The high pressure cylinder A, and the low pressure cylinder B, are both steam jacketted on all surfaces; F is the crank shaft, and the cranks f and f^1 are placed at right angles to each other.

The 'steam reservoir' consists of a steam jacketted vessel G, with a lining H, placed at a small distance from its sides. The lining is open at one end, but not the other, and the pipes from the high pressure and to the low pressure cylinder are so placed that the former leads into the space inside the lining, whilst the latter takes steam from behind the lining; the advantage of this will presently be seen.

The high-pressure cylinder A communicates with the space H, through the eduction pipe I, and the aperture h; whilst the low-pressure cylinder B communicates with the reservoir through the slide valve box M, and the aperture g^2. Thus it will be seen that the steam, after having done its work in the cylinder A, will pass through the pipe I into the space H, as shown by the arrows, and it is caused to pass through the narrow spaces g, g, between the sides of the lining H, and those of the reservoir G, whereby the whole of the steam is brought into intimate contact with the hot steam jacketted surfaces.

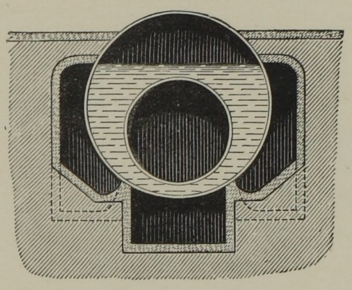
The surface condenser C consists of a number of vertical brass tubes, through which the whole of the water pumped passed in an upward direction (to assist in removing the air-bubbles deposited on the surface of the tubes). The steam to be condensed comes in contact with the outsides of the tubes. E is the ordinary air-pump.

The eduction pipe X would allow of the high-pressure engine being worked by itself, if such were ever required, and by means of the steam-pipe Y the low-pressure cylinder could be worked by itself.

A number of engines have been constructed on this plan, for various purposes, with excellent results. In all cases their action is found to be very steady and uniform.

The boilers supplying steam to waterworks engines are usually either of the Cornish or Lancashire type, the former having a single internal flue and the latter two internal flues, side by side.

FIG. 135.



On Plates 40, 41, 45, and 47 are illustrations of Cornish boilers, set with what is known as a 'wheel draught.' The products of combustion pass along the internal flue from the front to the back end of the boiler, then return through one side flue to the front, and finally pass along the other side flue to the back end again, whence they are led through the main flue to the chimney. A profitable method is the 'split draught,' with side and bottom flues, as shown in fig. 135. On leaving the internal flue the draught should be divided and led along the side flues to the front of the boilers; then as a single draught underneath the boiler, and away to the main flue. It is sometimes arranged that the draught shall pass from the internal flue first to the bottom flue, and then into the two side flues; the chief disadvantage of the latter method is that the greatest heat is brought to bear upon that part of the boiler where the most sediment collects, and where, consequently, the plates are thus more likely to be overheated. In setting small boilers it is usual to deepen the side flues, as shown by the dotted lines in fig. 135, in order to allow of a thorough examination of the boiler plates.

The following is an account of the boilers supplying some of the engines illustrated on Plate 8, and already described in this chapter.

Leipsic, fig. 2. For the two engines there are four Lancashire boilers, each 32 feet long, with shells 7 feet diameter; flue, 2 feet 8 inches; fire grate, 6 feet 6 inches long; working pressure, 45lbs.

Dover Castle, fig. 3. This engine has two Lancashire boilers, 26 feet long and 6 feet diameter, with tubes 2 feet 4 inches diameter; they are worked at 60 lbs. pressure.

Folkestone, fig. 5. For two engines there are two Cornish boilers, each 18 feet long, 5 feet diameter, and with internal flue 2 feet 6 inches diameter; fire grate, 4 feet long.

Crossness, fig. 9. To supply four engines there are twelve Cornish boilers, each 30 feet long, with shell of $\frac{3}{8}$-inch plates, 6 feet diameter; internal flue 3 feet 3 inches diameter for one-third of the length, then reduced to 2 feet 11 inches; area of fire grate, 23 square feet.

Eastbourne, fig. 12. Here are two Cornish boilers, each 16 feet long, 5 feet 6 inches diameter, and with internal flue 3 feet diameter; fire grate, 4 feet long.

Berlin, fig. 13. The two engines are supplied with steam by eight Cornish boilers, each 28 feet long; shells, 6 feet diameter; internal flues, 3 feet 6 inches diameter; pressure, 40 lbs. per square inch.

West Middlesex, fig. 14. The engine shown by fig. 14, and a similar one, are provided with ten Cornish boilers of 6 feet 6 inches diameter; three of them, each 24 feet long, are made of steel; the remainder are 28 feet long; pressure for all boilers, 40 lbs.

Isle of Wight, fig. 16. To supply this engine there is one Cornish boiler 20 feet long, and 5 feet 3 inches diameter, the flue being only 2 feet 9 inches diameter. It is worked at a pressure of 55 lbs.; fire grate, 4 feet long.

