CHAPTER VII.

DETAIL PLANS.

ART. 40. THE SEWER-BARREL.

SEWERS have been made of almost every conceivable shape and the walls built of all kinds of materials. A few shapes and materials are of almost universal applicability, others are adapted to peculiar circumstances only, and some are freaks of invention adapted to no circumstances.

The shape of cross-section is to a certain extent controlled by the material of which the sewer is constructed. The smallest sewers cannot be advantageously built of brick, but are usually composed of earthenware or metal pipes or of cement. Earthenware sewers are made from 2 to 42 inches interior diameter. They are seldom made other than circular, owing to the liability of other shapes to become distorted in burning. Metal pipes are employed where the sewer will be under pressure, as in a siphon, or where there is a great deal of ground-water; also sometimes to better resist disturbing forces, as in made or treacherous ground or outlets under water or in shifting sands. The only metal commonly employed is iron. Metal pipes have always been made circular, although there are none but economic reasons why other forms could not be made.

Concrete and cement sewers are made of all sizes and shapes—circular, egg-shaped, rectangular, etc. Concrete is used for both, but the particles of the aggregate for the smaller are so fine as to make it practically coarse mortar, and these are called cement sewers.
Wooden-stave sewer-pipe has been used in the West, and in the East to some extent. On the Los Angeles outfall sewer are 34,100 feet of 36- and 38-inch pipe of this description. The outlet sewers in New York and Brooklyn are many of them creosoted wooden-stave pipe of 3 or more feet diameter.

For all sewers the circle is the most economical shape, and generally the most desirable, if they are never to run less than \( \frac{3}{4} \) full, except that the use of platform foundations may modify the first statement. But if they are to be used as combined sewers the egg shape is to be preferred, or a form similar to Plate VII, Figs. 2 and 6.

In Brooklyn, N. Y., and a few other cities cement sewer-pipe has been used, and in general all sizes of this above 12 inches—in Brooklyn all sizes—are egg-shaped. Sections of this pipe are shown in Plate VI, Figs. 1 and 2. The flat base is given the pipe to prevent its rolling in the trench after being placed in position and to strengthen the bottom against crushing.

In the case of large sewers, particularly those whose diameter exceeds 4 or 5 feet, it frequently becomes necessary to make the width greater than the height, because the depth of the invert is limited by sewer-grade requirements and the height of the arch by the street grade. A great number of shapes have been designed to meet these conditions. Some of the best are shown in Plate VI, Fig. 5, and Plate VII, Figs. 9 and 10. Plate VII, Fig. 4, shows a design for very low head-room, but the thrust of the arch is considerable and the side walls should be heavier than shown unless they are firmly backed by rock or solid earth. Plate VIII, Fig. 1, is a better design to employ where the head-room can be slightly increased.

The use of steel beams for supporting the roof, with vertical side walls, as shown in Plate VII, Figs. 9 and 10, is becoming quite common, and is probably the best construc-
tion for soft ground with limited head-room. Fig. 10 is adapted to storm-water only, or to a flow of house-sewage never less than 15 inches deep. The egg-shaped sewer in Fig. 9 is intended for the house-sewage, the larger channels for storm-water.

Plate VIII, Figs. 2 and 3, show substitutes for egg-shaped sewers where the head-room is contracted. In Fig. 3 the semicircular invert should be sufficiently deep to admit of carrying the maximum house-sewage flow, that the sloping benches may not be fouled by it. Fig. 2 is especially adapted to an exceedingly variable house-sewage flow, as from a factory district whose Sunday and holiday flow is inconsiderable.

Plate VI, Figs. 5 and 9, Plate VII, Figs. 4, 5, and 10, and Plate VIII, Fig. 1, are best adapted to storm-sewage only, although they may be used as combined-sewer mains if the depth of the house-sewage flow is never less than 4 to 6 inches at the shallowest part, and the velocity is then sufficient. Plate VI, Figs. 1, 6, 7, and 8, are intended for house-sewage only. In Fig. 7 the flat invert is permissible owing to the constant depth of the sewage flow, which consists of intercepted house-sewage from a number of residence suburbs.

Plate VI, Figs. 2 and 3, Plate VII, Figs. 1, 2, 3, 6, 7, and 9, Plate VIII, Figs. 2 and 3, are intended to act as combined sewers. In Plate VII, Figs. 5 and 6, the side bench is horizontal, that it may serve as a sidewalk for sewer inspectors and cleaners.

The circular or egg-shaped form demands for strength a solid support under its invert. Where the soil is clay or firm loam, or a mixture of these with sand or gravel, or rock easily shaped, such a sewer may be built with walls of uniform thickness, the invert bearing upon ground shaped to receive it. If the ground is not firm, however, or cannot be readily shaped, the sub-invert spaces must be filled with concrete,
brick, or stone masonry, as in Plate VI, Figs. 3, 5, 6, 8, and 9. If the arch is of such dimensions that the horizontal thrust becomes more than the soil can receive without yielding, then the side walls must be designed to receive this thrust, as in Plate VI, Figs. 5, 6, 8, and 9. The general principles of arches apply, of course, to arched sewers, one of the most important being the necessity for stiffness of the haunches.

The circle, as has been stated, is the most economic shape for a sewer when the invert requires no backing. When this is necessary, however, the circle becomes an expensive shape, and the most economic is one with vertical side walls and bottom flat or conforming generally to the shape of the trench bottom. This is seen by an inspection of Plate VI, Figs. 6 and 8, Plate VII, Figs. 4 and 10. It is for this reason that most of the flat-bottomed sewers are built. Permanency of construction demands a covering for timber platforms, which are liable to abrasion and also to rotting away if exposed as the sewer bottom. This covering, forming the sewer bottom, is usually given a curved form, as in Plate VI, Fig. 5, or a sloping one, as in Plate VIII, Fig. 1, for two reasons: to concentrate small streams and decrease deposits, and to give strength to the bottom to resist the upward pressure which will exist when the soil is soft mud, quicksand, or similar material.

