the timber for this purpose is exposed in tanks, properly constructed, for a sufficient time to ensure saturation.

Payne's process.

Payne's process consists in first saturating the timber with a solution of sulphate of iron, and afterwards treating it with a solution of some of the alkaline carbonates, which have the effect of decomposing the sulphate of iron and producing within the interstices of the timber an insoluble oxide of iron.

Charring timber.

Timber is also occasionally protected in some situations by being charred or burnt on the exterior surface, the exposed charcoal surface being less liable to decay than the natural timber. Pigments of various descriptions, having for their basis the oxides of lead, iron, or zinc, are universally used to protect timber from the weather. Tar, pitch, and its compounds are also extensively used, and are very efficient for the protection of timber in works of sewerage.

Pigments.

Strength of timber.

The strength of timber when used in sewer or other work may be arrived at by reference to the following Table, which shows the tensile and compressive strength of various kinds of timber; also the value of the coefficients E and S as used in the formula of Professor Barlow in arriving at the strength and deflection of timber girders and other structures.

Professor Barlow's rules for calculating strength of timber beams.

In the application of the Table the rules for finding the strength of a rectangular beam of timber fixed at one end and loaded at the other, are given by Professor Barlow as follows: "Multiply the value of S in the Table of Data by the area, and the depth of the section in inches, and divide that product by the leverage in inches, and the quotient will be the weight required in lbs.;" or "to determine the strength of a rectangular beam of timber when it is supported at the ends, and is loaded in the middle of its length: *rule*, multiply the value of S in the Table of Data by four times the depth in inches, and by the area of the section in inches, and divide the product by the distance between the supports in inches, and the quotient will be the greatest weight the beam will bear in lbs."

Table of strength of timber.

TABLE No. 52.

Description of Timber.	Specific Gravity.	Tensile Strength.	Compressive Strength.	Reduced Value of E.	Value of S.
		lbs. per sq. in.	lbs. per sq. in.		
Teak	·745	8,000	12,000	349	2110
English oak ..	·934	19,000	10,000	209	1672
Canadian oak ..	·872	..	..	310	1766
African oak ..	·972	..	..	165	2589
Dantzic oak ..	·756	..	..	172	1470
Ash	·76	17,000	9,300	237	2026
Beech	·696	22,000	9,300	195	1556
Elm	·553	13,200	10,300	101	1013
Pitch pine	·66	..	..	177	1632
New England fir	·553	..	..	317	1102
Dantzic pine ..	·649	8,000	5,400	..	1426
Mar Forest fir ..	·696	..	..	93	1144
Larch	·556	10,200	5,500	152	1127
Norway spar ..	·577	..	..	210	1474
Spruce fir	·512	10,100	6,500	..	1490
Memel deal ..	·590	..	..	116	1731
Christiana deal	·689	12,000	5,850	115	1562

NOTE.—The reduced value of E in this Table is found by dividing the original value of E, as given by Professor Barlow in his work on the 'Strength of Materials,' by 1728.

Mode of taking dimensions.

One-fourth the breaking weight the limit of safety.

Beams loaded at intermediate points.

If the beam is not placed horizontally, the distance between the supports must be measured horizontally, and will be the length of bearing. A fourth of the breaking weight, as given by the formulæ, will be the greatest load to which a beam ought to be subjected in practice. "When the load is applied at any other point than the middle, it will be as the rectangle of the segments, into which the point divides the distance between the supports, is to the square of half that distance; so is the weight found by the rule to the weight the beam will sustain at the given point." When a beam is uniformly loaded, its breaking weight is twice that of a beam whose load is applied at the centre. The following formulæ of Professor Barlow will give all the information required for calculating the strength and other particulars of beams, &c.

Beams uniformly loaded.

Formulæ for strength of beams.

1. When the beam is fixed at one end and loaded at the other.

$$W = \frac{S\,a\,d^2}{l}.$$

$$l = \frac{S\,a\,d^2}{W}.$$

$$a = \frac{l\,W}{S\,d^2}$$

$$d = \sqrt{\frac{l\,W}{a\,S}}$$

In square beams

$$a = d = \sqrt[3]{\frac{l\,W}{S}}.$$

2. When supported at both ends and loaded in the middle.

In this case therefore

$$W = \frac{4\,a\,d^2\,S}{l}.$$

$$l = \frac{4\,a\,d^2\,S}{W}.$$

$$a = \frac{l\,W}{4\,d^2\,S}$$

$$d = \sqrt{\frac{l\,W}{4\,a\,S}}$$

In square beams

$$a = d = \sqrt[3]{\frac{l\,W}{4\,S}}.$$

3. When the beam is fixed at both ends and loaded in the middle.

Strength of beams.

$$W = \frac{6\,a\,d^2\,S}{l}.$$

$$l = \frac{6\,a\,d^2\,S}{W}.$$

$$a = \frac{l\,W}{6\,d^2\,S}$$

$$d = \sqrt{\frac{l\,W}{6\,a\,S}}$$

In square beams

$$a = d = \sqrt[3]{\frac{l\,W}{6\,S}}.$$

4. When the beam is supported at both ends, and loaded at an intermediate point.

$$W = \frac{l\,a\,d^2\,S}{m\,n}.$$

$$l = \frac{m\,n\,W}{a\,d^2\,S}.$$

$$a = \frac{m\,n\,W}{l\,d^2\,S}$$

$$d = \sqrt{\frac{m\,n\,W}{l\,a\,S}}$$

In square beams

$$a = d = \sqrt[3]{\frac{m\,n\,W}{l\,S}}.$$

5. When the beam is fixed at both ends, and loaded at an intermediate point.

$$W = \frac{3\,l\,a\,d^2\,S}{2\,m\,n}.$$

$$l = \frac{2\,m\,n\,W}{3\,a\,d^2\,S}.$$

$$a = \frac{2\,m\,n\,W}{3\,l\,d^2\,S}$$

$$d = \sqrt{\frac{2\,m\,n\,W}{3\,l\,a\,S}}$$

In square beams

$$a = d = \sqrt[3]{\frac{2\,m\,n\,W}{3\,l\,S}}.$$

In the above formulæ

W = breaking weight in lbs.
l = length in inches.
a = breadth in inches.
d = depth in inches.
S = the tabular value given in Table No. 52.
m and n represent distance from the points of support when the load is applied at an intermediate point on the beam.

Deflection of beams.

Prof. Barlow's rule for arriving at the amount of deflection.

In order "to determine the dimensions of a beam capable of supporting a given weight with a given degree of deflection when fixed at one end: *rule,* divide the weight in lbs. by the reduced tabular value of E, multiplied by the breadth and deflection, both in inches; then the cube root of the quotient multiplied by the length in feet will be the depth required in inches." "When the weight is uniformly distributed over the length of the beam, the deflection will be only $\frac{3}{8}$ths of the deflection from the same weight applied at the extremity, and in the rule consider the weight reduced in this proportion." "If the beam be a cylinder, the deflection will be 1·7 times the deflection of a square beam, other circumstances being the same." "To find the dimensions of a beam capable of sustaining a given weight with a given degree of deflection when supported at both ends: *rule*, multiply the weight to be supported in lbs. by the cube of the length in feet. Divide this product by sixteen times the reduced tabular value of E, multiplied into the given deflection in inches, and the quotient is the breadth multiplied by the cube of the depth in inches."

Deflection in beams with uniformly distributed load.

Cylindrical beams or shafts.

Note 1.—"If the beam be intended to be square, then the breadth is equal to the depth, and the fourth root of the quotient is the depth required."

Note 2.—"If the beam be a cylinder, multiply the quotient by 1·7, and then the fourth root will be the diameter of the cylinder."

"To determine the dimensions of a pillar or column to bear a given stress in the direction of its axis without sensible curvature: *rule*, multiply the weight to be supported in lbs. by the square of the length of the pillar in feet, and divide the product by forty times the reduced tabular value of E, the quotient will be equal to the breadth multiplied by the cube of the least thickness; therefore, either the breadth or thickness will require to be fixed upon before the other can be found."

Strength of columns of timber.

Note 1.—"If the pillar be square, its side will be the fourth root of the quotient."

Note 2.—"If the column be a cylinder, multiply the tabular value of E (Table 52) by 24 instead of 40. The fourth root of the quotient in the rule will be the diameter of the cylinder."

The following formulæ as to the strength of wooden

Formulæ for strength of columns.

columns, as given by Mr. Eaton Hodgkinson, will be found useful:—

LONG COLUMNS.

$$W = 10 \cdot 95 \frac{D^4}{L^2}, \text{ solid square Dantzic oak (dry).}$$

$$W = 7 \cdot 81 \frac{D^4}{L^2}, \text{ solid square of Red-deal (dry).}$$

SHORT COLUMNS.

$$w = \frac{W \,.\, C}{W + \cdot 75\, C}.$$

W = breaking weight of long columns in tons.

w = breaking weight of short columns, less than 30 diameters long, in tons.

L = length of the column in feet.

C = crushing force of material as given in Table No. 52, multiplied by sectional area of column.

Relative strength of columns in reference to form of section. Safe load for columns.

The relative strength of columns having the same sectional area, but differing in the form of section, will be for a circular column = 100, triangular ditto = 110, square ditto = 93. The safe load to be applied to columns should not exceed one-tenth of the breaking weight.

CHAPTER XXIV.

IRON AND OTHER METALS.

IRON and some other metals are extensively used by the sanitary engineer in carrying out his varied description of works. Iron is more or less found in every country, and in every geological formation. It is employed in the construction of sanitary works in three forms: either as cast iron, which is a carburet of iron; as wrought iron, which is cast iron decarbonized, or freed from its combined carbon; and as steel, which is iron having a smaller amount of carbon in combination than is found in cast iron. Cast iron is largely used in works of sewerage and water supply. It is a metal which is easily moulded to any shape, and is well adapted for the formation of pipes, cylinders, flushing-doors, penstocks, columns, gullies, and a variety of other details. Of the quality of cast iron, it is classed by the manufacturer as No. 1, 2, 3, or 4, according to the amount of carbon which is in combination with the iron. No. 1 is an iron which is most highly carbonized, the carbonization diminishing with the number of the iron. The amount of carbon in combination with the iron varies from 2 to 4 per cent. The proper admixture of the iron in the foundry is one of considerable importance in order to ensure a perfect casting; for as different varieties of iron have different points of fusion and varying rates of cooling, unless a proper admixture is ensured the casting will have within itself an element tending to produce its own destruction, for while some of the metal may be in perfect fusion, other parts may be imperfectly fused, while again others may be burnt;

Forms in which iron is used.

Use of cast iron.

Classification of cast iron.

Admixture of iron.

or in cooling, some of the metals may cool faster or slower than others, consequently the casting may be thus brought into a state of unequal tension, or, as it is technically termed, "hide-bound," when such slight influences as sudden change of temperature may lead to its instant destruction. Experiment has shown that castings which are made by remelting the iron in the air furnace are capable of bearing a slightly greater tensile strain than those made direct from the blast-furnace; therefore it is the practice of some engineers to stipulate that the metal shall be remelted in the air furnace. In the ordinary course of manufacture some of the largest and best makers of cast-iron pipes cast them direct from the blast furnace, and if care is exercised no evils arise from this practice, as the men employed in the manufacture know from long experience, from the appearance of the flower on the molten metal, if it is or is not fit for pipe making, and if not suitable it is run into pigs, and afterwards remelted with an admixture of other iron in the air furnace. In all castings the engineer should see that they are free from air-bubbles, scoria, cold-shot, and other imperfections of casting, and that they are allowed to cool slowly. There are, however, faults to which all articles made of cast iron are liable, and which may escape observation even after the most careful scrutiny, and in consequence there will ever remain a certain degree of uncertainty as to the strength of iron castings, for there are numerous circumstances which may, more or less, affect the quality of the manufactured article, such as unequal contraction in cooling, imperfections from latent flaws which may be concealed by a covering of sound metal, the brittle nature of the material, the presence of some deleterious agent in the metal itself, all tending to render cast iron more or less uncertain and liable to fail without warning. The presence of phosphorus in iron, which is more or less present in most of the ores of this country, greatly detracts from the quality of the

Unequal tension in iron castings.

Air furnace.

Blast furnace.

Faults of cast-iron work.

Fails without warning.

Phosphorus in iron.

material, and gives it a quality commonly known as "cold-short." The iron in this case appears to set in large crystals, and is brittle and very liable to fracture. The presence of sulphur in iron, on the other hand, gives it a quality known as "red-short," while the presence of arsenic is supposed to improve the quality of the material. The Lowmoor iron is supposed to derive its excellent quality from the presence of arsenic.

Sulphur in iron.

Arsenic in iron.

Some other metallic bases when present have also a beneficial influence in purifying iron in the course of its manufacture, and are occasionally added by the manufacturer for this purpose, such, for example, as silica and manganese. Formerly iron was procured entirely by means of the cold blast, but the hot blast is now generally used, as a much larger yield of iron is produced at a less cost, and ores that could not be reduced with the cold blast are now successfully operated upon with the hot blast. It has been generally supposed that the hot-blast iron is inferior to cold blast, and practical tests applied to both irons appear to favour this view; yet the slight inferiority of the hot-blast iron may not be due to the nature of the blast, but, as some persons of great experience in this branch of manufacture ascribe it, to the inferior ores which are now smelted as compared with those used when the cold-blast iron was more in vogue. Cast iron is more generally used in sanitary works in the form of cylinders or pipes, and it is customary for small pipes with bands for drilling to be cast in the foundry on a bed laid nearly horizontal, or at an angle of 45°. Larger pipes of six inches and greater diameter are best cast vertically. In vertical castings the socket ends, if they are socket and spigot pipes, may be cast downwards, or upwards, as required. If large pipes are cast horizontally, the cores are apt to float, so that the pipe, when made, is liable to be thinner on one side than the other. Unequal thickness may occur in pipes vertically cast if

Purification of iron.

Comparison between cold and hot blast iron.

Cast-iron pipe manufacture.

the core is not placed truly concentric, or if it warps in the drying process. In horizontal-cast pipes core nails are required for fixing the core in position, and these are afterwards hammered up, so that it is easy to detect, by the presence or absence of these core nails, if the pipe has been horizontally or vertically cast. In all iron pipes the engineer should be careful to see that the castings are all truly cylindrical, and that the spigot of every socket pipe fits properly into the socket; that all special pipes, such as bends and junctions, are truly shaped and will join properly with the straight pipes; that the sectional area of every pipe be truly concentric, and any pipe which deviates more than one-fourth from the specified thickness at any point should be rejected.

Matters to be observed in pipe manufacture.

Effect of moving loads on cast iron.

The elasticity of cast iron is such that an alternating load of one-sixth the breaking weight will injure it.

Strength of cast iron.

The safe load for cast iron should not exceed one-tenth the breaking weight, and the average tensile strength may be taken at seven tons per square inch.

Strength and thickness of cast-iron pipes.

When cast iron is used in the form of pipes, the mode adopted in practice, of arriving at the proper thickness of the pipe, is based equally on the experience of casting them as upon the calculated thickness that would result when taking into account the pressure they would have to bear; and it will be found that any pipe which can be cast sound in the foundry will bear the ordinary pressure to which it may be subjected in practice. The reason for this is that cast iron is slightly porous, and is liable to considerable defects in casting, especially when the metal is thin; therefore all pipes are made of considerably greater thickness than that required to ensure their stability when subjected to a given bursting pressure. Some engineers make the thickness of a pipe equal one-fifth of the square root of its internal diameter in inches, which gives a thickness safe in practice for all ordinary pressures. The resistance which a pipe offers for every inch of its length to the internal pressure tending to burst it, equals that of the cohesive strength of the thickness of its two sides. The effective area of pressure upon the pipe tending to cause rupture equals its internal diameter. If the tensile strength of cast iron is taken at 15,000 lbs. to the square inch, the weight of a cubic foot of water being 62·449 lbs., then the thickness of a pipe to resist water pressure is

Formula for strength of casting pipes.

$$= \frac{62\cdot449 \text{ H D}}{2 \times 144 \times 15000} = \cdot000144 \text{ H D}.$$

H = head of water in feet.
D = diameter of pipe in inches.

With this thickness the pipe would be at the point of bursting. All pipes should be made of sufficient thickness not only to bear the steady working pressure, but the shocks to which they are subjected when water is put in motion through them or the current is suddenly stopped. In practice it may be taken that pipes should be capable of sustaining ten times the greatest pressure, or the strain to which at any time they may be subjected, which is the pressure used in testing them; therefore if pipes are so made, the following formula will give their thickness, ·000144 H D:

Pipes should be made to resist ten times the bursting pressure.

Formula for thickness of pipes.

H = head of water in feet.
D = internal diameter of pipe in inches.

Pipes are usually tested in a hydraulic machine to a test of three or four times the greatest working pressure to which they will be subjected in practice. When pipes are made according to the formula ·000144 H D, the safe head of water to which they should be tested equals one-tenth the bursting pressure. Example, a 12-inch pipe is required to be made to work under a constant pressure of 125 feet head of water. This pipe would be tested say to $125 \times 3 = 375$ feet, and its thickness should equal $\cdot000144 \times 375 \times 12 = \cdot648$ inch, while its bursting pressure $= \frac{648 \times 2 \times 15000}{12} =$ 1620 lbs. per square inch. A machine for pipe testing

Example.

Pipe testing by pressure.

is illustrated in Fig. 52. It consists of a frame carrying a movable head A. The apparatus is capable of being lengthened at pleasure by means of the nuts B, B, so as to take in pipes of varying length. The pipe C to be tested is rolled up an inclined plane, usually of timber, into its position; the movable head is then screwed up, the pipe being kept water-tight at the ends by means of packing, composed of either platted hemp or a disk of india-rubber or leather. The pressure is applied by means of a force-pump; a gauge is fixed upon the apparatus in order to record the pressure, and as the pipe fills with water provision is made for the escape of the air, this precaution being absolutely necessary, or otherwise a pipe bursting would explode with considerable violence. The thickness of the pipes is usually tested by means of a pair of callipers, as shown in Fig. 53.

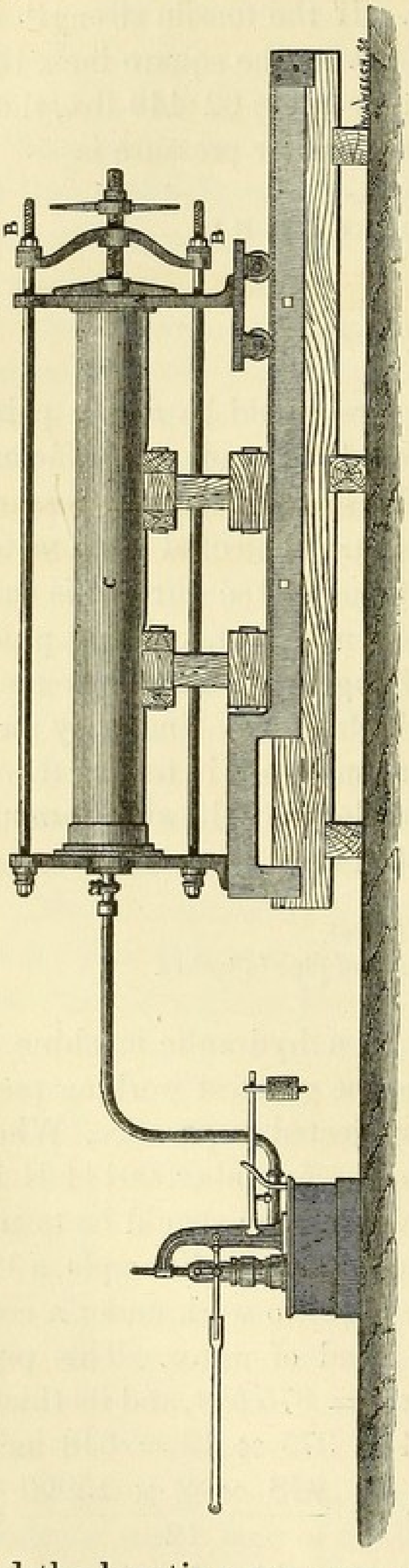


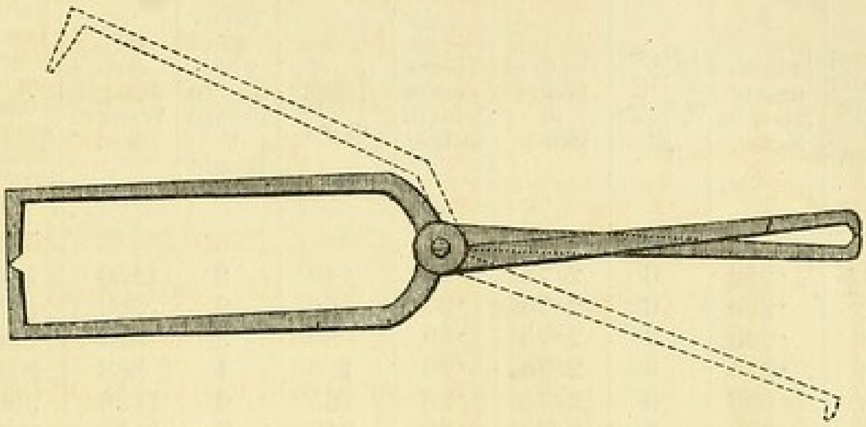
Fig. 52.

Pipe testing for thickness.

Table No. 53.

In Table No. 53, the diameter, thickness, length, weight, safe head of water, and the bursting pressure are given for pipes of from $1\frac{1}{2}$ inch to 48 inches diameter. In cases in which the thickness for pipes required does not correspond with the thickness given in the Table, the weight of the

Fig. 53.



pipe may be arrived at by taking its cubical contents in inches and multiplying it by ·27 lb., the weight of one cubic inch of cast iron. How weight of pipes ascertained.

[Table No. 53.

TABLE No. 53.—Showing the SIZE, WEIGHT, SAFE HEAD, and STRENGTH of CAST-IRON WATER PIPES.

Internal diameter of Pipe in inches.	Thickness of Metal in inches.	Length of Pipe in work, in feet.	Depth of Socket in inches.	Thickness of Joint in inches.	Weight of Pipe in lbs.	Deviation which may be allowed in Weight in lbs.	Safe Head of Water in feet.	Bursting Pressure in lbs. per sq. in., tensile strength taken at 15,000 lbs. per sq. in.
1½	·250	6	2·75	·20	42	2	1150	5000
2	·250	6	2·75	·20	56	2	863	3750
3	·250	9	2·75	·20	80	3	575	2500
3	·375	9	2·75	·20	120	4	863	3750
3	·500	9	2·75	·20	165	6	1150	5000
3	·625	9	2·75	·20	210	7	1438	6250
4	·250	9	2·75	·26	110	4	421	1875
4	·375	9	2·75	·26	160	6	647	2812
4	·500	9	2·75	·26	210	7	863	3750
4	·625	9	2·75	·26	260	8	1078	4687
5	·250	9	2·75	·26	135	5	345	1500
5	·375	9	2·75	·26	195	7	518	2250
5	·500	9	2·75	·26	270	8	690	3000
5	·625	9	2·75	·26	330	10	863	3750
6	·375	9	2·75	·26	230	7	431	1875
6	·500	9	2·75	·26	255	8	575	2500
6	·625	9	2·75	·26	385	11	719	3125
6	·750	9	2·75	·26	470	14	863	3750
7	·375	9	2·75	·26	275	8	370	1607
7	·500	9	2·75	·26	360	10	493	2142
7	·625	9	2·75	·26	450	13	616	2678
7	·750	9	2·75	·26	540	15	739	3215
8	·375	9	2·75	·26	310	9	323	1406
8	·500	9	2·75	·26	410	12	431	1875
8	·625	9	2·75	·26	510	15	539	2343
8	·750	9	2·75	·26	610	18	647	2812
9	·375	9	2·75	·26	345	10	288	1250
9	·500	9	2·75	·26	450	13	383	1666
9	·625	9	2·75	·26	560	16	479	2083
9	·750	9	2·75	·26	680	18	575	2500
10	·375	9	2·75	·26	380	10	259	1125
10	·500	9	2·75	·26	500	15	345	1500
10	·625	9	2·75	·26	620	18	432	1878
10	·750	9	2·75	·26	775	20	518	2250
11	·500	9	2·75	·26	545	15	313	1363
11	·625	9	2·75	·26	680	18	392	1704
11	·750	9	2·75	·26	815	24	470	2045
11	·875	9	2·75	·26	960	27	549	2386
12	·500	9	3·00	·33	595	17	288	1250
12	·625	9	3·00	·33	740	20	359	1562
12	·750	9	3·00	·33	890	22	431	1875
12	·875	9	3·00	·33	1040	30	503	2187
14	·625	9	3·00	·33	890	24	308	1339
14	·750	9	3·00	·33	1060	30	370	1607
14	·875	9	3·00	·33	1230	35	431	1875
14	1·00	9	3·00	·33	1400	40	493	2142

TABLE No. 53.—Showing the SIZE, WEIGHT, SAFE HEAD, and STRENGTH of CAST-IRON WATER PIPES—(*continued*).

Internal diameter of Pipe in inches.	Thickness of Metal in inches.	Length of Pipe in work, in feet.	Depth of Socket in inches.	Thickness of Joint in inches.	Weight of Pipe in lbs.	Deviation which may be allowed in Weight in lbs.	Safe Head of Water in feet.	Bursting Pressure in lbs. per sq. in., tensile strength taken at 15,000 lbs. per sq. in.
15	·625	9	3·00	·33	945	27	288	1250
15	·750	9	3·00	·33	1125	32	345	1500
15	·875	9	3·00	·33	1315	35	403	1750
15	1·00	9	3·00	·33	1495	40	460	2000
16	·625	9	3·50	·33	1005	28	269	1171
16	·750	9	3·50	·33	1200	35	323	1406
16	·875	9	3·50	·33	1395	39	377	1640
16	1·00	9	3·50	·33	1595	45	431	1875
18	·625	9	3·50	·33	1125	32	239	1041
18	·750	9	3·50	·33	1340	36	276	1200
18	·875	9	3·50	·33	1530	42	335	1458
18	1·00	9	3·50	·33	1745	50	383	1666
21	·625	12	3·50	·33	1750	50	205	892
21	·750	12	3·50	·33	2075	56	246	1071
21	·875	12	3·50	·33	2410	68	288	1250
21	1·00	12	3·50	·33	2855	70	328	1428
24	·625	12	3·50	·33	1980	54	180	781
24	·750	12	3·50	·33	2350	65	217	937
24	·875	12	3·50	·33	2800	70	251	1093
24	1·00	12	3·50	·33	3185	80	288	1250
30	·75	12	4·00	·33	3080	78	173	750
30	1·00	12	4·00	·33	3940	105	230	1000
30	1·125	12	4·00	·33	4205	110	259	1125
30	1·25	12	4·00	·33	4955	112	288	1250
36	·75	12	4·00	·33	3675	100	144	625
36	1·0	12	4·00	·33	4785	111	192	833
36	1·125	12	4·00	·33	5195	113	216	937
36	1·25	12	4·00	·33	5900	125	239	1041
42	·75	12	4·50	·33	4365	110	123	535
42	1·0	12	4·50	·33	5645	120	164	714
42	1·125	12	4·50	·33	6300	130	185	803
42	1·25	12	4·50	·33	6940	140	205	892
48	·75	12	4·50	·33	4980	112	108	468
48	1·0	12	4·50	·33	6450	132	144	625
48	1·125	12	4·50	·33	7180	142	162	703
48	1·25	12	4·50	·33	7615	150	180	781

Example of uncertainty of cast iron.

As a practical example of the uncertainty of cast iron and the difficulty of ascertaining the soundness of iron castings, a circumstance came under the author's attention, when carrying out a portion of the water-works of Croydon, which is worthy of being recorded. A 12-inch water main, five-eighths of an inch in thickness, was laid through the district, and the pipes were tested, previous to being laid, at the manufacturer's works, to a pressure of 500 feet head of water. The greatest working pressure on the main did not exceed 120 feet head of water. When this main was first put in operation several pipes burst, and on this account it was thought expedient to test the main again, which was accordingly done, to a pressure equal to 400 feet head of water; in spite of this second test, after some few months had elapsed, three pipes, each at some considerable distance apart, burst simultaneously, causing considerable damage to property. It should be observed that this main was laid in a porous gravel soil in a trench 4 feet deep, and that for some weeks previous to the bursting there had been almost uninterrupted rainfall; consequently the ground was thoroughly saturated with moisture, and a few hours previous to the bursting of the main there was a fall of several inches of snow followed immediately by rain.

Description of pipes used.

Inquiries made as to the mode of the manufacture of these pipes showed that they had been hastily made, and probably too rapidly cooled; impurities may also have been present in the metal which had deranged the crystalline process, and these circumstances combined to render them "cold-short," and probably "hide-bound," and

Cause of failure.

the sudden change of temperature caused them to fly to pieces in a manner analogous to the breaking of an unannealed glass by the pouring in of hot water. In support of the foregoing view as to the cause of the failure of these pipes, it may be said that they could not have failed from pressure, as the main in question drew its supply from a larger main, which was relatively not so strong, and, moreover, samples of the burst pipes when tested were found capable of sustaining a pressure exceeding eight tons to the square inch of section. It is, moreover, well known from experience,

Effects of sudden changes of temperature.

that cylinders of cast iron have flown to pieces when subjected to any sudden change of temperature, especially such as cold rain or severe frost, and that the majority of breakages in cast-iron water pipes usually occur in time of frost, a sudden, severe frost being almost sure to cause considerable breakage of pipes.

Wrought Iron forms more or less an essential feature in constructions for sanitary purposes. Its use for tubes for gas and water, girders, valve gear, tide valves, steam boilers, machinery, and a variety of other purposes, is well known, and its value consists in its great strength and capability of being easily worked into various forms. Like cast iron, it is subject to differences in quality; it is as a rule divided into two kinds, according to the nature of the fracture, one of which is said to be fibrous, tough, or "red-short," and the other granular or "cold-short." The presence of foreign substances in wrought iron has an analogous effect upon it to that which they have upon cast iron; for example, phosphorus is said to render wrought-iron bars "cold-short," while sulphur renders them "red-short." The late Sir William Fairbairn, in his work on Iron Manufacture, says, "The former is the most ductile, and is a tough, fibrous material, which exhibits considerable strength when cold; the latter is more brittle, and exhibits a highly crystalline fracture, almost like cast iron, but the fact is probably not generally known that the brittle works as well, and is as ductile under the hammer as the other when at a high temperature." Of all the qualities of iron preference should be given, as Mr. Kirkaldy states, to puddled iron, instead of scrap iron, which latter may be composed of a variety of qualities of iron, all of which may differ as to their welding points; when therefore they are worked together, one portion may be too much heated, and so destroy the value of that particular iron, while other portions may not be sufficiently heated, and an imperfect quality of iron is the result of such amalgamations. All plates and bars, especially when rolled, are much stronger in the direction of the fibre than in the contrary way. The long-continued heating of wrought iron has a tendency to render it crystalline in character, and to injure its quality. In the manufacture of

Use of wrought iron.

Variations in quality of wrought iron.

Sir W. Fairbairn.

Mr. D. Kirkaldy gives preference to puddled iron.

Influence of fibre on strength.

Assortment of wrought iron.

wrought iron its quality is designated by the number of times the iron undergoes working in the course of manufacture; for instance, it is called best, best best, treble best, &c., according to the number of times it has been worked; but there is a limit to the value of iron so re-worked, as Mr. Kirkaldy has found that after five or six workings the tensile strength of the iron is deteriorated, so no advantage results from incurring the greater cost of re-working an unlimited number of times.

Breaking weight should be stated.

In ordering wrought-iron work it will be well for the engineer to stipulate the breaking weight he expects the iron to bear. Many engineers also take into consideration the amount of elongation taking place in the specimen before fracture. Mr. Kirkaldy, who has given a considerable amount of attention to the quality of iron, considers that it is better to take into consideration the contraction of the area in breaking, because then you will get to know the quality of the iron you have to deal with; and he says, "It seems most remarkable that an element of the highest importance should have been so long overlooked, namely, the contraction of the specimen's area when subjected to considerable strain, and the still greater contraction at the point of rupture which takes place in a greater or less degree as the material is soft or hard, and the consequent influence this reduction must have on the amount of weight sustained by the specimen before breaking. The apparent mystery of a very inferior description of iron suspending, under a steady load, fully a third more than a very superior kind, vanishes at once when we find that the former had the benefit of retaining to the last its original area only slightly decreased, whilst the latter on breaking was reduced to very nearly a fourth of its original area—the one a hard and brittle iron, liable to snap suddenly under a jerk or blow, the other very soft and tough, impossible to break otherwise than by tearing slowly asunder." Therefore, in selecting wrought iron for any particular purpose, it will be well

Contraction of area in breaking should be noted.

Quotation from Mr. Kirkaldy.

for the engineer to state the degree of contraction he will expect when it is tested in the breaking apparatus. Degree of contraction should be stated.

In Tables Nos. 54 and 55, some experiments on the strength and contraction of metals are given which will aid the engineer in the prosecution of his works.

TABLE No. 54.—Showing the SPECIFIC GRAVITY, TENSILE and COMPRESSIVE STRENGTH of various metals. From experiments by Mr. D. KIRKALDY and others.

Description of Metal.	Specific Gravity, Water = 1·000.	Reduction of Fractured Area per cent.	Tensile Strength in lbs. per sq. in.	Compressive Strength in lbs. per sq. in.
Cast steel for tools from Acadian iron	7·823	4·7	132,900	
Bessemer steel for tools, in bar	7·820	22·3	111,460	
Ditto cooled in oil	..	..	211,072	
Blister steel bars	7·720	21·4	104,290	
Krupp's steel bars	..	34·0	92,000	
Mersey puddled steel bars ..	..	35·3	71,480	
Ditto steel plates for ships ..	..	5·4	93,200	
Ditto mild steel plates ..	..	10·5	72,360	
Blochairn steel boiler-plates	7·64	7·1	85,000	
Homogeneous metal rolled bars	..	36·6	90,600	
Ditto forged bars	..	26·0	89,700	
Ditto plates	7·802	15·2	96,700	
Lowmoor iron bars	..	48·5	60,360	
Ditto plates	7·699	15·9	51,250	
Bowling iron bars	..	45·3	62,400	
Ditto plates	..	11·1	49,380	
Glasgow B best bars	7·650	39·6	58,880	
Ditto best boiler-plates ..	..	8·8	51,340	
Swedish bars	..	60·0	50,000	
Cast iron	7·000	..	13,440	80,600
Ditto	7·600	..	29,120	143,360
Wrought iron	..	..	..	35,000 to 40,000
Steel	..	..	..	200,000 to 336,000
Cast brass	8·400	..	18,000	
Gun-metal	8·462	..	34,000	
Copper, cast	8·607	..	18,800	
Ditto, sheet	8·780	..	30,000	
Tin, cast	7·290	..	4,500	15,000
Zinc, cast	7·000	..	7,400	
Silver	10·474	..	40,760	
Gold	19·361	..	20,400	
Lead, cast	11·360	..	1,800	7,000
Ditto, sheet	11·400	..	3,360	
Aluminium, bronze	7·68	..	71,650	130,120
Platinum, sheet	23·000	..	..	
Bismuth, cast	9·822	..	3,200	

TABLE No. 55.—SCALE of TESTS for WROUGHT IRON prepared by Mr. KIRKALDY and adopted by the Secretary of State for India.

Description.	Class C.		Class D.		Class E.		Class F.		Class G.	
	Ultimate Stress per sq. in.	Contraction of Area per sq. in.	Ultimate Stress per sq. in.	Contraction of Area per sq. in.	Ultimate Stress per sq. in.	Contraction of Area per sq. in.	Ultimate Stress per sq. in.	Contraction of Area per sq. in.	Ultimate Stress per sq. in.	Contraction of Area per sq. in.
	tons.	per cent.	tons.	per cent.	tons.	per cent.	tons.	per cent.	tons.	per cent.
Bars, round or square	27	45	26	35	25	30	24	25	23	20
Ditto, flat	26	40	25	30	24	25	23	20	22	16
Angle, and T or I	25	30	24	22	23	18	22	15	21	12
Plates, lengthways / Ditto, crossways	24 / 22 } 23	20 / 12 } 16	23 / 20 } 21½	15 / 9 } 12	22 / 19 } 20½	12 / 7 } 9½	21 / 18 } 19½	10 / 5 } 7½	20 / 17 } 18½	8 / 3 } 5½

N.B.—Class A and B are reserved for any special qualities of iron which might be required at any future time.

Tests for ascertaining the fibre of the iron.

It is also advisable to ascertain the nature and texture of the iron, whether it is coarse or fine, or whether the fibres lie in the direction in which the strain is likely to be brought upon the material. For this purpose Mr. Kirkaldy introduced a very simple method of examining the fibre of the iron. He immersed pieces of the metal in dilute hydrochloric acid, which, acting on the surrounding impurities, has the effect of removing them, leaving to view only the metallic portion of the iron. By a simple test of this kind it is easy to ascertain whether the iron is fibrous or crystalline.

Board of Trade regulations as to strains on structures.

In this country the regulations of the Board of Trade with regard to structures limit the stress that any particular bridge or work should bear to five tons per square inch. This seems about the right limit for safety,

Dr. Fairbairn's experiments.

for the late Sir William Fairbairn showed that structures liable to changes of load were not safe when subject to a strain of seven tons per square inch of section. In all works of engineering, except in cases in which the materials are welded together, it is more or

Riveted joints.

less necessary to secure the work by means of riveted joints. Rankine has calculated that, with rivets and bolts which fit accurately the holes in which they are placed, the resistance to shearing varies exactly as the sectional area of the material in the place of rupture, and may be taken as 32,500 lbs. per square inch for cast iron, and 50,000 lbs. per square inch wrought iron. Sir William Fairbairn calculated that in consequence of the punching of a plate the strength is reduced as follows:—

Shearing strength of iron.

Assuming for the strength of the plate	100
The strength of the double-riveted joint will be ..	68
And that of the single-riveted joint	46

Relative strength of riveted joints.

For riveted joints some engineers advise that the diameter of the rivet used should be twice the thickness of the plate, and the pitch or the distance from centre to centre of rivet should be two-and-a-half times the diameter of the rivet. This rule makes the rivets rather stronger than the plates. To arrive at perfectly correct results the tensile strength of the plate between the rivet holes and the shearing strength of the rivets should be equal. The tensile strength of good Staffordshire or Yorkshire plates, after allowing for the weakening of the plate by punching, may in practice be taken at 18 tons per square inch, and the shearing of the rivet at 25 tons per square inch. Wherever great strength of joint is required, double riveting should be resorted to, and in bridge work chain riveting is used. Both cast and wrought iron are affected by the influence of frost, being much more brittle in time of frost than at higher temperatures. The practice of galvanizing wrought and cast iron, which is common in sanitary works, somewhat impairs the strength of the iron, but as the oxidation of all iron work should be particularly guarded against, or otherwise rapid destruction will follow, galvanizing forms one of the best protections when iron is brought into contact with sewage or the moist air of sewers.

Rule for riveted joints.

Strength of plates and rivets.

Double riveting.

Influence of frost on strength of iron.

Oxidation to be prevented.

Steel is another form of iron. In its chemical composition it stands midway between that of cast and wrought iron. Steel is largely used for the bearings of machinery and in cases where great strength and lightness of structure are required. In the manufacture of

Use of steel, and its manufacture.

steel the object to be gained is either to carbonize wrought iron, or to decarbonize cast iron. The process now generally adopted, known as Bessemer's process, is one that has caused a complete revolution in the manufacture of steel. It has already been shown that cast iron contains from 2 to 4 per cent. of carbon. If this carbon be reduced to 1 per cent. and the metal freed from other impurities, we have steel. The Bessemer process consists in decarbonizing cast iron as distinguished from the older process of carbonizing wrought iron. The mode of operation consists in forcing air and steam through the molten cast iron in a suitable vessel, when the heat generated by the combustion of the carbon in combination with the cast iron is so intense as to keep up the operation without the aid of any further fuel. Owing to the impurities in the iron and the difficulty of arriving at a proper amount of decarbonization, it is found desirable in practice to make a selection of pure irons for the manufacture of steel by this process, and to completely decarbonize them, and then to add a quantity of iron containing a known amount of carbon. This process is now so satisfactorily performed, that metals of uniform quality and strength can be produced with the greatest certainty, and the cost of production is even less than that of wrought iron when manufactured by the old plan. Steel and wrought iron are also made by Mr. Heaton's process, which consists in at once converting cast iron by the use of nitrate of soda into iron or steel. The salts of iron have been largely used for the deodorization and precipitation of sewage matter, and also as a disinfectant.

Bessemer's process.

Heaton's process.

Salts of iron.

Use of copper.

Copper is a metal that is used in sanitary works, more especially in connection with waterworks and the interior fittings of houses, as for the construction of baths, hot-water apparatus, floating balls for cistern valves, &c. It is also extensively used alloyed with other metals, as with tin, zinc, and lead. When mixed in the proportion of one of tin to nine of copper the alloy is termed gun-

Gun-metal.

metal. This metal is extensively used in the bearings of machinery, the spindles, nuts of sluices, and other valves. Gun-metal is also made by mixing tin and copper in other proportions, varying from 1 to $2\frac{1}{2}$ oz. of tin to 18 oz. of copper, the former making a soft material, and the latter a material of considerable hardness. When mixed with zinc it forms brass, which is used for many purposes in connection with sanitary works, more especially for the details of house fittings, and for the construction of stop and bib-cocks in connection with waterworks. A very good alloy for the construction of water fittings consists of 14 lbs. of copper, $1\frac{1}{4}$ lb. lead, and 1 lb. block tin. Muntz's metal, another form of brass, is now extensively used, especially for the protection of ships' bottoms. It consists of various preparations of zinc and copper, varying from 37 of zinc to 63 of copper, to 50 of zinc and 50 of copper. The alloys of copper are very much stronger than the original metals when subject to either compressive or tensile strains, as will be seen on examination of Table No. 54. The salts of copper are largely used for disinfecting purposes.

Brass.

Alloy for water fittings.

Muntz's metal.

Strength of the alloys of copper.

Salts of copper.

Tin is a metal that is extremely valuable for sanitary works, especially for the conveyance of water in its pristine purity. It offers great resistance to the action of certain ingredients in water which rapidly act upon other metals, and lead to serious inconvenience by rendering the water unwholesome. It is used as a wash and lining for pipes of other metals, such as iron, lead, &c. The great expense of tin precludes its entire use in water fittings, except to the wealthy; but it is used as a lining for lead pipes, and owing to its having a greater tensile strength than lead, it can be used in combination with this latter metal; thus a lead pipe with a tin lining may be made equally strong as an ordinary lead pipe, and at about the same cost.

Use of tin.

Tin-lined pipes.

Lead is largely used in sanitary works, especially for the formation of small service pipes in waterworks. It

Use of lead.

is made of various sizes and thicknesses, in accordance with the circumstances and pressures of water it is to withstand, and it is extremely convenient for use in practice on account of its ductility. It is also used for the lining of cisterns, and the construction of ordinary household pumps, but care in its use needs to be exercised on account of the action of some waters upon it, whereby soluble salts of lead are formed, which if taken up into the system of the water-drinker lead to serious internal disorders. The oxides of lead are largely employed as the base of most pigments used in protecting iron and wood work.

Value on account of ductility.

Danger of lead pipes.

Lead used as a pigment.

Use of zinc.

Zinc is also a material very extensively used in sanitary works. On account of its cheapness it is ordinarily employed in the construction of ventilating pipes, cisterns, baths, rain-water pipes, and a variety of ornamental purposes in connection with sanitary works. Zinc pipes are extremely sensitive to the influence of sewer air, and are soon destroyed by it; therefore on no account ought any pipe of this material to be used within a house. The thinness of the material usually used in connection with zinc work also renders the work very liable to failure at the joints, and to warp and fail from the effects of changes of temperature. Zinc is now extensively used as a coating for the protection of other metals, as in galvanizing. The objections to the use of zinc in connection with waterworks are as great as those against lead, as waters which will affect lead will equally attack zinc, forming dangerous salts. The salts of zinc are largely used for disinfecting purposes, and for the preservation of timber, and its oxide is employed as a pigment.

Objections to use of zinc.

Salts of zinc.

Use of silver.

Silver is used in sanitary works to some extent, many articles being plated with it. It has also been employed as a lining for lead water-pipes. In the days of antiquity both pipes and cisterns of solid silver were not uncommon. "In the Baths of Claudius the water ran through pipes of silver."

CHAPTER XXV.

FOUNDATIONS FOR SEWERS.

In some districts, owing to the treacherous or unstable character of the subsoil, it is necessary to make provision for securing a good foundation for sewers, as they must always be constructed at a certain definite level in order to effect their object, and they cannot be carried below that level to obtain, at a greater depth, a more stable foundation. Therefore the best mode of providing artificial foundations when sewers have to be constructed in unfavourable situations, is a question for the engineer to consider. In some cases a good foundation may be secured by excavating the sewer trench to an additional depth, and afterwards filling it up to the level of the sewer with suitable materials. For example, in districts in which rubble-stone or boulders are plentiful, rough rubble walling may be resorted to; under other circumstances a continuous wall of concrete may be constructed under the sewer; or, as has been done in the case of the northern outfall sewer of the metropolis, when passing through the marshes below Barking, where, in order to save the great cost of excavating the ground down to a firm formation, piers of concrete were constructed at intervals along the course of the sewer, which were afterwards connected by brick arches, so as to form, as it were, a kind of subterranean aqueduct. This kind of foundation will be found in some cases extremely serviceable. The arches, as well as the piers, may be constructed of concrete, the earth being excavated so as to form the natural centre for the concrete arch. In carrying out the sewerage works of Redhill in 1867, the author had to

Necessity of constructing sewers at fixed levels.

Excavation of trench to greater depth.

Rubble wall foundation.

Concrete wall foundation.

Pier foundations.

Concrete arches for foundations.

Example: sewers at Redhill.

contend with very unstable soil in which to construct the sewers, the ground through which the sewers were carried in many cases being so extremely soft and boggy as to be dangerous to walk on; yet the sewers have been executed in the rotten bog and quicksand of this district in a perfectly satisfactory manner. The mode adopted was similar to the designs for the foundation of sewers illustrated in Plate V. When the ground was moderately solid, an entire concrete foundation was used, as shown in Plate V., Fig. 1. Where the ground was more treacherous, three lines of timber, $5\frac{1}{2}$ inches square, were laid in the trench, which was excavated to a width of 6 feet in the clear. These poles were laid so as to break joint; on the top of these poles, or sleepers, closely wattled hurdles were placed, and on these the concrete was laid, as shown in Fig. 2, Plate V. In other cases, when the foundation was found extremely treacherous, a similar arrangement of fir-poles or sleepers as before was used, but they were closely covered with 3-inch planking, which was securely spiked down to the longitudinal sleepers, as shown in Fig. 5, Plate V. Owing to the large amount of water present when excavating these works, it was found that if for only a short time the operation of pumping was discontinued, the subsoil water would rise and force its way through the newly-laid concrete or brickwork of the sewer; consequently it became necessary to make provision for admitting this water into the sewers during the progress of the works, in such a way as to allow the materials a fair chance of consolidation before finally excluding the water. This was done as shown in Fig. 54, which represents a sewer constructed upon an artificial plank and concrete foundation. At suitable intervals along the line of sewer ordinary sewer pipes were placed upon the planks socket downwards, and afterwards filled with clean gravel, a communication being made by means of a land drain communicating with the bottom of the

Description of Plate V. Concrete foundation.

Timber, hurdles, and concrete foundation.

Plank foundation.

Admittance of subsoil water into sewer.

Description of Fig. 54.

ARTIFICIAL FOUNDATIONS FOR SEWERS.

Fig: 1.

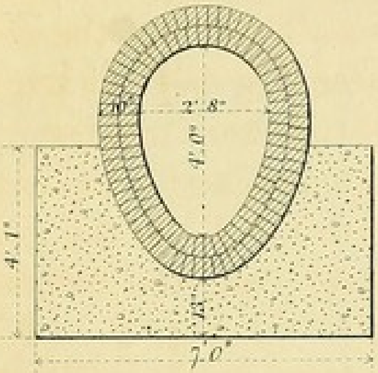


Fig: 2.

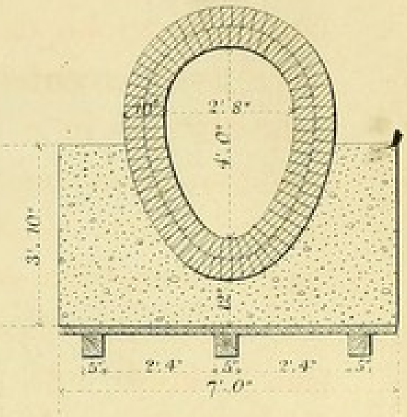


Fig: 3.

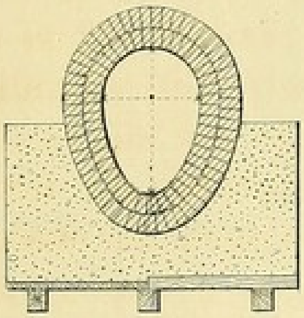


Fig: 4.

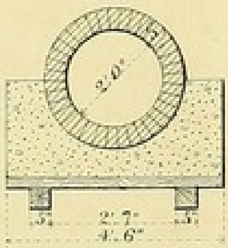


Fig: 5.

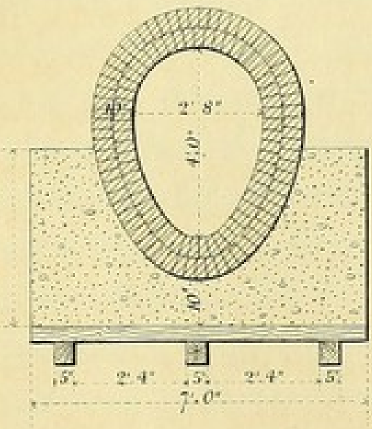


Fig: 6.

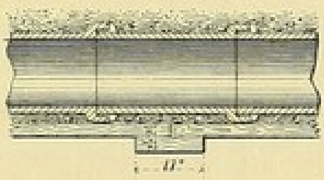


Fig: 7.

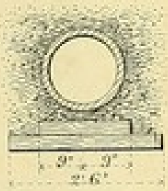


Fig: 8.

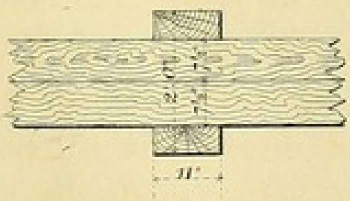


Fig: 9.

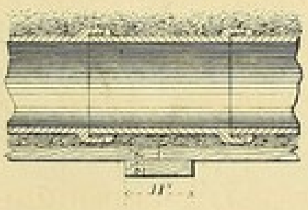
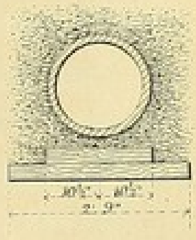


Fig: 10.

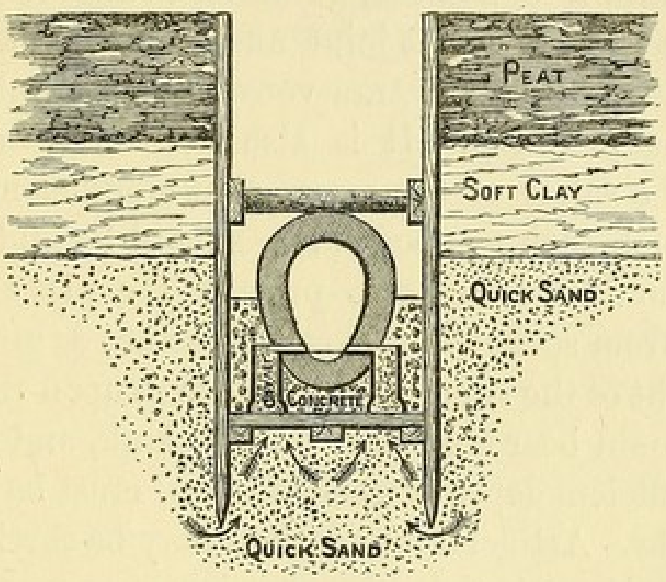


London: E. & F.N. Spon, 46, Charing Cross. Thomas Kell, lith.

sewer. The water passed up through the planked floor and gravel, discharging itself, free of sand, into the sewer; so that the water, having a free escape, did not

Separation of sand from water.

Fig. 54.



injuriously affect the work, and pumping could therefore be dispensed with after the completion of the lower portion of the sewer; and owing to the small apertures left for the purpose of admitting the spring water into the sewer, at any time that may be thought desirable after the consolidation of the work, the spring water could be effectually shut out. In Plate V., Fig. 3, is shown the design for the artificial foundations of one of the sewers of Dantzic, which in some portions was intended to be constructed on wattled hurdles, and the other portions on closely planked foundations. Fig. 4 also represents a 2-feet sewer upon a plank and concrete foundation. Fig. 5 represents an oval sewer upon a plank and concrete foundation. Fig. 6 shows a longitudinal section of a plank foundation for earthenware pipes of 12 inches and smaller diameter. Fig. 7 shows a transverse section of the same. Fig. 8 shows a plan of a plank foundation for sewer pipes of 15 inches and larger diameter. Fig. 9 represents a longitudinal section of the same, and Fig. 10 a transverse section. It is only necessary to add, with regard to these planked

Foundations of Dantzic sewers.

Description of Plate V.

Precautions to be taken with plank foundations.

foundations, that in cases where single planks are used for the foundation of a sewer, as shown in Figs. 6 and 7, a cross-sleeper should be laid under the ends of the planks; or, in cases where two planks are laid side by side to form a foundation, as shown in Fig. 8, the plank should be laid to break joint, and at the point at which the joints are broken a transverse sleeper should be laid under the planking. It is also necessary, in order to ensure the safety of the sewer, that a sufficient amount of material, such as good earth, should be laid over the

Pipe must not rest on sockets.

plank foundation, so as to prevent the pipes taking a bearing from socket to socket, and so act as girders with the weight of the superincumbent earth upon them. The pipes should bear uniformly on the plank, and to secure this a sufficient depth of good material must be laid upon

Artificial foundations constructed for sewers of any size.

the planks. Artificial foundations may be carried out on the foregoing principles for carrying sewers of any size, as it is quite possible to construct a raft foundation of sufficient area to carry the heaviest sewer over the most unstable ground. It would, however, be well in carry-

Experiments should be made to test new foundations.

ing out such artificial foundations that experiments should be made before the work is fully carried out, by first constructing a length of the work and testing its capability of carrying its intended load, by weighting it to an amount equal to the weight of the sewer with its charge of sewage and the superincumbent earth which may rest upon it. This test was applied in

Test at Redhill.

the case of Redhill, and it was found that a sewer 3 feet by 2 feet 6 inches internal diameter, constructed in ground which would not bear men to walk upon without sinking, with an artificial foundation 6 feet wide, when weighted, showed after fourteen days no perceptible subsidence, and the work was prosecuted to completion, and has not since shown the slightest sign

Pile foundations.

of settlement or failure. In some cases, in constructing the foundations of sewers it may be necessary to introduce piling with cap-sills and close planking. This is especially necessary in the case of an outfall sewer constructed in unstable ground and liable to be undermined by the action of the sea. When it is necessary to construct pile foundations, experience alone can guide the engineer as to the best mode of procedure in such cases.

CHAPTER XXVI.

JUNCTIONS WITH SEWERS.

In carrying out works of sewerage one of the most important points for the consideration of the engineer is the proper mode of forming the junctions with sewers.

Junctions in early sewer-work.

In the early sewerage works of this country the ordinary house-drains were usually placed at a level from 18 inches to 2 feet above the invert of the sewer, in order to ensure the drains being kept open or free from the deposit which it was known would surely take place in the imperfectly constructed sewers of that period; but now that the principle of forming sewers is better understood, and as sewers ought not now to be any longer liable to accumulations of deposit, and as the mode of forming junctions very materially influences the working of a system of sewers, this work should be performed in a proper and scientific manner.

Junctions materially affect the working of the sewers.

It should be laid down as a rule that branch sewers, or drains communicating with sewers, should be made to discharge into the main sewer in the direction of the established current of the sewer, and that the velocity of the discharge of the subsidiary sewers or drains should at least equal that prevailing in the main sewer.

Junctions should join sewers in direction of established current.

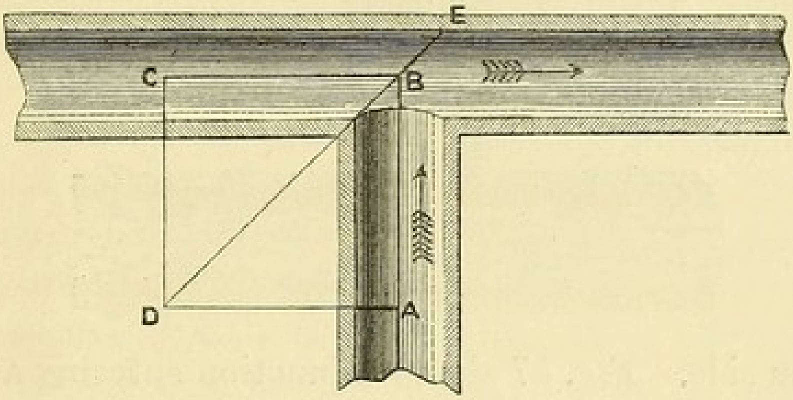
Right-angled junctions.

Right-angled junctions, both lateral and vertical, have been and are still used for forming the junction with sewers; such junctions, however, have the effect of producing eddies, which check the flow in the sewer, and lead to injurious accumulations of deposit.

The effects of such a junction may be explained by the parallelogram of forces. In Fig. 55 the line A B represents the direction and force of the branch stream, the line C B representing the force or momentum of the stream in the main sewer; by completing the parallelogram A, B, C, D, the diagonal D B will represent

Parallelogram of forces applied to junctions.

FIG. 55.



the force and direction of the combined current, showing the effect of such a junction would be to cause the stream of sewage to impinge upon the sewer at E, whereby the velocity of the stream through the sewer is diminished as a portion of the velocity or momentum is expended in causing eddies, and experience shows that such eddies lead to the accumulation of deposit above the point of junction, the cause of which is due to the flow from the branch sewer, which has a tendency to cause the sewage to rise at the opposite side of the sewer, or at E, and the continuity of the inclined plane, which should mark the surface of the flowing stream through the sewer, is broken, so that the portion between B and C is less inclined, or may be level, or in some cases may have a fall against its proper head. The consequence of this is that the velocity of the liquid in this portion of the sewer is materially diminished, and deposit takes place. An examination of sewers, connecting at right angles, shows that invariably a shoal is formed above the point of junction, diminishing in depth as it advances up the stream. Fig. 56 shows a right-angled junction entering at the crown of an ordinary pipe

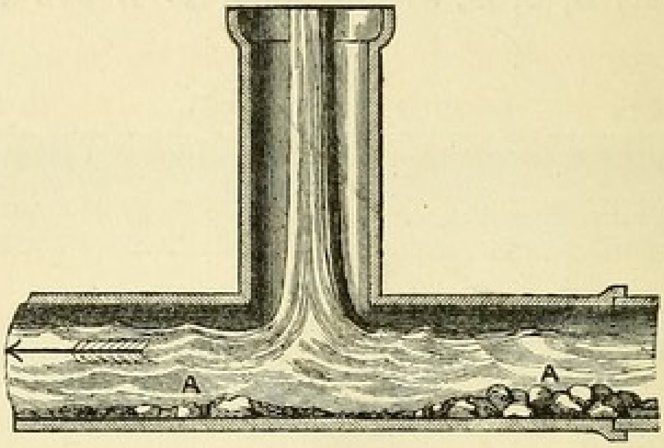
Eddies lead to deposit.

Deposit caused by improper junctions.

Right-angled junction entering the crown of a sewer.

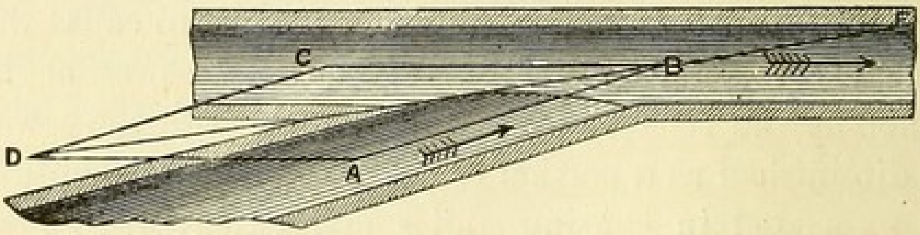
sewer. In this woodcut the effects are shown by the deposit at A A, which is always greatest on the up-

FIG. 56.



stream side. Fig. 57 shows a junction entering at less than a right angle.

FIG. 57.

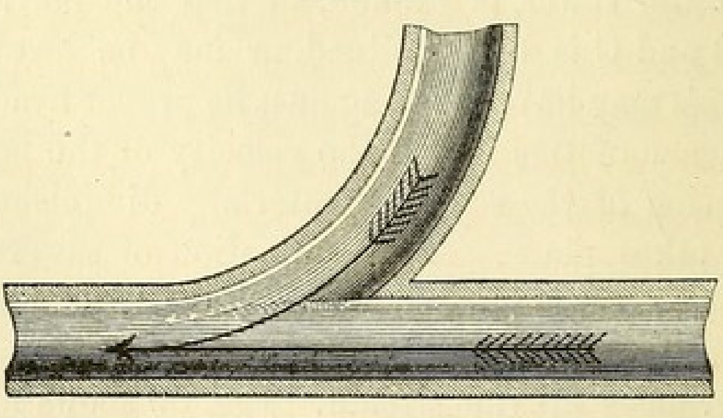


Oblique junctions.

It will be seen, by completing the parallelogram A, B, C, D, in this case, that the more acute the angle the less disturbance will be caused by the flow of the branch sewer, as the point E is removed a considerable distance down the sewer; but with a curved junction,

Curved junctions.

FIG. 58.



as shown in Fig. 58, which is constructed "by a curve tangent to the direction of both sewers, eddies are avoided, and when the radius of the curve is great the diminution of the velocity is almost inappreciable." It is customary in practice, when curved junctions are formed, to give the branch sewer or drain a rather greater amount of fall in the curve, in order to make up for the resistance of the bend. Junctions made at points above the flow of the ordinary water-line in the sewer, even when joining the sewer at an angle, act prejudicially in causing eddies by diminishing the velocity. For example, a junction made in the crown of the arch of the sewer, produces the same effect upon the flow as a junction at right angles, as shown in Fig. 46, because a body of water falling from a height on to the surface of a flowing stream, retards the velocity in the same way as a right-angled junction. The proper position for a junction is within the water-line, but not so low that the flow from it would be checked by the sedimentary deposit that will be rolled along the bed of the sewer. It will be seen that when junctions are so placed that the outfall of a house-drain will be below the water-line, the drain will be trapped at its outlet, and therefore the ventilators of house-drains cannot judiciously be used to ventilate sewers, and moreover house-drains, by reason of the sealing of their outlets, require special means for ventilation, in a manner hereafter described.* The junctions between brick sewers and pipe sewers or house-drains should be formed by the use of a proper junction block, as shown in position in the sewer in Fig. 59. A section of the block used is shown in Fig. 60.

Curves in junctions have increased fall.

Effect of junctions in crown of sewer.

Proper position for junctions entering sewers.

Effect of junctions on house-drains.

Junctions with brick sewers.

These blocks should be built into the sewer as the work proceeds. Such blocks are made of fire-clay, or of stone-ware, and the branch enters the sewer in an oblique direction, and forms the best mode of terminating pipe sewers or drains with brick sewers; otherwise where pipes are used to form the junction, it is generally necessary to cut them to fit the brickwork at the proper

Objections to pipes in forming junctions with brick sewers.

* Vide p. 355.

angle, and in cutting pipes the work is not usually so carefully done but that some imperfection remains

Fig. 59.

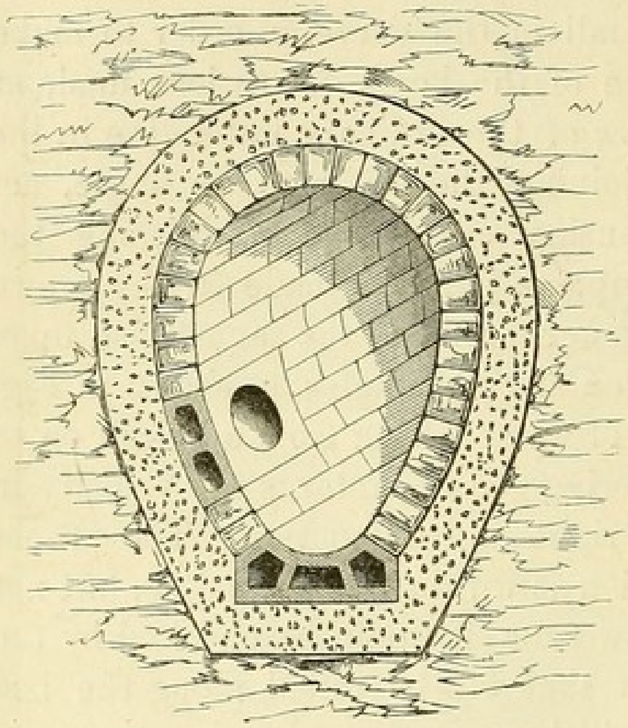
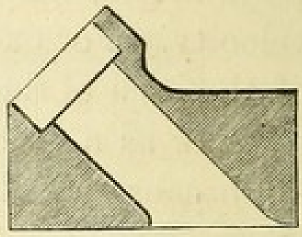


Fig. 60.



Mode of forming junctions with pipe sewers.

which detracts from the merit of the work. The junctions of pipe sewers, or drains with pipe sewers, when curved, are struck from a centre at right angles with the centre line of the pipe, the inside of the straight pipe meeting the inside of the branch at a tangent on a radius line from which it is struck. Where more pipes than one are required for forming a curved junction, the end of each pipe when manufactured should be cut to the radius of the curve with which they are described. The greater the radius of the curve used in forming a junction with a sewer, the less will be the resistance offered to the flow, and the more perfect will be the work. Where sewers are laid in straight lines they may communicate at right angles when they discharge into manholes the outlet from which is placed at a lower level than the inlet. It is also a good plan to form curved channels in the floors of the manholes for the purpose of connecting the several sewers entering a manhole with the outlet

Form of ends of pipes.

Great radius of curve the best.

Circumstances under which right angles may be allowed.

sewers passing out of a manhole. This arrangement requires extra fall to be taken at the manholes, in order to secure the advantages of having the sewers laid in straight lines for facilitating the purpose of examination. The junctions between brick sewers and brick sewers, when sewers are of nearly similar size, are formed as shown in Plate IV.; Figs. 7 and 8 in this plate show the arrangement of forming junctions where two or three sewers join with one main sewer. The plan usually adopted with such sewers is to construct a bell-mouth, which receives the sewers at its largest end, and gradually diminishes at the lower end to the size and shape of the sewer which will convey the whole volume to be discharged; but where small sewers meet larger sewers they usually join with a curved junction, as shown in the woodcut, Fig. 58.

Junctions of brick sewers with brick sewers.

Description of Plate IV.

Use of bell-mouth sewers.

Junctions of small brick sewers.

CHAPTER XXVII.

FLUSHING ARRANGEMENTS OF SEWERS.

Flushing necessary.

In all works of sewerage it is important that arrangements should be made for flushing the sewers in order to keep them thoroughly cleansed and in efficient working order. It has already been shown that a certain velocity of flow is necessary to prevent the deposit of sedimentary matter in a system of sewers.

Intermittent flow.

Now as every sewer has, more or less, an intermittent flow, and in some cases, especially in those receiving rainfall, the volume flowing through the sewer may at times be so small, when compared with the size of the sewer, that such a retardation of the natural velocity may arise as will lead to the deposit of sediment. It is therefore at periods when the flow of sewage is at its minimum, that the arrangements for flushing are most required.

Object of flushing.

The works necessary for flushing sewers have for their object the maintenance, for a sufficient time, of an effective velocity through them, so as to remove any deposit and cleanse the sewer. This velocity may always be created by the discharge of a sufficient volume of water or sewage through a properly constructed sewer. In practice it will be found that it is not necessary, in a well-devised system

Volume necessary for flushing.

of sewers, to provide for flushing purposes a volume equal to the full discharging capacity of the sewers, as theoretically a better velocity is provided with a smaller volume, for by reference to Tables 23 and 24 at pages 116 to 119, it will be seen that an oval sewer running two-thirds full, has a greater velocity than the same sewer has when running full. The volume required to get good flushing power is therefore considerably less than the full discharge of the sewers, as will be seen by reference to Table 30 at page 135, which shows the relative areas of the channel, and Tables 33 and 34, at pages 142 to 145, show the relative volume discharged. As an example, an oval sewer of the old form, 2 feet by 3 feet, laid at an inclination of one in a thousand, when running full, will have a velocity of 141 feet per minute, and discharge 648 cube feet in the same time, while the same sewer running two-thirds full will have a velocity of 148 feet per minute, and discharge only 447 cube feet in the same time. Circular sewers have theoretically the same velocity of flow when running half full as when they run full; and although it may appear paradoxical, there is a point in the flow of all sewers when they discharge more than when running full. Various plans have been suggested and adopted at different times in order to effect the flushing of sewers. Mr. Roe, when surveyor of the Holborn district, introduced the system of damming up the sewage within the sewers, and then suddenly liberating it, so that the ordinary sewage itself became the natural agent for flushing the sewers. Independent supplies of water are now often furnished in such quantities as to increase the ordinary flow, accelerating the velocity to such a degree as to cleanse the sewers. When the ordinary sewage of a town is to be made use of for the purpose of effecting the flushing of the sewers, special flushing gates or sluices are fixed in the sewers, which when used have the effect of damming back or heading up the sewage in the upper reach or section of a system of sewers, and then by suddenly liberating it into the lower reaches the flushing and cleansing of the sewers are effected. Flushing gates are of various descriptions, and may be worked in various ways. They are made as half, three-quarter, and whole gates, just in proportion as they fill the sectional area of the sewer. Some engineers prefer the use of half flushing gates, as shown in detail in Plate VI. Half and three-quarter gates have this to recommend them, that if the flushing party neglect to remove the dam at the proper time, no serious evil will arise, as the ordinary sewage would escape by flowing over the gate, and pass away into

Example as to volume and velocity.

Circular sewers.

Mr. Roe's system of flushing.

Additional water supplies.

Flushing gates.

Description of flushing gates.

Advantages of some forms of flushing gates.

the lower portion of the system of sewers without causing any damage. Whole gates are used when a large volume of sewage is required to be dammed up in order to secure a sufficient volume to produce the requisite velocity in the sewer to render it self-cleansing, and it is advisable to use such gates when sewers of comparatively small size are constructed at small inclination. Such a gate is illustrated in Plate VII. All flushing gates are usually worked by being closed against the current, and when not self-acting are fixed in position by a stay having a cam head working in a cast-iron trough, as shown in Plate VI. Fig. 1 in this plate shows the plan with flushing gate fixed across the sewer and secured by the stay. Fig. 2 is a section. Fig. 3, front elevation of the gate. Figs. 4, 5, 6, 7, and 11, show the details of the flushing gate and its cast-iron frame. Figs. 8 and 9, details of cast-iron trough. Fig. 10, details of the stay and cam for fixing the gate in position. Fig. 12 shows the plan and sections of a foot-iron for a manhole. After the gate is fixed and the sewer is filled to the proper extent, the flushing man strikes the stay upwards, when it slides along the trough, owing to the pressure of water opening the gate so soon as the cam is liberated, and the whole of the pent-up charge of sewage is precipitated to the lower reach of the sewer with a considerable velocity. In cases where whole doors are used and the sewer is running nearly full, to obviate the inconvenience that would arise to men approaching the door, a rack and pinion movement should be provided, which is connected with the flushing gate, and is worked from the street level, as shown in Plate VII. Fig. 1 in this plate shows the plan with the flushing gate fixed in position across the sewer: the stay in this case is attached to a rack that slides in the fixed trough. Fig. 2 shows the section of the gate and stay when fixed across the sewer. Fig. 3, front elevation of the flushing gate. Fig. 4, plan of the shaft, showing in the angle the spindle and ratchet apparatus for fixing the door. Fig. 5

Whole gates, when they should be used.

Working of flushing gates.

Description of Plate VI.

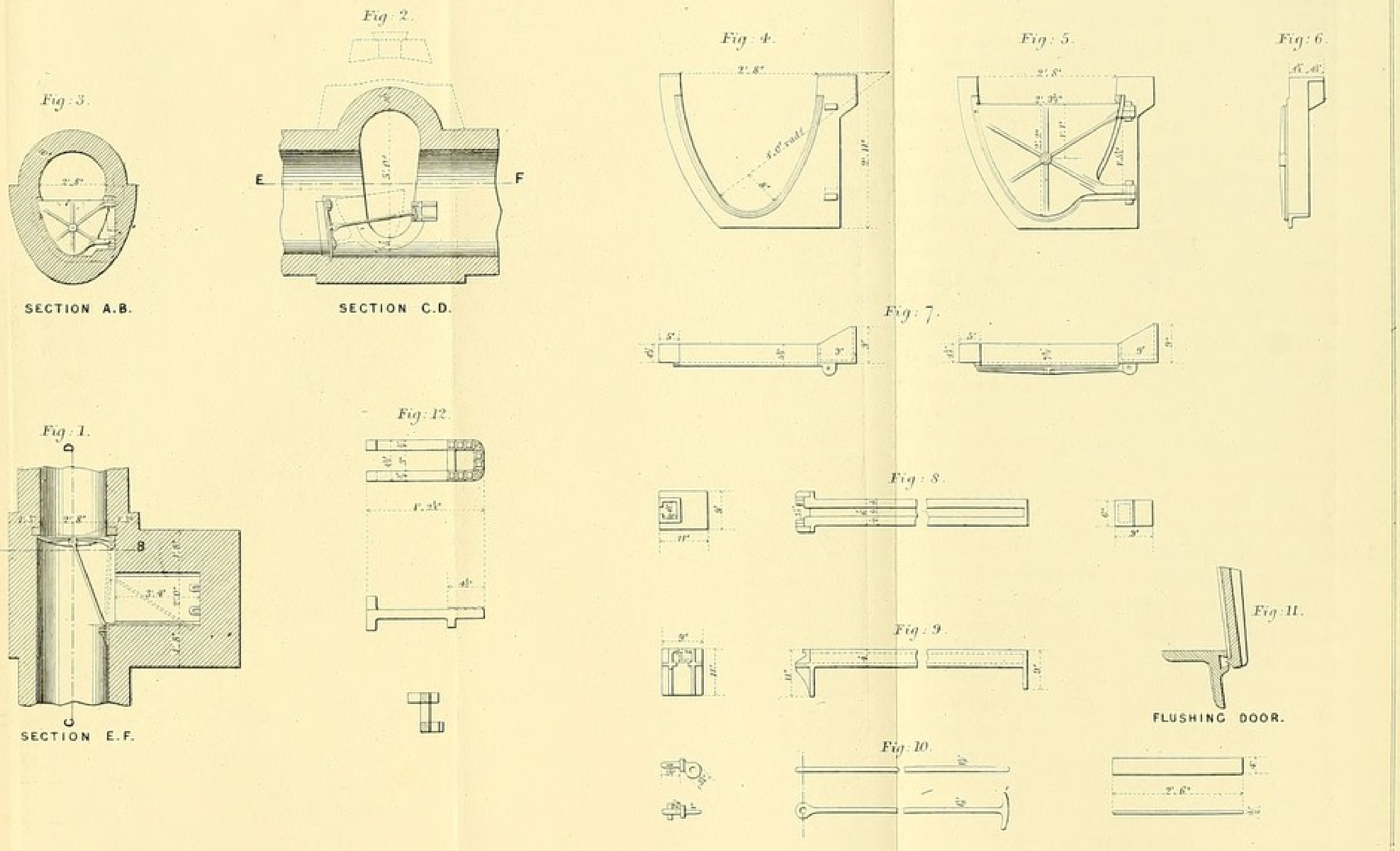
Plate VI.

Flushing gates worked from street level.

Description of Plate VII.

HALF FLUSHING GATE,

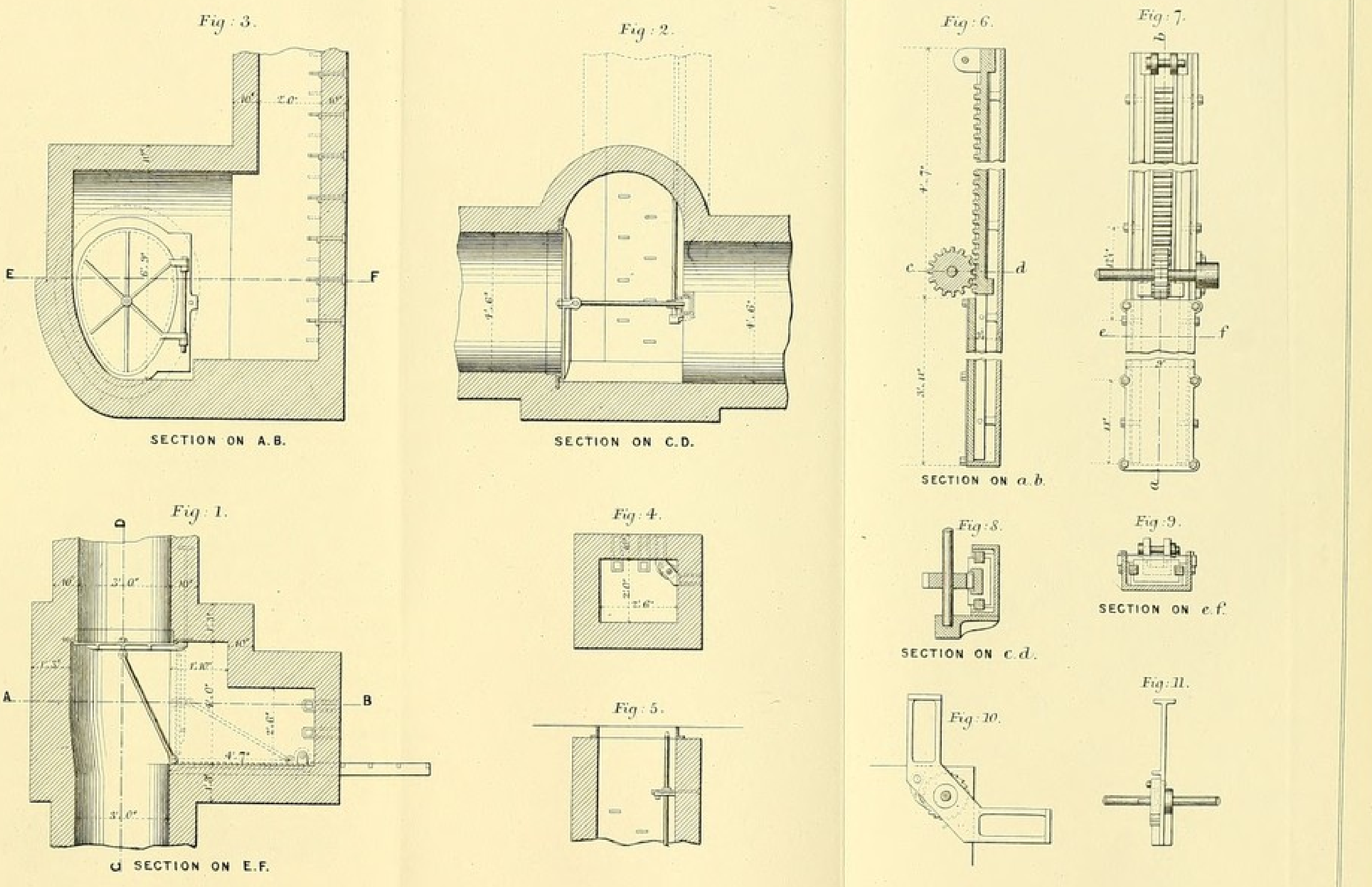
AS USED AT DANTZIC.



London: E. & F. N. Spon, 46, Charing Cross.
Thomas Kell, lith.

WHOLE FLUSHING GATE,

AS USED AT DANTZIC.



London: E. & F.N. Spon, 46, Charing Cross.
Thomas Kell lith.

shows mode of guiding and staying the spindle by which the apparatus is worked. Figs. 6 and 7 show a section and elevation of the rack and pinion movement. Figs. 8 and 9 show sections of the trough and rack and pinion movement. Figs. 10 and 11, the details of the ratchet movement for securing the flushing gate in position. This gate is fixed in position with a key from the street level, and when it is shut it is secured by a catch working in a ratchet fixed on this spindle near the street level; the pressure of water on the gate throws the strain upon the spindle, which is kept from moving by the catch before referred to, but so soon as this catch is liberated, the spindle revolves, the rack slides back, and the gate opens. Occasionally these flushing gates are connected with a self-acting apparatus, so that they shall open themselves at the proper time, or so soon as the sewer behind the flushing gate has filled to the requisite height. This arrangement is shown in Plate VIII. Fig. 1 in the plate shows the plan of a self-acting flushing gate. Figs. 2 and 3, sectional elevations of the same. In this case the door is fixed by the stay A, which is provided with a rule joint shown at X. When the sewage in the sewer has risen to the requisite height, it begins to overflow by the pipe B, and to fill the chamber C, and so soon as the volume in this chamber is sufficient in weight to overbalance the counterweight shown on the same shaft, it falls, and in falling a part of the apparatus strikes the stay upwards at the joint, which when once deflected out of the straight line in which it was fixed, is no longer capable of withstanding the strain upon it, and the pressure of water behind the gates completes the work by causing the joint in the stay to give, and so

Self-acting flushing gates.

Description of Plate VIII.

Fig. 61.

the gate opens to its full extent. A very simple form of self-acting flushing gate is shown in Figs. 61, 62, and 63;

Tilting flushing gates.

Fig. 62.

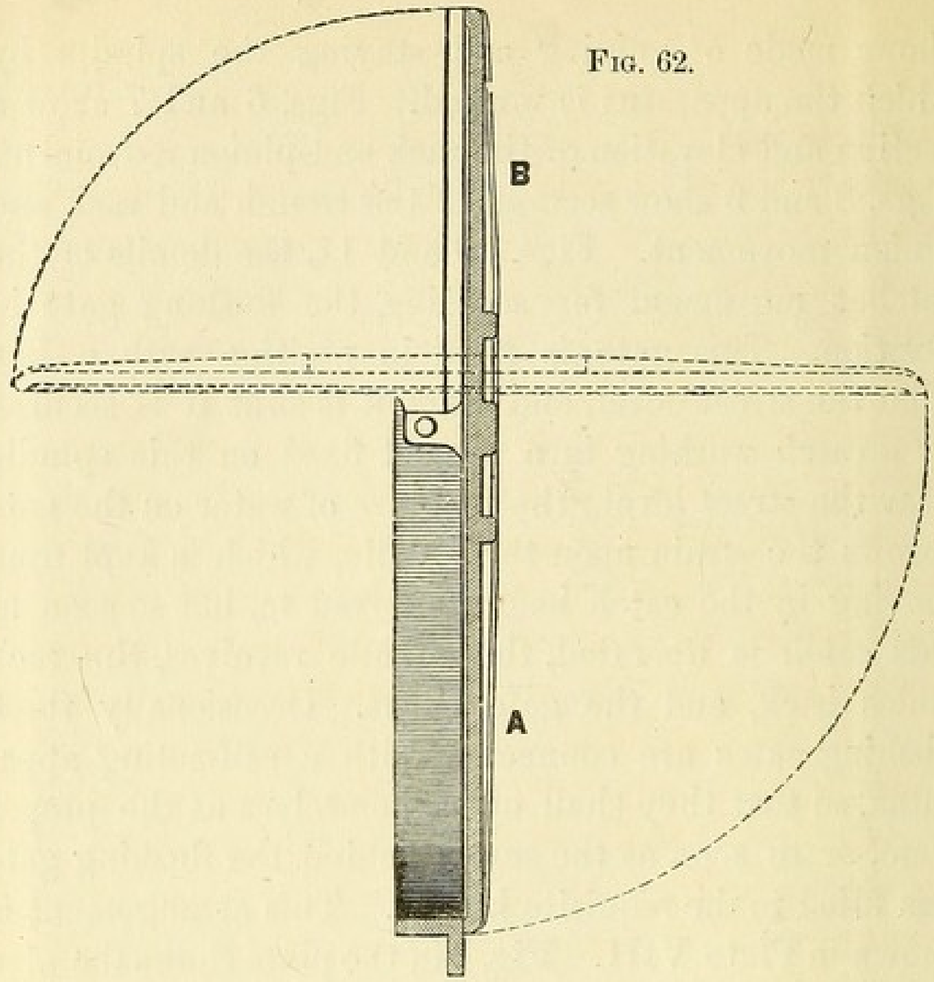


Fig. 63.

