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# Performance Evaluation of Cement Grouting by Universal Testing Machine to Improve the Bearing Capacity of Sandy Soil

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## Abstract

The sandy soil of coastal areas of rivers and oceans due to permeable nature and high water table always provide weak foundations for construction purposes. Due to shear failure and excessive settlements, the sandy soil reduces the safe bearing capacity for high rise building and dam construction purposes. Because of these poor soil properties, several methods are reported to enhance the capability of the soil and apply different grouting materials for its improvement. In this study, several tests were applied to investigate the physicochemical properties of sandy soil and to improve their properties such as shear strength, reduction in settlements and increase the bearing capacity. The properties of sandy soil was measured such as size and moisture content by Sieve analysis, in-situ density by sand cone replacement method, specific gravity by using pycnometer. In similar fashion, cement was characterized such as fineness by sieve analysis, standard consistency, initial and final settlement time was measured by vicat apparatus, soundness and specific gravity of cement was checked by Le-chatlier flask. After material characterizations, shear strength and permeability tests were done to investigate the suitability of sandy soil for grouting applications. Normal and shear stress was measured by direct shear stress apparatus and both stresses increases with increase in load. The permeability of sandy soil was measured by constant head permeability and hydraulic conductivity was reported in medium range which is suitable for plate load test. The plate load test was done by Universal Testing Machine (UTM) for sandy soil. The high settlement of sandy soil by applying load revealed the low bearing capacity and grouting was needed. Cement grout was applied in different water cement ratios, such as 7:1 to 4:1 range. At ratio 7:1 (G1) the settlement was higher while applying the load than 4:1 (G4), which has the lesser settlement. However, when the water content was decreased than G4, then the work ability and flow of the grout was much less for applications. It is concluded that G4 is the best combination of cement grout which has least settlement and maximum bearing capacity which can be preferred combination for construction on sandy soils at coastal areas and deserts.

**Keywords:** Sandy soil; Shear strength; Permeability; Plate load tests

## Introduction

Grouting is an important technique for improvement of bearing capacity of sandy soil which could be achieved by reducing the void present in the soil and binding of these soil particles applying different grouting approaches. The sandy soil has much permeability which is dangerous in case of high rise building on coastal areas. Different scientists have developed different grouting methods to make possible the stable foundations for building on sandy soils [1-6]. Grouting techniques have various applications such seepage control in rocks and soils under dams and advancing tunnels, construction on coastal areas and deserts [7,8]. Ground improvement or modification at site is essential as without these engineering procedures, the natural soil has no potential to be used for any civil engineering activity. Different parameters of ground improvement such as shear strength, reduction in permeability and modification in physicochemical properties of the soil are required for civil engineering purposes. Many scientists have developed new methods and still are exploring as needed for construction activities. Excavation of poor soil and replacing it with soil of choice is very economical and sometime impossible if the water table is above 3 m. The dewatering technique in this case is very expensive before replacing with normal soil. Alternative methods are required in this case or in relevant cases where the only option left is the improvement of soil by the most suitable method [8-10]. In this study, the samples were collected from coastal areas of river Kabul so that to evaluate their composition, particle size and its stability and bearing capacity by applying different loads. This is essential in case when construction of dams is required on river where the sandy soil will not be that of good quality to tolerate the load. This is similar to the sandy soil of deserts or coastal areas of ocean where the high-rise building for hoteling/industries is needed when there is no other option left. Many engineers and scientist are exploring different methods such as grouting techniques to make the soil with improved bearing capacity and strong foundation for buildings.