The materials of which sewers are commonly composed are brick, stone, and concrete masonry, cement and vitrified salt-glazed pipe, and, under special conditions, cast- or wrought-iron or steel pipe.

Stone and brick masonry is usually built up in cement mortar, and cement is always used for concrete. The stone masonry is usually rough, but compact and well-built, rubble. In arches brick is usually employed rather than stone, as being cheaper and also stronger unless the stone are carefully dressed. The interior surface of the sewer, when this is built of stone, is usually lined
with a 4-inch ring of brick, because a brick surface can be more easily made smooth than can stone masonry (see Plate VI, Fig. 9). If much wear is anticipated smooth-dressed granite or trap blocks or hard paving brick are frequently used as invert-lining (see Plate VI, Fig. 8).

Where the foundation is yielding a concrete base is frequently used under the sewer, as in Plate VII, Fig. 8, Plate VII, Fig. 9. But if it is soft a platform or 8-inch tiles should be used under the concrete.

If arches of small radius are built of brick-work laid with radial joints much cement is used, the arch is often weak, and the inner surface a polygon in section rather than a curve, unless brick especially shaped are used. If laid well such arches are also expensive in labor. To meet these objections, which apply particularly to inverted in egg-shaped brick sewers, invert-blocks of vitrified clay have been used. There are objections to these, the principal of which is that a joint entirely through the sewer is made, and where the hydrostatic head is greatest, which is almost sure to permit the leakage of water into or out of the sewer. They are also rather expensive, and are but little used now. A section of such a block is shown in Plate VI, Fig. 11.

A better plan for constructing short-radius inverts is by the use of concrete or brick, lined on the inside with vitrified sewer-pipe split into thirds, which is approximately the arc of the small invert-circle in the egg-shaped sewer. Such a construction is shown in Plate VIII, Fig. 2. This construction is also well adapted to such sewers as are shown in Plate VII, Figs. 2, 6, and 7, Plate VIII, Fig. 3.

Vitrified pipe are used for lining to circular sewers up to 42 inches diameter, when the pipe is not used alone on account of the additional strength or tightness of joints required.

Concrete is being used extensively for sewers of 24 inches
diameter and larger, and of all shapes. Perhaps the majority are either round or "horseshoe," "basket-handle" or similar shape. A great many, especially of the larger sizes, are reinforced with steel rods, coarse wire screen or expanded metal.

Concrete pipe two to five feet in diameter is used in many cases instead of depositing the concrete in place; the pipe being generally made along or near the trench. It is frequently reinforced (there are three or four patented styles of reinforced pipe) and generally contains a mixture of one part cement and about

![Diagram of bell and spigot ends shown separately and also when placed together.](image)

**Fig. 5.—Joint of a "Lock Joint" Reinforced Concrete Pipe.**

three of sand and grit and three of 3/8-inch stone. One patented style is built of four segments or voussoirs, made in moulds and reinforced.

Concrete possesses the advantage over brick that it does not require skilled labor, and is generally cheaper; and it can be made to any desired form by using the necessary forms and centres. When well made it is equal if not superior to the best hard-burned sewer brick in resistance to abrasion in inverts. Concrete inverts at Duluth twenty years old show no appreciable wear under conditions which made it necessary to renew brick inverts in six or seven years. But the invert should be of
rich mortar—about 1:1—well mixed and troweled down smooth.

There is no fixed rule for the thickness of sewers, which depends upon the shape and diameter of bore, the material, the pressure received from the surrounding soil, and other circumstances. Brick sewers less than 30 inches diameter are frequently made about one ring—4 inches—thick; from this up to about 60 inches 2 rings or 8 inches thick; from this up to 120 inches, 3 rings or 12 inches thick. This applies to the arch more particularly, unless the surrounding ground is very firm, when the invert may be made of equal thickness, or even 8 inches thick only when the arch is 12 inches or more thick. Some engineers never use less than two rings of brick in a sewer-arch; some use one ring up to diameters of 3 feet or more. The latter may give sufficient strength against crushing, but is hardly stiff enough to resist distortion except under unusually favorable circumstances.

The thickness of the side walls, when these are vertical, must be such as to enable them to withstand the pressure of the soil without or of the water within the sewer when it is full; also to receive the thrust of the top arch when the soil is not capable of doing so. For the thickness of concrete walls there seems to be no recognized standard rule. Mr. Wm. B. Fuller's rule is: For crown and invert \( \frac{1}{12}d + 1 \) inch; for haunches, \( 1 \frac{1}{2} \) times crown; with a minimum of 3 inches for crown and 6 for invert and haunches.

Of fifteen different designs in 1909 four followed the above rule; five had the thickness \( \frac{1}{12} \) the diameter; one \( \frac{1}{12} + 3 \) inches, one \( \frac{1}{12} \); one \( \frac{1}{3} \); one \( \frac{1}{2} \); and two \( \frac{1}{4} \). One make of reinforced concrete pipe has a thickness \( \frac{1}{12} \) the diameter +2\( \frac{1}{2} \) inches.

Mr. C. D. Hill, chief engineer of sewer construction of Chicago, uses the formula \( t = 0.08\sqrt{R} + 0.1 \) ft.; which gives approximately \( \frac{1}{12}d + 1 \) in. up to 6 ft.; 8 in. for 8 ft. and 9 in. for 10 ft.

In general, reinforced concrete sewers are made as thick as
those not reinforced, and Frederick W. Taylor says (in "Concrete, Plain and Reinforced") "The use of steel reinforcement is not usually advisable under ordinary conditions, because of the cost and the difficulty of properly placing the metal." The cost of the steel in most cases might better be placed in additional concrete, unless the sewer is to be under internal pressure.