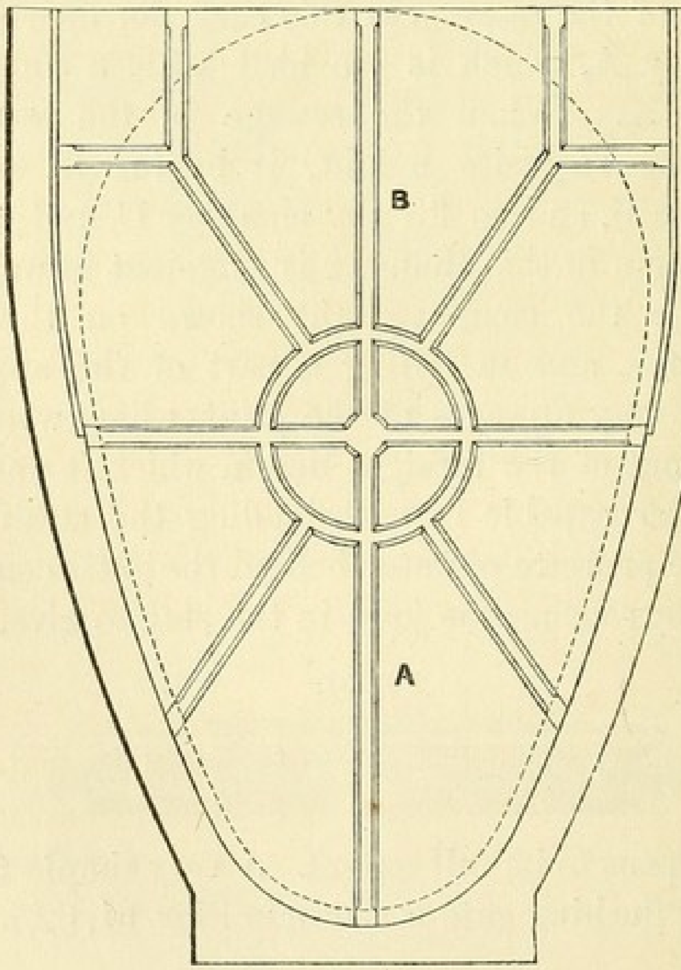


Fig. 61 showing plan of gate, Fig. 62 its vertical section, and Fig. 63 its front elevation.

This gate is hinged below its centre, and somewhat resembles a large throttle-valve of a steam engine. The ordinary pressure of the sewage on that portion of the gate marked A, which is below the hinge or pivot in which it turns, tends to fix the gate in position, but so soon as the sewage rises above the level of the pivot, it relieves the lower portion from pressure, and as the area of the gate marked B above the pivot is greater than the area below, a point is reached when the pressure on the upper portion of the gate overcomes the pressure on the lower portion, and the gate tilts and the sewage escapes. The upper portion of these gates being made heavier than the lower portion, when the gate tilts, it falls upon catches provided, and remains horizontally in the sewer, as shown by the dotted lines in Fig. 62. Flushing gates are usually provided with lead seatings and V faces, lead being more durable than any other description of metal, not being so liable to be acted upon by the sewage as other metals. The working parts of self-acting flushing gates should all be bushed and cased with gun-metal, or otherwise they are apt to get fixed in the work. For small sewers the author has used an earthenware flushing block, which is built into the head of every sewer running out of a manhole, as shown at A in Fig. 64. These flushing blocks have a ground face, against which a wooden disc B is placed. The pressure of the water tends to fix the disc in its position, and the disc is connected to a chain, and to guard against neglect the float C is fixed on the chain, so that if the disc is left fixed in the sewer, when the manhole fills with sewage to such an extent that the float begins to swim by its power of flotation, it liberates the wooden disc from the mouth of the sewer and the sewage escapes to the lower level. Figs. 65 and 66 illustrate an improvement made by the author in the form of earthen-

Mode of working tilting flushing gates.

Seatings of lead.

Working parts should be bushed.

Earthenware flushing blocks.

Description of block and disc flushing.

Fig. 64.

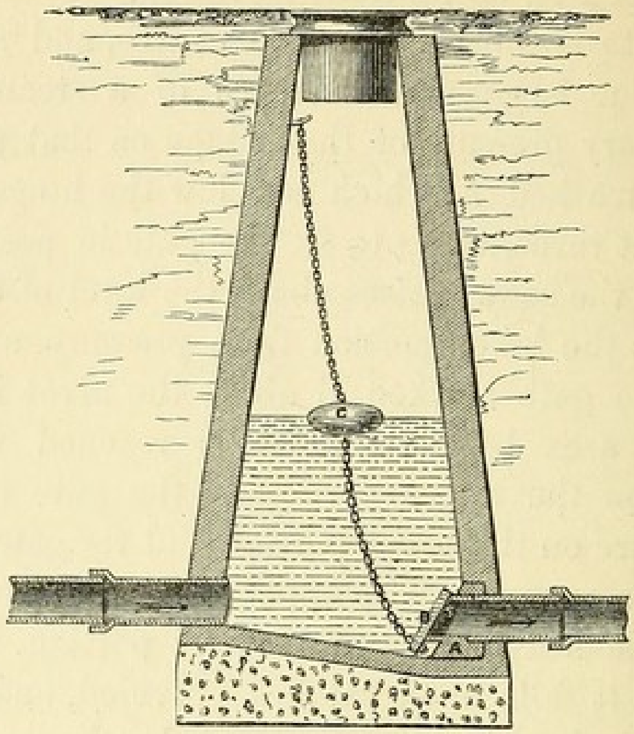


Fig. 65.

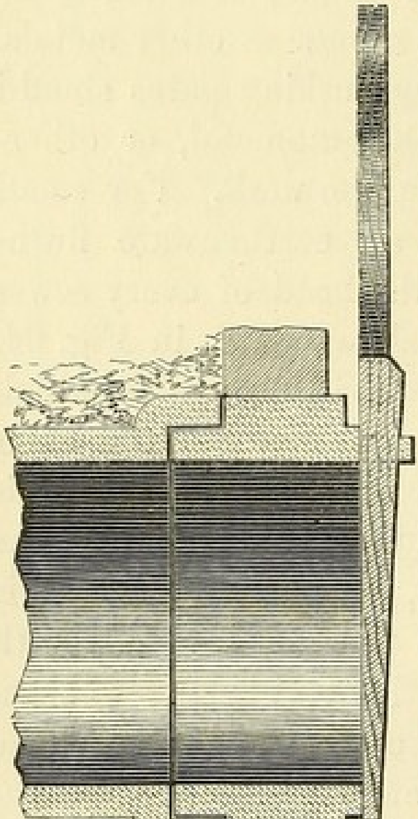
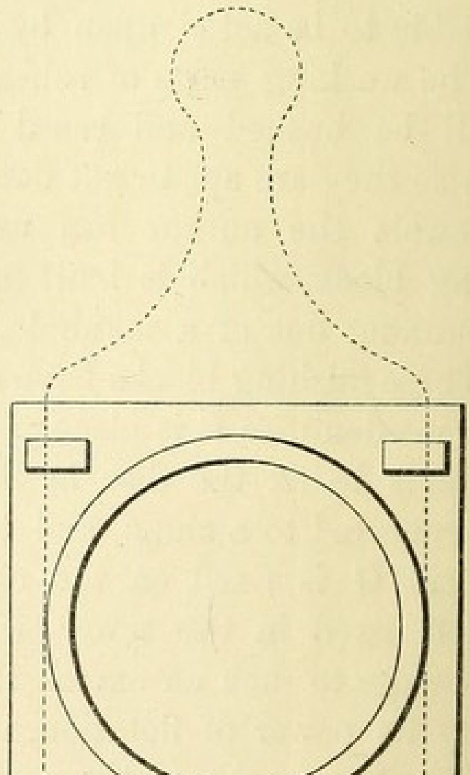
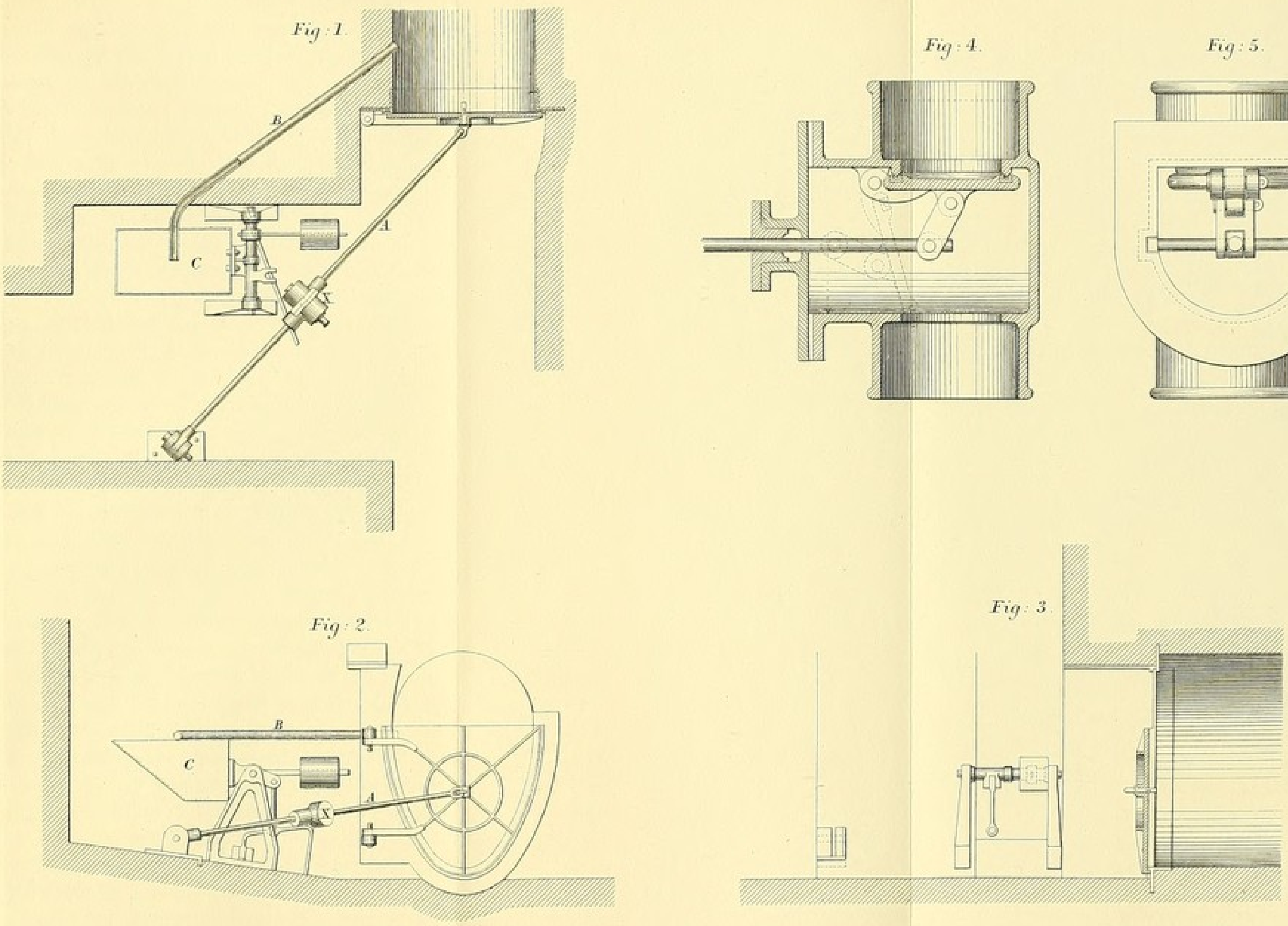


Fig. 66.



FLUSHING APPARATUS.



London: E. & F. N. Spon, 46, Charing Cross. Thomas Kell, lith.

ware flushing blocks. The improved block has a vertical face, and is better adapted for building into the side of a manhole than the inclined faced block, in consequence of the latter form of block projecting in rather an awkward manner into the manhole. The new block has two projecting iron studs that clip the shuttle or door; the back of the door being made wedge-shaped, it can be wedged up close to the ground face of the block, and so forms a water-tight joint. The earthenware blocks were introduced on account of their being more durable than metal when in contact with sewage. It is an advantage in a system of sewers to make as much provision as possible for flushing the sewers, but as fixed flushing gates form an expensive item in an estimate, they should be used at as long intervals apart as will be sufficient for effecting the purpose intended, and at all the intermediate manholes grooves should be formed in the brickwork for the reception of boards, so that a ready dam can at any time be formed for flushing purposes. Where flushing arrangements are provided, it is advisable, as a means of security, to provide overflows communicating above the flushing doors with the lower portion of the sewer; so that if, from neglect or accident, the doors remain fixed, the sewers may be relieved of pressure, and the sewage may be allowed to escape without flooding the low-lying portions of the district in which the sewers are located. It may be here noted that the flushing gates which have already been spoken of are not applicable for flushing the upper portions of a sewer, and it is requisite that arrangements should be made for effecting the flushing of the sewers at their upper ends. For flushing the heads of sewers, tanks are usually provided, the contents of which are periodically discharged by means of a self-acting syphon, a plug or valve similar to that shown in Plate VIII. Figs. 4 and 5. In some cases where tanks are used at the upper ends of sewers, they are made self-acting, as shown in

New form of flushing block.

Abundance of means for flushing should be provided.

Grooves in brickwork.

Overflows should be provided.

Flushing gates not applicable for heads of sewers.

Flushing from tanks.

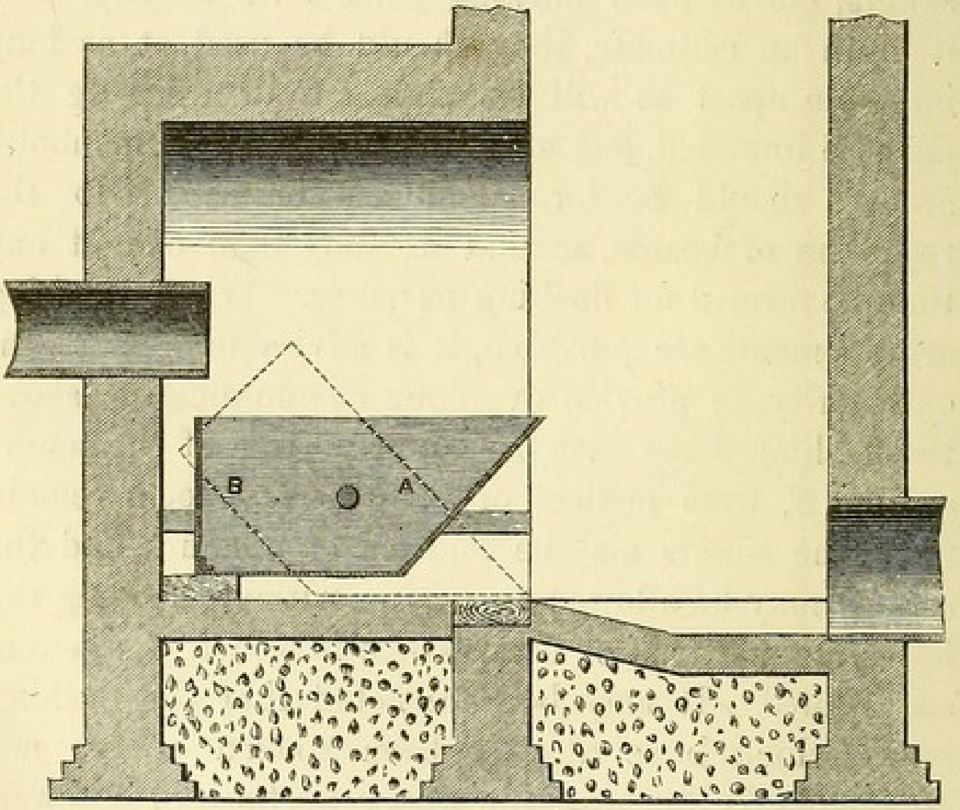
Plate VIII.

Description of Plate No. IX.

Plate IX. Fig. 1 represents the plan of the tank and discharging apparatus. Fig. 2 shows the section of the tank and apparatus with the valve closed, and Fig. 3 shows the apparatus with the valve open. The apparatus acts as follows:—So soon as the water rises to a certain level in the tank, it overflows by the pipe B into the chamber C, and the accumulation of water in this chamber overcomes in time the resistance of the counterweight fixed in the same shaft, when the chamber C falls and opens the valve A and discharges the contents of the tank into the sewer. A very useful tilting flushing apparatus is shown in Fig 67. It

Tilting tank for flushing.

Fig. 67.



consists simply of a tank moving on trunnions. When empty this tank would remain level, as the portion B behind the trunnion is heavier than the portion A before the trunnion, but when the tank fills with water or sewage the portion A becomes the heaviest, and the consequence is the tank tilts, discharging its contents suddenly into the sewer below, and afterwards righting itself ready to receive a fresh charge. Fig. 68 repre-

FLUSHING TANK.

Fig: 2.

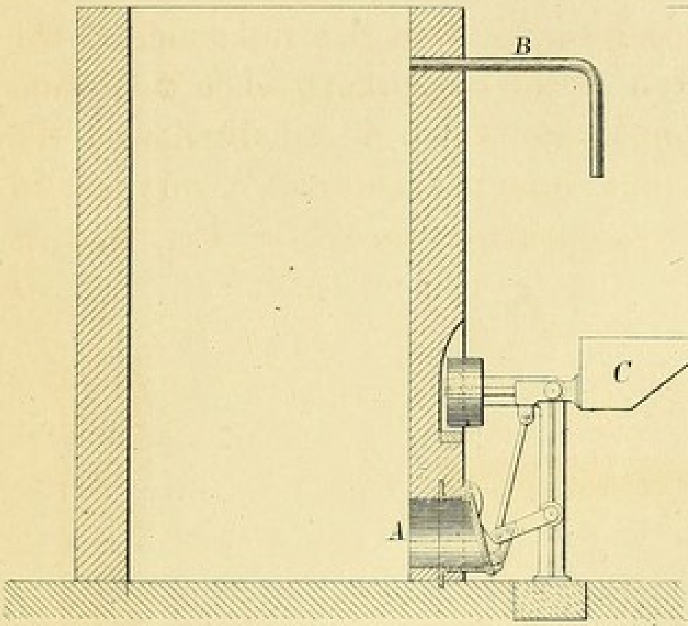


Fig: 3.

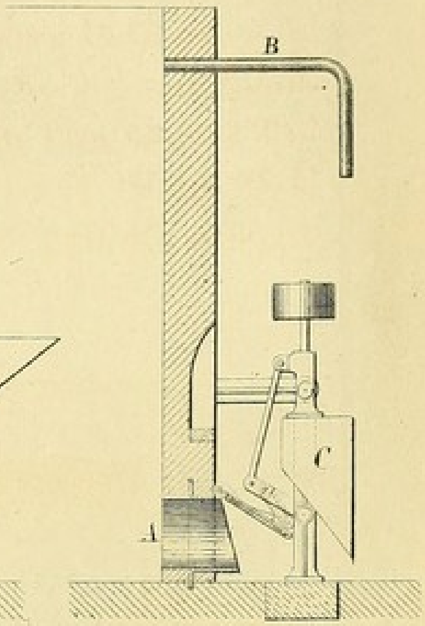
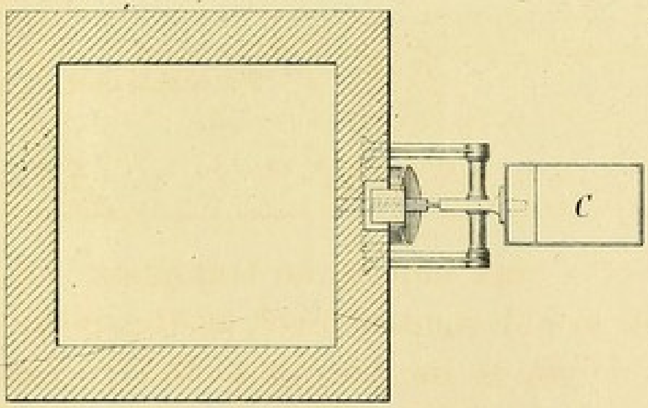
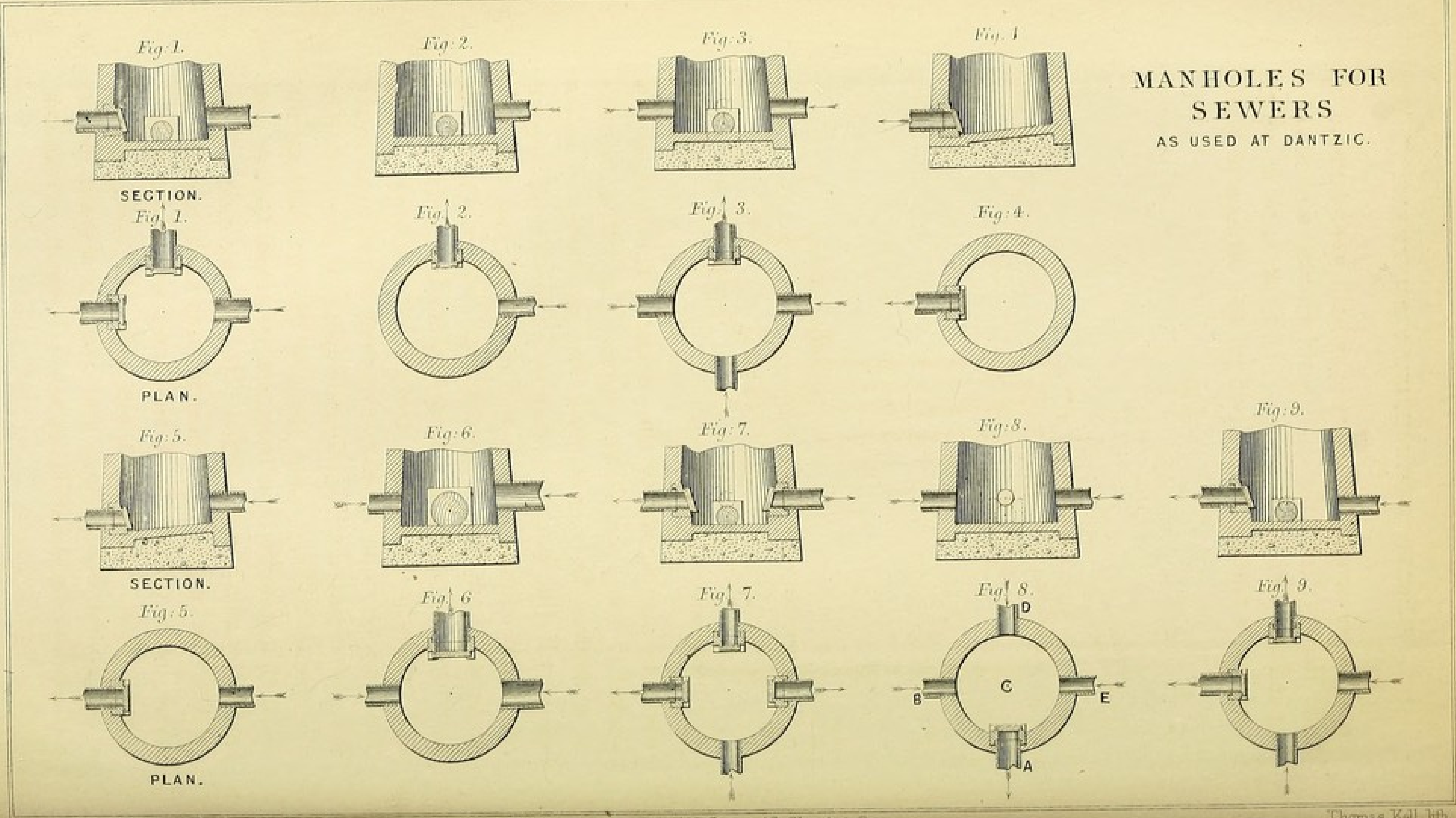


Fig: 1.



London: E. & F. N. Spon, 46, Charing Cross. Thomas Kell, lith.

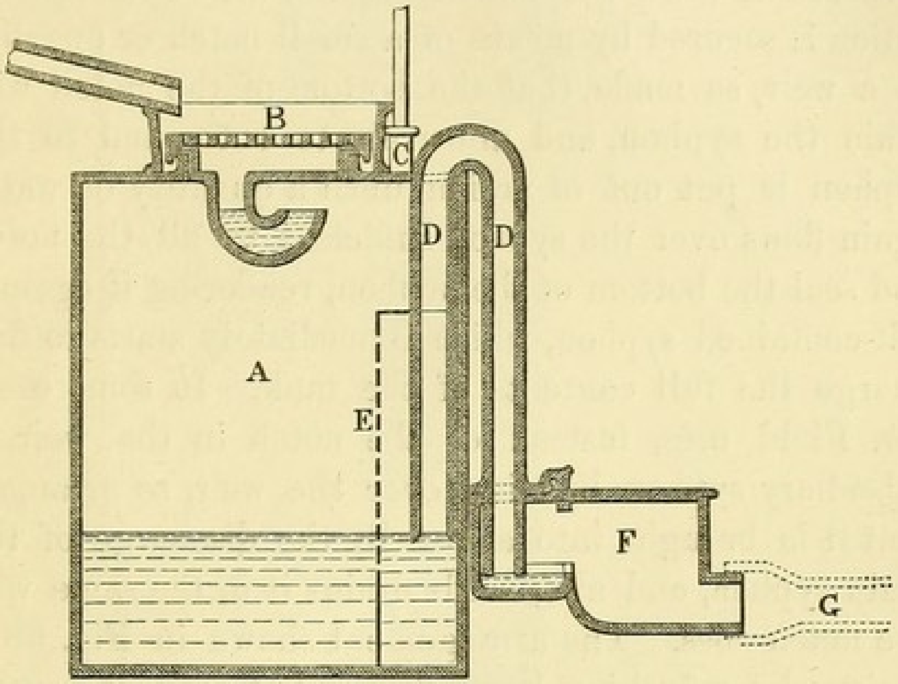


London: E. & F. N. Spon, 46, Charing Cross.
Thomas Kell, lith.

sents a section of the patent flushing tank invented by Mr. Rogers Field, C.E. "The apparatus consists of a cylindrical water-tight iron or stoneware tank A. This tank has a trapped inlet B, which also forms a movable

Mr. Rogers Field's flushing tank.

Fig. 68.



cover to give access to the inside of the tank, and a socket C for a ventilating pipe. The outlet consists of a syphon D, so arranged that no discharge takes place till the tank is completely filled with liquid, when the syphon is brought into action and the contents are immediately discharged. The inner end of the syphon is protected by a strainer E, and the outer end enters a discharging trough F," discharging into the pipes G. The action of this tank is due to an ingeniously contrived self-contained syphon, so arranged that the syphon will not come into play without discharging the full contents of the tank, and its action then ceases until the tank is again filled. It has long been known that if the longest leg of a syphon is made to dip into water, or is turned up at the end so that water will remain in it, that it becomes what has been termed a self-contained syphon; but such a syphon being self-contained was and is constantly liable to continuous

Self-contained syphon.

action, and may discharge such feeble currents as to be valueless for flushing purposes. In this syphon arrangement of Mr. Field's a simple self-acting arrangement is made for putting the syphon out of action after each discharge, and the syphon cannot be again brought into action until the tank is again full. This special action is secured by means of a small notch or opening in a weir, so made that the bottom of the notch will drain the syphon, and allow air to enter, and so the syphon is put out of action until a quantity of water again flows over the syphon sufficient to fill the notch and seal the bottom of the syphon, rendering it again a self-contained syphon, which immediately starts to discharge the full contents of the tank. In some cases Mr. Field uses, instead of the notch in the weir, a subsidiary syphon bending over the weir, so arranged that it is brought into action by the discharge of the main syphon, and afterwards drains it in the same way the notch does. The arrangement shown in Fig. 68 is designed for flushing house-drains, but may, of course, also be used for flushing sewers. When used for this purpose, however, a modification is generally desirable, whereby the syphon is enabled to be put in action by a very small constant flow of water; this is effected by making the discharging limb of the syphon and its connection with the bend of the syphon in such a way that a small quantity of water flowing over the bend, instead of running down along the sides of the discharging limb, is caused to descend clear of the sides, whereby it is rendered more effective in displacing the air in the discharging limb, and thereby starting the syphon. A convenient arrangement for this purpose is an annular form of syphon. By these means, a large syphon can be put in action by a very small flow of water, so that a large flushing tank may be fed, for instance, by the constant flow from a small water-tap which takes a day or two to fill it, and yet the tank will discharge itself automatically as soon as it is full.

Syphon put out of action.

Mode in which syphon is made to act.

Mode of making small volume of water start syphon.

Automatic discharge.

The annular form of syphon is shown in Figs. 69 and 70, Fig. 69 being a plan, and Fig. 70 a section of the

Annular syphon.

FIG. 69.

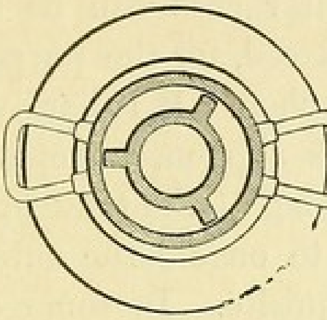
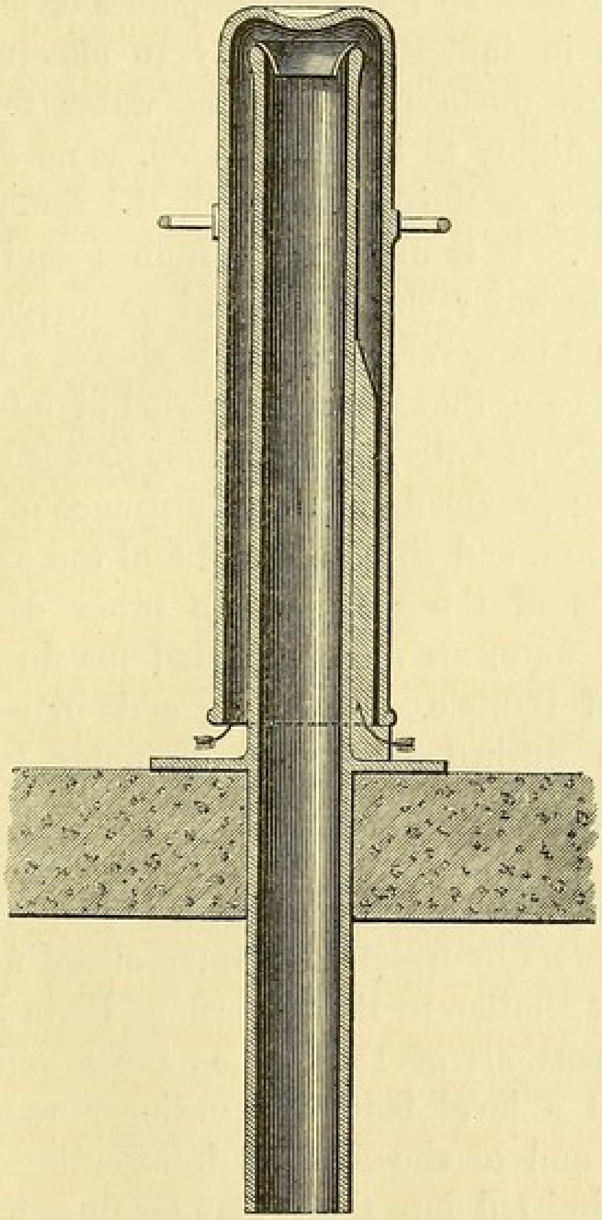


FIG. 70.



annular syphon. This form of syphon may be built into a flushing tank, and is admirably adapted for

Convenient form of syphon.

flushing either large or small sewers. Moreover, such is the construction of the syphon, that it is capable of being easily taken to pieces in case of any stoppage occurring. The outer case can be readily lifted off, and as readily replaced, for the purpose of examining or cleansing the syphon. It is hardly necessary to say that, in fixing this syphon, an opening ought to be formed in the covering of the tank over the position of the syphon, so as to enable the outer covering to be removed when requisite. In some districts water is taken direct from the fire-plugs on the water-mains, and carried by hose into the lampholes or manholes of the sewers in sufficient quantity to effectually flush them. This mode of supplying water for flushing purposes is highly to be commended, as no direct communication is established between the sewers and the water-mains. It is undesirable, from a sanitary point of view, that water should be laid on direct from any water-main to a sewer, for there is always a liability, if such is the case, that during a period of intermittence in the supply of water, sewer-air may pass back through the opening provided for the admittance of the water into the sewer, and so aerate and foul the water in the water-mains of the district. In other cases special supplies of water are often provided for flushing, as in the case of Dantzic. The upper ends of some of the sewers are flushed by means of water brought by special pipes from a stream in the neighbourhood, as shown in the general plan of the works, Plate II. In this case the water is admitted from these pipes into the sewers by means of a valve closed with a lever and weight similar to that shown in Plate XI. Fig. 2. In other portions of Dantzic, as the sewers are constructed at a level below the ordinary water-level of the river, and of the streams intersecting the town, water is admitted into the sewers for flushing purposes by means of valves communicating with the river or other streams as shown. Plate XI., Fig. 1, shows the

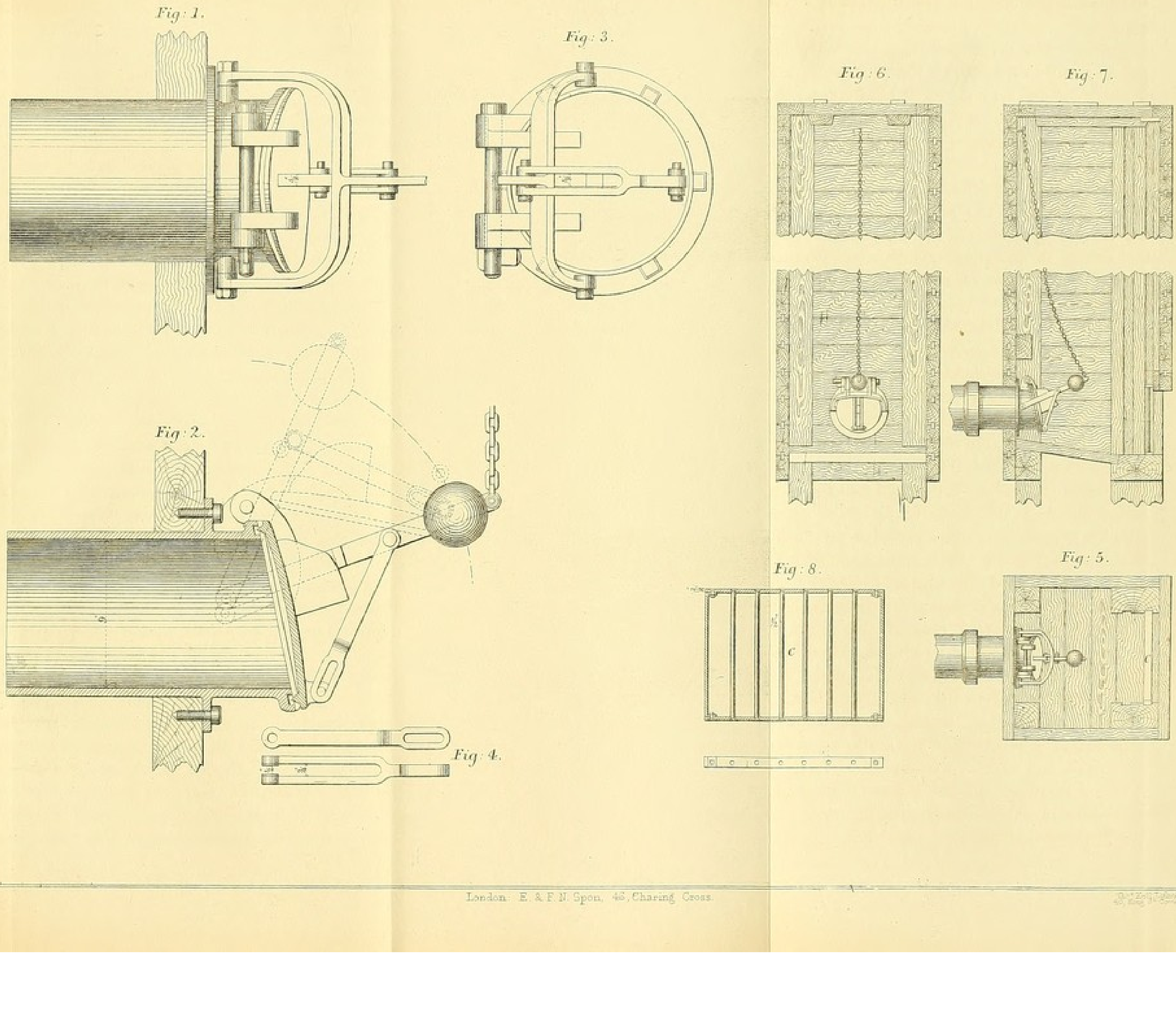
Use of hose.

Special supplies of water.

Description of valves used.

Description of Plate XI.

FLUSHING VALVES.
AS USED AT DANTZIC.



London: E. & F. N. Spon, 46, Charing Cross.

plan of the valve. Fig. 2 shows a section of the same. Fig. 3, elevation of front of valve. Fig. 4, the slotted link for opening valve. Fig. 5, the plan showing arrangement of fixing valve. Figs. 6 and 7, elevation and section showing fixing of valve. Fig. 8, grating for protecting valve. In this case the valves are protected by a grating in the front to prevent the entrance of sticks or other matter liable to choke the sewer. For this purpose a small wooden chamber is made outside the valve, and in the outer framework two grooves are formed similar in construction to an ordinary wooden sluice-frame. In each of these grooves a grating, or sluice-door, can be inserted at pleasure; the object being that if the grating gets choked below the water level, another grating can be placed in the spare groove while the other is removed, or a sluice-door may be inserted in the groove in order to enable the valve to be taken out for repair. The operation of flushing sewers should be commenced in the lower portions of the district, and the work proceeded with from the lower to the upper, the sewers in the highest portions of the district being the last to be flushed. In introducing flushing arrangements in which the sewage itself is to form the motive power for flushing, care must be exercised, otherwise it will be found that the damming up of a volume of sewage for a considerable time will lead to the deposit of sedimentary matter, which, when the flushing gate is open, will accumulate some distance below it, and for this reason it will be well to combine in the system of sewerage more than one mode of effecting the flushing. Sewers are more thoroughly cleared with pure water than with sewage. The admittance of rainfall into sewers is of considerable value as a flushing agent. In all flushing it is necessary not only to remove the deposit, but also to wash the sides of the sewer free from the mucous matter which adheres thereto, and in which, it is supposed, lurks something that is dangerous to life and health.

Protection of flushing valves.

How flushing should be conducted.

Sewage must not be dammed up to cause deposit.

More than one system should be adopted.

Value of rain-water.

Removal of mucous matter.

In periods of epidemic disease flushing of sewers should be frequently practised, and when flushed they are sometimes disinfected. The disinfection of sewers, unless carried out upon a scale of such magnitude that it would be very costly, is of little or no benefit. The enormous dilution of the disinfecting agent, when combined with the flow of sewage of a town, renders the action nugatory. Moreover, continuity of the discharge of a disinfectant agent in every house drain and every branch or main sewer in sufficient volume to be effective, is also absolutely necessary in order to secure any certain benefit from the system. But as such continuity in practice cannot be established, all hope of deriving absolute immunity of disease from the disinfection of the sewage as it flows through the sewers of a town must be abandoned as being too expensive and too uncertain in its application for any material advantage to be gained from it. The advantages and results of flushing sewers were very clearly demonstrated by Mr. Roe, the author of the system, in several reports on the subject. The following extracts are taken from the first report of the "Health of Towns Commission":—

Disinfection of sewers of little value.

Dilution of disinfecting agent.

Results of flushing.

"Taking it as affording the best approximation that we can at present find, a series of experiments was commenced in order to ascertain what velocity could be obtained in the sewers; and it appeared that deposit might be removed by the means of dams placed in certain situations to collect heads of water, at less expense than by the usual method.

Mr. Roe's report.

"Another series of experiments was made for the purpose of endeavouring to ascertain the proportion of decomposed animal and vegetable matter, and detritus from the roads, carried through the sewers to the river Thames by the common run of water. Several square boxes were constructed to hold one cubic foot of water each. These were filled with water from different sewers. After allowing the turbid water to clear itself

Amount of matter present in sewage.

by precipitation, I ascertained the relative amount of the precipitate. The following were some of the results:—

Sewers.	Proportion of decomposed Animal and Vegetable Matter and Detritus from Streets and Roads held in mechanical suspension.	Remarks.
River Fleet sewer, near outlet	.. 1 in 96 ..	The run of water was 10 inches in depth and 10 inches in width, having an average velocity of 83·47 feet per minute, passing 692·8 cube feet of water per minute; the matter conveyed being 7·21 cube feet per minute, or 103,660 cube yards per annum.

"The river Fleet sewer conveys the drainage of 4444 acres of surface, or about four-sevenths of the surface of these divisions. That great quantities in addition to the above are carried away by the force of water in rainy weather is certain; allowing this source, and the remaining three-sevenths of the district to only equal the discharge by the river Fleet sewer, there appears to be a quantity of upwards of 200,000 cube yards of matter carried to the Thames, per annum, from these divisions in mechanical suspension, and by the force of velocity, weight, and volume of water. The quantity of deposit taken from the sewers in these divisions, by the prevalent method of cleansing, has averaged about 2200 cube yards per annum; therefore the quantity flushed to the Thames, by the flushing apparatus, is as 1 to 100 of that which was already conveyed by the force of water.

Fleet sewer.

Quantity of matter transported by sewers.

"Some experiments were made with the water taken from the sewer at the top and bottom of a long street having numerous courts and alleys on each side. The following is the result:—

Amount of matter present varies in length of sewer.

"At the upper end of the street, matter held by the water in mechanical suspension .. .. 1 in 96
"At the lower end of the street .. .. 1 in 39

Proportion of solid matter to water removed.

" In another main sewer, where the run of water is always sufficient to keep it clear from deposit, the proportion was 1 in 80, composed of equal proportions of decomposed animal and vegetable matter, and silt or detritus from roads and streets. In another main line of sewer, kept always free from deposit in a similar manner, the proportion was 1 in 66, the proportion of decomposed animal and vegetable matter being greatest.

" The next experiments were made with the intention of ascertaining what quantity of matter would be carried away (in addition to that held in mechanical suspension) by the transporting powers of bodies of water ponded back and suddenly set in action. The result may be stated as follows, viz.:—

" 1st. A two-feet head of water	Deposit in sewer composed of soft mud and all descriptions of filth and a little silt.

Volume of matter transported when flushing.

" The proportion of matter carried away by the united action of the weight, velocity, and volume of the water, was as 1 to $6\frac{1}{2}$ of water. This was conveyed 2400 feet to a main line of sewer which has a body of water constantly passing through it with sufficient force to keep it always clean; the only sign left of the passage of the loaded water was a discoloration of the sides of the sewer to the height the water of the flush had reached.

" 2nd. A two-feet head of water	Deposit in sewer composed of small pieces of brick, stones as large as walnuts, oyster-shells, decomposed animal and vegetable matter, and silt. Proportion of matter 1 in 16 of water.

Flushing proved satisfactory.

" The Commissioners of Sewers for the Holborn and Finsbury division having satisfied themselves of the advantages of a systematic use of flushing in cleansing sewers, have for upwards of three years followed out the principle; the results are such as they anticipated. In carrying out the plan the construction of new sewers with side entrances, and the inserting side entrances to old sewers, the forming gully-holes and shoots on a plan that may supersede cleansing as formerly obtained, and the delivery of the water through them in such a manner as to assist the current of water in the sewer, and these and other minor improvements, by the use of which there is a saving effected, are carried on in one comprehensive system connected with the systematic flushing of the sewers.

System of keeping sewers free from deposit.

"The great principle intended to be carried out is, that instead of occasional cleansing as formerly, the sewers should, when once cleansed, be kept free from deposit. The pecuniary saving is, I consider, the least advantage of this mode of cleansing; the great points attained are the avoidance of all accumulations of filth in sewers and the stirring up in removal, and consequent disagreeable effluvia are also avoided; the streets and pavements are undisturbed; the men engaged in cleansing sewers have a more healthy employment than heretofore; private individuals are saved from the annoyance of their drains being choked; and as this plan of flushing affects the health and cleanliness of the inhabitants, the accomplishment of it, on a general and systematic principle, should be deemed of the utmost importance." Again, in reporting at a later period on the question of flushing, he states as follows:—

Advantages of flushing.

Further report of Mr. Roe.

"Your Commissioners some years back constructed a new sewer in Goldsmith's Row, Shoreditch. Prior to letting the contract you directed me to apply to Mr. Beek, the Surveyor of the Tower Hamlets, to learn at what depth a proposed outlet sewer by that Commission would be brought up Warner Place to the junction of the two Commissions; the reply stated a depth of 14 feet 6 inches; and your sewer in Goldsmith's Row was put in accordingly; as, however, the then existing outlet (an open sewer) was several feet above the level of the sewer put in Goldsmith's Row, and as the outlet in

Warder Place was not built for several years, an accumulation of foul deposit obtained in Goldsmith's Row sewer, which it was considered necessary to remove when the new outlet was brought up; an order was therefore given that men should flush the same away. Before the flushing began, the Commissioners of the Tower Hamlets wrote to your Board requesting to be informed when the flushing would take place, and Mr. Unwin, their clerk, told me that the request was made with a view 'to ascertain what deposit from your sewers might be washed into and lodged in the Tower Hamlets sewer.' Openings were made to ascertain the depth of the existing deposits in both lines of sewer, and three men were then set to flush out the Goldsmith's Row sewer with wood dams, &c., which they accomplished in three and a half days; the quantity of deposit in which sewer measured 55 cube yards, and at the former cost of such would amount to 18*l*. 15*s*. 10*d*. When the sewer had been washed out, and a number of flushes of water sent through the Tower Hamlets sewer to ensure the passage of the deposit, I wrote to Mr. Beek to inform him, and to say that on the Tuesday following it was intended to try what effect a flush of water from the Finsbury sewer would have upon the Tower Hamlets sewer on the east side of the Regent's Canal culvert at Rhodeswell Common, a distance of 2 miles and 3 furlongs from the Finsbury flushing gate. The means used and the results were as follows, viz.: several square boxes (which we have before used in experiments of this nature), each holding one cube foot of water, were taken on this occasion. Some of these were filled from the common run of water at both ends before the flush was let off, others were filled with the water after the flush had reached the lower end. After allowing the turbid water to clear itself by precipitation, I ascertained the relative amount of the precipitate; the following are the results and particulars:—

Example of flushing.

Flushing with wood dams.

Quantity of deposit removed.

Further experiment.

Mode of ascertaining the amount of solid matter in the sewage.

" Distance of sewer at Rhodeswell Common from the

Finsbury flushing gate in the Hackney Road, 2 miles and 3 furlongs.

"Height of flushing gate, 4 feet.

"Quantity of water headed up for one flush, 26,605 cube feet. Volume of sewage used.

"Time required for head to rise varies from 6 to 24 hours.

"Proportion of decomposed animal and vegetable matter, and detritus from streets and roads held in mechanical suspension:— Proportion of solid matter present.

"1st. In the water used for the flush ..	1 in 810
"2nd. In the common run of water at Rhodeswell Common before the flush was let off	1 in 540
"3rd. The proportion of matter in the water when the flush was at the highest at Rhodeswell Common, carried away by the united action of the weight, velocity, and volume of the flush-water added to the common run of water ..	1 in 80
"The sectional area occupied by the common run of water at Rhodeswell Common was	3 ft. $1\frac{1}{2}$ in.
"The sectional area occupied by the united waters of the flush and common run at the same point was	5 ft. 1 in.
"The velocity of the current of the common run of water at Rhodeswell Common before the flush	$95\frac{1}{3}$ ft. in 1 min.

Area of water-way.

"The velocity of the current, when the flush was passing Rhodeswell Common, 114 feet in 1 minute. The effect of the flush began to be felt at Rhodeswell Common in 1 hour after the head was let off in the Hackney Road, showing a velocity of 209 feet in 1 minute in the covered sewer. For 42 minutes the height of water from the flush gradually increased until it reached the highest point, and it continued at that point for 13 minutes, when it gradually decreased, and in 3 hours' time from the effect being first felt the flush ceased to operate at Rhodeswell Common. Velocity of current.

"After deducting the amount of matter held in mechanical suspension by the flush of water before let off, and that in the common run of water at Rhodeswell Common before the flush reached it, there remains the quantity of 21 cube yards of matter passed from the Tower Hamlets sewers by the use of this one flush.

Quantity of matter removed.

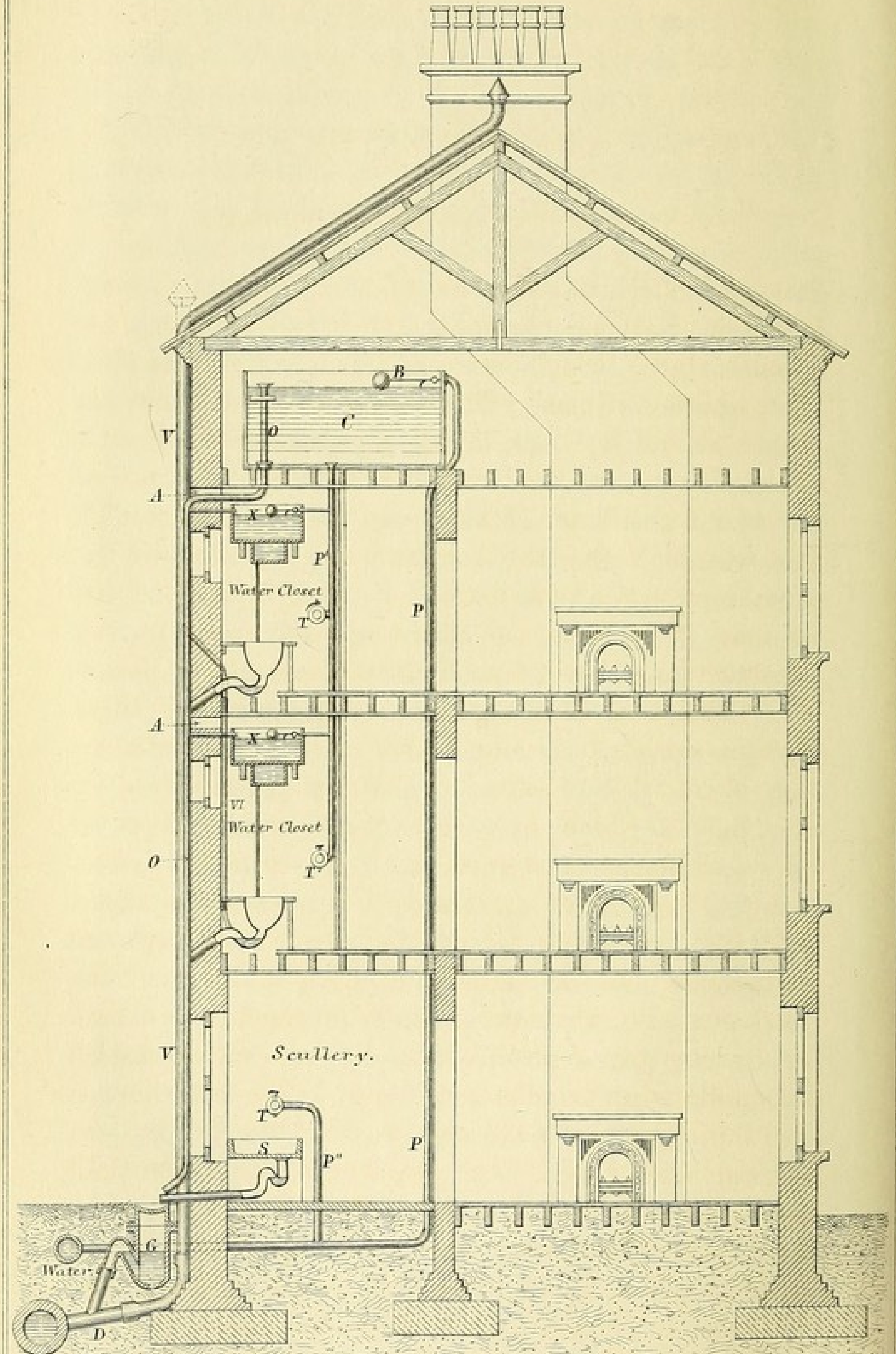
Experiment in removing bricks by flushing.

" One of your honourable Board then suggested that experiments should be made with bricks to see what distance the flush-water would affect them. This was accordingly done, first with brickbats, and then with bricks. After the first flush had passed, the bat nearest the gate was found to have gone 261 feet, and the farthest 529 feet. By the second flush the foremost had reached 1170 feet from the gate, and the hindermost, with one exception, 670 feet. After the third flush the whole were found to have passed a distance of 1300 feet from the gate. With the whole bricks we had time only for two flushes. After the first flush the nearest brick was 248 feet from the gate, and the farthest was 760 feet distance. The second flush moved the whole of the bricks, the foremost 160 feet farther, and the hindermost 40 feet.

Benefit of flushing manifest for considerable distance.

" The time was now come when the holes were to be opened for taking the depths of the deposit again; the result of which shows that flushing from the Finsbury sewers through the Tower Hamlets sewers does not increase the amount of deposit in the latter, but the contrary; and the result of the particulars taken at Rhodeswell Common evidenced the fact that the extraordinary head of flush-water of the Finsbury sewer in Hackney Road is beneficially felt through the whole of the 2 miles and 3 furlongs of the Tower Hamlets sewer, and doubtless thence to the river Thames."

HOUSE-DRAINAGE AND WATER-SUPPLY.



CHAPTER XXVIII.

VENTILATION OF SEWERS AND DRAINS.

Evil effects of sewer air known to ancients.

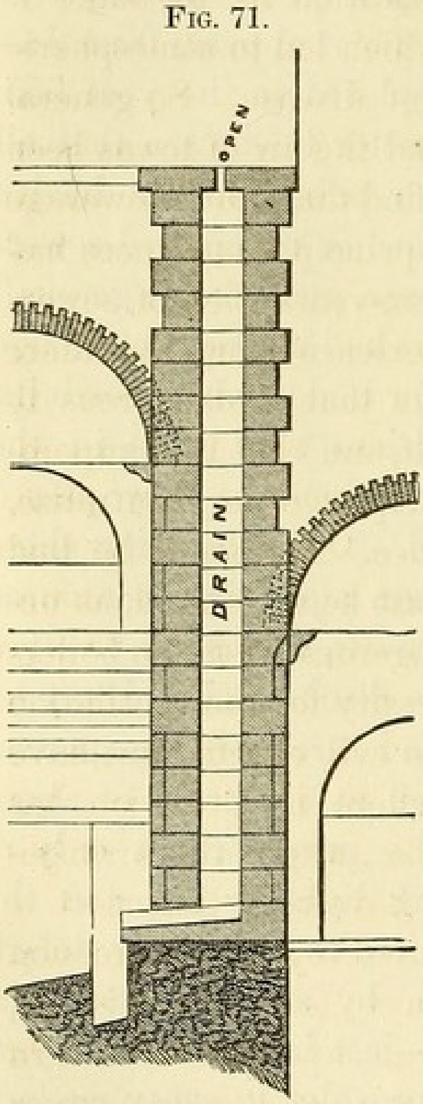
THE evil effects of sewer air upon public health were known in the ages of antiquity, for it appears from Justinian's Digest, which was completed in the year 555, that, quoting Ulpian, "The Prætor took care that all sewers should be cleaned and repaired, for the health of the citizens, because uncleaned or unrepaired sewers threaten a pestilential atmosphere, and are dangerous."

Roman ventilation of underground conduits.

It is also plain that the Romans had a clear knowledge of the necessity of ventilation for underground conduits, as may be seen in the provisions they made in the construction of their aqueducts whenever they passed below the level of the ground. On examining these ancient works, it is found when aqueducts contoured the side of a hill, "putes," or shafts, were sunk, to allow the vapours which arose to be discharged. Many of these shafts were steined, and are still in perfect order. They were constructed at intervals of about 120 feet apart, and served the purpose, not only of ventilation, but of "admitting light or air, and the workmen, also, who were required to repair any defect, or remove any deposit which, by any circumstance, accumulated in the channel"—just in the same way as ventilating manholes are now provided in every modern system of sewerage. The drainage works of the Coliseum of Rome show that the Romans had a very clear knowledge of what was required for the drainage of a large public building. An examination made by Mr. Cresy as to the drainage works of this building shows that the designer introduced works of drainage as an essential feature in its construction. Within its massive walls were formed drains hewn out of the solid stone, or, in other cases, so arranged in grooves cut in the stone-work, as to be entirely hidden from view. We also find that provision was made for collecting the sewage and rain-water, and for the prevention of the vapours or offensive effluvia from the drains entering the building, for the drains in the outer corridor, which conveyed away the sewage and rainfall, were covered by stone slabs, so arranged as to leave apertures at the sides, the space around being filled in with stone chippings; the drains from the building discharged into the space occupied by these stone chips, and the liquid entered the sewer after filtering through the chippings. These chippings were covered on the top with a layer of cement so as to prevent moisture or odour entering the building. In Fig. 71 is shown the mode adopted of ventilating the drains, and it should be observed that every descending drain of the entire building is open at its head, and that the head of all the drains of the building terminated in the outer corridors which were open to the atmosphere. It may be here noted in connection with these ancient works that the sewers were used to convey fæcal and other decomposable matter, and that ventilation under such circumstances was an absolute necessity. In the early drainage works of this country the sewers were principally used for the

Mode of preventing vapours entering the building.

FIG. 71.



Sewers conveying fæcal matter.

conveyance of surface water, and ventilation was of no material importance; but so soon as sewers were made to convey foul matter, and to communicate directly with the interior of houses, the means of preventing the entrance of sewer air becomes a matter of vital importance. The evil effects arising from the non-ventilation of sewers appear after the revival of sanitary science in this country not to have received any marked attention; the reason probably being that towns generally were in so bad a sanitary condition as to make it difficult to separate the causes which led to atmospheric pollution and the propagation of disease. So general were nuisances, and so impure had the air of towns been rendered, it is not surprising to find that, until sewerage works were carried out, and the principal nuisances had been abated, the ill-effects of non-ventilation of sewers became apparent. Present experience shows that there is something in the air of sewers that is dangerous to health, and pestilent to life itself, and that it is imperative, by proper ventilation, to dispose of, or neutralize, the effects of its deadly influence. It should be laid down as a rule that all sewers must be ventilated, as unventilated sewers may be as dangerous as steam boilers without safety valves. The necessity for the ventilation of sewers has been shown by the evil effects that have occasionally arisen in places where no provision has been made for their ventilation, or, where the arrangements which have been adopted have been imperfect.

Evils of sewer air: why not discerned.

Sewer air dangerous to health.

Unventilated sewers dangerous.

Necessity for ventilation of sewers.

The author does not wish to convey the impression that unventilated sewers are always the cause of disease, but what he does desire to impress upon all is, that in the absence of ventilation, there is great danger of sewer air entering our habitations, and although this sewer air may not, *per se*, be the cause of disease, nevertheless, the effect of breathing such air is to produce a state of malaise, and render those that breathe it less able to withstand the onslaught of disease. A few years ago, the author had an opportunity of seeing

Sewer air not always cause of disease.

Effects of sewer air.

Example in a London hospital.

what the effect of sewer air was in an hospital in London. This hospital had become so unhealthy that the surgeons declined to perform operations, as the wounds would not heal, and generally, the patients did not do well. The hospital was closed, and an examination made by the author revealed the fact that the building was largely aerated direct from the sewers. It was re-drained, and the direct communication with the sewers cut off, and again opened, and has since been used with great advantage to those resorting to it.

Dr. Robert Angus Smith's opinion of sewer air.

Dr. Robert Angus Smith has stated, and the author is inclined to agree with him, that "a rather wild clamour has taken place about sewers, and bad as their gases are, the danger arising from them has been much exaggerated."

Effect of temperature of houses.

The normal condition of the generality of houses has an important bearing on the necessity for the ventilation of sewers and drains. The superior temperature of the air of houses, and the draught caused by chimneys, have the effect of causing the various traps that are used to seal the drains to be relieved from pressure. Consequently, as there is less atmospheric pressure upon traps within houses than upon external traps, and, moreover, as many of the traps used within a house have far less seal than those usually employed out of doors, when no ventilation is provided, gases are prone to escape into houses, as it is the point of least resistance.

Effect of non-ventilation of sewers at Croydon.

Experience at Croydon.

In the former edition of this work, reference was made to Croydon as an example of the evil effects arising from the want of ventilation of the sewers, and it was stated that several epidemics of typhoid or enteric fever had been supposed to have occurred in consequence of the neglect to thoroughly ventilate the sewers. However, the ventilation of sewers and house-drains has been pushed to a greater extent in Croydon than in any other town in the United Kingdom, yet in spite of this ventilation, the town has not been freed from these epidemic outbreaks. An investigation of the epidemic of 1875 and 1876 by the author, showed,

Ventilation of sewers at Croydon not freed town from enteric fever.

very conclusively, that there had been a great mistake committed in attributing the origin of these outbreaks in Croydon to sewer air. From what has already been stated in reference to Croydon at pages 13 to 16, and after the most searching investigation, extending to the whole of the epidemics that have visited Croydon, there cannot remain a shadow of doubt that the epidemics of enteric fever that have occurred in Croydon were not due to sewer air, but to unwholesome water. The necessity for the ventilation of sewers as a preventive to enteric fever having been principally based on the supposed experience of Croydon, it must be clear that if the fevers of Croydon are due to other causes than sewer air, the fabric which has been built upon so baseless a foundation must crumble and fall. It only tends to put us off our guard in searching for the causes of enteric fever to ascribe it to something that may satisfy us for the time being, but which experience afterwards amply demonstrates cannot always be the right cause. The author is satisfied that numerous outbreaks of enteric fever have occurred that have been attributed to sewer air, and although sewer air may have been present, yet it played no part as a direct cause of disease. Dr. A. Carpenter* has said in reference to disease, "that all contagia are neither æthereal nor gaseous; that they are in themselves particulate and non-volatile." If this is so, it must be difficult for the poison of enteric fever to become largely disseminated in the air of sewers. The author must not be understood to say that no cases of enteric fever are directly or indirectly due to sewer air, which may have conveyed the poison, but even in the generality of such cases, the action will be first to contaminate either our water or our food. But what the author is quite clear about is the fact that, no wide-spread epidemic of enteric fever is due to the breathing of sewer air. It should also be said here, that while direct investigation is showing that epidemics of enteric fever

Epidemics in Croydon not due to sewer air.

Outbreaks of fever attributed to sewer air.

Dr. A. Carpenter's opinion.

Cases of enteric fever may be due to sewer air.

Wide-spread epidemics of enteric fever not due to sewer air.

* 'Preventive Medicine and Public Health,' p. 221. London, Simpkin, Marshall, and Co., 1877.

are not caused by sewer air, but by other causes, generally either by infected food or drink, investigation from a medical point of view is also beginning to show that, as the lesion of this disease occurs in but a short length of the lower intestines, the simple breathing of the poison would not convey it to the necessary seat of the disease, hence we find such an able sanitarian as Dr. B. W. Richardson, F.R.S., saying that "Sewer air may become the bearer of those poisons of the spreading or communicable diseases which are volatile and easily diffusible. Some think typhoid fever and cholera may be communicated in this manner; but I must candidly admit that in all my own inquiries on these diseases, and in this mode of communicating, I have not been able to satisfy myself that the poison was actually conveyed by the air, and was actually absorbed in the process of respiration. Most frequently sewer emanation, charged with the specific poison of the said communicable diseases, is carried into the water cistern, into milk, or into some other article that is partaken of as food or drink." Dr. Maclagan points out, in his book on the 'Germ Theory of Disease,' that whenever a germ of typhoid fever is received into the system by being inhaled, it will pass into the circulation, then "it will be sent from the heart along with the general column of blood; it may pass into the carotids, the subclavians, or down the aorta and into the iliac arteries, or into any of the aortic branches, except those which lead to the glands specially involved in the disease, without the chance of being propagated, and therefore without the chance of doing harm." It is also pointed out by Dr. Maclagan that "in typhoid fever the local lesion is confined to narrow limits, the glands scattered over a foot or two of the small intestine. It is only in this limited space that the contagion of typhoid fever finds that second factor, contact with which is essential to its propagation;" and then he goes on to say that, "the quantity of blood which goes to the glands involved in the local lesion is

Medical testimony against sewer air theory of the cause of enteric fever.

Opinion of Dr. B. W. Richardson, F.R.S.

Opinion of Dr. Maclagan.

Influence of aerial impurities in causing enteric fever.

such a fractional portion of the general mass of the circulating fluid, that the chances must be very much against its containing the minute particle which constitutes the contagium. There are, too, so many chances in favour of the contagium passing out of the system by the lungs, skin, or other eliminating organ, that it is probable that the majority of typhoid germs which gain entrance to the circulation through the lungs, or otherwise than through the glands specially involved in the disease, are eliminated without ever coming in contact with their second factor, and therefore without causing disturbance." It is further pointed out that the contagium of typhoid "may be taken in with the food or drink," and that it "does frequently enter the system through the alimentary canal, especially through the medium of contaminated water; and experience shows that, when thus received, it acts more certainly than when inhaled from the atmosphere." "Typhoid fever is more readily communicated through drinking water than through the atmosphere," as the contagion is carried with "more certainty by way of the digestive canal than by way of the circulation. Dr. Duncan, in a work on 'Typhoid Fever, its Cause and Prevention,' speaking of an outbreak of this disease at Crosshill, near Glasgow, in 1874, says: "The facts mentioned with regard to the eight tenements in 'No Man's Land' would lead me to believe that, under ordinary conditions, sewer gas would not propagate the disease, even when typhoid excreta were present in the sewers." We have also the very important fact that towns in which there is a total absence of sewer ventilation do not suffer from epidemics of enteric fever.

Influence of food and drink in causing enteric fever.

Dr. Duncan and experience at Crosshill.

Experience in towns that have no sewer ventilation.

Table No. 56 represents the fever rates in four towns: first, Bristol, in which there is no ventilation of the sewers or drains; second, Plymouth, a place in which there is but one ventilator on about every five miles of sewer, and no house-drain ventilation; third, London, representing a place in which the sewers are ventilated, but the house-drains for the most part are unventilated;

Description of Table No. 56.

and fourth, Croydon, representing a town in which both the public sewers and house-drains are ventilated. It will be seen by reference to this Table, that ventilation of sewers does not, apparently, influence the spread of fever, and especially enteric fever; in fact, there are greater extremes in the thoroughly ventilated town of

Table No. 56 shows that ventilation or non-ventilation of sewers does not affect enteric fever.

TABLE No. 56.—Showing the FEVER DEATH RATES per 1000 of the POPULATION living in BRISTOL, PLYMOUTH, LONDON, and CROYDON, for a period of Eleven Years from 1865 to 1875 inclusive.

Fever rates, Bristol, Plymouth, London, and Croydon.

Year.	Bristol and Clifton.		Plymouth.		London.		Croydon.	
	Fever Rate.	Typhoid or Enteric Fever Rate.	Fever Rate.	Typhoid or Enteric Fever Rate.	Fever Rate.	Typhoid or Enteric Fever Rate.	Fever Rate.	Typhoid or Enteric Fever Rate.
1865	1·18	..	1·21	..	1·07	..	1·32	1·32
1866	·86	..	·71	..	·88	..	1·25	1·11
1867	·94	..	·88	..	·79	..	·26	·26
1868	·62	..	1·26	..	·79	..	·71	·69
1869	·69	·39	·67	·38	·75	·33	·36	·32
1870	·74	·39	·45	·26	·62	·30	·33	·29
1871	·62	·50	·47	·27	·51	·26	·39	·39
1872	·43	·32	·70	·55	·39	·24	·47	·40
1873	·58	·45	·53	·39	·44	·26	·17	·17
1874	·37	·27	·53	·38	·44	·25	·34	·23
1875	·50	·39	·47	·29	·36	·23	1·39	1·36
Averages	·68	·38	·71	·36	·64	·26	·63	·59

Croydon than in any of the other places indicated in the Table. The foregoing Table shows at once that ventilation of sewers does not influence the fever rate, as we have both very unhealthy and very healthy years, so far as fever or typhoid fever is concerned, both with and without sewer ventilation. Prior to 1869, enteric or typhoid fever was not separately recorded in the published Registers of Death, so that for Bristol, Plymouth, and London, the record of the deaths from this disease commences at this period. With reference to Croydon, it ought to be observed that the typhoid fever rates, between 1869 and 1876 inclusive, were ·54 per thousand within the Croydon Water District, and but ·24 per thousand outside the Croydon Water District. In 1875 the enteric fever rate in

Enteric fever rates in Croydon.

Croydon Water District was 1·64 per thousand against ·36 per thousand in the districts outside the Croydon Water District; and in 1876 the respective rates were ·73 per thousand within the water district against ·14 per thousand in the district outside the water district.

At the present time, there appears to be a very strong feeling to extend the system of open and unprotected sewer ventilation to such a degree as would lead to the almost continuous opening of sewers. The author would point out that extremes are often dangerous. It has been shown that the multiplication of open ditches containing foul matter has militated against the health of particular localities. On the other hand, it is believed that hermetically sealed sewers cannot be used for conveying decomposing fæcal matter without danger to the health of the district using them. Those who would advise the construction of our sewers entirely open, would carry us back to the period of the old foul ditches, or to adopt such systems as may be seen in operation in most continental towns, where it receives, however, daily attention from scavengers; yet there can be no doubt, looking at the health of the places where such systems are in operation, that it militates against the health of the people. Security to health with regard to ventilation is only to be had where there is ample ventilation without undue exposure, which would bring into operation the agencies whereby decomposition and noisome air are increased.

Evils connected with over-ventilation.

Evils of open sewers.

Experience in continental towns.

Security to health secured by ample ventilation.

London is supposed to afford a striking example as to the good influence of sewer ventilation. Here the sewers are ventilated, though no general plan is adopted for dealing with the noxious effluvium escaping from the ventilators, and yet London stands at the head of all large towns by reason of its small death rate, which has been ascribed by more than one eminent authority to the somewhat rude ventilation provided for the sewers.

Example of London.

It should be borne in mind that in the case of London, house-drain ventilation is a matter almost entirely neglected, and yet no great evils are shown to

House-drain ventilation not generally adopted in London.

follow the neglect of this practice. The good health enjoyed by the inhabitants of London tends rather to show that moderate ventilation is attended with benefits which might be interfered with, if a more extended system was adopted. Excess of ventilation in crowded places * may be attended with other evils, due to the impregnation of the air with foul products from the sewers, unless these products are destroyed as they escape.

Excess of ventilation may bring evil.

Theories as to the cause of disease.

There are three theories as to the cause of disease. The first is known as "Liebig's theory," viz. that disease is due to organic matter in process of decay communicating the elements of decomposition. The second is called "Pasteur's theory," which ascribes the cause of disease to organized germs. The third theory is that of Dr. Richardson, F.R.S. In this case it is held that the poison of disease is organic and particulate, and is formed in the process of disease; a glandular secretion takes place, which contains the poison, and which, if brought into contact with a similar organ that has produced the poison in a person susceptible to the particular disease, the disease will be thus conveyed to that person; that the poison of disease is like that of other organic poisons, and is capable of dilution and inactivity, and of being concentrated and becoming virulent. The experiments made some years since by Dr. Fordyce with the virus of smallpox used in inoculation, showed that variolous matter might be diluted with water, and that up to a certain point dilution had no effect in destroying the effects of the matter, but with a given amount of dilution the poison was altogether destroyed. The history of our fever hospitals points to the same conclusions, that where we have dilution by sufficient ventilation, disease ceases to be contagious, but overcrowding or bad ventilation are favourable conditions for the spread of infectious diseases.

Dr. Richardson's theory of disease.

Experiments on dilution of disease poisons.

Organic forms found in sewer air.

Organized forms have been found by Dr. Dundas

* Vide p. 389.

Thompson in the air of sewers, but whether disease is due to the presence of these organized forms or not, it may be laid down as a rule, that in those periods when some diseases are epidemic, and no ventilation of sewers or drains is provided, the spread of disease is facilitated by the communications which exist between houses through the sewers and drains. Cases of this kind have come professionally under the author's attention. To take one case. In the year 1870 an outbreak of scarlet fever occurred in a market town in Kent, and in making an investigation the author found a row of detached houses, in every one of which there was scarlet fever, and yet no communication had taken place between the various occupants. Upon inquiry it was found that a case of scarlet fever was imported into one of the houses, and the disease rapidly spread to all the others. All the houses were drained by one common sewer into a cesspool, no provision was made for the ventilation of the drains, and a branch drain was brought within each house. All the drains were either untrapped or imperfect, so that any gases present in the sewer or cesspool must pass into the houses as the only mode of escape; in fact, the method of draining into the cesspool, as in this case, was similar to that of draining into a bottle, all the liquid and solid matter passing into the drains, liberating an equal amount of the foul air, conveying no doubt the germs of disease which escaped into the houses. In the author's experience stoppages in the sewers of a large town, which have had the effect of causing an increase of pressure in the sewer air, have not unfrequently been found to coincide with an outbreak of disease in houses which were affected by the stoppage. In a system of unventilated sewers, every house in a district is placed more or less in communication, and as a natural consequence, diseases may be transmitted from house to house by the sewers and drains, as evidenced in the case already referred to. If further evidence were needed as to the

Disease spread by sewers.

Example.

Effects of stoppages in sewers.

In absence of ventilation all houses are in communication.

ill effects of sewer air, this fact is often forcibly brought to our attention by the loss of the lives of men who are employed to work in our sewers, or in the confined places in which sewage is treated; but it should be here noted that the cause of these deaths is traceable to the chemical impurities of the air of the sewers as distinguished from that more general impurity which escapes detection, but which is believed to be the cause of disease.

Loss of life in sewers.

Unbelief in danger of sewer air.

There are some persons who consider that the emanations from sewers are not dangerous, in the sense of producing disease. They base their observations on the fact that the gases which are known to be present in sewers have not been shown to be the means of producing disease. It is true that in a very dilute form some of the gases are innoxious.

Dilute sewer air.

Air that has been used will not sustain life.

It should be remembered that it has been very conclusively shown by Dr. R. Angus Smith and others, that air that has been inspired and expired contains after the process about 15 per cent. of oxygen, yet the oxygen of this air, although apparently it retains, so far as at present discovered, its proper chemical composition, is incapable of supporting life; consequently we find air that has thus been used is unfit for further use: so while we may discover no injurious property in sewer air, it must not be lost sight of, that this is air that has been in such a position that in all probability it has lost its vital power, and becomes injurious by reason of taking the place of vital air. It is not so much the presence of gas of known composition that is so injurious, as the organic vapours and germs of disease which are carried in the air of sewers, and which are ever active to feed or spread disease until effectually destroyed. Dr. R. Angus Smith has pointed out that "Organic matter in contact with water constantly gives off an odour of some kind, and especially if heated, so that it would appear as if steam or vapour were capable of taking up much more than that which we call volatile matter." Cabbage water may be taken as an example. The

Sewer air improper to breathe.

Organic matter in contact with water.

same eminent authority states that "A certain amount of moisture is almost essential to the escape of odour from many bodies. It probably arises from two causes. The vapour of water is a vehicle for organic matter, and water favours decomposition in bodies, so that as they decompose the vapour is given out. From whatever cause, it will be found that moisture rapidly facilitates the escape of odour. Mineralogists avail themselves of this when they breathe on a mineral and then ascertain the smell. The moisture of an evening, or even artificial moisture, causes the flowers to give their scents, and the moist state of the atmosphere before or after a shower causes also a great fragrance in the flower garden. But whilst this is caused, the same laws are operating for injurious effects wherever there is a reservoir of putrid matter; for then exhalations are also abundant, and bubbles may be seen to rise from filthy water. It is not improbable that the state of the atmospheric pressure may cause this."

Moisture facilitates the escape of odours.

The Proceedings of the Royal Society for April, 1877, contain a paper by Dr. Frankland, F.R.S., on 'The Transport of Solid and Liquid Particles in Sewer Gases.' After referring to an outbreak of Asiatic cholera that had occurred at Southampton in 1866, and which was attributed by the late Professor Parkes, F.R.S, "to the dispersion of infected sewage through air," the dispersion in this case was alleged to be "produced by the pumping of the infected sewage and its discharge, in a frothy condition, down an open channel 8 or 9 feet long. The effluvium disengaged from this seething stream was described as overpowering, and was bitterly complained of by the inhabitants of the adjacent clean and airy houses, amongst whom a virulent epidemic of Asiatic cholera broke out a few days after the sewage received the infected dejections. Nevertheless, the discharge of the frothy liquid was kept up day and night for about a fortnight, and 107 persons perished. At length a closed pipe was substituted for the open conduit; from that day the

Dr. Frankland on transport of solid particles in sewer air.

Outbreak of cholera at Southampton.

number of cholera cases diminished, and within a week of the protection of the conduit the epidemic was virtually over." In this case Dr. Frankland has assumed that the zymotic poison was in the disengaged air set free, when the bubbles of the frothy current burst and projected part of the liquid sewage into the air, or the violent agitation might cause small particles of the sewage to be taken up by the air. It is a matter of some value to know that particles of a liquid may, under certain conditions, be present in the air from causes other than by evaporation, and while we may reasonably doubt that an epidemic of cholera of so virulent a description as that which occurred at Southampton was spread by breathing infected air, we cannot but value the labours of a man like Dr. Frankland, who endeavours to inform us in what way particles of sewage may be projected into the air of sewers, while it is not necessary to believe in the "propagation of typhoid fever by sewer gases," to see that the experiments made by him are of great value to the sanitarian. In order to test whether or not the particles of a liquid can be thrown into the air by agitation, such as would occur in a properly constructed sewer, Dr. Frankland* took and "violently agitating a solution of lithic chloride in a glass cylinder 3 inches in diameter and 30 inches high, with a wooden rod, and ascertaining whether the atmosphere at the mouth of the cylinder became impregnated with the liquid, by testing it with the flame of a Bunsen burner; but no trace of lithium could be detected at the mouth of the jar, even after an agitation much in excess of what would ordinarily occur in a sewer;" and the conclusion drawn from this class of experiment was, that it is "exceedingly improbable that the mere flow of foul liquid through sewers can impregnate the circumambient air with suspended particles." Another class of experiment was made in order to ascertain the result of the bursting, on the surface of a liquid, of

Effect of bursting bubbles.

Particles of a liquid may be present in air.

Dr. Frankland's experiments.

Flow through a sewer does not affect air.

* 'Experimental Researches in Pure, Applied, and Physical Chemistry.' London, J. van Voorst, 1877.

bubbles due to the escape of gases generated during the process of putrefaction. It is well known that on the bursting of the bubbles generated in the mixture of acids and alkalies in water or other liquids, particles of the liquid are projected into the air to a considerable distance, an example of which can be seen in the case of any of the effervescing drinks we use. Dr. Frankland's second experiment consisted in taking "a quantity of a strong solution of lithic chloride," which "was placed in a shallow basin and acidulated with hydrochloric acid; fragments of white marble then were added, and a paper tube, 5 inches in diameter and 5 feet high, was placed vertically above the basin. So long as the effervescence continued, abundance of particles of lithium were visible in a Bunsen flame held at the upper end of the tube. A tin-plate tube, 3 inches in diameter and 12 feet long, was now placed in such a position as to bring one of its open ends over the top of the paper tube. The tin tube was nearly horizontal, but slightly inclined upwards from the paper tube, so as to cause a gentle draught of air to pass through it when it was slightly heated externally near its lower extremity. A Bunsen flame placed at the end of this tube furthest away from the effervescing liquid, showed that the suspended particles of solution of lithic chloride were not perceptibly less numerous than at the mouth of the paper tube; neither were they much diminished at the further end of the tin tube when the height of the paper tube was increased to 9½ feet;" and the conclusion drawn from this experiment by Dr. Frankland is, that "these particles, which had been carried along by a gentle current of air for a distance of 21 feet, would be similarly conveyed to very much greater distances." In practice no one would compare the slowly formed bubbles arising during fermentation or putrefaction, and the liberation of their contained gases with the brisk action that arises when powerful acids or alkalines are used to produce effervescence, and it is consoling to know that the special disease, typhoid fever, which

Dr. Frankland's second experiments.

Particles carried by gentle current of air.

Sewers of decomposition.

Decomposition destroys poison of disease.

Experience at Dantzic. Fever banished from town.

has been attributed to sewers and sewer air, is not rife in districts in which the sewers are mostly sewers of decomposition, as for example in London, or the case of the defective sewers already referred to in note on Croydon, page 14. Some authorities have concluded that the changes which occur with decomposition, destroy the poison of this disease. On the other hand, it is the districts such as Croydon, with sewers that discharge before decomposition can arise, the air of which is said to be the cause of typhoid fever. There are, however, numerous instances to show that even the modern self-cleansing sewer is not the agent that produces typhoid, as for example in the Seventh Report of the State Board of Health of Massachusetts, page 281, it is stated in reference to the health of the town of Dantzic, the sewerage works of which were designed by the author, that since the prosecution of the works of sewerage " in Dantzic typhoid fever has become chiefly a disease of the suburbs, where there are no sewers."

Property of organic poisons.

Importance of sewer ventilation not generally acknowledged.

Sewer gas escaping into the streets, and combining with large quantities of atmospheric air, is less injurious than when allowed to escape into the more limited atmosphere of our houses. All the organic poisons can be diluted to such a degree as completely to palliate their destructive effects ; but still they may retain all their poisonous properties when again concentrated. Pure atmospheric air has the power of diluting and probably of oxidizing or destroying organic compounds, but when sewer air enters the generality of houses, especially at night, when the house is closed and the whole atmosphere has been robbed of its vital properties, the air carrying the products of decomposition, or the elements of disease, may become a deadly poison. Sewer ventilation has received, in some quarters, a considerable degree of attention, but its importance is by no means generally acknowledged, nor are works of this class carried out to the extent which is absolutely necessary if the full advantage procurable by the prosecution of sanitary works is to be realized. There are many towns in this country, in which no provision has been made for the ventilation of sewers or drains. There are others in which the sewers are but imperfectly or partially ventilated. It is the author's intention in this chapter to point out the nature of the gases found in sewers, the forces at work within the sewers, and to give examples of the various modes that have been proposed or adopted for effecting the ventilation of sewers and drains.

Gases present in sewers.

The gases found in the air of sewers are carbon dioxide or carbonic anhydride, nitrogen, carburetted hydrogen, sulphuretted hydrogen, ammoniacal compounds, the vapour of water, and fœtid organic vapour.

Carbonic anhydride.