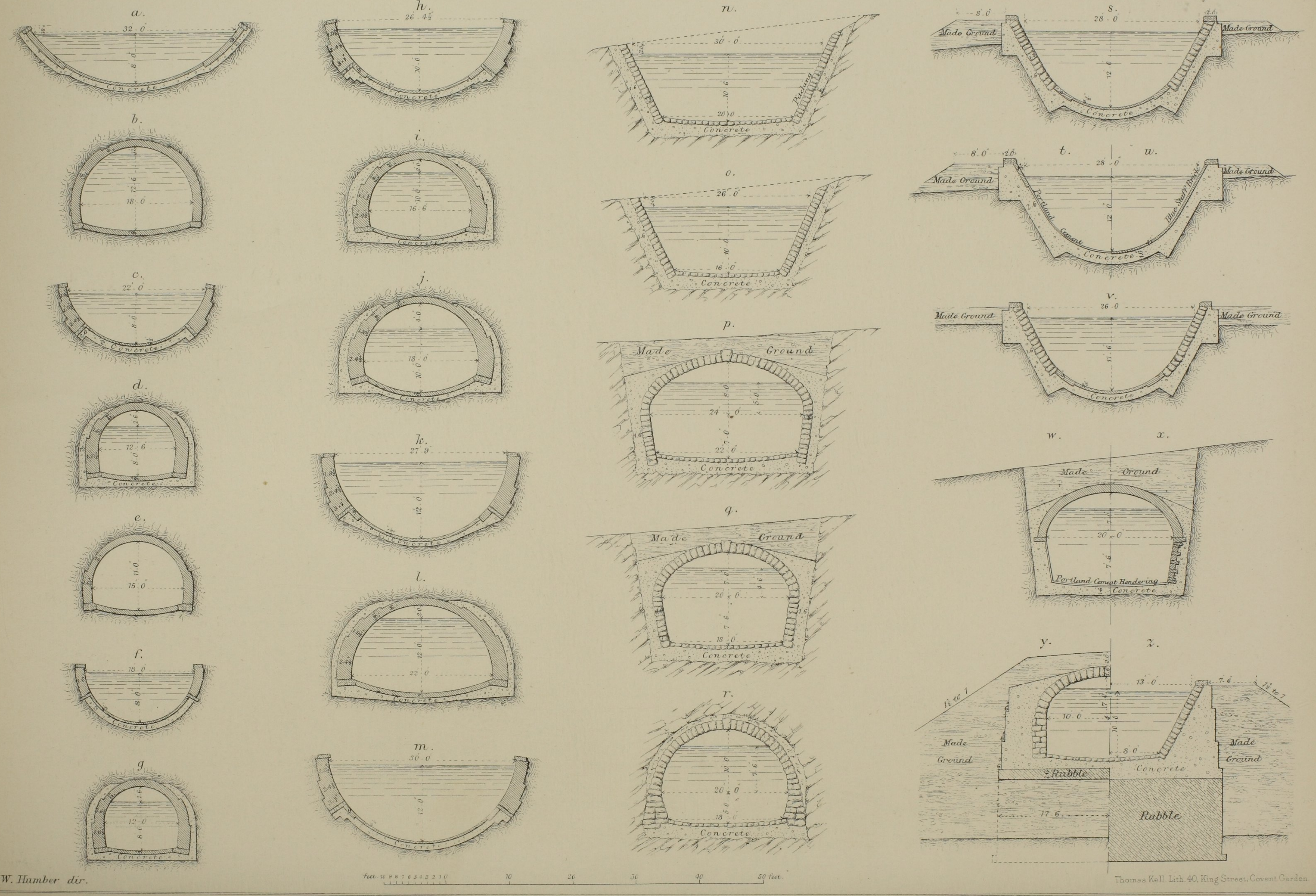
Kharknow, fig. 17. For the two engines shown there are three Cornish boilers, each 27 feet long and 5 feet 6 inches diameter, with an internal flue 3 feet diameter; fire grate, 5 feet 6 inches long.

Kent (Crayford), fig. 19. For this engine there are two Cornish boilers, each 30 feet long; diameter of shell, 6 feet at front end, reduced to 5 feet 6 inches behind the fire grate; tube, 4 feet diameter at fire grate, reduced to 3 feet 6 inches; working pressure, 40 lbs.

Gorlitz, fig. 21. For the pair of engines, as illustrated, there are two boilers of peculiar construction; each boiler consists of two inclined tubes, each 17 feet long and 13 inches diameter, which are connected with each other by means of a transverse steam chamber 5 feet 6 inches long and 2 feet 8 inches internal diameter; a pipe 9 inches diameter connects each boiler tube with this chamber. Both ends of the tubes are closed by wrought iron covers, and the lower ends are connected with each other by means of a 3-inch copper pipe, to which are fastened feed-valves, one for the steam pump and the other for the injector.*

* 'Engineering,' Vol. X., p. 419.

CONDUITS.



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CHAPTER XII.

