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“The Formation of a Concrete Well-Lining by Cement-Grouting Under Water.”

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THE work described in the following Paper illustrates one of the almost innumerable uses to which Portland-cement grout may be put. The method of carrying out the work was partly suggested by the Paper¹ on “The Use of Cement Grout at the Delta Barrage in Egypt,” by Sir R. Hanbury Brown, K.C.M.G., M. Inst. C.E., read before the Institution in 1904.

About 5 years ago the Kidderminster Corporation decided to increase their water-supply, and a new well about 10 feet in diameter was sunk to a depth of 50 feet, the last 35 feet being through New Red Sandstone rock, *Figs. 1*. From the bottom of this well a bore-hole 20 inches in diameter was carried down for a further depth of 250 feet, and a plentiful supply of water was obtained. Steel tubes, 8 feet in diameter and 8 feet in length, were provided for lining the upper portion of the well. For various reasons it was then decided to postpone the completion of the scheme, and the matter remained in abeyance until the beginning of 1905, when it was decided to proceed with the erection of new pumping-plant, etc., and to utilize the above-mentioned well and steel lining. The well is situated not far from the River Stour, and the surrounding ground is saturated to a level of only a few feet below the surface, the level varying of course with the state of the weather. A centrifugal pump which had been originally installed to deal with this surface-water had been left in the well and had consequently become so badly corroded as to be useless when work was recommenced; pulsometer pumps were therefore requisitioned. The old timbering which supported the top 15 feet of gravel and soil was also in a very bad state, and had to be renewed. In the top of the bore-hole at the bottom of the well a cast-iron pipe had been inserted

¹ Minutes of Proceedings Inst. C.E., vol. clviii, p. 1.

Figs. 1.

and fitted with a plug, through which a 6-inch pipe was taken up the well to the surface of the ground, the water from the bore-hole rising in this pipe to an average level of 5 feet above the level of the surrounding surface-water, although on Sundays (owing no doubt to the cessation of pumping in a number of other wells in the district, from which water is drawn for manufacturing purposes) it often poured out of the top of the 6-inch pipe at a level above the surface of the ground. It is therefore clear that the surface-water cannot contaminate that which is tapped by the bore-hole at a depth of 300 feet. As the surface-water is liable to a considerable amount of pollution, it was essential that the steel tubes forming the lining of the well should be absolutely water-tight, and as they were also intended to support the pump-barrels it was considered necessary that the space surrounding the tubes, between them and the rock sides of the well, should be firmly packed with concrete. The construction of this concrete presented difficulties, as it was found when the well was emptied that a large quantity of water exuded from the rock, chiefly in small jets from fissures, the force of the jets becoming very considerable towards the bottom of the well. To place concrete between the rock and the steel tubes in the ordinary way was impracticable, as the cement would have been carried away by the moving water.

It was therefore decided that the space surrounding the tubes should be packed with gravel as the tubes were fixed in position, and that this gravel should be subsequently converted into concrete by grouting with liquid cement when the water should have been allowed to rise to its natural level in the well, and would therefore be at rest.

A concrete floor was formed while the well was kept dry by pumping, and the bottom length of tube was then lowered into position. The space outside the tube was then packed with gravel, and the remainder of the tubes were placed in position one above the other, the space surrounding each tube being packed with gravel. The pump was drawn up as the work proceeded, the water being allowed to rise so that the level was kept just below each joint as it was being made. As the gravel packing was put in, six columns of 4-inch earthenware pipes, perforated with $\frac{1}{2}$ -inch holes, were placed in it at equal intervals around the well, the object of these pipes being to facilitate the subsequent grouting process. In order to ensure these columns of pipes being kept vertical while the gravel was being packed round them, a wooden rod was inserted in each, and fastened by clips to the top edge of each steel tube in turn, the rods being drawn up and refixed in position when the next