Carbon dioxide or carbonic anhydride, or choke-damp as it is commonly termed in mining districts, is one of the gases usually present in sewer air. It is the result of decomposition, or the combination of oxygen with carbonaceous matters, and is extremely deadly * when present in large quantity, and to inhale it in a concentrated form causes instantaneous prostration, followed very speedily by death. In some cases this gas is emitted from the earth when constructing sewer work through decayed matter, or in the proximity of old cesspools, but its principal delight is to haunt unventilated sewers. The deadly lake of Java, whose borders are said to be strewed with mortal remains, lends its testimony to the destructive effects of this gas. Fresh air or fresh slaked lime will remove or destroy its poisonous effects.

Nitrogen.

The excess of nitrogen present in sewers may be accounted for by the fact that the oxygen of the atmosphere has been used up in entering into combination with certain organic compounds which are present, leaving the nitrogen free. Nitrogen has not been shown to be a poisonous gas, although it will not support animal life.

Carburetted hydrogen.

The presence of carburetted hydrogen gas is due in a

* Carbon dioxide is not poisonous in itself any more than water is poisonous to those that fall into it and are drowned.

great measure to the leakage from gas-pipes. Such gas also arises from the decomposition of vegetable matter, and is formed in a manner analogous to that in which marsh gas is produced, spontaneously, in low-lying districts abounding in decomposing vegetable matter. This gas is extremely explosive when mixed with a certain proportion of atmospheric air, on which account it is unsafe to enter sewers with naked lights. As a measure of precaution, all sewers should be lighted with safety lamps when it is necessary to enter them.

Use of safety lamps.

Sulphuretted hydrogen.

Sulphuretted hydrogen is a gas which is the product of decomposition. It is found more or less in sewers, being always present in those in which the sewage has assumed a certain degree of putridity. It is distinguishable by its disagreeable odour, and is heavier than ordinary atmospheric air. It has been known to fire in sewers. It is the most poisonous of all the gases of known composition. Experiments have been made with it by various authorities, which show that one part of the gas and 250 parts of the air will kill a horse; one of the gas and 500 of air will kill a dog; one of the gas and 1500 of air will kill small birds; that a rabbit was killed in a few minutes by being placed in a bag of this gas, although its head was not enclosed, and it was free to breathe pure atmospheric air. Numerous deaths have been recorded in past times among the workmen employed in emptying cesspools in which it had accumulated. The injurious effects of this gas can be destroyed by considerable dilution, or, better still, can be readily absorbed by the use of charcoal or some of the oxides of iron.

Ammoniacal compounds.

The ammoniacal compounds present in sewer air are the result of the evaporation and decomposition of the sewage, and are also due to its elimination from the sewage by reason of a rise in temperature.

Fœtid organic vapour.

The fœtid organic vapour, which is more or less present in all sewers, is the most subtle and dangerous matter present in the air of a sewer. Of its exact nature and composition but little is known; either it is itself the cause of disease, or it carries the germs of disease, which are supposed to float about in the air of sewers, like the fine pollen of flowers floats about in the atmosphere. This vapour or the germs of disease can alike be effectually absorbed and destroyed by the use of charcoal.

Value of charcoal.

Experiments made by the late Dr. Letheby, on the generation of sewer gas from sewage, show that a gallon of sewage, containing 128·8 grains of organic matter, when excluded from the air, gave, in "nine weeks, 1·2 cubic inches of gas per hour, consisting of 73·833 of marsh gas, 15·899 carbonic acid, 10·187 of nitrogen, and 0·081 sulphuretted hydrogen." It should be noted that this is the result of a laboratory experiment, and after decomposition has, purposely, been allowed to take place. In a well-constructed sewer the decomposing matter would flow with such a velocity as to prevent stagnation; therefore the period of duration of such matter, in a sewer, is too short to admit of such decomposition as to lead to so large an evolution of gas as shown by the foregoing experiment. When atmospheric air is present in sewers, the gases found are "carbonic acid and nitrogen, with but mere traces of sulphuretted hydrogen." The air in a sewer of the City of London, ventilated and fitted with charcoal for deodorizing the escaping gases, was found by Dr. Letheby to contain 79·96 per cent. of nitrogen, 19·51 per cent. of oxygen, and ·53 per cent. of carbonic acid, with mere traces of ammonia, marsh gas, and sulphuretted hydrogen. Dr. W. J. Russell, in September, 1870, collected the air from the Ranelagh sewer at Paddington, which was ventilated by open shafts of the ordinary London type, and he found that it contained 0·40 per cent. of carbonic anhydride, 20·79 per cent. of oxygen, and 78·81 per cent. of nitrogen, and when tested for sulphuretted hydrogen, by allowing the air to pass over acetate of lead paper after five minutes' contact, no discolorization took place. The air of badly ventilated sewers contains much less oxygen than shown in the case of well-

Dr. Letheby's experiments on generation of sewer gas.

Rapid transit of matter through sewer prevents decomposition.

Gases found when air is present in sewers.

Composition of air of ventilated sewers.

Air of badly ventilated sewers.

ventilated sewers. Parent Duchâtell found that the air of a choked sewer, in Paris, which was not ventilated, and after the sewage had been agitated, contained but 13·79 per cent. of oxygen, pure atmospheric air containing 20·61 per cent. In the ventilation of sewers, air must be admitted as a matter of necessity into all sewers in which men are compelled at times to labour, and in the case of the ventilated sewers of London, chemists are agreed that men may safely labour in them on account of the large percentage of vital oxygen present in the air.

Forces at work in a sewer.

An examination of the forces at work within a sewer will show how necessary it is that ventilation should be provided, and, from a study of the forces at work, the engineer will be led to form correct opinions as to what measures should be taken for the purpose of securing perfect ventilation.

Heat.

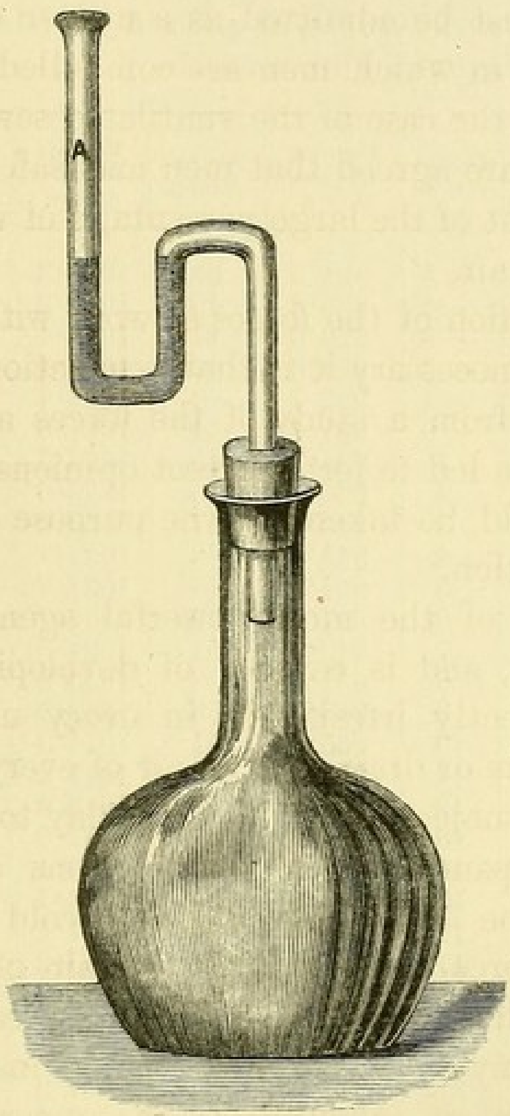
Heat is one of the most powerful agents at work within a sewer, and is capable of developing a force which is perfectly irresistible in every unventilated system of sewers or drains. The air of every sewer and house drain is subject throughout the day to a repeated number of expansions and contractions of the air arising from the admittance of hot or cold water. So great is the force exercised by the air of drains in expanding under the influence of an increase of temperature, that any ordinary trap is totally inadequate to resist its influence. A very simple experiment will show this. In Fig. 72 is represented a glass flask, corked, and having a bent glass tube (forming a trap) inserted as shown in the figure. Let the trap be filled with water—if the hand is placed on the flask its natural warmth will cause the air within the flask to be heated, and in consequence it will expand with sufficient force to throw all the water out of the trap, although the leg A of the glass tube is several inches long. This flask not inaptly represents the frequent condition of an unventilated house drain, sealed at its

Experiment as to power of expanding air.

lower end by reason of an extra flush of water in the sewer. The ordinary effect of pouring water into such a drain would be to unseal the traps, as no water could

Effect of pouring water into drain.

FIG. 72.



enter without displacing an equal volume of the air of the drain; but, apart from this, assuming that water could enter, and that such water had been used for boiling vegetables, or for any other domestic purpose, and was at the temperature of boiling point,—that the normal temperature of the air of the sewer at the time of its admittance was at 50° Fahrenheit, and that by reason of the admittance of a large volume of this hot water the temperature of the air of the sewer was raised to 150°,—the effect of this increase of temperature

Effect of hot water.

may be calculated from the increase in volume as given in Table No. 57, for the pressure is inversely as the space occupied.

TABLE No. **57**.—Showing the RELATIVE VOLUMES of AIR at VARIOUS TEMPERATURES, as given in Dr. LARDNER'S 'HANDBOOK OF NATURAL PHILOSOPHY.'

Temperature.	Volume in cube inches.	Temperature.	Volume in cube inches.	Temperature.	Volume in cube inches.	Temperature.	Volume in cube inches.
−49	834·7	− 5	924·5	39	1014·3	83	1104·1
−48	836·7	− 4	926·5	40	1016·3	84	1106·1
−47	838·8	− 3	928·6	41	1018·4	85	1108·2
−46	840·8	− 2	930·6	42	1020·4	86	1110·2
−45	842·8	− 1	932·7	43	1022·4	87	1112·2
−44	844·9	− 0	934·7	44	1024·5	88	1114·3
−43	846·9	1	936·7	45	1026·5	89	1116·3
−42	849·0	2	938·8	46	1028·6	90	1118·4
−41	851·0	3	940·8	47	1030·6	91	1120·4
−40	853·1	4	942·9	48	1032·7	92	1122·4
−39	855·1	5	944·9	49	1034·7	93	1124·5
−38	857·1	6	947·0	50	1036·7	94	1126·5
−37	859·2	7	949·0	51	1038·8	95	1128·6
−36	861·2	8	951·0	52	1040·8	96	1130·6
−35	863·3	9	953·1	53	1042·9	97	1132·7
−34	865·3	10	955·1	54	1044·9	98	1134·7
−33	867·3	11	957·1	55	1046·9	99	1136·7
−32	869·4	12	959·2	56	1049·0	100	1138·8
−31	871·4	13	961·2	57	1051·0	101	1140·8
−30	873·5	14	963·3	58	1053·1	102	1142·9
−29	875·5	15	965·3	59	1055·1	103	1144·9
−28	877·6	16	967·3	60	1057·1	104	1147·0
−27	879·6	17	969·4	61	1059·2	105	1149·0
−26	881·6	18	971·4	62	1061·2	106	1151·0
−25	883·7	19	973·5	63	1063·3	107	1153·1
−24	885·7	20	975·5	64	1065·3	108	1155·1
−23	887·8	21	977·6	65	1067·3	109	1157·1
−22	889·8	22	979·6	66	1069·4	110	1159·2
−21	891·8	23	981·6	67	1071·4	111	1161·2
−20	893·9	24	983·7	68	1073·5	112	1163·3
−19	895·9	25	985·7	69	1075·5	113	1165·3
−18	898·0	26	987·8	70	1077·6	114	1167·3
−17	900·0	27	989·8	71	1079·6	115	1169·4
−16	902·0	28	991·8	72	1081·6	116	1171·4
−15	904·1	29	993·9	73	1083·7	117	1173·5
−14	906·1	30	995·9	74	1085·7	118	1175·5
−13	908·2	31	998·0	75	1087·8	119	1177·6
−12	910·2	32	1000·0	76	1089·8	120	1179·6
−11	912·2	33	1002·0	77	1091·8	121	1181·6
−10	914·3	34	1004·1	78	1093·9	122	1183·7
− 9	916·3	35	1006·1	79	1095·9	123	1185·7
− 8	918·4	36	1008·2	80	1098·0	124	1187·8
− 7	920·4	37	1010·2	81	1100·0	125	1189·8
− 6	922·5	38	1012·2	82	1102·0	126	1191·8

TABLE No. 57.—*continued.*

Tempe-rature.	Volume in cube inches.	Tempe-rature.	Volume in cube inches.	Tempe-rature.	Volume in cube inches.	Tempe-rature.	Volume in cube inches.
127	1193·9	155	1251·0	182	1306·1	209	1361·2
128	1195·9	156	1253·0	183	1308·2	210	1363·3
129	1198·0	157	1255·1	184	1310·2	211	1365·3
130	1200·0	158	1257·1	185	1312·2	212	1367·3
131	1202·0	159	1259·2	186	1314·3	213	1369·4
132	1204·1	160	1261·2	187	1316·3	214	1371·4
133	1206·1	161	1263·3	188	1318·4	215	1373·5
134	1208·2	162	1265·3	189	1320·4	216	1375·5
135	1210·2	163	1267·3	190	1322·4	217	1377·5
136	1212·2	164	1269·4	191	1324·5	218	1379·6
137	1214·3	165	1271·4	192	1326·5	219	1381·6
138	1216·3	166	1273·5	193	1328·6	220	1383·7
139	1218·4	167	1275·5	194	1330·6	230	1404·1
140	1220·4	168	1277·5	195	1332·6	240	1424·5
141	1222·4	169	1279·6	196	1334·7	250	1444·9
142	1224·5	170	1281·6	197	1336·7	260	1465·3
143	1226·5	171	1283·7	198	1338·8	270	1485·7
144	1228·6	172	1285·7	199	1340·8	280	1506·1
145	1230·6	173	1287·8	200	1342·9	290	1526·5
146	1232·7	174	1289·8	201	1344·9	300	1546·9
147	1234·7	175	1291·8	202	1346·9	400	1751·0
148	1236·7	176	1293·9	203	1349·0	500	1955·1
149	1238·8	177	1295·9	204	1351·0	600	2159·2
150	1240·8	178	1298·0	205	1353·1	700	2363·3
151	1242·9	179	1300·0	206	1355·1	800	2567·4
152	1244·9	180	1302·0	207	1357·1	900	2771·5
153	1246·9	181	1304·1	208	1359·2	1000	2975·6
154	1249·0						

Formula for increase of pressure caused by heat.

Let V = the original volume of the air of the sewer at its normal temperature; V^1 = the volume of the air after its increase of temperature; and P = the original pressure, say atmospheric pressure 14·6 lbs. per square inch, or to a column of water 34 feet high; P^1 = the pressure after the increase of temperature: then we have $V : V^1 :: P : P^1$, whence in the foregoing case we have 1036·7 : 1240·8 : : 34 feet : 40·7 feet, showing an increase of pressure of 6·7 feet head of water was caused by the increase of temperature, which is an amount of force that no trap could resist; hence the necessity for free ventilation. The difference of temperature between the external atmosphere and the internal air of a sewer, is one of the forces at work by which the ventilation of sewers is effected. The following Table, compiled by Lieutenant Colonel William Haywood in

Difference of temperature.

1858, shows the difference of temperature between the internal air of the City sewers and the external atmosphere :

Experiments of Lieut.-Col. Haywood.

TABLE No. 58.—Showing the SUMMARY of OBSERVATIONS as to the TEMPERATURE of the CITY of LONDON SEWERS. By Lieut.-Col. WILLIAM HAYWOOD, C.E.

Time of Year.	Temperature in External Atmosphere in Shade.			Temperature in Sewer.			Mean Temperature of Sewer.	
	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Above External Atmosphere.	Below External Atmosphere.
	°	°	°	°	°	°	°	°
Summer ..	72	55	65·04	68	56	61·92	..	3·12
Winter ..	34	30	32·37	52	40	43·98	11·61	..
Spring ..	61	46	52·46	59	48	52·52	0·06	..
Autumn ..	68	48	59·90	70	53	62·97	3·07	..
Average of whole year	..	..	50·24	..	..	55·35	5·11	..

By reference to this Table it will be seen that on the average of the year the internal temperature of the sewers was 55°·35, and the external atmosphere in shade 50°·24; so that, on an average of the whole year, the sewer possessed a temperature of 5°·11 only above that of the atmosphere. In the summer months the average temperature of the sewer was below that of the atmosphere. In the spring the temperature of both sewer and air are equal; while in the autumn and winter the average temperature of the sewer was in excess of that of the atmosphere. During the year 1870 experiments made by the author at Croydon showed that on 220 days the external air rose to a higher temperature than the highest temperature of the sewage, and on 145 days the highest temperature of the air was lower than the temperature of the sewage. There were 313 days when the external air fell to a lower temperature than the lowest of the sewage, and 52 days when the lowest temperature of the sewage was less than the lowest temperature of the external air. In the case of the City of London, the temperature of the

Summer temperature.

Spring temperature.

Autumn and winter temperature.

Temperature of Croydon sewage.

sewers in winter was considerably below the mean temperature of the summer months, as the water supply is principally taken from surface streams, which are subject to the same variation of temperature as the atmosphere.*

Entrance of hot liquids into sewer liberates foul air.

The entrance of hot liquids into the most perfect sewer, by increasing the temperature of the sewage, diminishes its capacity for air, hence foul gases are liberated by the addition of water of a temperature above that of the sewage.

Force of ebb and flow of sewage.

The next force which will be considered, and which renders a system of ventilation of sewers absolutely necessary, is the varying ebb and flow of the sewage. This ebb and flow of the sewage leaving the sides of the sewers alternately wet and dry, naturally leads to the production of much vapour or sewer gas. The ebbing and flowing of the sewage within all sewers has also the mechanical effect of compressing or dilating the air present in the sewers. According to the law of Boyle and Mariotte, the pressure is inversely as the space occupied; therefore it is clear that, unless openings are made as outlets and inlets, the natural consequence of the rise and fall of the sewage in the sewer must be to draw in and expel foul air at points out of control. For example, suppose we have a sewer running half full, and that by an increase in the rate of flow it begins to run three-fourths full, the air which originally occupied half the sewer, when the sewer runs three-fourths full will be compressed into a quarter of the sewer, and being compressed into half the space it originally occupied, its pressure would be increased by an amount equal to that of one atmosphere, or a column of water 34 feet in height. Against such a pressure (if the sewers are perfectly air-tight) no traps could resist the effort of the imprisoned air.

Production of vapour.

Law of dilatation of gases.

Example.

The most perfect material used in the construction of

* Recent experiments made by the author show that the source of the water supply makes little difference to the temperature of the sewage, as all water delivered to the consumer acquires the temperature of the ground at the depth at which the delivery mains are laid.

sewers is not entirely impervious to air; the openings in the material are so minute that currents of air will pass through it which may escape our attention; but nevertheless, such is the porosity of the material used, that while the ebb of the flow of sewage in a hermetically sealed sewer tends to produce a vacuum, in practice a vacuum is never created. This very porosity of the materials used in the construction of sewers only shows the necessity of providing openings for ventilation, so that the air may not be forced through the materials used in the construction of the sewers. It may be laid down as a rule, that in the main lines of sewer, from morn till noon, sewers are expelling foul air by virtue of the rate of fluctuation of the flow, and from noon to morn they are drawing in fresh air by reason of the same force being at work. Of course these results are greatly modified by the effect of sudden storms. Sewers discharging into the sea, or into tidal rivers, are liable to be tide-locked twice a day. During the period they are so tide-locked, as they fill up with sewage the sewer air will be expelled, and when the sewers discharge their contents at ebb tide, fresh air will be drawn into the system of sewerage. In consequence of this rate of fluctuation, it must be clear that all those propositions which have been made, and which hereafter will be referred to, of making down-cast and up-cast shafts for the purpose of the ventilation of sewers, will prove abortive, for when the sewers have within them a force which at one period naturally expels air, all shafts, whether up-cast or down-cast, will at that period become up-cast shafts, and when the air is drawn into the sewer all shafts will naturally become down-cast shafts. It may be here noted that the rate of fluctuation of flow in a sewer or drain is a very powerful agent in promoting natural ventilation; that is, if sufficient openings are formed in the sewers or drains, air will naturally be drawn in at these openings at one period of the day, and will be expelled at another period. This fluctuation in the flow, which takes place naturally in every sewer or house drain, may be augmented, so

Materials used in construction of sewers porous.

Sewers discharging into the sea.

Down-cast and up-cast shafts will not act.

Fluctuation in flow may be made use of for augmenting ventilation.

as to lead to an artificial filling and discharging of the air of certain sections of a system of sewers. To effect this, self-acting flushing valves may be used, so arranged that certain sections of the sewers would be allowed to fill with sewage at certain periods of the day, and this pent-up sewage should then be rapidly discharged, so that the double purpose of flushing the sewers and of ventilating them will be served.

Barometric change, a force.

Barometric changes affect the amount of foul air present in sewers. The diminution in barometric pressure leads to the escape of gases which are stored in the interstices of the sewage, and favours decomposition. An increase of barometric pressure enables sewer air to carry a larger amount of the vapour of water, and for the sewage to retain a larger volume of the offensive gases due to decomposition or absorption without parting with them.

Condition under which sewage retains gases.

Foul air in water of sewers.

Air held in the interstices of water is subject to the same laws with respect to its pressure and dilatation as free air under like circumstances. It naturally follows, that increased temperature of water tends to dilate the air held in the interstices, and consequently a portion of the air will escape, and such air, driven off from sewage, will be offensive; hence an increase of temperature makes the air of sewers offensive. Again, during the period of rapid falls of the barometer, air again becomes dilated, and as a natural consequence, escapes with the same effect as increase of temperature, and with a rise in the barometer the capacity of sewage or water for air is increased, a fall of temperature in the water also increasing its capacity for air. Temperature and barometric changes are therefore the fruitful agents by which air is liberated from sewage, and it is consequently during atmospheric changes that sewers, which appear to be sweet at other times, become offensive and noxious. It has been supposed by some, that the offensive odour occasionally given off by sewers is a sure sign of defective construction. This, however, is not the case, for as long as offensive matters are put into sewers, however perfectly they are constructed, at

Diminution of atmospheric pressure liberates foul air from sewage.

Influence of atmospheric changes in sewers.

times foul odours must, as a natural consequence, escape, unless provision is made for arresting them. The fall of sewage from a high to a low level in a system of sewers increases the capacity of the sewage to retain air, for sewage at a high level contains air of less tension than sewage at a low level, so that as sewage flows from a high level to a low level it has a tendency to take up more air, and so to a great extent by a natural law foul air is retained in flowing sewage.*

Vapour of water a force.

The vapour of water may be considered a force within a sewer affecting ventilation, as it gives lightness to the air. At 32° the vapour of water is about one two hundred and seventieth part ($\frac{1}{270}$) the density of dry air, and at 212° it is over half as dense as dry air at the same temperature.

Weight of dry air.

The weight of a cube foot of vapour of water at 60° Fahrenheit, 30 inch barometer, is 5·77 grains. The weight of a cubic foot of dry air at the same temperature and barometric pressure, is 536·3 grains. The weight of a cube foot of dry air at 32° being 566·9 grains, the weight at any other temperature may be found by dividing this number by the relative density given in Table No. 57.

Example: Required to know the weight of a cube foot of dry air at 100° Fahrenheit. The relative density is 1 to 1·1388 and $\frac{566 \cdot 9}{1 \cdot 1388} = 497 \cdot 8$ grains, the weight of a cube foot of dry air at 100°. A cubic foot of air at 32° saturated with moisture = 565·6 grains, at 60° = 532·7 grains, and at 100° = 484·7 grains. These weights show at once that the mixture of the vapour of water with air very considerably lightens it; so that at all ordinary temperatures the vapour of water will materially affect the density of the air of sewers.

Wind a force.

Wind blowing over the surface of ventilators in a street has a material effect in changing the currents of air within the sewers.

Effect of position of outfall.

The position of the outfall of the sewers in reference

* Vide p. 345.

to its exposure to the prevailing winds of a district, has also an effect upon the ventilation of the sewers. If an outfall sewer is open to the prevailing winds, rapid currents of air are produced in the sewers, and which may escape so quickly at the ventilators as not to be under control. On this account every outfall should be protected so as to prevent currents of air entering in uncontrolled volume.*

Protection of outfall.

Friction and leakage both play their part as forces at work within a sewer affecting the general question of ventilation. It may also be noted that sewers may act like an ordinary chimney shaft, especially in those districts in which the fall of a sewer is great; so that, when there is an uniform rate of flow through the sewers, there is a tendency for air to enter the openings at the lower points of the system of sewerage, and escape at the higher points.

Friction and leakage.

Sewers may act as shafts.

The law of the diffusion of gas tends to modify the forces at work within a sewer. It also modifies the poisonous effects of sewer air. All gases diffuse themselves through each other (although they may not combine) with a rapidity varying with the respective density of the gases. By this law light gases descend and the heavy gases ascend; the rate of diffusion being inversely proportional to the square root of the density —as, for example: if we have two gases, one of which is four times the density of the other, the heavy gas, in this case, will therefore require twice the time the rarer gas would require to diffuse itself in an equal volume. The laws which govern ventilation are the well-known laws of gravitation, currents invariably being produced by the difference in pressure or weight of different columns of air. At 60° Fahrenheit, and with a barometric pressure of 30 inches, a cube foot of dry atmospheric air weighs 536·3 grains; or 13·05 cube feet weigh 1 lb. When the pressure of the atmosphere is equal to 14·6 lbs. to the square inch, as there are 22,550 cube inches in 1 lb. of air, that number multi-

Diffusion of gas modifies result.

Laws of gravitation govern ventilation.

Atmospheric column.

* Vide p. 73.

plied by 14·6 will give the height of a column of air corresponding to the pressure of the atmosphere, or 329235 inches = 27436 feet. Air will flow into vacuo with a velocity equal to that which a heavy body acquires in falling a distance equal to the height of the atmospheric column, or with a velocity $\sqrt{2\,g\,H}$, consequently it would rush into vacuo with a velocity $\sqrt{64 \cdot 4 \times 27436} = 1329$ feet per second. Air flows from one atmosphere into another less dense with a velocity equal to that which would be acquired by a heavy body falling through a space equal to the difference of the pressure represented by the respective columns of air. The differences in pressure are arrived at by noting the differences of temperature, for temperature and pressure bear a constant ratio to each other. M. Regnault determined that air is dilated $\frac{1}{491 \cdot 13}$ part, or ·0020361, for every degree Fahrenheit its temperature is raised; consequently a column of heated air being lighter than an equal column of cold air, a difference of pressure exists, or there is a tendency for the cold air to flow into the heated air, or for the heated air to escape with a velocity equal to that which a heavy body would acquire when falling from a height equal to that of the vertical column representing the difference of pressure. A cubic foot of air loses 1·093 grains in weight for each degree that it is heated. For example, supposing a ventilating shaft 60 feet high and 1 foot sectional area, the difference in temperature between the external and internal air is 150°, then $\frac{150° \times 1 \cdot 092 \times 60 \text{ feet}}{536 \cdot 3} = \frac{9837}{536 \cdot 3} = 18 \cdot 34$ feet, or the height of the column of air that will produce motion, which in this case is equal to a pressure of 1·40 lb. per square foot.

Velocity with which air rushes into vacuo.

Velocity of air flowing from one atmosphere to another.

Pressure determined by temperature.

Loss of weight of air when heated.

Example.

The foregoing calculation is not quite correct, as the quantity of heat lost at every degree is a diminishing quantity, and not uniform as assumed in this calculation. Example: At 60° the weight of a cube foot of air = 536·3 grains, which multiplied by ·0020361, the amount of dilation for 1° Fahrenheit, gives the loss for 1° at this temperature 1·093 grains per cubic foot, but at 212° the weight of a cube foot = $\frac{566 \cdot 9}{1 \cdot 3673}$ = 414·6 grains, and 414·6 × ·0020361 = ·844 grains, the loss of 1 cube foot at this increased temperature by an increase of 1° Fahrenheit of temperature. In practice the mode of calculation adopted is to multiply the difference of temperature between the external and internal air by the height of the shaft in feet, and divide the product by 491·13, which will give the height of the column of air producing motion. The formula fully stated is as follows:— Heat lost not uniform.

$$v = \sqrt{2g\,\mathrm{H}\,a\,(t - t')}.$$ Formula.

v = velocity of discharge per second.
H = height of shaft in feet.
t = internal temperature.
t' = external temperature.
$2g$ = 64·4.
a = ·0020361 dilation of gas for 1° Fahrenheit, or in degrees centigrade = ·003665.

Applying this formula to the foregoing example, it will be found that the velocity of the escaping air will equal $\sqrt{64 \cdot 4 \times 60 \times \cdot 0020361 \times 150} = 34 \cdot 35$ feet per second, or 2061 feet per minute, which also equals the discharge in cube feet, as the shaft is 1 foot sectional area. This calculation is entirely theoretical, and in practice a deduction must be made for friction. In calculating the discharge of circular ventilation shafts or pipes the following formula, which is used for calculating the discharge from gas pipes, will be found applicable:— Formula for discharge from pipes.

$$\mathrm{D} = \frac{19400\sqrt{d^5}}{\sqrt{s\frac{\mathrm{L}}{\mathrm{H}}}}.$$

D = discharge per minute in cube feet.
d = diameter in feet.
L = length in feet.
H = pressure in inches of water.
s = specific gravity, air = 1·0.

Example.

If this formula is applied to the preceding example, $d = 1 \cdot 13$ foot, L = 60 feet, H = 220 inches of air, but as water is 813·67 heavier than air, = ·27 inch of water, then we have as the discharge,

$$\frac{19400\sqrt{1 \cdot 13^5}}{\sqrt{1 \times \frac{60}{\cdot 27}}} = \frac{19400 \times 1 \cdot 357}{\sqrt{222 \cdot 22}} = 1767 \text{ feet.}$$

Comparison between theoretical discharge and result of formula.

By this formula the discharge is found to be 1767 cubic feet per minute for a shaft 1 foot sectional area against 2061 cube feet per minute, the theoretical discharge. It may be here noted that the draught of a chimney 250 feet high, with a difference of 200° temperature between the external and the internal air, would represent a column of air, = 101·78 feet in height, or equal a pressure of 7·793 lbs. per foot, which is equal to a vertical column of nearly $1\frac{1}{2}$ inches of water. Such a draught, if it could be brought to bear on the ventilation of sewers, would force and unseal all the ordinary traps now in use within our houses.

Draught would force all traps.

Ventilation of sewers compared to ventilation of mines.

The ventilation of sewers has often been compared to the ventilation of mines, and the same measures which have been proposed for the ventilation of mines have been proposed over and over again for the ventilation of sewers; but those who have made the proposition have not fully understood the nature of the work to be performed, or of the forces at work within a sewer, which dispel all those beautiful theories of ventilation which have been advanced. A few words of explanation, pointing out the difference between mine ventilation and that required for sewers and drains, may prove of service.

Ventilation of sewers easy and safe.

The ventilation of sewers, although differing from that of mines, is easy and safe, for only make sufficient openings, and the sewers will ventilate themselves. It is very different in the case of a mine, and no greater mistake can be made than to confound the system of ventilation as required in a mine with that necessary for a system of sewers. In the case of a mine it is usual to have one down-cast shaft and one up-cast shaft, or one set of down-cast shafts to convey fresh air through the workings of the mine; on its way to the up-cast shaft the circulation of the air being kept up by artificial means, so as to secure the proper amount of air which should be admitted to the workings, and the discharge of the vitiated air. In a system of sewers such a mode of ventilation as this would prove entirely inoperative, on account of the peculiar features present in a system of sewers, and on account of the forces which are naturally at work within the sewers, whereby all untrapped openings may at one period of the day become down-cast shafts, and at other periods up-cast shafts, as has already been pointed out in referring to the forces at work within a sewer.* A sewer may be compared to a tube perforated entirely throughout its length. If the introduction of a special means of ventilation, similar to that adopted in mines, could be brought to bear in a system of sewers, it would have the effect of causing powerful currents of air to pass into the sewer from the nearest openings, to the exclusion of any current at all from the more remote openings into the sewers.

Mine ventilation.

System used in mines not applicable to sewers.

Sewer is a perforated tube.

The modes proposed for effecting the ventilation of sewers after the fashion of mine ventilation are natural, and mechanical, appliances.

Modes proposed for ventilation of sewers.

Natural ventilation embraces all those modes which cause the air to move by reason of difference in temperature or weight of the respective columns of air. In the ventilation of mines, natural ventilation has hitherto been considered the simplest and least liable to derangement, which is a point of considerable recommendation and importance when it is considered what a vast number of individuals are dependent for their health and lives upon the perfection of the machinery for changing the air within a mine. Some difference of opinion has, however, been expressed amongst authorities as to whether natural or mechanical ventilation

Natural ventilation.

Difference of opinion.

* Vide p. 326.

of mines is the best system: many persons contend that greater mechanical effect is produced by a given quantity of fuel, when the power is directed through properly constructed machinery for pumping air in or out of a mine, than when a like quantity of fuel is used in heating a column of air, and so creating a natural current.

Mechanical ventilation.

The mechanical contrivances for the ventilation of mines embrace all those modes or means of producing, by machinery, currents of air, either by forcing air into, or by drawing it out of, the mine. When it is forced in it is called the Plenum system, and when it is drawn out it is called the Vacuum system. The plenum system of ventilation would not be admissible in connection with a system of sewers, as the discharge of air at high pressure into sewers would naturally lead to the forcing of the traps and the escape of the air and foul gases into the houses. The effect of the ventilation produced by drawing air out of sewers has been tried, and the results show that all these arrangements affect a very limited length. In Paris and Antwerp shafts have been tried for the purpose of ventilating the sewers, but the results were not sufficiently satisfactory to admit of their use as a general system for promoting ventilation. Numerous experiments have also been made with shafts and furnaces as a mode of sewer ventilation. In the report of Sir J. W. Bazalgette, C.B., on the ventilation of sewers, addressed to the Metropolitan Board of Works in January, 1866, some results as to the efficiency and the cost of this mode of ventilation are given. Quoting from evidence given by himself and Lieut.-Colonel Haywood, the City of London Surveyor, before a Parliamentary Committee in 1858, which is here reproduced, Lieut.-Colonel Haywood said: "A down-draught, so complete as to be superior to the diffusive power of the gases, you cannot start with a velocity of less than two miles an hour; and suppose the whole district has been so arranged as to have a sufficient exhaustive power,

Plenum system.

Vacuum system.

Effect of ventilation by drawing air out of sewers.

Experiments with shafts.

Sir J. W. Bazalgette and Col. Haywood.

the mere opening of a water-closet, or the enlarging or the putting in of a new drain into a sewer, or the making a hole a foot square, or a servant taking up a bell trap in a sink, or a sewer man lifting a side-entrance covering, would very much destroy the power of the furnace, and unless you had a gigantic power sufficient to guard against all these casualties, the system could only be a failure." Sir J. W. Bazalgette, in his evidence before the same Committee, says, "A furnace ventilating any large district would require to produce a very large volume of air, and to keep up a velocity sufficient to ventilate all the branch sewers, and the drag would consequently be so great through the main that it would force open any house-drain traps or water traps we could form before it would influence the remote branches; but, putting those difficulties out of the question which appeared to us insuperable, we found that the consumption of coal to extract the required quantity of air, supposing that the sewers could be laid out like the channels of mines, would be something enormous." Speaking of the ventilation experiments with the clock tower of the Houses of Parliament, he says, "I found that the furnace of the clock tower of the Houses of Parliament was supposed to have been connected with the adjoining district to the extent of about a quarter of a square mile, and with about six miles and a half of sewers in length when added together, but that the ventilation had in reality been intercepted by a flap, so that the benefit supposed to be derived therefrom was purely imaginary. . . . Having come to that conclusion, the next thing I directed my attention to was, supposing the whole of the air extracted by that furnace was produced from the sewers, and supposing that all the intermediate channels could be stopped, and that it could be directed from the most remote ends of each of the sewers and distributed over those sewers with the most perfect theoretical accuracy, so as to have a uniform current passing

Cases of derangement of ventilating apparatus.

Furnace ventilation.

Experiment, clock tower, Houses of Parliament.

throughout each of the sewers towards that chimney, still the effect upon those sewers would be nothing; and the way in which I prove my statements is this: the total area of the $6\frac{1}{2}$ miles of sewers now connected with the furnace is 713 feet; the total area of the channel through which the air has to be brought from them is 8 feet, that is, about the 90th part of 713; the air was passing at the rate of 542 feet per minute through the 8-foot area. Therefore if I could divide that over the whole district, the velocity in all those sewers would be 6 feet per minute, or $\frac{1}{15}$th of a mile per hour. But we have shown already that there exist in the sewers from other causes velocities amounting to 100 feet per minute and upwards; and 6 feet per minute is, practically speaking, stagnation and not ventilation." He further stated, that "supposing you could obtain theoretic perfection, and all the air produced by this furnace was spread through this district, you would only then get up a velocity of $\frac{1}{15}$th of a mile per hour, which is no ventilation whatever. But I have gone farther with the inquiry. Whilst we were making our observations, on Tuesday, the furnace, being kept up, was consuming at the rate of eight chaldrons of coke per day; but I will assume that the defective arrangements, that is, the chimneys being stopped up, the circuitous connections, and so forth, necessitated a very much larger consumption of fuel to produce the same effect, than could be produced with better arrangements with a less quantity. I will assume that four chaldrons of coke per day, or half the quantity actually used, would produce that current of air, and that when produced it would effectually ventilate the $6\frac{1}{2}$ miles of sewers, which I think I have shown to be impossible; but supposing it were possible, then I find that for 1500 miles of sewers 230 such furnaces would be required, and the cost of the coke at each of those furnaces would be 876*l.* per annum at four chaldrons per day . . . giving a total for the whole ventilation

Velocity caused by ventilating shafts.

Velocities found in sewers.

Consumption of fuel.

Cost of furnace ventilation.

of the metropolitan sewers of 201,480*l.* per annum upon the consumption of coke, without any labour or incidental expenses. The prime cost of those 230 chimneys and furnaces and establishments I have put down at 2000*l.* a piece; that would give 460,000*l.*, or half a million of money." In the same report it is stated that in 1858 he "visited some of the best ventilated coal mines in the North of England and in South Wales, with a view, if possible, to the application of some more perfect system of ventilation to the London sewers. I entered carefully into the comparative advantages of ventilating fans and furnaces, and into the expenditure of fuel requisite for the extraction of a given quantity of air under various conditions. But I found that whilst it was not difficult to conduct a current of air through the continuous passages of a mine having but one inlet and one outlet, and a tolerably uniform sectional area, I found that such a system could not be applied to sewers. The areas of the branch sewers discharging into any one main sewer are, probably, much more than a hundred times its capacity; therefore, even supposing it were possible that they could be all hermetically sealed at all points excepting the extreme ends, a velocity of current equal to 100 miles an hour (which is next to impossible) would have to be obtained in order to secure a current of one mile per hour in each of the branch sewers. But it is not possible to obtain such a condition of things; and this difficulty lies at the root of all proposed modes of ventilation, by extracting the foul gases by furnaces, fans, or such other appliances." Mr. Henry Austin, C.E., the consulting engineer to the Commissioners of Sewers, reported, in 1849, on some experiments that had been made with a view to remove a local nuisance arising from sewer gas by means of furnaces, and as to the advisability or not of trapping the openings in connection with the sewers. He said, "In September, 1848, the sewer in Friar Street, since

Relative area of sewer and its branches.

Mr. H. Austin's Report, 1849.

rendered so notorious, being then, as now, charged with dangerous gases, Mr. Roe and myself joined in a recommendation of Mr. Phillips to try the experiment of drawing off the foul atmosphere from that spot by means of fires, leaving the question of any chemical objection which may exist to such a process to those more adequate to pronounce an opinion upon it. Further experience and consideration have led me to the conviction that whatever local benefit, as in the case of Friar Street, might be derived by such a method, even if it could practically be adopted as a system, the results would be far from satisfactory." The conclusion arrived at by persons well acquainted with the working of a system of sewers, is almost unanimous with regard to the inapplicability of a system of mine ventilation to be applied to sewers, while all agree that there may be some special cases in which a partial adoption of such a system may be attended with advantage.

Furnace ventilation not satisfactory.

Proposals made for preventing formation of sewer gas.

A glance at some of the propositions which have been made, either for the purpose of preventing the formation of sewer gas, or for the purpose of ventilating sewers and the destruction of the gas, will not be without interest. It has been already stated that the early sewer works of this country were intended for the purposes of leading away rain and subsoil water from the sites of our houses, and as a natural consequence the openings, such as street gullies, into the sewers were left untrapped; but when the sewers began to convey fæcal and decomposing matters, the gases generated were discharged by the gullies. The nuisance of the noxious effluvium escaping from these gullies was so great that it became necessary to trap them. The effect of trapping without ventilation brought its own train of evils, which, in the case of London, led to the adoption of a system of ventilation. Ventilating openings communicating with the sewers were formed in the centres of streets, which had the effect of removing the point of escape of the sewer air farther from the passenger traffic and from the

Trapping of gullies.

Open ventilators.

houses, and of aiding the dilution of the escaping gases; but the palpable nuisance of the escaping gases from the openings made for ventilation was the ultimate cause of a vast amount of attention being paid to this special subject. Various suggestions have been made for dealing with sewer gas, or for the purpose of preventing its formation. Of the various expedients which have been proposed to prevent the emanations arising from sewers, one of the most common was that sewers should be so constructed as to maintain through them such a high velocity of flow that all matters liable to decomposition should be conveyed with such speed that no time would be allowed for decomposition and the escape of noxious gases. The failure of this theory has already been referred to * in connection with the physical properties of liquids containing air, as in the case of sewage however fresh or rapidly discharged, the foul air is always liable to be liberated either by changes of temperature or barometrical pressure, and even by abrupt falls of the sewage itself.

High velocity of transit.

It has been proposed to deodorize or disinfect all materials previous to passing them into the sewers, in order to pickle or stay the period of decomposition, and so prevent noxious effluvia arising during their transit through the sewers. To attempt to deodorize all matters which are passed into sewers would prove an extremely expensive operation, and those who are acquainted with the general habits of a town population know full well that to enforce a system of general disinfection of materials passed into sewers would be an impossibility.

Deodorization of materials passed into sewers

The deodorization of the sewage, as it flows through the sewers, by various chemical agents, has been proposed, in order to prevent the formation of sewer gas. This plan has, to some extent, been tried, but with no material advantage. The fluctuation in the flow of the sewage itself is an element which renders it difficult

Deodorization of sewage by chemical agents.

Causes of failure of deodorization of sewage.

* Vide p. 333.

to apportion the proper amount of disinfectant to the volume of sewage which may, for the time being, be flowing through the sewers; and as every system to be successful must embrace not only the sewers but the house drains, this system of deodorizing the sewage proper of the sewers, leaving that of the house drains untouched, would only palliate, and could not entirely relieve, any district from the effects of undeodorized sewage.

Absorbing materials within sewers.

It has been proposed to place within sewers materials which would absorb the sewer gases as they were generated.

Introduction of chemicals to destroy sewer gas.

Certain chemical agents have been introduced into sewers to give off gases which are supposed to destroy the noxious properties of the sewer gas.

Charcoal.

Charcoal was applied at an early period within sewers so as to absorb the foul gas.

Pipes within sewers.

It has been suggested to lay within the sewers pipes for the purpose of discharging chlorine or other gas, which should be specially manufactured for the purpose, and on being liberated would destroy the noxious properties of the sewer air.

Electric and galvanic agents.

Electric and galvanic agency has also been proposed as a means of destroying the noxious properties of sewer air. A patent was taken out in 1858 by Mr. John Chisholm, having for its object the use of these agents. The inventor states, " The application of electricity or galvanism to the vitiated and noxious gases contained in confined places, produces effects analogous to those of ozone, acting naturally on matters exposed to its influence in situations where atmospheric air has free access and circulation, but as this natural action is neutralized or destroyed in localities where free access of atmospheric air is prevented, as in crowded towns and structures, drains, sewers, and other confined places, I propose to apply electric or galvanic agency to them and their contents, and thereby produce or disengage ozone; and this agent, which is absorbed almost as rapidly as produced, destroys with it a quantity of deleterious and vitiated gases, and the electric or galvanic action being exerted continuously, ozone is formed as rapidly as it became absorbed; or electricity or galvanism may be so applied as to burn the vitiated gases, and thereby decompose, disinfect, and destroy them."

A slight amount of consideration will show that all those agents which have been proposed to be applied in the form of gas in order to destroy the noxious property of sewer air must be combined with ventilation, in order that after combination the resulting products may be discharged, or otherwise the air within the sewer would require such a degree of tension as to force a passage at some point into the adjacent houses. It is clear that those who have proposed many of these methods of preventing the formation or destruction of sewer gas could not have been acquainted with the real nature and property of what they call sewer gas, nor with the forces which are at work in every system of sewers. All those plans which relate to the introduction of chemical agents, or the insertion of pipes to discharge gases into sewers, would be liable to be disarranged in the first storm, when the sewers would be flooded. Many sewers, moreover, are of so small a calibre that no room could be found for the insertion of pipes and other receptacles which would be required to be inserted at frequent intervals. No one of these propositions for defecating the air of sewers would render their ventilation less necessary. At the same time, there can be no doubt that many of the agents proposed to be used would considerably modify the poisonous products of the sewer air; but in their turn they might prove as inimical to health as the gases they are intended to destroy. All those propositions that have been made with a view to deodorize sewage and prevent the formation of sewer gas are entirely inoperative in practice, because it has already been

Chemical agents must be combined with ventilation.

Sewers of small calibre.

Defecation dees not render ventilation unnecessary

Reasons why deodorization of sewage fails.

mentioned that the ebb and flow within the sewers cause the sides of the sewer to be alternately wet and dry, exposing a large evaporating surface, from which foul vapour is constantly given off, and this vapour passing into the air of the sewer forms what is commonly called sewer gas. Moreover, it must be admitted that, as contact with foul matter will pollute those that touch it, so air brought into constant contact with the foul matters conveyed by sewers will contract impurities which will be increased by the organic vapours constantly being given off by sewage, and in some cases by organized germs and other matters found floating in the air of sewers. In the ventilation of sewers and drains, the essential points to be kept in mind are:—1st. That the system shall be simple in its operation and not likely to get out of order, and that it shall be independent of uncertain mechanical aid. 2nd. That it shall admit of the expulsion of all sewer air and the supply of fresh air at all periods. 3rd. That the escaping gases shall be so diluted with atmospheric air as to be rendered harmless, or that they shall be destroyed or arrested. 4th. That the system shall not impede natural ventilation. 5th. That it shall not be costly in execution or maintenance.

Points to be observed in carrying out sewer ventilation.

Project for ventilating sewers.

Various propositions have been made or have been brought into operation, in order to secure the ventilation of sewers, and in noticing such projects, it will be well to fully consider their merits and defects.

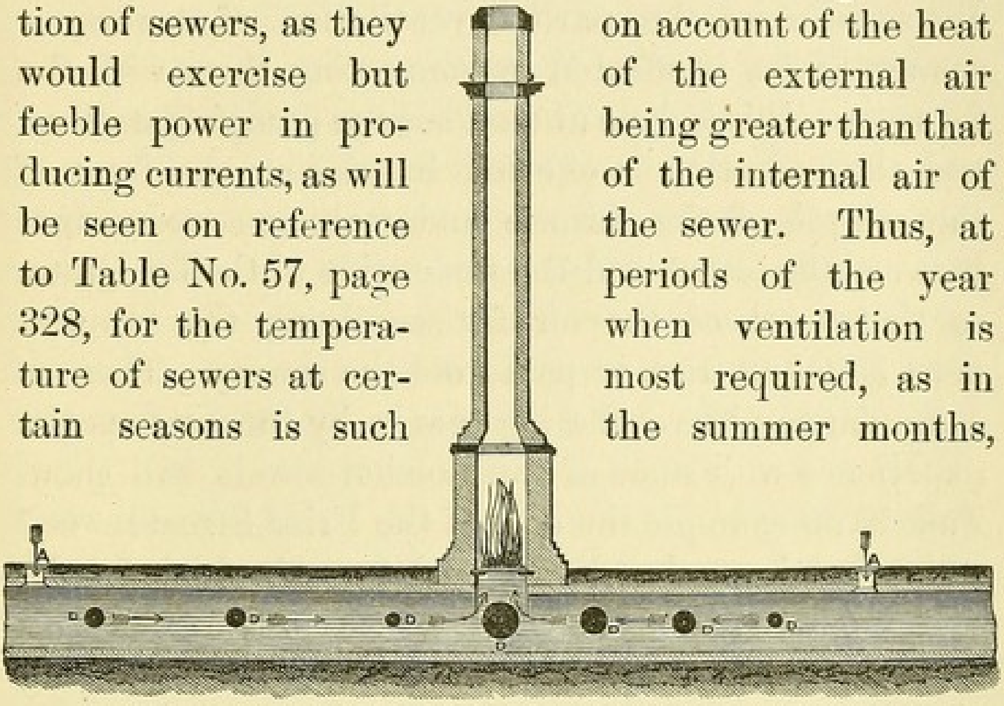
Shafts.

Of all the propositions that have been made, the use of lofty shafts of various kinds, sometimes aided by artificial heat or mechanical apparatus, as in mine ventilation, has been by far the most general, and this system has been partially adopted for sewer ventilation. In carrying out this mode of ventilation lofty shafts are constructed to carry the sewer gas to a considerable altitude above the adjoining buildings, where it may be dissipated in the air, or when furnaces are used, the gas is first passed through the fire, in order to oxidize and destroy its noxious properties. This latter plan is illustrated in Fig. 73, which represents a lofty chimney with furnace at the bottom, which can only be supplied with air from the sewers with which it communicates. Shafts without furnaces would not materially influence the ventilation of sewers, as they would exercise but feeble power in producing currents, as will be seen on reference to Table No. 57, page 328, for the temperature of sewers at certain seasons is such that they would be entirely inoperative, on account of the heat of the external air being greater than that of the internal air of the sewer. Thus, at periods of the year when ventilation is most required, as in the summer months, the variation between the internal and external air is so extremely slight, that for all practical purposes these shafts would be perfectly useless, and the feeble currents that would be produced at other periods would only affect the sewers for a short distance from the shaft.

Shafts with furnaces.

Shafts inoperative at certain seasons.

Fig. 73.



A very common proposition, and one which has been largely advocated, and to some extent put in practice, is to make use of the chimney shafts of manufactories; but objections are raised to this method by the manufacturers, for the connection of the sewers with them materially interferes with their efficiency as chimneys, and must lead, if universally adopted, to the construction of larger shafts than requisite for the purpose of manufacture. Assuming this system to be perfect in itself, the ventilating apparatus being in private hands,

Use of chimney shafts of manufactories.

Objections to system.

no control could be properly exercised by the authorities in regulating the amount of air that should be passed into the shaft or through the furnace. Again, as these shafts would only be efficient as ventilators when the fires were burning, and when the establishments were not at work, as on holidays, unless the furnaces were kept lighted this plan of ventilation would be very irregular.

Cases in which shafts are used.

In some cases the partial ventilation of sewers, or sewage tanks, is effected by connecting them with the furnaces. This is done at most sewage pumping stations, and the operation is effected by closing the front of the ash-pit of the furnace and making a connection between the sewers and the under-side of the fire-grate, so that most of the air for supplying the furnaces must be taken from or pass from the sewers. There is some danger in ventilating sewers by furnaces, as the experience with some of the London sewers will show.

Danger of connecting sewers and furnaces.

Take as an example the case of the Friar Street sewer,* which has been already referred to, and which for the purpose of ventilation was connected "with the furnace of a soap factory, a jet of fire burst from the connecting pipe and caused an explosion in the sewer." Of course this was an exceptionally foul sewer, and the introduction of a system of general ventilation would so modify the air of sewers as to render the accumulation of combustible gases an impossibility, except at such times when there was an extensive leakage of gas from the gas mains of a district. It has been suggested by Mr. Peter Spence that the sewers of a town should be used not only for the purposes of sewerage, but as flues for conveying away the products of combustion from the fires of our houses and the furnaces of manufactories, the gaseous products in this system thus being led to gigantic chimney shafts; and by this method it is contended that the sewers and drains would be ventilated. The smoke and gases

Mr. P. Spence's system of combined sewers and flues.

* Vide p. 344.

produced in the process of combustion of our coal fires would combine with the sewer gases and destroy their noxious quality, and the resulting compound would ultimately escape with the smoke and heated vapour by the shafts.

In connection with the subject of ventilation by means of fires and shafts, it may be mentioned that in the year 1723 Desaguliers made use of flues and fires for the purpose of ventilating the old House of Commons, but his plan met with unexpected opposition, as recorded by Dr. Guy. "Mrs. Smith, the housekeeper, was disturbed in the possession of her rooms, and with skill equal to his own, baffled his designs, and daily stifled the House, without incurring its displeasure. Her plan of operation was simple and effectual. Instead of lighting the fires before the House met, she waited till the House was heated." After this (in 1736) he invented and applied to the House a fan for throwing in and drawing out the air. The method of extracting foul air from ships of war was proposed by Mr. Samuel Sutton about the year 1736. This method consisted in making use of "fires already existing on board ship, and led a pipe from the ship's well, or from any other part of the vessel where change of air was needed, to the ash-pit, and so caused the foul air to blow the fire, and pass away up the chimney." Sutton received "the magnificent reward of 100*l*." from the Admiralty, but after all his "troubles, trials, and disappointments innumerable, he had the satisfaction of seeing his pipes fixed on board all His Majesty's ships." A modification of this system of ship ventilation, together with the same method of ventilating sewers, has been recently patented in this country by Mr. Henry Stott.

Desaguliers' mode of ventilation by means of flues.

Ventilating old House of Commons.

Mr. Samuel Sutton's mode of ventilation of ships of war.

Mr. H. Stott's system.

Special pipes, usually made of metal, have been used for the ventilation of sewers and drains. They are connected with the crown of the sewer, and carried

Special pipes.

under the roadway and up the external walls of the adjoining houses. One objection to the use of these metallic ventilating pipes is that in cold weather, when the sewers have such a temperature as to produce a natural tendency to discharge their gaseous contents into the air, the vapours ascending by these long metallic tubes become so chilled as to condense the aqueous portion, and check the natural tendency of ventilation. Such pipes may be used in many places with advantage, and especially in connection with the ventilation of house-drains, as they will act efficiently for the purpose of allowing air to escape when it becomes compressed, as for example, when any water is passed into a sewer or drain, for it may be taken as a rule that every drop of water poured into a sewer or drain causes the displacement of an equal amount of the foul air of the sewer, and in a system of sewerage the same volume of water may be made to displace several times its volume of sewer air. The use of ventilating pipes in connection with house-drains is hereafter further considered at page 399.

Ventilating pipes recommended for house-drains.

Ventilation by lamp columns.

Several suggestions have been made from time to time in reference to the use of the lamp columns in our streets as ventilators for the sewers. Some persons have suggested that the ventilation should be aided by the combustion of gas; others, that the lamp columns should be simply used as ducts for conveying away the sewer air.

It has been proposed to supplement the ventilation by special pipes with mechanical agency; and in Liverpool, a large number of ventilating pipes have been fitted up with cowl heads and Archimedean screws, for the purpose of exhausting the air from the sewer. The apparatus used is illustrated in Figs. 74 and 75.

Liverpool mechanical sewer ventilator.

When the wind blows it causes the cowl head to revolve, which gives motion to the screw shown in

Fig. 74, and the action is supposed to be to withdraw the sewer air; but a slight amount of calculation will show that such an apparatus will oftener be driven

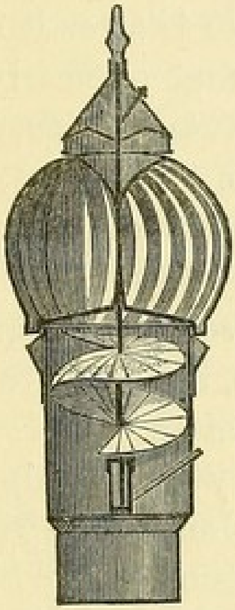


Fig. 74.

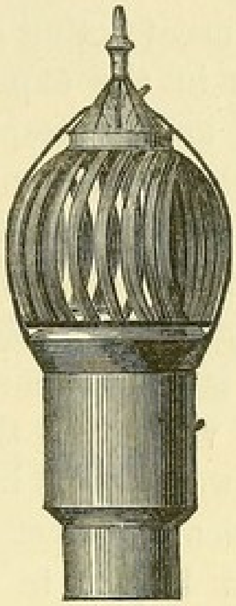


Fig. 75.

by the escaping sewer air than it will withdraw air from the sewers, and therefore it more generally acts as an impediment to ventilation rather than an aid to it.

Cowl head used in house-drains.

In the case of house-drains trapped between the house and sewer and an opening provided for the admission of fresh air a ventilating cowl head may be used with advantage.

Sewage used to drive ventilating fans.

Mr. John Philips proposed to use the mechanical effect of the sewage to work fans to extract the air from sewers.

Steam-jet.

The use of the steam-jet was proposed by Sir G. Gurney, in combination with properly constructed shafts for the ventilation of sewers. The action of the steam-jet is due in a measure to the rarefaction of the air, the partial vacuum created, and to the velocity of the escaping vapour, which drags along with it the sewer air. The efficiency of the steam-jet for the purpose of promoting ventilation was fully tested some years ago by Mr. Nicholas Wood, and he stated, in a paper read by him when President of the North of England Institute of Mining Engineers, that "In conclusion, the practical results of all these experiments is, that within the limits or range of furnace ventilation, the steam-jet acting as a substitute is attended with an increase in the expenditure of fuel of nearly 3 to 1, without any corresponding advantage either in the steadiness, security, or efficiency of ventilation. On the contrary, from its simplicity of construction, the steadiness of its action, its less liability to derangement, its economy, and its efficiency in cases of emergency, the furnace is more secure, more safe, and a more eligible mode of ventilation than the steam-jet."

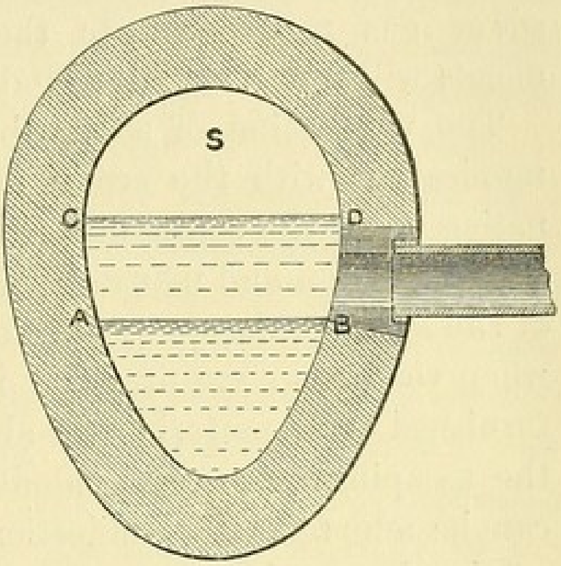
Ventilation by rain-water pipes.

Rain-water pipes have been very extensively adopted for the ventilation of sewers and drains. In Mr. Henry Austen's Report to the Commissioners of Sewers in 1849, he strongly recommended the use of these pipes in preference to shafts or furnaces. The system has many disadvantages, as under certain conditions rain-water pipes are rendered totally inefficient as ventilators. For example, when ventilation is most needed it cannot be carried out by the rain-water pipes, for these pipes are invariably connected with the house-drains, and the house-drains are connected with the sewers; and if it is to be assumed that the rain-water pipe is to serve for the ventilation of the public sewers as well as the house-drain, in time of heavy rainfall, when the sewers are gorged with sewage, and when the rain-water pipes are doing duty in their legitimate capacity in carrying away the rainfall, this system becomes totally inefficient for the purpose of ventilation, as the illustration, Fig. 76, will show. First, as regards the public sewers; because every junction made with a public sewer is made, or ought to be made, at such a point that if there is a small quantity of sewage flowing through the sewer the house-drain may have a free outlet, as shown by the line A B, and at such times the

Rain-water pipes used as ventilators.

rain-water pipes may serve as ventilators for a portion of the sewer; but the moment the sewers begin to fill in time of rain, and naturally to expel the sewer air which is present, the outlet of the house-drain is effectually sealed with water, which may be of considerable depth, as shown by the water-line CD; consequently the whole of the air which has accumulated in the upper section of the sewer S, and above the entrance of the house-drain, becomes compressed, and soon acquires sufficient power to force a passage for itself, and in such a direction as least anticipated. The sealing of house-drains in times of storm shows the necessity of carrying out a system of public sewer ventilation totally independent of the ventilation to be provided for house-drains. Moreover, as has been already mentioned, the rain-water pipes, during the time of rainfall, are doing duty in their legitimate capacity, consequently at such times they naturally form inefficient ventilators, even for the purpose of house drainage.

Fig. 76.



Necessity of public sewer ventilation.

It can be demonstrated that a current of water passing down a pipe will carry air with it, hence rain-water pipes cannot be used with any degree of security to discharge air from a sewer or drain when they are carrying only moderate quantities of rain-water. This action of falling water is shown in Mr. Rogers Field's syphon flushing apparatus, already referred to at page 295. There are also other objections to the use of rain-water pipes terminating under the eaves of a house or near windows, as the gases which may be

Currents of water carry air with them.

Objection to rain-water pipes.

discharged at certain periods will certainly find their way into our habitations. Rain-water pipes terminating under the eaves of a house are dangerous, as there is usually a space between the eaves and the roof communicating with the interior of the building; so the sewer gas may permeate the building, and its evil effects will sooner or later be discovered.

Ventilation of sewers by shafts.

The ventilation of sewers by means of shafts communicating with the crown of the sewer, and terminating about the centre of the roadway, has been carried out in London and many other places. In the opinion of the author this system of ventilating public sewers, when ventilators are provided in sufficient number and furnished with materials for absorbing and destroying the escaping gases, is decidedly the best system that can be adopted. The objection raised against the use of simple openings into the sewer is that deleterious gases escape from them, and are left to take their own course comparatively uncontrolled. In combating this objection it should be borne in mind that gases escaping in the centres of roads may become considerably diluted before they can arrive at the footpath or houses.

Dilution of sewer air.

The amount of dilution, supposing the gas to be uniformly distributed through the atmosphere, would be proportional to the cube of the distance from the point of discharge,* and dilution means in this matter something more than the dilution of effect.

Shafts in roads efficient ventilators.

These open ventilating shafts act, at certain periods, both as up-cast and down-cast shafts, and the fact should not be lost sight of that they can be made as efficient when viewed in the light of ventilating shafts as the lofty shafts which have been before referred to, and at considerably less expense. The efficiency of a shaft is proportionate to the square root of its height; consequently short shafts of larger area may be made quite as effective as smaller shafts of greater altitude. For example, take the case of a simple shaft termi-

* Vide p. 359.

nating in the centre of a roadway, the sewer being 9 feet deep. Now such a shaft, theoretically, if made three times the area of a shaft 81 feet high, would be quite as efficient; while in practice the low shaft would be the more efficient, as there would be less friction. Moreover, less pressure will be exercised throughout a system of sewerage where ventilation takes place through low instead of high shafts. It may be here noted that any appliance, such as a chimney shaft or other special ventilating shaft, which is intended continuously to withdraw currents of air from the sewers, apart from its insufficiency as a ventilator, is bad in principle, for the fluctuation in the flow through sewers, causing the dilatation and condensation of the air, brings into play forces far exceeding the power created by the ordinary draught of any chimney or shaft, even when aided by the heat of a furnace, so that despite the influence of these shafts, when air is being naturally expelled from the sewers all openings would discharge it, and when drawn in (if other openings were not provided) a current would be created down the chimney or shaft into the sewers. What therefore would come of such propositions as those of Mr. Spence * and others, who advise us that the drains and chimneys of our houses ought to be combined in one system, if at any moment we should be liable to an influx of sewer air and smoke into our houses? But apart from this grave objection, even if the combination could be made successful so far as our houses are concerned, the atmosphere of the sewers would be such that it would not be expedient to send men into them when they required repair, alteration, or the removal of obstructions. All shafts or chimneys of every description when used for the ventilation of sewers must be looked upon as having but little or no power in themselves to produce ventilation, but must be considered as a simple extension of the sewer for

Principle of continuously drawing off sewer gas bad.

Atmosphere of sewer such that men could not enter.

* Vide p. 350.

facilitating the discharge of noxious matter at some convenient point where it will be harmless.

Disposal of sewer gas.

One of the most important things to be considered in connection with the ventilation of sewers is the disposal of the sewer air in an innoxious manner. It should be observed, in reference to this matter, that the mere evidence of smell, or its absence, is no indication, or otherwise, of danger. Smelling gases may be harmless, while those matters which are most pernicious are usually devoid of odour. It has been already pointed out that the great safeguard against the evil effect of sewer air is dilution;* only allow the gas to combine with sufficient pure air and it is harmless, even if conveying the germs of disease. Evidence on this point is very conclusively shown by reference to our fever hospitals, as, in bygone days, when over-crowded and ill-ventilated, the death-rate among patients and attendants was awful to contemplate; since these institutions have been provided with perfect ventilation, disease seldom spreads—in fact, if an attendant contracts disease, it is looked upon as sure evidence that the ventilation is defective, or in other words, that the dilution of the fever poison is insufficient.

Evidence of effect of dilution.

Absorption of sewer gas by charcoal.

The absorption of sewer gas by different substances has been proposed at various times, and is now very successfully carried out in practice. It is well known to chemists that all porous substances have, more or less, the power of condensing gases within their pores. Wood charcoal, as an absorber of sewer gas, is decidedly the most efficient and the cheapest agent that has hitherto been used for the purpose of absorbing or destroying the noxious property of sewer air.

Evil of unprotected sewer ventilators.

The evil of unprotected sewer ventilators has not escaped the attention of sanitarians, and while it is true that dilution may remove the noxious properties of sewer air, it is often demonstrated in practice that there are times when currents of foul air escaping

* Vide p. 356.

from open unprotected sewer ventilators may be carried to considerable distances, and will produce very baneful effects. There is, moreover, always a danger in some towns, arising from the fact that children will play over or near the open sewer ventilators. These evils have been very clearly demonstrated in the case of Salford. The question of sewer ventilation in Salford has received much attention. A joint Committee of Health and Building Departments of the Corporation received a report from Dr. Tatham, the Medical Officer of Health of the borough, in which "he explains at the commencement that his inquiries into the subject have been occasioned by serious complaints from medical gentlemen and others, that the practice recently adopted by the Corporation of opening sewers into the narrower streets of the borough, by means of untrapped manholes, had been followed by results most disastrous to the inhabitants where such communications existed. He has noticed that where openings have been made down to the sewer in narrow streets, and in other confined situations, that there has been a most sickening odour;" and then he goes on to say that "in London, and in many other towns, as well as in many of the wide streets of Salford, the sewers are ventilated by direct openings into the streets, and this plan is generally considered free from objection, provided that the sewers are properly constructed, and that the streets with which they communicate are sufficiently wide. In all other cases, viz. in confined situations, it is clearly the duty of a sanitary authority to provide for the perfect deodorization of the sewer air before permitting it to escape into the streets;" and he further adds, "it is not my province, nor do I presume to decide as to which is the best form of charcoal tray for the trapping of sewer inlets; but I believe I am correct in stating that certain recent modifications of it have proved effectual in obviating the defects of its earlier forms, and that, as at present arranged, charcoal traps are

Danger to children.

Sewer ventilation in Salford.

Dr. Tatham's report.

Odour from unprotected sewer ventilators.

Dr. Tatham's opinion on use of charcoal.

Dr. R. A. Smith's opinion on use of charcoal.

effective purifiers of foul air." Dr. Robert Angus Smith says, in his book on 'Air and Rain,' that "the ventilation of sewers is, in many cases, very important, —but the ventilation is of course not a pleasant idea, because the gases are thrown into the air, and when there, we scarcely can tell what they will do. They become diluted certainly, and their power of mischief diminished, and for some this may be as good as destruction. This advantage we gain by ventilating directly into the open air. It is the least of two evils. To remove this objection, the charcoal filter was invented by Dr. Stenhouse; at least this was one of its applications, and it is certainly a great step."

Action of charcoal.

Then Dr. Smith says, "The advantage of charcoal as a filter is peculiar; charcoal not merely absorbs gases and vapours, but it decomposes thoroughly some of them, and, by a process of oxidation, makes the most noxious innocent. It may be said to go on for ever, at least I am not aware that Dr. Stenhouse has found any

Limit to durability of charcoal.

limits in time to its work, so long as it is supplied with air. No mere mechanical absorbent has this advantage. A greater activity was found when the charcoal

Dr. Stenhouse's platinized charcoal.

was platinized, and this substance is peculiarly Dr. Stenhouse's. It is not, however, used in a platinized state in large quantities, simply because it is too expensive."

Action of charcoal on gases.

Dr. R. A. Smith also states, "Wherever charcoal, a porous body, is filled with one gas and is put into another, a certain amount of the first is driven out with great force; the result is not a mere mixture taking place quietly, but an instant forcible diffusive and absorbent

Professor Muspratt's evidence.

action." Professor Muspratt says that "the absorbing powers of charcoal are so great, that some have doubted whether it is really a disinfectant. This opinion has probably arisen from imperfect views of its *modus operandi*, since it not only imbibes and destroys all offensive emanations, and oxidizes many of the products of decomposition, but there is scarcely a reasonable ground of doubt remaining that it does really possess the property of a true disinfectant, acting by destroying those lethal compounds upon which infection depends." A piece of charcoal placed in a volume of sewer gas will absorb that gas. It is not necessary for the gas to be mechanically brought into contact with the material, but just as the loadstone attracts iron, so charcoal attracts the noxious ingredients of sewer air. Dr. Voelcker, F.R.S., says of charcoal, "It possesses the power not only of absorbing certain smelling gases —sulphuretted hydrogen and ammonia—but also of destroying the gases thus absorbed; for otherwise its purifying action would soon be greatly impaired. It is very porous, and its pores are filled with condensed oxygen, to the extent of eight times its bulk. We have therefore in charcoal, oxygen gas (which supports combustion or lights fires) in a condensed and more active condition than in the common air which we breathe. Hence it is that organic matter in contact with charcoal is so rapidly destroyed. The beauty of charcoal is that the destruction takes place imperceptibly, and that its power of burning organic matter is continually renewed by the surrounding atmosphere, so that it is a constant carrier of atmospheric oxygen in a condensed state in its pores. The oxygen that acts on organic matter and burns it up is speedily replaced, and the process goes on continually. Hence it is that a comparatively small quantity of wood or peat charcoal is capable of destroying a very large quantity of organic matter."

Charcoal attracts impurities of sewer air.

Professor Voelcker on powers of charcoal.

The absorption of gas by different varieties of charcoal is given in Table No. 59.

Table No. 59.—Compiled by Dr. Stenhouse, showing the Quantity of Gas in Centimetres absorbed by Half a Gramme of Charcoal.

Dr. Stenhouse on charcoal.

Kind of Charcoal.	Ammonia.	Hydrochloric Acid.	Sulphuretted Hydrogen.	Carbonic Acid.	Oxygen.	Sulphurous Acid.
Wood	98·5	45·0	30·0	14·0	0·8	32·5
Peat	96·0	60·0	28·5	10·0	0·6	27·5
Animal ..	43·5	..	9·0	5·0	0·5	17·5

Professor Liebig.

Professor Liebig says, in his letters on chemistry, that "one cubic inch of beechwood charcoal contains pores equal in area to 100 superficial feet." As to the efficiency of charcoal for ventilators, Dr. Stenhouse says, "The efficiency of the charcoal appears never to diminish, if it is kept dry, and its pores are not choked up by dust." "The only precautions to be observed are, that while the filters shall be sheltered from rain and moisture, free access shall be given to the air." He also says, with regard to the construction of filters, "I should prefer using two or more thin filters, placed at short distances, say 2 inches from each other; these thin filters disinfect the air quite as efficiently as a single thick one." Dr. Letheby recommended charcoal air-filters as being the cheapest and best, as well as the most effective, plan for dealing with noxious exhalations from sewers. He says that charcoal has the power of "absorbing and oxidizing the miasmata of organic decomposition, when with atmospheric air they are passed over it." The charcoal used in the ventilators of the city sewers has been examined, and in the joint Report of Colonel Hayward and the late Dr. Letheby, on the use of the charcoal ventilators, it is stated, "Charcoal from the ventilators has been submitted to chemical examination after having been in action for nine to twenty months, and when treated with water it yields abundance of alkaline nitrate, showing that some of the organic miasmata have undergone complete oxidation. But besides these compounds, others are present, namely, peculiar alkaline salts, which indicate the fixation not only of ammonia, but also of other volatile nitrogenous bodies which are peculiar to organic decomposition. The nature of these compounds has yet to be determined, for all that can be said of them is, that they have a remarkably bad odour, compounded of urine, sewage, bad meat, ammonia, and stale tobacco; attempts have been made to isolate them, but without success. This, however, is

Dr. Stenhouse on charcoal air filters.

Dr. Letheby recommends charcoal.

Report of Col. Hayward and the late Dr. Letheby.

Matters arrested by charcoal.

not surprising when we consider that chemists have hitherto failed to separate and identify the miasmata of organic corruption." In the same Report it is further stated as to the power of charcoal, that "let them, however, be what they may, either physically suspended organic molecules, or complex volatile alkalies; and be the morbific agent either the one or the other, there is in charcoal a perfect means of arresting and oxidizing all the noxious compounds contained in these gases. This is demonstrated not merely by their absence in the sewer air which has passed over charcoal, but also by the presence of the alkalies, and the changed molecules in the charcoal itself."

Dr. Parkin's opinion on charcoal.

Dr. Parkin, in his work on "Causation of Disease," * says of charcoal that it "is both antiseptic and a disinfectant, for it not only arrests the process of putrefaction, but it also absorbs and neutralizes the gaseous products of decomposition." Speaking of disinfectants more generally, he says, "All these substances, although employed for that special object, have, like the two former classes, been utterly useless in preventing or arresting the spread of epidemic and endemic disease. There is one exception, however, and that is charcoal, which, as we shall presently find, does possess that property;" and for the prevention of the diffusion of malaria he recommends that charcoal should be employed, and that it should "be spread over the surface, so as to absorb the gaseous matter at the moment of its extrication. If in sufficient quantity, the poison would not only be absorbed, but decomposed and destroyed, and its diffusion in the air be thus effectually prevented." Speaking further of the excellent properties of charcoal, the same writer states, "As, also, this substance possesses the property of combining with all septic substances, or the products of putre-

* 'Causation and Prevention of Disease,' by John Parkin, M.D., late Medical Inspector for Cholera in the West Indies. London: John Churchill, 1859.

faction, there will be a double advantage in the employment of this agent; it would neutralize the elements of disease, and destroy the offensive odours which are generally given out at the same time." From what has been stated, it is clear that charcoal kept dry is practically a most efficient material for purifying sewer air, as it is not only a disinfectant, but it destroys or burns up the noxious gases. Some doubts may arise as to its use in connection with sewer ventilators, on account of the escaping vapours being highly charged with moisture; therefore on this point it is well that we should be assured that the moisture taken up from the sewer air aids rather than impairs the efficiency of charcoal. In a paper on "The Absorption of Mixed Vapours by Charcoal," read before the Chemical Society on the 20th January, 1870, J. Hunter, Esq., M.A., gives the results of experiments with charcoal and moist vapours. These experiments show that if charcoal is introduced into a mixed vapour, the vapour "which is nearest to its point of condensation is first absorbed, and this in its condensed state in the pores of the charcoal aids the absorption of the other vapour. According to this view a succession of condensations is going on. The theory is strikingly illustrated in experiments with a mixture of water vapour and ammonia gas (obtained by heating an aqueous solution of ammonia of specific gravity 0·88), when the mixture is much more largely absorbed than either the gas or vapour separately." "The mean of a set of experiments made at 100° and a mean pressure 706·2mm. was 316·6 volumes of the mixture absorbed by one volume of charcoal." These experiments confirm our faith in charcoal as an absorbent of sewer gas, for they prove that the vapour of water, when near the point of condensation, as is the case with sewer air, instead of being prejudicial, greatly assists the absorbing power of the charcoal.

Charcoal a most efficient agent.

Effect of vapour of water on charcoal.

It should be here mentioned that, when Dr. Frankland was experimenting with acidulated lithic chloride and marble, he says, "In some of my earlier experiments, I had noticed that the suspended particles in a current of air were diminished in number, or sometimes altogether removed, when the current had to pass a right-angled bend in a tube; and it therefore appeared to me not unlikely that a stratum of small fragments of charcoal would arrest them. This surmise, however, did not prove to be correct; for the particles of lithic chloride solution suspended in air, when the latter was moving very slowly, passed easily through a stratum 2 inches thick, composed of fragments of charcoal varying in size from ¼ to 1 cubic inch, and even when the thickness of the stratum was increased to 5 inches, the particles still came through, although in greatly diminished numbers." In this case the substances presented to the charcoal are of mineral origin, therefore charcoal could not exercise its peculiar property of absorbing and destroying them, as would be the case with organic vapours. In this instance, it was simply the mechanical effect of the charcoal as a filter that was brought into operation, and the experiment shows that even charcoal in mass, under such circumstances as here shown, does not so materially interfere with the escaping air as has been generally supposed.

Dr. Frankland's experiment.

Dr. Frankland's experiments show that charcoal does not obstruct ventilation.

Dr. W. A. Miller, F.R.S., made a number of experiments on some of the metropolitan sewers, in order to ascertain to what extent charcoal trays impeded ventilation, and how frequently the charcoal required to be renewed. Considerable difficulties arose in properly ascertaining how charcoal, when used as in this case in trays in mass so as to completely fill the ventilator, acted in retarding natural ventilation, as so many sources of error might arise. In Park Street sewer the average current of air without charcoal in the ventilator, the ventilators being located about 150 yards apart, was 4254 feet per hour, and after the

Experiment by Dr. W. A. Miller, F.R.S., on use of charcoal in sewers.

Amount of diminution of velocity caused by charcoal sewers.

introduction of the charcoal, the average velocity of the current of one set of experiments gave 3263 feet per hour, and another set gave 2005 feet per hour. Dr. Miller said, "It was ascertained by direct trial that air passed freely through the charcoal in the trays, but no sewer odour was ever perceived in the escaping air; though if the box of charcoal were purposely removed from the ventilating shaft, an immediate and powerful odour of sewage was observed. The charcoal, therefore, did its work in absorbing the offensive products." Samples of air collected from Park Street sewer, both before and after the use of charcoal in ventilators, the average of eighteen experiments, gave ·106 parts per cent. of carbonic acid, while open air gave ·040 per cent. The oxygen in sewer air was 20·71, and in open air 20·96. After the introduction of charcoal, the carbonic acid was ·132, and of oxygen 20·79, no sulphuretted hydrogen being present. Another experiment with a foul sewer—Great Smith Street sewer—which was also a tide-locked sewer, and had not so great a number of ventilators as in the former example, the distances in this case of the ventilators varying from 223 to 730 yards apart, before charcoal was introduced into the ventilators the proportion of carbonic acid found was ·307 per cent., and after the introduction ·251 per cent. The diminution in the amount was ascribed to the fall in the temperature, as it was found, in the course of these experiments, that as the temperature declined, the amount of carbonic acid also diminished. In this foul sewer it was found that the proportion of oxygen, after the introduction of the charcoal, was 20·7 per cent.

Charcoal absorbed sewer air.

Experiment, Park Street sewer.

Experiment, Great Smith Street sewer.

Durability of charcoal.

With reference to the durability of charcoal * in the ventilators, Dr. Miller found that in the Park Street sewer it was used for nearly six months. After this time "it contained nearly one-fourth of its weight of moisture, but appeared as though dry when handled.

* Vide pp. 360, 381.

This moisture had been condensed in the pores of the charcoal, and had not penetrated the box from the road. One hundred parts of the damp charcoal gave off, when heated, 19·7 parts of water, and a small quantity of an offensive ammoniacal liquid. Nitrates were also found in small quantities in the products retained by the charcoal." In the case of the charcoal from Great Smith Street sewer, which was a very foul sewer, with but few ventilators, after it had been in use about ten weeks, "it had absorbed 37·2 per cent. of moisture, and the water which was distilled off had the peculiar odour of the sewage gases."

Experiments on absorption of matters by charcoal.

Dr. Miller said that "the important practical conclusion is that charcoal, though thus saturated with moisture, does not obstruct the escape of air, which it still effectually purifies."

Opinion of Dr. Miller.

Other materials have been proposed to be used in connection with the abstraction and destruction of sewer gas; such, for example, as carbide of iron, a material which has been extensively used in the filtration and purification of water, and of which Mr. Spencer (its inventor) says, it is an extremely useful and durable material for the purpose of absorbing and destroying foul gases, and for the purification of air generally, and it was recommended by him to a Committee of the Houses of Parliament as the best means of removing the unpleasant odours from the air supplied to those Houses.

Carbide of iron.

Lime has been used and repeatedly recommended as an agent for neutralizing or purifying the gases escaping from sewers. It has been proposed for this purpose on account of its having proved efficient in purifying ordinary carburetted hydrogen as used for the purpose of illumination. It is difficult of application to sewers, and will not prove so successful as charcoal.

Lime.

Chlorine gas has also been proposed as a means of destroying the noxious property of the gases which escape at the ventilators provided for the sewers.

Chlorine gas.

Various modes have been suggested for liberating this gas; as, for example, by the use of common salt and nitric acid, or by placing materials rich in chlorine, such as chloride of lime, in trays, from which the chlorine would slowly evaporate into the surrounding air. Sulphurous acid has been proposed in connection with the deodorization or oxidation of sewer air, and experiments have been made with it by the Metropolitan Board of Works. The results of these experiments, so far as they are known, are given in a Report of Sir J. W. Bazalgette, C.B., from which the following quotations are taken:—"At the suggestion of Mr. Cook, the member for the Poplar district, I have been for some time past engaged in trying experiments upon the deodorization of the foul effluvium from the sewers by means of sulphurous acid. The experiments were carried out in Northumberland Street, at the junction of the Euston Road with the Tottenham Court Road. Near the bottom of and within the shaft, at a point a little above the crown of the sewer, porous earthenware pipes were placed horizontally on the four sides, so as to form a continuous tube 7 feet 6 inches long and 2 inches in the clear diameter. From thence an inch leaden pipe was continued upwards for a height of about 5 feet 6 inches, at which point it was connected with a glazed stoneware jar capable of holding about one gallon. The tube was then filled with sulphurous acid, and the pressure maintained therein by always keeping a supply of liquid in the jar. By this means the acid was kept constantly exuding through the pores of the pipe and brought into contact with the sewer effluvium as it ascended in the shaft. The wet evaporating surface presented to the current of foul air by the outer surface of the pipes was about 224 square inches."

Sulphurous acid gas.

Sir J. W. Bazalgette's Report.

Experiments on deodorization of sewer air with sulphurous acid gas.

"The mean results of many experiments, made under an average hydraulic pressure of 5 feet 10 inches, showed a consumption of less than 2 lbs. of acid of a specific gravity of 1·040 in twenty-four hours." "So far as the observations have gone, this agent, whilst in action, appears to have neutralized the foul smells." "Owing to leakages in the few pipes that were made for the purpose of the trial, there has been no opportunity for a continuance of the experiment in its original form, but upright porous pipes have been placed in this shaft, and in two other air shafts in Camden Road, of which complaints had recently been made, and these are now in working order."

Messrs. McDougall's apparatus.

