weight of the finished sewer. Of course, if the tunnel is of considerable diameter there is difficulty in a pressure sufficient to keep the bottom in place being too strong for the top and causing blow-outs and a general lowering of pressure. This is more apt to occur in sand, however, and it may then be necessary to use a shield with separate compartments.

Tunnelling in Sand and Gravel.—In another instance about 1,500 feet of 4-foot diameter sewer lay below a street along which ran four lines of rails. Several engineering works had frontage on these streets and much heavy freight traffic passed along the rails. Coarse sand and gravel containing a varying quantity of mud was found here, but although much charged with water, it drained freely. Undoubtedly this ground would have lent itself to cap-and-leg tunnelling had it not been for the hammering action of the trains above a cover of 15 feet. A brick-lined tunnel would have necessitated dependence on the timbering alone for too great a time, and in consideration of the danger to traffic that might arise through any subsidence, it was decided to build the sewer in iron.

A great quantity of water drained into the tunnel and in places the gravel was overlaid with a bed of earthy mud containing decayed vegetable matter. This loose top became exceedingly troublesome during a spell of very wet weather, and to combat the difficulties it presented the method of timbering shown in Fig. 3 was adopted. The peculiarity of this system lies in the iron rib used as a temporary support for the head piles.

Assuming the length has been taken out for two rings, the procedure is as follows: The three lower plates for two rings are bolted in position and the piles are driven over the iron rib under the cross-head tree and raking side trees round the top. The remaining plates of the two rings are keyed up, the leading ring gripping the ends of the piles and thus relieving the rib which may then be taken down. One face leg at a time can now be taken down and, after excavation, re-erected on a foot block under shelter of the piles. The lower half may be either poled circularly with horizontal boards or piled vertically.

Erection of Iron.—As all plates weighed about 300 pounds, or under, no difficulty was experienced in handling them and no special appliances were used. In getting in the key it was usual to put the upper plates in position and, while they were lightly held by their bolts, a screw jack 8 in. long was inserted in the key space and used to press them outwards. Then they were bolted tightly and, on withdrawing the jack, the key could be pushed up from below. By easing the upper plate bolts these plates came inwards and gripped the key when all bolts could be tightened up. Each wooden packing slip was tied to its flange by strings through the bolt holes to keep it in position till in place.

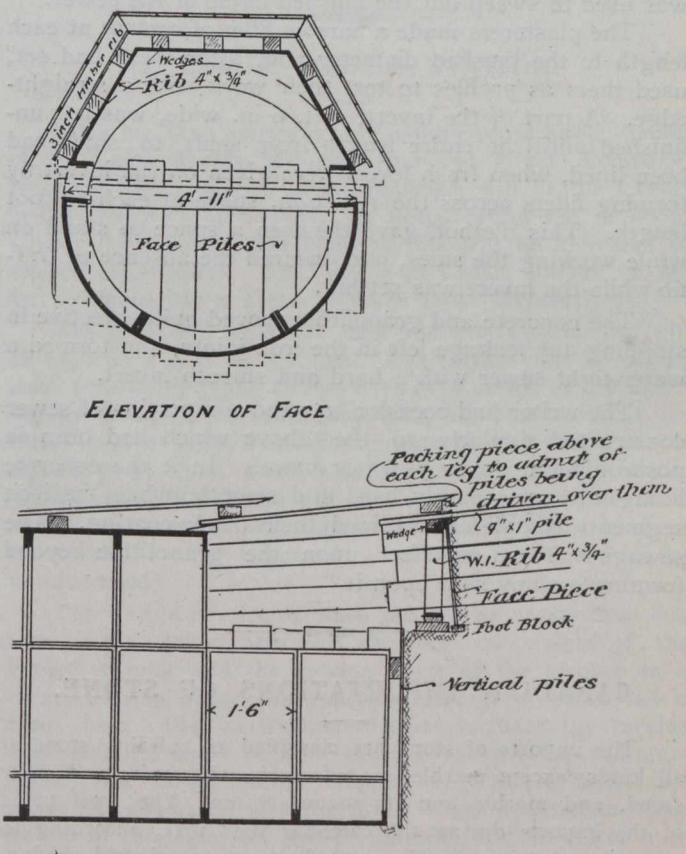
Pressure Grouting.—After erecting from eight to ten rings the face was poled up while these rings were grouted with lime under a pneumatic pressure of from 30 to 40 pounds per square inch. Air for grouting was supplied by small compressors used for this purpose alone. The usual type of grouting pan with paddles was used, its diameter being 1 ft. 6 in. and its overall length 3 ft.

In small tunnels a very low truck or bogie should be provided for the pan, to give free room above for filling in lime quickly as it is important to do this with all speed, for the lime that was used set very quickly.

The quantity of lime varied very much, according to the ground and the method of tunnelling it.

In grouting rings 6 ft. 5 in. diameter which had been driven through clay with timbering, only two to four bags of lime were necessary, but no less than eight were used for each ring (5 ft. 5 in. external diameter) in the timbered excavation through sand and gravel. As all water from the face drained over the lower plate to the shaft, it was difficult to locate open joints before grouting, and a certain quantity of grout found its way back into the tunnel through the lower joints.

Lining With Concrete and Granolithic.—When the tunnels had been driven through from shaft to shaft, all dirt was removed from between the flanges. This, of course, meant lifting and re-laying the rails.



ELEVATION OF FACE

LONGITUDINAL SECTION

Fig. 3.

The lining concrete consisted of one part cement, two parts sand, and one part whinstone or chert, broken to pass through a 1¼-inch diameter ring.

Starting from a point midway between two shafts, the bottom plate was fitted, the road being lifted but not the rails. This occupied a few days, by which time the concrete in the mid-length had set hard. A length of rails (12 feet) was lifted at the mid-point and fresh concrete laid on, bringing the surface up to 1 inch below water-run. Laggings 3 inches thick were laid upon this, and circular iron ribs erected on these laggings, the ribs being kept in position by distance pieces from the flanges. Above the bottom plate concrete was packed in as each lagging was run in from the end, until the key was reached, when block laggings were used, the latter being of varying width, to give greater freedom at cross-flanges. The block laggings were 1 ft. 6 ins. long and were placed transversely to the axis of the tunnel and rested on the two last longitudinal laggings which were grooved to receive them.

This method was very successful, there being but few defects or vacant spaces in the concrete when the