CONDUITS.

Considerations affecting the choice of a route—Stability of the bed of the Conduit—Cross sections of Conduits of Glasgow, Aberdeen, Marseilles; Conduits of the proposed Welsh and Lake Schemes for the Metropolis, and their cost—Open *versus* covered Conduits—Tunnels—Aqueducts: Roquefavour; Loch Katrine; Pipe Aqueducts—Earthenware Pipe Conduits—Controlling Apparatus.

WHEN the source of a water supply is at any considerable distance from the point of distribution, the main conduit leading from the former to the latter is necessarily an important feature of the works. This is especially so in the case of conduits in which the water runs free—that is, not under pressure. Pressure conduits are comparatively simple as engineering works; for having once gone to the expense of enclosing the water in an iron pipe, the shortest route may be selected without any restriction as to regularity of descent, except that nowhere should we rise above a certain inclined line, known as the hydraulic gradient.

In the determination of the best route for a long conduit, questions of importance will arise apart from considerations of hydraulics. If a populated district intervene, the practicability of supplying it from the conduit, either by a detour of the same or by branch works, will demand careful attention. In the first place, this is a matter of common right; the district nearer to the source has *primâ facie* the better claim to the benefits derivable from it. In the second place, such combination will generally result in economy. The cost of the necessary addition to the works will be more than covered by the increased revenue. In the Cumberland Lake scheme for supplying the metropolis, it is proposed by Messrs. Hemans and Hassard that, for distributing with advantage amongst towns in Lancashire, the Potteries and the Midland Counties, about 33 per cent. should be added to the quantity of water required to be conveyed by the conduit for London alone. Mr. Bateman, speaking of the advantages received by towns lying adjacent to the conduit, in his scheme for supplying London with water from Wales, says: ‘There are no towns on the line which require water at all until we get into the Midland districts, and then we get within 10 miles of the centre of a district which is probably the most difficult to supply of any large manufacturing or very populous district in England, namely, Wolverhampton, Dudley, Walsall and all the Staffordshire coal district, and Birmingham. They lie on the highest table-land in England, from which the water sheds in all directions; there are no hills near them from which they can obtain a supply of water, and I think a district ought to be considered in any large scheme which would take the water near those places in its course.’ It is sometimes urged that there is a disadvantage in two or more communities being dependent upon one conduit for their supply, but this objection should be made not against the number of communities, but upon the gross number of inhabitants. London itself may be considered secure, with its eight independent conduits; but regard should rather be had to the fact that about one million of the inhabitants have to rely entirely upon the integrity of one conduit, the New River. The disastrous consequences which would be entailed by the sudden failure of such a conduit can be more economically and advantageously prevented (as far as the attendant drought is concerned) by town or service reservoirs of ample capacity than by any system of duplicating the conduit.

The general character of the conduit will necessarily be determined by the conformation of the country through which it is to pass, and the proximity of materials suitable for its construction. Mr. Bateman, in an account of the Loch Katrine Waterworks, describes the advantage of the route, and the geological character of the country through which the conduit passes, as follows:—

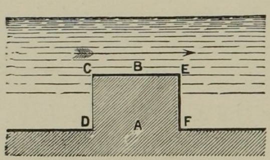
‘After finding the narrowest point at which the ridge between Loch Katrine and Loch Chon could be pierced, the country consists of successive ridges of the most obdurate rock, separated by deep wild valleys, through which it was very difficult in the first instance to find a way. There were no roads, no houses, no building materials, nothing which would ordinarily be considered essential to the successful completion of a great engineering work for the conveyance of water. But it was a consideration of the *geological character* of the material, which gave it the romantic wildness of the district, that at once determined me to adopt that particular mode of construction which has been so successfully carried out. For the first ten miles, the rock consists of mica schist and clay slate, close retentive material, into which no water percolates, and in which, consequently, few springs are found. The rock, when quarried, was unfit for building purposes. There was no stone of a suitable description to be had at any reasonable cost or distance, no lime for mortar, no clay for puddle, and no roads to convey materials; ordinary surface construction was out of the question, but I saw that, if tunnelling was boldly resorted to, there would be no difficulty beyond the cost and time required in blasting the rocks and making a perfectly water-tight and enduring aqueduct.'

From the principles of hydraulics enunciated in a former chapter, it is seen that the discharge of any conduit being given, the fall or gradient will be dependent on the hydraulic mean depth, and *vice versâ;* the discharge is, of course, the product of the sectional area of the water and its mean velocity; and thus, in the planning of the conduit, the relationship subsisting between these different quantities has to be regarded at the outset. The discharge is a fixed quantity in the calculations; it should never be less than equivalent to the maximum daily consumption of the dry season, and in excess of this it will of course vary with the extent of the provision made for future requirements.

The limits which must be assigned to the velocity of flow in a conduit are determined, on the one hand, by the nature of the conduit itself, and, on the other, by the quality and condition of the water.