When two sewers intersect, one or both should be curved in the direction of flow of the other. If one or both are small, the curve may be made in a manhole (Plate VIII, Fig. 5). If one is many times larger than the other, the curve may be omitted, the branch making an angle of 45° with the main sewer at the junction. Where they are each larger than 30 to 36 inches diameter the intersection should be made by bringing the two barrels gradually into one. This will require considerable skill in both design and construction when the tops and inverts are both arched. When the top is a girder construction the plan is much simplified, and still more so if the bottom also is flat. The crown of the sewer a short distance below the junction should be as low as that of the lower of the two sewers a few feet above it. A plan of a junction of two circular sewers is shown in Plate VIII, Fig. 6, and another in Fig. 7 with I-beam roof construction for supporting heavy loads or where the head room is limited.

Art. 41. Pipe Sewers.

Pipe is ordinarily used for sewers up to 20 or even 30 inches diameter. Above this up to 42 inches vitrified clay pipe is sometimes used, but many engineers are doubtful of the strength of the larger sizes against crushing. The smaller sizes up to 18 or 24 inches, when made of good clay well burned, are sufficiently strong for ordinary locations, although the "double-strength" pipe (having a thickness of shell \( \frac{1}{8} \) the diameter) is recommended rather than those of the standard thickness, which is less than \( \frac{1}{2} \) the diameter by a difference which increases with the diameter.
It is probable that if this thickness be maintained the largest sizes of pipe are amply strong for ordinary circumstances.

In many instances where vitrified clay pipe has been crushed in the ground it has been found that this was probably due to the fact that the pipe had a bearing on the bottom at only one or two points instead of along its entire length, or that stones or frozen earth were thrown upon it in back-filling. If earth is well tamped under and around a vitrified clay pipe it will not usually collapse, even when broken, although it may leak. Such pipe ordinarily breaks along four lines—at top, bottom, and each side—into pieces of almost equal size. For this reason fire-cracks and slight imperfections which do not cause the rejection of a pipe should be placed at a point about 45° above the horizontal in laying, and not at the top.

Several tests have been made of the strength of vitrified clay pipe. In one series, in which the pipe were bedded in sand and the load applied to the entire length of the top,

8-inch pipe broke when the weight per foot of length was 1363 to 2256 pounds
12 " " " " " " " " " " " " " " " " " " " 1227 to 2756 "
15 " " " " " " " " " " " " " " " " " " " 1261 to 2297 "
18 " " " " " " " " " " " " " " " " " " " 1464 to 2093 "

From similar tests made in 1897 F. A. Barbour of Boston deduced the expression \( p = \frac{\pi \cdot \epsilon}{d^2} \), in which \( p \) is the pressure per lineal foot in pounds at the first cracking, \( t \) is the thickness in inches, \( d \) is the diameter in inches, and \( \epsilon = 33,000 \).

Tests made by T. H. Barnes on the strength of 12-inch vitrified clay pipe when acting as a beam between supports 2 feet apart gave the following results:

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Cracked at (Pounds)</th>
<th>Broke at (Pounds)</th>
<th>Equal to (Lbs. per Lin. Ft.)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3''</td>
<td>1100</td>
<td>2750</td>
<td>1890</td>
<td>Fire-crack</td>
</tr>
<tr>
<td>4''</td>
<td>2090</td>
<td>2000</td>
<td>1330</td>
<td></td>
</tr>
<tr>
<td>6''</td>
<td>2690</td>
<td>2810</td>
<td>1370</td>
<td></td>
</tr>
<tr>
<td>8''</td>
<td>2220</td>
<td>2450</td>
<td>1630</td>
<td></td>
</tr>
<tr>
<td>10''</td>
<td>2110</td>
<td>2535</td>
<td>1090</td>
<td></td>
</tr>
</tbody>
</table>
The Borough of Brooklyn, New York, maintains a pipe-testing laboratory, and tests all pipe used on city work. These tests have been carried on since 1906, during which time many hundred have been made. They consist of external crushing, internal hydrostatic pressure and drop-weight tests. Branches or spurs also are tested, to determine whether they are firmly attached to the pipe.

The crushing test is made by bedding the pipe in a box of sand and applying pressure by a Reihle machine, a strip of hard wood bearing along the full length of the top of the pipe being used to transmit the pressure, plaster of paris being placed between the pipe and this strip. Of over 1,000 pipes tested, the average pressure, in pounds per linear foot, required to break each of several sizes of pipes, together with the lowest and highest results, were as follows:

<table>
<thead>
<tr>
<th>Size, Inches</th>
<th>Pressure, in Pounds per Linear Foot of Pipe, required to crush Vitrified Clay Pipe.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average.</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>6</td>
<td>4,275</td>
</tr>
<tr>
<td>9</td>
<td>3,983</td>
</tr>
<tr>
<td>12</td>
<td>4,666</td>
</tr>
<tr>
<td>15</td>
<td>5,016</td>
</tr>
<tr>
<td>18</td>
<td>6,531</td>
</tr>
<tr>
<td>24</td>
<td>9,866</td>
</tr>
</tbody>
</table>

Cement pipe tested in 1909 showed average crushing pressure per linear foot as follows: 12-inch circular pipe, 2 years old, 1,983 pounds; 1 month old, 1,689 pounds. 12-inch egg shape, 1 year old, 1,911 pounds. 15-inch egg-shape, 1 year old, 1,962 pounds; 1 month old, 1,800. 18-inch egg-shape, 2 years old, 1,978 pounds; 1 month old, 1,767.

Impact tests were made by dropping a 10-pound ball from various heights onto one spot on a sewer pipe until it cracked. The specifications call for a fall of 18 inches, and at least two
blows. Under this test, in 1909, 18-inch vitrified clay pipe received 2 to 98 blows; 15-inch, 6 to 7 blows; 12-inch, 2 to 4 blows; 6-inch pipe all broke at the first blow. Complete failure required from 2 to 200 blows, combining all sizes.

The hydrostatic test is seldom used, practically all vitrified pipe successfully resisting the specified pressure of 33 pounds per square inch.