"The Messrs. McDougall, the manufacturing chemists, have introduced a modification of the application of sulphurous acid, as first suggested by Mr. Cook, and which has been tried in an air shaft in Robert Street, Hampstead Road. The apparatus consists of a stoneware jar containing sulphuric acid, which is made to drop slowly upon a shallow tray containing a solid base, consisting, I believe, chiefly of sulphite of lime, which results in the liberation of sulphurous acid gas, to the action of which the ascending gases from the sewer are exposed. Difficulties, however, have presented themselves in the working of this arrangement, as the proper, or uniform, intermixture of the two agents has not yet been effected for any lengthened period." From a further Report as to the experiments in Tottenham Court Road, read on the 21st of January, 1871, the following is taken:—"In the ventilating shaft in Tottenham Court Road, in place of the rectangular pipes laid horizontally at the bottom of the shaft (but which had become fractured), a length of about 5 feet 6 inches of 2-inch porous pipes was placed vertically in the shaft, and connected with the reservoir near the surface of the roadway which had been used in the original experiment. This was kept supplied with acid, and the result of twenty-seven days' continuous working gave a consumption of about 53 pints of acid, or rather less than a quart per day." "At Robert Street the process has been varied by the introduction of a strip of flannel, which is placed in the shaft under the stoneware receiver that had been used in the former experiment with the solid base at this

Difficulties of applying the system.

place, and by means of a stoneware tap the acid is regulated to drop upon the flannel, previously moistened with water. The results of thirty-eight days' working upon this system showed a consumption of about 65 pints of acid, or rather less than $1\frac{3}{4}$ pint per day, and in this case also the reports are to the effect that there is no apparent escape of effluvium from the shaft."

Action of sulphurous acid.

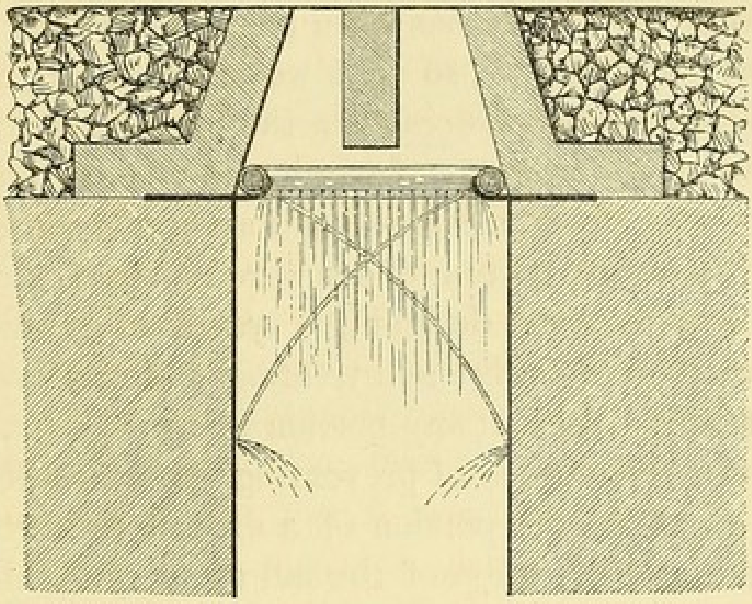
With regard to the action of sulphurous acid gas, in the words of Dr. Angus Smith, " it first deodorizes, but it gives off its oxygen easily, and acts as an oxidizer. It also acts as an acid, and dissolves animal matter. Its action is complex; it causes coughing, and it is in great quantities injurious to the lungs; how much in small quantities it is not known. It purifies the air from putrid matter, destroying that when in a state of vapour, as it destroys putrid and living bodies dissolved or in a liquid state, and it is therefore an excellent fumigator. How much it brings of other evils is an important question. It alters the air of towns entirely; every coal-burning town is compelled to breathe it." This gas, if present in excess, when escaping from a ventilator, would be very disagreeable to many persons on account of its sulphurous smell, and when gas is used at those periods of the day when there are in-currents into the sewer the diffusion of a large quantity of sulphurous acid gas would be attended with great inconvenience to the men who may be engaged within the sewers. There are great difficulties in applying the proper quantity of acid to manufacture gas for the destruction of gas. The gas, manufactured, itself becomes an impurity when present in excess, and if not present in sufficient quantity the sewer air would not have its poisonous properties destroyed. Neither sulphurous acid gas nor other gases have proved at present so efficient as charcoal, when properly applied, and moreover they are attended with considerably greater cost, and are by no means so easy of application.

Sulphurous acid may become an impurity.

Spray ventilator.

A spray of water has been suggested and used experimentally, in order to prevent the offensive effluvia escaping from sewer ventilators in London. Fig. 77 represents a section of the Patent ventilator of Mr. Edwin Rumbold. Mr. E. Rumbold.

Fig. 77.



It must not be lost sight of that the only way in which water could act in a ventilator is: 1st, in washing the sewer air, and probably carrying down any suspended matter; 2ndly, by absorbing the gaseous matter present; 3rd, by carrying the air downwards, or preventing its escape at a particular point. In this case, the sewer air, in all probability, would be sweeter for being washed, but the amount of foul air that would be absorbed by the spray of water would be insignificant, and while the spray will carry atmospheric air down with it, as well as the sewer air, and so produce dilution, and probably some oxidation, it is very doubtful if a system of this kind would act if universally adopted, for if every opening into a sewer is fitted with an appliance for carrying the sewer air back from the street level, what is to become of it, especially when natural forces are at work in the sewers to expel it? It cannot be overlooked that water in falling may carry down comparatively pure air into the sewage, and this air may be fouled in its passage

Principle of spray ventilator.

Effect of falling water.

through the sewage, so that when it escapes from the sewage it may become a source of impurity in the air of the sewers.*

Sewers need to be constructed with view to ventilation.

Under certain circumstances the ventilation of sewers cannot be properly carried out unless the system of sewers has been constructed with special reference to their ventilation. It has been pointed out that sewers may act as chimneys, so that warm sewer air may be transferred by the sewers from the lower to the higher portions of the system. In order to obviate the evils arising from the transference and accumulation of foul air in the higher portion of a sewered district, measures must be taken, when designing a system of sewers, so as to ensure the discharge and treatment of the sewer air as fast as it arises in any portion of the system. The mode usually adopted of preventing the transference of sewer gas from one portion of a district to another, is to take a small portion of the fall at every manhole or ventilator, forming, as it were, a step, which breaks the sewer into short lengths, so that the gas found in one length of sewer is allowed to escape at the upper portion of each separate section, instead of traversing the whole length of the sewers from the lowest to the highest points. Figs. 78 and 79 illustrate the principle involved in the system. Fig. 78 represents a branch sewer discharging into the main sewer at A. This branch sewer may be of indefinite length, and is drawn with one uninterrupted fall, therefore the gases generated would naturally tend to ascend towards B, or be driven upwards in that direction by any increase in the flow of the sewage causing the sewer air to be compressed. If a ventilator is inserted at A, and another at B, there are certain times when air would enter at A and rush up the sewer to B with a velocity determinable by the altitude of B above A, and even supposing that there is an opening midway between the two points, or at C, the gases moving from A in the

Mode adopted to prevent sewer air travelling through the sewers of a district.

* Vide p. 374.

direction of B, having a given velocity, are moving in the same plane as the line of sewer, therefore they may leap across the opening at C and still continue to ascend the sewer and to accumulate in the neighbourhood of B.

Fig. 78.

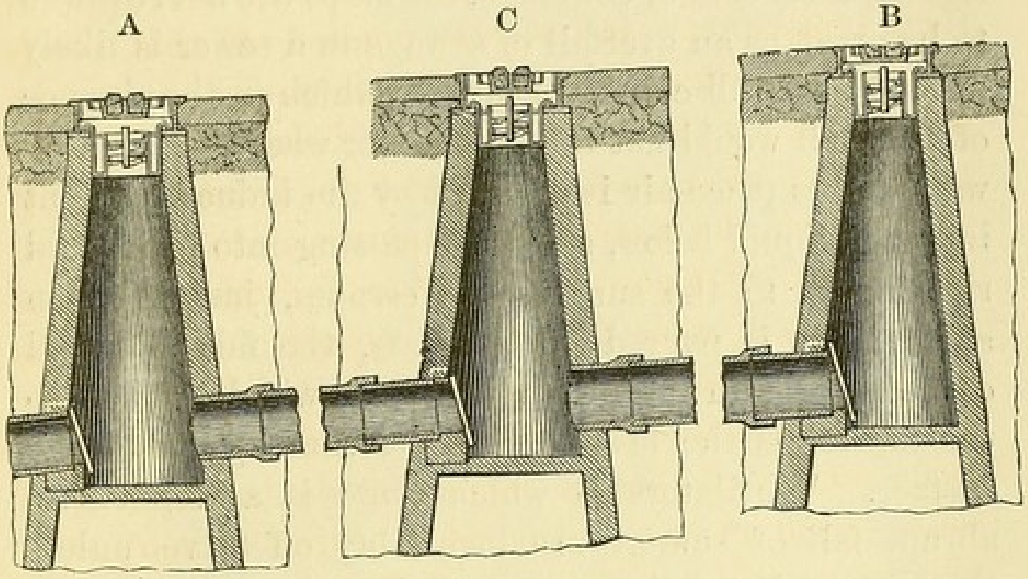
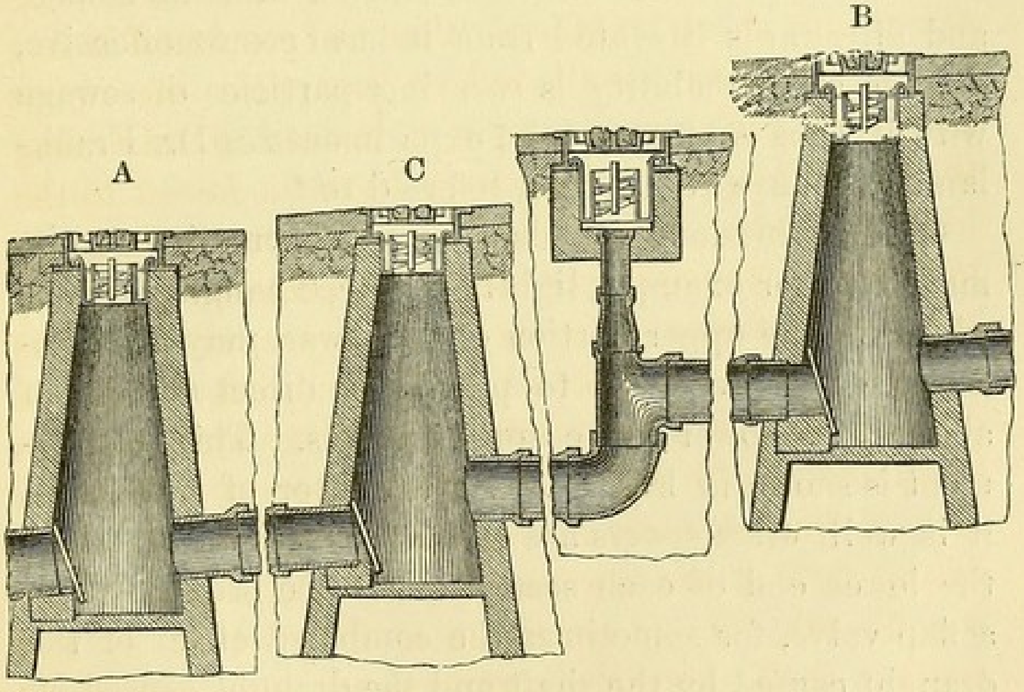


Fig. 79.



Sewers constructed in steps.

To remedy this defect and prevent the undue accumulation or transfer of sewer air, the sewers are broken up into a series of steps, as shown in Fig. 79. The gases, therefore, that are found at A or between A and C have a tendency to be discharged at C, because the sewer above C is not in the same plane as the sewer below C, and the gases, consequently, are directed out of the line of plane in which they were travelling, and are necessarily compelled to escape at C.

Waterfalls in sewers lead to discharge of foul air.

Steps in sewers tend to break up the system, but in designing a scheme of sewerage, the steps are not required to be great, as an overfall of sewage in a sewer is likely to lead to the discharge of foul air which in the absence of this fall would not take place, for whenever a fall of water takes place air is dragged by the induced current into the liquid below, and after passing into the liquid rises again to the surface and escapes, just as when ale or beer is poured into a glass, the falling liquid carries air with it into the glass, which rising to the top forms the head or bubbles that appear on the surface. Ventilators in which there is a step or an abrupt fall of sewage are invariably offensive unless they are effectually protected by charcoal screens, showing that the air which is carried into the sewage and afterwards liberated from it has become offensive, and in all probability is carrying particles of sewage with it, thus confirming the experiments of Dr. Frankland that have before been referred to.*

Reason why some ventilators offensive.

Flap valves used in connection with ventilation.

Other provisions are also necessary sometimes to be made; as, for example, lightly-balanced hanging valves, which fill the upper portion of the sewer, may be introduced with advantage to prevent a direct current of air from the lower to the upper districts. This arrangement is shown in Fig. 80. As a matter of precaution it is well, when sewers are constructed with steps, that the lower end of each section should be provided with a flap valve, for sometimes the combined effect of the draught caused by the shaft and the draught caused by the upper portion of the sewer may be such as to lead the gases onward up the sewer.

Balance valve.

In Figs. 81 and 82 is shown a new balance valve invented by the author and manufactured by Messrs. Henry Doulton and Co. Fig. 81 represents a front

* Vide p. 319.

Fig. 80.

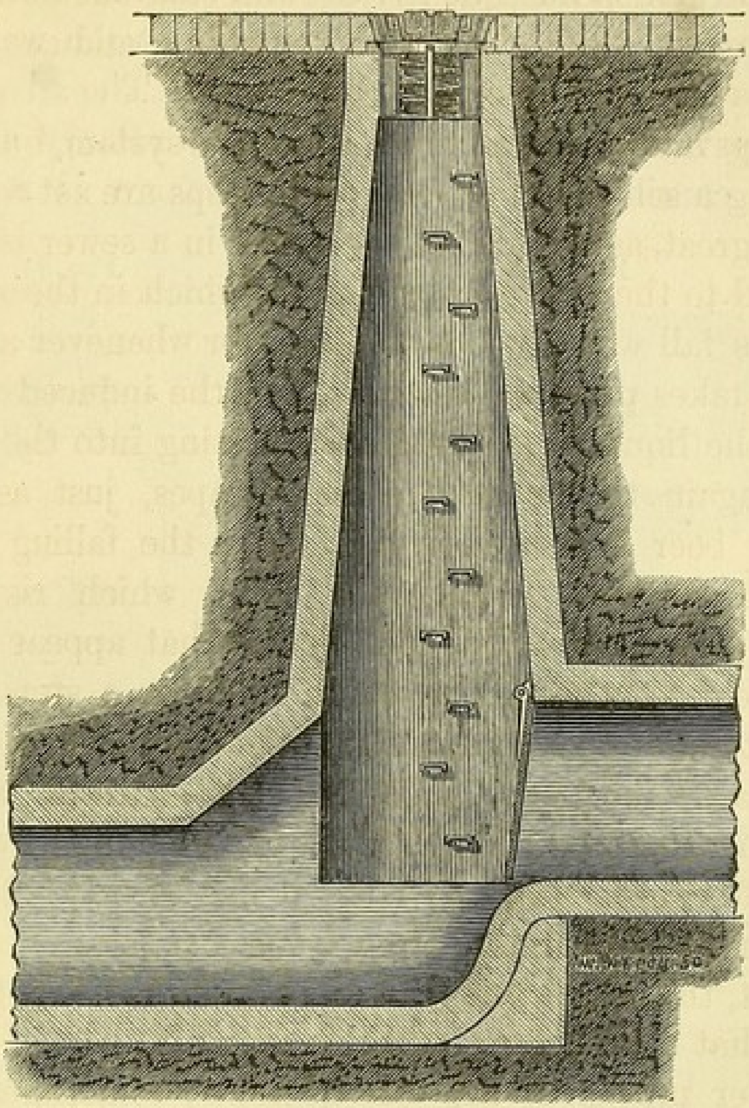


Fig. 81.

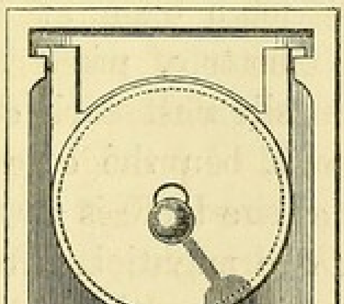
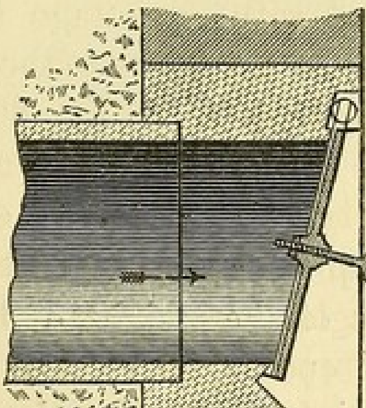


Fig. 82.



elevation, and Fig. 82 is a section of the valve. The flap of this valve is hung at the top and can be balanced to any degree by merely screwing in or out the weighted spindle fixed in the centre of the flap. The advantage of this valve, as compared with an ordinary shackle valve, consists in the fact that no force is required

Advantages of balanced valve.

Fig. 83.

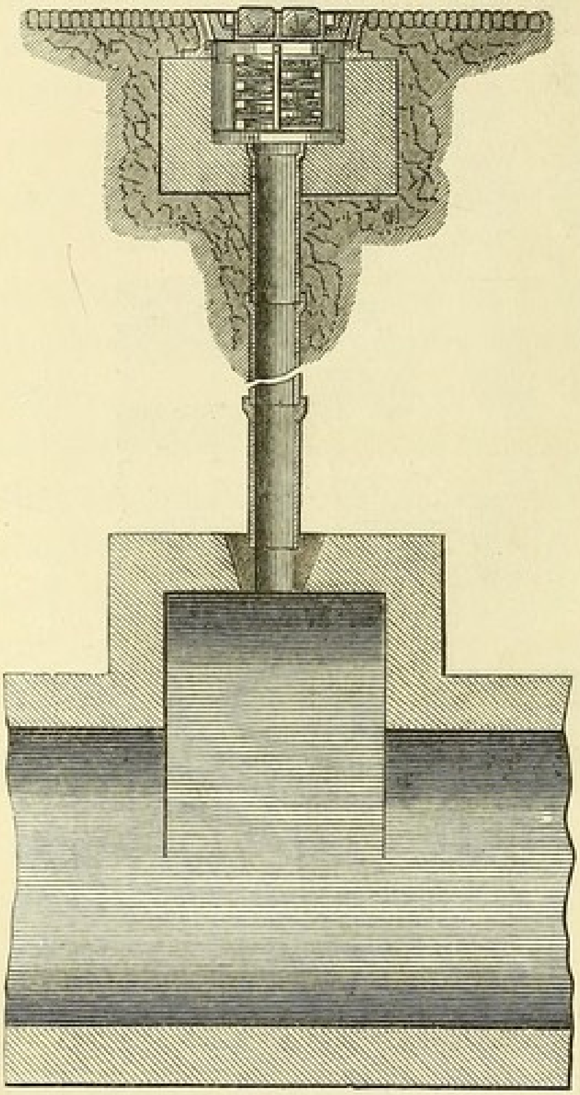
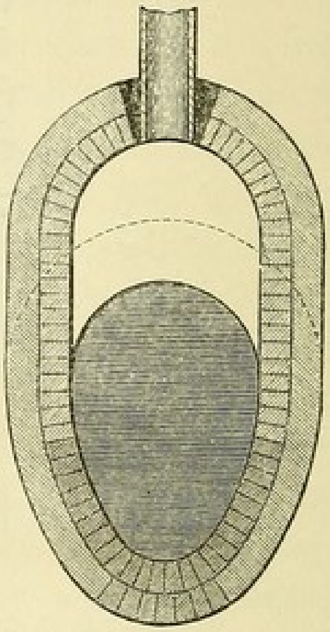


Fig. 84.

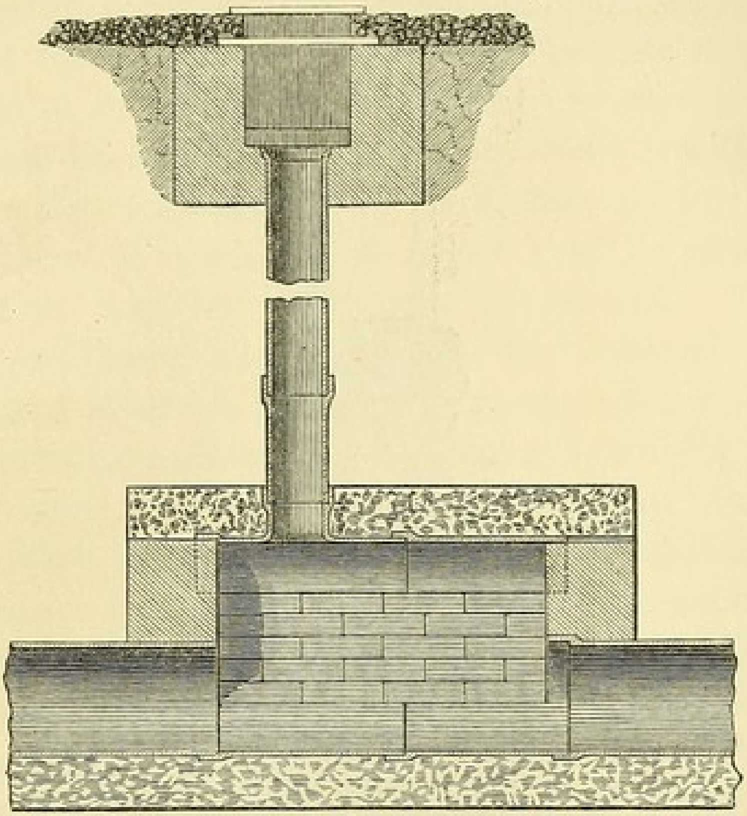


to open it, and no lodgment of solids can take place behind it, for the valve may always be so adjusted as to remain open at the bottom, when the slightest back current of air or liquid would close it. In the case of the shackle and tankard valve, of course there is always part of the weight of the flap to be moved before it will open. In sewers of flat inclination the author has introduced chambers, in which air may accumulate, and discharge through a shaft ascending from the upper part of the chamber, as illustrated in Figs. 83, 84, and 85.

Ventilation of sewers of small gradient.

Fig. 83 represents the longitudinal section of a ventilating chamber for a brick sewer, Fig. 84 the transverse section of the same, and Fig. 85 represents the longitudinal section of a ventilating chamber formed

Fig. 85.



in a pipe sewer. In this case the top and bottom of the chamber are formed of split earthenware pipes covered with concrete, and the sides are constructed of brickwork. These chambers in practice are found equivalent to the breaking up of the system of sewers as before described.

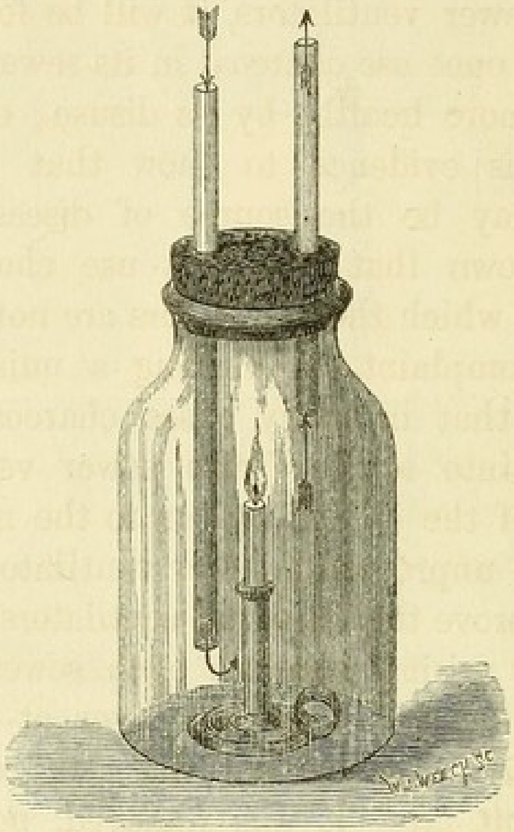
It has been already stated that charcoal is a most valuable and efficient agent for absorbing sewer air, therefore no system of sewer ventilation is complete without an arrangement for containing it. Various forms of charcoal ventilators have from time to time been introduced. In using charcoal, it should, however, be borne in mind that whenever it is employed it should be so arranged as not to obstruct natural ventilation, and it should be kept as dry as possible, for it loses its power if it gets completely saturated with water. All those ventilators in which charcoal is placed in mass, so as to completely fill the aperture provided for venti-

Forms of charcoal sewer ventilators.

lation greatly interfere with the natural ventilation of the sewers, as anyone may ascertain for themselves if they will but make a single experiment with an ordinary bottle, such as is used in experiments on ventilation. The experiment is illustrated in Fig. 86,

Experiment on natural ventilation.

Fig. 86.



which represents a wide-mouthed bottle having two tubes inserted in the cork; a light being placed within the bottle, a current of air is set up down one tube and up the other, as shown by the arrows. Now if a perforated tray containing a thin layer of charcoal is placed on the top of either of the tubes, ventilation is obstructed, and the lighted candle soon goes out. So it is with charcoal used in mass in sewer ventilators. Moreover, charcoal used in mass is liable to concrete together, and the pores and space between the pieces get stopped up with the dust blown and drawn into the open ventilators, so that in course of time the way through the charcoal is blocked, and ventilation completely stopped. Then the air of the sewers is corked up, and may acquire such a degree of

Drawback to the employing charcoal in mass.

tension as to be attended with inconvenience if not with danger.

The alleged evils arising from the choking of sewer ventilators with charcoal have been the means of bringing into disuse this most valuable material for destroying the organic compounds of sewer air. If we inquire into the facts in connection with the use and disuse of charcoal in sewer ventilators, it will be found that no town that did once use charcoal in its sewer ventilators has become more healthy by its disuse; on the other hand, there is evidence to show that unprotected ventilators may be the source of disease.* There is not any town that does not use charcoal in its ventilators, in which the ventilators are not the subject of constant complaint, as creating a nuisance. It is well known that in many cases charcoal has been reintroduced into some of the sewer ventilators, in consequence of the complaints as to the nuisance and danger of the unprotected sewer ventilators. Experience goes to prove that charcoal ventilators will prevent any nuisance arising from an open sewer ventilator. During an epidemic of typhoid fever at Croydon, in 1875 and 1876, the charcoal was removed from the ventilators, but after it was removed, no abatement occurred in the fever, which continued until the springs had risen in the early part of the year 1876, and then, and not till then, did the epidemic disappear. The experience of fever again at the usual period in the rise of the water in the springs in 1876 and 1877, shows that the cause is not in sewer air; but, on the other hand, since the removal of the charcoal from the sewer ventilators, Croydon has not been more healthy; in fact, there have been a greater number of deaths from diphtheria, croup, and other kindred diseases in the district since the charcoal was removed from the ventilators than was ever known at any previous period. Table No. 60 shows this very clearly, and this increased death rate

Inquiry into use and disuse of charcoal.

Consequences attending removal of charcoal from ventilators at Croydon.

Increase of diphtheria and croup at Croydon.

* Vide p. 359.

TABLE No. 60.—Showing the DEATHS from DIPHTHERIA and CROUP in CROYDON between the years 1869 and 1877.

Year.	Estimated Population of District.	No. of Deaths from Diphtheria.	Diphtheria Death Rate per 1000.	No. of Deaths from Croup.	Croup Death Rate per 1000.
1869	51,755	5	·096	11	·212
1870	54,075	3	·055	9	·166
1871	55,663	0	·000	5	·089
1872	56,356	4	·070	2	·035
1873	57,099	8	·141	12	·210
1874	60,792	4	·065	13	·213
1875	63,000	7	·111	5	·079
1876	64,500	26	·403	19	·294
1877	66,000	43	·651	24	·363

from these diseases has been combined with a greater number of complaints of the nuisance of the open ventilators. In fact, since the removal of the charcoal more complaints have been made in a single week of the nuisance of ventilators than occurred in the whole previous ten years, during which time the charcoal was in use. Here then we see nuisance increased, and no sanitary benefit accruing, simply because somebody has said that charcoal, however good in itself, impedes ventilation, and the consequence has been that, at Croydon as elsewhere, charcoal has again been put into some of the ventilators complained of as creating a nuisance, as the only means of remedying the evil. Sir J. W. Bazalgette, in his Report on the Ventilation of the Sewers of London, stated that "the experiments already made appear to me to have given results sufficiently favourable to warrant my recommending that charcoal ventilators be fitted to such ventilating shafts as may be the source of annoyance." It ought here to be observed that the full benefit of charcoal cannot be secured unless all the ventilators are filled with it, as the effect of air passing over charcoal into the sewer is to carry with it an increase of oxygen in a nascent form, ready to oxidize the oxidizable matter present in the air of the sewer. If, however, air can enter the sewers without passing over the charcoal, the effect charcoal produces on the entering air is not

Complaints of nuisance at Croydon.

Sir J. W. Bazalgette's recommendation of charcoal in sewer ventilators.

To get full benefit all the ventilators must be supplied with it.

secured. Moreover, the in-currents of air into a sewer over the charcoal freshen the material, and thus secure its constant activity; if any air enter the sewers at openings other than those protected with charcoal, the revivifying of the charcoal itself is not so readily or perfectly secured. In the construction of all sewer ventilators provision should be made for dealing with surface water, rainfall, and the water produced by the condensation of moist vapour. So long as charcoal is brought into contact with the moist air of sewers it will retain its efficiency, but the moment it becomes completely saturated with water the condensed oxygen within its pores is driven out, and it ceases to absorb or destroy the noxious gases. Wherever ventilators are placed in the surface of streets (as all streets have, more or less, a fall longitudinally), in time of rain the ventilator often becomes the receptacle for the water flowing from a very large area; as for example, the water flowing downhill (especially in the case of a macadamized road) follows the ruts made by carriage wheels, which if not allowed a free point of escape into the sewers would soon fill the receptacle provided for it, and then overflow and destroy the charcoal. Lieut.-Colonel Haywood and the late Dr. Letheby stated, in their Report to the City authorities, that "if the situation of the ventilators could be so arranged as to keep the charcoal dry, we are of opinion that it would not require renewal more frequently than once a year,* but under existing circumstances many of them require to be changed not less than once a month." It has been proposed to prevent the water entering the ventilators by raising them above the general level of the road, but this plan is attended with inconvenience, and only partially meets the difficulty. Many attempts have been made to get rid of this water without injuring the charcoal, but most of such attempts have not been very successful, as the channel provided for the escape of the water also allows of the escape of the sewer air, or it is

Influence of air entering the sewer on the charcoal.

Charcoal is destroyed by getting wet.

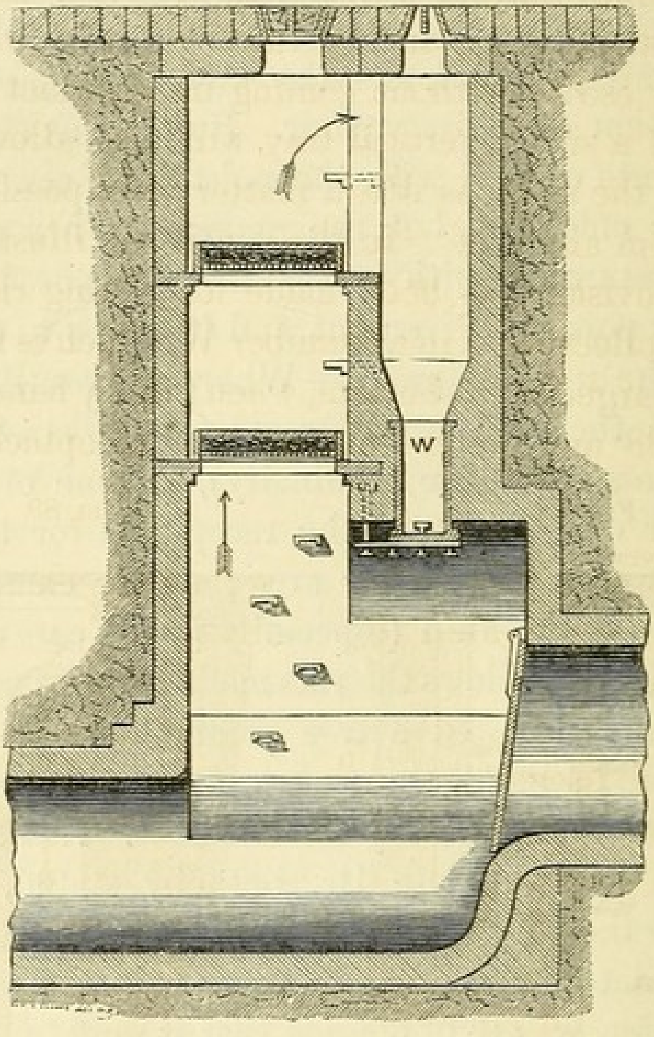
Duration of charcoal if kept dry.

Mode of preserving charcoal from wet.

* Vide, pp. 360, 366.

liable to get stopped up, and then the charcoal is destroyed by the overflow, just as if no channel had been provided for its escape. In the ventilator illustrated in Fig. 87 the charcoal is placed in trays which

Fig. 87.



Objections to forms of charcoal ventilators.

completely fill the shaft of the manhole. The introduction of trays of charcoal into manholes, as here illustrated, is objectionable; the charcoal being placed in mass interferes with the natural ventilation; especially when the pores get clogged with dust or dirt drawn in from the street. Moreover, as these trays cannot be made to fit tightly round the sides of the manhole, sewer gases may pass without being brought into contact with the materials used for its destruction. This plan is also attended with much additional labour in renewing the material, or removing the trays from the manhole when men are required to enter the sewers. Fig. 88 shows a mode in which the charcoal is arranged vertically; it is still used in mass. The objection to this plan is, that whenever charcoal is placed in vertical trays, unless jammed in its position so tightly as to obstruct natural ventilation, in course of time it settles down, leaving an aperture over it by which the gases may escape without coming into contact with it. The use of a single vertical tray will also allow gas to escape at the sides, as it is a matter of impossibility to render them air-tight. In the ventilator illustrated in Fig. 87 provision has been made for getting rid of the water by collecting it in a chamber W, which is intended to be discharged at the bottom, when full, by hand labour. In Fig. 88 any water entering the receptacle W is

Effect of charcoal in vertical trays.

Fig. 88.

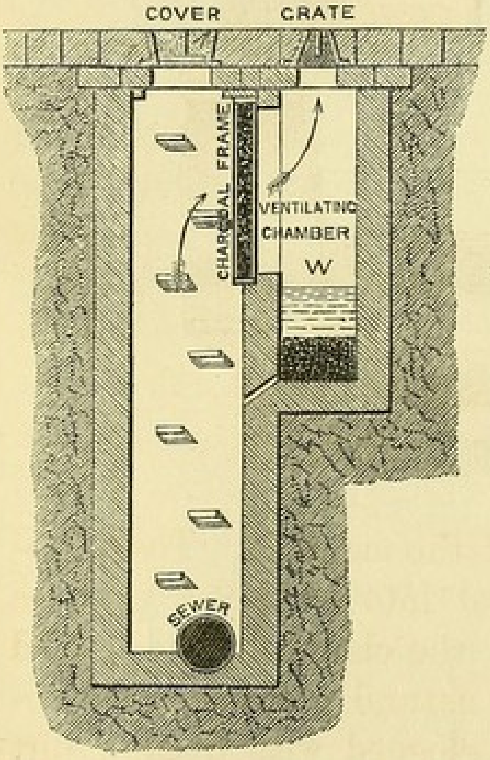
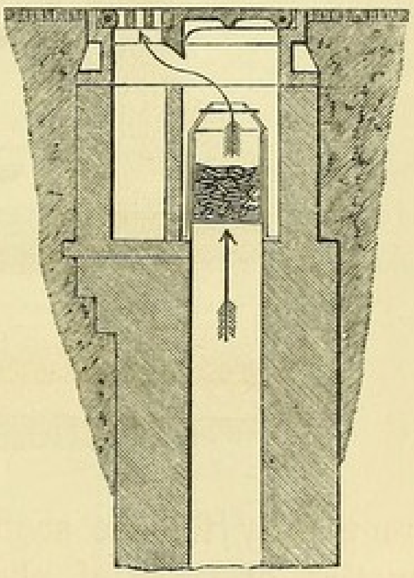


Fig. 89.



intended to filter through the filtering medium at the bottom of the shaft to the sewer, but though such a filter as this is at first very porous, admitting of the escape of gas, in the course of time it becomes choked from the sludge entering by the open granting, so that when a large amount of rainfall is passed into the receptacle it does not flow away, but overflows and wets the charcoal. Fig. 89 illustrates an arrangement adopted by the Metropolitan Board of Works for experimental purposes. It consists of a single tray, containing charcoal placed over a vertical pipe leading directly from

Metropolitan Board experimental ventilator.

FIG. 90.

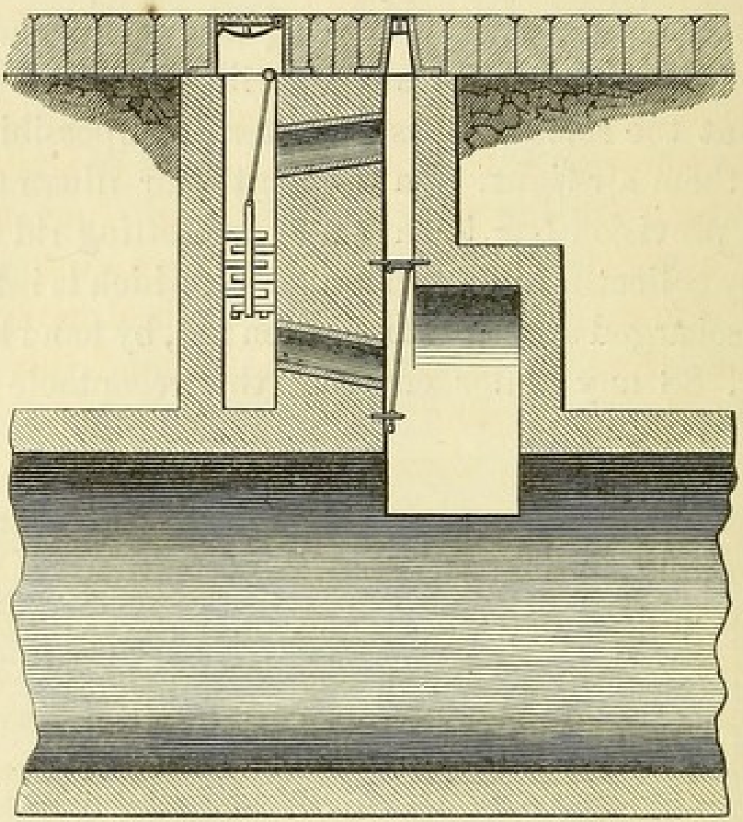
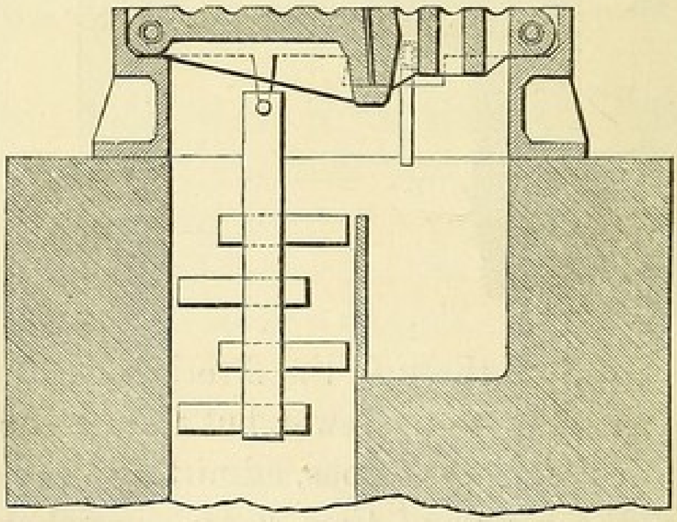


FIG. 91.



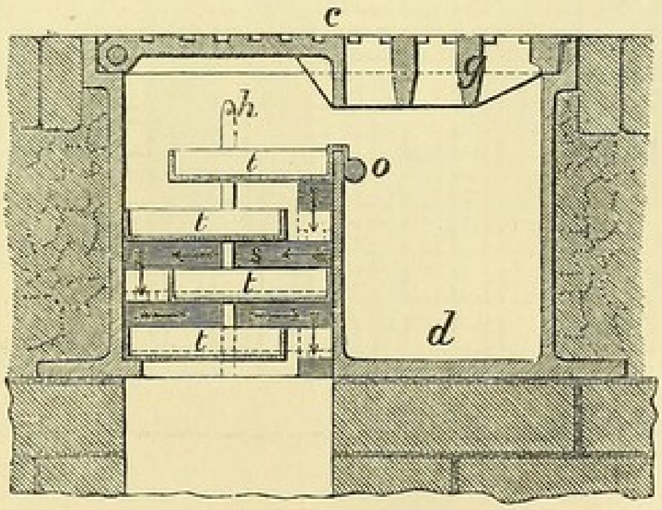
the crown of the sewer. The charcoal in this case is placed in mass, and no provision is made for getting rid of surface water. Figs. 90 and 91 illustrate the arrangement adopted in some of the metropolitan districts for the ventilation of the sewers. Fig. 90 represents the system adopted in the City sewers. The trays containing the charcoal do not fill the entire aperture of the ventilating shaft, but are laid zig-zag, so that there is an open space through the ventilator. This arrangement is decidedly superior to any system in which the charcoal is laid in mass, as an opening is left communicating with the atmosphere on one side and with the sewer on the other. The charcoal is placed in trays, which are inserted in the shaft of the ventilator in such a position that the gas is brought into contact with it, while no pressure can be exercised in expelling the gases from the sewers. The faults of this system are that the ventilating trays cannot be made to fit tightly at the sides, therefore a small amount of gas can escape without oxidation by the sides of the trays. The dirt-box, moreover, is so small that in times of heavy rainfall it is quite inadequate, and speedily gets filled with water, which, overflowing, destroys the charcoal. The author, having used this description of ventilator very extensively, and finding that the

City sewers charcoal ventilator.

Faults of this ventilator.

Latham's improved ventilator.

FIG. 92.



charcoal so speedily got destroyed, introduced an improvement upon it, which is illustrated in Figs. 92, 93, Description of improved ventilator.

and 94.* The improvement consists of an arrangement by which the water, after filling the dirt-box, can be passed away to the sewers in such a manner as not

Fig. 93.

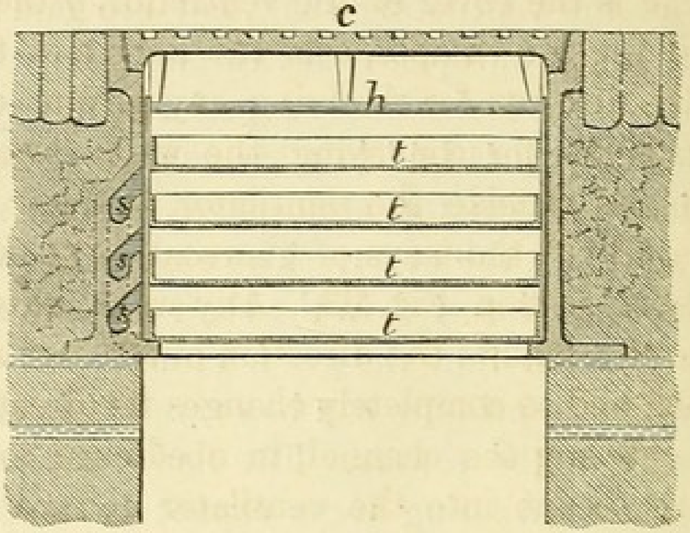
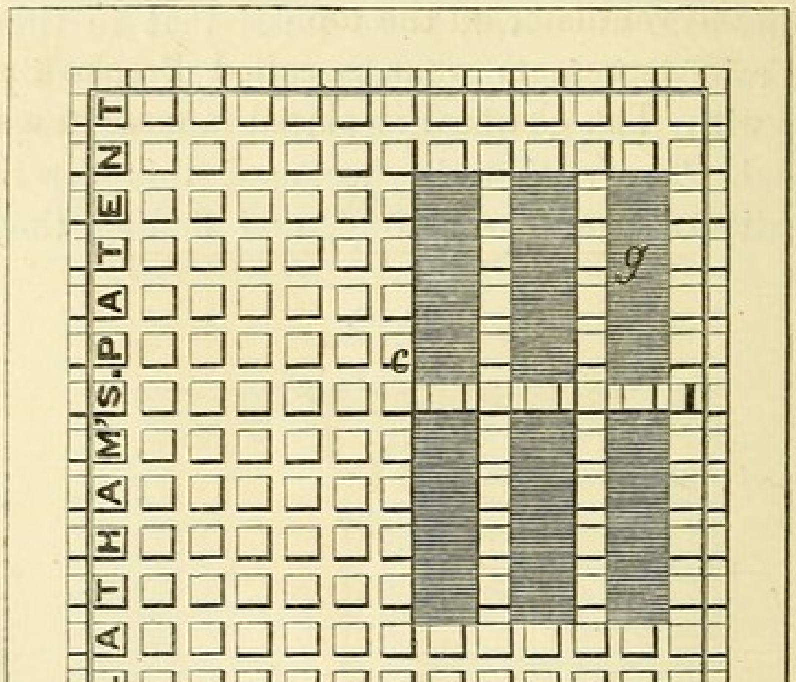


Fig. 94.



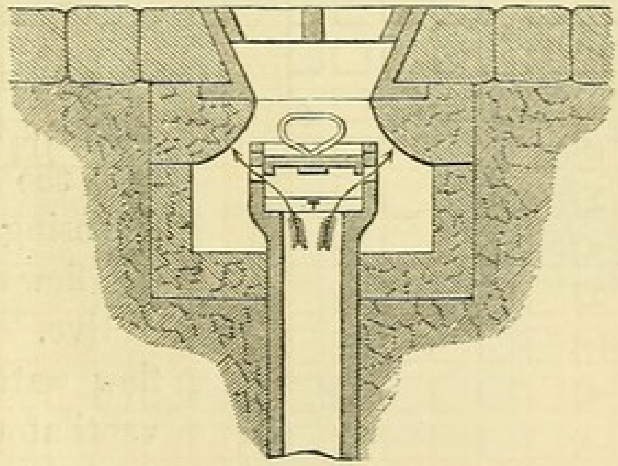
to destroy the charcoal, and at the same time the channel for the escape of the water is so formed as to

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

prevent the escape of the gas without its being brought into contact with the charcoal. Fig. 92 represents a section through the improved ventilator. *d* is the dirt-box, *t* the trays containing the charcoal, *h* the handle, by which the trays are raised or lowered when required, *c* is the cover of the ventilator, *g* the grating by which the air escapes, *o* is the mouth of the overflow in the dirt-box for receiving any surplus of water, *s* the troughs for conveying the water away; they are arranged outside the ventilator, and are open to the underside of the trays of charcoal, as shown in the longitudinal section Fig. 93. Any water entering by the opening *o* follows the direction of the arrows shown in Fig. 92, and so completely changes its direction that any gas entering the channel, in obedience to natural laws, must escape into the ventilator and be brought into contact with the charcoal, while the water flows away without touching the charcoal. Fig. 94 shows the plan of the ventilator on the top.

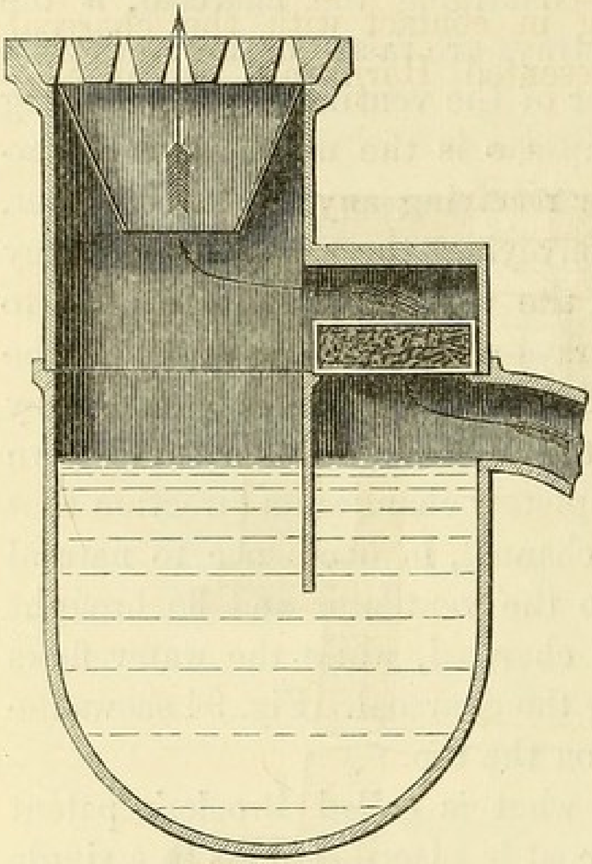
Fig. 95 represents what is called Brooke's patent ventilator. The charcoal is placed in mass in a single Brooke's ventilator.

Fig. 95.



tray T, placed upon the top of the ventilating shaft in a manner analogous to that shown in Fig. 89. No provision is made for getting rid of any water which may enter the open ventilator, which is left to soak away, or overflow and destroy the charcoal. Messrs. Brooke have also another form of ventilator, which is used in combination with a street gully, and is illustrated in Fig. 96.

Fig. 96.

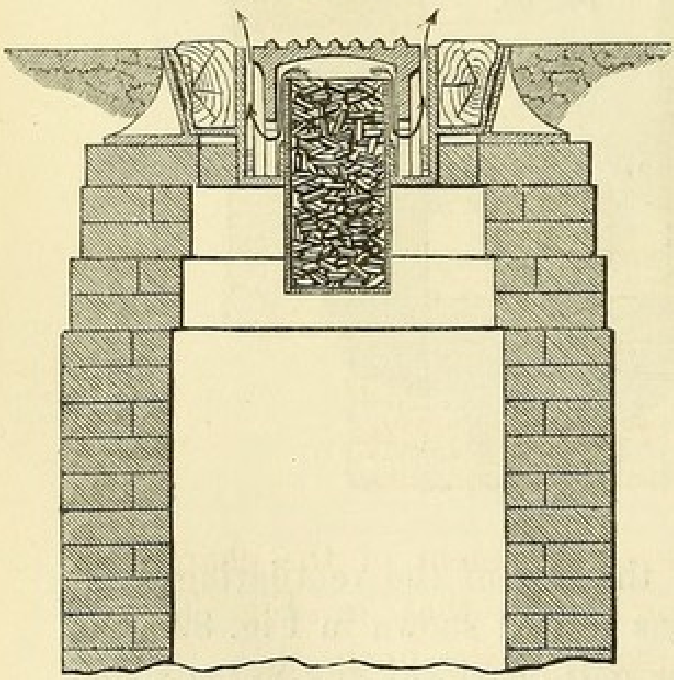


Mr. A. Jacob's patent charcoal sewer ventilator is represented in Fig. 97.

This ventilator is extremely compact in form, and is intended to be used in combination with a manhole, the charcoal arrangement forming part of the manhole cover. The charcoal is placed in a perforated cylinder in mass. The receptacle for the dust, dirt, and water is very small, so that the apertures provided for ventilation are liable to be speedily choked with dust or mud, and the means of disposing of the overflow water is defective. The overflow water in this ventilator is intended to be got rid of by small syphon pipes dipping into the dirt-box, but as these pipes will get speedily choked with mud, or may be frozen up in winter, they will soon become

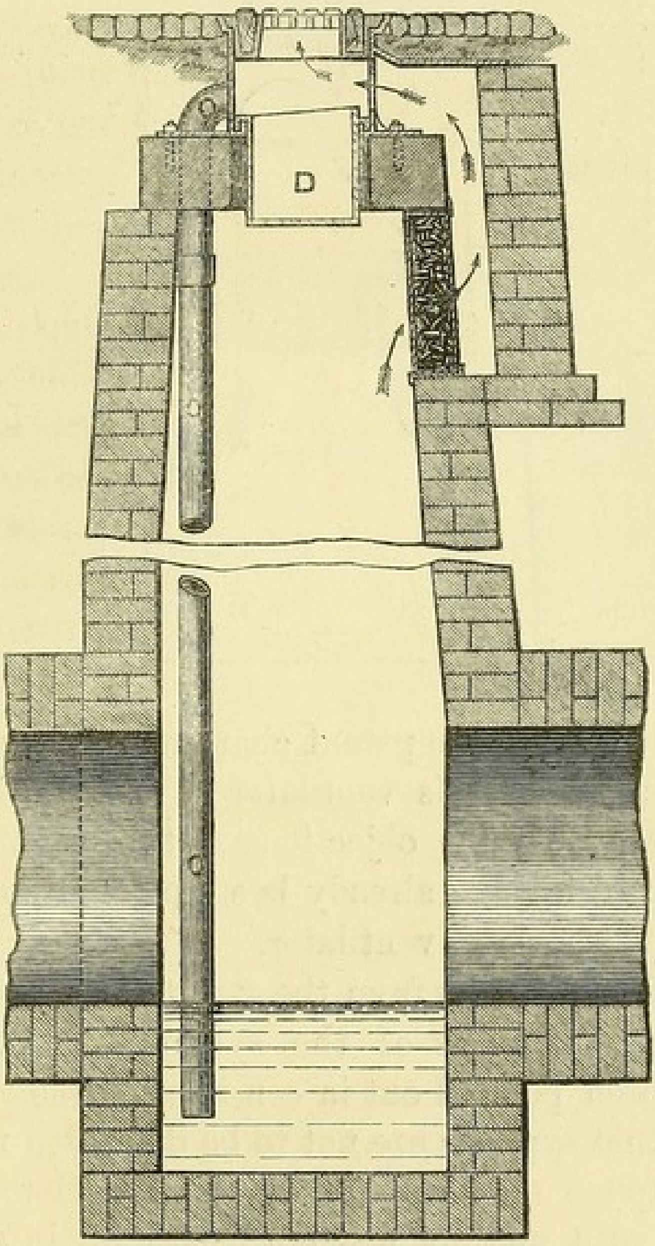
Jacob's ventilator.

Fig. 97.



inoperative, and in the summer, should the dirt-box be emptied and the ventilator is not kept filled with water to seal the syphons, sewer gas will escape by them without coming in contact with the charcoal. In Fig. 98 is represented Harrison's patent char- Harrison's ventilator.

Fig. 98.

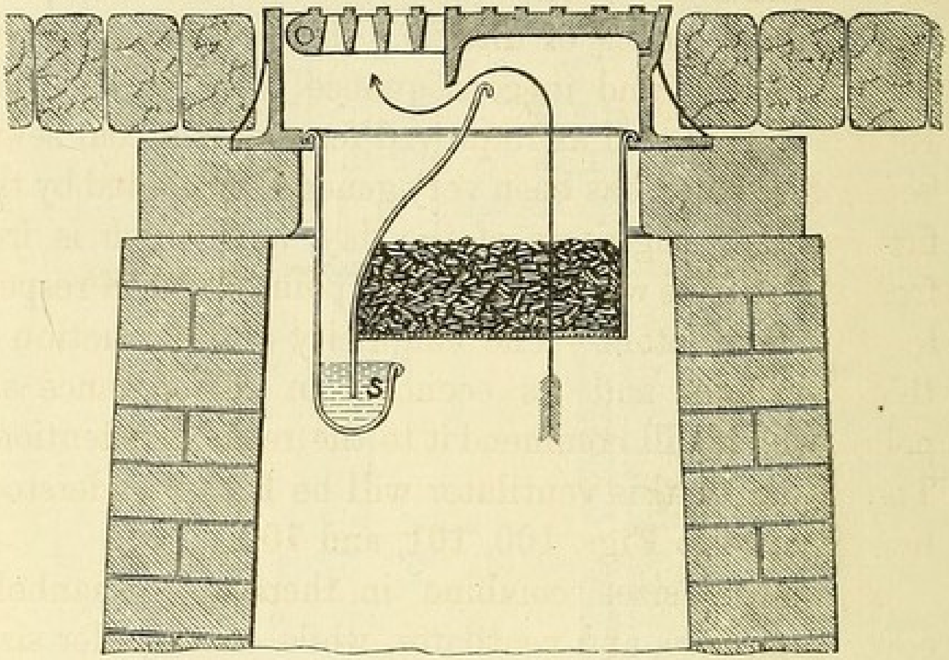


coal ventilator. The arrangement of the charcoal in this ventilator is similar to that in Fig. 88, and the observations already made upon that form of ventilator equally apply to this form.* The improvement in this ventilator consists of a movable dirt-

* Vide p. 383.

box D, with an overflow pipe from the top carried down to the bottom of the manhole, where it is made to dip into a pool of sewage, so that there is always an amount of sewage equal to the area of the descending pipe which is open to the street. In Fig. 99 is

Fig. 99.



Hildred's ventilator.

represented Hildred's patent charcoal sewer ventilator. The charcoal in this ventilator is placed in mass,* and consequently the objections to the use of charcoal in mass which have already been pointed out equally apply to this form of ventilator.

The overflow water from the streets is intended to be got rid of by means of the syphon trap S. It has already been pointed out in considering the ventilator, Fig. 97, that syphons are not to be depended upon, and if the syphon arrangement of this ventilator did not block up with mud, or was not frozen up in winter, in summer it would become unsealed from the evaporation of the water in the trap, unless it was constantly renewed.

In Fulton's patent charcoal ventilator, the charcoal is simply placed in a horizontal tray the top of which is

* Vide p. 382.

covered, the cover having openings at the side to let out the air, which prevents the water and dust from the street falling on to the top of the charcoal, but no provision is made to carry away any water that may enter the ventilator.

Fulton's patent charcoal sewer ventilator.

The imperfections in the various forms of charcoal sewer ventilators which have been brought into operation was the means of directing the author's attention to the subject, and in consequence early in the year 1869 he introduced an improved form of charcoal sewer ventilator, which has been very generally adopted by the first sanitary engineers of the day, and which is free from the defects which have been pointed out in respect to other ventilators. The simplicity of construction of this ventilator and its economy in maintenance are points which will commend it to the reader's attention.* The action of this ventilator will be better understood by reference to Figs. 100, 101, and 102.

Latham's patent spiral ventilator.

The larger sizes combine in themselves manhole-cover, lamphole, and ventilator, while the smaller sizes fulfil the two last offices. Each of the large ventilators consists of four parts :—

Description of ventilator.

1st. The frame *a*, for receiving the cover, and on the bottom of which hangs the dirt-box and charcoal ventilator. These frames may be made either circular or square, as shown in Fig. 102; the square form is best for paved streets or for square shafts, the circular for macadamized roads.

2nd. The cover *c*, the centre part of which is solid, so as to form an efficient cover for the charcoal and protect it from rain or the water used in street watering. *g* is the open grating in the cover by which air escapes or is drawn into the sewers. The openings of this grating are arranged concentrically, as shown in Fig. 102, and are formed with the aperture wider below than at the street level, so that mud is not likely to

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

adhere, or if it does is soon removed and falls directly into the dirt-box immediately below the grating. Fig. 102 shows the cover, which in the illustration is shown

Latham's spiral ventilator.

Fig. 100.

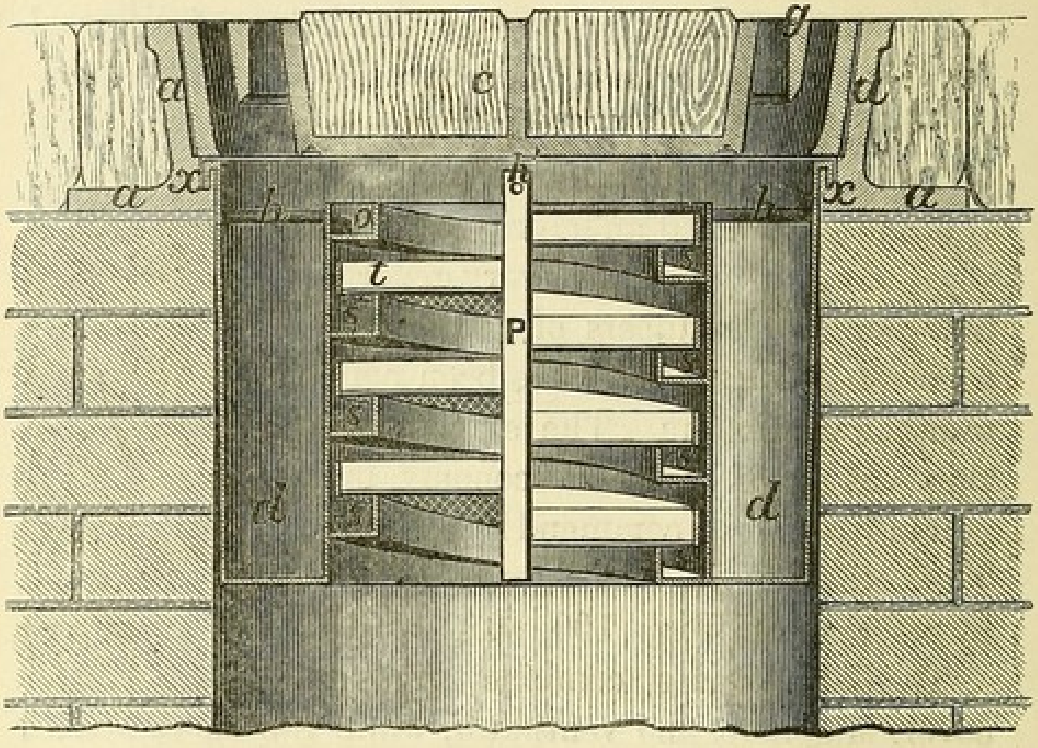
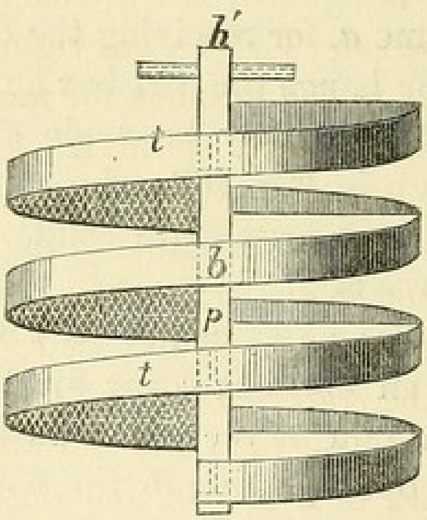


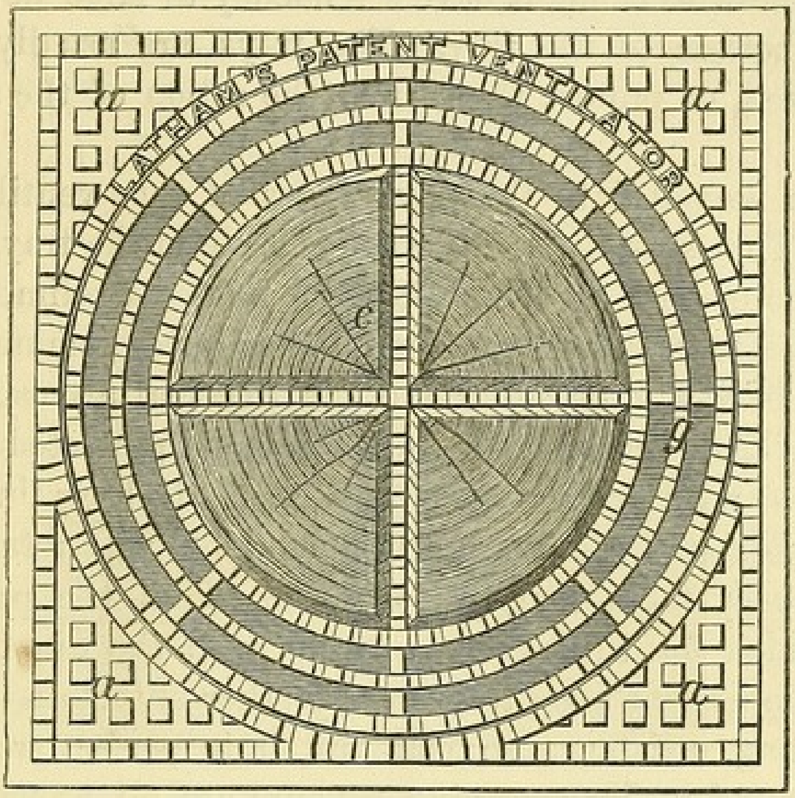
Fig. 101.



filled in with wooden blocks (placed endways of the grain) for deadening the sound and giving an efficient foothold for horses. The covers, however, may be filled with any other suitable material, such as stone, concrete, or asphalte.

3rd. The dirt-box *d* hangs in a groove *x*, made in the lower part of the frame *a*. The dirt-box is circular on plan, and the groove *x* is intended to be filled with

Fig. 102.



fine sand. The weight of the dirt-box and ventilator pressing into the sand forms a gas-tight joint. *h h* are handles attached to the dirt-box for raising or lowering it. *s* represents an open spiral trough which forms part of the dirt-box, and which is used for conveying away the overflow water from the dirt-box to the sewer. *o* is a slot in the side of the dirt-box, communicating with the upper portion of the spiral trough, through which the water enters the trough.

4th. The spiral trays *t*, for containing the charcoal. The tray is shown in Fig. 101, and when the ventilator is in use the tray, after being filled with charcoal, is screwed into the ventilator over the spiral trough *s*, by means of the handle *h*. Each tray consists of a central shaft *p*, which is square, and out of every face project arms of T-iron, as shown by the dotted lines at *b*, Fig. 101. These arms are attached at the extremities by a strip of iron coiled spirally, and the bottom of the trays is filled in with network. The arms divide the whole tray into so many compartments for retaining the charcoal, which in consequence is kept in position, or otherwise it might have a tendency to slide down to the bottom of the tray. The trays are usually galvanized, to protect them from the action of the sewer air.

Advantages of Latham's ventilator.

To recapitulate the advantages of this ventilator: 1st. That should the charcoal concrete in the tray, or if its pores are stopped with dust, no impediment is offered to ventilation, as there exists a free communication between the sewer and the external atmosphere. 2nd. That the charcoal is completely protected from rain or water entering the ventilator or leaking through the joints of the cover, consequently it will retain its efficiency for a long period. 3rd. That the passage provided for the overflow water from the dirt-box is not dependent upon traps or any other uncertain device needing assistance to maintain it in perfect working order. 4th. The escaping vapours are all brought in contact with the charcoal, it being impossible for any to escape by the sides of the tray or in any other way.

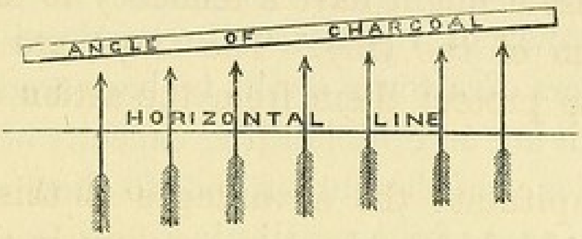
Action of Latham's ventilator.

The action of the ventilator may be explained as follows:—The spiral tray having been filled with charcoal broken the size of filbert nuts and screwed into the dirt-box, and the cover being placed in position, any mud or dust passing through the open grating will fall directly into the dirt-box. Any water entering at the grating would first fill the dirt-box, but when it had risen as high as the slot *o*, communicating with the upper portion of the spiral trough, it would overflow by this channel passing under the trays of charcoal to the sewer. The gases ascending from the sewer, in obedience to well-known laws, have always a constant tendency to ascend, and as the charcoal of the spiral tray is laid at an angle slightly diverging from the horizontal, the

Arrangement of charcoal.

gases impinge upon the charcoal at every point of their ascent, as will be seen by reference to Fig. 103, which shows the angle at which the charcoal trays are placed;

Fig. 103.



the arrows show the direction of the gases upon the trays of charcoal. Any gases ascending by the spiral trough for conveying away the overflow water, are brought in contact with the charcoal just the same as if they ascended by any other part of the apparatus. In this ventilator if the trays do not fit tightly at the side of the chamber no escape of gas will arise, as the trough for conveying away the overflow water projects into the ventilator, and any gas escaping by the side of the tray will be thrown against the projecting trough above, and so into the mass of charcoal. The circular form of the passage through the ventilator, moreover, causes the gases to move by a series of deflections, all of which tend to bring it more intimately in contact with the charcoal, and the trays all being perforated there is nothing to interfere with the ready absorption of the gas by the charcoal. An advantage of this ventilator consists in the fact that the tray of charcoal has to be screwed into the ventilator, and consequently it cannot be overfilled so as to obstruct ventilation. It has already been mentioned that the larger sizes of these ventilators combine a manhole-cover, lamphole, and ventilator, for by removing the cover and withdrawing the charcoal it forms a lamphole; by further withdrawing the dirt-box it becomes a manhole. The arrangement of having each part separately movable has its advantages, as the charcoal and dirt cannot get mixed. The dirt-box can be speedily and easily

Trays not required to fit tightly.

Advantages of circular passage.

Advantage of spiral tray.

Advantages of movable parts.

emptied by removing and capsizing it. The apparatus is easily fixed, and is economical in cost, as a much smaller amount of brickwork is required when it is used in connection with a manhole than is required in some other forms of sewer ventilator.

Number of ventilators to be provided.

The number of ventilators to be provided for the public sewers of a town ought to bear a constant ratio to the receiving and discharging capacity of the sewers. The experience of the author goes to show that the sum total of the area of the ventilating gratings should equal the discharging capacity of the sewers; the discharge from the ventilators should be computed as taking place under a pressure not exceeding one-tenth of an inch head of water. The ventilators should be placed closer together in the lower parts of a district, and the space between them may be somewhat increased in the upper part of the district. In no case in which houses are connected with the sewers should the distance between ventilators be more than 200 yards.

Position of ventilators.

Duration of charcoal.

As to the duration of the charcoal in sewer ventilators, the late Dr. Letheby and Lieut.-Colonel Haywood considered that the charcoal would last for twelve months if kept perfectly dry.* In the author's experience, its duration depends upon its being kept dry, and also upon the work it has to perform. One ventilator cannot be expected to perform the work that should be distributed over a dozen, and a ventilator containing only a small amount of charcoal cannot remain efficient as long as a ventilator containing a much larger bulk of absorbing material, for the ultimate power of the absorption of the gas by the charcoal bears a constant ratio to the volume of the charcoal in use. It is true wisdom therefore to renew the charcoal at short intervals of a month, and revive it by reburning, rather than allow it to remain so long in the ventilators as to be practically useless. The amount of charcoal used in different kinds of ventilators varies very considerably;

Amount of charcoal used.

* Vide pp. 360, 366, and 381.

for example, the quantity used in a ventilator similar to those shown in Figs. 91 and 92, having four trays each 14 inches by $5\frac{1}{4}$ inches, is $3\frac{1}{4}$ lbs. The quantity used in the author's spiral ventilator, Fig. 100, when combined with a 20-inch manhole-cover, is 6 lbs. The cost of maintaining the efficiency of a system of charcoal ventilators may be arrived at from actual experience at Croydon, where there were, in the year ending the 25th of March, 1872, 562 public charcoal ventilators of various kinds at work, and which were maintained in a high state of efficiency by having the charcoal renewed every month. The cost of these ventilators, including labour, new charcoal, fuel used in reburning the old charcoal, &c., was 4*s.* $1\frac{1}{2}$*d.* per ventilator per annum, or the whole system would have been covered by a rate of one-tenth of a penny in the pound, levied over the whole district. The charcoal was renewed at Croydon by being reburnt in a set of iron retorts, atmospheric air being excluded during the process. The escaping vapours are led away from the retorts by small pipes inserted in the end of each retort. After red heat has been maintained for a short time, the fires are allowed to die out and the whole apparatus to cool before the charcoal is withdrawn from the retorts.

Cost of charcoal ventilators at Croydon.

Reburning the charcoal.

The ventilation of house-drains is of equal importance to that of the ventilation of sewers, for reasons that have been already pointed out and explained in Fig. 76, page 355. Sewers cannot be ventilated efficiently through house-drains, and on the other hand house-drains cannot be ventilated by the public sewers. Every branch sewer and every branch drain needs its own separate and distinct ventilator. From the observations that have been already made with reference to the sealing of house-drains in periods when the sewers are gorged with sewage, every house-drain, unless ventilated, becomes a hermetically sealed chamber, and every drop of water entering a drain under such conditions compresses its atmosphere until it gains such a degree

Ventilation of house-drains.

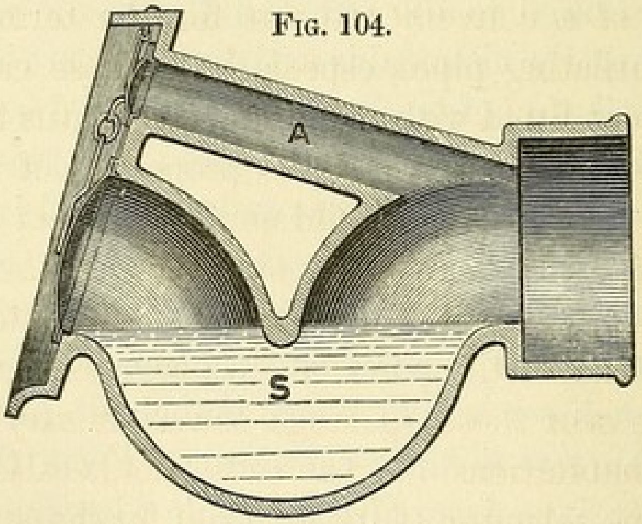
Ventilation required for every branch.

of tension as to force an exit, and the points of escape for sewer air are usually the weakest traps, which, as a general rule, are always found in the interior of houses.

Propositions made for ventilation of house-drains.

All kinds of propositions have been made for the ventilation of house-drains by shafts and flues of various descriptions, including up-cast and down-cast shafts as used in mine ventilation, but as the effects of various kinds of shafts have already been considered in connection with the ventilation of sewers, it is unnecessary again to consider them. It may be observed, however, that as all such systems fail to ventilate sewers, when applied to house-drains the failure is more marked and decisive, as the forces at work within a house-drain are the same as have already been pointed out as at work within a sewer, but are much more violent and irregular in their action. House-drains are liable to constant and extreme changes of temperature, and to intermittent flow through them, conditions which materially affect ventilation, and at the same time render it indispensable if our houses are to be ensured against the escape of sewer air into them. Notwithstanding the reasons that have been given, and which show that

Fig. 104.



house-drains cannot ventilate sewers, it has been seriously proposed to ventilate house-drains into the sewers. Fig. 104 represents a form of trap intended to be introduced at the junction of a house-drain and sewer, whereby it is intended that the sewage should

Proposal to ventilate drains into the sewers.

flow through the syphon trap S, and the sewer gas should flow from the house drain through the pipe A into the sewer. There are conditions, as the inventors of this trap declare, when a current of air may take place in the direction intended; but it should be observed that air would only take this direction when forced; as would be the case in a hermetically sealed drain, and when a volume of water is passed into it, which, by increasing the pressure within the drain causes the imprisoned air to acquire sufficient force to escape by this passage into the sewer; but it would never naturally take that direction. On the other hand, the circumstances may often be such that it would be easier for the air to force a trap within a house than to put in motion a descending column of air; moreover, what is to become of such a system of ventilation as this when the sewers are flooded, and when both the house-drain and its air outlet are sealed with water, as illustrated in Fig. 76, page 355?

Objections to ventilation of drains into sewers.

In the experience of the author, the best way of ventilating house-drains is the true Roman type of carrying up ventilating pipes at the heads of the drain and it branches. Care must be exercised as to the selection of a convenient point for the termination of these ventilating pipes, especially in those cases where they are not fitted with a charcoal apparatus for absorbing or destroying the noxious properties of the sewer air. The point of exit should neither be near a window, ventilator, or the top of a chimney, as there are at certain periods currents of air at these points into the house, so that if the point of discharge is permitted to terminate near these openings, sewer air may be drawn into our habitations. Great care should also be exercised in the selection of the material for the construction of ventilating pipes, and for forming their joints, especially in cases where they have to pass through the interior of houses, for it must never be lost sight of that the superior temperature of the air of a house has always a natural tendency to favour the escape of sewer

Best mode of ventilating house-drains.

Termination of ventilating pipes.

Selection of materials for ventilating pipes.

Plate XII.

air within rather than without the house. In Plate XII. is represented the section of a house with its arrangements for drainage, water supply, and ventilation of the drains. In this case it is assumed that the range of water-closets forms the head of the house-drain, and the soil pipe V is carried up and forms the ventilating pipe, which may terminate above the eaves of the house if there are no windows near, or may be carried up the slope of the roof either inside or outside the building, and made to terminate a few inches above the ridge of the house. V^1 shows a branch ventilating pipe communicating with the main ventilating pipe above the upper closet, the object of which is to counteract the influence of the induced current created by the falling water, which may untrap the lower closet in the absence of this branch ventilator.

Shafts formed in walls.

In the construction of new houses, the shafts for ventilating the drains may be formed within the walls of the house, in which case they must be made air-tight, and should be lined with glazed impervious tubes securely jointed. Where there are a number of branches to a drain, as for example, Fig. 105, A, B, C, and D represent branches communicating with one common drain. Ventilation provided at the head of the drain, or for the pipe A, will not always give immunity to the other branches, and for safety, all these branches should be ventilated for the following reasons:—Induced currents will untrap all branch drains not provided with ventilation; or a wave or succession of waves of water, as shown at W, Fig. 105, has the effect, as it moves forward down the drain, to compress the air in front of the wave and to create a partial vacuum in its rear. The effect of the wave is to drive the air up the branches in its front and to draw the water out of the traps behind it as it moves forward down the drain. If a house drain at any time runs full bore, it is liable to drain in succession every trap on the branches A, B, C, and D, unless each of these branches has been

Necessity of ventilating all branches of drains.

Influence of induced currents and waves of water.

separately ventilated. This is due to the effect of an induced current. This action of moving water was discovered in the year 1797, by M. Venturi. Fig. 106 is an illustration taken from Ewbank's Hydraulics, in

Fig. 105.

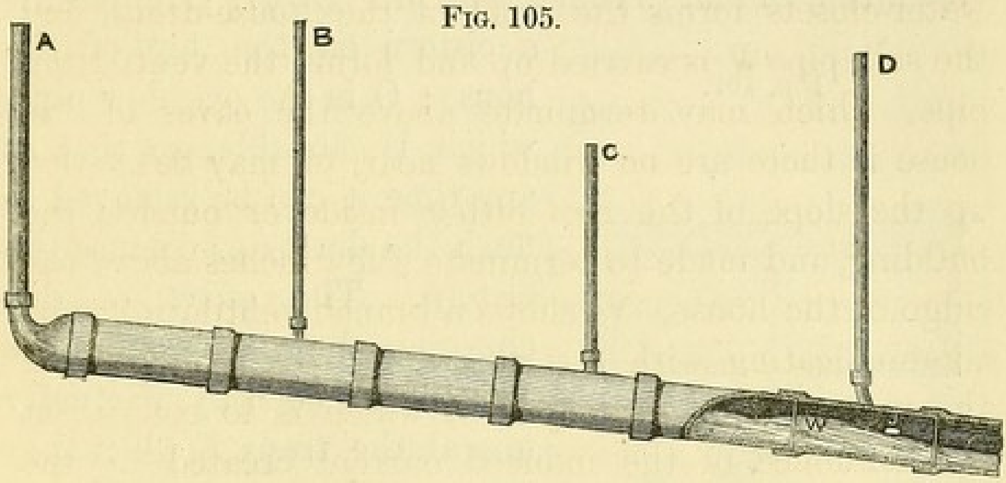
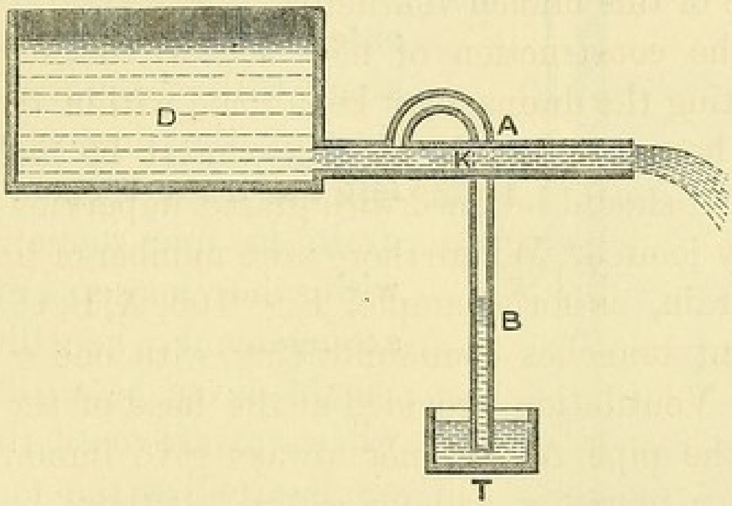


Fig. 106.



Venturi's experiment.

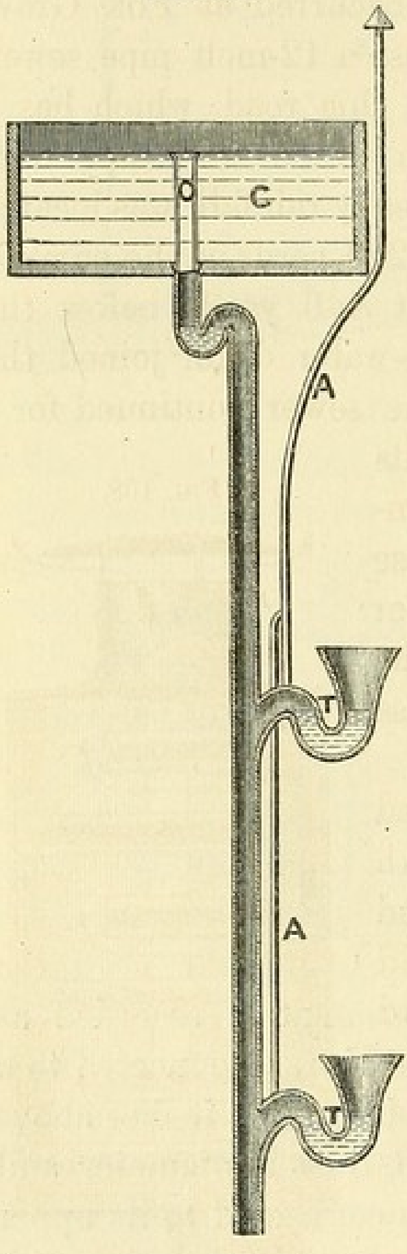
which an account of the experiment is recorded as follows:—"The cylindrical tube K was connected to a reservoir of water D, the surface being 32½ inches above its orifice. The pipe K was 18 lines in diameter and 57 long. A glass tube A B was connected to its upper surface at the distance of 8 lines from its junction with the reservoir. The other end of the glass tube descended into a vessel T, containing a coloured liquid. When water flowed through K, it dragged the air at the mouth of the glass tube with it, the remaining air dilated, and finally the whole was carried out with the effluent water, and the coloured liquid rose to the height of

24 inches in A B. The glass tube was then shortened to about 22 inches, when the contents of T rose up and were discharged from K."

Experience as to effects of induced currents.

The author has seen an arrangement of drains in operation similar to that shown in Fig. 107. C represents a cistern on the top of the house; O is the overflow pipe, which is movable, so that at any time it can be removed to flush the drains or cleanse the cistern. The effect of discharging the contents of the cistern has been to effectually unseal the traps T when they have not been ventilated, and to induce a current of air to enter by these traps and pass along with the water, and so soon as the flow subsided it left the traps T open, and the drain in free communication with the house. Such an arrangement as here illustrated should never be used except when separate ventilating pipes are inserted at the top of the traps, as shown by the pipes A. If ventilation is introduced in this way, the effect of the induced current still remains, but air can enter the drain, and the traps will remain intact.

Fig. 107.



Ventilation prevents injurious action of induced currents.