The bed of a conduit should be in a condition of stability—that is to say, there should be no perceptible disturbance or wearing away. The velocity of the current near the perimeters of the channel may be estimated at about as much below the mean velocity of the stream as the maximum surface velocity is above it. Formulæ for the latter have been given in Chapter V. (p. 78); but it will be sufficient for the present purpose to regard the greatest mean and least velocities as being in the proportion of the numbers 5, 4, and 3. The velocity of the water in contact with the bed of the channel at any point is to be regarded quite independently of the hydrostatic pressure at that point, for the abrading action or 'friction' is not found to increase with the pressure. This law has been enunciated in a former chapter (p. 79). If A (fig. 136) be any magnified irregularity in the bed of the channel B, it will be seen that to whatever degree the action of the water on the up-stream side C D might be increased by an increase in the depth of the current, the counter-action on the down-stream side E F would be increased to the same extent. The resistance which the projection offers to the current will depend simply on the velocity of the latter; and as this resistance is found to increase very nearly as the square of the velocity, it may be inferred that the disturbance (if there be any at all) of the channel bed will increase in the same proportion.

Fig. 136.



The wasting away or abrasion of the bed of a channel is not due to any mechanical action of the water upon the smooth solid surface of the material with which it is formed or lined. The resistance of a smooth bed of solid clay to comparatively high velocities is surprising. The constant action of a current of water in iron mains fails to remove the lime whiting with which they are frequently lined. It is maintained by some that in such cases the water in motion glides over a thin film of water adhering to the sides of the pipe or channel and thus protecting it. On the other hand, the existence of loose particles or detached portions of the bed, or foreign substances, which are liable to be rolled along by the current, will naturally result in wear and tear; even fine sand in suspension in currents of high velocity is probably a very active agent in abrading the bed of a conduit.

The following are the velocities at which it has been ascertained that different material may be moved by running water:—

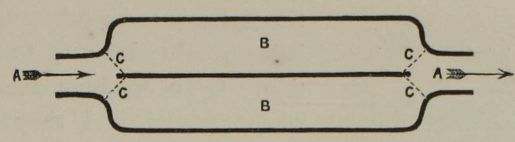
6	inches	per second	will transport	fine sand.
8	”	”	”	coarse sand.
12	”	”	”	fine gravel.
24	”	”	will roll along pebbles 1 inch diameter.	
36	”	”	will sweep along angular stones as large as hens' eggs.	

Conduits for the supply of water to towns, where not formed of iron pipes, are now generally protected with a lining of masonry or brickwork, and the necessity for curtailing the greater velocity of the water flowing through them, from fear of damage to the lining, will be very rare. The engineer will more frequently have to reduce the loss of head to a minimum, and keep down the velocity with this object alone. If the conduit be lined with unprotected puddle or be cut in the solid clay itself, it is then advisable to confine the velocity to from one and a half to two feet per second at the most.

The velocity in a conduit, when at its normal flow, should never be low enough to permit of the deposit of suspended matter, or, better still, water should not, if possible, be admitted into a conduit in a turbid condition. Specially designed settling-ponds should be constructed; and if for other reasons it be expedient to place these at the town end of the conduit, the velocity should be high enough to prevent deposit *en route*; thus the maximum velocity allowable will be dependent on the quality and condition of the water.

Where these conditions cannot be conformed to, advantage may be derived from the introduction on the line of conduit (A A, fig. 137) of double chambers (B B), of a joint width not less than about three times that of the conduit, and having their bottom carried a few feet below the bottom of the conduit. Much of the heavier suspended matter would here be trapped, and, as often as necessary, the chambers could be cleaned, one at a time, by the insertion of stop-planks at C C C C, so as not to interfere with the clearness of the water beyond.

FIG. 137.



The best forms, theoretically, for the cross-section of a conduit are the circle for a closed conduit running full, and the semi-circle for an open conduit, for with these figures the wetted perimeter is a minimum with a given area of the stream. Thus the hydraulic mean depth is at a maximum, and consequently also the velocity, and therefore the discharge of the conduit. At the same time, the girth of construction is at a minimum. The best form for a straight-sided cross-section is obtained by making the sides and bottom tangents to a semicircle, having its centre at the water-line, as in the annexed figure. On Diagram A are shown the various sections designed by Mr. Bateman, and by Messrs. Hemans and Hassard, for their proposed Welsh and Cumberland Lake schemes respectively. Fig. A is the section of a proposed flood watercourse, lined with Staffordshire blue bricks, and is designed for a mean velocity of nearly *eleven* feet per second. Figs. B and C are tunnels for flood water, with mean velocities of 10 feet 6 inches and 11 feet 6 inches per second respectively. The remaining sections to fig. *m* are for open and covered or tunnelled conduits, with velocities varying from 1·82 foot per second in the former to 2·84 feet in the latter. The quantities and cost per lineal yard for the different sections is given in the table below. The proposed sections for the Cumberland Lake scheme differ from the foregoing not only in their form, but also in the use which is made of rubble masonry, where the conduit is carried through rocky districts. They are designed for velocities of from 1·76 to 2·2 feet per second. Comparison may with advantage be made of the sections on Diagram A with the sections of the Loch Katrine conduit in the annexed cuts, figs. 139, 140, and 141; and in figs. 10, 11, and 12, plate 28, also, with the sections of the Aberdeen conduit, plate 37.