The exact amount of pressure brought to bear upon a sewer by back-filling is uncertain. For a few feet of depth it probably bears the entire weight of the earth immediately above it. With granular material the proportion of pressure to weight of back-filling probably decreases but little, while with other soils it decreases more or less rapidly after the depth equals the width of the trench. But it is probable that, while the latter material gives an almost vertical pressure, the former acts more as a fluid, pressing normally to the surface of the sewer, and is not so liable to crush it. Little, however, is known on this point. From certain experiments in which natural conditions were only partially reproduced it was thought probable that for trenches 10 feet or more deep the percentage of weight of back-filling transmitted to the sewer equalled 1—(coefficient of friction of the material); that gravel transmits 36 per cent and wet clay 65 per cent of its weight; that up to 10 feet the percentage transmitted decreased from 100 per cent as the square or cube of the depth. If the depth of covering is small there is danger that outside weight from road-rollers or even heavy wagons may crush it. But this danger appears to be very slight when the depth of covering equals or somewhat exceeds double the width of trench.

The joints of vitrified clay pipe sewers are generally made of the bell-and-spigot pattern, as shown in Plate VIII, Fig. 8. The ring-joint (Fig. 9) is not now very extensively used, as its supposed advantages are found to be largely
imaginary, while its disadvantages are not. It is almost impossible to make tight joints with the ordinary ring-joint and the expense is greater.

The joint of a bell-and-spigot pipe is made sometimes of clay, but in this country cement mortar is almost universally used. Clay has cheapness alone to recommend it as compared with cement. Other materials have been used for sewer-pipe joints, such as the Stanford preparation, a tar-and-sulphur compound. In Germany asphalt has been used for some years and good results reported. Sulphur and sand has been used in Newark, N. J.; and pitch pine tar and cement kneaded together, in Atlantic City. Most of these materials are more expensive and less durable than Portland cement, and are probably to be preferred to it only under certain circumstances, if at all.

A glazed clay pipe offers a poor surface for cement to adhere to, and consequently with it an absolutely tight joint is very difficult of construction; but if faithful care be taken with each joint a practically tight sewer is possible. But such sewers are rare. After a short period of use, however, a fairly good cement joint will become so stopped with matter strained from outfiltering sewage as to be practically water-tight. But if the head of ground-water is greater than that of sewage the flow will be inward and the joint will probably not become tighter than it was at construction. Under such conditions special precautions should be taken, such as surrounding each joint with concrete.

If much sewage leaks out through a joint there is danger that the remaining fluid will not be sufficient to keep the sewer clean of deposits. But, as just stated, such a condition seldom continues for a long time after the sewer is put into use if the joints were well made.

Several modifications of the ordinary joint have been designed to overcome this difficulty, such as grooving the outside
of the spigot end and the inside of the bell. One style of patent joint is shown in Plate VIII, Fig. 11. Such complicated joints are expensive and difficult both to manufacture and to lay, and are seldom used. If there is considerable ground-water it is better to lay the pipe as shown in Plate VII, Fig. 3, or to use light-weight or second-quality cast iron, or wrought iron or steel. Carefully made concrete or brick sewers may also be used for the larger sizes, of extra thickness to resist percolation, or water-proofed with layers of tar paper or with a surface coat of water-proofing compound.

The amount of ground-water which may leak through a cement joint depends very largely upon the shape of the bell and the manner in which the joint is made. If the annular cement-space in the bell is too small the cement is likely to be improperly compacted therein or not to enter at all at some points. Experiments seem to show that the deeper the ring of cement in the joint the less the leakage. If for any reason the cement draws away from either bell or spigot a leak is caused. Hence it seems best, particularly in wet soils, to use extra deep and wide sockets. The present standard of width is \( \frac{3}{8} \) inch for pipe from 4 to 10 inches diameter and \( \frac{1}{2} \) inch from 12 to 24 inches diameter; but “deep and wide socket” pipe are made having \( \frac{3}{8} \)-inch space for all sizes, from 5 to 24-inch. The depth of socket on “standard pipe” varies from \( 1\frac{1}{2} \) inches on 2-inch pipe to 3\( \frac{1}{4} \) inches on 24-inch. “Deep and wide sockets” are from \( \frac{1}{2} \) to \( \frac{3}{4} \)-inch deeper, and are to be preferred, in our opinion.

With poor joints the amount of leakage may be limited only by the amount of ground-water, but with the best of cement joints in very wet ground the leakage may amount to 5000 to 20,000 gallons per day per mile of sewer. In very many systems it is more than ten times this amount.

Experiment seems to show that neat Portland cement makes the tightest joints, Portland cement and sand \( 1:1 \) the next,
natural cement and sand 1:1 the next and natural cement neat the most porous joint.

Since the joint is the weak place in a pipe, the fewer joints there are the better. The expense of laying, also, is decreased by decreasing the number of joints. For these reasons the use of 3-foot rather than 2-foot lengths of pipe is advised. Vitrified clay pipes more than 3 feet long have not as yet been manufactured with success, but 3-foot lengths can be furnished by most pipe-manufacturers as the same price per foot as the 2-foot lengths. Some prefer to use the 2-foot lengths when the diameter of the pipe exceeds 15 or 18 inches, as the 3-foot lengths of the larger pipe would require a derrick for handling.

There are some advocates and users of cement sewer-pipe. The city (now borough) of Brooklyn, N. Y., used it almost exclusively for thirty-five years or more, but has laid practically none since 1905. It has the advantage over clay pipe that it can be moulded to exactly the size and shape desired, while the clay shrinks and sometimes warps in burning. It is therefore possible to obtain a sewer with a more uniform bore by using cement pipe; also to obtain the advantage (not very considerable under most circumstances) of a flat base, as shown in Plate VI, Fig. 1.

When this pipe is made of good cement and sand and this is properly proportioned and mixed it should give a material which will improve with age. It is, however, more difficult to detect the quality of a cement than of a vitrified clay pipe, and much worthless cement pipe has consequently been put upon the market. Clay pipe has a somewhat smoother surface, but this difference grows less with age, owing to the coating which forms on each.

Cement pipe weighs from 50 to 100 per cent more than clay pipe of the same diameter, and hence both freight and expense of handling are increased. Good cement pipe is in most places more expensive than good clay pipe.
ART. 42. MANHOLES, LAMP-HOLES, FLUSH-TANKS, ETC.

