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A study on the role of grouting in ground improvement

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Abstract
Cement grouting can be profitably used for strengthening foundation beds. The shear strength parameters, c & Ø, shows phenomenal increase when grouted with cement. The cement-water ratio of the grout act as a key parameter in the control of strength gain of sandy soils. The investigation on improvement of bearing capacity of sandy soils by grouting shows that there is considerable promise and scope for developing cement grouting as technique to improve foundation beds and their bearing capacity, especially in case of cohesionless soils.

Keywords: grouting, improvement, cement grouting

Introduction

Cement grouting by impregnation in granular media is a widely used technique in civil engineering, applied in order to improve the mechanical characteristics of soils. The idea consists in incorporating a pressurized cement grout in the pore space of the soil. The setting of cement grout in the pore space increases both the strength and stiffness. The resulting microstructure is a heterogeneous material made up of sand grains, cement and pores. The injection by impregnation method does not modify the structure of the granular assembly. Several experimental studies on reference sand have been devoted to the increase of the strength due to cement grouting. These works show that the grouted material remains a frictional one, the strength of which is correctly modelled by Mohr –Coulomb criterion. Grouting is mainly responsible for the grain in cohesion by the material and only marginally affects the friction angle.

The cohesion linearly varies with cement content, the magnitude of the cohesion gained by grouting and also the friction angle is a slightly increasing function of cement content. The increase in angle of friction is negligible with respect to cohesion (Maalej *et al*. 2007).

Axelsson and Gustsfson (2006) developed a robust method to determine the shear strength of cement-based injection grouts in the field. Based on that the method to determine the yield strength of a grout by letting a stick sink into the grout seems to be a robust method to measure the yield strength in the field.

At a medium porosity, the shear box gives angle Ø the same order as that of given by the tri-axial. Denser samples give a higher angle in the shear box, looser samples a lower angle. (Nash *et al*. 2003)

Introduction of a cementing agent into sand produces a material with two components of strength- that due to the cement itself and that due to friction. The friction angle of cemented sand is similar to that of uncemented sands. Weakly cemented sand shows a brittle failure mode at low confining pressures with a transition to ductile failure at higher confining pressures. For brittle type cementing agents, the cementation bonds are broken at very low strains while the friction component is mobilized at large strains.

Density, grain size distribution, grain shapes and grain arrangements all have a significant effect on the behavior of cemented sand (Clough *et al*, 2001).

Generally, the strength of the soil is estimated by Mohr-Coulomb's failure criterion. It is generally accepted that grouting effectively increased the compressive strength of the sand by filling the voids and by imparting a cohesion or adhesion factor, yet the grout contribution cannot simply be added to the sand strength. The introduction of silicate grout into the sand particles and modifies the type of failure of grouted sand (brittle failure at strains less than 0.3%) (Ata and Vipulanandan 2009) [3].

Yoshida *et al*. (2001) studied the effect of saturation on shear strength of soils and found that the cohesion intercept tends to decrease sharply with increasing saturation until it reaches a value of equal to about 80%, but it becomes almost equal to zero, irrespective of soil type and density, when the sample is fully saturated with the saturation ratio of 100%.

In low cement contents and low confining pressures the highest shear strength of cemented soils belongs to the soil cemented with Portland cement.

Increasing the confining stress, the shear strength of soil cemented with Portland cement drops lower than the shear strength of the soil cemented with gypsum. However, it is still higher than the shear strength of soil cemented with lime. The rate of increase in shear strength of soils cemented with Portland cement reduces with increase in confining stress when the amount of cementation is low. When the cement content increases to 4.5% the shear strength of the soil cemented with Portland cement is always higher than the shear strength of the soil cemented with gypsum and lime (Haeri *et al*. 2006).

Cementation bond plays a dominant role on the strength characteristics of the cement admixed clay. Even if the cementation bonds is broken down, the shear resistance contributed from the cementation bond still persists. The shear resistance does not reduce with the increase in the effective confining pressures.