FIG. 138.

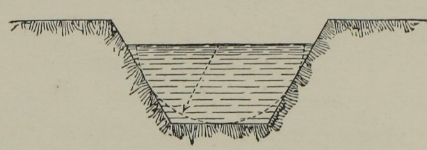
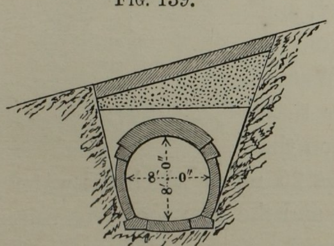
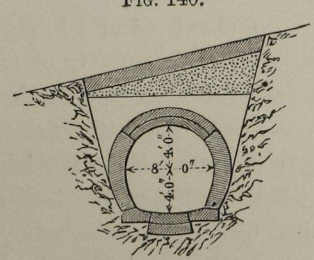


FIG. 139.



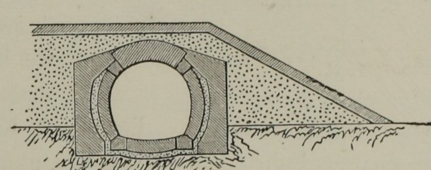
Section where open cutting is water-tight, but requires lining.

FIG. 140.



Section where open cutting is not watertight.

FIG. 141.



Section where the aqueduct is above the natural surface of the ground.

The following table gives the estimated cost per lineal yard of the proposed main Conduit for Welsh Lake Scheme, as given by Mr. Bateman in his evidence before 'The Royal Commission on Water Supply,' the letters having reference to the diagram sheet.

Fig.	Excavation			Concrete			Brickwork			Ashlars			Sundries	Total
	cubic yards	s.	£ s. d.	cubic yards	s.	£ s. d.	cubic yards	s.	£ s. d.	cubic feet	s.	£ s. d.	£ s. d.	£ s. d.
a	30	2	3 0 0	4¾	10	2 7 6	2½	40	4 13 4	3	2	0 6 0	0 13 2	11 0 0
b	30	6	9 0 0				7½	30	11 0 0	11	2	1 2 0	0 18 0	22 0 0
c	30	2	3 0 0	2¼	10	1 2 6	4	20	4 0 0	12	2	1 4 0	0 13 6	10 0 0
d	40	2	4 0 0	5·35	10	2 13 6	5⅚	20	5 16 8	13⅙	2	1 6 4	0 8 6	14 5 0
e	21	10	10 10 0				5½	30	8 5 0	9	2	0 18 0	0 7 0	20 0 0
f	25	2	2 10 0	2⅓	10	1 3 4	2⅑	20	2 2 3	7½	2	0 15 0	0 9 5	7 0 0
g	36	2	3 12 0	3¾	10	1 17 6	5½	20	5 10 0	13¼	2	1 6 6	0 14 0	13 0 0
h	35	2	3 10 0	4	10	2 0 0	5¼	20	5 5 0	14¼	2	1 8 6	0 6 6	12 10 0
i	50	2	5 0 0	7	10	3 10 0	7½	20	7 10 0	15½	2	1 11 0	0 9 0	18 0 0
j	60	2	6 0 0	6⅔	10	3 6 8	8½	20	8 10 0	17	2	1 14 0	0 9 4	20 0 0
k	45	2	4 10 0	4	10	2 0 0	5½	20	5 10 0	14½	2	1 9 0	0 11 0	14 0 0
l	70	2	7 0 0	8	10	4 0 0	9⅔	20	9 13 4	18	2	1 16 0	1 0 8	23 0 0
m	50	2	5 0 0	4½	10	2 5 0	5⅔	20	5 13 4	14½	2	1 9 0	0 12 8	15 0 0

Figs. 142 and 143 are sections of unlined tunnel of the Marseilles conduit; the former has a fall of 1 in 100, and the latter 1 in 333. Figs. 144, 145, 146, and 147 are also sections of this canal.

Fig. 142.

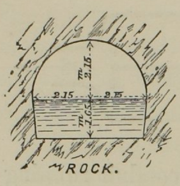
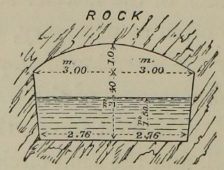


Fig. 143.