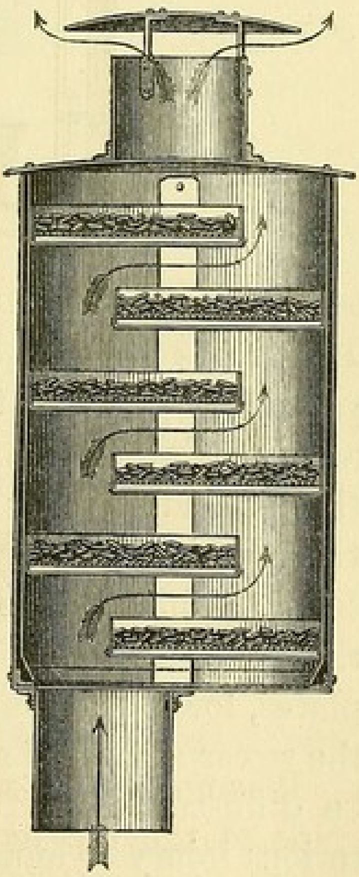
Not sufficient to carry soil pipes up for ventilation.

It is not always sufficient to simply ventilate the soil pipe at the top by carrying it up for the purpose of ventilation, as the author has seen a case in Kensington, in which a bucket of water poured into a housemaid's sink, at the top of a lofty house, untrapped four similar sinks below on the same line of pipe, notwithstanding that the soil pipe in this case was open to the atmosphere at its upper end. It is not generally known that the induced current produced in a small sewer having a steep gradient will unseal the traps in the contiguous houses. A case of this kind was brought to the author's attention by Mr. Thomas Graham, builder, of Beckenham, Kent, which occurred at Fox Grove Road, Beckenham. In this case a 12-inch pipe sewer, without ventilation, ran down this road, which has a steep gradient. The house, in which the traps were usually drained every time of heavy rainfall, was located near the top of the hill, within 200 yards of the summit of the sewer, at a point about 440 yards below the house in question. A surface-water drain joined the sewer, and after the junction the sewer continued for a length of about 300 yards to its outfall. A few gullies were connected with the sewer, but these were all trapped. After the sewer in the road was ventilated, the effect on the traps of the house in question ceased.

Effect of induced current in small sewers.

Case at Beckenham.

Fig. 108.



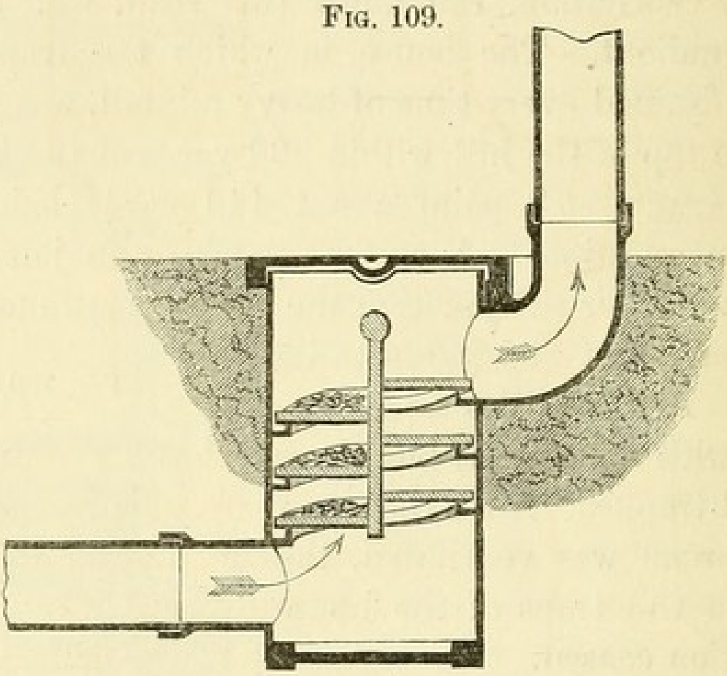
Charcoal may often be applied with advantage in connection with the ventilating pipes of sewers and drains; but in using it, it should be remembered that if not placed at the top of the ventilating pipe, it must be protected from the moisture which at some periods of the year will condense on the sides of the pipe, and trickle down and wet the charcoal so as to destroy its efficiency. Ventilating pipes, as used in connection with the City sewers, have been fitted with an apparatus containing charcoal, which is placed on the summit of the pipe, as illustrated in Fig. 108.

Charcoal applied to house-drain ventilators.

City sewers.

This arrangement is good if the trays fit the enclosing cylinder tightly, so as not to allow the gas to pass by the sides of the trays; but it is sometimes inconvenient to place an apparatus that requires attention in a position which is not always convenient of access, and on this account the author has applied a form of his piral ventilator to ventilating pipes. For example, Fig. 109 represents a ventilator which may be placed

Fig. 109.



at the head of a drain and below the ground level. The lid is kept tight by a sand-tray, from which a passage is provided to the spiral trough for conveying away to the sewer any water which may leak through the lid, and any condensed vapour descending the ventilating pipe also flows away by the spiral trough to the sewer. This form of ventilator * should be used for the ventilation of sewers in courts, alleys, or confined places, for if from mischance the charcoal is neglected, the sewer air would ascend by the ventilating pipe, and be diffused in the atmosphere without causing any serious injury or annoyance. In Fig. 110 is represented another form of this ventilator, which may be fixed at any intermediate point between the ground line and

Ventilation for confined places.

Charcoal ventilator applied above ground level.

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

the top of the ventilating pipe. If this form of apparatus is fixed near a window or other opening, it may be conveniently got at, and the charcoal renewed from

Fig. 110.

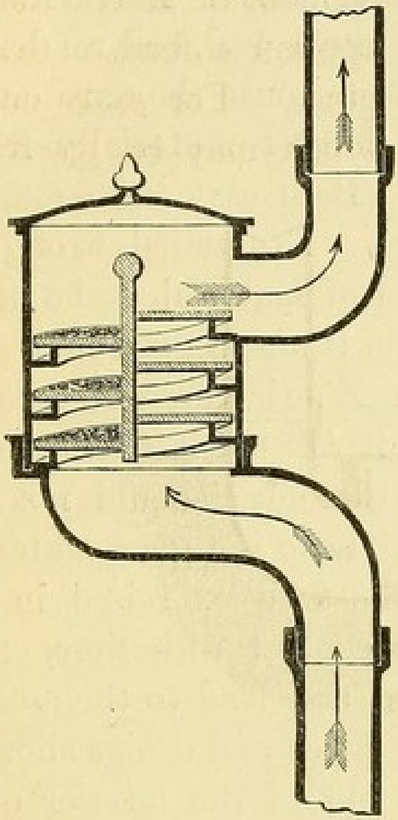
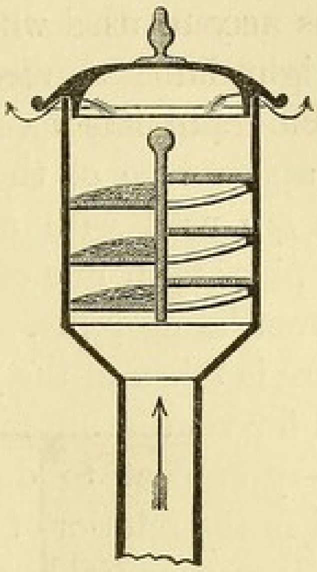


Fig. 111.



time to time as required. Fig. 111 represents another form of the same description of spiral ventilator, which is applicable to the summit of a pipe. The arrangement of this ventilator is such that the projecting worm in the interior of the apparatus prevents any gas passing by the side of the tray and so escaping contact with the charcoal. Charcoal ventilation for top of pipe.

The number and size of ventilators required for the efficient ventilation of a house-drain ought to be equal to the discharging capacity of the house-drain when working under a pressure not exceeding one-tenth of an inch head of water. As a rule, the number and size of ventilating pipes now in use are too few and small for efficient ventilation. As an example, from Table No. 32, page 138, a six-inch house-drain, laid at an inclination of 1 in 50, would discharge 60·17 cubic feet per minute. Now a 3-inch ventilating pipe 50 feet long, calculated by the formula given at page 337, would only discharge 27·06 cubic feet of air per minute, so that Number and size of ventilating pipes for house-drains.

it would require at least two 3-inch ventilating pipes each 50 feet long to effectually ventilate this drain.

Materials used for making ventilating pipes.

The materials used in the construction of ventilating pipes are copper, earthenware, iron, zinc, and lead. Copper is a good material, but expensive. Earthenware pipes may be used when built into a wall, and rendered air-tight, but if applied outside a house they are cumbersome and ill-looking, and detract materially from the appearance of the house. Both cast and wrought iron are used with advantage. Enamelled wrought-iron pipes form one of the best of materials to be used for ventilating pipes. Cast iron is also a good material if care is taken in the jointing. Zinc is very extensively used for ventilating pipes, but it will not last long, as it is very subject to decay; it therefore should not be used in the interior of a house. Lead is a good material and is very durable. Care must be exercised in its use that it is not brought in contact with lime, or it will soon become honeycombed and lead to the escape of sewer air.

Ventilating pipes and drains kept out of houses.

All ventilating pipes and drains should, as far as practicable, be kept out of the interior of a house, and they should be so arranged as to be easily examined at any time.

Testing the pipes.

All soil and ventilating pipes fixed in a house should be tested under water pressure to ascertain if they are air-tight, before being connected with the drains; and it will be well also, in long lengths of ventilating pipes, to form expansion joints, for, if the pipe is fixed tight at any point, it is, from its contraction and expansion under change of temperature, very liable to fail, and lead to the escape of sewer air.

Expansion joints.

Angles and bends.

Angles and bends in ventilating pipes should be avoided as much as possible. Ventilating pipes need not detract from the architectural appearance of a house; indeed, on the contrary, they may be arranged in combination with vanes, bannerets, &c., so as to give architectural effect; therefore the unsightliness of a ventilating pipe should be no excuse for not providing this very necessary safeguard of our drains.

Arrangement of ventilating pipes.

As an historical fact, one of the first examples of the ventilation of a house-drain in this country is recorded in a patent, No. 11,218, of the year 1846, which was secured by Mr. John Walker Wilkins. The title of the patent is "Water Closets," and the introduction of a ventilating pipe is shown on the top of the bend of the trap, and is described as "an air pipe, which leads from the soil pipe to the external atmosphere, or to any open place within doors." It is clear from this description that the author of this patent set no particular value upon the importance of a ventilating pipe, from a sanitary point of view, or he could not have thought the air discharged very injurious, if it might be discharged in an open place within doors,—presumably, by this he meant within the house. The use of this pipe was to make the closet noiseless, for its author claims in his patent "the employment in water closets of an air pipe to prevent noise," or, as it is described in another part of the specification, as "the air pipe prevents any noise which might arise from the displacement and re-adjustment of the air within the receiver and soil pipe." At this period evidently more was thought of the disagreeable noise caused by the escape of the confined air than of the injurious action of this air on the health of those brought into contact with it.

J. W. Wilkins and ventilating pipes.

Use of air pipe.

It is on record* that early in 1853 the Friends' School and other houses at Croydon had their soil pipes ventilated, and the author has been informed by John Teevan, Esq., of Woodside Court, Croydon, that the ventilation was copied in Croydon from what had been done by Messrs. Cubitt, the eminent builders in London, the results of which were communicated by Mr. Teevan to W. Drummond, Esq., the Chairman of the Croydon Local Board of Health, and the principle was at once adopted by the Croydon Board of Health.† On further inquiries from Mr. Thomas Graham, builder, of Becken-

Ventilation of drains at Friends' School, Croydon.

Introduction of ventilation into Croydon from Messrs. Cubitt.

* Evidence given before Dr. Neil Arnott and Thomas Page, Esq., C.E., at inquiry into the causes of fever at Croydon in 1853.

† The first epidemic of fever in Croydon was ascribed to the want of ventilation; but the ventilation of the drains at Friends' School did not save the inmates from an attack of fever in the first epidemic in 1853.

Mr. T. Graham's experience.

ham, who was for many years engaged with Messrs. Cubitt in their plumbing department, the author has learned that it was the practice to introduce air pipes into the soil pipes, over thirty years ago, whenever two or more closets communicated with the same soil pipe. At first these air pipes were but 1 inch diameter, but this size was often found inadequate, and larger pipes for ventilation came into use. Mr. Graham also informed the author that he ventilated the soil pipes of the workhouse, St. Mary Axe, London, about the year 1844.

Air pipes used when more than one closet was connected to soil pipe.

Ventilation in 1844.

Improved ventilation of house-drains.

During the last three or four years various suggestions have been made in order to render more perfect the system of house-drain ventilation, and it is now generally thought that openings should be provided both for the entrance of air into the house-drains at one point, and provision should be made for its extraction at another point. The recent model bye-laws issued by the Local Government Board require "two untrapped openings to the drains," "one opening being at or near the level of the surface of the ground," and is to be on the house side of a trap to be inserted in the line of house-drain, and "the second opening" is to be "as far distant as may be practicable from the point at which the first-mentioned opening shall be situated," and from this second opening "a pipe or shaft" is to be carried up to a proper and convenient height. This is in fact the system patented in April, 1875, by Mr. W. P. Buchan, a plumber of Glasgow, who evidently understands his business, and who is the author of a very useful treatise on 'Plumbing,' in Weale's Rudimentary Series. Fig. 112 is a representation of Mr. Buchan's system. On the right is shown an opening communicating with the drain in combination with a trap, and the soil pipe is shown extended upward, and terminates with an exhausting cowl head, for the purpose of ventilating the house-drain. It should be said that there is nothing new in the arrangement for the admittance of air in connection with a trap as here represented. In Fig. 150, page 488, is shown the ordinary mode adopted of cutting off a pipe from a sink.

Model bye-laws of Local Government Board.

System of W. P. Buchan.

It will be seen that this figure is a correct representation of the trap introduced by Mr. Buchan into the soil drain

Fig. 112.

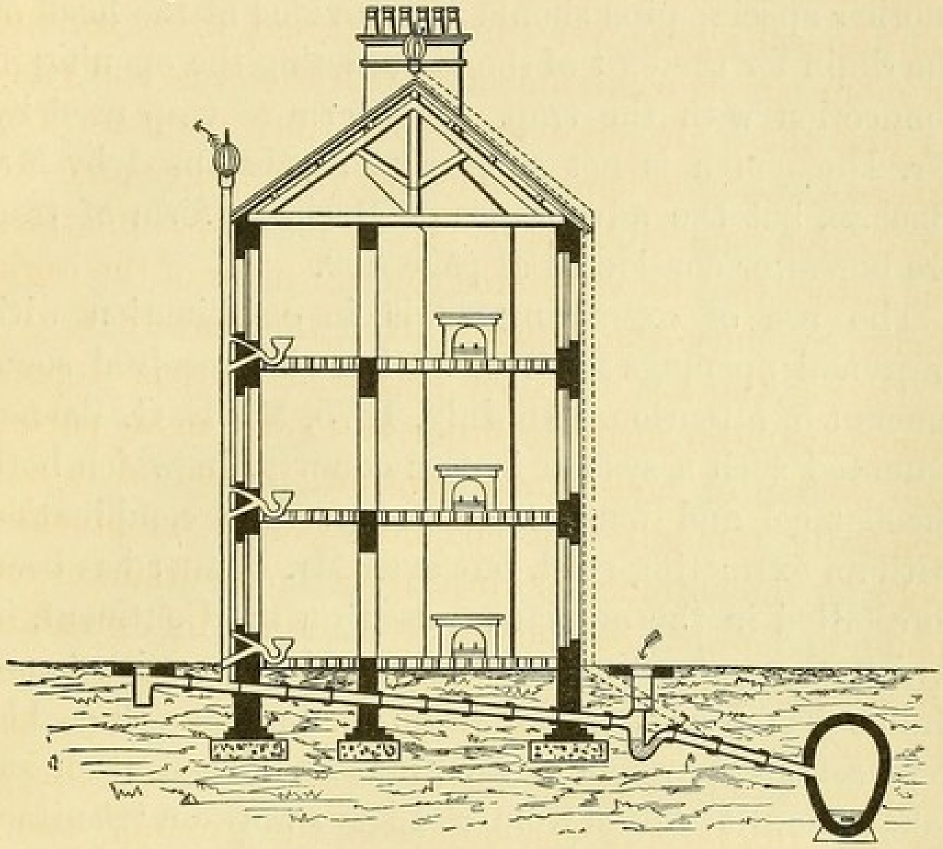
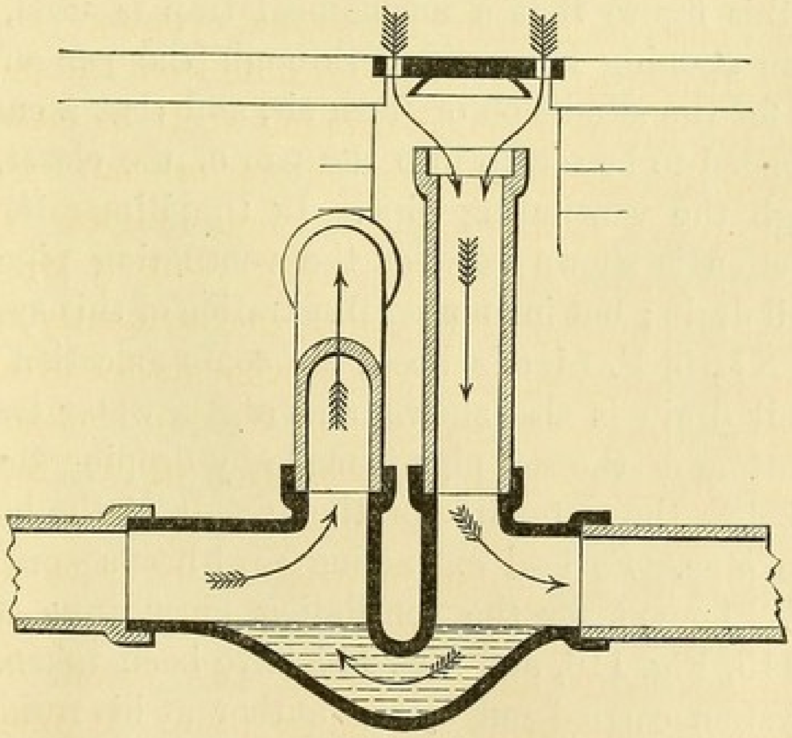


Fig. 113.



of a house. Fig. 113 represents what is called the Somerset trap, which was designed by Mr. John Honeyman, F.R.I.B.A., in 1858. The arrow within the water line shows the direction of the flow of the sewage, Honeyman's Somerset trap.

the other arrow shows the direction of the air currents. Of course when this trap is used it was the intention of its author that the soil pipe should be carried up, or another special pipe should be provided at the head of the drain for the exit of the air entering the opening in connection with the trap. The form of trap used by Mr. Honeyman is not so perfect as that used by Mr. Buchan, but the advantages of Buchan's form of trap are hereafter considered at page 500.

Mr. E. G. Banner's patent system.

The use of extracting cowls in combination with traps and openings for fresh air has also received some amount of attention. In July, 1875, Mr. E. G. Banner patented such a system in this country, in which both mechanical and water traps are used in combination with an extracting cowl, but even Mr. Banner has been forestalled in the appliances used on the Continent, in which the extracting cowl in combination with house drains has been used for some years past.

System of M. Flament.

F. Liger's work, 'Sanitary Appliances.'

Fig. 114 represents the system of M. Flament. The author has taken the illustration from F. Liger's work on 'Sanitary Appliances,' published in Paris in 1875. It will be seen from this figure that a mechanical trap is used, and that an opening is provided through the pan of the closet for the admission of fresh air, and that a current is intended to be set up into the pan of the closet, and through the ventilating pipe. In the illustration no connection is shown between the ventilating pipe and the soil drain; but in another illustration of this system,

Plate XI., F. Liger's book.

Plate XI., in F. Liger's book, the communication with the soil drain is also shown, and also a water trap at the bottom of the soil pipe is made by dipping the soil pipe below the water line of the cesspit at the bottom of the pipe.

M. Flament's exhausting cowl head for soil pipes.

Several extracting cowl heads were used by M. Flament for the ventilating pipes, from which Fig. 115, Fig. 116, and Fig. 117 have been taken. In the system carried out by the author at his residence, in combination with a trap and opening for air, illustrated in Fig. 159, page 501, a ventilating cowl head *

* This cowl was brought to the attention of the author by Mr. Rogers Field, C.E.

FIG. 114.

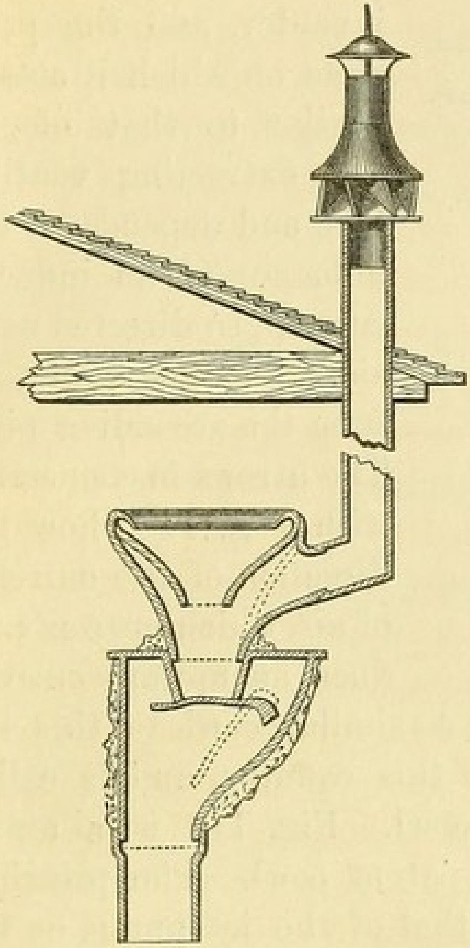


FIG. 115.

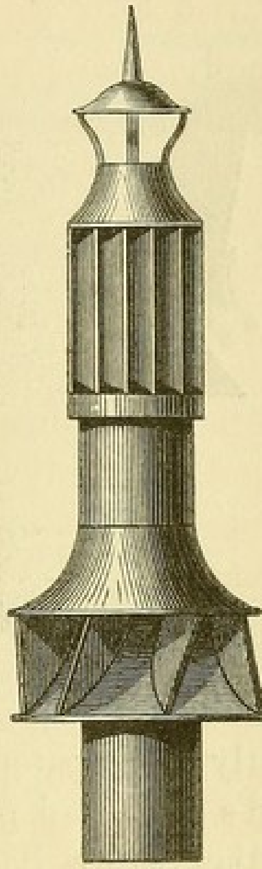


FIG. 116.

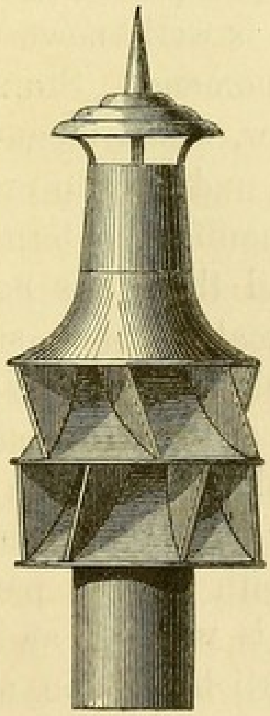
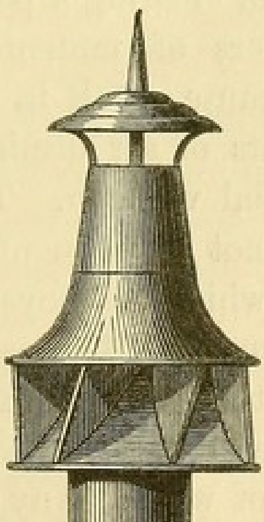


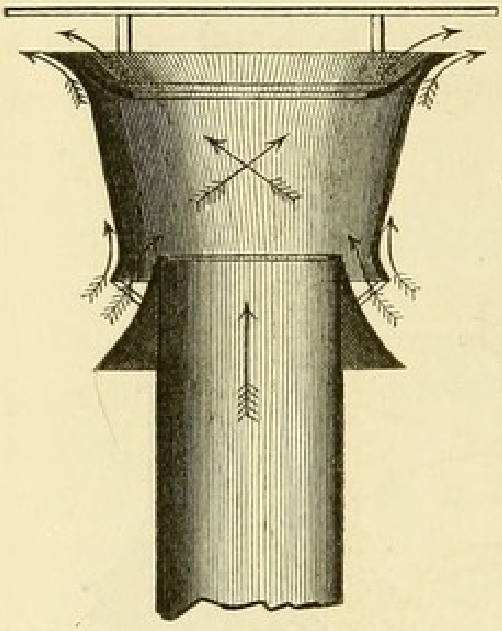
FIG. 117.



Wolpert's cowl.

is used, Fig. 118. This form of cowl is the design of

Fig. 118.



Mr. Wolpert, a German inventor, and the principle on which it acts is similar to that of all the extracting ventilators, and depends on the influence of an induced current, so directed as to aid the escape of the air from the ascending pipe. The arrows in connection with Fig. 118 show the direction of the currents of air, which currents induce an upward current in the ventilating pipe. A similar cowl to this has recently been patented in this country, and is called Lloyd's improved patent cowl. Fig. 119 is a representation of Mr. Banner's patent cowl. The principle of this cowl is similar to that of the jet pump, or the blowing tube, the action of which has been known for a long period.

Banner's cowl.

Effect of currents of air.

That currents of air, even in open places, have the effect of creating a partial vacuum is well known to the observers of meteorological phenomena. Storms of wind cause a fall in the barometer, which means that currents of air diminish pressure, and tend to produce a partial vacuum. This is very manifest in tornadoes, when not unfrequently it is found that it is not the blast which destroys, but the creation of a sudden vacuum, and houses have been destroyed in time of such storms by the expansive force of the imprisoned air on the sudden removal of external pressure by a rapid blast of wind. Any fluid moving in contact with another fluid at rest, drags along with it some particles of the fluid through which it is moving, and with which it is in contact. The particles set in motion in their turn impart their movement to other con-

Tornadoes

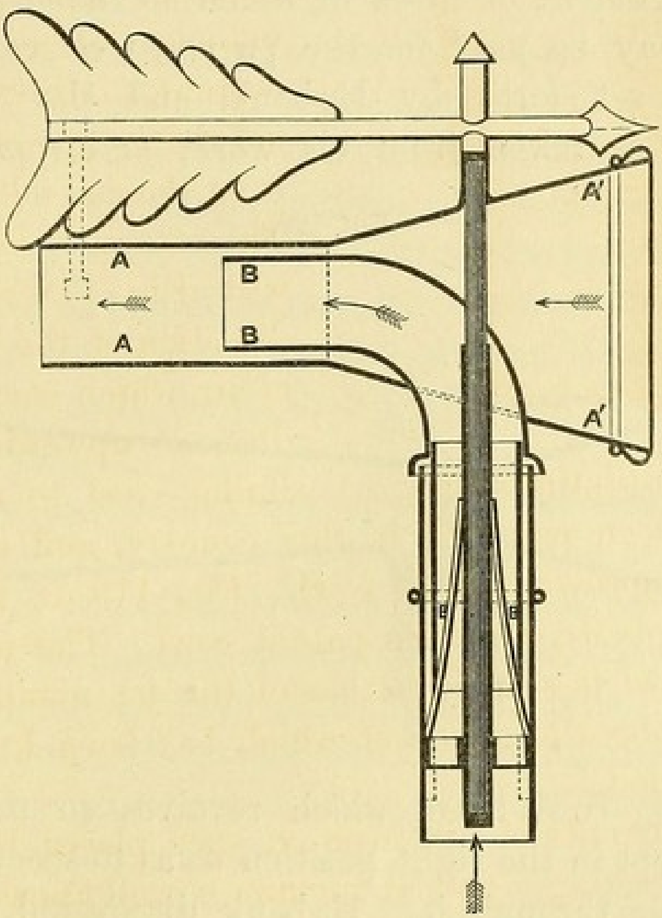
Expansive force of air.

Theory of induced currents.

tiguous particles, and so on until a mass of the fluid is put in motion and moves with the current of moving liquid. This action is now called the influence of an induced current. The power of such a current has been known from the ages of antiquity, for

Antiquity of principle of induced currents.

FIG. 119.



we have in the Trombe, which was described two thousand years ago, an instrument for creating a blast of air for a furnace, a practical application of the influence of an induced current of water carrying along with it air which was separated from the falling water and used for the above-named purpose. Water falling down a shaft has been used for the purpose of conveying air into a mine. Mr. G. C. Greenwell, in his work on mine engineering, gives several examples, in one of which the water discharged from two holes, each 1 inch diameter, falling down a shaft 63 fathoms deep, carried 3171 cubic feet of air per minute into the mine, in addition to the quantity supplied by a furnace. The

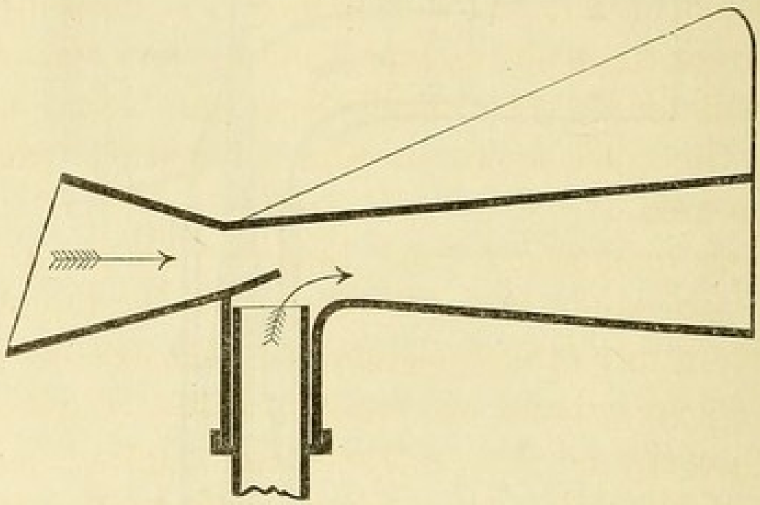
The Trombe.

use and investigation of the tube for creating currents, known as the "blowing tube," received very considerable attention at the hands of Mr. Thomas Ewbank, C.E., of New York, in the years 1834 and 1835. These experiments are all fully set forth in his interesting and excellent work on Hydraulics. The best form of an arrangement of tubes in which an induced current of air may be used for the purposes of ventilation, is fully set forth by Ewbank, and the following Fig. 120 is taken from his work, and represents a

Ewbank's investigation on blowing tubes.

Ewbank's cowl.

FIG. 120.



ventilating cowl head, which revolves so that it is always kept in the right position so as to secure a current of air through it. Ewbank discovered that the efficiency of these appliances was greatly increased by adding an expanding tube after the junction with the suction tube, and therefore in his cowl head both the blowing tube and discharge tube are made to taper, the blowing tube contracting inwards and the discharge tube expanding slightly outwards. Moreover, he also recommended that "the upper side of the blowing part of the tube should be cut partly away at the end, so as to facilitate the entrance of descending currents of wind," as shown in Fig. 120. From the various illustrations shown by Ewbank, and the result of his experiments, it is clear that the patent ventilator of Mr. E. G. Banner (Fig. 119) is not such a perfect appliance as that introduced by Ewbank over forty years

Efficiency of cowl increased by expanding tube.

Ewbank and Banner's cowl compared.

ago, and which was constructed in accordance with results deduced from careful experiment. Mr. Banner describes the action of his ventilator as follows:—"The larger end of a funnel-shaped tube A′, placed horizontally, is always directed towards the wind, and a current of wind passing in there is pressed forward through the circular space between the two cylinders A B, and when it reaches the end of the inner one, B, it expands all round it, and in its passage out at the smaller end, A A, a vacuum is created round the point of the inner cylinder, B, which, by suction, draws out its contents into the open air, and this induces an upward current of air from the shaft or pipe leading from the place to be ventilated." As a mechanical ventilator for house drains, the cowl shown in Figs. 74 and 75, page 353, may be used.

Description of Banner's cowl.

As an exhausting cowl Boyle's "air-pump ventilators" are well adapted for fixing on the top of a soil pipe, or in any other position in which exhaustion produced by an induced current is of value. Boyle's ventilators consist of four sections, each acting independently of the other, and when fixed on the top of a ventilating pipe present a large acting surface to the currents of the atmosphere. The arrangement is extremely simple, and consists of a series of guiding and deflecting plates, so arranged that a current of air passing in any direction through the ventilator tends to create a partial vacuum in the central chamber of the ventilator, and a current of air is in consequence set in motion towards the central chamber, which, as fast as it is exhausted, is supplied with other air, and so a continuous current is set up through the ventilator.

Boyle's cowl.

In all cases in which the extracting cowl heads are used, it must be borne in mind that they only act when the wind blows (in calm weather they are of no service), and that the fall of water down a soil pipe will reverse any air current, even when set up by the most powerful extracting cowl that can be devised. To get the full benefit from a ventilating cowl it must be placed above

Extracting cowl heads only act when wind blows.

Reverse currents.

Cowls should be placed in air current.

the ridge of the roof in such a position as to be freely exposed to an air current. Cowls are often placed on the head of a ventilating pipe, which is in such a position that the roof of the house protects it from the action of the prevailing winds. In such cases cowls only act in preventing down-draughts. Whenever the air within a ventilating pipe has a temperature of two or three degrees Fahrenheit above that of the external atmosphere, the ventilating pipe will act more efficiently as a simple shaft without a cowl than with a cowl, for under such a condition a cowl may obstruct ventilation.

Cowls may obstruct ventilation.

When the air in the drains or ventilating pipes has the same temperature as the external air, then an extracting cowl in a good breeze will act most efficiently. When the air in the drains or the ventilating pipe is colder than the external air, then a cowl working against a down-draught is useful. When warm air ascending from a warm drain is chilled in a cold ventilating pipe a cowl is of service. Although cowls under the conditions in which they work when placed on soil pipes only set up occasional and feeble currents, yet they are of value in preventing down-currents, and so in a measure protect other openings into the drains, which become, under the influence of an extracting cowl, intakes for fresh air. Further, when selecting points for an opening into a house-drain for the admission of fresh air, it must not be forgotten that, owing to the natural forces that are at work within all sewers or drains, these openings for the admission of fresh air will at times become openings for the discharge of air from the drains. It was for this very reason that the author has fitted the opening for the admission of fresh air into his own house-drain with a spiral charcoal ventilator, so that when a reverse current is set up, the escaping air may at once be oxidized by being passed through the charcoal.

Conditions under which cowls act.

Cowls prevent down-draughts.

Selection of points for openings into house-drains.

Application of charcoal to openings.

CHAPTER XXIX.

MANHOLES AND LAMPHOLES.

No system of sewerage can be said to be complete unless amply provided with manholes and lampholes, in order to secure at all periods the proper supervision and control of the works. It has already been pointed out, at page 163, that sewers should be laid as nearly as possible in straight lines, with manholes at every point of lateral deviation, and manholes or lampholes at every vertical point of deviation. An illustration is given at page 165, Fig. 15, showing the way in which manholes and lampholes are used in case of a stoppage in the sewers. Previous to the introduction of manholes into the system of sewerage, great expense and inconvenience were often incurred in consequence of the stoppages arising in the sewers making it necessary to have recourse to breaking up the streets, probably in many places, before the stoppage could be discovered and the sewer cleared. Mr. Roe, when Surveyor of the Holborn district, gave it in evidence before the "Health of Towns Commission" that the cost of removing the solid deposit from sewers in the Holborn district, when provided with manholes, was 6*s.* 10*d.* per cube yard, as against 11*s.* per cube yard when the sewers were not provided with manholes. Moreover, it was stated that the Commissioners of Sewers of this district, in the year 1843, after paying the cost of constructing side entrances and flushing apparatus, had saved, at the end of the year, a considerable sum of money over and above what would have been their expenditure, in breaking up and restoring streets, and removing the deposit from the sewers, if the ordinary

Manholes an lampholes required for supervision of works.

Position of manholes and lampholes.

Expense and inconvenience of breaking up streets.

Cost of removing silt from sewer with manholes.

Saving arising from use of manholes.

mode practised before the use of manholes had been adopted. The manholes of modern sewers are simply wells properly steined with brickwork, by which men can descend into the sewers, or in the case of small sewers, to the sewer level. Lampholes are small shafts used for the purpose of suspending a lamp in order to throw a light into a particular part of a sewer, so as to enable men to inspect it from a manhole. Both manholes and lampholes should serve the double purpose of acting in their proper capacity, and also as ventilating shafts. Manholes are constructed either as perpendicular shafts, entering the sewer directly over its crown, or immediately by its side, or in the case of some towns, and in streets of great traffic, by means of side entrances placed either in the footpath, or at the side of the street, out of the way of the traffic. In Fig. 121 is represented the plan of a manhole, with side entrance, as used in the London sewers. Fig. 122 represents a section, showing the way in which the connection is made between the sewer and the side entrance. The object of a side entrance into a sewer is to enable the operations necessary to be carried on in connection with a system of sewers, such as the raising or lowering of materials to or from the street level, to be done without obstructing the street traffic, or the prosecution of the work being inconvenienced by the traffic. No doubt the construction of side entrances into the old sewers of London was a great advantage, but the advantage is not so great in the case of a modern system of sewers so constructed as to be self-cleansing, and consequently not requiring the streets to be obstructed with the solid deposit raised from the sewers. Side entrances, except in rare cases, are not imperative; they add materially to the cost of construction, and have some disadvantages, as they are apt to lead sewer air to points near the houses. If it is necessary to introduce them they should be ventilated by pipes connected with the side entrance at the highest

Description of manholes.

Description of lampholes.

Side entrances.

Object of side entrances.

Side entrances not required in self-cleansing sewers.

Ventilation of side entrances.

practical point immediately below the cover, and carried up to some convenient point.

Accumulation of filth in side entrances.

Side entrances often accumulate filth in flood time, and as the flow of the sewage cannot wash it away, it gives rise to noisome smells. Side entrances are, as a rule, not so clean an appliance as an ordinary manhole, the bottom of which forms part of the sewer, and

FIG. 121.

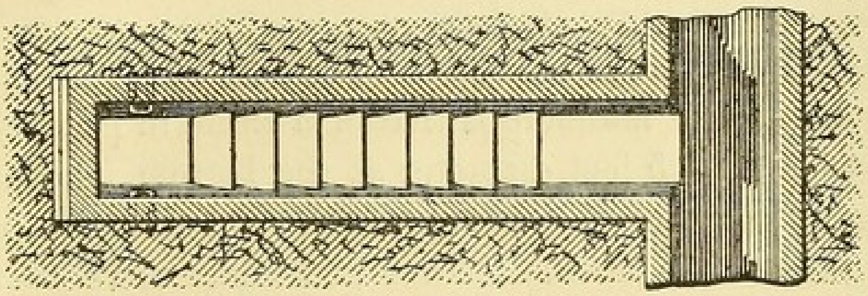
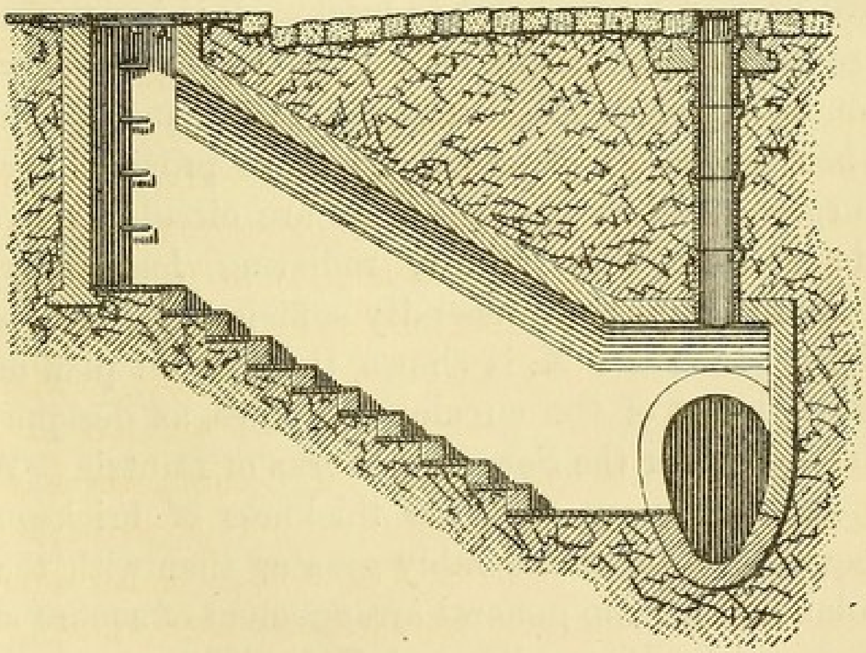


FIG. 122.

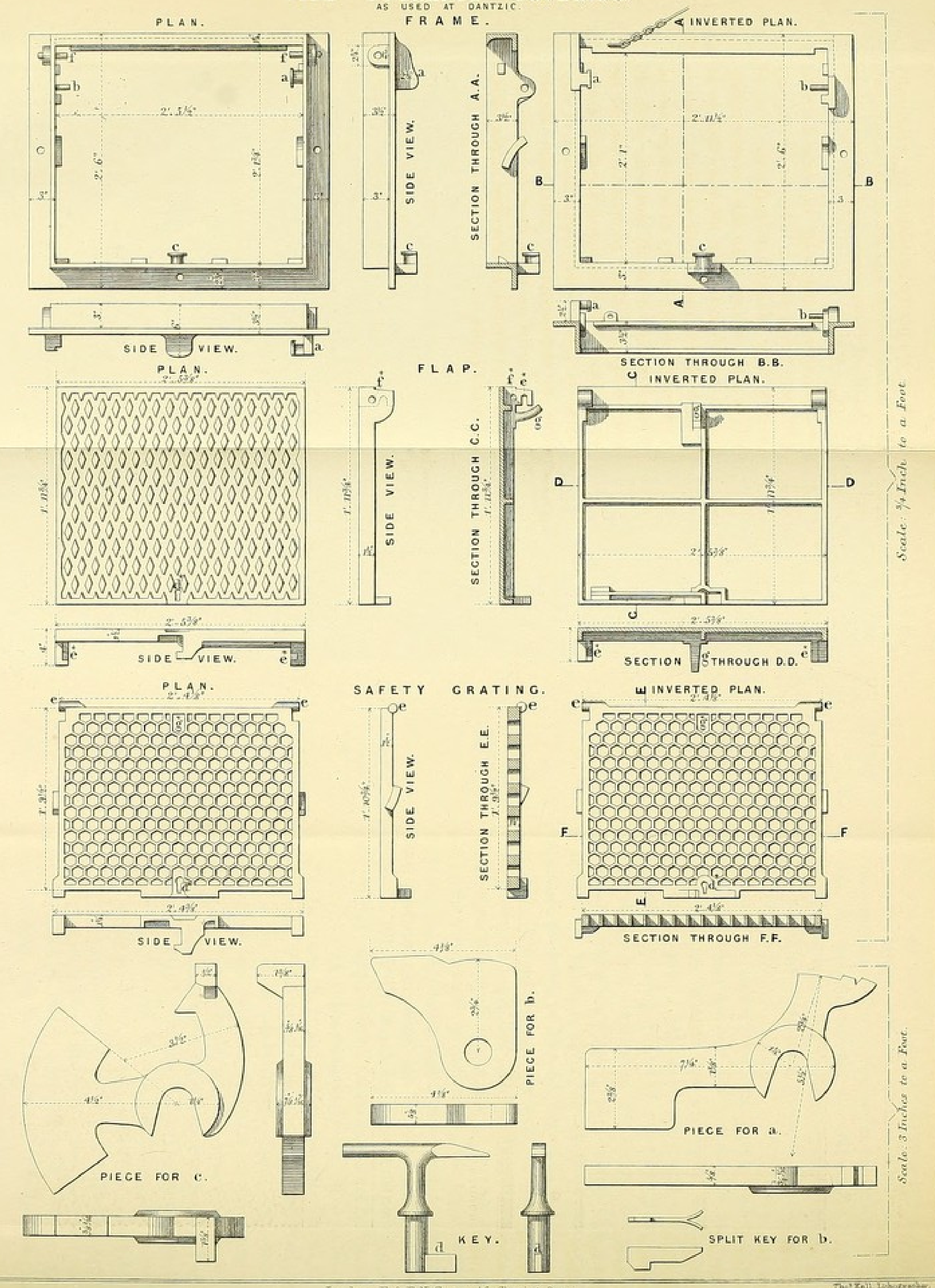


from which everything offensive is washed away. In all ordinary cases a manhole, arranged near the centre of the street, is preferable to a side entrance, for then the manholes can be used as ventilating shafts, and moreover the removal of a simple manhole cover, having an opening not more than 2 feet in diameter, is,

Manholes preferable to side entrances.

SIDE ENTRANCE COVERING.

AS USED AT DANTZIC.



London: E. & F. N. Spon, 46, Charing Cross.
Thos Kell, Lithographer, 40, King St, Covent Garden.

tricts, the sewers are partly ventilated by periodically opening the manhole covers and fixing the safety gratings. The details of these covers and safety gratings are given in Plate XIII. Plate XIII.

In the construction of manholes in some districts, especially in cases where sand is liable to find its way into the sewers, it is advisable to make the floor of the manhole at a lower level than the sewers running in or out of it, as shown in Fig. 98, page 389, so as to form a catch-pit for the deposit of sand. This is especially necessary where works of sewerage are in progress of construction in sandy districts: after all the works are completed these receptacles should be filled up, and a channel formed across the floor of the manhole, so as to prevent the accumulation of any matter liable to decomposition. Manholes should always be so constructed as to be used for storing up sewage for flushing purposes, as described at page 291, and illustrated in Fig. 64.

Catch-pits in sewers, Fig. 98.

Manholes used for flushing sewers.

CHAPTER XXX.

GULLIES AND TRAPS.

Gully.

A GULLY is an opening provided for receiving surface or waste water, slops, and the urine of men and animals.

Trap.

A trap is a barrier placed between the sewer on the one side, and the external or interior air of our houses on the other side. Ewbank says, "The origin of traps is, we believe, unknown. The principle is precisely the same as that of water lute of the old chemist."

Gullies and traps bear close relation.

Gullies and traps are closely related, for although we may have traps without gullies, no modern gully can be considered complete without a trap, and the trap and the gully are often so constructed as to be inseparable.

Necessity for caution in use of traps.

Both gullies and traps are liable to a series of contingencies, arising from defects in construction or accidental derangement in working, rendering it extremely necessary to be cautious as to the mode of introducing trapped openings communicating with sewers or drains within our houses.

Description of traps.

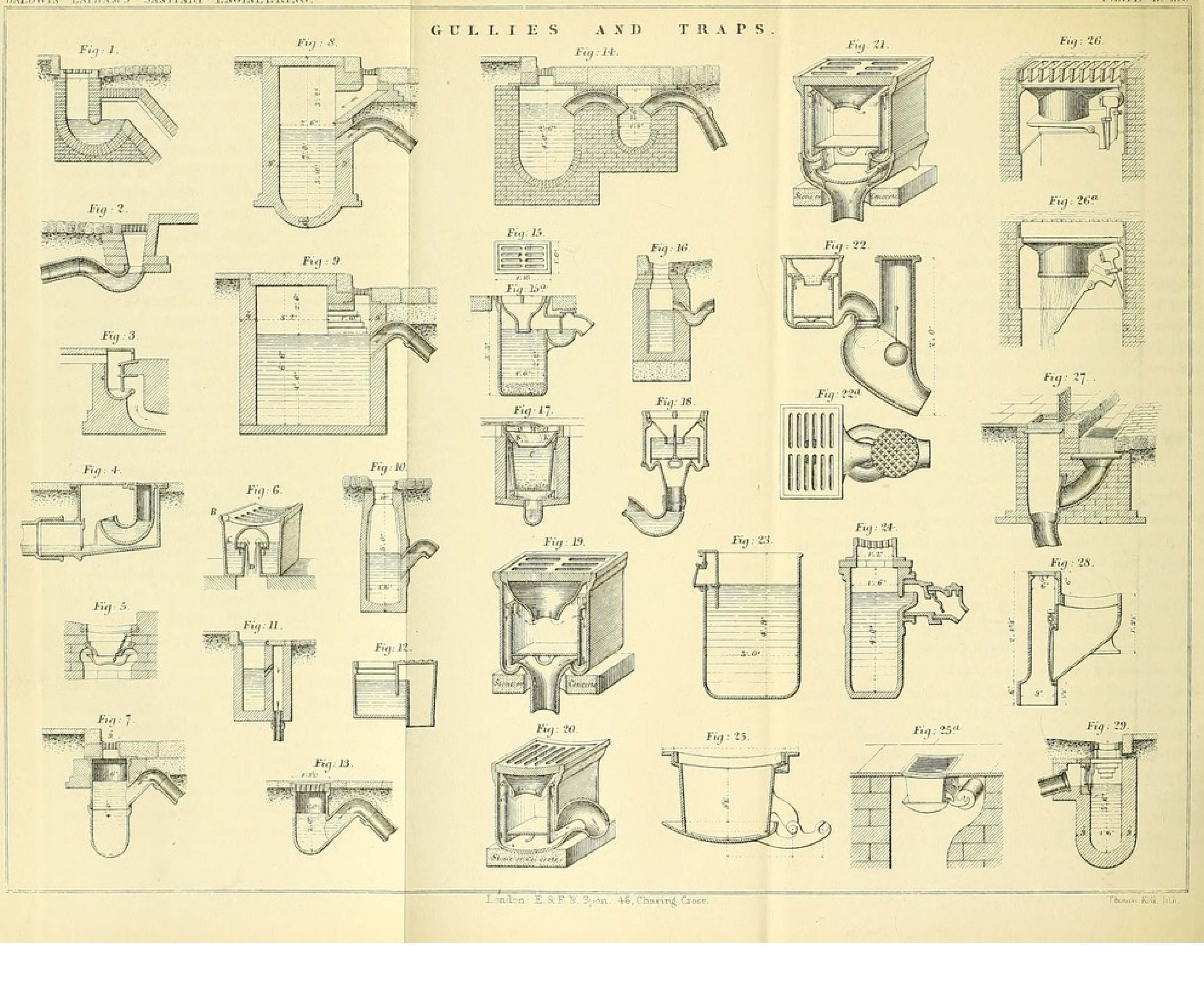
All gullies and traps are now formed either on the water trap or valve trap principle, or by a combination of both these principles.

Causes of failure of syphon traps.

Water traps usually partake of the character of an inverted syphon, and are liable to become untrapped from running full bore and acting as a syphon proper, in which case the induced current tends to create a vacuum below the trap; air follows the flowing water, and drives or sucks out sufficient water from the trap to leave the aperture unsealed.

Remedy, ventilation.

The remedy for this defect (which is constantly occurring in the case of small pipes) is to provide free ventilation below the trap, to make the trap of rather larger bore than the pipe communicating with it, and to cut off all direct communication with


GULLIES AND TRAPS.
Fig: 1.
Fig: 2.
Fig: 3.
Fig: 4.
Fig: 5.
Fig: 6.
Fig: 7.
Fig: 8.
Fig: 9.
Fig: 10.
Fig: 11.
Fig: 12.
Fig: 13.
Fig: 14.
Fig: 15.
Fig: 15a.
Fig: 16.
Fig: 17.
Fig: 18.
Fig: 19.
Fig: 20.
Fig: 21.
Fig: 22.
Fig: 22a.
Fig: 23.
Fig: 24.
Fig: 25.
Fig: 25a.
Fig: 26.
Fig: 26a.
Fig: 27.
Fig: 28.
Fig: 29.
Stone or Concrete

the drains of our houses in a manner hereafter considered under the head of House Drainage, page 481. Another, and not uncommon cause of the failure of a trap is, the entry of some substance which will act as a syphon, and drain every drop of water out of the trap, leaving it unsealed. For example, the traps of sinks are very apt to become untrapped in consequence of a thread or two of a dishcloth entering and hanging partly in the water of the trap and partly down the drain, when it acts as a syphon and drains the trap. The only remedy for this defect is the exercise of constant surveillance over all traps, and seeing that they are kept properly clean, and, where possible, preventing all direct communication between our houses and the drains. Traps are also particularly liable to fail from the evaporation of the water which forms the seal against the escape of sewer gas. Valve traps are more defective than water traps, for it must not be forgotten that as traps are used with the sole intention of preventing the passage of sewer air from our drains or sewers into the houses or elsewhere, that as water flows down, air is displaced, and may flow up the drain, so that, taking the case of the ordinary valve known as the shackle valve, Plate XV., Fig. 22, when this is open, and water is passing through the lower portion, sewer air can easily pass back over the water through the upper portion of the valve. Other kinds, such as floating valves, have been used, but all valves are liable to leakage from the admission of some foreign substance into the valve seat which prevents its closing. Moreover, the oxidation of the valves, and the injury the valve faces often sustain, render them a very imperfect and unsafe mode of ensuring the trapping of any opening communicating with our sewers, and such valves can only be looked upon as a palliative against the movement of sewer air, and not as an effectual remedy to check its escape. The failure of traps has so often been proved that persons have been found

Draining of syphon traps.

Remedy, frequent cleansing of traps.

Evaporation unseals traps.

Shackle valve.

Valves will leak.

Valve traps not to be depended upon.

Uncertain action of traps.

to advocate their entire abolition, and the substitution of free ventilation in their stead. Others have increased the number of traps in our house-drains, in the hope of excluding more effectually sewer gas.

Use of traps.

Traps are useful for closing the openings between sewers and houses, or even between houses and the external air, for, if openings are left untrapped, and they simply communicate with the external air, at times disagreeable currents of air would be set up, which may be attended with inconvenience. On the other hand, if free ventilation is provided, unless openings communicating with drains are trapped, as air and gas always take the course of least resistance, there is a danger of foul air escaping into our houses.

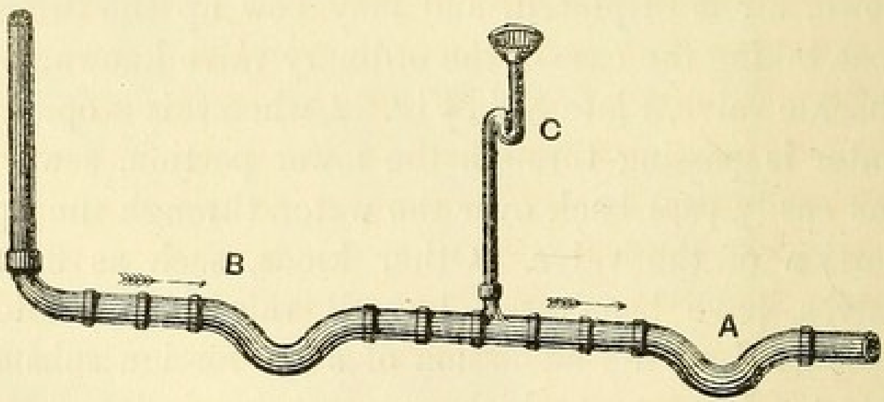
Evil of multiplying traps.

The multiplication of traps has also its dangers. For example, if two or more syphon traps are fixed in the same line of air-tight pipes, the lower syphon will effectually untrap the upper syphons, as for example

Description of Fig. 123.

Fig. 123. The syphons A and B are placed in the

FIG. 123.



course of a drain with no free opening between them, water is passed into the drain above the syphon B it will drive out the air in the pipe between A and B, which, as a general rule, would bubble up through the water of the trap at C. The air being excluded between A and B, all the syphons act in unison, and anything affecting the trap A or B will equally affect the trap C. For example, if the drain runs full bore, all the syphons would be drained, or in another case the lower syphon will effectually untrap the upper syphons; for if we suppose that water is running through the drain, aud that it suddenly ceases to flow, the flow would gradually subside between B and A, causing a vacuum in this portion of the drain, and air will then enter through the syphons B and C, which will drive out the water in the trap, leaving it unsealed. The only remedy for this action of a syphon trap is to provide sufficient ventilation, so that while the action of the syphon remains, air may be supplied from external sources without having to pass through the traps. It cannot be too fully impressed upon all persons using traps, that no trap can be relied upon unless protected by a ventilator to relieve it from pressure.

Every trap protected by ventilation.

Dr. A. Fergus says, "Sewer air is absorbed by the water on the sewer-side of the trap, and discharged from the house end of it." One thing is certain with reference to malaria, that all authorities are agreed that it is never extricated from a water surface. It is only after a swamp has become dry that malaria makes its appearance and commits its ravages. If we admit with Dr. Fergus that sewer air may be passed through the water of a trap, we may be assured, on the other hand, that anything injurious held in the sewer air would be washed out and remain harmless in the water of the trap; for, however offensive, and however overloaded water may become, so long as water remains, all experience goes to prove that no evil consequences follow. This was abundantly shown by the condition of the water of the Thames in the dry year of 1858, when, burdened as the water was with sewage—so much so, that the stench given off was unbearable—yet we find that neither the health of London generally nor that of those living near the river suffered from the consequences, but that this particular year was one of the healthiest known in London.

Dr. A. Fergus on water trap.

Malaria never extricated from a water surface.

Water washes sewer air.

Evidence of condition of River Thames in 1858.

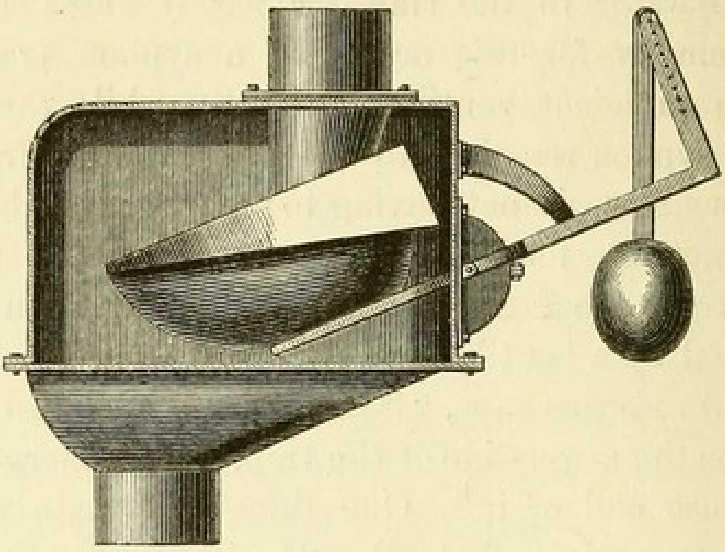
Mechanical or balance traps have been used both in

Mechanical, or balance traps.

Banner's patent trap.

soil pipes and in connection with water closets, gullies, &c. Fig. 124 is a representation of Mr. E. G. Banner's trap, patented in July, 1875, and intended to be used on the soil pipe of a house. The pan of this trap is provided with a stop, which prevents its being entirely emptied,

Fig. 124.



and a water seal is thus preserved when the balanced pan tilts. The illustration shows the position of the pan when open. This trap looks a formidable piece of machinery for effecting so simple an operation as that of trapping a soil pipe, and as the working parts pass from within a chamber in connection with the sewer, to its exterior in connection with the house, wear and tear, in the absence of attention, may lead to an escape of sewer air. It is questionable if this trap is any advance upon a similar description of trap that has been in use in France for many years past, illustrated in Fig. 125, and the invention of Rogier Mothes, which obtained a first-class medal at the International Exhibition of 1855. The trap consists simply of an arrangement of balanced valve or pan, that may be fitted either to the container of a closet, or on the soil pipe. It has been applied in both these positions in France, and has also been used both in latrines without water and in connection with water closets.

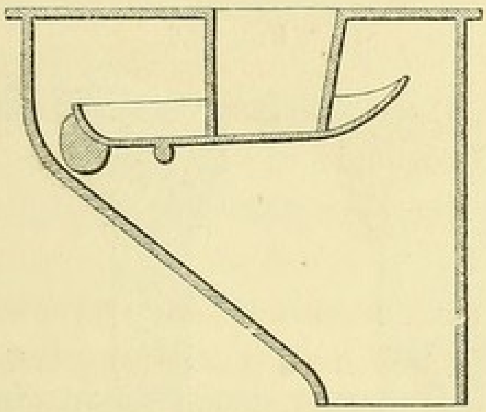
R. Mothes' balance trap.

Bowers' trap is an American invention, which was illustrated in the 'Engineer' of the 15th February, 1878, and consists of a combined water and mechanical trap. The pipe to be trapped dips into a vessel containing a ball of india-rubber, copper, or other material lighter than water, and which, by its buoyancy, rises and seals the bottom of the pipe that dips into the vessel of water which forms the water trap. A trap of this kind entirely depends upon the water trap, and if the water trap fails from the evaporation of the water, or the loss of water from any other cause, the mechanical trap is of no service. This valve is similar in

Bowers' float trap.

Bowers' trap compared with float tide-valve.

FIG. 125.



principle to the float valves that have been used as tide valves for small sewers in this country, and described at page 458. Bowers' trap may be used with advantage in positions liable to back-flow from the sewers.

The gullies in use at the present time are of two varieties, those which are intended to pass everything entering them to the sewers, and those intended to intercept all heavy matter, such as road detritus. In some districts where the sewers have ample fall and abundance of water for flushing, thus creating great velocity and transporting power, all such matters as enter gullies may be passed into the sewers, but in the generality of towns it is advisable to intercept the road detritus and other matters of this character, and to prevent their entrance into the sewers, as such matters are prone to concrete when they enter a sewer, and

Varieties of gullies in use.

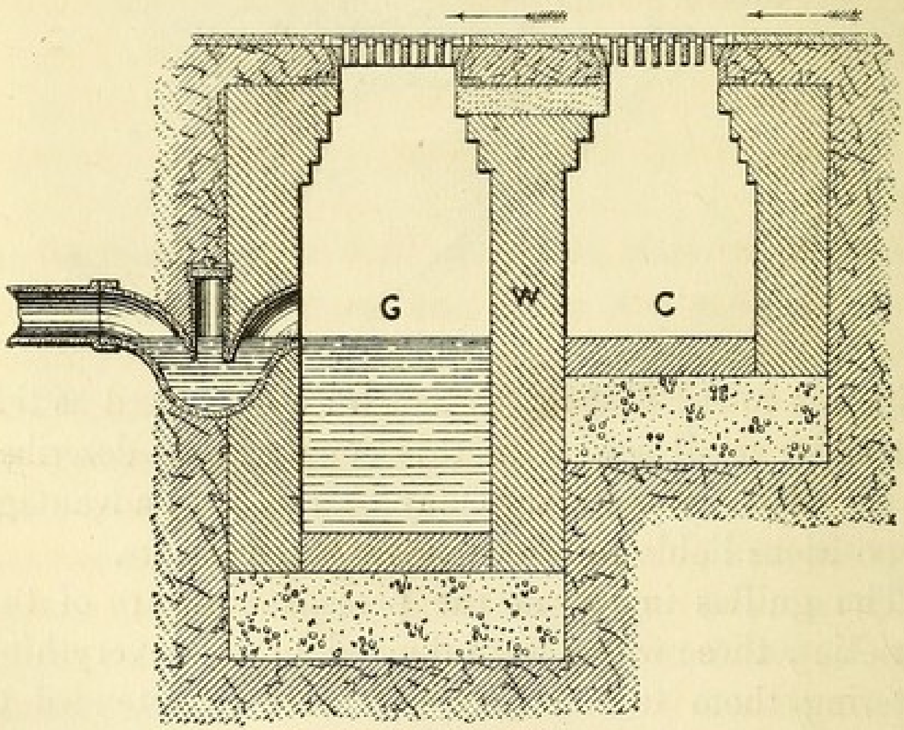
Advisable to intercept road detritus.

create stoppages which are both difficult and expensive to remove. All modern street gullies should therefore be constructed to intercept road detritus, and this can only be secured by making the catch-pit below the point of overflow into the sewers of considerable depth and size, and of such form at the bottom, that a rush of water entering the gully in time of storm, is not liable to stir up the deposit and carry it away. In some sandy districts the author has found it convenient, in order to intercept the sand carried down a steep road in time of storm, to provide a special catch-pit outside the ordinary gully, in which the sand may subside. This arrangement is shown in Fig. 126.

Mode of intercepting detritus.

Special catch-pit.

Fig. 126.



Description of Fig. 126.

G is the gully-hole proper, and C the catch-pit for sand. When necessary a communication closed by a valve may be fixed in the wall W between the sand catch-pit C, and the gully-hole G. Water flowing downhill in the direction of the arrows first flows over the open grating of the catch-pit before arriving at the gully grating; therefore, in time of storm, this catch-pit fills with water, and the heavy sand subsides in the water, the lighter substance flowing on to the gully. In a sandy district, in which such an arrangement as this is used, the walls of the catch-pit may with advantage be built in porous brickwork, so that, when a storm has subsided, the water may percolate into the subsoil, leaving the sand in a fit state for removal. Some engineers introduce two gullies placed close together, in order to intercept more readily the solid matter brought down in time of storm. Use of two gullies.

All trapped gullies should be constructed so as to be impervious to water, otherwise a loss of water may take place from leakage, which in many varieties of gully will lead to their becoming untrapped. Some gullies are liable to become untrapped by reason of the removal of the accumulation of deposit, which has the effect of lowering the water line. The gullies, Figs. 14, 15, 16, and 21, Plate XIV., are not liable to fail from this cause, and on this account are preferable to other forms. Gullies should be impervious. Effect of removal of deposit.

Gullies are liable to fail in time of frost, especially in very cold countries, as the gullies and traps get completely frozen up, and, when a sudden thaw takes place, they are found locked up with ice, so that the water cannot readily escape, and the streets in consequence get flooded. The remedy for this is to remove the water in the gully as far as possible from the surface. In some of the northern towns of Germany the water line is removed 5 feet from the surface, and the gullies are constructed with special reference to the breaking up of the ice in the traps, should it accumulate. Fig. 11, Plate XIV., represents the section of a street gully which has been used very successfully at Carlsruhe, Germany. The gully is made in two portions, with a trap in the division wall. Should the trap get frozen, the stone S is removed from that portion into which the trap discharges, and a suitable tool may be inserted to break up the ice. It may here be stated that gullies communicating with the sewers proper of a town in this Effect of frost on gullies. Carlsruhe gully.

country are not very liable to have their traps frozen, as the superior temperature of a sewer in winter effectually prevents the freezing of the traps; but in cases where a separate system is provided for surface drainage, the traps of gullies are very liable to become frozen. In all cases gullies are liable to become untrapped from leakage or from evaporation; therefore, to ensure the integrity of the traps, they should have the water constantly renewed in dry weather. This is readily done in the summer months by the ordinary water carts; at other times a special supply of water should be provided. All gullies should be regularly scavenged, not less frequently than once every six or ten days, as matters of a decomposable character are often passed into them, which decay and give off an offensive effluvium if left too long in the gully. After every storm the deposit in a gully should invariably be removed from the catch-pit in order to prevent its being washed into the sewer. Gullies placed in situations more as a security against flooding, as in the floors of strong rooms and such-like situations, are better sealed with oil, glycerine, or other liquid not so liable to evaporate as water. The gullies for stables and cow-houses should invariably be constructed with good-sized catch-pits, in order to prevent, as far as possible, the matters entering the sewers and choking them. Gullies are usually provided with grated coverings. Those for streets consist of bars, which should be arranged at right angles to the traffic, or otherwise narrow-wheeled vehicles are liable to get injured in the openings between the bars of the gratings. The gratings for yards and sinks are usually perforated, and are made either of iron, brass, or earthenware. Care should be taken when selecting a gully, that, if the grating is removed, the trap cannot also be removed, otherwise, from the inadvertence or carelessness of servants, the gullies or traps will be unsealed; this is invariably the case with the form of trap now in general use in most houses,

Temperature of sewer prevents freezing.

Water should be renewed in gullies.

Scavenging of gullies.

Fluid used to seal some gullies.

Gully gratings.

Selection of gullies.

called the bell trap, and illustrated in Fig. 1, Plate XV. In this trap the bell forming the seal is attached to the grating, and the removal of the grating, which enables servants more easily to pass matters into the drain, leaves the house in direct communication with the sewer. The locking of the gratings of sinks is an evil in an opposite direction. Every grating should be made loose, so that the traps may be freed and cleaned of all matters contained in them, such as have already been mentioned, as likely to lead to the unsealing of the traps. The size of pipe used for connecting gullies in streets with the public sewers depends upon the area of surface a gully may drain, but in practice the pipe should not be less than 6 inches in diameter, and for yard drainage pipes of not less than 4 inches diameter should be used to connect the gully with the drain.

Bell traps.

Locking gratings.

In Fig. 127 we have a plan, and in Fig. 128 a section of a gully designed by the author for the purpose of yard drainage. The trap in this gully will not be unsealed by the removal of the detritus from the pit, and on the other hand, the trap itself can readily be got at from the inside of the gully. In Fig. 129 is shown a plan of a very similar gully, and in Fig. 130 a section of the same gully, designed by the author, and which is adapted to the purpose of street drainage.

Gully for yard drainage.

Street gully.

A great variety in the form of both gullies and traps has, from time to time, been produced. In Plate XIV. we have a number of illustrations of different forms of gullies.

Description of Plate XIV.

Fig. 1 is a representation of a section of a street gully as used at Ixelles, France. It forms a simple trap in itself, and is intended as far as possible to transmit all matter, both solid and liquid, to the sewer.

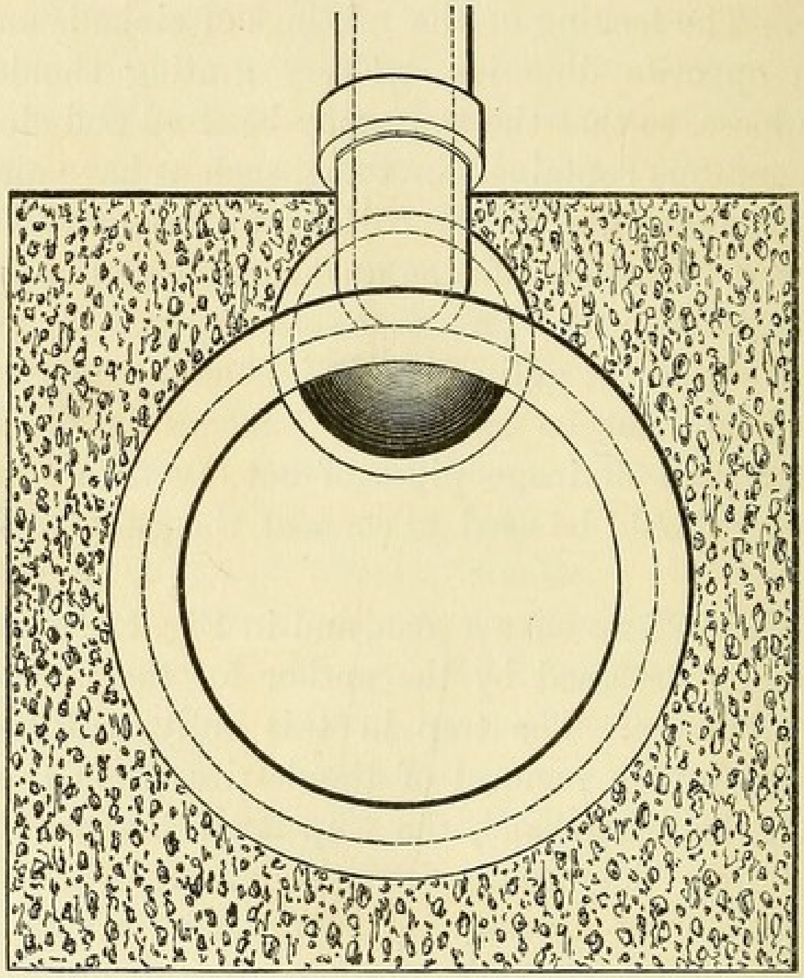
Ixelles gully.

Fig. 2 represents an English form of gully with a simple trap formed of earthenware at the bottom of the gully, and is constructed to transmit all matters to the sewers.

Gully with bottom trap.

Cast-iron continental gully. Fig. 3 represents a continental form of gully constructed entirely in cast iron, and intended to transmit all matters to the sewers.

Fig. 127.



Janniard gully. Fig. 4 is the representation of a gully invented by M. Janniard, architect to the French Government. It is constructed in iron, and is intended to transmit all matters to the sewers.

Walker's gully. Fig. 5 is a representation of Walker's trap. It consists of a pan hung with chains, so that the sides of the gully dip into the pan and form the trap. The pan can be detached on one side so as to enable any solid matter to be emptied out of it, which is then passed into the drain below.

Austin's gully. Fig. 6 is a representation of Austin's gully trap. It is an improvement upon the common bell trap, the bell not being attached to the cover, but loose, having a perforated bottom, and dropping down on the centre cone D. The top grating is hinged and can be raised, so that the trap can be easily cleaned out. B is the level of the surface, and C of the water; the arrows indicate the direction of the passage of the water to the drains.

FIG. 128.

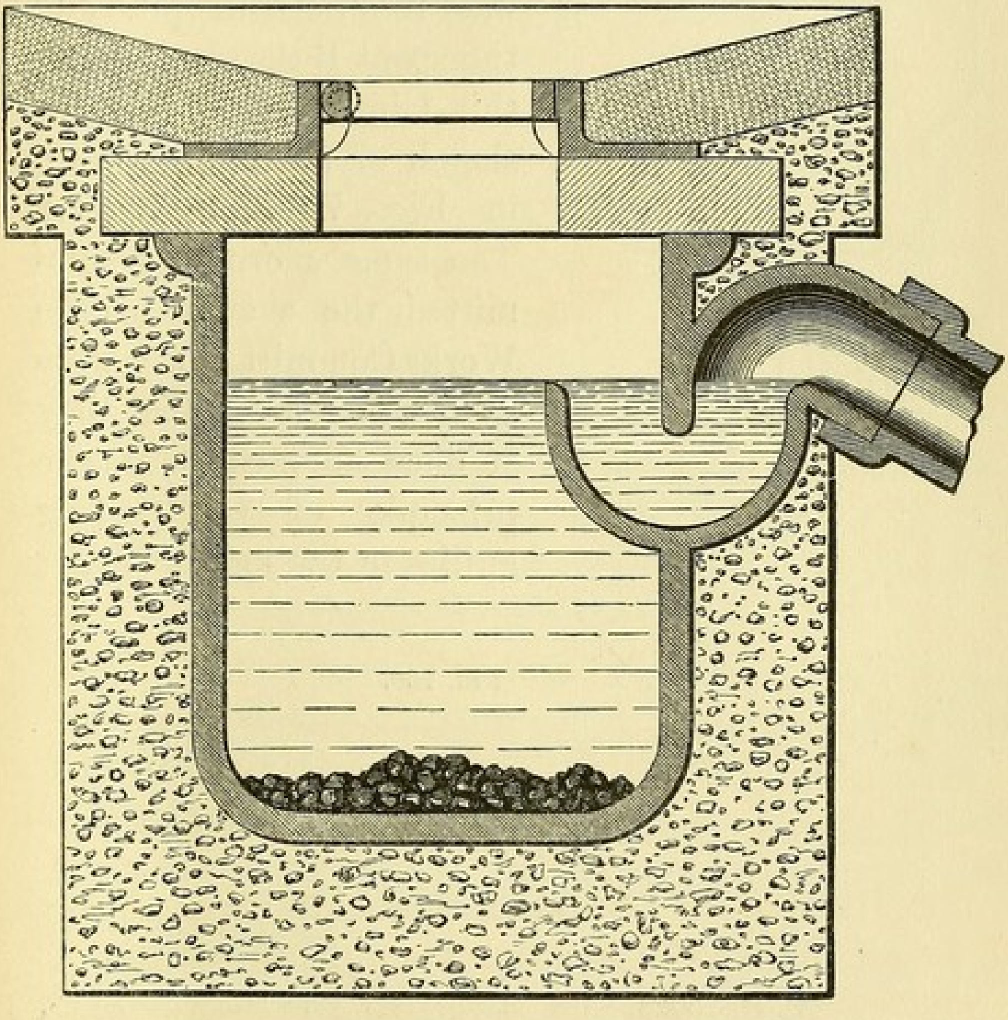
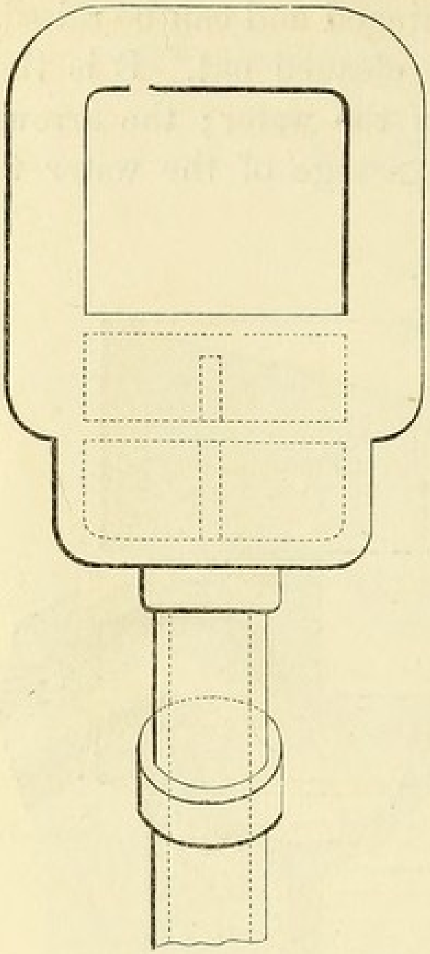


Fig. 7 is a representation of a gully invented by Mr. John Phillips, C.E., under the following circumstances, which he communicated to the author: "There had been a discussion by the Works Committee of the Metropolitan Commission of Sewers as to the trapping of gullies. I told the committee that not only should the gullies be trapped, so as to prevent the gases in the sewers from escaping near the footway, but that they should be constructed with a deep pit, to keep the road detritus out of the sewers. The problem was

How trapped gullies came to be invented by Mr. John Phillips.

Fig. 129.



solved as follows: While I was sitting at breakfast one morning, I saw in the form of the coffee-pot before me on the table, the identical gully required. The lower part of the pot A, Fig. 131, was the detritus pit, and the spout B the trap. From this I immediately made a sketch of the gully (shown in Fig. 7, Plate XIV.). The same morning I submitted the sketch to the Works Committee, who were so pleased with it that they at once adopted it as the principle of constructing gullies in the metropolis."

Fig. 130.

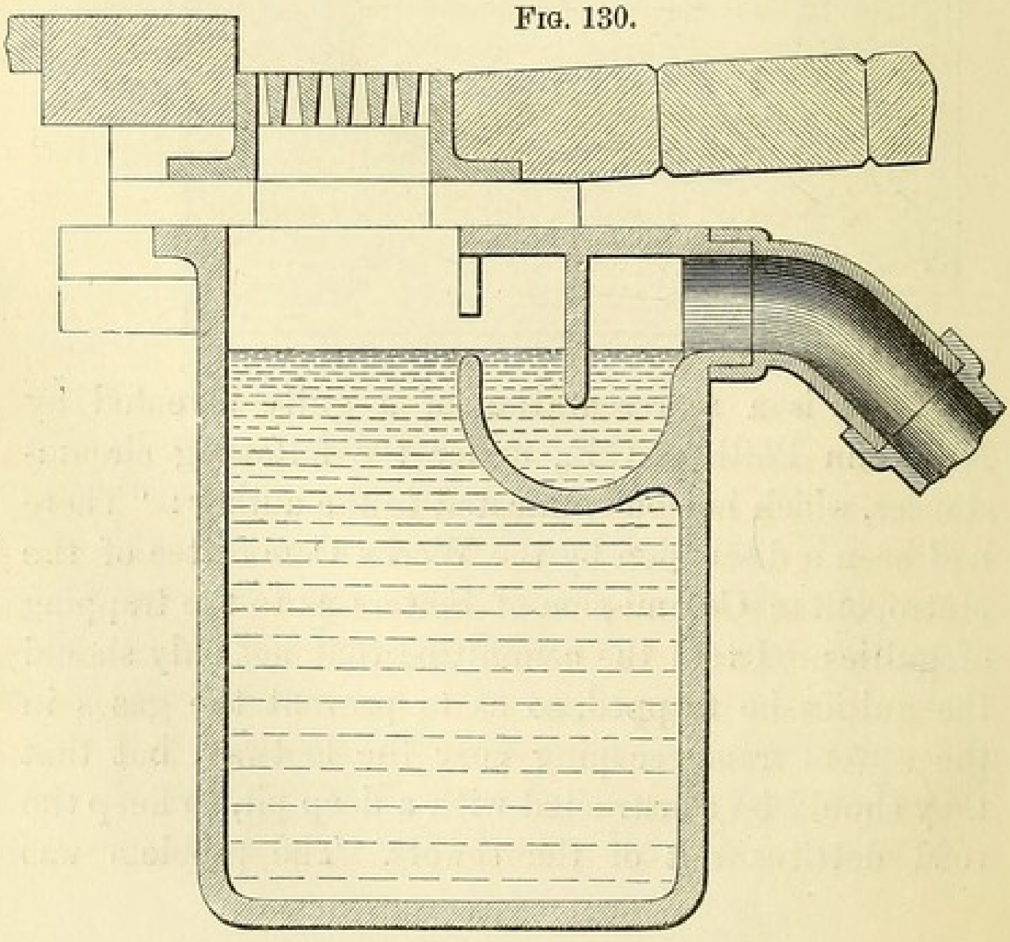


Fig. 8 is the representation of a London gully-hole, with the catch-pit constructed under the footpath. The catch-pool is placed in this position to facilitate its being cleansed, and this form was considered suitable for narrow streets of great traffic. London gully for narrow streets.

Fig. 9 is the representation of a large gully with catch-pit under the footpath. This form was considered suitable for streets of great traffic, where there was a large amount of road detritus to be intercepted. Gully for streets of great traffic.

FIG. 131.

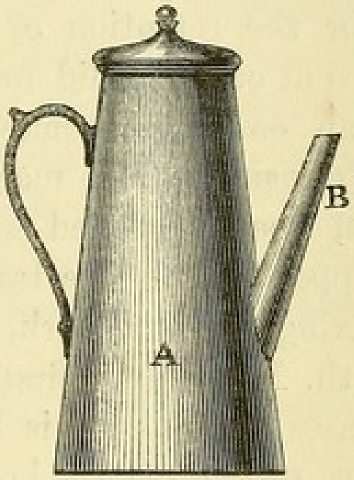


Fig. 10 is a representation of a street gully with earthenware trap. This gully is made of concrete and in one piece. Wrought-iron bands are introduced into the interior of the concrete to tie the whole together. It has been used in Dantzic, and the material is found to withstand the effects of the severe climate. Dantzic gully.

Fig. 11 is a form of German gully used at Carlsruhe, which has before * been referred to in connection with the influence of frost on street gullies. Carlsruhe gully.

Fig. 12 represents a section of Lowe's Patent Gully. This is a good form of gully for yards and such-like places. Lowe's gully.

Fig. 13 is a representation of an earthenware gully suitable for small yards and courts, but the curved bottom with the outlet near it renders it liable, with a large volume of water flowing through the gully, to transmit detritus and other materials into the sewers. Earthenware gully.

Fig. 14 is a representation of a double-trapped London street-gully; the smaller catch-pit B in this case is not so liable to the influence of evaporation as the exposed water area of the catch-pit A, and, moreover, the emptying of the larger catch-pit still leaves the gully trapped. Double-trapped London gully.

Figs. 15 and 15A represent the plan and section of

* Vide page 429.

Newton's gully. Advantages of Newton's gully.