Several geotechnical engineers have reported about the improvements of soil of different nature and proposed different materials as grouting agents and defined different processes to improve the bearing capacity and provide strong foundations on loose soils [11-13]. There are some parameters which describes the grouting method such as grout ability, stability, setting time, and permeability. Grouting is classified such as permeation grouting, compaction grouting, hydro fracture grouting and jet grouting. These grout methods can be applied based on the soil structure, in which cement grouting can be used to fill the voids, reduce soil permeability and also binds the soil particles together and need optimized curing period for settlement with the passage of time. The soil with low bearing capacity is reported to cause shear failure and excessive settlement. This could be due to the high water table on coastal areas which provide less soil for foundation and reduces the safe bearing capacity. In this case, when grouting was applied, the plastic limit, liquid limit and compaction and bearing

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capacity has been increased [12]. In addition, permeation grouting is reported in which air void/pores in the soil particles are filled with cement slurry and improve the engineering and bearing capabilities of the soil [13,14]. In the present study, several tests were applied to characterize the sandy soil and analyze different processes to have better grouting before application for construction purposes.

The aim of this study is to study the physical properties of the sandy soil by using different tests and to apply the grouting on sandy soil to reduce the settlement and improve the bearing capacity of sandy soil exist in coastal areas of river and ocean for civil engineering applications.

## Materials and Methods

In materials, we have collected sandy soil from the bank of river Kabul and cement was collected of Kohat Cement Factory. Different tests such as sieve analysis, in-situ density of sandy soil, specific gravity etc. was done to characterize sandy soil. In similar fashion, different tests such as fineness test, standard consistency test, initial setting time and final setting time, soundness of cement, and specific gravity tests were applied to characterize and screen out different properties of cement collected from Kohat Cement Factory. The above mentioned tests were done by methods available in literature [1,3]. The following methods were used to characterize the sandy soil and its strength for construction purposes.

### Shear strength test

Sandy soil was taken and perforated metal plates were placed on upper side and beneath the sample. Then pressure plate was placed on the top. Then these components were placed in trolley and experiments were done in the direct shear test apparatus. Then vertical load was applied through a static weight hanger and then sample was sheared which resulted in two halves by a horizontal force and they moved relative to each other. The shear load was measured by means of a proving ring. The dial gauges was used to measure the shear and vertical deformation. This procedure was applied on four samples with different normal loads. Normal stress and shear stress was calculated by dividing the normal and shear force by the nominal area of the sample. The shear stress values at failure were plotted versus normal stress of each test [4,5].

### Permeability test

The constant head permeability tests were done for sandy soil to investigate the voids in the sample and their potentials of permeability. The mould was filled of sandy soil keeping the dry weight as 14.5 KN/$m^3$ in the standard concrete permeability apparatus [4,6,7]. Water is passed under a constant head in the sand medium and discharge was measured when steady state condition is obtained.

### Plate Load tests

Plate load tests were done for sandy soil (without grout) and sandy soil (with grout) using universal testing machine (UTM). In case of plate load test (without grouting) the mould was filled with sandy soil in loose form. Then sample was investigated in the two compressed jaws of UTM machine and load was applied by 6 inch circular plate in uniform fashion. The sand was compressed and load settlement curve was obtained from the data reported during experiment.

Then plate load tests (with grout) was conducted in the same UTM machine after curing period of one week. Before that several sample with different ratios of water and cement was made such as 7:1 to 4:1. Four PVC perforated pipes was taken with 36 holes in each pipe surrounded by sandy soil in UTM machine (Figures 1 and 2). Then four different grout with different ratios of cement and water was poured in those pipes to check their strength and to investigate the potentials of load in real applications.

## Results and Discussion

In this study, the sandy soil was collected from coastal area of river Kabul from 3 to 6 feet depth and cement was selected from Kohat Cement Factory. These materials (sandy soil and cement) were characterized and physicochemical properties were measured as given in Tables 1 and 2, by applying various tests using optimized protocol available in literature [7-10]. The different particle sizes of sandy soil and cement were measured by Sieve analysis test. In this study fine sand was reported in high amount as given in Table 1 in comparison to rough sand.


