COMPACTION GROUTING FOR BUILDING PROTECTION

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Abstract

Compaction grouting has been adopted in contracts CH218 and CH221 as a method for building protection. This paper reports the results of trials performed and discusses factors affecting its performance. Data indicate that, in soft clays, although compaction grouting was able to heave up the ground during the operation, the subsequent dissipation of porewater pressures led to settlement which was equal to or even greater than the heave. In sands, a large amount of grout was required for the heave to be significant.

擠壓灌漿與建物保護

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摘　要

擠壓灌漿是一種建物保護之新工法。台北捷運系統新店線218標及221標擬採用擠壓工法以作為其建物保護之方案。目前並完成試灌以驗証其效益。本文就試灌結果進行分析、並討論影響其成效之因素。資料顯示、在軟弱黏土層中施作擠壓工法雖可導致隆起、但因孔隙水壓之消散所有隆起量在一週內即消失殆盡。在砂土層中則須注入大量漿材方可達到隆起之目的。

I. Introduction

Compaction grouting is a very new technique with very little experience to guide the design and operation. This is particularly true in Taiwan where no case histories have been reported. The principle of compaction grouting is very simple - inject a certain amount of solid into the ground to heave up the desired portions of a structure so the stresses induced in the structural members as a result of ground movements can be relieved. It can be used in other ways, such as underpinning, ground improvement, etc. as well. However, in the opinion of the authors, these applications are not the principal functions of compaction grouting and there are other techniques, such as micropiling, jet grouting, chemical injection, etc., which can do a better job.

II. Trial Grouting for CH218 Contract

Trials were carried out in four grouting holes (GH), namely, GH- A, B, C and D. As shown in Figs. 1 and 2, GH-A and B were inclined holes with an angle of 15 degrees from the vertical, and GH-C and D were vertical. GH-D was located at a distance of 3m from an excavation to see the effects of grouting on struts while all other three were located in free fields with level ground.

A. Grout and Grouting

The composition of the grout was as follows (per cubic meter) :

Gravel (2 to 10 mm in size)	320	kg
Silt & Sand (2 mm or less in size)	1040	kg
Portland Cement	160	kg
Water	426	kg

The grout, with an average slump of 25 mm was injected into the ground by pressures up to 40 bars. In each hole, 20 bulbs were formed at 0.5 m intervals with a volume of grout of, roughly, 134 liters in each bulb. For a few bulbs, the volume of the grout was slightly less because the grout pressure exceeded the pre-set limit of 40 bars and/or the heave exceeded the pre-set limit of 5 mm per bulb. The total volume injected in each hole was about 2.5 cubic meters.

B. The Results

The measured ground heaves for all the four holes are shown in Figs. 1 and 2. The recorded maximum heaves were 15 to 30 mm and the influence extended to a distance of 4 to 5 m from the locations of the holes. The heaves were smaller for the case of GH-D, conceivably, due to the lateral movement of the diaphragm wall.

The heaves measured at a point which is 1m away from GH-C are shown versus the progress of grouting in Fig. 3a. As can be noted that: a) the heave was un-noticeable when grouting was carried out in sands, and b) the heave was much larger when grouting was carried out in the clays. This might give a false impression that it is more effective to grout in clays than in sands. More discussion will be given in Section IV.A.

For the case of GH-D, the increments in strut loads were 7 tons for the second level strut and 7.7 tons for the third level strut. These values are insignificant in comparison with the design loads of the struts. As shown in Fig. 2, at the time GH-D was grouted, the bottom of excavation was at a depth of 10 m and three levels of struts were in place. Adopting the idea of apparent pressures, a value of 0.4 t/m2 was back-calculated from the above-mentioned load increments in struts. It should be noted that grouting was carried out at a distance of 3m away and the influence would have been greater if the distance were smaller.