Mr. John Newton's gully. The advantages claimed for this gully are:—"1st. A perfect trap at all times, the ordinary syphons ceasing to act when the level of the water is reduced by the removal of deposited matters. 2nd. Very little evaporation in summer, and no liability to freezing in winter. 3rd. Ample space for the retention of the road detritus. 4th. In the event of any solid matter accumulating in the trap, it can easily be removed when the gully is emptied. Provision is also made for flushing the drains through an aperture fitted with an air-tight stopper in the upper part of the trap. 5th. Unusual facilities in the fixing, no brickwork, stone, or cement, being required. 6th. Economy in first cost and durability." In ordinary cases gullies of this kind 1 ft. 6 in. × 1 ft. × 2 ft. 9 in. are recommended, but when the gullies are less than 40 yards apart a smaller size may be introduced, or 1 ft. 2 in. × 1 ft. × 2 ft. 2 in. These gullies are made entirely of cast iron.

Size of gullies.

Gully designed by author.

Fig. 16 represents a form of gully that has been used by the author for many years past. The trap is of the flat syphon variety, and is not affected by the lowering of the water line in the gully. Instead of being provided with a plain syphon of the variety shown in the drawing, it may be furnished with a syphon and junction for inspection, as shown in Plate XV., Fig. 16*a*.

Butt's gully with loose dirt-box.

Fig. 17 is a representation of the section of "Butt's" Gloucester gully, with loose dirt-box. "The grating *a* and the dip *b* are made separate for the convenience of casting and for lifting off, and the lower part of the dip *b* drops into a sediment box, which box rests on and is regulated by half bricks *d d*. By these means a stench trap is formed with the water surface reduced, so as to lessen the evaporation, a desideratum in times of drought. The sides are formed of brickwork. As the water and filth pass through grating *a* and down the dip *b*, they are finally lodged in the box *c*, which can be emptied by one man, by merely lifting out the box by the handles and emptying it into the scavenger's cart, thus avoiding the offensive and expensive mode of cleaning hitherto practised of pit traps; the water running over, in the direction of the arrows, ultimately escapes through the drain pipe *e*." It should be observed that unless the drain *e* is trapped, the removal of the dirt-box leaves the drain untrapped.

Sharp's gully.

Fig. 18 is a representation of Sharp's Lancaster double-trapped gully with movable dirt-box. This form of gully is very similar to that shown in Fig. 17, and unless provided with a trap below, as shown in this illustration, the removal of the dirt-box leaves the gully untrapped.

Clark's double-trapped gully.

Fig. 19 is a representation of Clark's Carlisle double-trapped gully, with movable dirt-box and bottom discharge. This form of gully would be untrapped by the removal of the dirt-box.

Clark's gully, with side discharge.

Fig. 20 is a representation of Clark's double-trapped Carlisle gully, with movable dirt-box and side discharge. This gully would remain trapped after removal of the dirt-box, provided there is sufficient volume of water retained in the bottom of the casing to compensate for the loss arising from the displacement of the water by the removal of the dirt-box.

Clark's treble-trapped gully.

Fig. 21 is a representation of Clark's treble-trapped gully, with movable dirt-box. The great advantage of this form of gully consists in the fact that it remains trapped when the dirt-box is removed. In all the forms of Clark's gully the dirt-box is provided with a perforated gallery round the top, so that they will retain some floating substances, an advantage which the other forms of gully we have considered, with movable dirt-box, do not possess; consequently in the gullies with the imperfect form of dirt-box such matters are washed over the lip of the box into the drains.

Gully for low situation.

Figs. 22 and 22A are illustrations showing the section and plan of one of Clark's gullies combined with a

Young's valve chamber. "These chambers and valves are constructed for the purpose of preventing the back-flow of sewage from drains in low situations in times of flood. They consist of a chamber fitted to the outlet pipe of a street or yard gully, in which is suspended an india-rubber ball, which on ordinary occasions hangs clear of any surface water entering the chamber from the gully, and in times of flood is floated into a gun-metal seat at the mouth of the chamber, thus preventing any back-flow from the drains reaching the surface. These ball valves are self-acting, requiring no attention after once being fixed. The interior of the chamber is provided with guides to conduct the ball into its seat, and so made that the ball cannot possibly become fixed. A movable water-tight cover is also provided for the purpose of inspection if required." Another form of this gully and valve chamber is made, and is specially adapted for smaller drains; it can be readily applied to a house-drain, and is very suitable for the drainage of cellars and other places liable to be flooded from the sewers.

Prevention of flooding of cellars.

Brighton gully.

Fig. 23 is an illustration of the section of a catch-pit and valves of an iron gully as used at Brighton. It combines both a dip and valve trap.

Doulton's gully.

Fig. 24 is an illustration of the section and valves of a very similar gully to the former. It is made of earthenware by Messrs. Henry Doulton and Co., and is intended to be used as a street gully. As valves cannot be implicitly depended upon as efficient traps, these forms of gullies should all be filled up with water after being freed from sediment, in order to bring into action the water trap which is provided.

Balance gully.

Figs. 25 and 25A are representations of a totally different kind of gully from those which we have hitherto been considering. It is called a balance gully. The gully may be allowed to fill up with water or dirt until the load accumulated overcomes the resistance of the balance weight attached, when the valve tilts and discharges the contents of the gully into the drains below. This form of gully, although in use in many towns, cannot be recommended, for after careful examination the valves are never found to be tight, materials get under them to prevent their closing; and, moreover, every time they discharge their contents, they allow air to escape, as every discharge displaces at least an equal volume of the sewer air.

Valves never remain tight.

Discharge of the sewer air.

Figs. 26 and 26A are representations of Thompson's balance trap. The advantage claimed for this particular form of balance trap is that it cannot gape, as other balance-valve traps do, with a load only slightly exceeding the balance weight; as, in addition to the balance valve, a balance latch is provided, and sufficient weight must accumulate to move both the latch and pan before the valve will open, when it opens suddenly, and quickly closes after discharging the contents of the gully. The pan is supposed to be kept air-tight by closing against a ring of vulcanized india-rubber. This form of trap has the same defects as have already been mentioned in considering the previous form of balance valve.

Balance gully with balance catch.

Fig. 27 represents a gully trapped with a shackle valve, with manhole for inspection provided in the footpath.

Shackle valve.

Fig. 28 is an illustration of a shackle-valve gully and inspection hole made in one frame of cast iron.

Shackle valve and hole for inspection.

Fig. 29 is an illustration of a gully with catch-pit and shackle-valve trap. This form of gully is used by the Islington Vestry. The catch-pit is built in bricks and cement, and is 1 ft. 6 in. × 3 ft. × 5 ft. 6 in. Such a gully as here represented cannot be recommended, as, whenever it is brought into action by water opening the valve, sewer gas can always escape by the open space above the water line. Moreover, it is liable to fail from other causes, which have already been considered when speaking of valve traps.*

Islington gully.

* Vide page 423.

Description of Plate XV.

In Plate XV. are represented numerous forms of traps which have been introduced at various times for sealing the inlets of drains and sewers, and preventing the escape of sewer gas.

Bell trap.

Fig. 1 is an illustration of the section of the ordinary bell trap. These traps consist of a bell attached to the grating and dipping into the water retained in the chamber of the trap, and covering the discharge pipe. The seal of these traps rarely exceeds one quarter of an inch of water in depth, and they cannot be depended upon, as servants will remove the grating and the trap with them, and so place the house in direct communication with the sewer. Moreover, the small amount of seal provided in traps of this class is soon lost by evaporation, especially in the heated rooms in which they are often placed.

Clark's valve trap.

Fig. 2 is an illustration of the self-acting valve trap of Mr. Clark, of Reading. It consists of a lead receiver $4\frac{1}{2}$ inches diameter, with a brass grate on the top. The receiver holds about half an inch of water, into which the outer edge of the hollow-turned copper ball dips when its indented bottom rests on the top of the outlet pipe, forming a valve trap. When water enters through the brass grating, the ball floats and allows it to escape, but so soon as the flow subsides, the ball resumes its position. This is a decided improvement on the ordinary bell trap, but is liable to be tampered with, and both the grating and valve may be readily removed, leaving the drain untrapped.

Trap for Surrey and Kent sewers.

Fig. 3 is a form of sink and syphon trap, introduced in the year 1848 for the Surrey and Kent sewers, and specially adopted for sinks of sculleries and areas.

Tye and Andrews' trap.

Fig. 4 is an illustration of Tye and Andrews' sink trap. Its advantage consists in the greater depth of seal provided. The gratings are usually locked, which is no advantage, as servants should be instructed not to cast matters down the gullies which they are not intended to receive, and also to periodically clean out the trap in order to free it from those matters liable to unseal it. Ample space, therefore, should be provided in all traps, so that the hand may be freely inserted for the removal of any matter prejudicial to the action of the trap. When the plan of cutting off the sinks from drains, which is hereafter considered at page 487, is adopted, servants will soon find out that to pass any matter not intended to be received by a trap, is not to get rid of it, as it will again be brought to light on the outside trap or gully.

Cutting off sinks from direct communication with drains.

Fig. 5 is a representation of Antill's trap with Stidders' lock grating. This forms a very efficient trap for a sink, as, like the previous trap, it cannot be tampered with when the grating is removed.

Antill's trap.

Fig. 6 is a trap manufactured by Mr. Finch, of Holborn, suitable for a lavatory, constructed in order to catch soap. The plug at the bottom may be removed, and the deposit of soap taken out. A is the pipe leading from the bottom of the basin, B is the overflow pipe from the basin, and O is the discharge pipe.

Finch's soap trap.

Fig. 7 is an illustration of an ordinary earthenware sink trap with square top.

Earthenware sink trap.

Fig. 8 is an illustration of a horizontal house trap by Messrs. Brooke, of Huddersfield.

Brooke's trap.

Fig. 9 is an illustration of another house trap by Messrs. Brooke, of Huddersfield, but supplied with a down outlet.

Brooke's trap, down outlet.

Fig. 10 is an ordinary house trap of Lowe's pattern.

Lowe's trap.

Fig. 11 is an illustration of a trap for a rain-water pipe, as manufactured by Mr. Clark, of Carlisle. Traps in connection with rain-water pipes cannot be depended upon, unless the means are provided for constantly renewing the water in the trap, as in periods of long-continued dry weather the water will evaporate and the trap be rendered useless.*

Rain-water pipe trap.

Traps useless in dry weather.

Fig. 12 represents a combined gully and trap. This form of apparatus will be found extremely useful in a

Gully and trap.

* Vide page 499 as to mode of treating rain-water pipes.

variety of places, when ordinary traps could not be depended upon. Such a trap as this placed upon the main line of a drain through which water is always flowing, would never become unsealed in dry weather, and therefore could be depended upon when other traps would fail for want of water to seal them.

Advantages of this trap.

Position of ventilation pipe.

Fig. 13 is an illustration of an ordinary trapped gully, showing the proper position of the ventilating pipe.

Mansergh's trap.

Figs. 14 and 14A are illustrations of the plan and section of Mansergh's trap. This trap is specially intended to prevent the ingress of sewer gas into houses by "waste and overflow pipes from cisterns, baths, lavatories, bath and lavatory safes, and sinks," and is always to be placed outside the house. In one piece of stoneware two water seals are formed, and between the two is an open communication to the air by means of the surface grating. If, therefore, the pressure in the branch drain is sufficient to force the gas through the first or lower seal, it will escape into the air, and cannot possibly pass the second seal, and so enter the house. It has the advantage of receiving the waste water underground, out of sight; there is, consequently, never any foul water on the surface. The open grating admits of its serving as a yard gully.

Advantages of this trap.

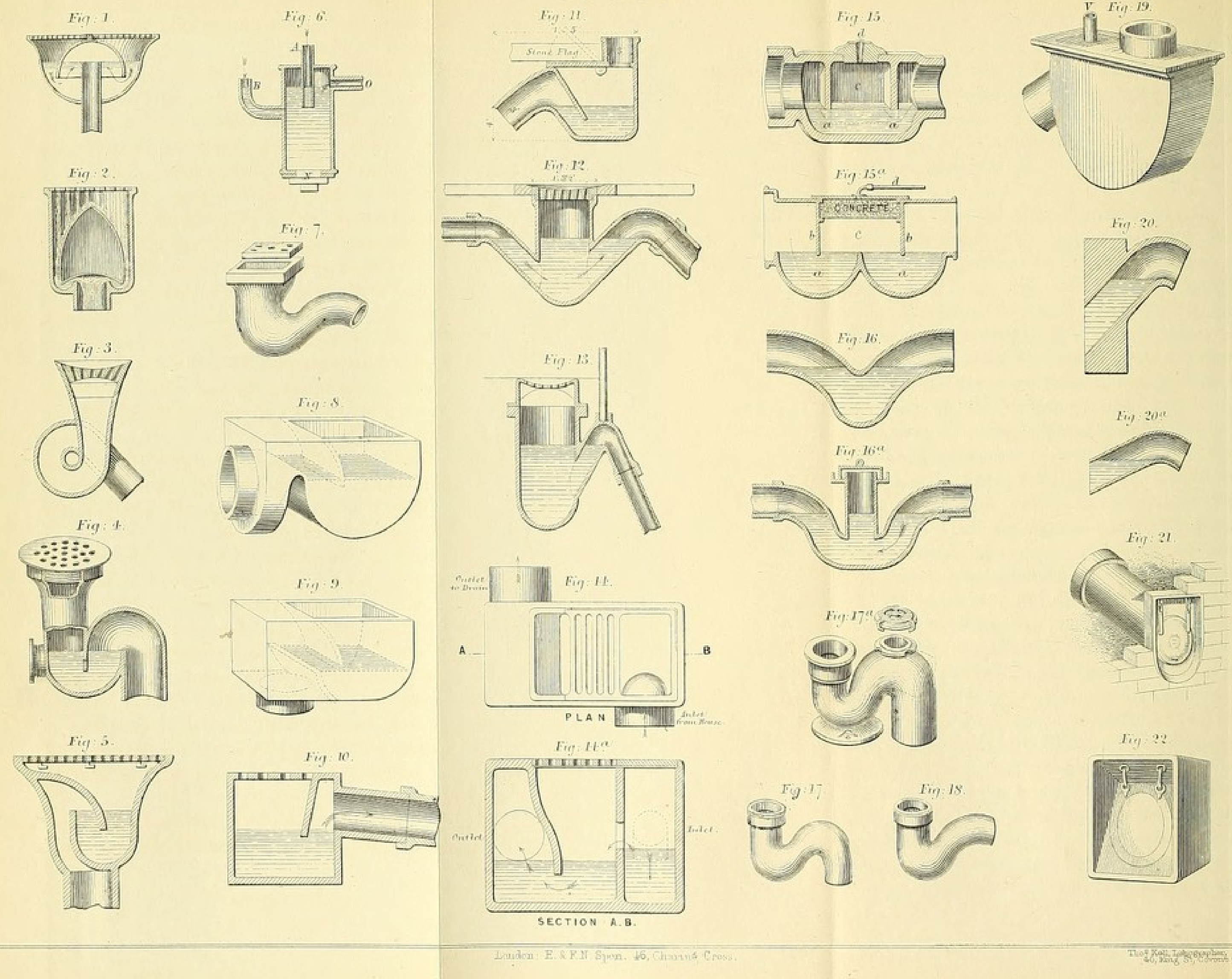
Cottam's trap.

Figs. 15 and 15A are illustrations of Cottam's traps. In Fig. 15 the trap is provided with a ventilating pipe, and in Fig. 15A charcoal is applied in mass, through which sewer air which may pass the trap is allowed to escape. This form of trap is called by its inventor the "Intercepter Trap," and is intended to be fixed close to the outer wall of the building. "The receptacle for the water-lute is in two compartments *a a*, into each of which a diaphragm or plate *b* dips, and an intercepting chamber *c* is thus formed, by means of which the sewer gas forcing a passage is caught and carried off by a pipe *d* to any convenient place for its escape."

Flat syphon trap.

Figs. 16 and 16A are representations of an ordinary

TRAPS.



London: E. & F.N. Spon. 46, Charing Cross.
Thos Kell, Lithographer, 40, King St, Covent Garden.

flat syphon trap. The latter illustration is provided with a junction for inspecting and cleaning the trap when required.

Figs. 17 and 17A are representations of an S trap, so called from its being of the shape of the letter S. The latter form illustrated is fitted with an opening on the top of the trap, closed with an air-tight cap, made after the manner of the stopper of a pickle jar. S trap.

Fig. 18 is an ordinary P syphon trap. This form of trap is largely used, and is well adapted to form the trap of a water-closet, and is much more readily flushed and kept clean than some other forms of syphon trap. P trap.

Fig. 19 is the representation of a D trap, with ventilating pipe V. This form of trap is very generally adopted by plumbers, and is usually made in lead. It is also made in earthenware. It is the dip of the soil pipe in the trap which forms the seal. This trap is not such a good form of trap as some of the other traps hitherto considered. D trap with ventilation pipe.

Figs. 20 and 20A illustrate two forms of trap used in connection with gullies, but they are not ordinarily so good as those represented in Figs. 16 and 16A, for reasons already given at page 429. Gully trap.

Fig. 21 is an illustration of a pipe fitted with a shackle valve. This pipe is supposed to be inserted into the outfall sewer, to prevent the entrance of foul air and vermin passing up the house-drain. The defects of this form of trap have already been pointed out in considering the subject of valve traps.* It may here, however, be observed that valves of this description may often be used with advantage in a line of sewer for the purpose of preventing the ascension of any large volume of sewer air, and so may be made to assist ventilation. Shackle trap. Traps of this description aid ventilation.

Fig. 22 is an illustration of a shackle valve attached to a block of earthenware, and usually called a block valve. Block valve.

* Vide page 423.

CHAPTER XXXI.

SEA OUTFALLS.

Outfall for seaside towns.

In considering the question of the best outfall for a district, it will generally be found that the best method of disposing of the sewage of a seaside place is to discharge it direct into the sea.

It may appear to many that the pouring so much sewage into the sea is a great waste of fertilizing matter; having regard, however, to the fact that no chemical process has yet been discovered that will abstract the fertilizing matter from sewage so as to leave a profit, and as experience has shown that the only mode of effectually removing the fertilizing and polluting matter from sewage is to apply it continually to land.

Difficulties of applying sewage to land.

In the case of most districts that use sea outfalls, in order to apply the sewage to land, it would have to be pumped. The cost of pumping, added to the cost of other necessary works, and the difficulties and expenses attendant on the procuring of land by a sanitary authority, and afterwards of working a sewage farm at a profit, are such that it becomes true economy to cast into the sea that which may appear a valuable commodity. It might also be added, that the places on the sea-coast that require sewering are usually health resorts, and the public when in search of health are very sentimental, and may object, in the present age of ignorance in sanitary matters, to the proximity of a sewage farm, or sewage work; and thus a prejudice, however foolish and unreal, would be created that might utterly ruin the reputation of the place. With a sea outfall it is equally important that the hydra-headed monster sewage should be really got rid

Economy to cast sewage away.

Prejudice against sewage application.

Sewage must be got rid of.

of when cast into the sea, and not left to hug the shore, or be returned by the tidal wave.

Position of sea outfall.

In considering the position of a sea outfall, due regard must be paid to tidal or other currents, and careful experiments should invariably be made to ascertain the direction of the flow at all stages of the tide, and extending over a sufficiently long period, so as to embrace high spring tides and the lowest ebb tides, and at the same time to ascertain the effect of the prevailing and other winds, both on the currents and the rise and fall of the tide. Experiments should also be made on the rise and fall of the tides, for although theoretically the tide both flows and ebbs six hours at a time, there are great exceptions to this rule of even ebb and flow. The estuary of a river, some peculiar formation of the shore, the prevailing winds, all tend to modify the equable flow and ebb of the tide, so that we have places on our coasts in which tides only flow four hours and ebb eight hours. In tidal rivers, as a rule, the tide always ebbs for a longer period than it flows, hence by the pouring of sewage into such rivers it is got rid of. If it were not for this difference in the periods of ebb and flow, sewage put into a tidal river would simply pass up and down until destroyed by exposure and oxidation. The tidal currents must always be ascertained with submerged floats. A float exposed to the action of the wind, or such as are only partly submerged and have a large part exposed to wind influences, cannot indicate the true direction of tidal currents. A very good and easily made float, and one that has been used by the author, consists of any ordinary biscuit tin, on which the lid may be fastened, and a few holes made in it to admit the water, and then suspend it to a float at the surface by means of a cord or light chain. This float may be used to ascertain the velocity and direction of tidal currents at various depths, and it is well that such experiments should be made at various depths, as very different currents may be discovered

Nature of the observations that should be made.

Unequal ebb and flow of tides.

Submerged floats must be used.

Description of float.

at different depths, a short distance from the shore. For rough experiments, an ordinary champagne bottle, corked and ballasted with water, so that it will swim with a part of the neck of the bottle only out of the water, forms a good experimental float for tidal observations. Other forms of tidal floats are used, all of which are constructed on the principle of exposing the largest possible area to the tidal current, and the least to the influence of the wind. Tidal observations having reference to the rise and fall of the tide, are best observed by a self-registering recording gauge.

Champagne bottle float.

Recording gauge.

It will be found that, not unfrequently, when a sea is driven by the prevailing wind, or other cause, on to the shore, there is a constant current at the surface on the shore, the tendency of which is to heap up, as it were, the water on the shore, and this raising of the water creates a ground swell, or current, which flows directly off the shore; and so what might appear to be an unfavourable condition for a sea outfall may, by proper selection of the point of discharge, become a very favourable condition for effectually getting rid of the sewage discharged into the sea. An eddy tide is by no means a rare occurrence on some coasts, or a tide the current of which moves round and round, so that anything cast within its influence is usually deposited on the shore at low water, instead of being carried out to sea. The formation of sand banks a distance from shore, and any other disturbing cause, which not unfrequently affects the flow of tidal currents, must be fully considered before the point of outfall is selected.

Currents in and off the shore.

Influence of an eddy tide.

Sand banks.

With reference to tidal currents and the place needing a sea outfall, it should be observed that the point of discharge should be ordinarily selected in reference to the tidal currents, that it should be located below the place needing the outfall, and not above it; that is, it should be below the place in the direction of the falling tide, and not above the place. If an outfall is placed in the tidal way above a town using such outfall, the sewage has to pass before the front of the town. This,

Point of outfall in reference to town.

in sea-coast towns, especially such as owe their attractiveness to bathing grounds, must be highly injurious to the place, for it must be always borne in mind that, in most seaside places, the discharge of sewage will mostly always take place on the ebb tide. What would be thought if the outfalls for the London sewers were made to discharge at Richmond instead of at Crossness; yet just as the position of Richmond is in respect to London, so are many sea outfalls located in respect to the places that have constructed them.

Sewage not to flow past town.

Improper positions of sea outfalls.

It is necessary that observations should be made on the rise and fall of the tide. This is necessary in order to ascertain if a gravitation outfall can be secured, or whether or not pumping will be necessary. It may be said that, in the generality of places, if due provision is made for storage, and if the principle of interception is also taken into account, that has already been referred to at page 172, there are few places in this country that need to resort to the expensive process of pumping the sewage in order to secure a free outfall into the sea. When once ascertained, the rise and fall of the tide at a particular place will be found to be very uniform, so uniform indeed, that Sir William Thompson has constructed a tidal machine that by clockwork arrangement shows the state of the tide at any period, at the particular place in which it may be adapted, without recourse to direct observation. At spring tides we get both the highest and the lowest water levels, and at such periods there is no difficulty in getting a good outfall. The most difficult period of discharge for a sea outlet occurs at neap tides, when the tides do not rise so high, and, on the other hand, do not fall so low as at other periods, and as it is the lowness of the tide level that increases the efficiency of the outfall, so it will be found that if our outfalls are calculated to work efficiently at the period of neap tides, we need not trouble ourselves about them at the period of spring tides.

Gravitation outfalls.

Interception.

Rise and fall of tides uniform.

Sir W. Thompson's tidal machine.

Spring tides.

Neap tides.

The discharge from a sea outlet at any time is due to the difference of the level of the water within and

Discharge due to fall.

without the sewer. In a long length of outfall, this may be reduced to the rate of inclination by observing that whatever the fall of the water, the length is a constant quantity. For example, assuming that the length of a sea outfall is 3000 feet, and that the lowest water at neap tides would give a difference of 6 feet between the level of the lowest water within the sewer and in the sea-way, then we know that the discharge, under such conditions, would be equivalent to a sewer having an inclination of 1 in 500. In practice, the diminution of head within a sewer properly adjusted follows the fall of the tide, so that the discharge is pretty uniform. This will be seen by the diagrams, Plate XVI., of the gaugings within the tank sewer at Llandudno. The fall in the water is represented by a pretty straight line, showing that the discharge, when it does commence, is proportionate to the varying capacity of the sewer, and the available fall due to the rate at which the tide ebbs. So long as the fall within the sewer follows the fall in the sea-way, or so long as the rise in the sea is followed by an equal rise in the sewer, the discharge will continue pretty equable, and will be due to the difference of level observed, and as the tide rises so as to gain upon the level of the water in the sewer, the discharge after this period would fall off to nothing. The quantity to be discharged after the period when the water in the sea-way begins to gain on and diminish the available fall, and also the period when there is an entirely free outfall, can only be ascertained after experiments upon the rate of the rise and fall of the tide at any particular place.

Diminution of head follows fall of tide.

Discharge from Llandudno sea outfall.

Quantity and period of discharge only arrived at by experiment.

It must not be omitted to be mentioned as a matter of very considerable importance in a sea outfall, that if the outfall is made to discharge against any current in the sea-way, the discharge will be very considerably impeded; on the other hand, if the outfall is carried out in lines nearly parallel with the currents, it will be found that whenever the current in the sea-way has a greater speed than the current in the sewage outfall,

Influence of sea currents on discharge.

the sea current will produce all the influences of an exhauster, and induce a current in the sewage outfall, which will very materially increase the discharge from it. In the case of the Llandudno sea outfall, the pipes are carried in such a direction into the sea-way that the full effect of the rapid current of the ebb tide out of the Conway river is used in aid of assisting the discharge, and consequently the actual observed discharge of this outfall is greatly increased by the sea currents, which often exceed 5 feet per second.* It must be clear to the most casual observer, after what has already been said, that sea or tidal currents may either greatly prejudice our sea outfalls, or may be made a valuable aid to promote discharge, the result depending entirely on the position chosen for the outfall, and also that the outlet must be submerged, so as to be entirely below the level of the water.

Increase of discharge in sea outfall.

Sea currents out of Conway river.

In properly adjusted sea outfalls, where we have large quantities of water to discharge, the largest quantity of water should be stored at the highest level, so that the period of discharge commences earlier, and is also continued for a longer period, and we thus get a correspondingly greater discharge when we have the largest quantity to discharge, whereas, with small quantities, the period of discharge is naturally diminished, as the head under which it is discharged is small.

Largest quantity of water stored at highest level.

Small quantities.

The oval form of section is well adapted for a tank sewer, as a large proportion of the sewage is stored at a high level which will facilitate its rapid discharge.

All sea outfalls should be designed to discharge the largest quantity at the period of neap tides, and if so calculated and constructed, they will be found efficient at all other states of the tide.

Neap tide to be the period for the basis of calculation.

It should also be observed in constructing a sea outfall, that the position chosen and the nature of the works must be such as not to interfere with navigation.

Navigation not to be impeded.

The prevailing winds may also have an effect in

* Vide p. 455.

Influence of prevailing winds.

some places, especially in the case where fresh sewage is discharged into the sea, as a part of such sewage will consist of floating fæcal, fatty, and other matters, which might be brought back on to the shore by the wind. In such cases it may be desirable, by suitable screens, to intercept the floating matter in the penstock chamber, which it will generally be necessary to provide in the case of a sea outfall.

Fisheries.

The position of a sea outfall should also be considered in reference to the fisheries. In the case of fresh sewage discharged into the sea from properly constructed, self-cleansing sewers, no evil will follow, but the case is very different when putrefying sewage is passed into the sea. The former is food for the fishes, the latter an agent that will either destroy, or drive away, what may be of considerable value and importance to the neighbourhood; and it should be borne in mind, in reference to sewers which are liable, from a variety of causes, to receive sea-water, that the action of such water very speedily sets up decomposition, so as to render the sewage poisonous to fishes.

Influence of sewage on fisheries.

Sewers receiving sea-water.

Importance of the protection of sea birds.

It ought to be observed that the gull and other sea birds are excellent scavengers, and in the case of a sea outfall, these creatures will carry off any floating matter, and therefore it is the true interest of a sanitary authority, using a sea outfall, to protect nature's scavengers, and to prevent them from being ruthlessly shot or driven away from the outfalls to which they are attracted.

Action of sea on outfall works.

When constructing a sea outfall, it must also be considered what will be the action of the sea on the structural works proposed. If we cast a stone on a sandy sea-shore, even in the calmest weather, we shall find that the effect of the tide is not to bury it up, but to wear away, or wash away, the sand from all around it, so that when the tide has receded, the stone is in a hole. This well-known action of the tide will undermine any superficial structure placed on a sandy shore.

On some shores, the sand itself is constantly on the move from the shore towards the sea, in fact this was found to be the case by the author at Llandudno, and so great was the movement of the sandy shore seaward, that the iron outfall pipe that was laid some 3 feet to 4 feet deep in the sand, was moved bodily forward by this action of the movement of the sand, and necessitated means being taken, by the introduction of piling, to prevent the lateral movement. Any structural work extending above the shore will, more or less, give a direction to the flow of the tidal current, and consequently a current will ordinarily be created parallel to the line of the exposed work, and which causes a scour that may undermine the work, unless measures are taken to prevent its action. The effect of storms and heavy seas will very materially increase the effect of scour, so that the destruction of a sea outfall may take place, partly by the undermining action, and partly by the increased pressure brought, at the same time, to bear on the structure. The author has adopted a mode of driving at intervals across, or at right angles to the line of sea outfall, a row of sheet piling, which tends to break the continuity of the current set up along the site of the outfall, and by a liberal use of stone, the intervening portion may be very effectually protected. It should be borne in mind that all long sea outfalls in exposed positions will require more or less constant attention, to guard them against injury, and the slightest damage that may occur should at once be made good, or much more serious and expensive repairs will inevitably follow.

Movement of the sea sands.

Shifting of outfall of Llandudno.

Structural work and direction of flow.

Scour and injury that follows.

Cross piling to break current.

Sea outfalls require constant attention.

In Plate XVI. are shown some of the details of the sea outfall designed by the author for Llandudno. It should be observed by way of caution to those using a sea outfall, that the recent system of sewerage carried out by the author at Llandudno was necessitated by reason of a former system having failed to provide those benefits that such a beautiful and attractive place required as a health resort. In the former scheme of

Llandudno outfall, description of Plate XVI.

Failure of former system of sewerage at Llandudno.

Defects in former system of sewers.

sewerage, owing to the superficial level at which the sewers were constructed, and the fact that all the surface water from the town and from a large contiguous area of agricultural land was admitted into the sewers, it is not surprising to find that the sewers were often overcharged, and the basements of the houses inundated. Moreover, many of the sewers were constructed of such sizes and with such falls, that it was impossible for them even to be self-cleansing, and the consequence was, as might be expected, that they blocked up. It must be confessed that it is a matter of considerable hardship for the authorities of a town who have already expended considerable sums in sanitary improvement, to find by experience, that they have not secured those benefits they might reasonably have been entitled to expect, and that they have to perform over again the works of sewerage. In a case of this kind, where the very existence of the town and the livelihood of its inhabitants are dependent upon the perfection of its sanitary arrangements, it became necessary, notwithstanding the large expenditure, that a new system of sewerage should be provided, together with a deep-sea outfall into Conway Bay, an outfall extending to such a distance and to such a point as to effectually remove all filth; and it is to be hoped that the public spirit shown by the inhabitants of this health resort will meet its just reward from the public, who may be assured that they will have considerable difficulty in finding a better drained town, or one in which the sewage is more effectually removed. At Llandudno the outfall is carried a distance of 3587 feet from the shore, and entirely in the sea-way. The point at which the sewage is discharged is in the estuary of the river Conway, and such is the configuration of the mouth of this river that all the tide flowing into it cannot enter the narrow gorge at Conway, so that a part turns outwards, and the consequence is that whether the tide is ebbing or flowing, at the point selected for

Bad falls and improper sizes of sewers, and the result.

Hardship of having to provide new works.

Necessity of perfect system of sewers.

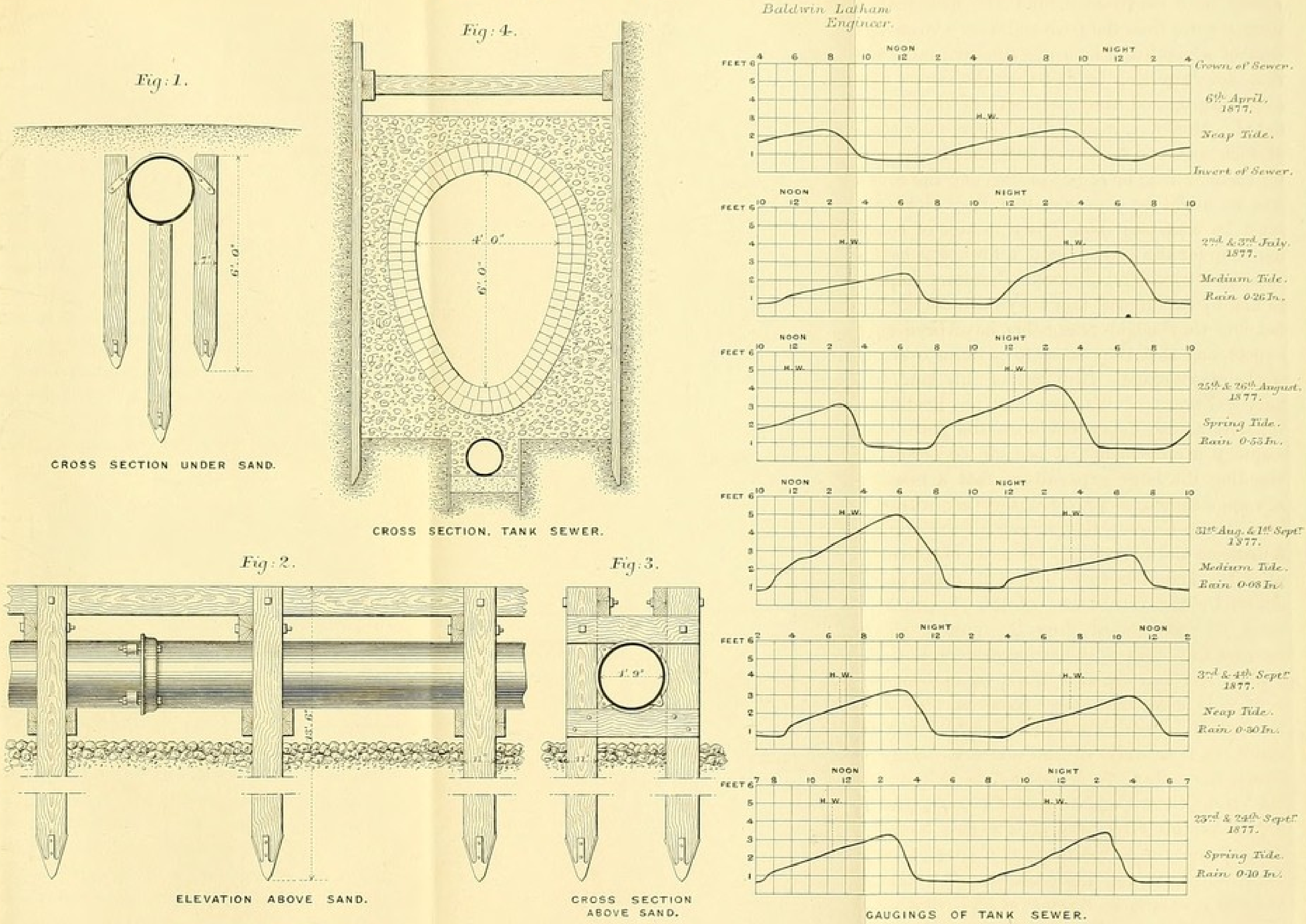
New outfall into Conway Bay.

Perfection of drainage of Llandudno.

Length of Llandudno sea outfall.

Sewage always carried out to sea.

LLANDUDNO SEA OUTFALL.



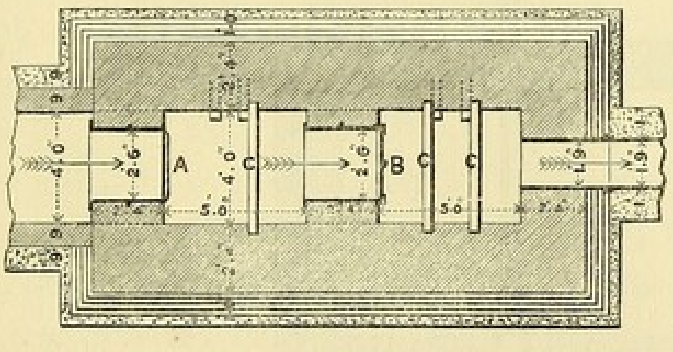
the outfall there is always a current out to sea which will carry the sewage with it. The former system of sewerage at Llandudno has been utilized by being made to do duty for the removal of the surface water, so that only such surface water as cannot be conveniently excluded is admitted into the new system of sewerage, and so it is not liable to any very serious strain in time of storm. In addition to the ordinary system of sewers, as usually provided for every town, at Llandudno a tank sewer, 2888 feet in length, of oval section (old proportion of oval sewer), 6 feet high and 4 feet wide, has been provided, a section of which is shown in Fig. 4, Plate XVI. This sewer will hold, exclusive of the capacity of the town sewers, 53,070 cube feet, or 331,687 gallons, but as it could at least be filled and emptied twice every day, its total daily capacity would be just twice the above figures. At the end of the tank sewer, a penstock chamber has been constructed, a plan of which is shown in Fig. 132.

Utilization of former system of sewers at Llandudno.

Capacity of Llandudno tank sewer.

Penstock chambers.

FIG. 132.



This chamber is divided into two parts. In the first wall is the tankard valve A, which is of the same description as shown in elevation in Fig. 133, and in section in Fig. 134, and on the exterior face of the division wall, and in front of the 21-inch outfall pipe, is placed a sluice or penstock B, the elevation of which is shown in Fig. 135, and the section in Fig. 136. This sluice is intended to be used for the purpose of flushing the outfall sewer, or in case of accident to the tankard valve. The grooves C are provided in the brickwork

Tankard valve.

Sluice valve or penstock.

Flushing outfall.

Grooves, use of.

Fig. 133.

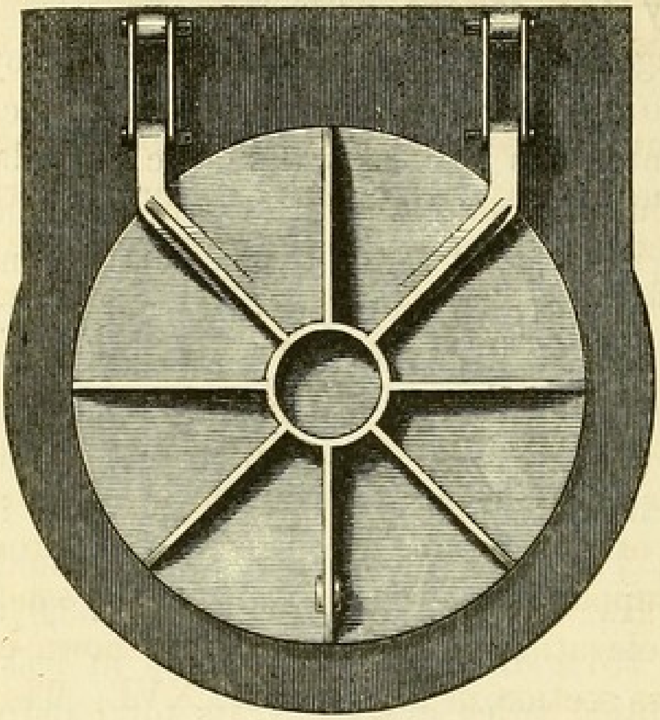


Fig. 134.

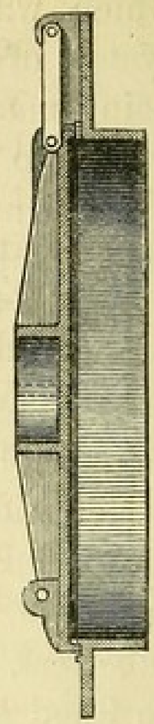


Fig. 135.

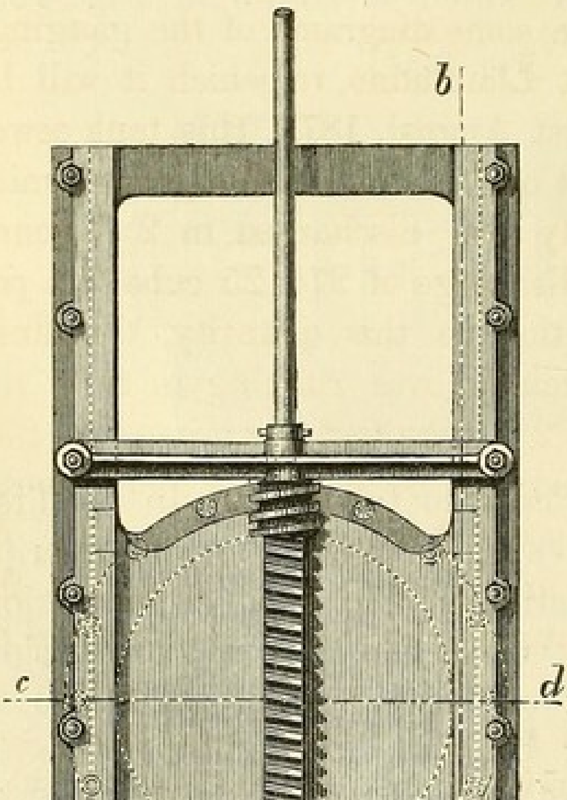
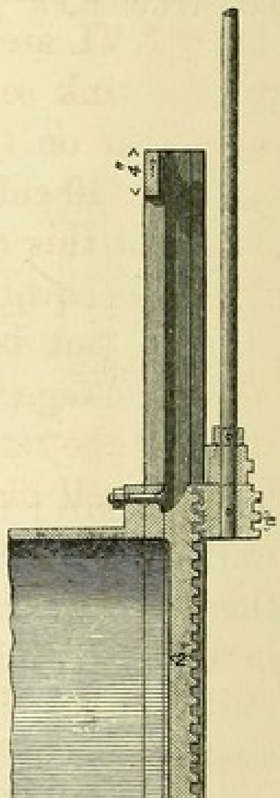


Fig. 136.



in the chambers, and are intended to be used, in case of necessity, either for placing temporary penstocks, or for the purpose of putting in planks to make a temporary dam.

The 21-inch outfall pipe, extending as before stated 3587 feet into the sea-way, is constructed for a short distance in earthen pipes, bedded in a mass of concrete; the greater portion, however, of the outfall is an iron pipe, partly laid under the sand, as shown in Fig. 1, Plate XVI. The piles shown in this figure were introduced in consequence of the shifting of the line of outfall by reason of the movement of the sand; the greatest portion of the outfall is constructed of iron pipes, as shown, supported by piles driven into the sand, a portion of the elevation of the work being shown in Fig. 2, and a cross section in Fig. 3, Plate XVI. This outfall is laid with a uniform inclination of 1 in 600, but of course the discharge takes place under various heads, and practically under variable inclinations. In Plate XVI. are shown some diagrams of the gaugings of the tank sewer at Llandudno, in which it will be seen that on the 31st August, 1877, this tank sewer held 41,440 cubic feet of flush water, sewage, and rainfall, and this quantity was discharged in 2·5 hours. This was equal to a discharge of 276·25 cube feet per minute, but in addition to this quantity, the flush water, sewage, and rainfall was running in from the town at the rate of 172·1 cube feet per minute, so that this outfall discharged 448·35 cube feet per minute, which was practically equal to a fall of 1 in 450. As this outfall has but an inclination of 1 in 600, the excess of discharge actually observed is that created by the induced current of the sea acting as an exhausting agent. The smallest fall observed at Llandudno was at neap tide, when the inclination for discharge through the outfall was 1 in 1200, and this would give a discharge of not less than 260 cube feet per minute; for $4\frac{1}{2}$ hours each tide the outfall would be perfectly free

Size and length of outfall.

Fig. 1, Plate XVI.

Fig. 2 and Fig. 3, Plate XVI.

Inclination of outfall.

Diagrams of gaugings.

Quantity of sewage in tank sewer.

Discharge of outfall.

Influence of the currents on discharge.

Fall at neap tide.

to discharge, so that under the worst condition of discharge, $260 \times 60 \times 9 = 140{,}400$ cube feet in 9 hours in two tides. To this, however, must be added a quantity that will be discharged as the water rises in the sewer, so that under the most unfavourable circumstances this outfall would discharge a million gallons per diem. This discharge is totally independent of the action of the induced tidal current on the discharge, which at neap tides is considerable, and will further increase the volume discharged beyond the quantity stated.

Discharge of outfall under most unfavourable circumstances.

Effect of dilution of sewage.

It may be said in reference to sea outfalls, that owing to the great mass of water into which the sewage is ordinarily discharged, and also owing to the more or less constant movement of the water, and to the action of the sea water itself in destroying organic matter, this mode of disposing of sewage is perfectly safe from a sanitary point of view, and every trace of sewage discharged under suitable conditions into the sea soon disappears. When we know by actual experience that the most perfect mode of dealing with sewage so as to purify it, will not remove more than eighty per cent. of the impurities present, it is clear that if one volume of sewage were mixed with four volumes of water containing no sewage, the mixture would be equal in purity to the purest sewage effluent. In a sea outfall the proportionate admixture would be much greater, and is sufficient to produce the effects of purification observed under some of the most favourable conditions for securing a pure sewage effluent.

Tide valves, penstocks.

In every system of sewers subject to tidal influence, tide valves, penstocks, and means for storing the sewage between the period the sewers are tide-locked, are more or less necessary. These matters are considered in the following pages.

CHAPTER XXXII.

TIDE VALVES.

WHEN it is necessary to carry an outfall sewer into a tidal stream or the sea, and the point of outfall is below high-water mark, the outfall must be protected with a tidal valve so as to prevent the ingress of water into the sewers of the district. It is also necessary, in some cases, to protect the rain outlets or storm-water overflows of sewers in a similar manner. This was found necessary in the case of the sewerage works of Dantzic, for although sufficient engine power has been provided in this town to raise both sewage and ordinary storm water, yet, as a matter of precaution, a number of storm water overflows have been provided, so that, if the engine power necessary to raise the volume of water brought down by the sewers should prove insufficient, or the engines should get disabled, the sewers would simply overflow and discharge into the river Mottlau and the branch streams communicating with it. Now, as the Baltic Sea, into which this river discharges, is a tideless sea, it might be thought a simple matter to arrange the storm water outlets so as not to require protection; but in order to ensure all the advantages of having a low outlet in time of storm, the level of these outlets was fixed at a lower point than the ordinary water level of the river; for although the Baltic is a tideless sea, the water level of the river Mottlau has been known to vary 7 feet, between extreme high and low water, in a season, the cause of which is principally due to the action of strong prevailing winds. The most remark-

Protection of outfall sewer.

Protection of rain-water outlets.

Dantzic an example.

able circumstance in respect to the rise and fall of the water in this river, and which led to the fixing of these rain-water outlets below the ordinary water level, is that when the district is visited with the heaviest rainfalls, the wind is in such a direction as to lower the mean height of the water in the river, and consequently, by fixing these outlets at a lower level than ordinary water-mark, the discharge due to heavy storms, should they occur, will take place under circumstances that are most favourable to the sewers. It has already been mentioned that it is necessary to protect an outfall sewer from currents of air entering and passing up them in uncontrolled volumes, and so deranging all the means provided for ventilation and the destruction of the noxious gases.* If outfalls are of such size, and in such situations, that they cannot be made to discharge below the water-line, so as to seal their mouths, they must be provided with tidal valves. Tidal valves are ordinarily of two varieties:—Tankard valves, deriving their name from being similar in action to the lid of a tankard, and float valves. The tankard valves are constructed of wood, and wrought and cast iron. Wooden valves are very extensively used in connection with drainage works in the Fen districts of this country, and, if made of good elm or oak, will last for a considerable period. Valves of this description made of wood are also formed like a lock-gate, or two doors meeting at an angle and closing against both bottom and cap sills. Wrought-iron tidal valves of cellular construction have been used with advantage for large outfall sewers. They are light, strong, and durable. Cast iron is the ordinary material used for tidal valves in works of sewerage. Float valves are usually made of copper, or india-rubber, or wood coated with india-rubber, but they are only applicable to sewers of small size. They consist simply of a float moving between guides, and when the water rises the

Prevention of currents of air entering outfall.

Tidal valves; two descriptions.

Wooden valves

Made like lock-gate.

Wrought-iron valves.

Cast iron ordinarily used for sewers.

Float valves.

* Vide page 335.

float rises into the bell mouth of a pipe and closes the aperture. Large tidal valves should be so balanced as to be capable of opening with the smallest amount of internal pressure, and to close with the least amount of external force. A properly constructed tide valve is entirely self-acting, and sewers fitted with tidal valves regulate their own discharge, for so soon as the height of the water outside the valve is lower than that within the sewer the discharge commences. All the working parts of a tankard valve should be bushed with gun-metal to prevent the valves sticking. The doors of cast-iron tankard valves should be strengthened with ribs, suitably disposed, so as to give them lightness and strength. These valves may either have planed faces to keep them water-tight, or lead seatings fixed in the frame may be provided, or in some cases both the face and seat may be formed of gun-metal. The doors of these valves are hung with both single and double hinges. The double-hinged doors have a greater amount of play, and in most situations are the best. The valve shown in Figs. 81 and 82, page 375, would form a most excellent tide valve, as it is extremely sensitive to any movement of a current either of air or water in consequence of its being capable of being so easily and truly balanced.

Tidal valves should be balanced.

Working parts should be gun-metal.

Hinges of doors.

Balanced valve.

In Plate XVII. is illustrated a number of different kinds of tide valves.

Description of Plate XVII.

Fig. 1 in this plate is an illustration of an ordinary shackle valve. This form is only applicable to sewers of small size.

Shackle valve.

Figs. 2 and 2A are illustrations of rain-water outlets as designed by the author for the Dantzic sewerage works. The rib R cast on the pipe attached to the valve is intended to prevent the water creeping along the sides of the pipe through the brickwork in which it is embedded. The door of the valve is provided with a lead face which closes against a V seating. The valve is provided with a ring O, to which a chain may be

Dantzic rain outlet valves.

attached in order to open the valve and admit water to the sewers, if required, for flushing or any other purpose.

Tide valve with link hinge.

Figs. 3 and 3A illustrate the front elevation and section of a cast-iron tide valve, hung with links, forming a double-jointed hinge. This description of valve is the one most generally used.

Tide valve fitted to pipe.

Figs. 4 and 4A illustrate an elevation and section of a cast-iron tide valve fitted to a length of cast-iron pipe, and hung with double hinges.

Tide valve with single hinge.

Figs. 5 and 5A illustrate an elevation and section of a cast-iron tide valve fitted to a length of cast-iron pipe, and hung with single hinges.

Tide valve for oval sewer.

Figs. 6 and 6A illustrate the elevation and section of a cast-iron tide valve for an oval sewer, provided with double hinges.

Oblong tide valve.

Figs. 7 and 7A illustrate the elevation and section of an oblong cast-iron tide or storm-water outlet valve, hung with double hinges.

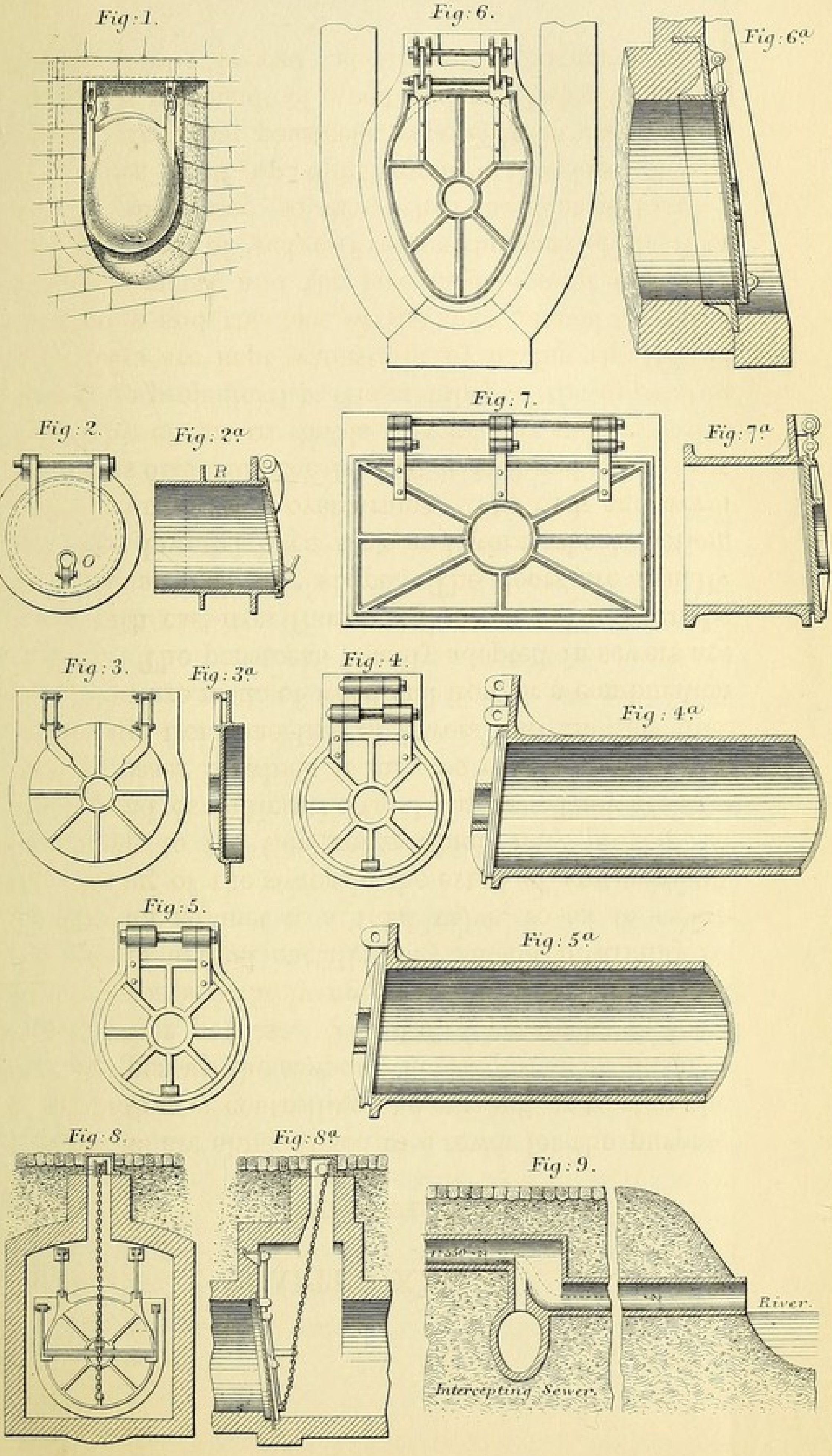
Tide valve in double flights.

Figs. 8 and 8A are illustrations of the elevation and section of a cast-iron tide valve opening in two flights. This form is adapted to the construction of large valves, but care must be exercised in their fitting and finishing, otherwise the hinge in the centre of the door will be liable to stick, and the valve to get out of order.

Mode of intercepting pure rainfall from sewers.

Fig. 9 is an illustration of the mode of intercepting large and pure rainfalls from sewers, and admitting the small and impure rainfalls. It is fully described at page 45.

TIDE AND RAINWATER OUTLET VALVES.



London: E. & F. N. Spon, 46, Charing Cross.
Thomas Kell, lith.

CHAPTER XXXIII.

PENSTOCKS.

PENSTOCKS are sluices fixed in a sewer for the purpose of regulating or controlling the current, or to stop the flow and pen up the sewage when required for flushing or any other purpose. The use of penstocks in some situations is absolutely necessary, as, for example, in the case of a tidal outfall; they should invariably be fixed as an adjunct to a tidal valve, so as to secure the closing of the sewer in the event of any accident happening to the tide valve which may prevent its closing and excluding the tidal waters. They are also used in cases in which it may be necessary to divert the sewage from one line of sewers into another line. Penstocks are made of wood and iron, or a combination of both. The penstocks usually adopted in sewers are made with cast-iron frames and doors. They can be made of any size or shape. The doors are usually raised or lowered by a rack and worm-wheel motion, or by chains passing over drums. The rack and worm motion is decidedly the best, as it is found that doors raised by chains are liable to move by sudden jerks, which are prejudicial to the stability of the apparatus. The doors are kept water-tight by having the face of the frame and the face of the door planed or fitted with gun-metal, and the faces are brought into contact by means of wedges fixed on the back of the door and in the frame, so that, when the door is lowered it wedges itself up tight against the face of the frame. In fixing penstocks, especially in cases where the doors are made of wood and are liable to spring, the hydraulic pressure should be so arranged as to

Use of penstocks.

Penstocks used as a safeguard.

Mode of raising doors.

Faces of doors.

Mode of fixing.

press the door with its rack against the worm-wheel. The doors of all large sluice valves are usually provided with counter-weights to balance the door and to diminish the labour of raising them. They are also often fitted with compound gearing for opening them, as, for example, Fig. 1, Plate XVIII.: A and B are two spindles; on the spindle A is fixed a small cog-wheel which gears into a larger wheel on the spindle B. If a man applies a key to the spindle A, he can bring great power to bear in moving the door, but it would be raised very slowly: so soon as he has started it he can place his key on the spindle B, and very quickly raise it to the full height. The openings in the bridges for carrying the spindle and worm-wheel, and every other working part liable to get fixed from rust, should be bushed with gun-metal. In Plate XVIII. the drawings of a number of different kinds of penstocks of cast iron are given.

Compound gearing.

Working parts bushed with gun-metal.

Description of Plate XVIII.

Penstock of circular sewer.

Figs. 1 and 1A are illustrations of the elevation and section of a penstock for a large circular sewer. It is fitted with a counter-weight, and compound gearing for lowering and raising the door.

Dantzic penstock.

Figs. 2, 2A, 2B, and 2C are illustrations of the elevation, plan, section through door, and section through the rack and worm gearing of a cast-iron penstock, as fitted, for flushing purposes, to the mouth of the syphons which are used at Dantzic, for conveying the sewage of the town under the rivers to the pumping station.

Penstock for oval sewer.

Figs. 3, 3A, and 3B are illustrations of the plan, elevation, and section of a cast-iron penstock fitted with counter-weights, and adapted for a sewer of oval section.

Penstock for large sewer in shallow cuttings.

Figs. 4, 4A, and 4B are illustrations of the elevation, section through gearing, and section through door, showing the wedges W for closing the door. It is a cast-iron penstock adapted for large sewers in shallow cuttings, or in cases where there is not sufficient headway to introduce a penstock of the ordinary construc-

PENSTOCKS.

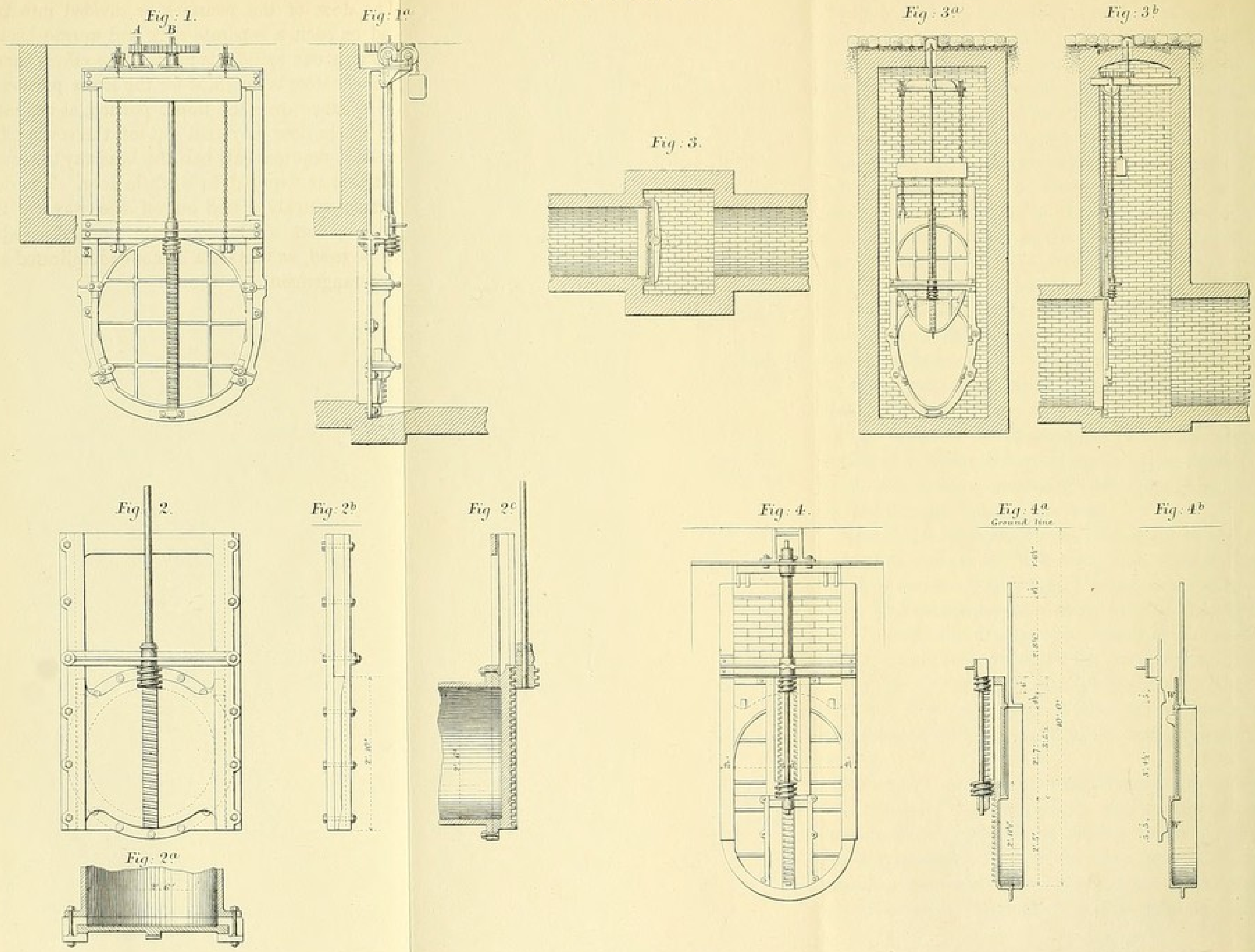


Fig: 1.
A
B
Fig: 1a
Fig: 3.
Fig: 3a
Fig: 3b
Fig: 2.
Fig: 2b
Fig: 2c
Fig: 2a
Fig: 4.
Fig: 4a
Ground line
Fig: 4b

tion. The door of the penstock is divided into two parts, and on each a separate rack and worm-wheel is fixed, but only one spindle is used. The effect, therefore, when the door is raised, is for the lower portion of the door to move over the upper portion, at the same time the whole door is raised out of the sewer; but when raised it requires only half the headway to accommodate it that is required by a whole door. The door is also more quickly raised out of the way by this arrangement; but whole doors are preferable when they can be used, as this form is more complicated and liable to derangement.

CHAPTER XXXIV.

TANK SEWERS AND SEWAGE RESERVOIRS.

Cases in which sewage must be stored.

All sewers that are tide-locked should be provided with the means of storing the sewage during the period the sewers cannot freely discharge their contents. In some cases, also, when it is necessary to raise the sewage of a district by artificial power, ample provision should be made for stowage, so that, in case of accidental derangement, or the temporary stoppage of the pumping machinery from any cause, the district should not be inconvenienced by an accumulation of sewage. Moreover, in some cases, it may be found more economical to store the sewage of a district for a limited period than to have resort to continuous pumping. In some cases, also, where it is desirable that the discharge of sewage into a tidal way should take place at a particular state of the tide, it may be necessary to store it. For example, the great outfalls of the London sewerage are so arranged, that, by means of reservoirs, the sewage is stored so as to be discharged near the point of high water. The advantage of securing the discharge near this point is that the ebbing tide carries the sewage away; and it has been calculated in this case that the reservoirs provided for impounding the sewage are equivalent in effect to the construction of twelve miles of outfall sewer. The means usually provided for storing sewage are open or covered reservoirs and tank sewers. If reservoirs are used, every step should be taken to prevent their becoming places for deposit. This can be done by so arranging the outlets and inlets as to be able to completely flush every part of the work. Covered reservoirs are preferable to open,

Discharge into tidal waters.

Mode of storing sewage.

Flushing reservoirs.

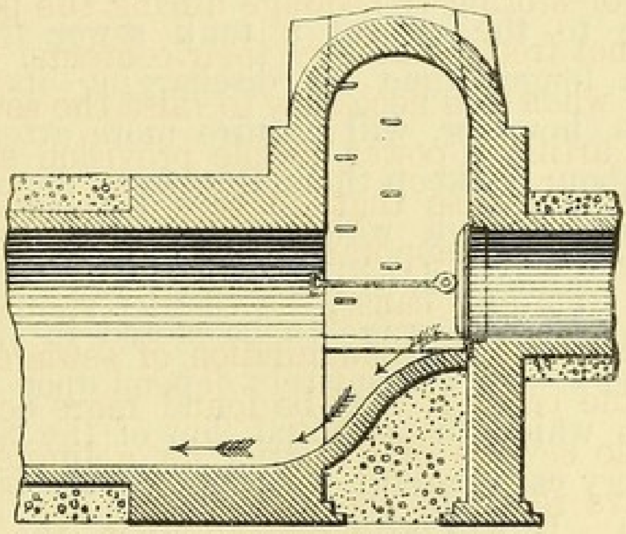
and they are generally covered with brick or concrete arches springing from the side walls and piers, or from cast or wrought iron girders which span the reservoir. Tank sewers are formed by either enlarging the outfall, or some convenient branch sewer, for a sufficient length, so as to make it competent to store all the sewage required during the period the sewers are tide-locked. Fig. 137 is a longitudinal section at the point

Construction of reservoirs.

Construction of tank sewers.

Description of Fig. 137.

FIG. 137.



of junction, at the head of a tank sewer, and the ordinary sewer, as designed by the author for the town of Bideford. The tank sewer in this case is oval in section, 5 ft. × 3 ft. 4 in., while the outfall sewer is circular, 2 ft. 3 in. in diameter. It will be seen from the above figure that the sewer is enlarged or deepened below the ordinary level of the town sewers, and that the enlargement meets the ordinary sewer in a line of double curve, so that, when the outfall is free, the sewage flows with considerable impetus into the tank sewer, washing everything to the outfall, and thus keeping this receptacle free from deposit. In this case the cleansing of this tank sewer from deposit should it arise from any cause, can be facilitated by damming back the sewage with the flushing door, shown at the end of the sewer discharging into the tank sewer in Fig. 137, so that a large volume of sewage may be

Tank sewers cleansed by flushing.

concentrated and suddenly discharged into the confined channel of the tank sewer.

In some works, when the construction of tank sewers would be more expensive and inconvenient, it may be desirable to construct reservoirs for storing the sewage, but for all ordinary works of sewerage the tank-sewer system is the preferable mode of storing sewage.

Tank sewers preferred to reservoirs.

Cases in which reservoirs must be used.

In cases in which a very large volume is intended to be discharged in a very limited period, a reservoir near the point of discharge, with ample outlets, may be preferable to the use of a tank sewer that would require a longer time for discharging its contents. Reservoirs, however, will require more attention and manual labour to keep them free from deposit than a tank sewer, through which a more or less constant current is maintained, which removes the deposit.

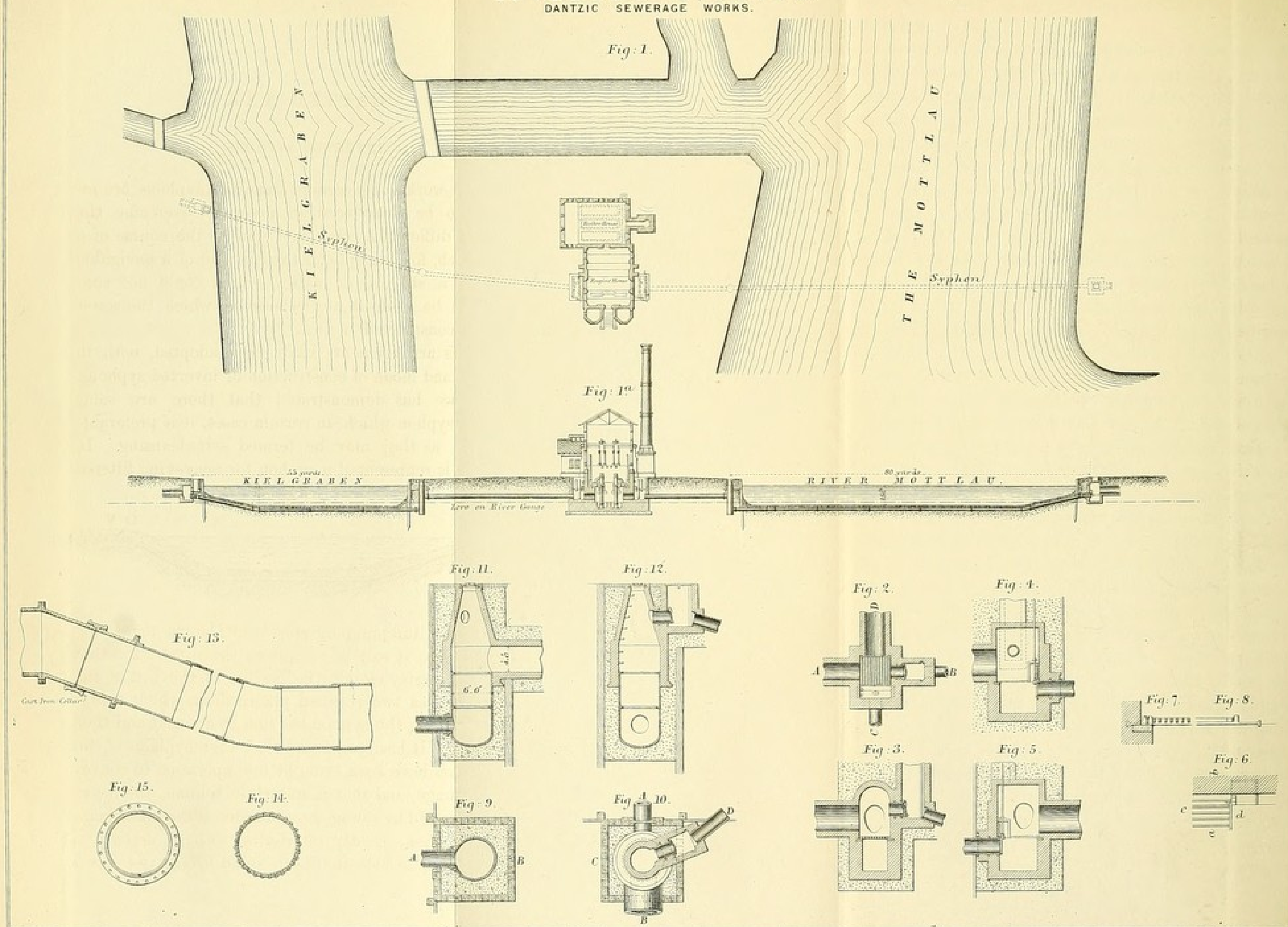
Volume of sewage to be stored.

The volume of sewage to be stored in the case of tide-locked sewers will entirely depend upon the period of time in which the ebb and flow of the tide occurs, and in every case careful observation must be made on this point. It will also depend upon the uncertain volume of storm water, if this water is admitted into the sewers; but in all cases where sewers are tide-locked, the principle of interception, as treated of at page 171, should be adopted, and as far as possible the storm waters should be excluded from the tide-locked sewers, so that but little provision need be made for the reception of an uncertain volume of sewage to be received at unknown periods. In some cases the mode of intercepting rainfall, described at page 45, and illustrated in Plate I. and Plate XVII., Fig. 9, may be adopted with advantage, in the case of sewers that are tide-locked, in order to relieve them from any large volume of rain water, which, if admitted into the sewers when they are full, might lead to the inundation of the low-lying premises draining to the sewers.

Storm water should be excluded.

INVERTED SYPHONS.

DANTZIC SEWERAGE WORKS.



London: E. & F.N. Spon, 46, Charing Cross.

CHAPTER XXXV.

INVERTED SYPHONS.

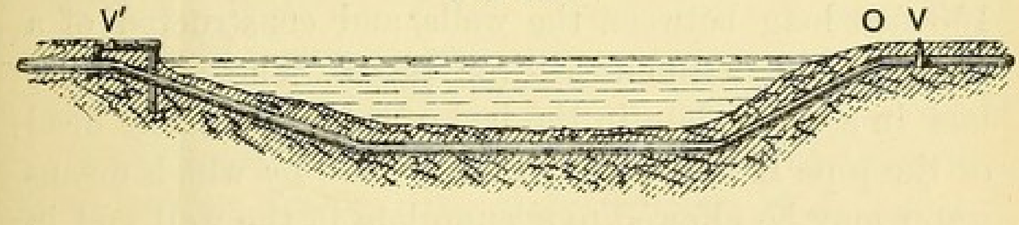
In many works of sewerage, inverted syphons are required to be introduced in order to overcome the physical difficulties often met with in the course of a sewer, such, for example, as the crossing of a navigable channel, a stream, or valley which could not conveniently be bridged at the level at which the sewer must be constructed.

Use of inverted syphons.

Various arrangements have been adopted, both in the form and mode of construction of inverted syphons. Experience has demonstrated that there are some forms of syphon which, in certain cases, it is preferable to adopt, as they may be termed self-cleansing. In Fig. 138 is represented a syphon for conveying filtered

Description of Fig. 138.

Fig. 138.



sewage from the pumping station at Dantzic across the Kiel-Graben; it will be seen from the illustration that it follows pretty closely the outline of the bed of the river. It has two inclined planes down which everything entering the syphon has first to descend and then to ascend. It has been found that when syphons of this description have been brought into operation to convey crude sewage, and that in uncertain volume, the heavy matter carried by sewage accumulates at the lower point of the syphon, greatly interfering with its action; so much so, that it has often been found necessary to lay a

Syphons liable to stoppage.

copper-wire rope through syphons of this description to which a brush may be attached, for periodically removing the deposit and maintaining the syphon in working order. In Fig. 138, V represents the position of a valve for closing the rising main, so that the sewage for flushing purposes can be directed through an outlet at O into the river. V′ is a valve on a 3-inch pipe, which may be opened at pleasure for the purpose of discharging air from the descending leg of the syphon. It was the knowledge of the difficulty of working a syphon of the foregoing description with crude sewage, at Warwick, which led the author, in designing the outfall works of that town, when it became necessary to convey the sewage of the district under the river Avon, to adopt the form of syphon shown in Fig. 139. This syphon is

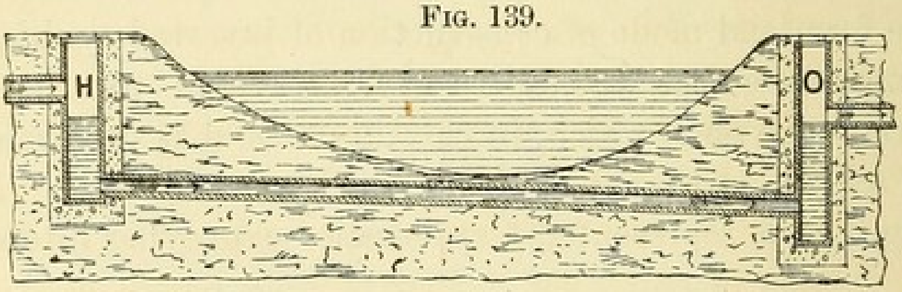
Removal of stoppages.

Flushing and ventilation of this syphon.

Warwick syphon.

Fig. 139.

Fig. 139.



150 feet long between the wells, and constructed of a single line of 24-inch cast-iron pipes. The pipes were laid in a coffer-dam in the bed of the river. The head of the pipe H is provided with a valve by which means water may be allowed to accumulate in the well and in the sewer above, which may afterwards be discharged with considerable velocity through the pipe, so as to effectually flush it. The well O at the lower end of the syphon is deeper than the bottom of the syphon, and ample space is here allowed for the accumulation of any solid matter which the velocity of the current will not carry upwards to the overflow sewer. The solid matter in the lower well may be removed by periodically dredging it out, and if this work is properly attended to, no fear need be entertained as to the working of this form of syphon, as the experience of some

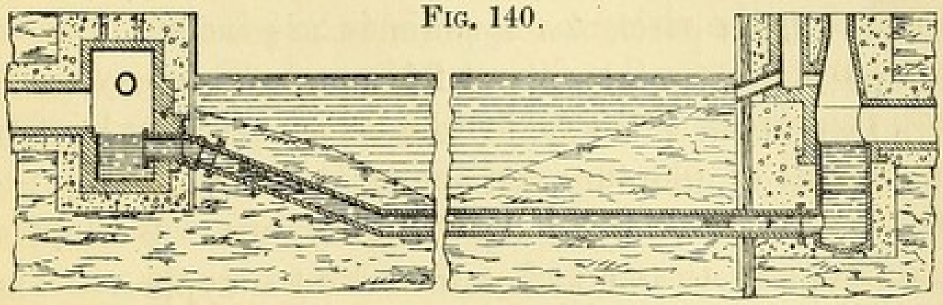
Flushing of this syphon.

Provision for deposit.

years' constant work clearly demonstrates. In Fig. 140 is shown the form of syphon designed by the author for the sewerage works of Dantzic. It will be seen by

Dantzic syphons for crude sewage.

FIG. 140.



reference to Plate II., that the sewage of Dantzic is conveyed by the sewers to the pumping station, which is located on an island. In order to get to this island, two navigable channels have to be crossed, and in these channels it is necessary to maintain a navigable depth of 15 feet of water, and as the foundations of the pumping station could not be carried very deep on account of the nature of the site, the only possible mode of connecting the sewer with the pumping station was by means of inverted syphons. The syphon under the Mottlau river is 80 yards long and 27 inches internal diameter; that under the Kiel-Graben is 55 yards long and 18 inches internal diameter; they are shown in Figs. 1 and 1A, Plate XIX. Both syphons are formed of wrought iron, and were each sunk in position in one piece. In carrying out the Dantzic sewerage works, inverted syphons form an essential feature in the scheme on account of the town being intersected by navigable channels, and surrounded with fortification ditches which divide the suburbs from the town proper, and over these ditches the authorities will permit no permanent works to be carried, and all works carried under the water in the fortification ditches are required to be constructed at such a depth as to maintain 6 feet of water over them when completed. Also, on account of the main river Vistula cutting off the town from the land on which the

Necessity for use of syphons at Dantzic.

Six large syphons used at Dantzic.

Description of syphon under Vistula.

Provision for flushing syphon

Flushing the Mottlau and Kiel-Graben syphons.

sewage has to be distributed, no less than six large wrought-iron syphons have been introduced. One of these is laid across the Vistula, and is 160 yards in length, over which a depth of 18 feet of water is maintained. This particular syphon is $22\frac{1}{2}$ inches internal diameter, and weighs about 24 tons. These syphons, like two others which deal with the sewage after leaving the sewage pumping station at Dantzic, are of the description shown in Fig. 138. This form was adopted for convenience, and is not so liable to stoppage as an ordinary syphon conveying crude sewage, as the sewage in this case has had strained from it, at the pumping station, all heavy matter, before being permitted to enter the syphons; moreover, ample provision has been made so that each of the syphons of this description can be effectually flushed, as a communication is made with the channels crossed, and the pumping engines are enabled to deliver, at the low elevation of these streams, such a volume of water as will effectually flush the syphons. It must not be forgotten, in the construction of all syphons, that either by artificial flushing, or naturally, such a velocity must be created through them as will effectually remove any deposit. In the case of those under the Mottlau and Kiel-Graben at Dantzic, which convey the crude sewage to the pumping station, each syphon is fitted with a penstock at its head, of the description shown in Fig. 2, Plate XVIII., so that by damming up the water, and pumping out the sewage well at the pumping station, and starting both engines to work, a velocity of 9 feet per second could be maintained for a short time through them. Both engines, without the sewage well, would maintain a constant velocity through the largest syphon of 3 feet per second, which is ample for ensuring its being properly cleansed. Moreover, each syphon forms an inclined plane, the first portion of which is much inclined, as shown in Plate XIX., Fig. 1A; then it is joined with an easy curve to the part less inclined. By this arrangement anything that may enter the syphon will be carried down the continuous inclined plane, and either be deposited in the catch-pit provided for its reception at the lower end of the syphon, or passed onward to the pumping station. These syphons are protected at their inlet by a horizontal grating which completely fills the shaft, and is placed at a level below the invert of the sewers, but above the mouth of the syphon. This grating is formed of bars of wrought iron about 3 inches apart, set in a frame, so that any large substance will lodge upon it and be prevented from passing into the syphon; the details of the syphons and gratings are shown in Plate XIX., Figs. 2 to 15. The grating is hinged so as to be capable of being raised out of the way, and to enable the catch-pit at the mouth of the syphon to be dredged. In Plate XIX. are shown the details of the construction of the syphons and wells as executed for conveying the sewage of Dantzic under the rivers.

Form of syphon, inclined plane.

Protection of mouth of syphon.

Description of Plate XIX.

Fig. 1 is a plan showing the general arrangement of the syphons under the Mottlau and Kiel-Graben, in reference to the position of the pumping station at Dantzic.

Plan of syphons.

Fig. 1A is a section through the syphons as used in crossing the Mottlau and Kiel-Graben at Dantzic, showing the general arrangement in respect to the pumping station.

Section of syphons.

Fig. 2 shows the plan of the manhole, with the sewers, syphon, and storm-water overflow, forming the inlet shaft to the Mottlau syphon.

Plan of inlet shaft.

Fig. 3 is a section on the line A B. It shows the storm-water overflow, the outfall sewers, and the horizontal grating used for the protection of the syphon.

Sections of inlet shaft.

Fig. 4 is a section through C D, looking east. It shows the mouth of the syphon with the penstock for flushing and the position of the guard grating.

Fig. 5 is a section through C D, looking west.

Fig. 6 is an enlarged plan of a portion of the guard grating.

Plan of guard grating.

Section of guard grating

Fig. 7 is an enlarged section of a portion of the guard grating, on line *a b*.

Fig. 8 is a section of guard grating on line *c d*.

Plan of outlet shaft.

Fig. 9 is the plan of the bottom of the outlet shaft.

Fig. 10 is a plan of outlet shaft at level of storm-water overflow.

Sections of outlet shaft.

Fig. 11 is a section of the outlet shaft on line A B.

Fig. 12 is a section of outlet shaft on line C D, showing the storm-water overflow.

Enlarged section of syphon.

Fig. 13 is an enlarged section showing the mode in which the syphons are constructed.

Fig. 14 is a transverse section of the syphons.

Fig. 15 is a transverse section showing the flange joints.

Materials used in constructing syphons.

The large syphons used in the Dantzic works are made of $\frac{3}{8}$-inch wrought-iron boiler plate, riveted together with $\frac{3}{4}$-inch rivets having a pitch of 2 inches. The rivet heads, in the lower half of the syphons, are all countersunk, as shown in Fig. 14, Plate XIX., so as to offer no impediment to the transmission of any solid matter through the syphons. The syphons were all built up in lengths of about 40 feet. Angle iron was riveted on the end of each length of pipe so as to form a flange joint. These sections were afterwards bolted together with $\frac{3}{4}$-inch bolts, the same number of bolts being used in the flanges as there were rivets encircling the pipe, and the pipes were susbequently sunk into their proper position. In cases in which there is an amount of traffic on any navigable river it is requisite to cross, the use of wrought-iron syphons, laid in one operation, will be found to be the most expeditious manner of crossing such channel. The mode adopted of laying the syphons at Dantzic was performed under the direction of Mr. Thomas Airey, C.E., the resident engineer on the works, and the following description of the work may be of interest:—A trench was dredged in the bed of the river to the requisite depth to receive the syphon. It was found in

Most expeditious way of crossing navigable channels.