**Figure 1:** Grout pouring in PVC pipes.

**Figure 2:** Permeation of cement grouting.

| Properties | Values |
|---|---|
| Specific gravity | 2.62 |
| Coarse sand % | 0.88 |
| Medium sand % | 4.18 |
| Fine sand % | 79.88 |
| D60 (mm) | 0.81 |
| D30 (mm) | 0.58 |
| D10 (mm) | 0.45 |
| Cc | 2.53 |
| Cu | 1.8 |
| $e_{max}$ | 0.75 |
| $e_{min}$ | 0.46 |
| $e_{avg}$ | 0.302 |

**Table 1:** Elaboration of the properties of the sandy soil after applying various tests.

In similar fashion, the fineness of cement was reported in 91% in Table 2 which is the recommended percentage for use. The cement consistency was also measured and 28% water was the best composition reported in standard consistency test as given in Table 2. Initial setting time for Kohat Cement was reported 33 minutes and final setting time was 279 minutes which is in the standard range reported for real application of the cements.

After materials characterization, the shear strength was measured by direct shear stress apparatus. Normal and shear stresses were measured while applying different loads and the data obtained for normal and shear stresses are given in Table 3. In this study, the shear stress and normal stress both were increasing while increasing the load.

This revealed a direct relationship between load and stresses as given in Figure 3. Surprisingly, the shear stress values were less than normal stress while increasing the load and this could be due to the friction among the particles.

| Properties | Values |
|---|---|
| Specific gravity | 3.13 |
| Grade | 43 |
| Consistency % | 28 |
| Initial setting time | 33 |
| Fineness % | 91 |
| Soundness test | 7.95 |

**Table 2:** The characteristics and composition of the cement used in this study determined by various tests.

The permeability of sandy soil was measured by constant head permeability test. Permeability of the material is important to know the seepage of water through its interconnecting voids. The hydraulic conductivity (denoted by k) which is the coefficient of permeability can be used to understand the permeability of the samples. The hydraulic conductivity was reported $k=2.64*10^{-3}$ m/sec in this study as given in Table 4. This hydraulic conductivity is considered as medium in range. This depends on the particle size of the sandy soil; if particle size is bigger then there will much chances to penetrate water and thus enhances permeability. Sandy soil is reported in medium range while clay has minimum and gravel has maximum permeability. This is the reason which prefers sandy soil in comparison to gravel and clay.

After characterization of sandy soil by above methods, the plate load test was done by Universal Testing Machine (UTM) for the sample without and with grouting. The plate load test for un-grouted sample is given in Figure 4, which revealed that increasing the load enhances the settlement of sandy soil. This could be due to porosity of sandy soil which reduces its bearing capacity.

The plate load test was conducted on sandy soil after cement grouting with different combination of cement and water. At ratio 7:1 (G1) the settlement was higher while applying the load than G4,

| S. No | Normal Force (N) | | Dial Gauge Reading m (mm) | Shear Force (F)=Dial Gauge Reading × 0.15 (Kg) | Normal Stress=N/A | | Shear Stress=F/A | |
|---|---|---|---|---|---|---|---|---|
| | Lb | Kg | | | (Kg/cm²) | psi | (Kg/cm²) | psi |
| 1 | 10 | 4.53 | 35 | 5.25 | 0.125 | 1.77 | 0.145 | 2.06 |
| 2 | 20 | 9.07 | 45 | 6.75 | 0.251 | 3.57 | 0.187 | 2.65 |
| 3 | 30 | 13.60 | 87 | 13.05 | 0.377 | 5.36 | 0.362 | 5.14 |