III. Trial Grouting for CH221 Contract

Grouting was carried out in three holes, namely, GH-1, GH-2 and GH-3. GH-1 and GH-2 were vertical holes and GH-3 had an inclination of 25 degrees from the vertical. All the three holes were sunk in free fields.

A. Grout and Grouting

For GH-1 and GH-2, the grout used was similar to that used in the trials in CH218. Grouting started at a depth of 18 m and continued to a depth of 2 m. There were a total of 32 bulbs with a volume of grout of 134 liters each, giving a total quantity of grout of 4.3 cubic meters.

For GH-3, the slump was increased to an average of 60 mm by adding bentonite and more water so more grout can be injected. Grouting was carried out in a pressure-control mode. Instead of keeping a constant volume for each bulb, casing was lifted only when the pressure exceeded 60 bars regardless of the amount injected. Between the depth of 13 m and 8 m, a total volume of 7 cubic meters was injected, giving an average intake of 1400 liters per meter which is 5 times greater than the intake (134 liters x 2) for all other holes.

B. The Results

The heaves of a point which is 1m away from GH-1 is shown versus the progress of grouting in Fig. 3b. Similar to the case for GH- C, heaves were insignificant when grouting was carried out in sands. In fact, the patterns of the two curves shown in Fig. 3 are almost identical. The profile of the heave shown in Fig. 4 is also similar to that for GH-C shown in Fig. 1.

The lateral displacements of an inclinometer installed 2m away from GH-1 are shown in Fig. 4. The maximum displacement exceeded 40 mm, much greater than the maximum heave recorded at surface. This might be due to the anisotropy of the clays. Sedimental deposits usually are weaker against horizontal loading.

The heaves for GH-2, as shown in Fig. 5, were smaller in comparison with all other cases for unknown reasons. The peak was only 6 mm. The lateral displacements of an inclinometer installed at a distance of 1m away, however, were greater than those obtained for GH-1, conceivably, due to smaller distance to the grouting hole.

For GH-3, grouting stopped below the clay/sand interface and the heaves were only a few mm despite the larger quantity of grout injected.

IV. Factors Affecting Performance

As mentioned previously, the purpose of compaction grouting is to jack up the portion of the structure where the settlements are the most severe so the stresses in the structural members can be relieved. The two basic requirements for this to be achieved are: a) the heave must be significant and permanent, and b) the heave must have a smooth profile to avoid localized stress concentration. The various factors affecting the performance of compaction grouting and measures for improvement are discussed in the following sections.

A. Soil Type

It is apparent that compaction grouting works better in incompressible media. For short-term loadings, clays are incompressible because of their low permeability disallowing volume changes and in the two trials mentioned above, more heaves, in comparison with grouting in sands, were indeed obtained during the operation which lasted for only a day for each hole. However, the subsequent dissipation of excess porewater pressures will result in settlements which can even exceed the heaves and defeat the purpose entirely. Fig. 6 shows the rates of reductions of heaves and strut loads, expressed in terms of percentages of their values at the completion of grouting. As can be noted that within a week (168 hours) after the completion of grouting in GH-2, Marker SP9 settled back to its original level, ie., 100 % reduction. Strut loads induced by grouting reduced at an even faster rate. As shown in the figure, the load increment in the 3rd level for the case of GH-D dropped to zero in 18 hours.

The high permeability of sands allows quick dissipation of porewater pressures and, therefore, the grout injected only densified the sands and contributed very little to heave. It is hypothesized that if sufficient quantity of grout is injected, sooner or later the surrounding sands will reach the densest state and any subsequent quantity will cause the ground to heave. The heaves, in this case, will be permanent because all the porewater pressures have dissipated during the operation.