Mode of laying syphons at Dantzic.

excavating these trenches to be better to go a little deeper than was absolutely necessary, in order to guard against the effect of currents filling the trench up before the syphon was laid. The trench having been dredged, the pipe was bolted together on the side of the river, and tested under hydraulic pressure to ascertain if it was tight. All being satisfactory, a few of the joints were separated, and the syphon was floated in sections on barges to the site where they had to be laid. The barges being placed in position over the site intended for the syphon, all the sections of the syphon were bolted together, the syphons were closed at the lower end, and in the case of syphons similar to that shown in Fig. 138, at both ends. The syphons were also thoroughly coated with a mixture of pitch and linseed oil, before being fixed in position ready for sinking. The joints were made with india-rubber and afterwards run with lead and caulked. The barges used in the sinking of the syphons were each 48 feet long by 10 feet wide, the syphon was laid across the ends of them, and they were adjusted as to their level by means of ballast which had been taken on board. A temporary derrick was erected in each barge, together with a crab, block, and falls, and used, as shown in Plate XX., for bringing the pipe into position. So soon as the pipe was lifted by uniform working of the crabs, it was slung forward free of the barges into the water, and in this position it floated. The syphon was now slowly filled with water by the aid of a fire engine, and gradually allowed to sink, the operation of lowering being checked by marks placed at equal distances in the fixed rope of the falls. When it had been sunk to the requisite depth it was held in position, and sand was thrown in from barges, which by the action of the water soon filled up every crevice and hollow place, and formed a firm bed for the reception of the pipe after it had been laid. The whole operation of laying these syphons at Dantzic was one of extreme simplicity; the work occupied but a

Test of syphons.

Use of barges.

Coating of syphons.

Plate XX.

Filling with water.

Filling of trench.

Sinking a simple operation.

short time, the principal labour being the supply of the necessary quantity of water to enable the syphon to sink. In sinking the large syphon across the Vistula, twelve barges with their crabs and derricks were used. In laying the syphon across the river Mottlau, the Kiel-Graben, and the fortification ditches, the bottom portion of the outlet shaft, as shown in Fig. 11, Plate XIX., was attached to the syphon and sunk with it. The success attending the laying of these syphons is such as to demonstrate the practicability of laying much longer and larger syphons should they ever be required.

Rugby syphon.

A good example of the application of an inverted syphon will be found at Rugby. Previous to the year 1866, all the sewage of the town of Rugby was allowed to flow down to the lower part of the district, from whence it was pumped up to land in the neighbourhood; the author, in the above year, designed a scheme, by which the sewage of the whole district was made to flow by gravitation on to the very land upon which it had been raised by pumping for some years. This was done by conveying the sewage from the higher portion of the town, across a valley, by an inverted syphon 12 inches diameter, and 1000 yards long, to the highest portion of the irrigated land, and the sewage of the lower district was passed by a sewer under the rising ground to the lowest irrigated fields.

Flushing of Rugby syphon.

In this Rugby syphon, arrangements were made by providing an outlet at the lowest point of the valley which communicated with the low-level sewer and the lower irrigated fields, by which means the syphon could be flushed out when required.

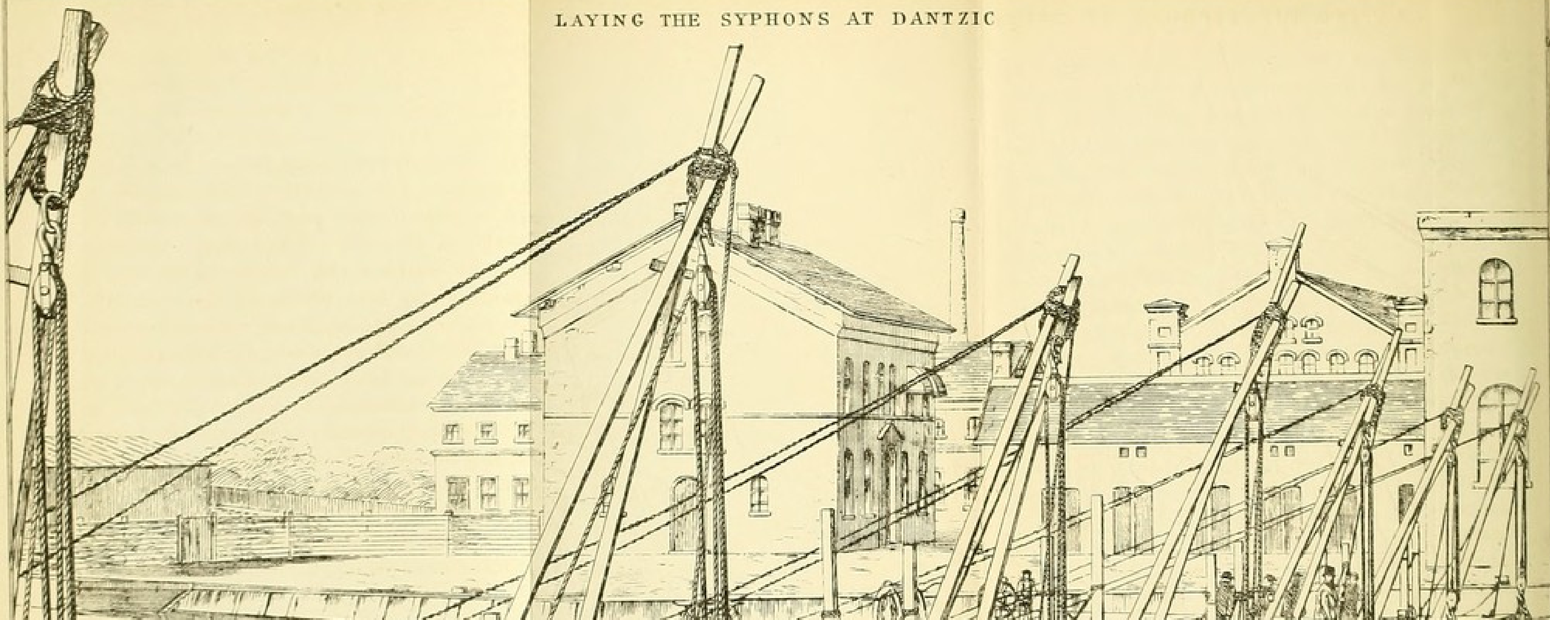
Syphon at Hamburg.

There is a syphon on the sewerage works at Hamburg, in which the velocity maintained is so great that, for the edification of visitors, cannon-balls are transmitted through it by their own impetus and the velocity of the current.

Ventilation of syphons.

In the construction of long inverted syphons ventilation must not be omitted, especially in the descending

LAYING THE SYPHONS AT DANTZIC



London, E.&F.N. Spon, 46 Charing Cross. Thomas Kell, lith.

leg of the syphon, or otherwise an accumulation of air, or gas, may greatly interfere with its discharging power. The simplest mode of ventilating syphons is by pipes carried up to such a level, that if the flow through the syphon is interrupted, the ventilating pipes will not overflow. Ball ventilating valves, similar to those used in lines of water pipes, are not suitable for sewage works, as the author found from experience that the frothy matter which escapes carries with it solid deposit, which soon blocks up the apparatus. For the purpose of calculating the discharge of a syphon pipe, it may be treated as an ordinary pipe, provided that if there are any bends the resistance offered by them must first be calculated by the formula given at page 166. The head necessary to overcome the friction of the bends being ascertained, and deducted from the actual head of water on the syphons, will give the head under which the discharge will take place, and which may be calculated from Weisbach's formula, given at page 130, or if worked out into the rate of inclination by dividing the length of the syphon by the head of water on it, the velocity and discharge may be ascertained sufficiently near for all practical purposes from Tables Nos. 22 and 32.

Mode of ventilating syphons.

Discharge of syphons.

CHAPTER XXXVI.

SUBSOIL DRAINAGE OF THE SITES OF TOWNS.

THE results arising from the drainage of the subsoil of a town in carrying out works of sewerage have already been referred to at page 58. The advantage of complete subsoil drainage of the sites of towns appears to be so great that every effort should be made, and no expense spared, in order to secure perfect works for drying and aerating the subsoil of all urban districts. The extensive works of subsoil drainage that have been carried out in every civilized country in the interest of agriculture, show beyond doubt that both the health of animals and plants is materially benefited by works of this character. In town districts, where the soil to some extent naturally becomes polluted by the absorption of gaseous impurities from the air, or by the admittance by percolation of decomposing matter from the surface, it is absolutely necessary, in order to render the soil capable of performing its function of oxidizing and neutralizing the elements of decomposition which are brought into contact with it, that works of sub-drainage should be prosecuted. It is now well known that the abundant admission of air into a soil enables that soil to exert the most powerful chemical influence upon all organic compounds, so great indeed as to be capable of purifying the crudest sewage. The effect of drainage upon the soil is to promote porosity, and the effect of porosity is to make the soil dryer, warmer, and less capable of conveying extremes of temperature. It is also well known that a soil perfectly saturated with water, which can only part with it by evaporation, is rendered cold and

Advantages of subsoil drainage.

Agricultural drainage.

Necessity for subsoil drainage.

Effect of aeration of soil.

unwholesome as a site for human dwellings, for all impurities that enter the soil accumulate. Soils which are naturally porous, and from which rain rapidly disappears, are known to be the healthiest situations for the sites of houses. In this case, the action of the soil oxidizes all organic impurities, the resulting product is washed away by the rain, and the soil remains sweet and wholesome. The advantages of site appear to have been known from the early ages of antiquity. Vitruvius in his works lays down special instructions for selecting the sites of towns and hospitals, mainly regarding the quality of porosity and the perfection of drainage; the absence of a water-logged soil being looked upon as the best situation for the location of buildings. It has been clearly shown from experiments that the effect of drainage upon ordinary agricultural land is to modify extremes of temperature. Undrained fields are sooner affected by the lower temperature of winter, or by sudden showers of sleet and snow, than fields of the same class that are drained. In summer the effect of the admission of water or rainfall into a soil which is drained, and through which it circulates freely, is highly beneficial. It has already been pointed out that drainage works promote porosity; so rain falling on the surface of a town and percolating through the soil, rapidly carries with it all those deleterious compounds which in the presence of air have been neutralized, and a healthy circulation takes place; the soil is, as it were, washed by every shower, and retains its virgin purity. In what way the works of subsoil drainage can be carried out in a town, with the greatest advantage, is a matter which has received some considerable degree of attention at various times. Formerly, when sewers were constructed with a view to carry off the surface and subsoil water, it was customary to construct the inverts of the sewer so porous as to readily admit water from the subsoil; the

Healthy soils.

Vitruvius.

Influence of change of temperature.

Rain washes a drained soil.

Pervious sewers.

sewers, being constructed in brickwork, had their inverts laid dry. It cannot be overlooked that where a system of modern sewers is designed to convey away all the refuse of the town, the effect of constructing the inverts of such sewers pervious, is, that at certain periods of the year the sewage will escape into the subsoil and poison the subsoil water of the district; therefore it is necessary that wherever subsoil drainage works are undertaken, they should be so designed and constructed, if it is intended to keep the subsoil water free from contamination, that it shall be impossible for matters to escape from the sewers so as to pollute the subsoil water. Various plans have been devised for effecting the subsoil drainage of a town. It has been proposed to construct the sewers of two parts, the upper to convey away sewage, and the lower to be pervious, to convey subsoil water, as shown in Fig. 141; but in practice it is found that it is almost impossible to make the joints of the sewers so tight but that at times they will leak, and in consequence sewage gravitates to the subsoil drains and pollutes the water. A modification of this plan has lately been patented by Messrs. Brooke and Sons, of Huddersfield, and is illustrated in Fig. 142. In this case, subsoil drains, D, of earthenware, are laid in the sewer trench, and these drains are so shaped as to serve for the foundation of the sewer. On these subsoil drains rests, R, are placed to receive the sewer pipe, which is carried above the subsoil drain. It is contended that by this mode of executing a sewer in bad and wet ground, the joints of the sewer may be properly made in cement, so as to

Subsoil water must not be contaminated.

Description of Fig. 141.

Fig. 141.

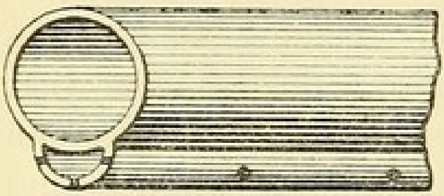
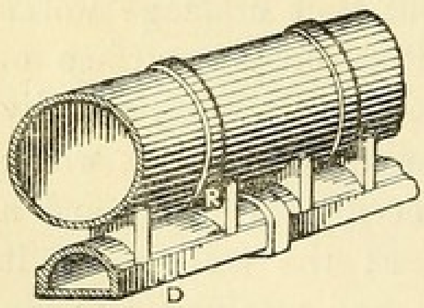


Fig. 142.



Brooke's system.

Description of Fig. 142.

render it water-tight; but still this system has the objection that if leakage does take place from the sewer, the water in the subsoil drain must become polluted. Moreover, this plan of carrying the pipes on rests causes every pipe to act like a girder, which, under some circumstances, may lead to their failure in the work. In carrying out the sewage works of Dantzic, Mr. Wiebe and the author introduced a plan of subsoil drainage which meets all the difficulties, and secures all the advantages which are required in carrying out works of this character. The method adopted is shown in Figs. 143 and 144. The sewer proper S, whether constructed of brickwork or earthenware pipes, was first laid in the trench and covered over with a layer of clay puddle C, which was well and carefully rammed into position. In some cases, over this clay, several feet in depth of the trench were filled in with selected gravel, shown by G, Fig. 143, which is perfectly pervious, and upon this gravel the ordinary materials excavated, E, were placed; the arrangements for the discharge of the subsoil water were so managed that

Subsoil drainage works, Dantzic.

Description of Fig. 143.

Fig. 143.

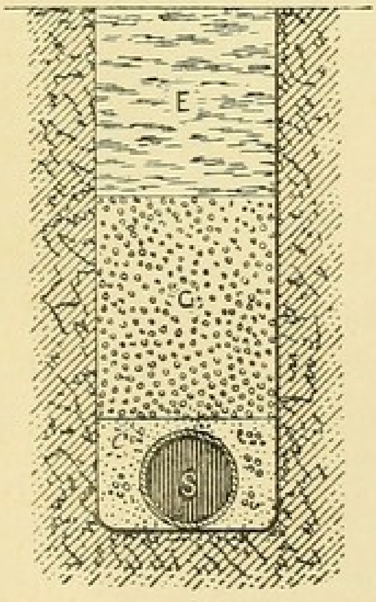
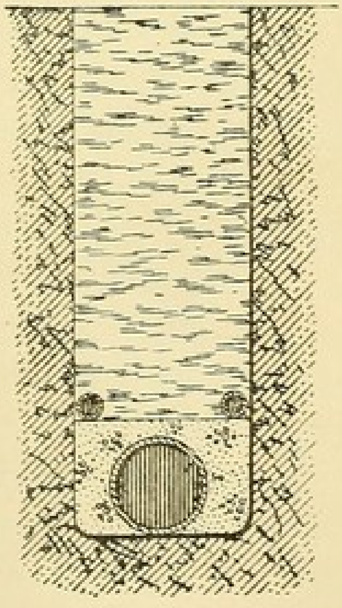


Fig. 144.



every lateral line of sewer is provided with a free discharge into the river. In other cases the method shown in Fig. 144 was adopted after the insertion of

Description of Fig. 144.

the sewer and its covering of clay; two lines of ordinary agricultural land drains were laid on each side of the trench, so as to communicate directly with the surface-water streams of the district. Subsoil drainage may be carried out in most places in the way delineated in Fig. 144, care being taken that the sewers are rendered impervious, so as to prevent the escape of sewage, porous drains being laid immediately above them; the subsoil water may be conveyed to any convenient point, and air may be admitted freely into the subsoil, while the expense of the work is trifling compared with the advantages to be gained. In some situations, such as in very low-lying and swampy districts, it may be necessary to admit the subsoil water into the sewer, in order that the soil may be effectually drained by having its surplus water pumped out of it. In such situations there would be little danger of the subsoil water becoming polluted from the sewers, if it is possible always to maintain a constant flow into the sewers, and not from the sewers outwards.

Expense of subsoil drainage trifling compared with advantages.

Admittance of subsoil water into sewers.

CHAPTER XXXVII.

HOUSE DRAINAGE.

THE work of house drainage is the crowning point of a system of sewers. Upon the care and skill bestowed in carrying out this portion of the sanitary requirements of a district will depend in a great measure the ultimate success of the works from a sanitary point of view. It cannot be overlooked that imperfect sanitary works in connection with the houses in which we reside will result in the malarious influence of the sewers and drains being brought to bear directly upon their occupants. As a rule the works of house drainage have been often carelessly and thoughtlessly carried out, and have, as a natural consequence, inflicted untold injury on the luckless occupants of the house in which they have been executed. It should be said in reference to the train of evils which often follow the improper execution of house-drainage works, that they are not always due to the character of the workmanship, but generally to faults in principle in the arrangements adopted.

Crowning point of system.

We will now consider what are the requirements necessary in carrying out house drainage, and how best this work can be performed. House-drains are intended to carry away from houses all liquid refuse, waste or surplus water, and fæcal matter; and, while performing this duty, they should be so designed and constructed as to prevent the entrance of sewer air into the house. The rate of flow through house-drains is liable to considerable fluctuation, and the temperature varies greatly; and these two causes, as already pointed out, require of necessity that ample

Work of house drainage.

Fluctuation in flow.

ventilation for the drains shall be provided, and the reasons for and the way in which this work should be performed have already been fully considered under the head of ventilation of house-drains, page 397. It has also been pointed out at page 81 that small drains, such as 4 inch, 6 inch, and 9 inch, the sizes generally used for connecting houses with the sewers, should not have a less rate of velocity of flow through them than 3 feet per second in order to render them self-cleansing. This would give, by reference to Table No. 8, page 91, the least inclination for a 4-inch drain, 1 in 92; for a 6-inch, 1 in 137; and for 9-inch, 1 in 206; but in order to produce this velocity in drains of this calibre, they would require to run half full, so that a 4-inch drain would require to be provided with water at the rate of 7·85 cube feet per minute; a 6-inch drain with 17·66 cube feet per minute; and a 9-inch drain with 39·76 cube feet per minute. Now it will be seen from these figures that there are but few cases in which the requisite volume of water could be provided for keeping the house-drains properly cleansed if laid so flat as the above rate of inclination, therefore, in order still to make the house-drains self-cleansing, they must, as a general rule, have a greater rate of inclination than that theoretically requisite to render them self-cleansing when provided with a sufficient body of water. In cases where a greater fall than given above cannot be secured, all house-drains should be provided with special means of being flushed. The means usually provided for flushing house-drains consist of a tank similar to the manhole, Fig. 64, page 292, which may be filled up with water; or, in other cases, the ordinary sewage may be made to act as shown in Fig. 67, page 294.

Size of house-drains.

Velocity of flow.

Inclination and discharge of house-drains.

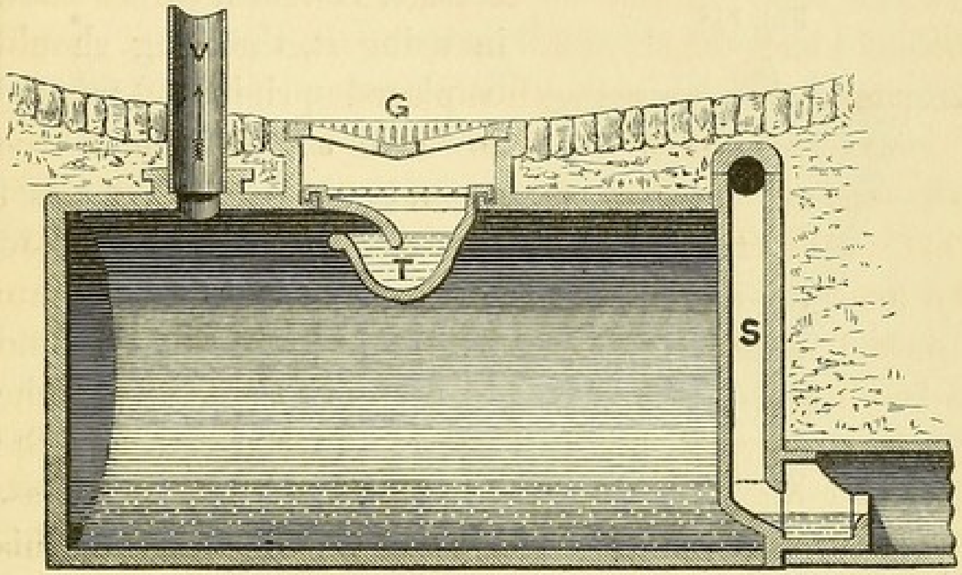
Greater fall must be given than theoretically requisite.

Flushing of house-drains.

Small flush tank of Mr. Rogers Field used as yard gully.

The flush tank of Mr. Rogers Field, C.E., is shown in Fig. 68, page 295, and Figs. 145 and 146, opposite page. Fig. 145 is a section of a small flush tank that may be used as a yard gully, or in any position in which gullies are usually required. G is the grating through which the drainage enters the gully, T is the trap on the inlet into the tank, and S represents the syphon at the end. A ventilating pipe is fitted to the tank in the position Figs. 145 and 146.

FIG. 145.



shown. In Fig. 146 SS represents the position of the syphon at the end of the tank, and W the weir with its

FIG. 147.

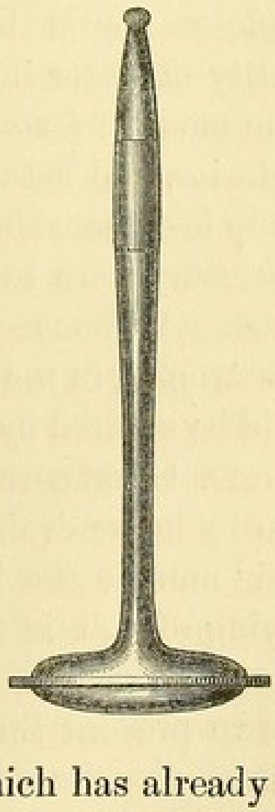
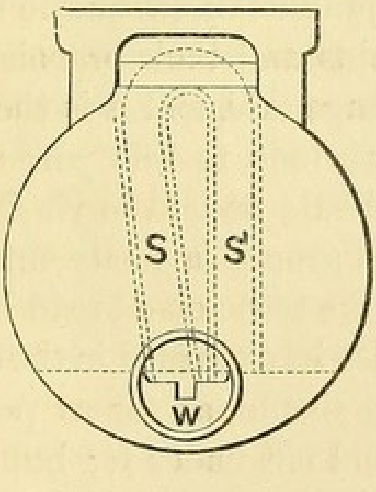


FIG. 146.

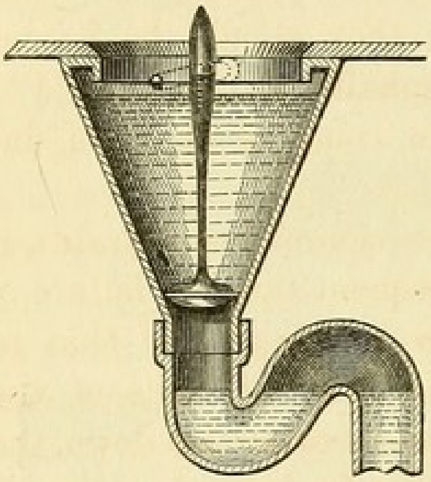


notch in the centre, the object of which has already been explained at page 296. In Fig. 147 is shown Messrs.

Harrison's flushing plug.

W. Harrison and Son's domestic flushing plug, and its application to the ordinary hopper water closet is given in Fig. 148. This appliance consists simply of a wooden plug fitted with a disc of india-rubber, and Messrs. Harrison direct that, in using it, the plug should be placed upright and pressed down in the bottom of the basin, the handle of the closet partially lifted so as to allow the water to flow gently into the basin, so as to fill it, and then simultaneously lift the handle of the closet to the full extent, and withdraw the plug. In the use of this simple appliance it is necessary to observe that care must be exercised to see that the induced current that will be created by the flow does not unseal the trap, and when the operation of flushing is completed, as a matter of precaution, the water in the trap of the closet should be renewed, by admitting a small quantity of water into the basin of the closet.

Fig. 148.



The mode of forming the junction between the sewers and drains, and between drains and their branches, has already been considered at page 280, and it is therefore unnecessary here to further allude to this part of the subject. All house-drains should be laid in virgin soil; if constructed in made or bad ground, a good foundation should be secured by laying the sewer on a broad base of concrete. Great care must also be exercised in the course taken by house-drains; they should, as far as possible, be laid outside the house, and not under it; but if the carrying of a drain under a house is unavoidable, every precaution must be taken in the laying and jointing, so as to prevent the escape either of sewage or sewer air from the drains. It must not be forgotten that when a house is built and the site drained, the soil

Laying of house-drains.

Laid outside house.

dries and becomes porous; at the same time, if clay is used in the jointing of the pipes (which is commonly the case), it is liable to dry and shrink. Mr. W. H. Wheeler, M.I.C.E., states that "a roll of wet clay 1 foot in length" was "found to shrink in length about half an inch" in drying. In cases where the passage of drains under houses is unavoidable, they should be jointed with gasket and cement or asphalte, or they should be embedded in Portland cement concrete of extra fine quality.

Jointing the pipes.

In considering the proper position of house-drains, it is well to call attention to a frequent cause of failure of drains in connection with new buildings, and that is, if a drain passes through the external walls of the building, and the building subsides or settles down, the drain is invariably injured either by being broken off, or the joints of the sewer pipe open, so as to lead to the ready escape of sewer air into the building. The remedy for this is to leave ample space at the points where walls are pierced, so that they may settle without injuring the drain. The materials used in the construction of house-drains, and the interior fittings of a house, require careful selection, and constant inspection is also needed to ascertain that the works are sound. House-drains are usually constructed of glazed stoneware socket pipes. The soil pipes for water closets, the pipes for baths, lavatories, and sinks, are constructed of iron, lead, and zinc. Lead is one of the best materials that can be used for soil pipes; but the pipes should be drawn or cast, and not soldered together, as is often the case, for with soldered pipes the two metals have unequal rates of contraction and expansion, and often rend at the seams. Moreover, a galvanic action is often set up, which is destructive to the pipe. Lead is injuriously acted upon by sewer air and lime, and not unfrequently a pipe gets honeycombed by the action of lime which had fallen into the pipes when they were first placed in position, and which lodging in a bend in contact

Effect of settlement in drains.

Selection of materials.

Lead pipes.

Action of sewer air on lead.

with water and fæcal matter soon perforates the pipe. In some cases fæcal matter will injuriously affect ordinary commercial lead. On account of its composite character galvanic action is set up, which rapidly destroys the pipe; care therefore should be taken in the selection of lead pipes, that they are made of pure lead, and not of composition.

Breakage of soil pipes.

It should be observed that lead soil pipes often break from being accidentally nicked by the plumber in jointing; and from the want of support when fixed, the weight of a long length of soil pipe often breaks the pipe at an imperfect joint. Iron pipes are used in some cases as soil pipes, but they are not so good as lead, as the interior of the pipe is liable to become coated by oxidation, and fæcal matter adheres to the rough surface. Whenever iron pipes are used as soil pipes, the material should be sufficiently stout to be jointed in the ordinary way with lead, like a water pipe. Joints made with putty should not be permitted to be used within a house. The position selected for the soil pipe should be such that the joints of the pipe can be easily got at all round for the purpose of being jointed, and not, as often happens, that the pipe can only be jointed for about two-thirds of the circumference of the pipe, the part against the wall not being jointed because it has been found inconvenient to get at it.

Iron pipes.

Jointing iron soil pipes.

Position of soil pipes.

Zinc pipes.

Zinc ought not under any circumstances to be used for conveying fæcal matter, as it is rapidly destroyed under its chemical influence. Earthenware pipes may be used for the soil pipes, and may be built into the wall, as already pointed out at page 406. In house drainage the sinks in the scullery and elsewhere are often the cause of much mischief, the traps provided for excluding sewer gas having such a small amount of seal that in practice they prove inoperative. Moreover, there are so many contingencies which injuriously affect traps, and which have already been referred to at page

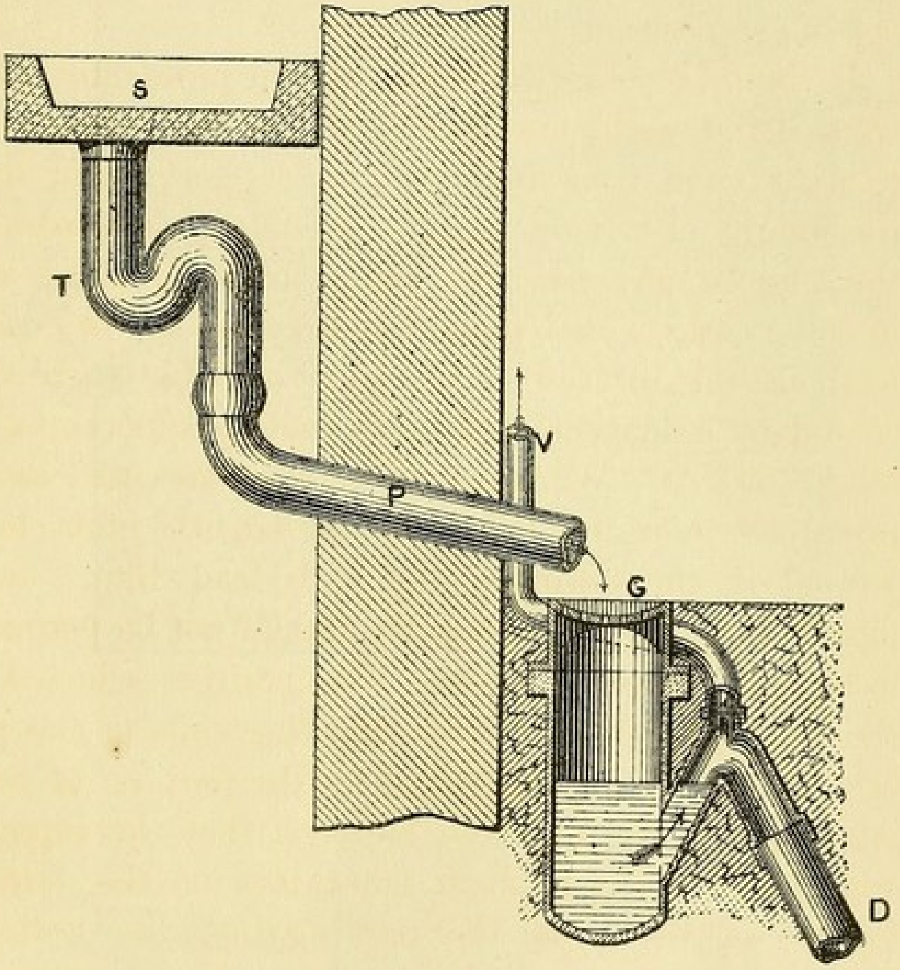
Earthenware pipes.

Drainage of sinks.

422, that it has been found necessary to cut off all direct communication between the sink and the house-drain. One of the best and most effectual ways of performing this operation is shown in Fig. 149, where S represents the sink; T the trap, which is merely used to prevent currents of air entering the house; P the pipe for conveying the waste water from the sink through the external wall and discharging it on the surface of the gully G; V is the ventilating pipe for the gully, which may be carried to any convenient point; and D is the pipe leading to the drain. When this plan cannot well be adopted, on account of the unsightliness of matters that may be deposited on the open grating, the pipe may be made to discharge into the gully, and still the direct connection between the house and the drain will be severed, as shown in Fig. 150. In some

Description of Fig. 149.

Fig. 149.



Description of Fig. 150.

FIG. 150.

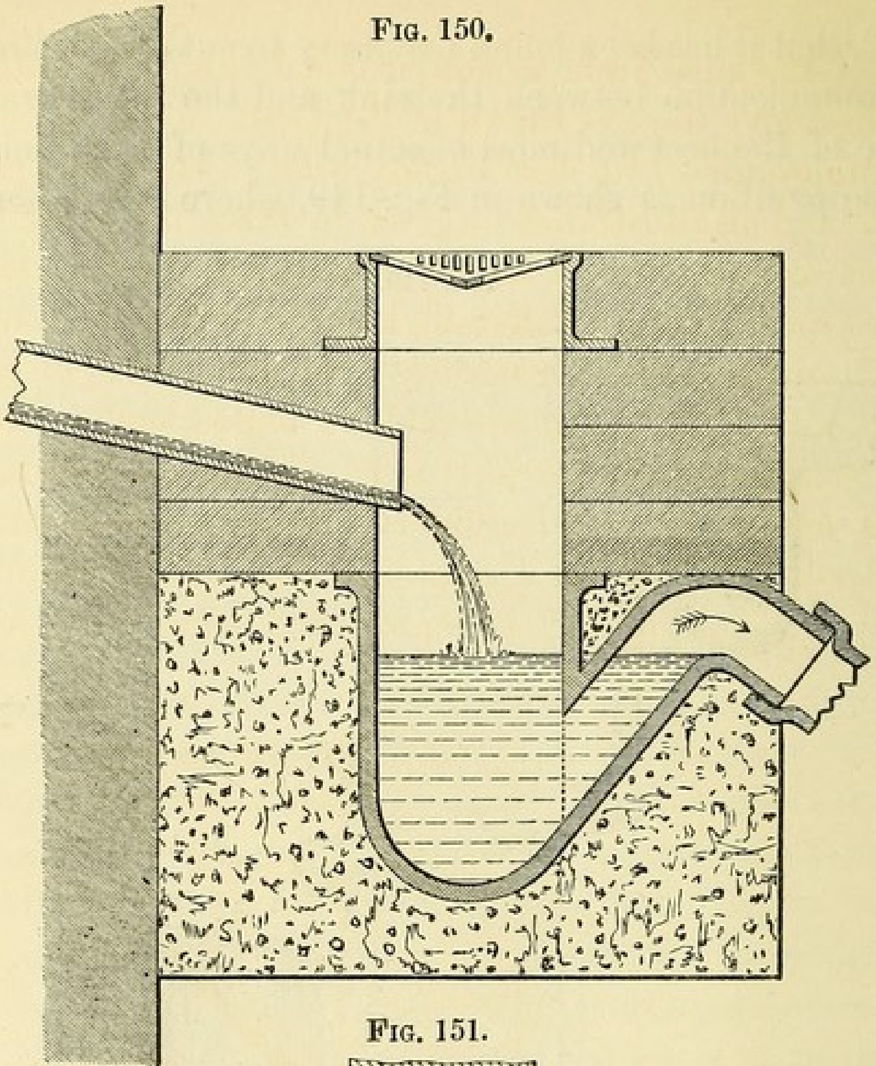
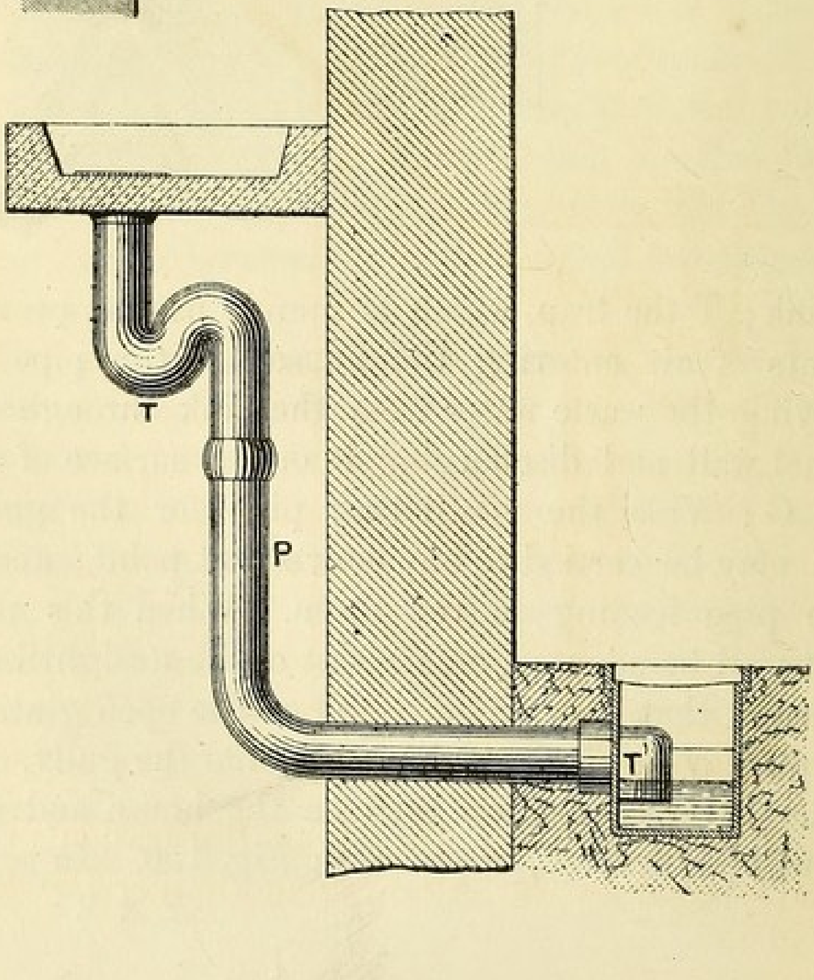


FIG. 151.



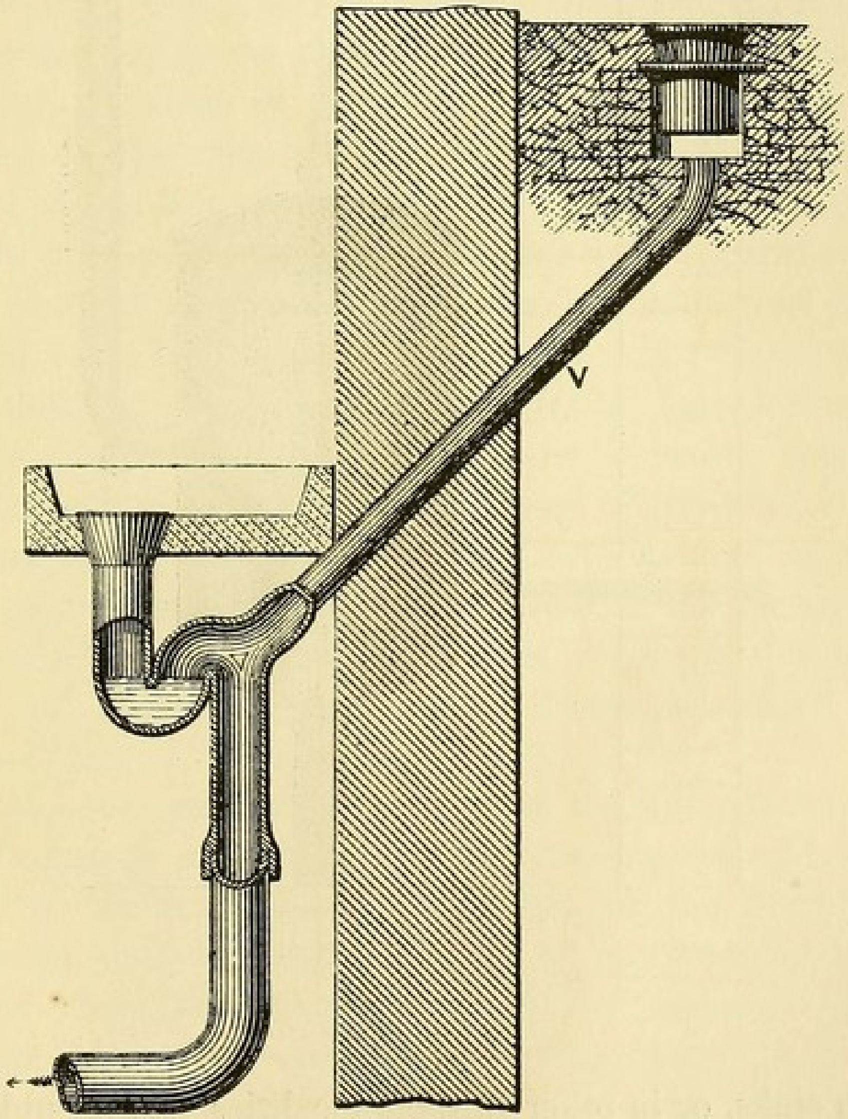
cases the pipe from a sink may be connected with a Mansergh's trap, as shown in Fig. 151.

Mansergh's trap has already been described at page 442, and an illustration is given in Plate XV., Fig. 14. This arrangement is not so good as the former; for if the pipe P is of great length, it is apt to become coated with grease and other matters; the air coming in contact with these matters would be fouled, and as every discharge through the pipe must displace a portion of this foul air, it would ordinarily escape into the house unless the trap T has a greater amount of seal than the trap T'. In Fig. 152 is represented another mode of dealing with a sink. This is an illustration of the mode adopted by the author in ventilating the drains

Description of Fig. 151.

Description of Fig. 152.

Fig. 152.



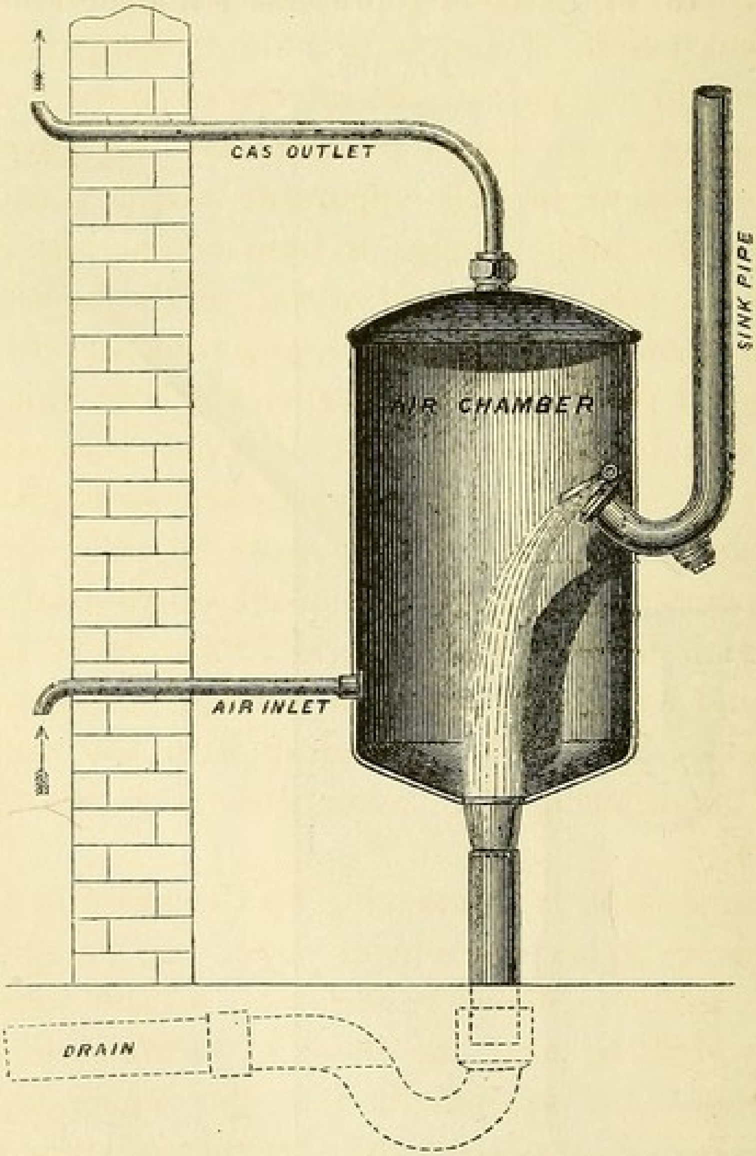
Blenheim Palace.

of the sinks in Blenheim Palace. In this case all the drains were already constructed in the interior of the palace, and the ground outside is at a considerable elevation above the sinks; a ventilating pipe V has therefore been taken from the trap under the sink, and carried some distance outside the palace, where it is made to terminate under a charcoal ventilator of the description shown in Fig. 100, page 392.

Mr. Baker's method of trapping sinks.

In Fig. 153 is shown an ingenious arrangement of Mr. W. Baker's, of Wakefield, to be used in connection

Fig. 153.



with sinks, or in other suitable localities. It should be observed in reference to this invention, that it should be placed in such a position that it can receive attention from time to time, as the grease of such water would be very liable to stop up the small ventilating pipes, by reason of the coating which the chamber must naturally receive in use. The valve on the end of the trap within the chamber, and which the inventor states is used "to prevent the probability of any back pressure of gas from the sewer, and to avoid the saturation with gas of the water in the bend, which takes place in an ordinary trap, rendering it inefficient," will also need attention from time to time, to prevent its clogging and sticking. The outlet pipe from the chamber may be continued up the outer wall to any convenient point. "Access to remove stoppages, &c., is obtained to any part of the interior of the apparatus by removing screw plugs provided for the purpose." An improvement in this apparatus would consist in fitting to the inlet air-pipe a light self-acting valve, fitted on the face of the exterior wall of the house, that would prevent back currents, for, as a rule, air will take the shortest passage for its escape, which in this case would often be the inlet pipe. It is only necessary to add that the gullies in areas or yards near houses should all be ventilated either by pipes or by other special modes pointed out under the head of ventilation of sewers and drains. The general arrangement of the drains and ventilating pipes of a house are shown in Plate XII. The mode of dealing with the drainage and of ventilating the water closets is shown in Fig. 154.

Ventilation of water closets.

Description of Fig. 154.

It consists simply in carrying up the soil pipe to the roof or some other convenient point, care being taken that no windows, house ventilators, or the flue of a chimney shall be near the point of termination, as at times there are in-currents into the house at these points. If it is necessary to carry the soil pipe up to the ridge, the pipes for this purpose may either be carried inside or outside the roof; but in all cases it is better and safer to place both the soil pipe and all

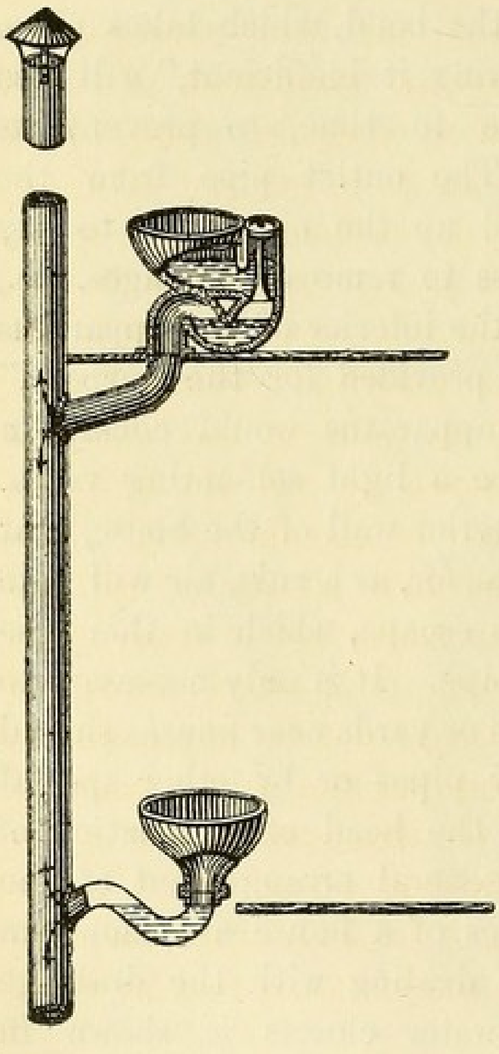
Pipes better outside of house.

other pipes in connection with the drains outside the house, protecting them with proper casings and packings from frost.

Carrying up of soil pipe not always sufficient for ventilation.

It should be observed that the ventilation of the soil pipe in the way shown in Fig. 154 is often not sufficient, except in cases where the soil pipe is much larger than the branches, or when but one closet or other source of supply communicates with it, as the effect of discharging the contents of two or more closets into one soil pipe is to create an induced current, which will unseal all the lower traps in communication with the soil pipe, in spite of the open ventilator at its head. An example of this action is given at page 402. The remedy for the effect of this induced current is, to carry a separate ventilating pipe from the top of the bend of each trap, either independently to the outside, as shown in Fig. 107, page 402, or to make these ventilating tubes communicate with the open soil pipe above the highest intake into the pipe.

Fig. 154.



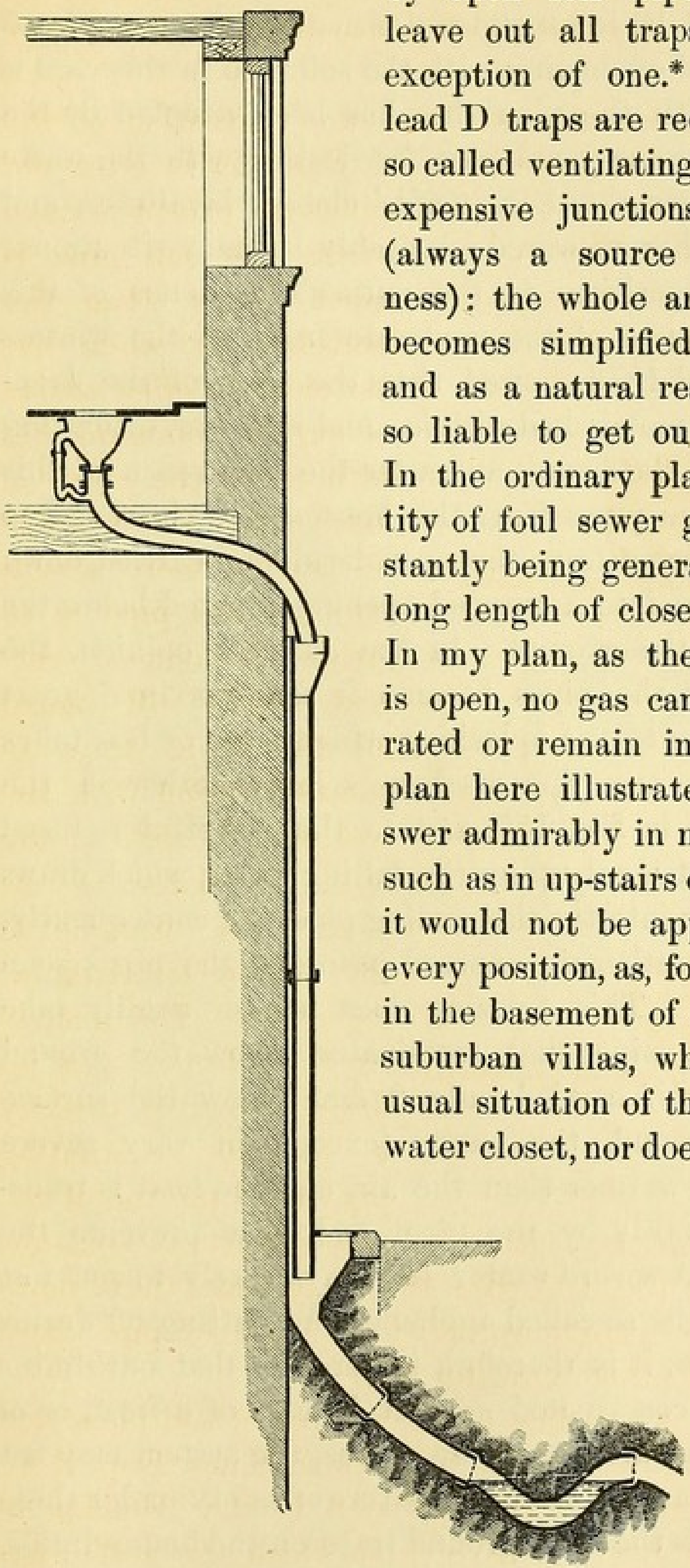
Influence of induced current of air in soil pipes.

Separate ventilating pipe required for each closet.

System of R. Norman Shaw, R.A.

Fig. 155 is a section of the system of soil pipes that has been introduced by R. Norman Shaw, Esq., R.A., a description of which appeared in the 'Builder' of the 12th of January, 1878, from which the author has taken the illustration. Mr. Shaw says, "The plan I have adopted is to connect the closets with the drains

FIG. 155.



by open soil pipes, and to leave out all traps with the exception of one.* Thus no lead D traps are required; no so called ventilating pipes; no expensive junctions to make (always a source of weakness): the whole arrangement becomes simplified at once, and as a natural result, is not so liable to get out of order. In the ordinary plan a quantity of foul sewer gas is constantly being generated in the long length of closet soil pipe. In my plan, as the soil pipe is open, no gas can be generated or remain in it." The plan here illustrated will answer admirably in many cases, such as in up-stairs closets, but it would not be applicable in every position, as, for example, in the basement of one of our suburban villas, which is the usual situation of the servants' water closet, nor does Mr. Shaw

System not applicable in every position of closet.

* The illustration shows two traps, one for the overflow of the closet, and the other in the soil drain.

Effect of frost on the system.

Method identical with plans pursued by the author.

appear to be aware of what the effect of such an arrangement would be in an exposed situation in time of frost. The method of dealing with the soil pipe in this case is identical with the plan that has been adopted by the author for some years past for dealing with the waste of up-stairs sinks, housemaids' closets, lavatories, and baths, and has answered admirably in many situations; but the experience at the author's residence of this system in time of the moderate frosts of the winters of 1875 and 1876 showed that the head of the drop-spouts became choked with ice, and ran over, saturating the wall of the house, and after the recurrence of this nuisance the pipes from the housemaid's closet had to be disconnected from the open head, and carried down to discharge into a trapped opening situated below the surface of the ground. In the author's opinion, the reason why the pipes became frozen was in a great measure due to the splashing which more or less takes place when one pipe discharges into another in the way shown in Fig. 155, and to the powerful reduced current that is set up by the falling water, which draws the cold air into the descending pipe, and consequently, in severe weather, in exposed positions, the pipes soon freeze up.* This freezing does not so readily take place in a pipe that terminates below the ground surface, for if carried only 2 feet below the surface of the ground, the earth (except in very severe weather) is warmer than the air, and the heat is transmitted upwards by the pipe, and thus prevents the freezing. A severe winter is always likely to put out of gear all the so-called appliances for cutting off drains from houses, it is therefore imperative that our drains should be constructed so that in case of a frost, or of snow closing all the air apertures, the system may act perfectly; and an essential feature of safety under these conditions is the underground traps on the house-drains,

Experience at author's residence of failure in time of frost.

Causes of failure.

Pipes discharging below ground level.

Severe winter will put appliances out of gear.

Precautions necessary against frost and snow.

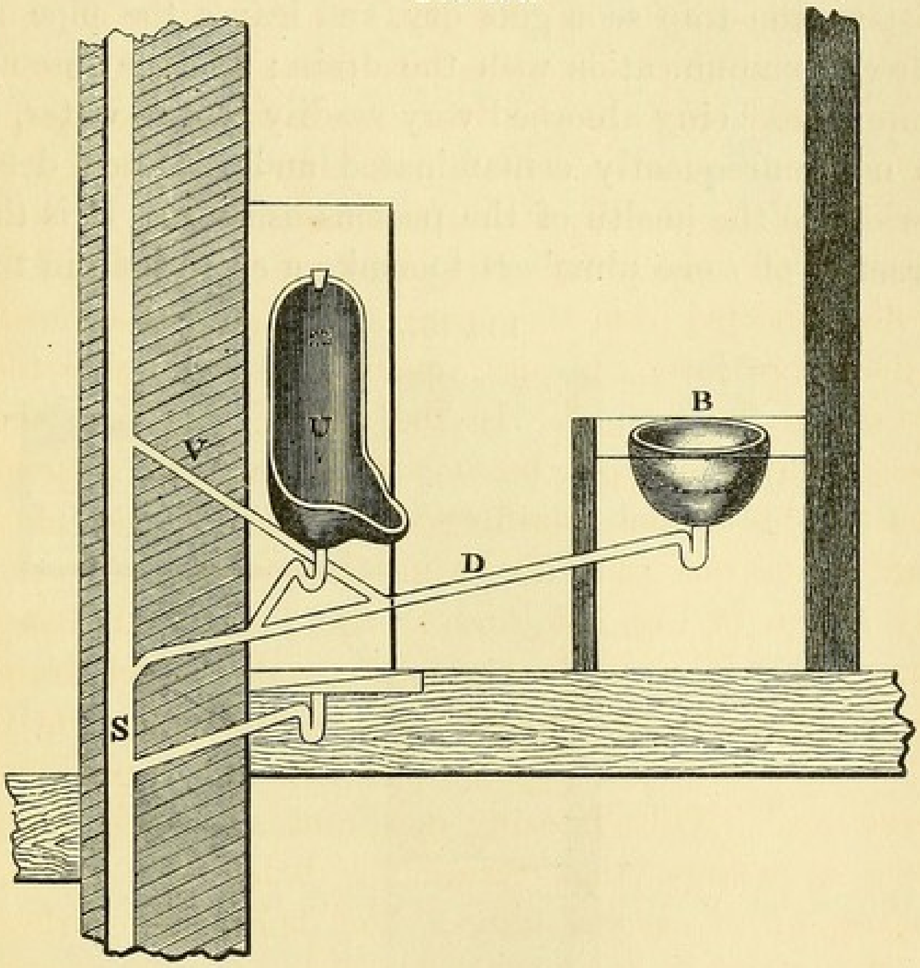
* Common salt, which is an excellent disinfectant, may be used with very great advantage in keeping traps open in the winter time.

when provided with openings for ventilation, or the admittance of fresh air or the exit of sewer air.

The same provisions should be made for the ventilation of urinals as for water closets. Urinals.

Fig. 156 shows an arrangement in a private house in the West End of London, in which the influence

FIG. 156.



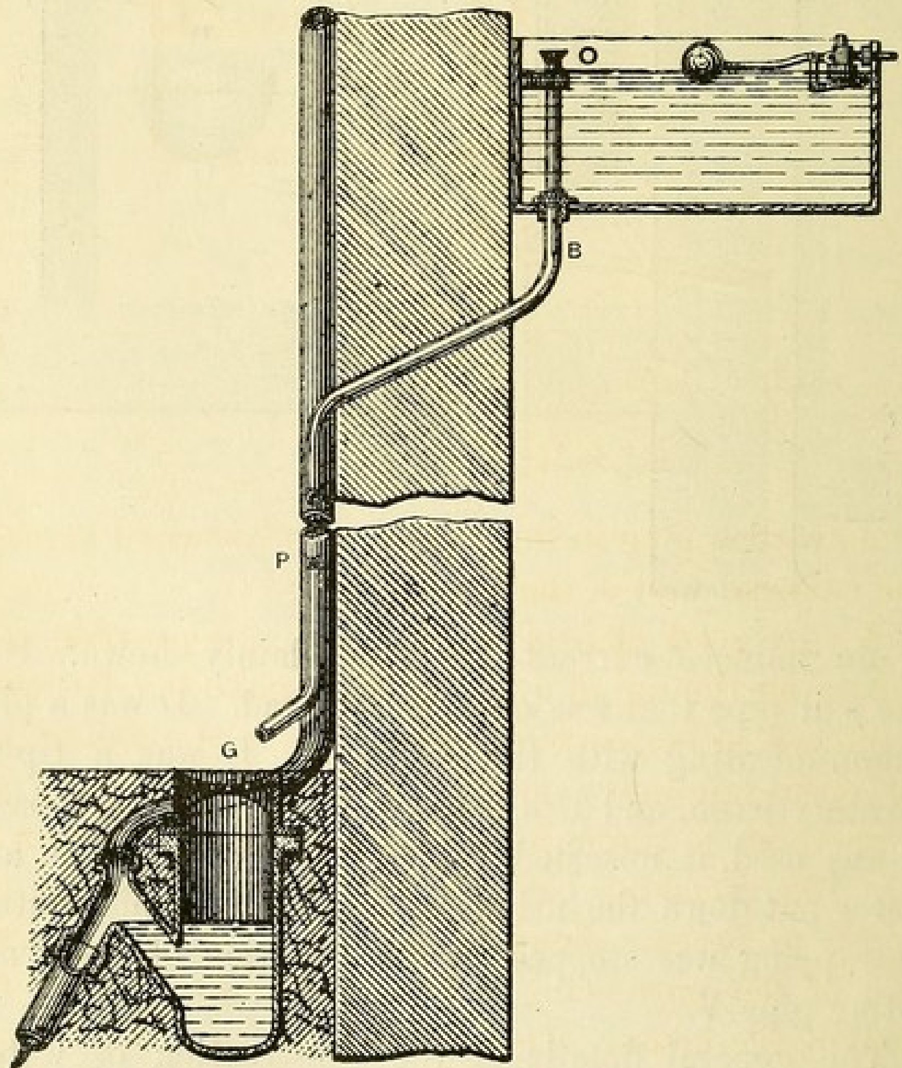
of an induced current was very plainly shown. S is the soil pipe that was open at its head. D was a pipe communicating with the soil pipe. B was a tip-up lavatory basin, and U a urinal. Every time the basin B was used, it unsealed the trap of the urinal U, and water put down the urinal untrapped B. This mutual untrapping was stopped by the insertion of the ventilating pipe V.

The general details of the construction of water-closets and urinals will be hereafter considered. The overflows from cisterns communicating directly with Overflow for cistern.

drains are the frequent cause of much mischief, and, moreover, often lead to the waste of much water. It is quite clear that if the water fittings of a cistern are in perfect working order, no water can overflow by the overflow pipe, which is usually provided with and sealed by a water trap. Now, as the water in the trap is seldom renewed, except by the overflow from the cistern, the trap soon gets dry, and leaves the pipe in direct communication with the drain; and the gaseous impurities being absorbed very readily by the water, it is not unfrequently contaminated and rendered deleterious to the health of the persons using it. It is the practice of some plumbers to make a small hole in the

Weeping holes provided in overflows.

Fig. 157.

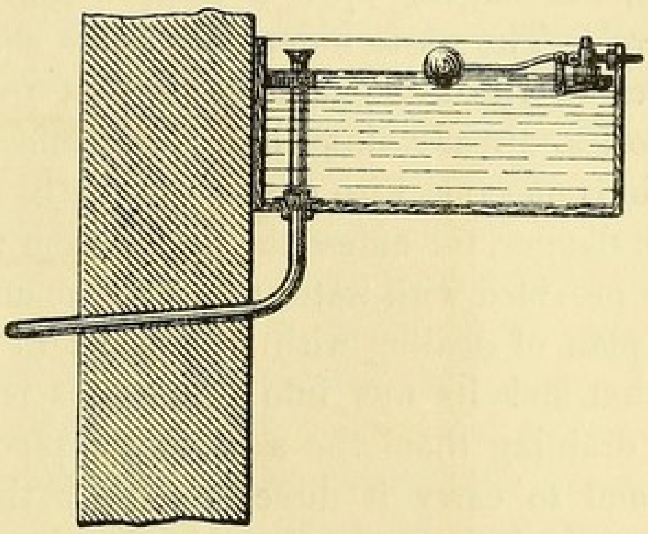


side of the overflow pipe, in order that the leakage, or the "weeping," as this leakage is technically called, may keep the trap supplied with water. The overflows and waste pipes of all cisterns should either be treated like a sink, as shown in Fig. 157, in which P is the wash out and overflow pipe of a cistern brought down the external wall and made to discharge on the top of an open gully G. This pipe may be trapped at the top O with an Antill's trap, described at page 441, and illustrated in Plate XV., Fig. 5, or it may have an ordinary syphon trap at B. These traps are merely intended to prevent currents of air entering the house by the overflow pipe. In some cases the overflow from the cistern may be treated as shown in Fig. 158.

Description of Fig. 157.

Description of Fig. 158.

Fig. 158.



The overflow pipe in this case is simply carried through the external wall of the house.

A very good plan of dealing with the overflow of a cistern on the top of a house is to make the discharge terminate either on the inclined slating of a roof or into an open rain-water gutter. When overflow pipes are simply taken through the outside wall, as shown in Fig. 158, a leaking ball cock will cause the walls of the house to become damp by the water falling from the end of the pipe being driven by the wind against the wall of the house. The author has seen much damage done to buildings from this cause. As a preventive for the undue waste of water, the outlet of every

Position of outlets of overflows.

overflow pipe should be arranged so that it can be readily inspected by the Waterworks authorities, but should not be put in such a position that a leakage may cause damage.

As the overflows from cisterns are not liable to be fouled* from the discharge which passes through them, they may be conveniently trapped at the bottom with Mansergh's trap, Plate XV., Fig. 14. The pipes for lavatories may be treated in a manner analogous to the method pointed out for sinks; or in some cases, when located in the upper floor of a house, the discharge pipe may be carried through the outside wall of the house, and there made to discharge into the open head of a pipe, discharging upon a trapped gully at the ground level. The waste water from baths should also be conveyed in the same manner as that from sinks and lavatories, already described. The safes or pans provided in connection with closets and baths are often a source of danger, for unless the drains from them are constantly provided with water they become untrapped. The best plan of dealing with the uncertain quantity of water that finds its way into these safes is to treat the pipes draining them the same as the pipes from a lavatory, and to carry it directly outside the house, after the method shown in Fig. 155, bearing in mind, however, what has been said at page 494 in reference to the influence of frost on this arrangement, and that in exposed positions it may be necessary to carry the pipes down to be made to discharge into a trap located below the level of the ground line. The safe of a water-closet is necessary in every case where a closet is used by housemaids for the disposal of slop water. Not unfrequently the closets overflow from the slops being either carelessly poured in or by being poured in faster and in larger volume than either the closet will hold or can carry away. A connection should be made in the supply pipe to the closet and the safe, so that a part of

Mansergh's trap used for trapping overflow of cistern.

Lavatories.

Baths.

Safes.

Safes of water closets.

* Vide pp. 488.

the water may pass into the safe every time the closet is used, so as to wash and carry away any matter spilt into it, and also to replenish the trap. In some cases the safes of baths may be effectually kept drained by the pipe provided for taking away the waste water; for if the top of this pipe terminates below the level of the safe, and is kept open, the waste water from the bath being conveyed into it by a distinct pipe, it will thus serve the double purpose of draining both the bath and its safe, and the volume of water contributed by the bath will keep the trap supplied. Rain-water pipes should not be connected directly with the drains, but cut off, as shown in the case of the cistern overflow, Fig. 157. On no account ought rain-water pipes to be used as ventilating pipes of the house-drains, for reasons already stated at page 354. It is only necessary to add that in the case of the drainage of cellars and low-lying places, whose level is but slightly above that of the drains, and which in time of storm are liable to be inundated, the trap for draining them ought to be provided with a valve similar to that described at page 438, and illustrated in Plate XIV., Fig. 22.

Rain-water pipes.

Drainage of cellars.

As a matter of security, barring the passage of sewer air from a sewer through the house-drain into a house, the insertion of a trap on the house-drain near the sewer, theoretically considered, is a desirable thing: The insertion of an ordinary flat syphon trap in an ordinary inclined house-drain has, in practice unfortunately, been found not to answer, and when so used they usually stop up in the course of a few years, and lead to the stoppage of the drains and other inconveniences. On inquiry at Beckenham, in which place traps have been systematically placed for some years on the house-drains between the sewer and the house, Mr. Thomas Graham, builder, informed the author that, in no case have they been found to answer for more than two or three years, when a stoppage of the house-drain occurs, and he said that at least in fifty places he had taken out the traps during

Traps on house drains.

Failure of flat syphon traps.

Experience at Beckenham.

Mr. Thomas Graham.

Removal of traps.

Local Government bye-laws.

the last six years. Seeing that the Local Government Board, in their model bye-laws insist on the insertion of a trap on the line of house-drain between the house and the sewer, the form of trap to be used must receive some more careful attention, as practice shows that it is quite clear that the ordinary flat syphon trap will not answer for this purpose. The author is of opinion that in all probability the stoppage of these traps might to a great extent be avoided if a good and perpendicular fall could be got into them, just as we find the traps of ordinary water closets, where such a fall into the trap is secured, work well, but under circumstances in which we have a long length of inclined drain, joining a flat syphon at its upper end, and an equally long length of drain connected with the lower end of the syphon, such conditions offer a considerable impediment to the flow, and as in the course of time the syphons get coated with grease, and catch hair and other matters, the feeble currents of water flowing down the bed of the pipe possess little or no power to remove the matters which have lodged in the trap, and consequently, in course of time, a stoppage occurs. The advantage of Mr. Buchan's trap, which has already been referred to at page 408, consists in the fall given to the water when entering the trap.

Form of traps must receive attention.

Opinion of author as to the cause of failure of traps.

Advantages of Buchan's trap.

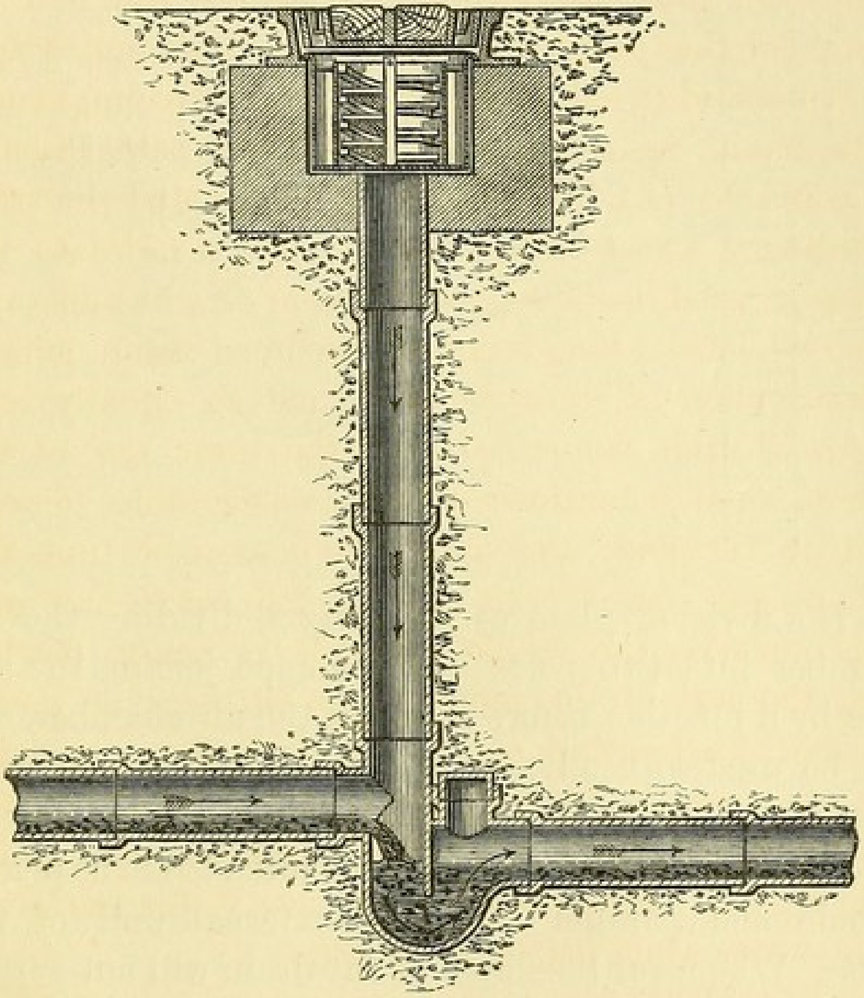
Improved trap for house drain.

In Fig. 159 is shown an arrangement of trap which the author designed, and is using experimentally in the house-drain of his residence at Croydon. This trap, which was inserted with a view to experiment and to test the efficiency of the system, was manufactured by Messrs. Henry Doulton and Co., of Lambeth, and has been in operation for over two years, and has so far answered perfectly. In this trap there is an abrupt fall of 6 inches from the house-drain into the trap. Provision is also made for the admittance of air on the house side of the trap, and for ventilation, where necessary, on the sewer side of the trap. The trap in this case is formed by a thin diaphragm not more than 1 inch in thickness,

Description of trap designed by author for house-drains.

so that the distance for any matter to travel is reduced to the shortest possible space, and the abrupt fall into the trap will secure any floating substance being

Fig. 159.

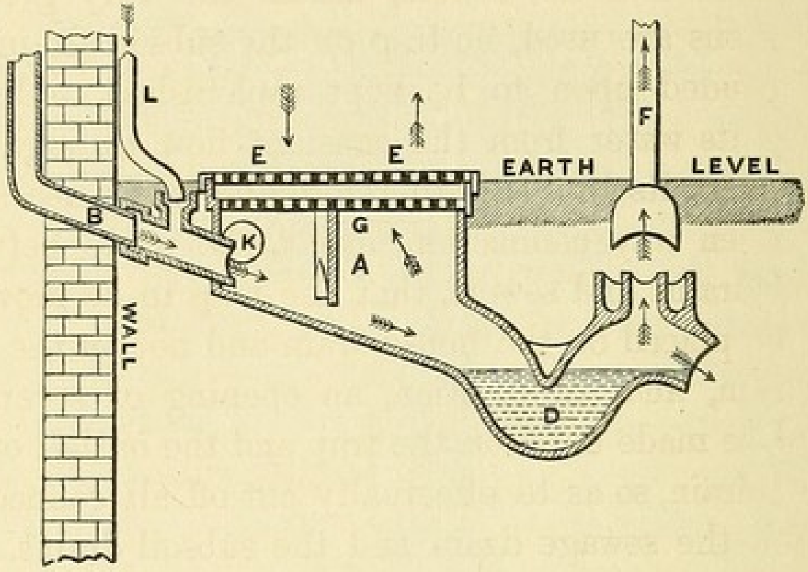


driven by the water under the diaphragm forming the trap. The difficulty in using traps of this description in existing drains, arises from the fact that few house-drains have sufficient fall to enable a trap of this kind to be inserted. Difficulty of inserting trap in existing house-drains.

Fig. 160 is a representation of "Pott's Patent Edinburgh Air-chambered Sewer Trap," which is described by its inventor as follows: "A represents an air chamber 2 feet 6 inches or 3 feet long; B is the soil pipe from the closet." The arrows show "the course of the soil through the trap. D is an ordinary water trap or syphon, E E an open grating raised two or Pott's patent trap.

three inches above the ground level, having a second grating or tray below it on which charcoal or other disinfectants may be placed." F is a ventilating pipe;

Fig. 160.



"G is a division plate or diaphragm, dividing the air chamber into two parts; L is a pipe joining the soil pipe by a junction before it enters the air chamber, and can be used with advantage as a rain-water pipe, or to convey waste or bath water; K is a side opening for an extra soil pipe. This apparatus is intended to be placed outside and parallel with the external wall of the house. Whenever the depth of the drain will not permit this trap to be placed on the surface, the sides of the air chamber should be carried up to the surface, and the grid placed on the top." The inventor, however, says that "in case the trap has to be fixed at a great depth below the surface, then circular or square pipes will do carried up—one next the house to a little above the ground, and the other next the sewer a foot higher. These pipes should be 12 inches diameter, and fitted on the air chamber, and the rest of the space covered in, and the soil replaced; in this case the grid cannot be used; but it is best always to build up the sides when possible."

Position in which Pott's trap intended to be used.

It is necessary that a word should be said in reference to the subsoil drainage of the site of a house, and the absolute necessity of avoiding all direct connection being made between the subsoil drains and a sewage drain. If a direct connection exists between the subsoil drains and the sewers, unless the very greatest precautions are used, no trap on the subsoil drain can be depended upon to be kept replenished, unless it derives its water from the constant flow through the house-drain itself. It is therefore absolutely necessary that, when any connection has to be made between subsoil drains and sewers, that the trap to be provided must be placed on the house-drain and not on the subsoil drain, and, in addition, an opening or severance should be made between the trap and the outfall of the subsoil drain, so as to effectually cut off all connection between the sewage drain and the subsoil drains. In many cases it will be found that if the drain is simply brought up to the external wall of the house, it will effectually drain the subsoil, and no opening need be made communicating directly between any of the drains and the lower floors. In this case the head of the drain should be closed against the escape of sewage in time of flood; or otherwise, where waste water will drain away, sewage may, by back-flow, enter, and the consequence may be that the whole of the subsoil under the house may be permeated with sewage matter, to the great detriment of the health of its inhabitants.

Subsoil drainage of sites of houses.

Traps in subsoil drains not to be depended upon.

Precautions against back-flow of sewage.

CHAPTER XXXVIII.

WATER-CLOSETS.

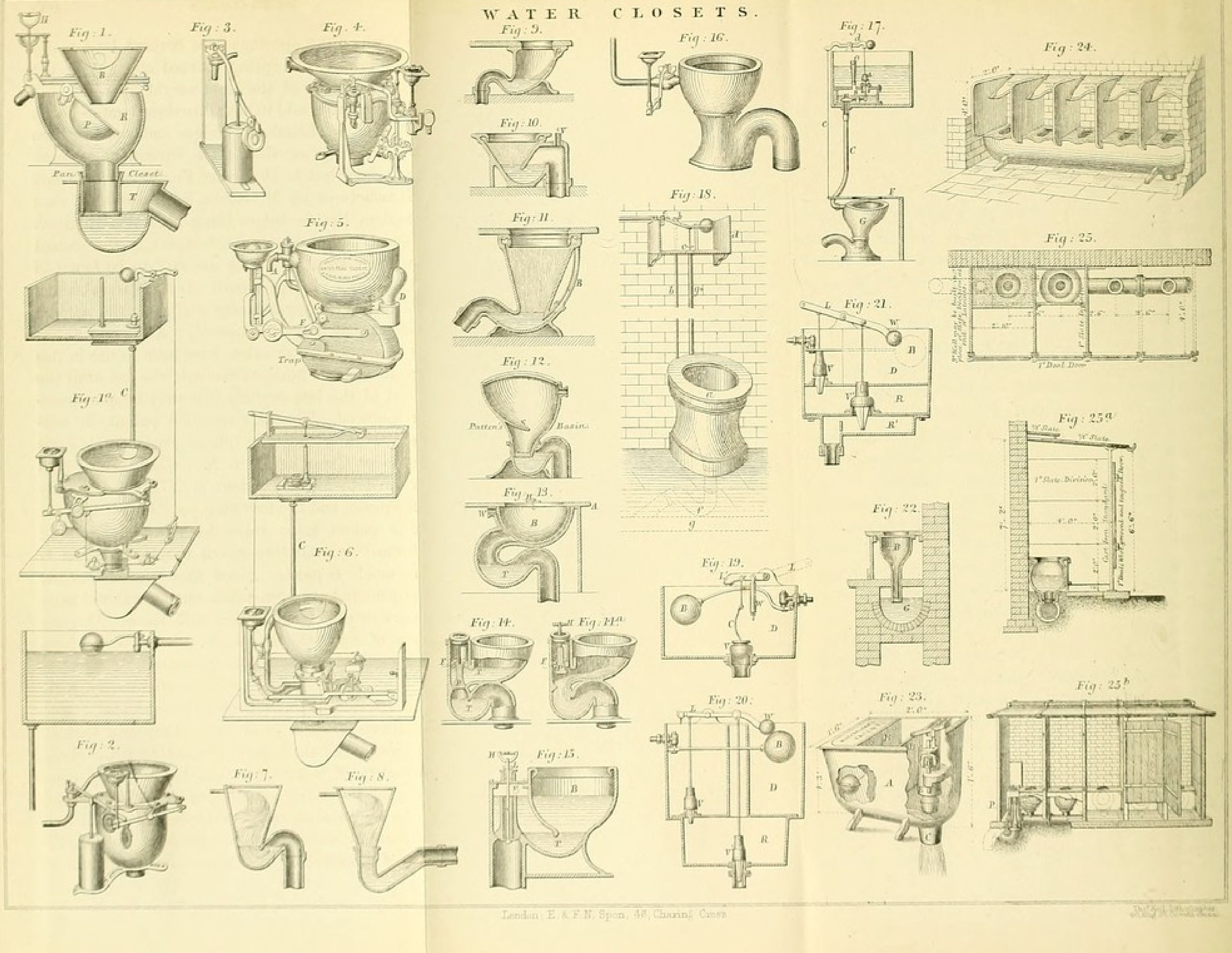
Water-closet ancient device.

THE water-closet is a very ancient device for receiving and carrying away in water fæcal matter. Its use has been traced to all nations that had arrived at a certain degree of refinement. In Ewbank's 'Hydraulics' it is stated that water-closets "are an ancient and probably Asiatic device. The summer chamber of Eglon, King of Moab (Judges iii. 20–25) is supposed to have been one. They were introduced into Rome during the Republic, and are noticed by several ancient writers. Those constructed in the palace of the Cæsars were adorned with marbles, arabesque, and mosaics. At the back of one still extant, there is a cistern, the water of which is distributed by cocks to different seats. The pipe and basin of another has been discovered near the theatre at Pompeii, where it still remains. Heliogabalus concealed himself in one, and whence he was dragged by his soldiers and slain. Water-closets seem to have been always used in the East, and for reasons which Tavernier and other Oriental travellers have assigned. Numbers are erected near the mosques and temples. A similar custom prevailed in old Rome, Constantinople, Smyrna, and probably all ancient cities. In the city of Fez, 'round about the mosques, are 150 common houses of ease, each furnished with a cock and marble cistern, which scoureth and keepeth all neat and clean, as if these places were intended for some sweeter employment.' (Ogilby's 'Africa,' 1670, p. 88.) In his 'Relation of the Seraglio,' Tavernier describes a gallery in which were several water-closets. 'Every seat (he observes) has a little cock.' He mentions

Quotation from Ewbank's 'Hydraulics.'

Ancient water-closets.

WATER CLOSETS.



London: E. & F. N. Spon, 48, Charing Cross.

others in which the openings were covered by a plate, which by means of a spring 'turned one way or the other at the falling of the least weight upon it.' Sir John Harrington is said to have introduced water-closets into England in Elizabeth's reign, and some writers have erroneously ascribed their invention to him. They are described in the great French work on Art and Manufactures by M. Roubo, who says they were long used in France before being known in England. Those which he has figured are, however, on the ancient plan, without traps, and such are still to be found in Oriental cities." In the buried cities of Herculaneum and Pompeii an apparatus very similar to the modern water-closet has been discovered. Although water-closets in some shape or other have been in use in this country about three hundred years, it was not until the latter end of the last century that they became generally introduced. The first recorded patent in connection with water-closets in this country was taken out by Alexander Cumming, 11th November, 1775. This was followed by another patent in 1777, taken out by Samuel Prosser, and the following year Joseph Bramah secured a patent for a valve-closet, which has been very extensively used throughout the country, and is still in much request. Since that period several hundred patents have been taken out for water-closets, or matters in direct connection with them. The descriptions of water-closets now in use are very numerous; but all closets resolve themselves into three classes, water-closets with valves, water-closets with traps, and water-closets with both valves and traps. The requirements of a good water-closet are, that it shall be inodorous, shall work efficiently with a minimum quantity of water, and shall be simple in construction and not liable to get out of order. There can be no doubt that many water-closets which are now in general use are extremely defective in the principle of construction, and when introduced into a

Introduction of water-closets into England.

First patent water-closet.

Bramah's valve-closet.

Water-closets of three classes.

Requirements of good closet.

Many defective closets in use.

house, instead of being a comfort and luxury, are a positive nuisance, and often endanger the health of its inmates. Most of the complaints which have been raised against the water-carriage system have been directed almost solely against the water-closet, as being the source of nuisance when introduced within a house. These complaints have in many instances been well founded, as there cannot be a shadow of doubt as to the nuisance caused by many descriptions of closets; but the remedy is not to abandon the water-carriage system, but to correct the defects in the form of closet which have given rise to these complaints. A good water-closet is the only appliance fit to be used within a house, for by it all matters are at once conveyed away and cease to have the power of producing evil so far as our houses are concerned; it is not so, however, with those systems that conserve fæcal deposits within or in close proximity to our dwellings, as there is always danger in storing any dangerous article, however carefully we may tend and guard against its evil effects.