The purpose of manholes, as the name implies, is to give admittance to the sewers, which is necessary for the purpose of inspection and cleaning. They should therefore be sufficiently large to permit a man of average size to enter and work in them.

Manholes are in general built immediately above a sewer and leading from it to the ground-surface. In the case of some large sewers in Europe they are built at one side of the sewer and connected with it by an underground passage, the chief advantages of which construction are the greater convenience for entering and the avoiding of manhole-heads in the street-paving. But this construction is very expensive and the passage is liable to be a collector of filth.

The size of vertical manholes is usually 24 inches, although sometimes only 22 or even 20 inches, diameter at the top, increasing towards the bottom to a size in which a man can work. The least size advisable for the bottom on lines of pipe sewers is 4 feet circular or 3 feet by 4 feet 6 inches oval. In manholes of this size the ordinary operations of inspection and cleaning of pipe sewers can be carried on. There is no particular advantage in having an ordinary manhole of more than 5 feet interior diameter.

Wherever possible the sides of the manhole should be built vertical from the side benches of the bottom (ab and cd, Plate VIII, Fig. 5) to a point 3 feet above, from which point they may be brought in with a straight batter to the smaller top, which is usually circular. Where the depth of the top of the sewer below the surface is less than 7 feet this construction becomes difficult, owing to the considerable angle which the upper walls must make with the vertical. The slope cannot well begin at a lower point than that stated and leave work-
ing-room at the bottom. If the depth of sewer is more than 5 feet this difficulty can be met by arching the walls (see Plate IX, Fig. 2), which construction requires careful workmanship. An alternative method, especially adapted to a depth of less than 5 feet, is to reduce the area of the manhole near the top by an offset, using either a brick arch or an iron beam to span the offset (see Plate IX, Fig. 3). If the manhole is more than 10 feet deep the diameter should increase more rapidly for the first 3 feet down from the top, being at least 2 feet 9 inches at that depth, as otherwise descent through the shaft will be difficult.

Descent through the manhole can be made by means of a ladder or a rope, but it is customary to build steps into the wall for this purpose. These may consist of protruding bricks or stones or cast- or wrought-iron pieces. The first offer but precarious footing, cast iron is not so reliable as wrought and costs little, if any, less: the last is therefore recommended. These steps are made of various shapes. The simplest and probably as good as any is one made of a round bar bent and the ends flattened as shown in Plate IX, Fig. 4. The steps should be placed about 14 inches (6 bricks) apart vertically, and either directly under each other or alternating on each side of a vertical line, the former in narrow shafts.

Manholes oval at the bottom are well adapted to locations where there are no intersecting sewers; those circular, to points of intersection.

Where one sewer crosses another without intersecting it a manhole of special construction, permitting of inspecting each sewer, is desirable. Such a one is shown in Plate IX, Fig. 5, in which the upper sewer is continued through the manhole by an iron trough.

While at the junction of a pipe-sewer main and lateral the latter should be at a somewhat higher elevation than the former, the difference in elevation of the crowns of the two should
not exceed 6 inches. To obtain this result the lateral may, if necessary, be lowered a sufficient amount at its end by increasing the grade from the previous manhole. If this would increase the depth of excavation by more than 3 or 4 feet a drop between the sewers may be made at the manhole. This should be so arranged that each sewer will be accessible for cleaning. The drop should not be made through the shaft of the manhole, but through a small, smooth channel. A good design is that shown in Plate X, Fig. 8.

When sub-drains are laid under large sewers arrangements for cleaning them may be made as shown in Plate VI, Fig. 6, by a vertical branch opening into a manhole; or if they are under the centre of the sewer such a pipe may open into the sewer-invert, the opening being ordinarily tightly closed by a cap or plug. When the sub-drain is under a small sewer the branch pipe should lead into a manhole, opening either in the sewer-invert or, better, in the bench. In either case the opening should be plugged so that absolutely no sewage can enter it (see Plate X, Fig. 9).

Manholes of special design will be required by unusual conditions, but in all the three principal requirements of a manhole should be met: it should offer easy access for inspection and cleaning of the sewer, and ventilation of the same; it should also be so proportioned as to resist the pressure of the surrounding earth. For this last purpose the curved form is better than the polygonal.

Manholes for sewers larger than 30 to 36 inches are usually built up from the sewer-arch and have no special bottom construction. The sewer-invert under the manhole should be reinforced, however, if the ground is at all yielding. The manhole-shaft is sometimes placed on one side of the sewer both for strength and for facility of access (see Plate IX, Fig. 6).

The foundation of a manhole should be perfectly solid.
If the soil is soft a plank platform may be used. Owing to the irregular shape of the bottom, concrete usually gives better results as to strength, shape, and imperviousness than does brick-work. The bore of each sewer should be continued through the bottom by a smooth channel of uniform section and slope, either straight or with a continuous curve. This channel can be plastered with Portland cement, lined with brick or with split vitrified pipe. The last method gives the smoothest surface and is the one most likely to give a straight channel of uniform size. For curved channels, if split bends of the desired radius cannot be had, brick plastered with Portland cement is recommended. The channels should have vertical sides carried up to a point at least 4 as high above the invert as the top of the sewer-pipe, and benches should slope up to the sides of the manhole at an angle of at least 10° or 15° with the horizontal.

The manhole walls are usually built of brick, 8 inches thick from the top to a point 10 or 12 feet below the surface, and increasing in thickness with the depth. If the bottom is a circle or a well-designed oval with no radius greater than 6 feet a 12-inch wall should be strong enough at any depth, unless the ground is a quicksand or similar material or is very wet. The outside of the manhole should be plastered with cement mortar to keep out ground-water or water used in settling the trenches, and to prevent the lifting of the top foot or two by freezing ground.

In several cities manholes have been built entirely of concrete. These are generally more water-tight than brick ones, and stronger. Special forms are required for their construction.