The role of the cementation is not only to introduce the cohesion to the clay but also to enhance the friction angle. The friction angle is boosted considerably by only adding small amount of cement to the base clay. (Horpibulsuk *et al*. 2004).

Review of Related Literature

Compaction grouting could be effectively used to mitigate liquefaction of the susceptible soils. The greatest improvement from grouting was achieved in sands. Silts were also improved but the grouting was less effective (Miller and Roycroft, 2004) [1].

Microfine cement suspensions with a water: cement ratio of 4 or higher can be successfully injected into fine sand (D10 as low as 0.15 mm with a hydraulic radius as small as 0.002 mm) under a pressure of about 10 psi and will have a depth of penetration of at least one-half meter. Cement particles are captured around the contact points between sand grains and are deposited on the grain surface to form a thick cake, which, upon hardening, provides the grouted mass with improved mechanical properties.

Microfine cement grouts are being proposed increasingly as an alternative to chemical grouts (which often contain one or more toxic components) for grouting fine sands, but their successful use is influenced strongly by the relationship between the suspended solids (individual particles or particle aggregations) in the grout the pores in the porous medium. Although advocated by some practitioners, the use of concentrated (low water: cement ratio) suspensions and high injection pressures can lead to non-homogeneity in the grouting of a soil formation due to the development of preferential paths during injection or hydraulic fracturing of the soil mass. (Arenzana *et al*., 2009) [2].

The concept of a limiting effect or a boundary effect of grouting is of great value in both theoretical research and the practical application of grouted sand. The selection of grouting for a specific job is mainly affected by the amount of improvement, in strength and/ or stiffness, that can be achieved, and the limitations for this improvement with increased depth or confinement (Ata and Vipulanandan 2009) [3].

Particle size distributions are used in characterizing the soil and to determine the groutability of soils (Vipulanandan and Orgurel, 2009).

The procedure adopted for preparation of a grouted bed in the laboratory was given by Dano *et al.* (2004) [4]. The sand was placed with a zero fall height in a transparent and rigid cylindrical column made of PVC of diameter of 80 mm and a height of 900 mm. A few simultaneous hammer stroke on the PVC tube compacted the soil. A fixed volume of grout equal to 1.2 times the initial volume of the granular skeleton was then injected from the base to the top of the column at a flow rate of 3cm3/s. column was kept in a humid condition for a period of 28 days.

Littlejohn (2002), Lowe and Standford (2002) [5] Clarke *et al.* (2002) De Paoli *et al.* (2002) [6] and Schwarz and Krizek (2002) made significant contribution on the study of grout materials, properties, equipment and procedure for grouting.

The safe construction and operation of many structures frequently require improvement of the mechanical properties and behavior of soils by permeation grouting using either suspensions or chemical solutions. The former have lower cost and are harmless to the environment but cannot be injected into soils with gradations finer than coarse sands. The latter can be injected in fine sand or coarse silts but are more expensive and, some of them pose a health and environmental hazard (Karol 2002, 2005).

Grouting has a minimal effect on the angle of internal friction of sands or yields an increase of up to 4.5 º. There are strong indications that pulverized, cementitious, fly ash with appropriate additives can be effectively utilized for permeation grouting of coarse sands (Markou and Atmatzidis, 2002) [7].

Boulanger and Hayden (2005) [8] reported that, in many situations, the bottom-up method can be used as effectively as the top-down method if appropriate modification are adopted at shallow depths. Even with the extra cost of much modifications, it is likely that the bottom-up method will be the most economical choice.

Berry and Buhrow (2002) [9] studied the settlement, structural failure and in-place repair of above ground storage tanks with many sizes and placed on foundations of varying nature. The causes of tank stress and failure are reviewed, including some environmental control concerns and causes, and related to tank foundation problems. The uneven movement and settlement of foundation soils can be stopped by grouting.