Conduits should always be covered in the neighbourhood of populated districts, unless the water is to be subsequently filtered; and even in the latter case it is scarcely advisable to expose the water to avoidable contamination. Open conduits are of course less costly in construction than when covered, and they offer greater facilities for cleansing and repairs, but the arguments used against their general adoption are numerous. They are liable to receive the wash of the country through which they pass, though such an objection may be lessened by the formation of catch-water drains on the upper side. This was one of the reasons given against carrying the water from the River Croton to New York partly in open cutting, and the whole distance of 38 miles was executed by a covered way of a costly kind, illustrated by figs. 148 and 149. Figs. 150 and 151 are sections of the conduits supplying Brooklyn. An open conduit is in any case exposed to the reception of a certain amount of vegetable refuse and dead leaves. It is certain, too, that the water cannot in summer be delivered at so low a temperature from an open as from a covered conduit. An impediment to the flow of water in open channels is the growth of weeds. Another objection made to open conduits is their exposure to frost and snow. The breaking of the ice on the New River has cost the Company as much as £500 in one season. Mr. Bateman, in speaking of this subject, considers that sufficient velocity can be given to conduits to prevent the surface of the water from freezing. He says that, 'In the winter of 1860 and 1861, which was one of the severest winters on record, a much severer one than that of 1813 and 1814, the temperature fell to 12 and 14 degrees below zero, about 44 or 46 degrees of frost, and we have no record in this country of anything equal to that. It was the year after the Loch Katrine Waterworks were completed. But Loch Katrine never froze; the water was never lower than 39 degrees Fahrenheit (7 degrees above freezing); there was not a particle of ice upon the whole surface of the Loch; and in the 26 miles which the water had to travel between Loch Katrine and the Maydoc Reservoir, near Glasgow, it gained two degrees of temperature, and emerged at 41 degrees. But it must be remembered that the Loch Katrine works are under many favourable conditions. The conduit is enclosed for the whole distance; and, moreover, two long tunnels are passed through on the route, and from these in winter, there is, no doubt, a great accession of temperature. The effect of even a thin sheet of fixed ice on the surface of the water in a conduit is to reduce the velocity of flow by increasing the frictional surface, and consequently reducing the discharge. On the breaking up of the ice, moreover, considerable obstruction is offered by its accumulation at various points, especially where there are gratings. A protection against snow-drift may be provided by carrying up the side walls of the conduit, thus gaining some of the advantages of a covered one, but if it be not a very wide channel, it is a question if it would not be better and cheaper to arch it over.

Fig. 144.

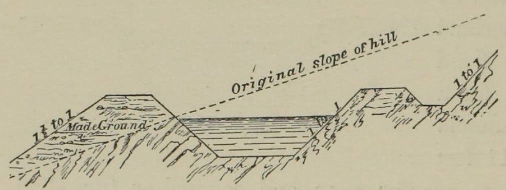


Fig. 145.

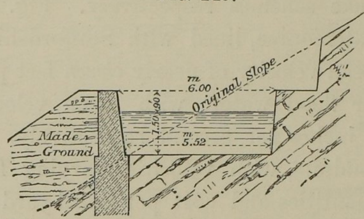


Fig. 146.

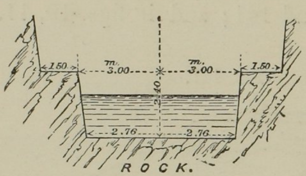


Fig. 147.

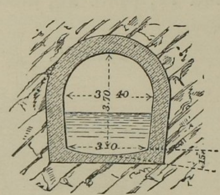


Fig. 148.

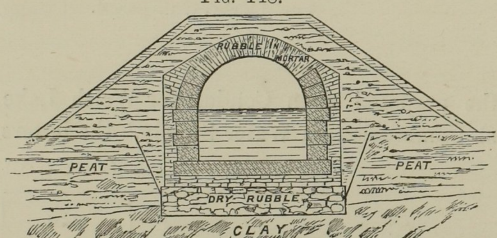


Fig. 149.

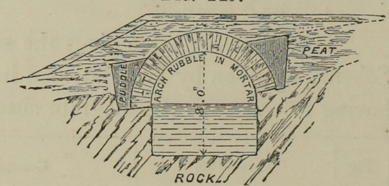


Fig. 150.

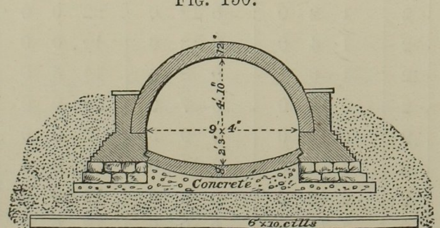
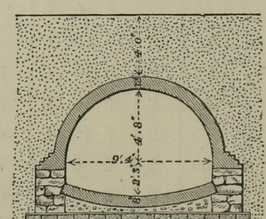


Fig. 151.



Tunnelling is occasionally a prominent feature in the line of a long conduit. In the course of the Loch

Katrine conduit there are seven tunnels of the aggregate length of more than 5½ miles, one of them being 2,640 yards in length. In the Marseilles conduit there are no less than thirty-eight tunnels of, together, 9¾ miles in length. Of these the tunnel of Les Taillades is 4,008 yards long, and is said to have cost £23 2*s.* per yard forward, exclusive, and £29 12*s.* inclusive, of shafts ; the Assassin tunnel is 3,798 yards long, and is said to have cost £10 18*s.* per yard forward, or, including shafts, £11 2*s.*; while a third, that of Notre Dame, 3,289 yards in length, is stated to have cost £18 18*s.* without the shafts, or £20 2*s.* inclusive.

