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The Consolidation of Sand and Gravel Foundations by Injections.

Verfestigung von sandigem und kiesigem Baugrund durch Injektionen.

Consolidation, par injections, de sols de fondations sableux et graveleux.

P. Bachy,
Ancien élève de l'Ecole Polytechnique, Kremlin-Bicêtre (Seine).

Sand and gravel soils are often considered as poor foundations on account of their instability and their tendency to settlement. For some years past specialists in injection have been concerned with improving the quality of such ground and have obtained remarkable results. These results are of course better with gravel than with sand, and where the granulometric composition of the gravel approaches more nearly the optimum granulometric composition for concrete aggregates.

In practice the granulometric composition of a concrete is never that which corresponds to the theoretical best, because regard must always be had for the materials that happen to be available. Very often, especially where it is a question of making a large mass of concrete in a foundation, the practice is simply to utilise the material dredged at random from (for instance) the bed of a river.

If, now, a bridge is to be built in that particular river, why found the piers by opening out a hole, dredging out the material, passing it through a concrete mixer, and putting it back again in the hole as concrete? The same thing can be carried out *in situ* by injecting cement, and the economy so realised will be considerable; moreover the concrete will be technically better in quality because the penetration of the cement into the voids of the aggregate is improved in proportion to the pressure at which it is effected.

It may be stated that whenever a material has a granulometric composition such that an acceptable quality of concrete can be made from it in its random form, a still better concrete might be formed by mixing it in place and injecting cement under pressure. Certain engineers have disputed this claim, and in fact certain tests have been misleading on the point, but that is because the tests were based on inadequate technical knowledge.

The essential condition for success is to work within an enclosed space, for otherwise the cement will always endeavour to escape by the line of least resistance and will not uniformly impregnate the aggregates which are to be formed into concrete. Where pile driving is possible the enclosure may with advantage be formed of a screen of sheet piles; in other cases it oan be formed less accurately but sufficiently well for the purpose by making injections at very low pressure into bore holes sunk very close to one another around the whole of the periphery of the ground to be treated, and in this way there is formed a kind of cofferdam free from any appreciable gap, which practically takes the place of a surround of sheet piling. It is true, of course, that the formation of such a cofferdam entails some loss of cement, but the example of work carried out under difficult conditions which is about to be quoted that such losses are relatively small and do not condemn the process.

This example was concerned not with an aggregate of sand and gravel but with a sand containing a superabundance of very fine grains. The following is an outline of the problems which arose: —

At Elne in the French Département of Pyrénées-Orientales the national road from Paris to Barcelona crosses a small river of torrential nature, the Tech, and the masonry bridge which is about 150 years old has a number of piers standing in the river. These piers rested on a foundation of limestone concrete which in turn was carried on old piles. Both the concrete and the piles had in fact practically disappeared, depriving the piers of almost any support other than the sand of essentially fluid nature which forms the bed of the river. Between November 14th and 21st 1932 heavy and persistent flooding of the Tech caused a dangerous settlement of the foundation under piers Nos. 2 and 3. Under the downstream end of the base of pier N° 2 the eddies had swept out a cavity 3 m deep which was filled with mud, and considerable settlement of the pier had occurred causing fracture of the arch connecting it with pier N° 1.

Pier N° 3, on the contrary, had been undermined by 4 m vertically under its upstream end and miscellaneous materials were 1.5 m below the pier itself. Very considerable settlement of this pier ensued, more on the upstream than on the downstream side, and the overturning movement was accompanied by a slight slip of the whole pier downstream, causing dislocation of the two arches abutting on it.

Various proposals for repairing the Elne bridge were examined, and the one decided upon as being at once the most practical and the most economical was to inject cement under pressure.

The repair of the masonry roadway will be of no interest to steelwork engineers, and without going into details of the repairs to the foundations of the two piers which had undergone settlement it may be stated simply that they were carried out in two successive phases as follows: —

1) Around each pier, at a distance of about 2.50 m from the outside face, an enclosure was built in the form of a line of vertical bore holes close together into which an artificial cement grout was injected at low pressure, the usual

mixture being one part of cement to one part of water. (The enclosure could not have been formed of sheet piling as the presence of the bridge made it impossible for piles to be driven.)

2) Within this enclosure, underneath the pier, injections were made of cement under high pressure. Of course no pretence could be made of transforming the substratum sand into concrete, or even into mortar, but the intention was simply to impregnate this material with cement in order to increase its strength and make it more difficult to erode.

The operations were entirely successful, and since their completion three years ago the work has remained perfectly stable in spite of renewed floods.

While all gravels (provided they do not contain foreign matter), and even many kinds of sand, can be penetrated by cement in such a way as always to produce concrete or some material of more or less suitable properties, this is not true of certain particularly fine sands. As regards these last, the practitioners of injection have been engaged for some years in an endeavour to find an alternative, and by new means of the silicating processes they have succeeded in "petrifying" quicksands.

The author has carried out very far reaching investigations and laboratory experiments, with particular reference to the Ypres sand which forms the subsoil of Brussels, as a result of which he has obtained complete success in agglomerating them and in converting this inconsistent material, the terror of Brussels architects, into good foundations.

As another example of silication of fine sand, mention may be made of works now in course of execution for founding the piers of the Neuilly bridge over the Seine near Paris.

In conclusion, engineers may be asked not *a priori* to reject subsoils as unacceptable for foundations because they are gravelly or even sandy. Before embarking on serious operations — such as lowering the water level, freezing, use of compressed air caissons, or even pile driving — bore holes should be sunk and laboratory experiments undertaken with a view to ascertaining whether the ground cannot be dealt with by injection. More often than not injection will prove to be the economic solution and the commonsense solution, for, generally speaking, nature has done her job well and only requires to be reinforced in certain places. Injections accomplish nothing that is sensational; they serve merely to improve, more or less appreciably, the existing qualities of a foundation subsoil — and generally that is all that is required.