**Table 3:** Data reported for normal stress and shear stress.

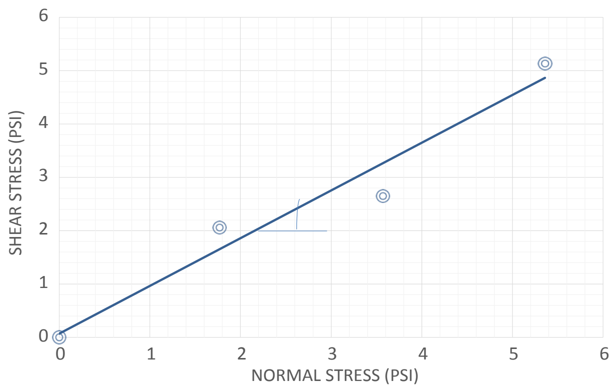


**Figure 3:** Normal stress as a function of shear stress.

| | | |
|---|---|---|
| **Diameter of the permeameter cylinder** | 7.5 cm | |
| **Cross-sectional area of cylinder=A** | 44.178 cm² | |
| **Distance b/w manometers tube outlets=L** | 10 cm | |
| **Q = Quantity of water discharged during the test** | 770 cm³ | |
| **t=Total time of discharge** | 120 sec | |
| **Water level in manometers tubes,** | H1 | 56 cm |
| | H2 | 50.5 cm |
| **h=Difference in head on manometers** | 5.5 cm | |
| **K=QL/A × t × h** | **$2.64 \times 10^{-3}$ m/sec** | |

**Table 4:** Data collected for permeability by constant head test.

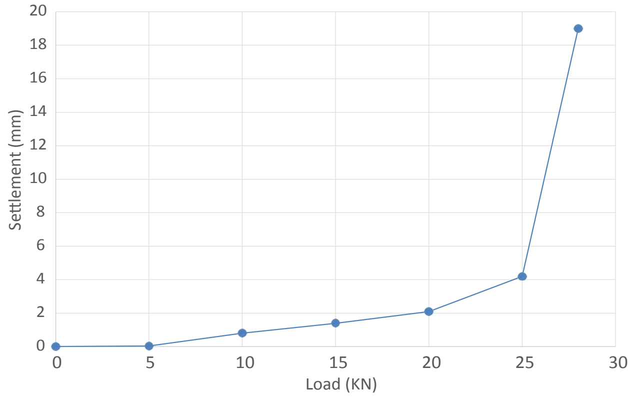


**Figure 4:** Plate load test (without grouting).

| Notation | Water | Cement |
|---|---|---|
| G1 | 7 | 1 |
| G2 | 6 | 1 |
| G3 | 5 | 1 |
| G4 | 4 | 1 |

**Table 5:** Mixing proportions of grout and their notations.

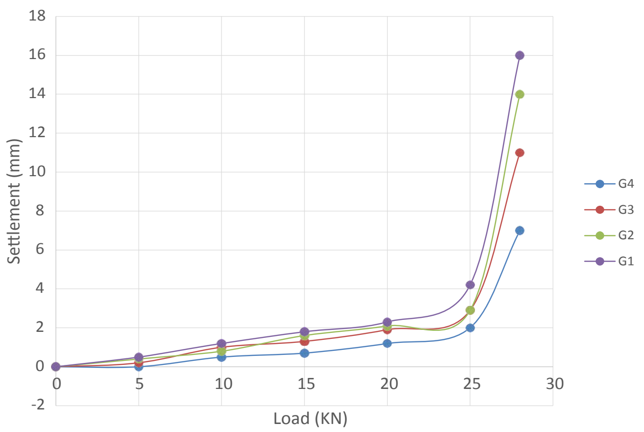


**Figure 5:** Different combinations of plate load test with grouting.

which has the lesser settlement. However, when the water content was decreased than G4, then the work ability and flow of the grout was much less for applications. The curing period is reported 14 and 28 days in a report, however, we preferred 7 days which is the optimum time for real time applications [8].

As given in Table 5 and Figure 5, G4 is the best combination which has least settlement and maximum bearing capacity which should be preferred combination for construction on sandy soils in coastal areas and deserts.

## Conclusions

Due to rapid increase in population, the need for high rise buildings is increasing day by day. This demands for in-depth investigations of civil engineering approaches to have strong and long standing buildings for human safety. In this study, the G4 (water cement ratio 4:1) is considered the best grouting combination in case of sandy soil. This grouting combination can be optimized for high rise buildings to improve the foundation beds of loose sandy soils exist in coastal areas and sandy deserts. This work can be applied for high rise buildings, dams and other designs of civil engineering in real time applications.

### Authors' Contribution

NK, IK, AU, MY conducted experiments, NK analyzed the data and wrote the manuscript and SN supervised and provided the funds for experiments.

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