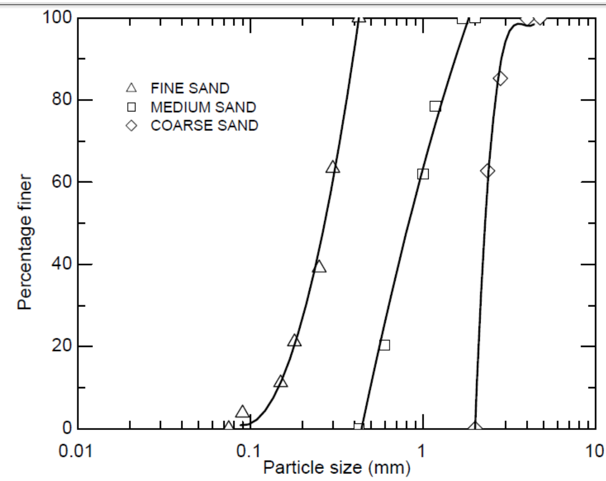
Research Methodology

Materials

The selection of proper grouting materials depends upon the type of granular medium and the purpose of grouting. Cement, bentonite, clay and lime are the grouting materials normally used for grouting a granular medium. In the present study sand was used as the grouting medium and cement (with or without admixtures), lime and clay were used as the grouting materials.

Sand

As mentioned, sand was used as grouting medium for this study. River sand procured from Kalady, which is a branch of the Periyar River - was dried and sieved into different fractions. River sand of three grades - fine (75 µm - 425 µm), medium (425 µm- 2 mm) and coarse (2mm- 4.75mm) fractions as per ASTM (D2487-10) and BIS (1498 -2000) classifications were used in the present study. The grain size distribution curves of different fractions of sand are shown in Fig.



Cement

43 grade Ordinary Portland cement conforming to IS 269 – 2009 was used for the preparation of cement grouts. The cement bags were kept in air tight bins to avoid any change in the properties with the time of storage. The experiments were planned in such a manner that once a bag of cement was opened, the whole cement was utilized within 10 days.

Bentonite

The bentonite used in this study is a commercially available, highly expensive one. Bentonite shows great affinity towards moisture. The percentage of water present in a sample of bentonite varies depending upon the climatic condition. So the bentonite, which was thoroughly mixed uniformly, was preserved in double layer of polythene bags. Again these bags were stored in airtight bins.

Cochin marine clay

Marine clay was collected from a site at Elamkulam in Greater Cochin area on the Western coast of India. Bulk samples of the clay were collected from bore holes advanced by shell and auger method.

The boring operations were taken to the clay layers for collection of samples. The boring operations were carried out as per IS: 1892: 2009, Code of practice for subsurface investigations for foundations. Care was taken not to include bentonite slurry during the boring operations as it could contaminate the soil samples. Samples collected from different locations were put together and mixed thoroughly into a uniform mass and preserved in polythene bags.

Lime

Specially selected uniform shells were used for preparation of lime for the study. The shells were burnt to remove CO_2 completely when they change to brittle white shells of calcium oxide which were preserved in airtight multilayer polythene bags. The required amount of water alone was sprinkled over the lone shells taken from these bags on each day of lime treated samples, till all the shells crumble to fine powder which was then sieved through IS 42 micron sieve. This method of preparation of lime was used because of its simplicity and the ease with which it can be prepared for field application.

Conclusion

The permeability and strength of grouted sand is strongly influenced by the method of grouting because different mechanism governs the deposition and packing of cement particles within the pore structure. During the injection process, preferential flow paths allow the migration of cement particles into the soil, and micro-structural packing undoubtedly varies within the pores of the grouted sand, this is in contrast to the more uniform distribution of cement particles in hand-mixed specimens.

The groutability ratio is not a universally applicable criterion, and values large or smaller than the limiting value of 25 do not necessarily indicated success or failure, respectively, of a specific grouting operation using a particulate grout; experimental evidence suggests that the grain size distribution and relative density of fine sands may control the grouting operation.

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