An addition to the supply is sometimes gained in a conduit tunnel by the interception of springs in the fissures of the rocks. From the Taillades tunnel nearly 2,000 gallons per minute were added to the volume of the canal. The Edinburgh Waterworks comprise a tunnel through which a line of pipes is laid 720 yards in length, and 70 to 80 feet under the surface of the ground.

The Croton conduit, like its Roman prototype, is provided with ventilating shafts, one being placed at every mile, and every third shaft having a door. Man-holes, two feet square, and covered with a stone slab, are also provided at every quarter of a mile.

The general practice in ancient times was to continue the conduit, without interruption of its uniform gradient, upon massive aqueducts, which were the chief features of the whole works of water supply. Some of the more remarkable of these monuments have been already described. The accompanying woodcuts, figs. 152 and 153, will give a general idea of their construction.

Fig. 152.

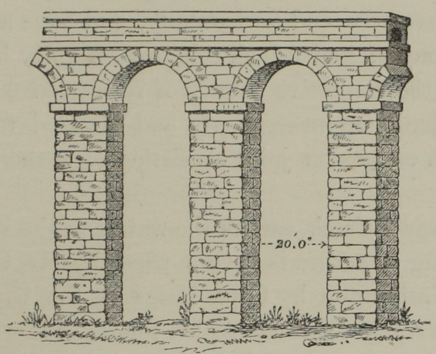
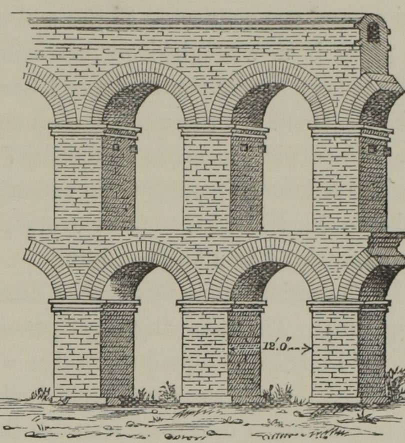


Fig. 153.



The majority of the cases which were in olden times met by the construction of aqueducts would now simply suggest one or more lines of iron pipes laid across the valley a few feet below the surface of the ground, through which pipes the water would be conveyed under a varying pressure corresponding with the amount of depression below the level of the water in the open conduit at either end. A notable instance, however, of a disregard of the means rendered available by modern science and art is to be found in the aqueduct of Roquefavour, upon which the conduit supplying water to Marseilles is carried across the valley of the Are. The engineer, M. de Montricher, appears to have had considerable fear that a syphon would have been rendered impracticable by the accumulation of deposit from the waters of the Durance. Be that as it may, the aqueduct, as such, is a very fine work, rivalling its Roman prototype. Its total length is 1,289 feet, and its height above the bottom of the valley 266 feet. It is constructed with three tiers of arches; n the lower tier are twelve arches of 15 metres (49¼ feet) span, in the middle tier there are 15 arches of 16 metres (52½ feet) span and 114½ feet in height, while in the upper tier there are 54 arches of 16½ feet span, three over each of those in the lower tiers. Fig. 154 is a transverse section of the aqueduct, taken through the centre of one of the arches ; and Fig. 155 is an enlargement, showing the detail of the water-channel, &c.; the dimensions given therein are in metres. The aqueduct is built with ashlar facing and rubble backing, and the total cost has been given as £148,000. Iron pipes of equivalent discharging capacity could probably have been carried across the valley, as an inverted syphon, for less than one-third of this sum. Cases will of course occur in which the saving to be effected by the substi-

Fig. 154.

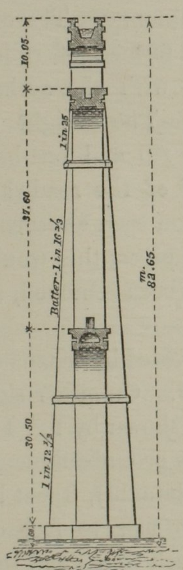
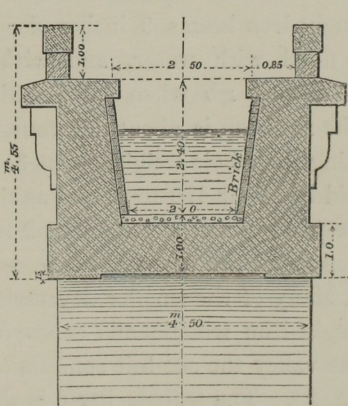


Fig. 155.



tution of iron pipes would not be worth the sacrifice made on the point of durability, for that there is such a sacrifice there cannot be a doubt.

Fig. 156.