B. Pattern of Grouting

It then follows that the effectiveness of grouting, expressed as the ratio of the volume of the heave to the volume of the grout injected, will increase as more grout enters the ground. Therefore, it will be more effective to form a large ball, refer to Fig. 7, instead of a series of bulbs. The latter has been proved to be ineffective as discussed above. Furthermore, in normal cases, grouting holes will be inclined as shown in Fig. 7. The trials indicate that the influence lines form an angle of 45 degrees from the vertical. It is thus reasonable to conclude this to be the optimum angle because all the heave will contribute to the lifting up of the structure. It is also desirable to grout at locations far below the bottom of the foundation so the zone of influence will be wider and the heave profile will be smoother. The deeper it is, the farther will it be away from the retaining walls and the less influence on strut loads. To match the settlement profile of foundation, it may be necessary to grout in several holes with different inclinations as shown in Fig. 8.

C. Grouting Pressure

Grouting pressure is a limiting factor. The facilities used have a system capacity of 140 bars, however, in normal operation the pressure is limited to 40 to 60 bars. High pressure can suddenly occur without warning and it is thus important to have an automatic pressure cutoff device to avoid damage to the facilities.

It is often stipulated in specifications on grouting that the pressure shall be limited to the overburden pressure. This restriction is to prevent excessive ground heave from damaging structures and is not applicable to compaction grouting of which the purpose is to jack up the structure. The amount of heave is governed by the quantity of the grout injected, not the pressure. So long as the rate of intake is under control, the restriction on pressure can be lifted.

D. Characteristics of Grout

Thick grout is usually used for two reasons - to avoid the grout from spreading too far and to reduce subsequent settlement as the grout consolidates. It is often mentioned in literatures that the thicker the grout is, the more effective it will be. This principle, however, is unsuitable for Taipei Basin. As mentioned above, the clay layer at the top is too soft for the compaction grouting to be effective and it is preferred to grout the underlying sands. The great overburden pressures due to the great depths of the sands call for higher nozzle pressures. It has been experienced that increasing the slump drastically reduces friction in the pipe and makes it much easier for the grout to enter the ground. Adding bentonite will also help. It is thus suggested to apply grout with a very high slump, say, 200 mm or even greater, at first to break the ground and create a balloon-like soft ball. As the size of this ball increases, it will become easier for the subsequent grout to enter. Drier grout can be used at the later stage if so desired. In other words, the composition of the grout should be adjusted as the work proceeds. The initial grout should have much water, much bentonite and no cement, and the final grout should have a low slump and more cement.

V. Summary

Compaction grouting is effective in incompressible media such as stiff clays and dense sands. In soft clays, high pressure grouting is able to heave up the ground initially, however, within a week or two, the ground will settle back to its original position. In loose sands a large quantity of grout is necessary for ground heave to be significant.

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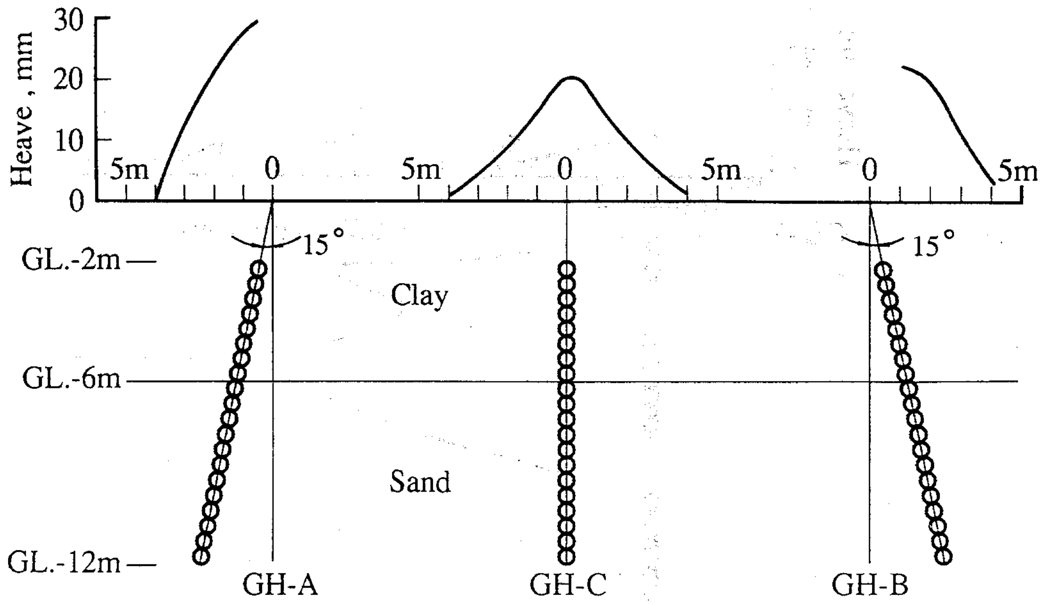