The top of the manhole is generally capped with an iron casting sufficiently deep to permit the laying close to it of brick or stone paving. This will be about 8 or 10 inches, except where the paving is made for heavy or city traffic, where it may need to be 12 to 16 inches.
Where the street is not paved, each manhole-head should be surrounded for a distance of at least 2 feet by cobble, rubble or stone block paving, to protect both it and passing vehicles.

The cover should be sufficiently strong to support the heaviest wheel-pressure. It should be provided with ventilation-holes giving as much area of opening as possible. Its upper surface should be roughened to provide foothold for horses. It should offer as little obstruction as possible to traffic, and be practically noiseless. The ventilation-holes should be through the elevated rather than through the depressed parts of the cover, since by this construction the stoppage of the holes by dirt and snow and the entrance of dirt into the sewer are considerably lessened. Such a manhole-head and cover, as used in Brooklyn, N. Y., is shown in Plate IX, Fig. 7. Covers are sometimes provided with locks to prevent the opening of the manhole by unauthorized persons, but much trouble is in some instances caused by these locks, particularly in freezing weather. A better plan probably is to make the covers so heavy that they cannot readily be raised without the use of some strong implement adapted to this purpose.

On roads and streets not paved with hard permanent pavement, more or less dirt will be sure to enter through the ventilation-holes and if allowed to reach the bottom of the manhole will tend, particularly in small sewers, to form stoppages. To prevent this a bucket of some kind should be suspended under the holes, smaller than the manhole-opening, that the air may pass up between the bucket and the walls, or a special construction of some kind should be designed for this purpose (see Plate IX, Figs. 8 and 9). These receptacles should be cleaned before they become filled with dirt, for which purpose the removable bucket of Fig. 8 is the more convenient. The bucket supports must be so strong that the bucket cannot drop into the sewer, even when filled with dirt or ice. Another objection
to Fig. 9 is the larger amount of street-surface occupied by the iron head.

Lamp-holes may be from 8 to 12 inches in diameter and are placed vertically above the sewer. They are sometimes made by placing in the pipe-line a T branch pointing upward and resting a vertical line of sewer-pipe in it. This is decidedly poor construction, as the branch pipe is liable to be crushed by the weight. The upright pipes should be supported by a foundation of brick or concrete or the entire shaft should be of brick. The latter is much to be preferred, since the pipe construction is almost sure to be pushed out of line by the settling of the back-filling.

The foundation of a lamp-hole should be firm, the invert formed as shown in Plate IX, Fig. 11. The head it would be well to provide with ventilation-holes, but this is seldom done.

A flush-tank should be water tight. It should be so proportioned as to hold the required amount of water without increasing the head on the sewer beyond the limit set (Art. 21). The flush-tank is usually set at the upper end of a sewer-line, toward which much sewer-air rises, and the sewer should therefore be provided at that point with ample ventilation. In spite of this, many automatic flush-tanks are so built as to afford the sewer absolutely no ventilation, forcing the adjacent houses to unwillingly, and usually unknowingly, provide it. Since flushing-siphons cannot permit of ventilation through their passages, a vent should be furnished the sewer just below the flush-tank. It is advisable to combine with this a lamp-hole, as in Plate X, Fig. 1. A still better plan is to place a ventilating-manhole just below, even in contact with, the flush-tank. However, if the sewer be ventilated through house connections much of this difficulty disappears.

Flush-tanks are usually built of brick with concrete bottoms, the whole being made water-tight. Concrete would probably
be preferable in most cases, reinforced with steel rods, as this would be tighter and stronger than brick.

The automatic flushing appliances in common use act on the principle of the siphon, the variations being in the method of starting the flow. Most of those now used have no moving parts whatever, such as the Rhoads-Williams and Miller tanks. A number of other ideas have been used for flush-tanks, such as a tank on trunnions, which tips when full and returns to its original position when empty; a collapsing tube which, as the water rises in the tank, is extended upward by an attached float until it reaches its full length, when the water, still rising, overflows into and through it to the sewer, the tube meantime collapsing.

The outlet of the flush-tank should be at some elevation, the more the better, above the sewer. If no automatic appliance is used the opening of the flush-tank may be in the bottom, stopped by a plug or cap, which is raised by an attached chain when the tank is full; or it may be in the side and be opened and closed by a valve, either sliding or hinged.

If water is led to the flush-tank by a pipe this should be kept below the effect of frost, turning and rising to a higher level inside the flush-tank if necessary.

Inlets are made with and without catch-basins (see Art. 36), and the openings are sometimes vertical, sometimes horizontal, and sometimes inclined. Their purpose being to admit water from the roadway to the sewer, the opening of each inlet should be sufficiently large to admit all the water which can reach it from the heaviest rain whose run-off the sewer is designed to carry. It may be so designed that a smaller opening leading to a house-sewer shall pass the water from small rains or the first washings of a rain, while another larger one leads to a storm-sewer. The opening should be at the gutter where the water flows, and which may be slightly depressed at this point. If horizontal in the bottom of the gutter one large opening is not
DETAIL PLANS.

permissible, but smaller ones, into which neither carriage-wheels nor feet of horses or pedestrians can enter, must be used. The plate through which these holes are made must be able to support the most heavily loaded wheels which are likely to come upon it.

If the openings are through the face of the curb, in a plane either vertical or slightly inclined, they may be much larger. In some cases one large opening is used, entirely unprotected, through which children could and sometimes do fall. Except for this danger such a clear waterway is an excellent arrangement. But it is advisable to so place one or more bars across the opening as to remove the danger referred to.

The total area of opening required may be found approximately by the hydraulic formulas for flow through horizontal or vertical orifices or over weirs, as the case may be. In the case of openings less than 2 inches across in any direction an additional allowance should be made for the occasional stoppage of some of them by leaves, paper, etc. The vertical openings, being larger, are less liable to stoppage. If horizontal openings in the gutter are in the shape of slots they should run across the line of the gutter. Large gutter inlets are preferable where the water approaches with considerable velocity. Otherwise the author prefers curb inlets.