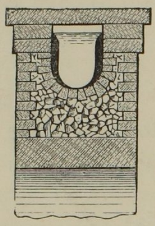


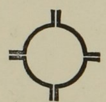
Fig. 156 is a transverse section of the arches of the Pont du Gard aqueduct, the darker portions representing the deposit 11 inches thick with which the sides have been encrusted.

On plates 27 and 28 details are given of aqueducts of masonry occurring on the line of the Loch Katrine conduit.

The aqueduct by which the conduit supplying the city of Washington is made to span the Cabin John Creek consists of a single arch of masonry, of 220 feet span—greater than that of any other masonry arch in the world. The rise of the arch is 57 feet 3 inches; the thickness of the crown is 4 feet 2 inches, and at the springing 6 feet 2 inches, the intrados being struck with a radius of 134 feet 3 inches. The arch is 20 feet 4 inches in width, and the water is conveyed in an iron pipe 9 feet in diameter, built in solid masonry.*

For carrying the water from the Roxborough to the Mount Airy Reservoir, over the valley of the Wissahikon for the supply of German-town, Mr. Frederick Graff, chief engineer to the Water Department of Philadelphia, has successfully adopted a skeleton pipe aqueduct which may be thus described: It consists of two parallel lines of 20-in. cast-iron flanged pipes, which serve as the top members of a series of inverted bowstring trusses. There are 4 spans of 169 feet 9 in. each; and the centre of the pipes is 100 feet above the ordinary level of the water in the creek below. The tension members of the trusses consist of two lines of wrought-iron links, 10 square inches in section, and are connected to the end-pipes of each span by means of a suitable casting. Under every joint of the pipes is a wrought-iron vertical strut, $5\frac{3}{4}$ inches in diameter, built up of segments rivetted together. The trusses are efficiently braced longitudinally, transversely, and horizontally, and have a maximum depth of 16 feet. There are three piers, each consisting of a group of four 9-inch columns carefully braced with wrought iron. These piers measure 14 feet by 7 feet, and are of the respective heights of 72 feet, 97 feet 6 inches, and 48 feet. The columns forming them are of wrought iron, built up in segments and rivetted together, as shown in Fig. 157. Over every piece is placed an expansion joint consisting of a short length of pipe working in a stuffing-box.

Fig. 157.



A curious aqueduct bridge, crossing the Georgetown Creek, carries the waters of the Washington conduit. The following description of this interesting structure is from a paper by Mr. Colburn:—

'In 1858 an aqueduct bridge was erected at Washington by Capt. Meigs of the United States Engineers, who used for this work two arched ribs formed of water-pipes, through which the water flows, the pipes being circular in section, as that form encloses the greatest quantity of water with the least amount of iron. The span of the bridge is 200 feet, the rise being 20 feet, and the width of the bridge, over all, 28 feet. The pipes are 4 feet in diameter inside, and $1\frac{1}{2}$ inches thick; they were lined with staves of resinous pine 3 inches thick, to prevent the freezing of the water. The pipes are not cast to the curve of the arch, but are in straight lengths of about 12 feet, with flanged joints faced in planes parallel to the corresponding radii of the arch. At the skewbacks the ends of the pipes are faced to large conical bases, admitting the water, and resting upon the masonry. There is no allowance for expansion or contraction. The roadway is of timber supported on spandrils formed of rolled wrought-iron beams 9 inches deep and weighing 90 lbs. per yard. The bridge was tested with the arched ribs filled with water, and with a load of 125 lbs. per square foot upon the roadway. The weight of each arched rib when filled with water is about 160 tons, that of the spandrils of each rib and one-half of the roadway is about 30 tons, while the test load was equal to 160 tons on each half of the roadway, making the whole weight about 350 tons on each rib. The thrust of one-half of the weight upon each abutment would be about 470 tons, and as there are $238\frac{1}{2}$ square inches of sectional area of iron in the pipes, this would correspond to a strain of about 2 tons per square inch. The pine lining of the pipes has since been removed, as it was found the water never froze in them.'

Many of the smaller depressions occurring in the route of the Loch Katrine conduit are crossed by means of wrought-iron troughs and tubes; one of these, near Culgarton, is illustrated on plates 28 and 29. On either side of the valley the conduit consists of a cast-iron rectangular trough, carried on a rubble wall, as shown by fig. 14, plate 28. The trough itself is shown enlarged by fig. 4, plate 29. Between the rubble walls or embankment, the conduit consists of a rectangular wrought-iron tube (fig. 13, plate 28, and figs. 5 to 8, plate 29), 8 feet in width, and 6 feet 6 inches in depth, extending over four spans of 50 feet, the distance from face to face of abutments being 215 feet. The bottom and sides of the tube are $\frac{3}{8}$ inch thick, the top being $\frac{7}{8}$ inch thick, and the whole is strengthened by angle and T-iron. It will be seen by fig. 5, plate 29, that the level of the wrought-iron tube I is three feet below that of the cast-iron trough J. The object of this arrangement is to ensure the

* For further details, see Waterworks of London, p. 161, E. and F. N. Spon, 1867.