Figure 1 Ground Heaves for GH- A , B & C

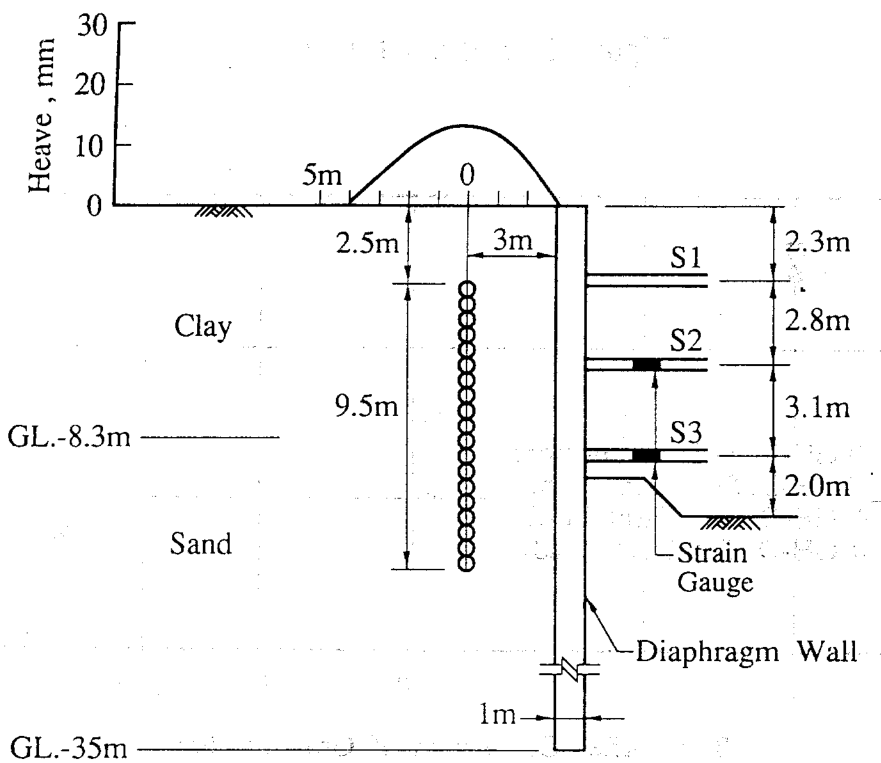

Figure 2 Ground Heaves for GH- D

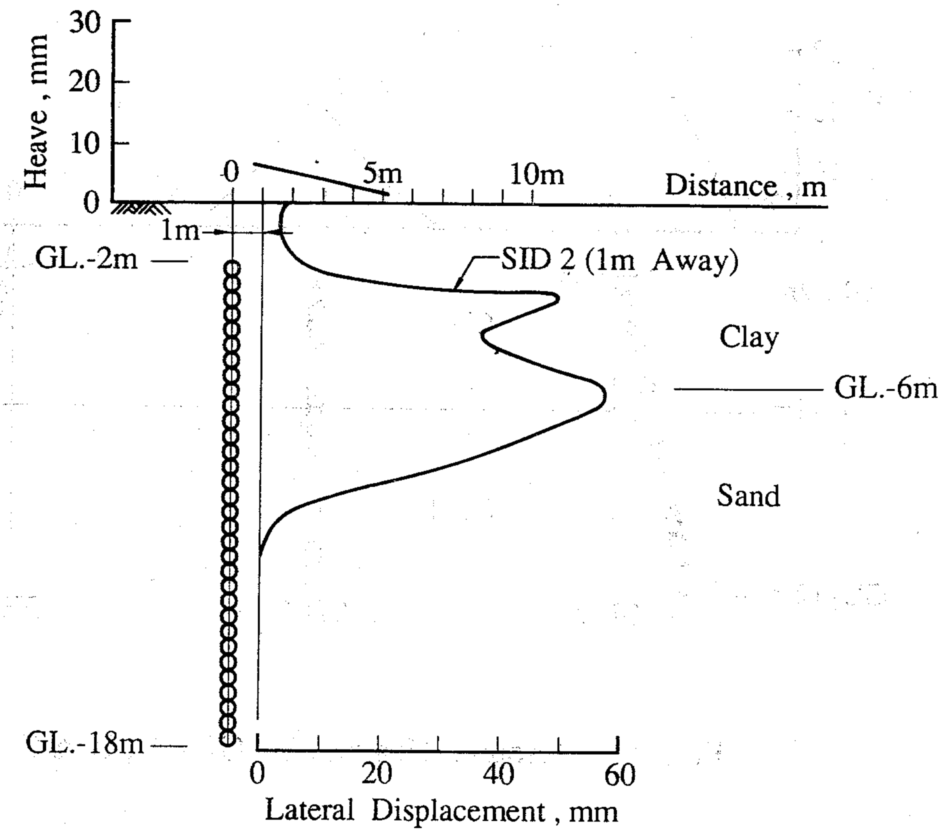