Between the openings and the sewer the channel should be straight or have as easy bends as possible, that the run-off may have an uninterrupted flow. The use of a catch-basin greatly interferes with this, the water seething and whirling in it during storms; consequently the channel connecting it with the sewer should be larger than if a simple inlet were used. In some instances a pipe leads directly from the opening to the sewer, either with or without a water-seal trap. It is better, however, to obtain a more substantial structure by setting under the opening a small basin with a curved bottom from which the pipe leads directly to the sewer. Where the
opening is horizontal the basin is desirable to support the weight which may come upon the grating and, where a trap is used, to enable it to be placed below danger of freezing. It also facilitates inspection and cleaning of the connection-pipe (see Plate X, Fig. 2). Figs. 3 and 4 show two designs for inlet-gratings, the latter particularly adapted to admitting large quantities of water.

A catch-basin usually consists of a well under the inlet-opening and below the connection-pipe to catch the heavier matters. It is sometimes placed between the inlet and the sewer on the line of the connection-pipe, and sometimes at the sewer in connection with a manhole. To be at all efficient it should extend more than 18 inches below the connection-pipe, since a heavy rain will keep the water in it so stirred up as to wash out any deposits above that point. The bottom of the catch-basin should be covered with a flag-stone or the most substantial of concrete or brick-work.

Inlet and catch-basin wells may be built of concrete or of stone, but are usually of brick. Catch-basin wells should be water-tight, that water may constantly cover the contents and lessen their odors. The gratings of catch-basins should be removable or the basins should be provided with manhole-openings and the wells be sufficiently large to be entered for the inspection and cleaning of the connection-pipes.

When the inlet-opening is in the curb, the well with its catch basin (if one is provided) is placed under the curb or sidewalk, and access to it is through a manhole-opening in the sidewalk. There is a great variety of inlet-tops for such construction, both cast iron and stone being used. The latter, where not too expensive, is usually preferable, being neater, more durable, and usually more like the contiguous sidewalk material than cast iron. A stone-topped inlet is shown in Plate X, Fig. 5, an iron-topped one in Fig. 6. In some cities reinforced concrete is used instead of stone.
Traps are frequently placed in catch-basins or the connecting-pipes to prevent the exit of sewer-air, unwisely, the author thinks (see Art. 36). The outside trap is usually a running or P pipe trap. Many varieties of inside trap have been designed, both fixed and movable. The former should not prevent access to the connection-pipe and hence should be at least 15 inches from its opening. Traps with movable parts should be as simple as possible in construction and any trap should compel the outflowing water to make the least possible number of angular changes of direction.

Instead of placing a catch-basin at each inlet it is sometimes preferable to place silt-basins along the line of the sewer at intervals of 1000 feet or more, with a manhole over each for ventilation and cleaning. These are particularly applicable to flat grades of storm sewers in the separate system. They consist of an enlargement of the sewer, and a depression of a foot or more in its invert, into which the heavier silt is washed, and from which it can be removed more easily than when deposited along a stretch of sewer. These, however, should not be used to encourage deposit, but only when deposits would occur along the sewer if they were not provided. Their advantage over inlet catch-basins is that the odors reach the outer air further from pedestrians, and that the difficulty and cost of cleaning is not so great. They should be used in sewers which carry house-sewage in exceptional cases only. Inlet catch-basins are generally preferable on lines of combined sewers where much heavy dirt reaches the inlet, or on storm-sewers where such dirt is washed in in very large quantities.
Art. 43. Interceptors and Overflows.

The best form of interceptor to be employed is determined largely by the character of the system at the point of interception. If the house-sewage is to be intercepted from tributary sewers which originally discharged into a near body of water, the interceptor shown in Plate XI, Fig. 1, may be used. This "leaping weir," it is believed, was first used by Baldwin Latham about 1876. The exact length of opening required in the invert can be only approximately determined. It may be made smaller than is thought necessary and cut to the right size, which is ascertained by trial, after the sewer is in use. It will also probably be desirable to increase the length from time to time as the amount of house-sewage increases. The principal objection to this form of interceptor is that, although the storm-water may leap the opening, much of the sand and other heavy matter carried along the invert of the combined sewer will fall into the small intercepting sewer and may be deposited there.

An interceptor which meets this objection, but which may more properly be called a divertor, is shown in Plate XI, Fig. 2.* The flap-valve shown is closed by the rising of the float, which occurs when the amount of sewage becomes greater than it is desired that the house-sewer carry. The joints of the mechanism should be of bronze. A sewer does not offer the best conditions for the continued proper working of any mechanism therein, but one so simple as this should give little trouble in its maintenance. Several other designs of automatic mechanism for accomplishing this purpose have been employed.

* See Engineering Record, vol. xxxii, p. 41.
When a sewer, because of improper designing or of changed conditions, becomes too small to carry all the sewage coming to it, the excess above its capacity may be diverted to and carried by a relief-sewer or -sewers. A relief-sewer may cross under and receive the excess from several gorged sewers, or a single sewer may overflow into several relief-sewers placed at intervals along its length and leading to near-by outlets.

An outlet sewer-main to combined sewers is sometimes provided with overflow outlets at several points to avoid increasing the size of the main beyond the smallest necessary dimension, which is usually that which will carry sufficient storm-water to afford such dilution to the house-sewage as will render it unobjectionable to discharge this into an adjacent stream. The diversion into such a relief-sewer or relief outlet is ordinarily made by means of an overflow, constructed as shown in Plate XI, Fig. 3, or as in Fig. 4, where the relief-sewer was constructed after the smaller sewers had long been in use.

**Art. 44. Inverted Siphons; Sub-drains; Foundations.**

Inverted siphons are usually circular in section, since always flowing full; usually of metal, since always under pressure, although the metal may be lined with brick or other material. The size required has already been referred to. When laid under water they should be so weighted or covered with earth or stone as to prevent their floating when pumped empty for inspection or cleaning, and should be absolutely tight. The inverted siphon is made sometimes to slope from both ends to a point near mid-length, sometimes with a vertical drop at one end, sometimes at both ends. The first should be adopted only when the siphon is sufficiently large
to permit the entrance of a man. When not of such a size it should be straight from end to end. This will usually require a shaft at one, sometimes at each, end, which may also serve as a manhole. It is in most cases advisable to place a catch-basin at the foot of such a shaft, although in place of this a basin in the bottom of an enlargement of the sewer just above the siphon is sometimes employed. A siphon with catch-basins is shown in Plate XI, Fig. 5, the valves on the ends of each siphon-pipe permitting either siphon to be closed to sewage and pumped out for inspection, while the other is in use.