tube was lowered. This process was continued until the steel lining had been completed to a level above that of the surface-water in the ground, the whole space between the steel and the rock being packed with gravel. The water in the interstices of the gravel was now at rest, the jets which had previously issued from the rock being neutralized by the pressure of the water in the gravel. It was arranged that grout should be poured down three of the earthenware pipes, the other three being used to contain floats, which consisted of wooden blocks adjusted by means of lead weights, so that they would float in cement-grout, but would sink in water. A line was attached to each float and was passed over a small pulley fixed on the top edge of the steel lining, a small balance-weight being attached to the other end, which hung down inside the well. The purpose of the floats was to indicate, during the process of grouting, the exact level to which the grout had risen in the interstices of the gravel. As the float-pipes were at the farthest possible distance from the grouting-pipes, the rising of the floats also indicated that the grout had spread through all parts of the gravel. For the actual process of grouting, a rough timber stage was constructed at ground-level, across the top of the well, and on this was placed a tub about 2 feet in diameter and 2 feet in depth, *Figs. 1*. Three india-rubber hose-pipes, each $1\frac{1}{2}$ inch in diameter and 50 feet in length, were led from the bottom of this tub down the three grouting-pipes, and the grout was poured into the tub by means of buckets, after being mixed by hand in iron troughs placed near. The grouting was continued without intermission, and occupied 12 hours. To avoid any possibility of the hose-pipes becoming choked, the grout was all poured through a fine sieve placed on the top of the tub, and little difficulty was experienced in getting the grout to flow regularly. As the surface of the grout rose in the interstices of the gravel, the hose-pipes were continually shortened by cutting off about 3 feet at a time, so that the grout might be delivered from their ends at or near the surface between the grout and the water, and so that any disturbance of the grout already in position might be avoided. The grouting-pipes were 10 feet apart, so that the grout had to travel 5 feet through the gravel in each direction to reach a float-pipe, and in order that there should be no difficulty in this the gravel was all screened, only that being used which was retained on a screen of $\frac{3}{4}$ -inch mesh. As a result it was found that the floats rose quite uniformly, and that there was hardly any appreciable difference between the levels of the grout in the float-pipes and in the grouting-pipes. There is therefore little doubt that a considerable admixture of finer gravel

might be retained with safety, thus effecting a considerable saving in the cement required to fill the interstices. The volume of the space surrounding the tubes was carefully measured before being packed with gravel, and this was checked by taking notes of the amount of gravel used, the quantity being 54 cubic yards. The interstices in the screened gravel were found by experiment to amount to 39 per cent. The total volume of water in the gravel was therefore 39 per cent. of 54 cubic yards, *i.e.* 569 cubic feet. It had been previously found by experiment that one volume of cement (shaken together in its dry condition) mixed with one volume of water formed $1\frac{1}{4}$ volume of grout, which finally set to a block whose volume was almost exactly 1, *i.e.* the original volume of the dry cement, the surplus water remaining uncombined. The volume of cement actually used in grouting the gravel was 587 cubic feet, making, when mixed with water in the ratio of 1 to 1 by volume, about 750 cubic feet of grout; the volume to which this grout finally set being 569 cubic feet, plus a small quantity which would no doubt enter the small fissures and holes in the sandstone rock, the actual result is seen to agree closely with that obtained by experiment. On account of the shrinkage in setting (namely from 750 cubic feet to 587 cubic feet) the level of the grout as indicated by the floats had to be brought sufficiently high above the required finished level to allow the settlement to take place, the extra height necessitated being about 8 feet. The surface of the water during the process of grouting was 8 feet above the top of the gravel, which was at the finished level required. As the whole of the ground surrounding the well was subsequently excavated to this level for the purpose of constructing engine-foundations, it became possible to examine the top of the concrete formed in this way, and it was found to be perfectly satisfactory. No doubt the concrete formed at the bottom under a head of nearly 50 feet of water would be still stronger.

It may be mentioned that it was found by experiment that in whatever proportions cement and water be mixed (provided there is sufficient water to form liquid grout), the amount of water finally taken up by the cement is always approximately the same, and the volume of the material when set depends therefore only on the amount of cement used, not on the quantity of water mixed with it, the final volume of the cement when set being approximately equal to the volume of the cement when shaken together in the dry condition. When, however, cement is mixed with the minimum quantity of water, say 20 per cent. of its original dry volume, it sets to about 75 per cent. of the original volume, and it is therefore to be

expected (as indeed proves to be the case) that grout when set, although quite satisfactory for such work as that described in this Paper, should not be as strong as cement mixed with a minimum quantity of water, as the same quantity of cement sets to a volume 25 per cent. smaller in the latter case than in the former.

The Engineers for the work were Messrs. Willcox and Raikes, for whom the Author acted as Resident Engineer, and to whom he is indebted for permission to publish the information contained in this Paper. The contractors were Messrs. T. Vale and Sons, Limited.

The Paper is accompanied by a tracing, from which the Figure in the text has been prepared.