Figure 5 Results for GH- 2

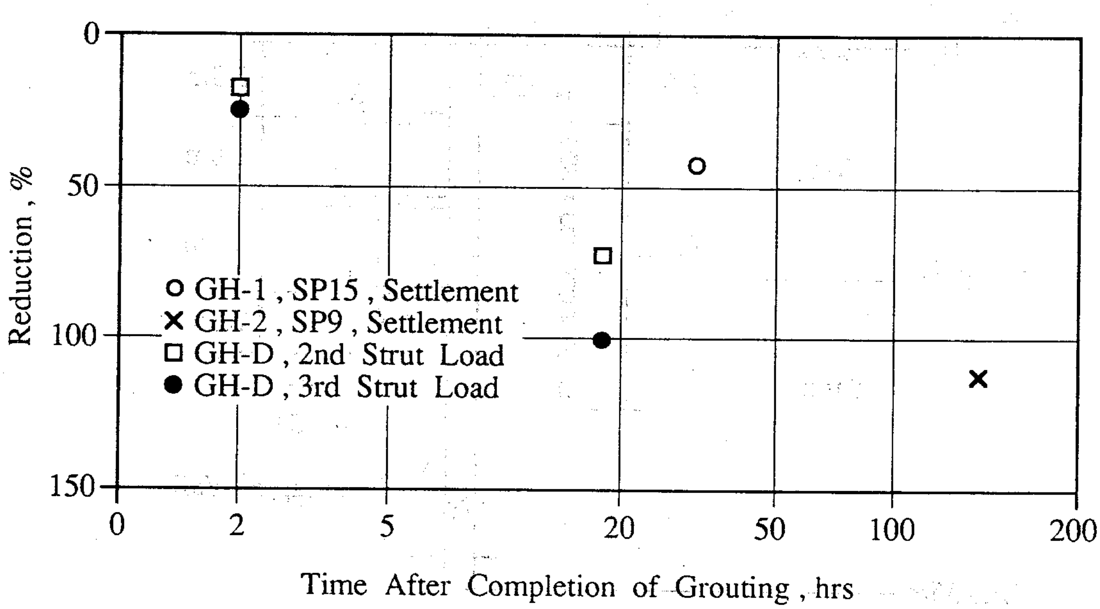

Figure 6 Post - Operational Reductions of Heaves and Strut Load