Unless a siphon under water is of large size and in tunnel or laid in a trench in a rocky bottom it should be protected from undermining by currents, or movement by shifting bottoms or channels. This protection is usually afforded by driving a row of sheet-piling on each side of the pipe, the space between these being in most cases excavated and filled with concrete. The softer the material in the bottom and the stronger the currents the deeper the sheeting should be driven. If the bottom is too hard to permit of driving sheeting, large stone rip-rap may be placed on both sides and over the siphon.

A sewer must sometimes pass either under or over an obstruction—such as a water-main, another sewer, etc.—by a siphon, either inverted or erect. The latter requires greater care in construction and constant attention to maintain a vacuum at the summit, and the former is in the majority of cases the preferable construction. Such a siphon is usually a few feet in length only and under but little head. A manhole should be placed over or near it when the sewer is 24 inches or more in diameter, since it will probably need more frequent cleaning than the other parts of the line. If the sewer is less than 24 inches diameter a manhole should be
placed at the upper end of the siphon (which should be straight from end to end), and at the lower end also, although a lamp-hole may be substituted here if the siphon is not over 150 feet long, and makes only an angle and not a vertical rise at this point. For such a case see Plate XI, Fig. 6.

Sub-drains are placed either directly beneath the sewer or at one side of the trench. When there are no artificial foundations under the sewer the latter position is to be preferred, but is in some instances much more difficult and expensive, particularly in quicksand. The sub-drain should be surrounded with broken stone or clean gravel, varying preferably from the size of a hickory-nut to that of a pea. There should be at least 3 inches of this under the drain and 6 inches at its sides and top. In quicksand or similar material these dimensions should be increased 50 to 100 per cent. This stone should be well compacted to prevent future settlement. The joints of the drain should be slightly open and a 5- or 6-inch strip of cheese-cloth or burlap wrapped around the pipe at the joint to keep out the dirt. Or, if bell-and-spigot pipe is used, a piece of jute may be calked loosely into the joint for this purpose.

If a sewer were laid directly over this there would be danger of a settlement of the same and of leakage resulting. For this reason the sub-drain should be laid at one side of the trench when the soil is firm, as in Plate XI, Fig. 7. In quick or running sand this is practically impossible unless the trench is very wide or unless close sheathing be driven on each side of the sub-trench and carried below its bottom; such sheathing not to be removed after the sub-drain is laid. It would usually be better and cheaper than this to lay the sub-drain in the centre of the trench (which must of course be close-sheathed in quicksand), and on the stone filling, when levelled off, to place a continuous platform on which to lay the sewer. Such construction is shown in Plate XI, Fig. 8. A still
better construction in any but firm soils is to lay a pipe sewer in concrete, as in Plate VII, Fig. 3. Where a foundation is necessary for the sewer the sub-drain construction is easily arranged. See Plate VI, Fig. 6 and Plate VII, Fig. 10.

The sub-drain should be laid to grade as carefully as the sewer itself. It is seldom that a sub-drain can be so arranged that inspection can be made of it, and therefore perfectly straight alignment is not necessary; but there should be no sharp angles in its line, which might cause obstructions or interfere with the future cleaning of it. If cellars and basements are to be connected with this drain, Y branches should be inserted to permit of such connections, and should be covered similarly to the house-sewer branches.

When house or combined sewers are placed with their tops more than 4 or 5 feet lower than the average cellar depth in that locality it is advisable to place a standing house-connection above each branch, bringing it to within 3 to 5 feet of the average depth of the cellar bottoms, but stopping at least 7 or 8 feet from the surface. This is to avoid compelling each householder along the line to dig down to a deep sewer branch in order to make a connection. These standing connections are built while the sewer-trench is open, and are covered at the top with a cap or cover similar to house-branches. They should not merely rest in the branch, but a foundation of concrete or brick masonry should support each. The vertical pipes should be held in place during back-filling, as by stakes driven into the bank. In the case of a rock cut, or where the banks are not firm, the standing connection may be inclosed by a vertical trough of planks, between which and the pipe earth is packed, this trough being held firmly in place until the trench is filled and tamped. If the banks are liable to cave, sheathing should be driven at each such connection, and neither it nor the braces removed when the trench is filled. A standing house-connection in firm soil is
shown in Plate X, Fig. 7. One in a rock cut is shown in Plate XI, Fig. 9.

A sewer in soft soil, like any other structure, requires a foundation. Since the weight is not comparatively great the service of the foundation is more often to distribute the pressure and prevent local settling or heaving than to prevent the subsidence of the sewer as a whole. This purpose is usually achieved by use of a cradle (Plate VI, Fig. 4) or a platform of plank (Plate VI, Fig. 5), the former in comparatively firm soils like damp sand or loam, the latter in swamp-muck, quicksand, etc. Where muck or other soft, water-sogged soil is encountered it may be necessary to drive piles and rest a timber platform upon these. Such a foundation is shown in Plate VI, Figs. 3 and 6. Where a platform is used it is necessary to fill the sub-invert spaces of the sewer with masonry. All sewers in soft soils should have their inverts arching downward to resist the upward thrust of the ground between the side walls, since the weight of the masonry is largely concentrated in these walls.

In rock excavations no part of the pipe sewer should come within 6 inches of the rock bottom, and the space between this and the sewer should be filled with sand or other soil which compacts readily, which should be thoroughly tamped to prevent settlements of the invert; or the pipes should be bedded in concrete, in which case the rock may be taken out only to the underside of the pipe. If the sewers are built of masonry this should be carried to rock everywhere under the invert.