Water-closet the best sanitary appliance.

By far the greatest number of water-closets in operation in the best houses of this country are expensive and cumbrous appliances, and cannot be introduced within a house without creating a nuisance. They are generally known as pan-closets, and a section of one is delineated in Plate XXI., Fig. 1. It consists of four distinct parts: 1st, the basin B, which is usually made of earthenware; 2nd, the pan P, which in the drawing is shown to be removed from its place at the bottom of the basin by the partial raising of the handle H; 3rd, the receiver R, in which the pan works; and 4th, T, the ordinary **D** trap. When ready for use, the pan P retains water, so that as the bottom of the basin B dips into it a trap is formed, and the fæcal matter is deposited in the water retained in this pan. When the handle H is raised to the full extent, the fæcal matter and water are thrown from the pan on to the sides of the receiver;

Defects of pan-closet.

from thence they fall down, or are washed down by the water flowing through the opening at the bottom of the basin into the trap T, and thence to the drain. The effect of this action of the closet is that the receiver R gets completely coated with fæcal matter, so much so that it is the practice in many establishments to have the closets removed once a year and have the deposit burnt out; but this cannot remedy, but only palliate, the nuisance, as the continual plastering of the interior walls of the receiver with fæcal matter in the presence of moisture causes decomposition to take place, and noisome gases are generated, which accumulate in the receiver between the two traps; and every fresh discharge from the closet displaces an amount of this foul vapour, which passes at once through the open basin into the apartment, and thence into the house, and no amount of ventilation of the receiver will remedy this defect, which is inherent to this particular form of closet and in a less degree to some other forms of closet constructed on this principle. The valve-closet (Plate XXI., Fig. 6) invented by Bramah is somewhat less objectionable than the pan-closet already described, for instead of having a receiver provided large enough for the large pan to work, this chamber in the valve-closet is reduced in size in order to admit only the working of a small valve; but this form of closet still retains the objectionable feature already pointed out, of an evaporative area coated with fæcal matter, and a space to collect the gases evolved by decomposition, and its direct passage into the apartment every time the water-closet is used. Owing to the nuisance arising from these particular forms of closet, it has been proposed to construct all water-closets in a separate building from the house, communicating by passages so arranged with doors, and provided with ventilation, as to prevent any escape of noisome vapour entering the house. In other cases double doors are used in connection with the entrance to the apartment in which the water-closet is placed,

Nuisance of pan-closet.

Defect of valve-closet.

Proposal to construct water-closet in separate buildings.

but such measures are only palliative; the true remedy is the introduction of a form of water-closet free from the defects pointed out. It will be found in practice that some of the simplest and cheapest water-closets are the best; in fact all those closets consisting of a simple basin and trap, usually called the hopper closet, if provided with ample water for flushing, can be used without causing any nuisance, as there is no space for noisome gas to accumulate and no exposed area plastered with fæcal deposit to generate foul gas; and if the closet is provided with ample ventilation* in the way already pointed out, or by carrying up the soil-pipe to some convenient point, no gases can pass back through the trap to cause any mischief. It should be here stated that many of the hopper closets in use, owing to defects in the construction of the trap and from the inadequacy of the flush of water, do not clear themselves at every discharge of the closet; the consequence is that fæcal matter is left in the trap, and its exposure often gives off a bad odour. Those who require a still more perfect closet than the simple basin and trap will find Mr. George Jennings' closet (Plate XXI., Figs. 14 and 14A) a perfect sanitary appliance. It consists of a basin and trap made in one piece of earthenware, but instead of the small quantity of water usually occupying the trap of a hopper closet, in this case a hollow plug P is used to dam up the water in the basin. The consequence is that the fæcal matter is at once dropped into a large volume of water, and to a certain extent it is immediately deodorized, as the organic odours given off by fresh fæcal matter are prevented from escaping, and when the handle H which lifts the plug is raised, everything in the basin is suddenly discharged into the trap below, and so into the drain. The hollow plug also serves as an overflow if the basin fills too high.

Simplest and cheapest closets best.

Defects of hopper closet.

Jennings' closet.

Advantages of large volumes of water.

Figs. 161 and 162 illustrate what is called "The

* Vide page 492.

Patent Trapless twin basin closet," the invention of Mr. E. Pearson. It will be seen by comparing the

Pearson's closet compared with Jennings and Lovegrove's closet.

Fig. 161.

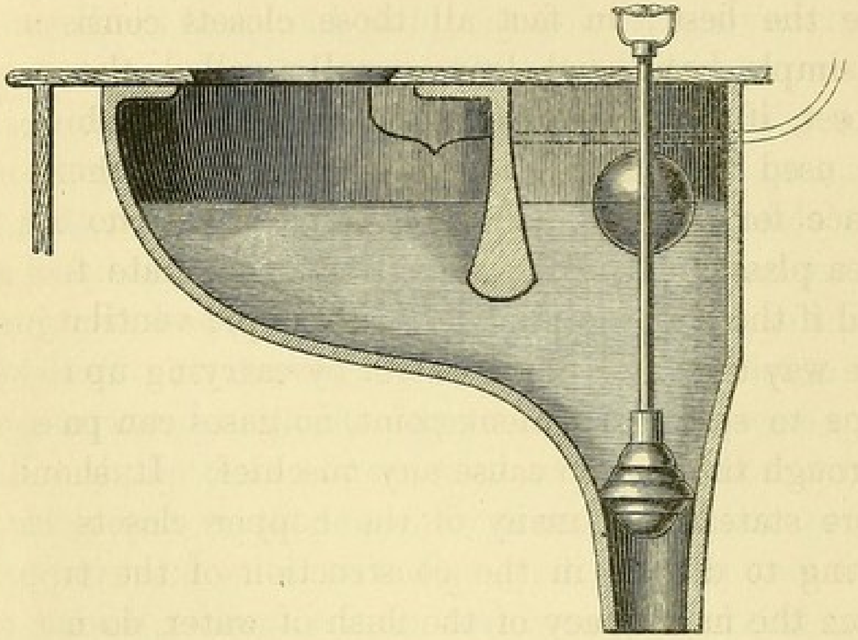
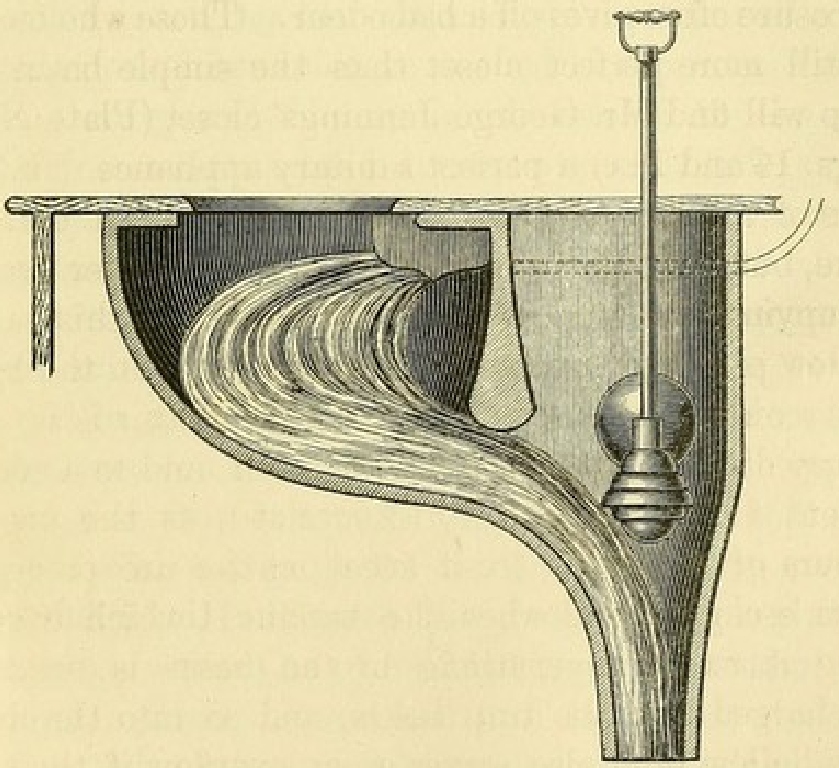


Fig. 162.



illustrations that this closet resembles the closet of Messrs. Jennings and Lovegrove, Figs. 14 and 14a, Plate XXI., minus the trap and the substitution of a solid instead of a hollow plug. The water supply in this closet is cut off in a manner similar to that shown in Messrs. Jennings and Lovegrove's closet by means of a valve worked by a float. Fig. 161 is a view of Pearson's closet with the plug down and the basin full of water, with the ball floating on the top of the water in the inner division of the closet. Fig. 162 shows the plug up, the ball down, and the water flowing through the closet. It is claimed as a special merit that this closet has no trap, but what may be looked upon as a point of merit by some persons, may, and very justly, be considered a doubtful improvement. The water trap does prevent direct communication between sewers and houses, and even between the external air and the house, and, moreover it washes or filters any sewer air that may pass the trap, and even in its most imperfect form it is an improvement on the ancient device of a trapless closet. Let us consider whether there are advantages or disadvantages in doing away with the water trap as in this closet. The closet would act just as efficiently with the trap as without it, as the experience gained in the use of Messrs. Jennings and Lovegrove's closet shows; but there are special disadvantages in this form of closet which must be considered. This closet depends for its safety in use, and the prevention of an escape of sewer air, on the induced current that is set up, and follows the direction of the flowing water when the closet is used. In judging of the efficiency of an induced current, we must not overlook the fact that there are powerful forces at work in a modern system of sewers which, if acting at the time the plug of this closet is raised, will overcome the influence of any induced current, and lead to an escape of sewer air through the closet into the house. Such a force we have in the rapid changes of temperature that occur in every house drain, due to the presence of a sudden flush of hot water; or another force is developed with the increase in the volume flowing in the sewer. These

Description of Pearson's closet.

Is any advantage gained by doing away with the trap.

Safety depends on induced current.

Forces that overcome influence of induced current.

forces, which are calculable, have been fully considered at pages 326 to 337. If we assume that when this closet is used a trap intervenes at any point between the closet and the sewer, the principle of the closet is destroyed, as under such conditions it is like any other trapped closet, but with an elongated chamber between the closet pan and the trap, in which foul matter may accumulate, and foul air be generated ready to escape at any favourable opportunity. In case a trap at a distance from the closet is used, will the foul air generated in the soil pipe be carried through the trap to the sewer by the induced current? Part of it will be so carried, but another part will flow back from the water surface and into the house, if there is no other mode of exit, just as experience has shown to be the case with the pan closet with its container. This may be readily ascertained by direct experiment by any one who will pour water into water, when it will be observed that a current of air follows the water, and part of the air enters the water, but rises again to the surface and escapes in bubbles, so that from the water surface there is a current of air given off moving in the opposite direction to the flowing water. A serious objection must be taken to this form of closet by reason of no overflow being provided for it, and all who have had experience with ball valves know what uncertain appliances they are, and how very liable they are to get out of order and leak, and a leak in this case means an overflow of the closet basin, for as there is no trap, no overflow can be provided into the drains. Another serious objection also to it is that it is not a water-waste preventer. The propping up of the handle of the closet, or the leakage of the plug, must either lead to waste of water or to the house being put in direct communication with the drains, and if from any cause the water supply is deficient, or even temporarily absent, the raising of the plug puts the house in direct communication with the drain or sewers. The same

Trap intervening between closet and sewer.

Generation of foul air.

Induced current will not carry all foul air away.

Compared with pan-closet.

Currents of air induced by falling water.

No overflow in Pearson's closet.

Not a water-waste preventer.

objections do not apply to the arrangement of trapless closets shown in Fig. 155, page 493. It may be here observed that the apartment of every water-closet ought to have external openings to the air. Air openings should invariably be formed near the ceiling for the discharge of foul air, and fresh air may be admitted at the floor-level.

Ventilation of water-closet apartment.

Supply of water to water-closets.

The arrangement for the supply of water to the water-closets of a house is one of extreme importance in a sanitary point of view; but how often do we find that the water supply of a district is intermittent, and that a single cistern only is provided for storing the water for all domestic and dietetic purposes, and for the supply of the water-closets and urinals. Frequently the apparatus for actuating the delivery of water to the water-closet is fixed in the only cistern, from which a pipe is carried to the closet, and wires are carried from the closet to the cistern for actuating the valves, as, for example, in Plate XXI., Figs. 1A 6, and 17. The effect of this arrangement is that the pipe C, which conveys the water to the closet, when empty, is supplied with air of very impure quality, or that which is drawn from the basin of the water-closet, and this air at the next discharge is carried up to and passes through the water of the cistern, from which water for culinary and other purposes is drawn. When it is generally known how prone water is to attract impurities, such a state of things will not be tolerated; for the least that can be said of the aeration of the water of the cistern from such a source is, that water so treated cannot be beyond suspicion. In a sanitary point of view, the placing of the valves for regulating the supply of water close to the basin of the closet is a great improvement on the older plan already referred to. Such an arrangement of valve is shown in Plate XXI., Figs. 2, 4, and 16; but with this arrangement, unfortunately, there is no control over waste, which is often a serious matter with water proprietors; for if the handle of the closet fitted

Cistern arrangement often defective.

Position of valve close to closet-basin.

No control over waste of water.

with this arrangement is propped up, a continuous flow of water would pass through the closet into the sewers. This arrangement of valves is, however, not a good sanitary arrangement, for, in cases where water is laid direct from the water-mains to the closet, unless provision is made in every house-service to prevent the back flow through the service pipes, should the valve of the closet be opened during a period when the water is being shut off the district, a flow of air would enter by the valve, and in consequence the water-mains may become filled with air of an objectionable character.* To guard against the evils of the valve arrangement, and to prevent the waste of water, a great number of very ingenious devices have been introduced. The simplest arrangement for the prevention of waste, and a good sanitary device to prevent the fouling of the general water supply of a house or district, consists in introducing a separate cistern for each water-closet. It may be fixed on brackets over the seat, and should derive its water supply from a store cistern, as shown in Plate XII., from which drawing the relative position of these cisterns with the store cistern will at once be seen. In Plate XXI., Figs. 19, 20, and 21, the form of cistern now commonly adopted for the supply of water to water-closets is shown. The great point with regard to these cisterns is that the outlet pipe to the closet should be of good size, say not less than $1\frac{1}{4}$ inch diameter, in order to supply water quickly to the closet; for it is found by experience that a small volume of water flowing quickly and at once through a water-closet is more effective than ten times the same quantity supplied in mere driblets. Water is usually distributed in the pan either by a flushing rim formed round the upper edge of the basin, or by a fan fixed against the back of the basin. In some of the com-

Aeration of water-mains from water-closets.

Water-waste and sanitary cisterns.

Plate XII.

Plate XXI.

Water-waste cisterns.

Advantages of large outlets.

Distribution of water.

* This aeration of the water of towns in which there is an intermittent supply is constantly going on. Hence the necessity for a constant supply.

moner closets simple apertures are made through which the water is discharged into the pan. The form of basin should be such as to have a receding back, so as to present no exposed area for the reception of fæcal matter; and the water supply should be directed not so much to wash the sides of the basin as to wash away through the trap all fæcal matter deposited in it. The quantity of water required for effectually flushing a closet varies much with the description of closet and other circumstances. As a rule, one gallon of water may be considered an ample supply for each flush of a good closet.

Form of basin.

Quantity of water required.

The position of a water-closet ought to be so arranged as to guard against the injurious action of frost. The pipe for conveying water should be placed in the interior wall, and every provision should be made for protecting it by suitable non-conducting clothing; and in some exposed cases, where the prevention of freezing cannot be obviated, a proper valve arrangement should be supplied by which the pipes may be emptied of water in time of frost. A very good water-waste preventive cistern, not liable to derangement in frost as there are no valves to freeze, is made by Mr. Hall, of Leeds. It consists simply of a tilting bucket actuated by the handle of the closet. Special care needs to be taken with outside closets to prevent both the traps and the supply pipes from freezing. In many cases where the sewers of a district are laid sufficiently deep, the whole closet may be formed with advantage below the ground-line; for if placed sufficiently deep and approached by a flight of steps and secured by a good door, no fear need be entertained of the effects of frost. A little common salt placed in the trap will prevent its freezing, and at the same time salt constitutes an excellent disinfectant.

Position of water-closet.

Protection from freezing.

Hall's water-waste cistern.

Outside closets.

Closets may be fixed below the ground-line.

In the case of outside closets, the laying of water on to them is often attended with great inconvenience, waste, and expense, as it is found impossible to so protect the

Objections to outside water-closets.

water-fittings from the effects of frost that these fittings may not become at times useless, and the closets remain unflushed. Some sanitary authorities have been so unwise as to insist upon water-waste preventer cisterns being fixed in exposed outside closets, the inevitable consequence of a severe winter being, in such cases, to convert all the waste-preventers into water wasters, and to destroy the fittings, which will require to be renewed at considerable expense to the owners of small property, who can least afford to pay for such mistakes. It must not be forgotten that a water-closet will not work efficiently without water, and in the case of closets to which the water is laid on, when from any accidental cause the water supply is withdrawn, these closets, as a rule, receive the least attention from the users, and the consequence is that, not unfrequently, the closets and drains get choked for want of attention. The case, however, is very different when no water is laid on to an outside closet; the users have habitually to pour the slop water into them, and consequently in some districts it is not considered necessary to lay on water to the outside closets, the pouring down of the ordinary liquid refuse into the basin of the closet being found sufficient for all purposes of keeping them clear. In these closets no difficulty can arise from the effects of frost, as there is always sufficient warm water used for domestic purposes to keep the closet from being frozen or to unfreeze it should it get frozen.

Water-waste preventer, cisterns and outside closets.

Water-closets without water.

Slop water and water-closets.

Outside closets without special water supply.

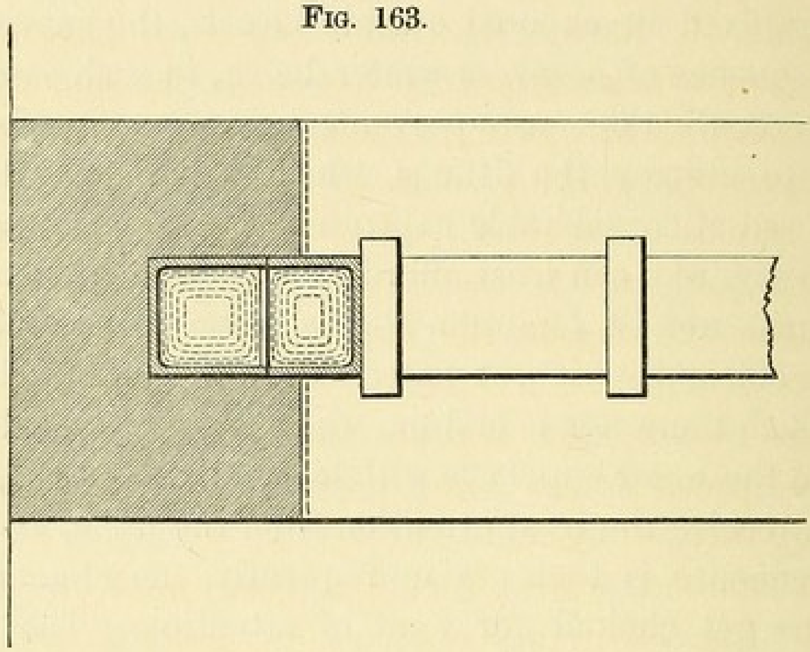
In Bristol a closet flushed by hand is used in the poorer class of houses, as shown in plan, Fig. 163, and in section, Fig. 164, and it is reported "to meet very efficiently the needs of the poorer classes of the population as to excrement disposal." This closet is constructed in accordance with the following regulations of the Bristol Urban Sanitary Authority: "The trunk of the privy to be of brickwork set in cement, and rendered on the four inside faces with cement, not less than one inch in thickness. The eject to be of free-

Bristol closets.

Regulations for construction of Bristol closet.

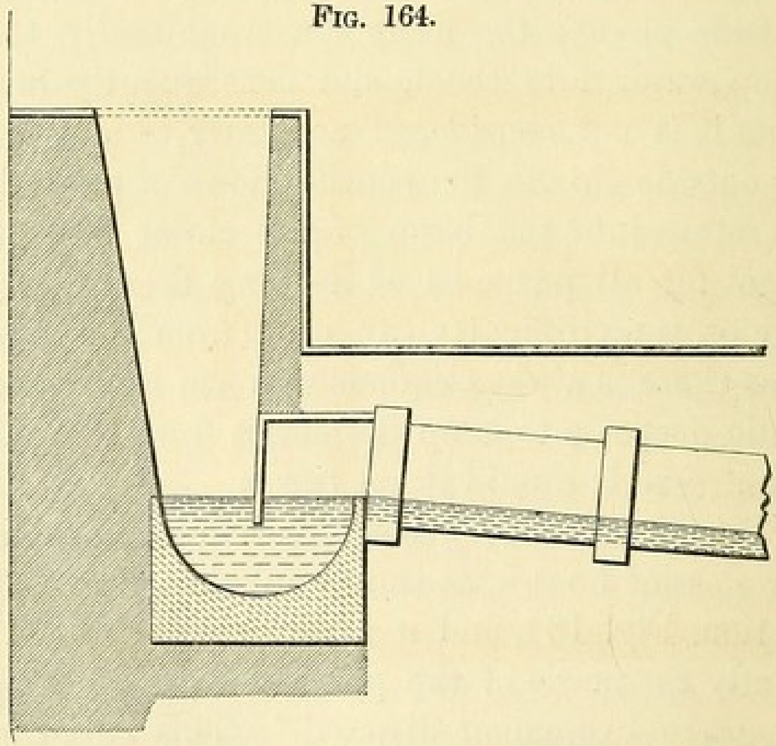
stone not larger than 18 inches long by 9 inches wide, and 12 inches deep, having the tongue standing at least 3 inches in the water." By the eject is meant the trap

Fig. 163.



Bristol closet.

Fig. 164.



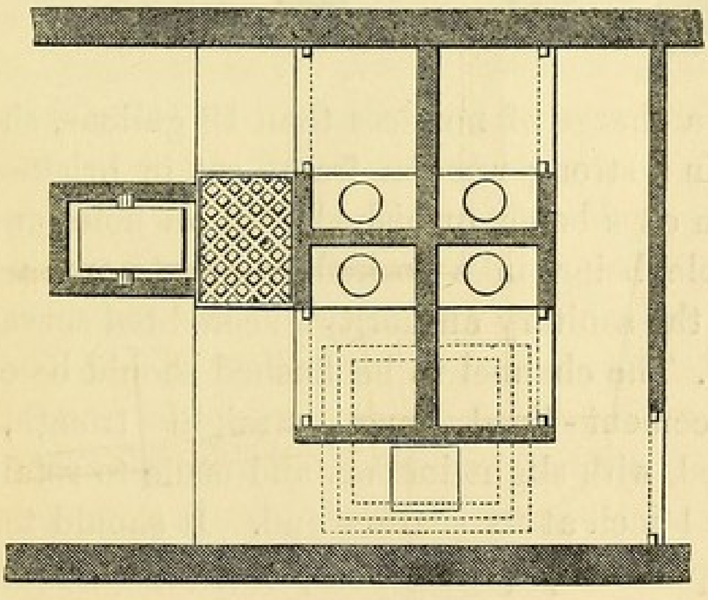
at the bottom of the "trunk" or basin of the closet. These ejects are also permitted to be made in stoneware. "The drain to be 9-inch stoneware pipes, properly laid and jointed, with a fall of not less than 1 inch in 5 feet." It should be added that in Bristol "where the arrangement can be made, the rain-water pipes and the yard drains are made to communicate with the ejects so as to secure the flushing action of rainfall and of the house slops."

Mr. J. N. Radcliffe's report on Bristol closet.

In Mr. J. Netten Radcliffe's report, of December, 1874, from which the author has made the quotations in reference to the Bristol closet, it is mentioned that the successful working of these closets is due to the very careful inspection instituted by the sanitary authority, and to the fact that the sanitary authority look after and cleanse the closets. The Inspectors of Nuisances at Bristol have under them men who attend to these closets, and who are "armed with a species of two-pronged iron rake, used for the purpose of clearing blocked ejects."

The tumbler water-closet has been used in some towns. Fig. 165 represents the plan, and Fig. 166 the

Fig. 165.



Leeds tumbler closet. Mr. J. N. Radcliffe's report.

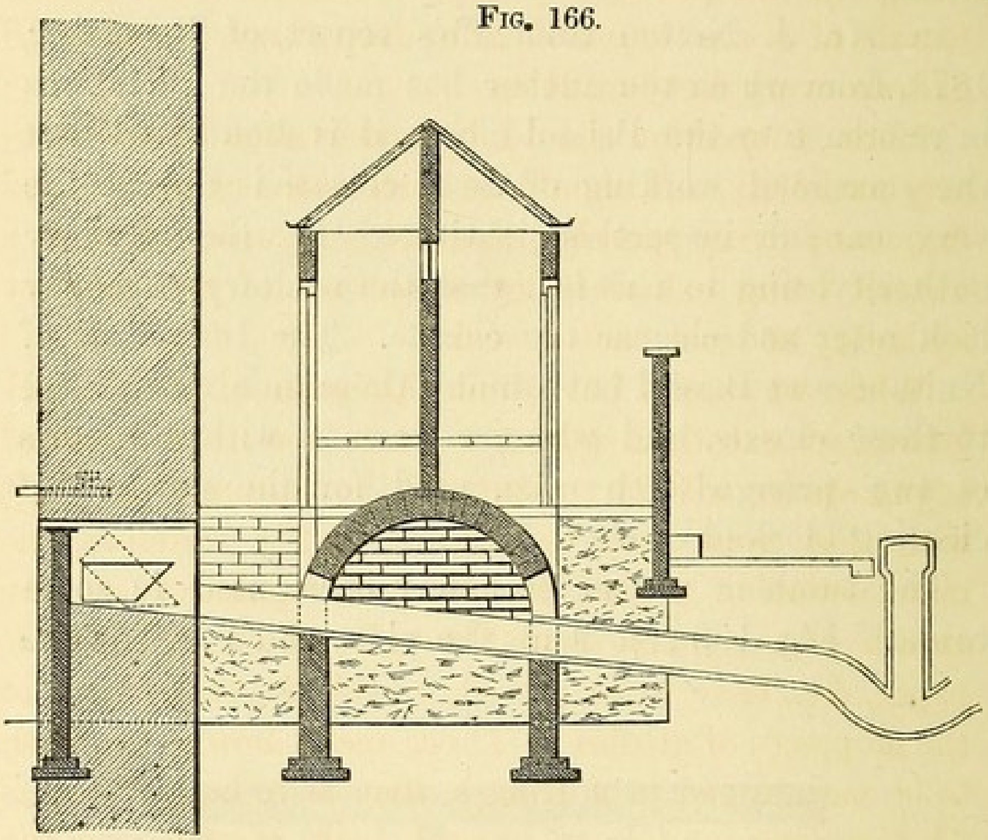
section of tumbler closets as used in Leeds. Mr. J. Netten Radcliffe, in his report, of December, 1874, says that in Leeds, "This form of closets is, in fact, now discountenanced, as wasteful of water and difficult to keep in order." The same gentleman, when reporting on a similar class of closets as used at Birkenhead, made

Tumbler closet at Birkenhead.

the following suggestions as to the construction and arrangement of the tumbler closet.

"1st. The tumbler, of iron, cast in one piece, and

Fig. 166.



Mr. J. N. Radcliffe's suggestions as to the construction of tumbler closets.

to hold a charge of not less than 18 gallons, should be swung in a strong wooden frame set in brickwork, the trunnion caps being furnished with oil holes and pegs, the whole being in a locked compartment accessible only to the sanitary authority's accredited servant.

"2nd. The channel to be flushed should be of brickwork, cement-lined, open, straight trough, round bottomed, with slight incline, and made to retain water at least 1 inch at its shallow end. It should terminate in a syphon trap protected by a grid, and should not measure more than 25 feet, or receive from more than 5 seats.

"3rd. The seats should be of wood, not painted, each in a separate locked compartment, each exclusively for the use of the occupiers of one house, and accessible only to the occupiers of one house and the sanitary authority's accredited servant.

"4th. The supply of water should be by cistern, the capacity of each cistern not being less than 1000 gallons (except in districts where the mains are always charged), and the service pipe should be fitted with a ferrule of a size to enable it to deliver not less than 18 gallons every forty minutes.

"5th. Inspection should be undertaken by the sanitary authority, and should be systematic, thorough, and frequent; every tumbler, channel, seat, and cistern in a district being examined by a servant of the sanitary authority at least once a week."

Objections to Mr. Radcliffe's recommendations.

While we cannot but admit that some of these regulations are excellent, others indicate a want of practical acquaintance with the nature of the matter to be dealt with that must lead to failure, as for example, the introduction of a grid, in the 2nd regulation, at the mouth of a syphon trap through which both fæces, paper, &c., have to be passed, would effectually lead to the stoppage of all flow. Then, again, how is the flush to be maintained in a trough that is to be inclined, is 25 feet long, and is to have 1 inch of water in the shallow end, and of necessity must have many inches in the deeper end, thus making a sort of elongated cesspool, with an overflow blocked with the grid, to which reference has been made? If a closet of the description set forth in the 4th regulation is to be supplied with 18 gallons of water every 40 minutes, this would be 27 gallons per hour, or 648 gallons per day, and as this closet would be used by 5 houses, at 5 persons to a house, by 25 persons, the consumption of water for such a closet would therefore be about 26 gallons per head per day. If this quantity is compared with the 1½ or 2 gallons required to flush an ordinary water-closet each time it is used, no wonder that the use of the tumbler closet is discountenanced by sanitary authorities. It appears to the author that it is a mistake to use pure water for the tumbler closet. The great value of such a closet as this ought to consist

Quantity of water required for Mr. Radcliffe's tumbler closet.

Comparisons of water supply with water-closet.

Mistake to use pure water in tumbler closet.

Slop water should be used in the tumbler closet.

in the fact that it would very satisfactorily use the slop water of the household for the purpose of flushing the closet, and such slop water would be ample in quantity for effecting all that is necessary in flushing a properly constructed closet of this description.

Objections to water-closets in exposed positions.

From what has already been said it will be seen that in a climate like that of this country the great drawback to the use of water-closets in exposed positions is that in the winter time they are not only liable to get out of order, but the apparatus itself is often destroyed by the action of frost. It is a point that has engaged the attention of sanitary reformers, as to how best to dispose of the fæcal matter of populations living under circumstances in which the receptacles of fæcal matter are naturally placed in exposed positions. All kinds of expedients have been attempted of collecting this matter in its dry state; but as all conservation of this material must naturally lead to its accumulation for a greater or less time in the immediate proximity of the dwellings of the people, from a sanitary point of view this cannot be considered to fully meet the necessities of the case. It is with satisfaction that the author gives an illustration of a closet shown in plan in Fig. 167, and in section in Fig. 168, invented by Mr. Alfred M. Fowler, C.E., of Newcastle-on-Tyne. The closet in principle is not unlike the Bristol closet, to which reference has already been made. The Fowler closet consists of an ordinary hopper pan-closet, with a junction formed on it above the level of the trap. The house-drain is made to communicate with this junction so that the whole of the water used in the habitation, or which may fall upon the paved surface of the yards, &c., is carried to the sewer through the closet; and in order to secure a sufficient fall for the house-drain, the hopper of the closet may be placed at any depth below the level of the surface, and a number of ordinary sanitary tubes may be placed upon the top, bringing the appliance

Fowler's closet.

Description of Fowler's closet.

up to the required level of the seat. The author has had a large number of these closets tested in the district of the Longton Corporation, and under most

Fowler closets in use at Longton.

FIG. 167.

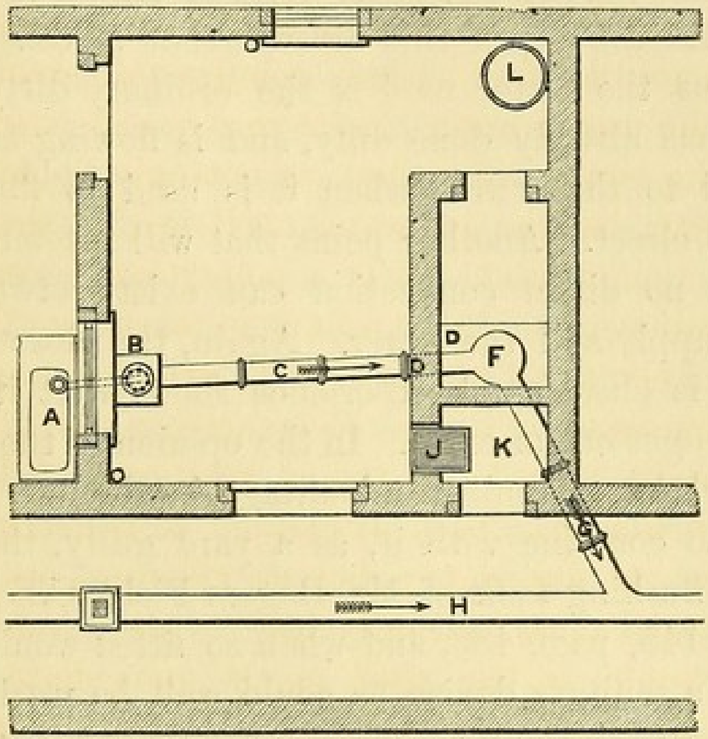
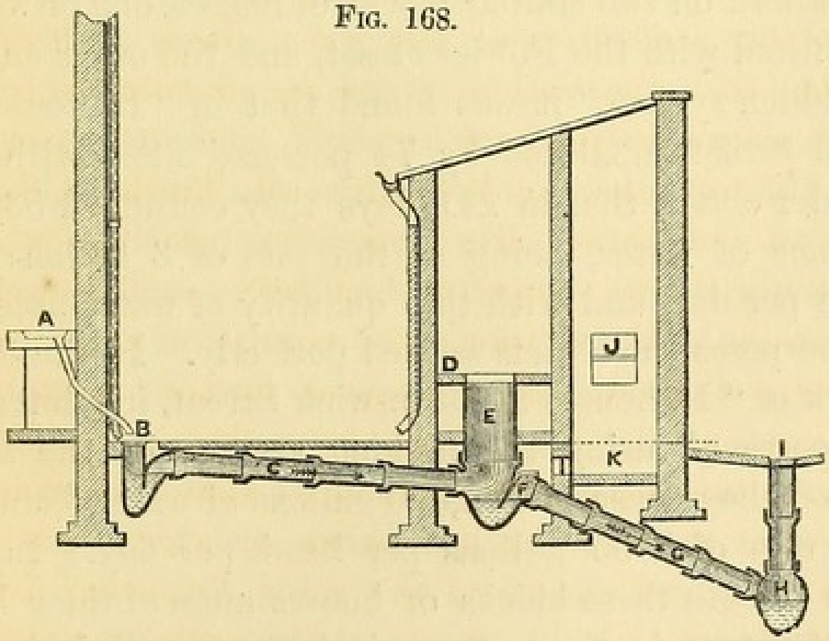


FIG. 168.



adverse circumstances, and they have been found to work admirably. The great advantage of this arrangement of closet is that it uses up the waste water that has served for domestic purposes, and which is

Fowler closet uses waste water.

Volume of water for flushing closet larger than in ordinary water-closet.

much larger in volume, when calculated per head of the population, than that ordinarily used in the most perfect water-closet to which water is laid on. Although in this form of closet a larger volume of water is supplied than in any other form of closet, yet at the same time the use of this arrangement of closet saves water, as the water used is the ordinary dirty water which has already done duty, and is flowing away on its road to the sewers when it is used to flush this form of closet. Another point that will recommend it is, that no direct connection can exist between the water supply and the sewer. Again, the closet is self-acting, is cheap, and experience shows that it is not liable to get out of order. In the opinion of the author it would be a manifest advantage in the use of this closet to combine with it, as a yard gully, the small syphon flushing tank of Mr. Rogers Field, C.E., shown in Fig. 145, page 483, and when so fitted would be as perfect a sanitary device as could well be used in the case of outside closets. From some experiments made at Salford on two similar blocks of houses, one of which was fitted with the Fowler closet, and the other on the "Midden system," it was found that in "18 houses in Ford Street, inhabited by 74 persons," fitted with the Fowler closet, that in 241 days they consumed 53,527 gallons of water, being at the rate of 3 gallons per head per day, and with this quantity of water used for all purposes the closets worked perfectly. In the other block of "18 houses in Brunswick Street, inhabited by 73 persons," using the midden system, in the same period they consumed 52,000 gallons of water, being at the rate of 2·95 gallons per head per day. In the case of both these blocks of houses none of them have "water taps in them, there is but one stand-pipe to each block."

Saving of water.

Connection between water supply and sewer severed.

Fowler closet combined with Mr. R. Field's flushing tank.

Experiments on quantity of water used in Fowler closet.

Saving in cost, and economy in water.

This experiment shows that the ordinary waste water as it flows to the sewers may be made to convey to the sewers the whole of the excreta of a population without the necessity of providing any additional water supply, and at the same time realizing a considerable saving in cost in all cases where the excreta have to be separately collected, removed, and disposed of at a very great loss.

Deodorization of water-closets.

In some cases it is the fashion to deodorize water-closets with special apparatus. One of the first suggestions for the use of fixed apparatus to disinfect a water-closet occurs in a patent taken out so recently as July, 1865, by Mr. Charles Nicholas. In this invention the disinfecting fluid was "contained in a small cistern, at the bottom of which is a small chamber acting as a measure. This measure is alternately emptied and filled by mechanism working in connection with the handle of the water-closet."

Nicholas's disinfector.

A. G. Brown's disinfecting apparatus.

The apparatus of Dr. M. A. Gardiner Brown, and supplied by the Chloralum Company, consists of a vessel containing liquid disinfectants, communicating by means of a small pipe with the supply pipe to the closet, so arranged that a portion of the disinfectant fluid flows out each time the closet is used.

Baker's disinfecting apparatus.

Baker's patent apparatus is a mechanical arrangement, fitted under the seat of the closet, and a given amount of disinfectant is displaced every time the handle of the closet is used. Mr. George Jennings also makes a disinfecting apparatus, which is fitted on brackets above the water-closet. It consists of a porcelain jar, having in the bottom a glass receiver. In the jar he fixes a syphon, the short leg extending into the glass measuring chamber, the longer leg being connected with a brass breeches-piece, from which two pipes pass, one being connected to the water-supply pipe of the closet, the other empties into the basin of the closet. When the handle is raised, the water passes up the one pipe as far as the breeches-piece, and flows down the other, and when the handle of the closet is closed the stoppage of the current tends to produce a partial vacuum in the pipe above the breeches-piece,

Jennings' disinfecting apparatus.

which actuates the syphon dipping into the glass receiver, and a charge of the disinfecting fluid is passed into the basin of the water-closet.

Disinfection of matters passed into sewers.

As a general rule, the disinfection of water-closets is not required unless in periods of epidemic or illness within a house, or in the case of a hospital, when steps ought, as a matter of duty to common humanity, to be taken so that the fæcal matter and other discharges from patients are properly disinfected before being passed into the sewers of a town.

Only safe mode of disinfecting fæces.

It should be observed in reference to disinfectants that the quantity of disinfecting liquid passed into the volume of water present in the basin of a water-closet becomes so diluted that it is quite useless, and the only safe and effectual way of disinfecting the fæcal discharge of persons suffering from fever or other diseases communicable through the evacuations, is to disinfect the discharge before it is placed in the water-closet or diluted with water.

Materials used to construct closets.

The materials used in the construction of water-closets are enamelled iron, earthenware, china, and glass. The basin and traps of water-closets should all be thoroughly well glazed. Enamelled iron will not wear like earthenware, as the enamel is apt to get chipped and cracked; when the water gets in contact with the iron oxidation takes place, which soon completes the destruction of the closet. With the common hopper closet it is usual to limit the size of the openings at the bottom of the basin to about 2½ in. diameter in order to prevent the entrance of matters into the drains they are not intended to convey. Water-closets inside houses should, when convenient, have the soil-pipe kept outside the house. Various modes have been adopted for actuating the working parts of a closet so as to render them self-acting, without requiring any particular action on the part of the person using the appliance. A very common mode is to attach the working parts to the seat, which is hinged,

Size of opening into drains.

Pipes kept outside houses.

Self-acting closets.

as shown in Plate XXI., Fig. 17. In other cases a portion of the floor may be hinged. In either case the weight of the person using the closet is made the motive power for actuating the valves which regulate the supply of water. In other cases the door of the apartment in opening or closing is made to perform the necessary operation. In some water-closets the valve arrangements are entirely out of the control of the person using the closet; as, for example, in latrines and trough closets, which are in use in some districts, and are emptied once a day by a scavenger opening the valve, which is under his control. Latrines and trough closets are very generally used in many public establishments, such as schools, workhouses, manufactories, barracks, &c. Illustrations of closets of this description are shown in Plate XXI., Figs. 23, 24, and 25. Trough closets are fitted with an overflow and plug for discharge. The bottom of the trough or pipe inclines to the end at which the discharge plug is placed. They may be filled with water by a regulator ball-valve fixed in a division of the trough, or by a valve actuated by the handle of the discharge apparatus, or from a stand-pipe or tap, but can only discharge their contents by the raising of the plug, which is usually locked up and kept under proper control. A very good arrangement and improvement on the trough closet is that shown in Plate XXI., Fig. 25. It is the representation of a range of closets or latrines as designed and executed by Mr. George Jennings. In cases in which there are no housemaids' sinks for conveniently discharging slops it is often the practice to make use of the water-closet as a receptacle for them, and in some cases already noticed, when water is not laid on to the closet, the slops are invariably poured down them. A water-closet within the house under these circumstances should be fitted with a safe* to catch any slops that may be spilled, and the seat of the

Water-closets not under control of persons using them.

Trough closets.

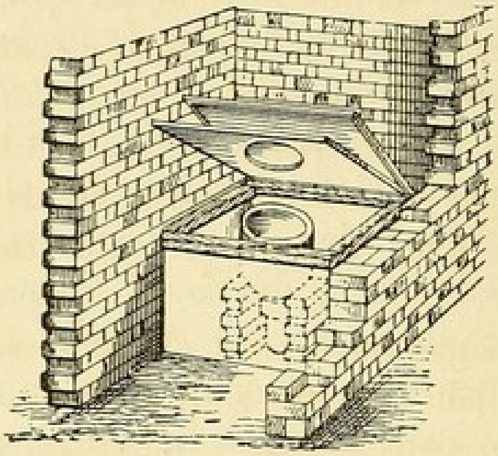
Latrines.

Water-closets receiving slops provided with movable seat.

* Vide page 498.

closet intended for the reception of slop should be hinged so as to turn up out of the way when slops are discharged, as shown in Fig. 169.

Fig. 169.



Description of Plate XXI.

In Plate XXI. is shown a variety of forms of water-closets which have been adopted at various times.

Pan-closet.

Figs. 1 and 1A represent the section and elevation of the ordinary pan-closet. This closet has already been fully described, and is not recommended for use. It was originally introduced to supersede the valve-closet invented by Bramah.

Pan-closet with regulator.

Fig. 2 is a pan-closet similar to the last, but the water supply is regulated by a valve near the closet, and this valve is kept from closing too quickly by an arrangement attached to the lever called Underhay's bellows.

Underhay's regulator.

Fig. 3 is an enlarged view of Underhay's bellows. It consists simply of a cylinder with piston. Air can enter the cylinder quickly when the handle of the water-closet is raised, but it can only escape slowly through a small opening, so that the lever with its weight will descend slowly, and consequently the valve can close without any shock, and water flows sufficiently long after the pan is closed for it to be filled up with water.

Eskholme's regulator.

Fig. 4 represents a pan-closet with valve arrangement. The valve in this case is kept from closing quickly by means of Eskholme's pneumatic regulator.

Fig. 5 is a representation of a pan-closet of another kind, the receiver in this case being rather smaller than in the former. Pan-closet.

Fig. 6 is an illustration of Bramah's valve-closet in its modern form. It differs from the pan-closet in the size of the receiver, which is smaller, and presenting a diminished area of evaporative surface. These closets constantly get out of order, and do not hold water, as a piece of paper or other material easily prevents the valve closing, and consequently the basin loses its water. Valve-closet.

Fig. 7 is a common conical closet or simple hopper closet with syphon trap, the trap and basin being formed of one piece of earthenware. This form of closet had its origin, no doubt, from the fact that water-closets of this description were ordinarily constructed of the cast-off moulds used in sugar manufactories. Conical hopper closet.

Fig. 8 represents another form of closet. The basin and trap are constructed separately. It is a form that was at one period extensively used. An improvement on this form of closet was made by Mr. Phillips, which consisted in making the back of the closet straight, so as not to be so likely to collect fæcal deposit. Conical closet and trap.

Fig. 9 represents an earthenware closet in one piece. This is a good form if the receding back as well as the front and sides are provided with a flushing rim. It was originally introduced by Mr. Geo. Jennings. Hopper closet, receding back.

Fig. 10 represents a conical closet invented by Mr. John Roe. In this form of closet the flushing rim is carried all round the basin, so that a good flush may be insured. V is a pipe inserted for the purpose of ventilation. The conical shape of the basin of this closet renders it very liable to collect fæcal deposit, when it cannot be efficiently washed and flushed except by the expenditure of a large quantity of water. This illustration gives a practical example of the proper way of ventilating the drains of a closet. Mr. J. Roe's closet, with ventilation.

Fig. 11 represents a conical closet with flushing rim, Closet with bye flushing pipe.

and supplied with a pipe B for more effectually flushing out the syphon trap at the bottom of the basin. This closet was patented in March, 1842, by Mr. Thomas Smith. This form of closet with bye flushing pipe was introduced to remedy the defect which sometimes attends the hopper closet,* by the ineffectual cleansing of the trap after the use of the closet. In practice it is found that in closets with basins of this description, so shaped that the back part projects, fæcal matter will soil the walls of the basin, but if the back is made to recede, as in the closet Plate XXI., Fig. 9, the fæcal matter will not strike the basin, and if it accidentally does touch, it is readily washed off by the flush of water.

Patten's basin.

Fig. 12 is an illustration of Patten's basin. It consists of an ordinary hopper and trap, with the addition of a screen S, the object of which is to hide from view the matter deposited in the trap. The objection to this form of closet is that fresh fæcal matter is often deposited on the screen, and not being covered with water, unpleasant effluvium is given off while the closet is being used, or until the matter is washed away or covered with water.

German closet.

Fig. 13 is a section of a water-closet of German pattern. It consists of a tilting basin, which forms a sort of movable basin within an ordinary water-closet, an arrangement very similar to the tilting basin now commonly used in lavatories. The movable basin B is attached to the front part of the seat, which is hinged at H. To empty the basin the front of the seat at A must be raised, when the basin tilts and discharges into the trap below, at the same time water is admitted by a valve arrangement through the pipe W for washing out the basin and trap.

Jennings and Lovegrove's closet.

Figs. 14 and 14A represent two sections of Messrs. Jennings and Lovegrove's water-closet. It is without doubt the most perfect closet introduced up to the present time. It is manufactured in one piece of earthenware, and may be fitted with a water-waste pre-

* Vide page 508.

ventive or sanitary cistern. It consists of a basin and trap T below. P in Fig. 14 is a hollow plug, which dams up the water in the basin, forming, when the basin is full, a second trap T′; when handle H is raised, as shown in Fig. 14A, the hollow plug rises with it, and the contents of the basin are rapidly discharged into the drains. Ventilation is now provided for these closets by a junction formed on the body of the basin at the top of the bend beyond the water trap.

Fig. 15 is the representation of a water-closet as designed by the author. It is an improvement on the ordinary hopper closet. The object of this closet is to get a large body of water in the basin B, in order that the fæcal discharge may at once be completely deodorized. The lifting of the hollow plug H causes the water-line to fall to the level of the water in the common hopper closet, at the same time the volume of water accumulated in the basin, and the subsequent flush, causes everything to be carried away through the trap T; and if the closet is not clear it will be at once seen, whereas in all closets in which the traps are hidden from view it can never be known for certain if the fæcal matter has been discharged or remains in the trap. The ventilation of the drain of this closet is effected by a pipe inserted at V, and by an arrangement of levers at L it may be fitted with water-waste preventive or any valve arrangement for the supply of water. Improved hopper basin.

Fig. 16 shows the arrangement of connecting an ordinary hopper closet, by means of a lever-valve, with the water service. It should be observed that with this form of water-fitting no control can be exercised as to the amount of water that may be consumed or wasted through the closet; moreover it is objectionable for the reasons that have already been considered. Water-fittings of hopper closet.

Fig. 17 is an illustration of Patten's water-waste preventer fitted in a cistern. If the cistern to which this apparatus is fitted is the only source of supply for a house, the arrangement cannot be justified; if, on the Patten's water-waste preventer.

other hand, the cistern is used solely for the water supply of closets and urinals it may not always prove satisfactory as a water-waste preventer. G represents the basin and trap; C, the pipe communicating with the cistern; B, a service box formed within the cistern; A and E are valves actuated by the lever *d* by the wire or chain *e*, attached to the hinged seat F of the closet; O is the overflow pipe for cistern. It also forms the ventilator for the service box. The action may be explained as follows:—The weight of a person sitting on the closet draws down the wire *e*, which raises the valve A, and the water fills the service box. When the person rises from the seat the valve A closes, and the valve E opens, which allows the contents of the service box to be discharged. It is quite clear, with this arrangement, that if only a sufficient weight were placed on the seat as only partly to lift the valve A, the valve E at the same time would be lifted, and a continuous flow of water would take place.

Clark's water-waste arrangement.

Fig. 18 represents Mr. Clark's (of Reading) mode of fitting up a water-closet to prevent waste. In this case the weight of a person sitting on the seat of the closet is used, through an arrangement of rods and levers, to liberate a ball-valve *e*, *b* being the lever which ordinarily holds the lever of the ball-valve; *c* is a small valve which closes the mouth of the pipe *g* when the rod *b* is raised upwards. The action is as follows:—When a person sits on the seat *a*, by a lever arrangement under the seat the rod *b* moves upwards and liberates the ball-valve *e*, at the same time the valve *c* falls into its seat. Water now fills the cistern *d*, from which, when full, the supply is cut off by the ball-valve floating on the water, and so soon as the person rises from the seat the weight of the rods causes the valve *c* to open, at the same time fixing the ball-valve that no further water can enter the cistern, the contents of which are discharged into the basin of the water-closet.

Single water-

Fig. 19 is a representation of a small cistern applicable to a water-closet; it is a water-waste preventer. The cistern is filled by means of a valve actuated by the ball B, which, so soon as it is filled, cuts off the supply. The action is as follows:—If the lever L is pulled down, the lever L′ rises, and in rising the weight W, which is slotted and passes over the arm of the ball-valve, first raises and then holds it. The slack chain C is then tightened, and by the continued depression of the lever the valve V is raised, and the contents of the cistern are discharged into the water-closet, and no more water can enter the cistern D until the valve V is returned, and then the ball-valve is liberated. This apparatus is a sure preventive against waste of water. In this arrangement only one charge is stored in the cistern D for the supply of the closet.

waste preventive cisterns.

Fig. 20 represents a double water-waste preventer. The cistern D in this case may hold several charges for the water-closet, but only one charge can pass at a time to the closet. The action is as follows:—The weight W at the end of the lever keeps the valve V raised so that water may pass into the lower chamber of the cistern R. Now if the lever L is depressed, it first lowers the valve V so as to prevent any more water entering this chamber R; it then lifts the valve V′, and the contents of the lower chamber are discharged into the water-closet, and no more water can be passed until the lever L resumes the position shown in the drawings.

Double water-waste preventive cistern.

Fig. 21 represents a water-waste preventer cistern similar to the last, with the addition of the chamber R′, through which the water flows from the chamber R, the object of this arrangement being that after the handle of the water-closet is lowered, water will still pass out of the chamber R′, so as to fill the pan of a pan-closet after the valve V′ is closed.

Cistern with after-flow.

This cistern was patented by Mr. J. Chandler, in October, 1869, but in an action which was brought by the patentee against Messrs. Guest and Chrimes for infringing his patent, and which was tried at the

Guildhall, in December, 1873, it was clearly established to the satisfaction of the jury that the trapping box was first introduced by Messrs. Guest and Chrimes, and had been very extensively used before the date of Chandler's patent.

Trough closet.

Fig. 22 is the section of a trough closet fitted with a basin B, of earthenware, and discharging into a trough G, below the level of the floor of the appartment. The trough may be arranged so as to discharge its contents either into a drain or into a liquid manure cart.

Macfarlane's trough closet.

Fig. 23 is a view of a Macfarlane's trough water-closet arranged for a single individual. The closet is shown to be supplied with water by means of a ball-valve fitted in a division at one end of the trough, and at the other the arrangement for discharging and the overflow pipe are shown. The plug in this case forms a trapped overflow for the closet. No arrangement of this kind should be connected direct with the water mains of a district, or there will be a likelihood of foul matter being passed into the water mains whenever the supply of water was intermitted.

Range of trough closets.

Fig. 24 is a view of a range of seats on a trough closet, applicable for barracks and such like places. Over the seat a hood is fitted for the purpose of preventing a person standing on the seat to use it. In some continental towns the water-closets at the railway stations are all fitted with backs sloping outwards at a considerable angle, so as to render it impossible to use the closet except by a person sitting down upon the seat. Such measures as these are sometimes necessary to preserve the cleanliness of the seat in some particular cases; but as a general rule they are not required, at least not in this country.

Mode of preventing standing on seat.

Jennings' latrines.

Figs. 25, 25A, and 25B, represent plan, transverse section, and sectional elevation of the latrine manufactured by Mr. George Jennings. It may consist of any number of basins of earthenware, which are fitted into a cast-iron pipe which joins them all together. A hollow plug P, shown in Fig. 25B, both regulates the height to which the water and other matter may rise, and serves the purpose of discharging the contents of every basin. Each basin is supplied with water, so that they can all be washed out. For schools and in some other cases the plug for discharging is out of the control of the persons using the closets, as it can only be raised by a lever. The general arrangement of this latrine is preferable in a sanitary point of view to the trough arrangement before referred to. Latrines preferable to troughs.

CHAPTER XXXIX.

URINALS.

Public urinals should be provided.

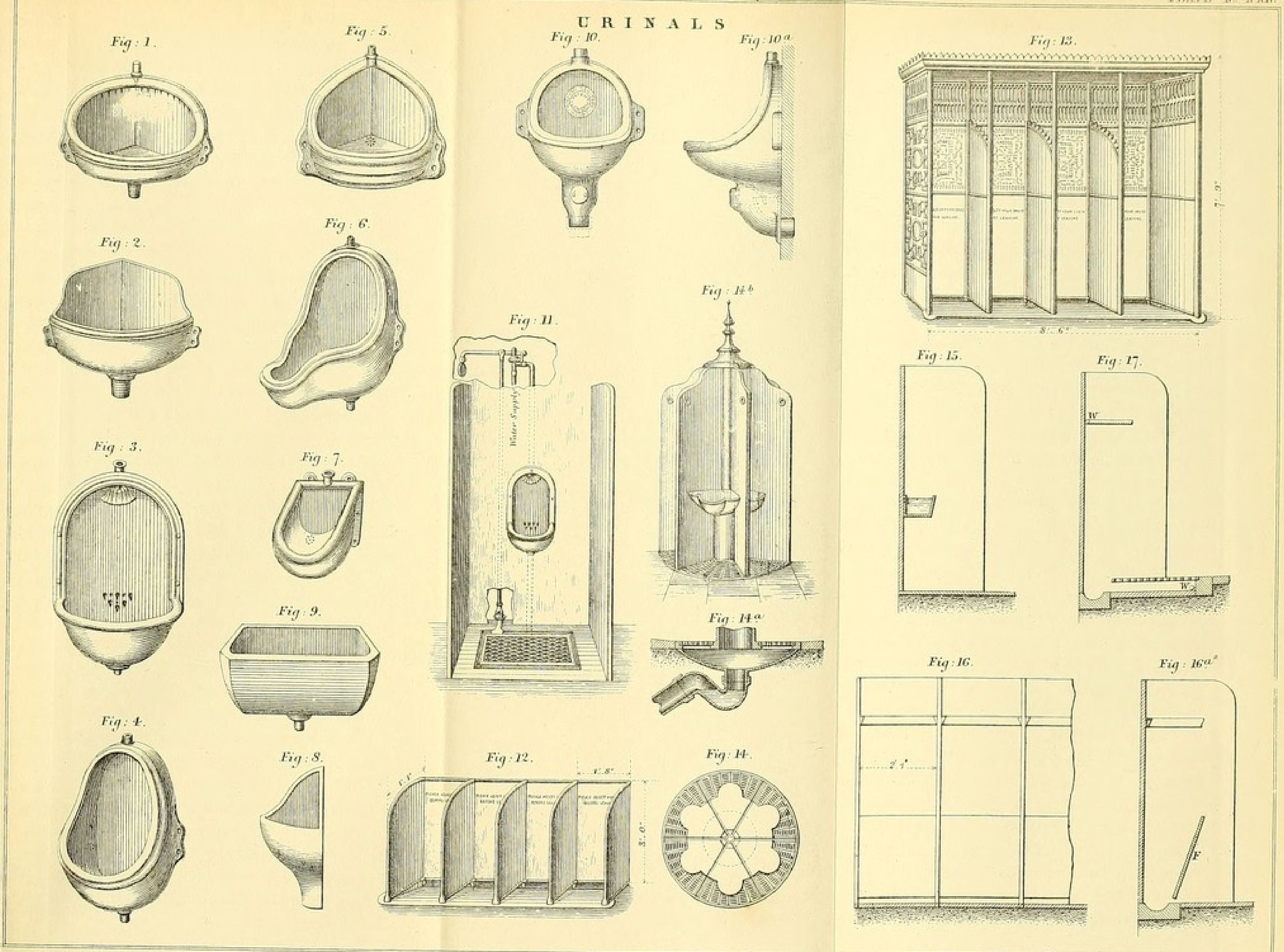
In all districts of an urban character, public urinals should be constructed as a matter of convenience, and as a preventive of nuisance being committed in places out of proper sanitary control. Urinals are also required to be constructed in houses, manufactories, and other places, where proper consideration and cleanliness is a matter of vital sanitary importance. A urinal not properly attended to soon becomes a frightful nuisance, as urine very rapidly undergoes fermentation and gives off a disgusting odour; and when in this state it has the power of rapidly turning fresh urine into the same state, hence the necessity of thoroughly cleansing and washing every part of a urinal. The disagreeable smell arising from a urinal is due to the ammoniacal fermentation which is very speedily set up when perfect cleanliness is not secured. The transformation of urea into ammonia and carbon dioxide, which is the cause of the unsavoury smell of a urinal, is due to the action of a specific ferment, one of the "torulacei," which is always present in the deposit in urinals, and which is not unlike the yeast plant only smaller, the little globules being only about ·0000078 inch diameter. The deposit of torulaceous matter often stops up the channel leading from the smaller urinals. These deposits may, however, be speedily removed by pouring down the urinal strong acids such as hydrochloric acid, but acid ought not to be used for this purpose by inexperienced persons, for unless the pipes are good lead, or earthenware, properly jointed, very serious damage may arise from the use of such powerful

Effects of fermenting urine.

Smell from urinals due to ammoniacal fermentation.

Deposit often stops up passages of urinals.

Removal of deposit with acid.



London: E. & F. N. Spon, 46, Charing Cross.
Thomas Kell, lith.

solvents. Urine, as a manure, is by far the most valuable part of town sewage. As compared with the solid fæcal discharges, the value of urine is as 6 to 1, therefore every effort should be made to secure the urine produced in a district for agricultural purposes. In some manufacturing towns urine is regularly bought and collected in lant carts for use in the fulling of woollen cloths.

A great variety of forms of urinals has been introduced at different times, and now urinal basins are articles of common manufacture by all firms manufacturing sanitary goods. In Plate XXII. is shown a variety of urinals now in very general use. They usually consist of simple basins fixed against a wall, or of stalls made for a person to enter, or of a basin fixed within a stall, so as to screen the person using the urinal from observation. Urinal basins are usually made of glazed earthenware, and sometimes of common stoneware. Stall urinals are made of iron lined with slate or plate-glass, rough plate-glass, slate, marble, and enamelled slate. The water supply in most public urinals is constant, but in private urinals it is only supplied as required, either by the person opening a valve, or by a treadle arrangement, by which the person standing upon a grating actuates the discharge of the flushing water, or sometimes by an arrangement actuated by the door of the apartment in which the urinal is fixed. Water-waste preventive cisterns may be fitted and applied to urinals in a manner similar to that already referred to under the head of water closets. In the distribution of water to a urinal, care must be taken that every part of the urinal is properly washed; and it is, moreover, desirable that a supply of water should be introduced below the feet, an open grating being provided on which the person using the urinal can stand, with a water supply below the grating to wash away urine that may have dripped on to the floor, or, in the case of children using the urinal, may not have reached the

Variety of form.

Materials.

Water supply.

Water required.

urinal basin. The volume of water required varies greatly with the description of urinal. In those cases in which the urine is discharged into a trough, and the water merely used as a diluent to assist in washing away the urine, the volume of water required is small; but in cases in which stalls are used, and a constant supply is provided,* this supply is often equal to half-a-gallon per minute per stall. The water in basin urinals is distributed by a flushing rim, and in stall urinals either from a perforated pipe or a spreader made specially for the purpose. In stall urinals the width of the stall varies from 1 ft. 8 in. to 2 ft. 6 in. As a general rule, stalls of less than 2 feet are very cramped, and lead to a nuisance outside the urinal, as some persons will not enter a narrow stall.

Distribution of water.

Width of stalls.

Trapping and ventilation.

Urinals are generally trapped with the ordinary syphon trap, and provision should be made for the ventilation of the drains communicating with a urinal, especially in cases in which they are constructed inside houses. The best mode of ventilating urinals is to carry up the drain pipe in the same way as the soil pipe of a water closet is treated. In many continental cities the provision of public urinals has had a fair share of consideration, and urinals are placed in the most prominent situations. The base of a lamp column is often converted into a one-person urinal, with hardly sufficient protection for decency sake. All public urinals ought to be so constructed that while they are readily accessible they are sufficiently screened from public view, that on entering them privacy can be secured. The same observations apply to public latrines, which unfortunately, in the towns of this country, are rarely ever supplied. Accommodation of this class as a rule is only provided at the various railway stations or hotels, and thither the roving public has to wander when requiring accommodation of this character.

Lamp-column urinals.

Privacy.

Latrines.

* The volume of water consumed by a urinal, having intermittent discharge, is equal to about half-a-gallon for each time it is used.

In Plate XXII. are shown various forms of urinals adapted for public and private purposes. Description of Plate XXII.

Fig. 1 represents an earthenware urinal called the Bedford urinal. It is fitted with flushing rim all round, and is intended to be fitted into the angle formed by the walls of a building. Bedford urinal.

Fig. 2 is an angular earthenware urinal with flushing arrangement at front. This form of urinal is also used without a supply of water, but such a mode of using urinals cannot be commended, as a urinal without water speedily becomes a great nuisance. Angular urinal.

Fig. 3 is a urinal constructed of earthenware, provided with both flushing rim and fan. From its shape it is called the cradle urinal. Cradle urinal.

Fig. 4 is a very similar urinal to the last, except that the back is flat. Flat-back urinal.

Fig. 5 is a very similar urinal to Fig. 1, differing only in the proportion of its parts.

Fig. 6 is a form of urinal now very generally adopted. It is called the lipped urinal, that is, it is drawn out very narrow in front so that the projecting lip may pass between the legs of the person using it, and so prevent dripping on the floor. This form of urinal was originally introduced by Mr. George Jennings. Lipped urinal.

Fig. 7 is what is termed a projecting urinal, with flushing rim all round.

Fig. 8 is a common angular urinal of a form made in stoneware. Common angular urinal.

Fig. 9 is an oblong urinal made either of earthenware or stoneware.

Figs. 10 and 12A represent an elevation and sectional elevation of a urinal fitted with an Antill's drain trap at A. B is a sealed opening provided for getting at the trap in case of stoppage. Antill's trap.

Fig. 11 shows the arrangement by which a cradle basin is fitted within the stall of a urinal, the water supply being actuated by the person standing on the grating, which forms a treadle and opens the valve as Cradle and stall.

shown. This arrangement of treadle grating may also be made to actuate the apparatus connected with a water-waste preventive cistern.

Stall urinal.

Fig. 12 is an illustration of a simple stall urinal as constructed by Messrs. Macfarlane in iron.

Fig. 13 is an illustration of a stall urinal constructed in iron by Messrs. Macfarlane, and is applicable for a street.

Jennings' urinal.

Figs. 14, 14A, and 14B represent plan, section below the ground line, and elevation of a urinal as made by Mr. G. Jennings. In this case the urine enters a central basin, in which is discharged a constant supply of water, and from which both water and urine pass by a trapped overflow plug. The basin can at any time be emptied by drawing the plug. The urinal is surrounded by an open iron grating, and any water dropping on the grating passes away to the drains by the arrangement shown in Fig. 14A. These urinals are very largely used in the metropolis and elsewhere. The divisions between the stalls are made of slate, the rest of the structure is of iron.

Urinal erected in 1846, designed by Mr. J. Phillips.

The first urinal of this form was constructed in 1846, and erected in the yard of the Sewers Office, Greek Street, Soho, from designs of Mr. John Phillips, C.E. The urinal had vertical slate divisions and sloping slates fitted between the divisions, with projecting lips for the persons using the urinal, so as to prevent any dripping on the floor.

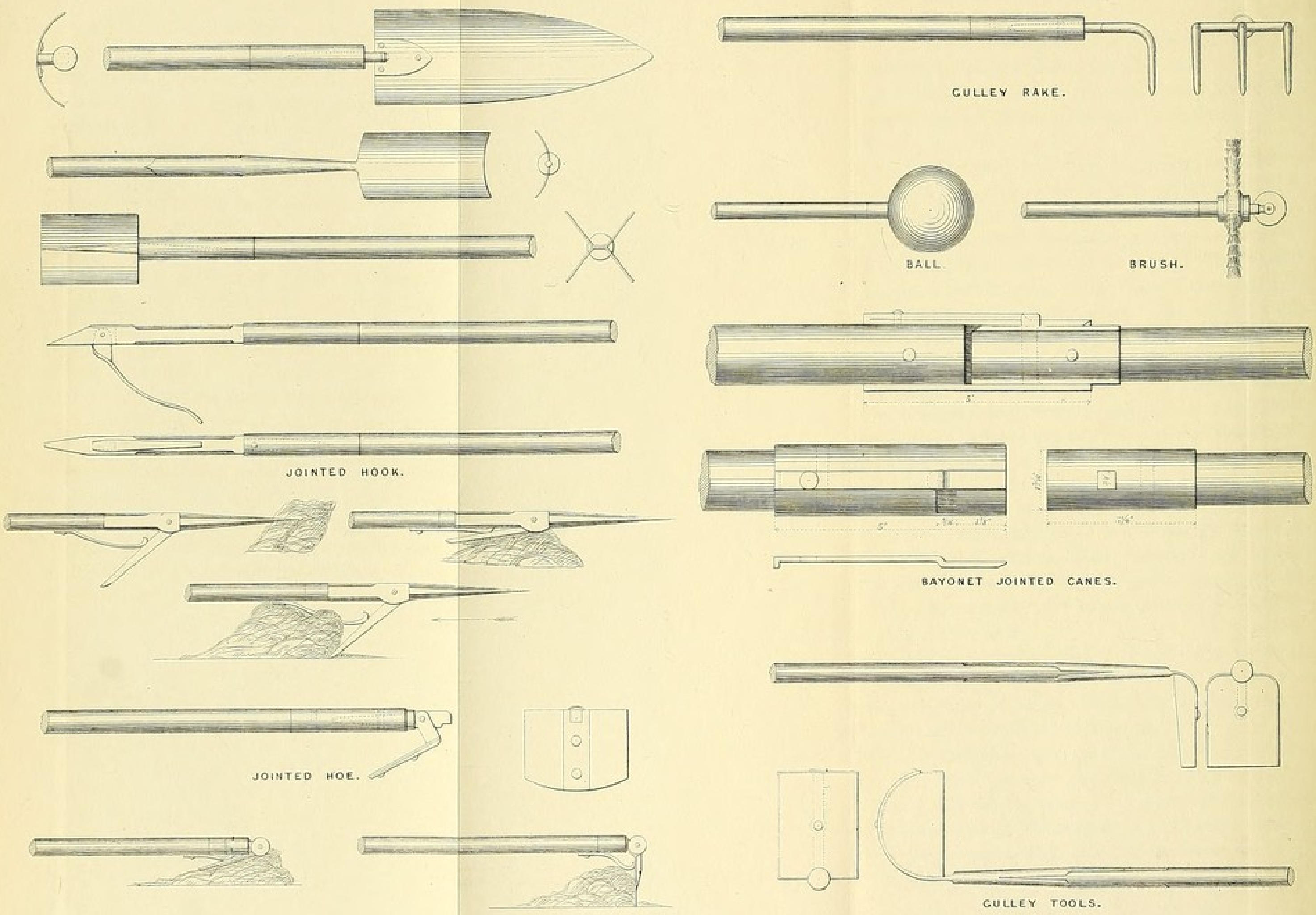
Trough urinal.

Fig. 15 is a section of a very old form of urinal, consisting simply of a cast-iron trough which passes through a range of stalls. This form has been superseded by the form shown in Fig. 16.

Stall urinal.

Fig. 16 and 16A represent the elevation and section of a stall urinal, as very generally adopted at railway stations. The fender-piece F is intended to prevent the splashing which takes place in some other forms of urinal when used. This fender-piece does not reach the floor. A space is left below for drainage, so that

TOOLS USED IN CLEANSING SEWERS.



London: E. & F.N. Spon, 46, Charing Cross.
Thomas Kell, lith.

every part of the urinal may occasionally be washed down, and any water and urine dripping on to the floor would find its way to the gutter.

Fender-pieces of urinals.

The fender-pieces often become the source of a very serious nuisance as they seldom or never get cleansed, and the consequence is that the continued fall of urine upon them, without either water to fall them or means of cleansing, causes them to create a frightful nuisance, and every urinal is better and much sweeter without these fender-pieces.

Fig. 17 is a representation of a section of a urinal designed by the author. An open grating is provided for the feet, and below this grating is an inclined floor, which is washed down by water from a distributing pipe. The urinal may have a continuous or intermittent action for the flow of water. In the arrangement of the apparatus for distributing water every part of the urinal should be washed. In many urinals the divisions between the stalls never get washed, and consequently such urinals are never entirely free from smell. In this urinal the pipes for distributing the water are returned some distance round the divisions of the stalls.

Use of sawdust in urinals.

In St. Petersburg and other northern towns on the Continent the water supply of urinals is cut off in the winter, and instead thereof fresh sawdust is used in the basins, through which the urine percolates to the drains.

CHAPTER XL.

TOOLS USED IN CLEANSING SEWERS.

In Plate XXIII. are shown some of the tools used in cleansing sewers.

In addition to the tools shown in the plate, others are not unfrequently used; as for example, specially constructed ploughs have been used in large sewers, which are either drawn through the sewer by hand, or are propelled forward by the sewage being headed up behind them. A stout rope forms a very excellent tool for the removal of stoppages from small sewers or house-drains.

Sewer ploughs.

The rods used in connection with most of the tools shown in Plate XXIII. are bamboo canes, similar to the rods used by chimney sweepers. Iron rods are now very extensively used for cleansing sewers. These rods have a hook-and-eye joint; the rods have each a hook at one end and an eye at the other. "The eye is of a peculiar formation, and the plan adopted for hooking them together entirely precludes the possibility of the rods becoming detached in the drain. To hook one to the other they must be folded close together, and then folded back; and *vice versâ* for unhooking them. The joint is most simple and strong." The tools used are attached to the rods by being welded on to one of the rods.

Rods used in sewers.

Rods with hook and eye.

The author has been informed by Messrs. James Dickson and Sons, of Chester, who supply these patent iron cleansing rods, that they were the invention of a Scotch blacksmith of the name of Thomas Pirie.

Messrs. Dickson and Sons.

Mr. T. Pirie the inventor of the rods.

CHAPTER XLI.

REPAYMENT OF LOANS.

When works of sewerage are executed by a sanitary authority, it is usual for the money necessary for the prosecution of the works to be borrowed upon the security of the rates of the district for repayment in a given number of years, depending upon local circumstances. Upon the recommendation of the Local Government Board, the Public Works Loan Board are empowered to lend sanitary authorities money for certain purposes, amongst others, for executing works of sewerage, at rates of interest varying from $3\frac{1}{2}$ per cent. per annum. With the interest a portion of the capital is every year paid off in such a manner that the principal and interest every year, for the whole period the money is borrowed, is an equal amount. Formerly it was customary to borrow capital for repayment in a given number of years, an equal amount of capital being repaid every year, in which case the ratepayers who lived in the district in the early periods of the repayment were unduly taxed, as they had to pay the full interest upon the whole of the sum of money advanced, and an equal proportion of capital, whereas those living in a district at the period of the expiration of the loan, would be called upon to pay a much less amount of interest, but an equal amount of the capital. It was owing to this unequal distribution of payment that the method has been adopted of equalizing the repayments during the whole period of the loan. Table No. 61 has been compiled with a view to facilitate the calculations of the engineer in respect to the sums necessary to be raised in a district to meet the

Money borrowed on security of the rates.

Mode of procedure to get loan.

Interest and portion of capital paid every year in equal instalments.

Description of Table No. 61.

Table No. 61.—For facilitating the Calculation of the Equal Annual Amount of Principal, combined with Interest, which is requisite for the Repayment of Loans, at rates of interest from $1\frac{3}{4}$ to 6 per cent. per annum, in any period from one to sixty years.

No. of Years in which Loan is to be Repaid.	$1\frac{3}{4}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	2 per cent. per annum. Average Annual Instalment of Principal and Interest.	$2\frac{1}{4}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	$2\frac{1}{2}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	3 per cent. per annum. Average Annual Instalment of Principal and Interest.	$3\frac{1}{2}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	$3\frac{3}{4}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	4 per cent. per annum. Average Annual Instalment of Principal and Interest.	$4\frac{1}{4}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	$4\frac{1}{2}$ per cent. per annum. Average Annual Instalment of Principal and Interest.	5 per cent. per annum. Average Annual Instalment of Principal and Interest.	6 per cent. per annum. Average Annual Instalment of Principal and Interest.	No. of Years in which Loan is to be Repaid.
1	1·017500	1·020000	1·022500	1·025000	1·030000	1·035000	1·037500	1·040000	1·042500	1·045000	1·050000	1·060000	1
2	·513166	·515050	·516937	·518827	·522611	·526400	·528299	·530196	·532097	·533998	·537805	·545437	2
3	·345070	·346755	·348445	·350137	·353530	·356934	·358642	·360349	·362060	·363773	·367209	·374110	3
4	·261032	·262624	·264219	·265816	·269027	·272251	·273869	·275490	·277115	·278744	·282012	·288591	4
5	·210623	·212159	·213700	·215247	·218354	·221481	·223052	·224627	·226207	·227792	·230975	·237396	5
6	·177026	·178526	·180033	·181550	·184597	·187668	·189212	·190762	·192317	·193878	·197017	·203366	6
7	·153031	·154512	·156000	·157495	·160506	·163544	·165074	·166610	·168152	·169701	·172820	·179135	7
8	·135043	·136509	·137985	·139467	·142456	·145477	·146999	·148528	·150065	·151610	·154722	·161036	8
9	·121058	·122515	·123982	·125457	·128434	·131446	·132966	·134493	·136030	·137574	·140690	·147022	9
10	·109876	·111326	·112786	·114259	·117231	·120241	·121762	·123291	·124830	·126379	·129505	·135868	10
11	·100731	·102177	·103636	·105106	·108077	·111092	·112616	·114149	·115693	·117248	·120389	·126793	11
12	·093114	·094558	·096015	·097486	·100462	·103484	·105013	·106552	·108103	·109666	·112825	·119277	12
13	·086673	·088115	·089574	·091047	·094030	·097062	·098597	·100144	·101703	·103275	·106456	·112960	13
14	·081156	·082600	·084061	·085535	·088526	·091571	·093113	·094669	·096238	·097820	·101024	·107585	14
15	·076377	·077825	·079291	·080767	·083767	·086825	·088376	·089941	·091520	·093114	·096342	·102963	15
16	·072199	·073649	·075116	·076596	·079611	·082685	·084245	·085820	·087410	·089015	·092270	·098952	16
17	·068516	·069971	·071443	·072929	·075953	·079043	·080613	·082199	·083800	·085418	·088699	·095445	17
18	·065245	·066702	·068177	·069671	·072709	·075817	·077397	·078993	·080607	·082237	·085546	·092357	18
19	·062321	·063782	·065261	·066760	·069814	·072940	·074531	·076139	·077764	·079407	·082745	·089621	19
20	·059691	·061157	·062641	·064147	·067216	·070361	·071962	·073582	·075220	·076876	·080243	·087185	20
21	·057315	·058785	·060275	·061787	·064872	·068037	·069649	·071280	·072931	·074601	·077996	·085005	21
22	·055156	·056632	·058129	·059647	·062747	·065932	·067555	·069199	·070862	·072546	·075971	·083046	22
23	·053188	·054668	·056171	·057696	·060814	·064019	·065653	·067309	·068985	·070682	·074137	·081278	23
24	·051386	·052872	·054380	·055913	·059047	·062273	·063919	·065587	·067275	·068987	·072471	·079679	24
25	·049730	·051222	·052737	·054277	·057428	·060674	·062332	·064012	·065714	·067439	·070952	·078227	25

26	·048203	·049700	·051221	·052768	·055938	·059205	·060875	·062567	·064283	·066021	·069564	·076904	26
27	·046791	·048293	·049822	·051377	·054564	·057852	·059534	·061239	·062967	·064719	·068292	·075697	27
28	·045482	·046990	·048525	·050088	·053293	·056603	·058296	·060013	·061755	·063521	·067123	·074593	28
29	·044264	·045778	·047321	·048891	·052115	·055445	·057150	·058880	·060635	·062414	·066045	·073579	29
30	·043130	·044650	·046199	·047777	·051019	·054371	·056087	·057830	·059598	·061392	·065051	·072649	30
31	·042070	·043597	·045153	·046739	·049999	·053372	·055100	·056855	·058637	·060443	·064132	·071792	31
32	·041078	·042610	·044174	·045768	·049047	·052442	·054181	·055949	·057743	·059563	·063280	·071002	32
33	·040148	·041687	·043257	·044859	·048156	·051572	·053324	·055104	·056911	·058745	·062490	·070273	33
34	·039274	·040819	·042397	·044007	·047322	·050760	·052523	·054315	·056135	·057982	·061755	·069598	34
35	·038451	·040022	·041588	·043206	·046539	·049998	·051773	·053577	·055410	·057270	·061072	·068974	35
36	·037675	·039233	·040825	·042452	·045804	·049284	·051070	·052887	·054732	·056606	·060435	·068395	36
37	·036942	·038506	·040106	·041741	·045112	·048613	·050411	·052240	·054097	·055984	·059840	·067857	37
38	·036250	·037821	·039428	·041070	·044459	·047982	·049792	·051632	·053502	·055402	·059284	·067358	38
39	·035594	·037171	·038786	·040435	·043844	·047388	·049209	·051061	·052943	·054856	·058765	·066894	39
40	·034972	·036556	·038178	·039836	·043262	·046827	·048659	·050524	·052418	·054343	·058278	·066462	40
41	·034382	·035972	·037601	·039268	·042712	·046298	·048142	·050017	·051924	·053862	·057822	·066059	41
42	·033821	·035417	·037053	·038729	·042192	·045798	·047653	·049540	·051459	·053409	·057395	·065683	42
43	·033287	·034890	·036533	·038217	·041698	·045325	·047191	·049090	·051021	·052982	·056993	·065333	43
44	·032778	·034388	·036039	·037730	·041230	·044878	·046754	·048665	·050607	·052581	·056616	·065006	44
45	·032293	·033910	·035568	·037267	·040785	·044453	·046341	·048263	·050217	·052202	·056262	·064701	45
46	·031830	·033453	·035119	·036827	·040363	·044051	·045949	·047882	·049848	·051845	·055928	·064415	46
47	·031388	·033017	·034691	·036407	·039961	·043669	·045578	·047522	·049499	·051507	·055614	·064148	47
48	·030966	·032602	·034282	·036006	·039578	·043307	·045226	·047181	·049169	·051189	·055318	·063898	48
49	·030561	·032204	·033891	·035623	·039213	·042962	·044892	·046857	·048856	·050887	·055040	·063664	49
50	·030174	·031823	·033518	·035258	·038865	·042634	·044574	·046550	·048560	·050602	·054777	·063444	50
51	·029803	·031459	·033161	·034908	·038534	·042322	·044272	·046259	·048279	·050332	·054528	·063239	51
52	·029447	·031109	·032818	·034574	·038217	·042024	·043985	·045982	·048013	·050077	·054294	·063046	52
53	·029105	·030774	·032491	·034254	·037915	·041741	·043712	·045719	·047761	·049835	·054073	·062865	53
54	·028777	·030452	·032176	·033948	·037626	·041471	·043452	·045469	·047521	·049605	·053864	·062696	54
55	·028461	·030143	·031875	·033654	·037349	·041213	·043204	·045231	·047293	·049387	·053667	·062537	55
56	·028158	·029846	·031585	·033372	·037084	·040967	·042968	·045005	·047077	·049181	·053480	·062388	56
57	·027866	·029561	·031307	·033102	·036831	·040732	·042742	·044789	·046871	·048985	·053303	·062247	57
58	·027585	·029287	·031040	·032843	·036589	·040508	·042528	·044584	·046675	·048799	·053136	·062116	58
59	·027314	·029023	·030783	·032593	·036356	·040293	·042323	·044388	·046489	·048622	·052978	·061992	59
60	·027053	·028768	·030535	·032353	·036133	·040088	·042127	·044202	·046312	·048454	·052828	·061876	60

payment of capital and interest, or the amount which it may be necessary to raise by rate for the prosecution of works of sewerage.

Example worked out.

If, for example, a sum of 10,500*l.* is borrowed for repayment in thirty years at $3\frac{1}{2}$ per cent. it will be found that 10,500*l.* multiplied by the decimal given in the Table under the column of $3\frac{1}{2}$ per cent. and opposite 30 years = ·054371, and 10,500 × ·054371 = 570·8955*l.*,* or 570*l.* 17*s.* $10\frac{3}{4}$*d.* is the sum necessary to be raised every year to pay the interest and pay off the capital in thirty years. If instead of being repaid annually it is paid half-yearly, the repayments would be spread over sixty instead of thirty payments. In this case if we calculate the repayment at half the interest, and for twice the number of years, we shall get the correct half-yearly amount necessary to repay the loan. If we take the former case as an example, half of $3\frac{1}{2}$ per cent. is $1\frac{3}{4}$ per cent., and twice thirty years are sixty years, so that under the column of $1\frac{3}{4}$ per cent., and opposite sixty years we find ·027,053 and 10,500 × ·027053*l.* = 284·0565*l.*, or 284*l.* 1*s.* $1\frac{1}{4}$*d.* is the half-yearly amount required to be raised, from which it will be seen that by paying half-yearly, the amount to be repaid will be a little less than if paid yearly.

Mode adopted in half-yearly payments.

Example worked out.

* The decimal is brought into shillings, pence, and farthings by first multiplying it by 20, the remaining decimal by 12, and what remains by 4 to bring out the farthings, thus:

```
 ·8955
    20
-------
17·9100
    12
-------
10·8200
     4
-------
 3·2800
-------
```

INDEX.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.