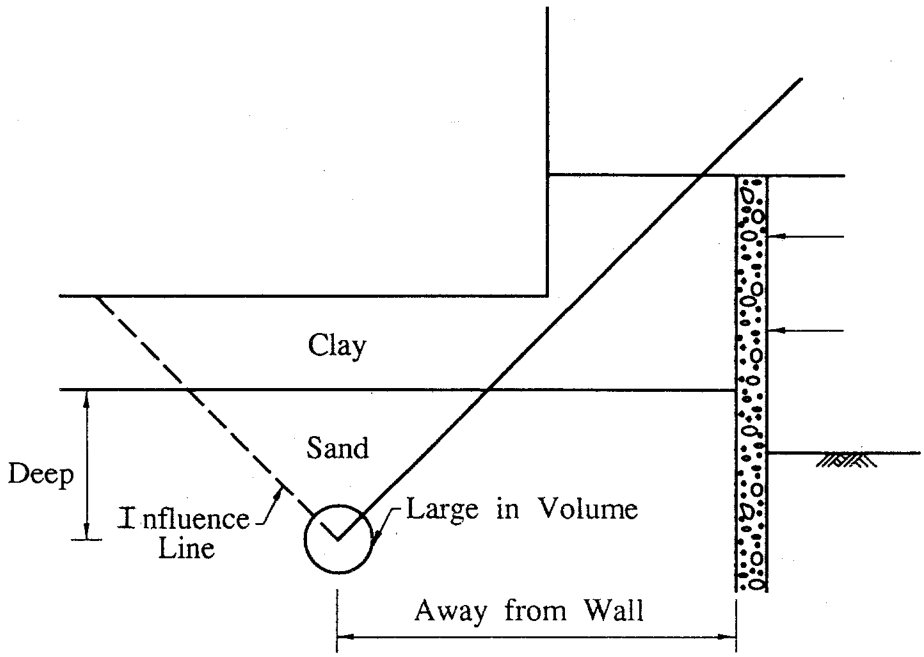

Figure 7 Optimum Pattern of Grouting

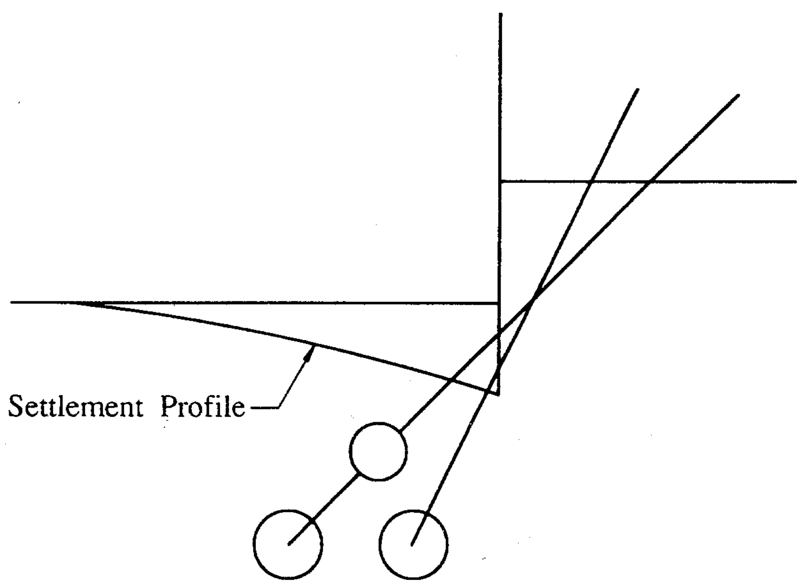

Figure 8 Arrangement for Settlement Correction