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Triaxial shear behavior of a cement-treated sand–gravel mixture

Younes Amini, Amir Hamidi*

School of Engineering, Kharazmi University, Tehran, 15614, Iran

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ABSTRACT

A number of parameters, e.g. cement content, cement type, relative density, and grain size distribution, can influence the mechanical behaviors of cemented soils. In the present study, a series of conventional triaxial compression tests were conducted on a cemented poorly graded sand–gravel mixture containing 30% gravel and 70% sand in both consolidated drained and undrained conditions. Portland cement used as the cementing agent was added to the soil at 0%, 1%, 2%, and 3% (dry weight) of sand–gravel mixture. Samples were prepared at 70% relative density and tested at confining pressures of 50 kPa, 100 kPa, and 150 kPa. Comparison of the results with other studies on well graded gravely sands indicated more dilation or negative pore pressure in poorly graded samples. Undrained failure envelopes determined using zero Skempton's pore pressure coefficient ($\overline{A} = 0$) criterion were consistent with the drained ones. Energy absorption potential was higher in drained condition than undrained condition, suggesting that more energy was required to induce deformation in cemented soil under drained state. Energy absorption increased with increase in cement content under both drained and undrained conditions.

1. Introduction

Cementation occurs due to the various geological processes that create bonds between soil particles like aging, chemical reactions, carbonates, silicates, iron oxides, and natural cementing agents. Due to the difficulties of in situ sampling, the mechanical characteristics of cemented soils are usually studied using artificial samples prepared in laboratory and cured by different cementing agents.

The mechanical behavior of cemented soils is influenced by a number of parameters including cement content, cement type, density, confining stress, grain size, and stress-strain history (Saxena and Lastrico, 1978; Clough et al., 1979, 1981, 1989; Acar and El-Tahir, 1986; Leroueil and Vaughan, 1990; Airey, 1993; Coop and Atkinson, 1993; Das et al., 1995; Malandraki and Toll, 1996; Cuccovillo and Coop, 1997, 1999; Huang and Airey, 1998; Consoli et al., 2000, 2007, 2009, 2010, 2011; Schnaid et al., 2001; Ismail et al., 2002; Rotta et al., 2003; Lee et al., 2010; Park, 2010; Baxter et al., 2011; Hamidi and Hooresfand, 2013; Shahnazari and Rezvani, 2013). According to the previous studies, the cementation can increase brittleness, shear strength, and dilative behavior of sands. However, it should be noted that most of the previous studies have focused on the mechanical behavior of cemented fine sands, rather than the mechanical behavior of coarse grained gravels or gravely sands.

In the last decade, a number of studies have been performed to investigate the mechanical behavior of cemented gravely sands or sandy gravels (Haeri et al., 2005a,b, 2006), in which a series of triaxial compression tests were performed on a representative gradation of the Tehran coarse grained alluvium. Cemented samples were prepared with different cementing agents including lime, Portland cement, and gypsum. They concluded that the strain associated with the peak deviatoric stress decreases as the cementation increases. Also it was indicated that the maximum rate of dilation and negative pore water pressure occur after the maximum shear strength is obtained.

Review of the literature shows that there is rarely particular study on investigation of the mechanical behavior of cemented poorly graded sand–gravel mixtures. Indeed, all previous studies on the behavior of cemented gravely sands concern fine sands or well graded gravely sands as the base soil. Therefore, the objective of present research is to investigate the mechanical behavior of a cement-treated poorly graded sand–gravel mixture. In this regard, a number of new features of the mechanical behavior of cemented soils are reported.

2. Testing program

Thirty groups of conventional triaxial compression tests were performed, among which 24 groups are considered in this study. Six groups of additional tests (25% of the total) were performed to

* Corresponding author. Tel.: +98 21 88830891.
E-mail addresses: amhamidi@gmail.com, hamidi@khu.ac.ir (A. Hamidi).
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check repeatability of the experiments and results. Also, 12 groups of unconfined compression tests were conducted and reported. Cement content and confining pressure were considered as the variables of testing program, and the triaxial compression tests were performed in the consolidated drained and undrained conditions.

2.1. Soil and cementing agent

Clean and uniform quartz beach sand with sub-round to sub-angular particles from the shores of the Caspian sea (specifically Babolsar, Iran) was first sieved using a #30 sieve and then was mixed with 30% uni-sized (9.5–12.5 mm) gravel grains. The mixed soil can be named as SP in unified soil classification system and was used as the base material. Gradation curves and physical properties of the base material are shown in Fig. 1 and Table 1, respectively. In Table 1, G_s is the specific gravity; D_{10} is the effective diameter; C_U and C_C are the uniformity and curvature coefficients, respectively; and $\gamma_{d,\ min}$ and $\gamma_{d,\ max}$ are the minimum and maximum unit weights, respectively. All physical characteristics were determined according to the ASTM (1998) standard methods.

Portland cement (Type II) with a setting time lasting for about 4 h was used as the cementing agent. It was first sieved using a #100 sieve and then added to the base soil.

2.2. Sample preparation and test procedure

The undercompaction method was used for sample preparation proposed by Ladd (1978). Required weight of the soil was mixed with desired cement content and about 7% distilled water. Samples were prepared using a split mold, 100 mm in diameter and 200 mm in height, and were compacted in eight layers. Each layer was poured into the mold and compacted using metal hammer until the desired height was reached. Cemented samples were stored at a (25 ± 3) °C humid room with >90% relative humidity for 24 h. After that, samples were extracted from the mold and were kept for 6 d at humid room. On the 7th day, the diameter, height and weight of the samples were measured. For unconfined compression tests, samples were prepared with curing times of 7 d and 28 d. The variables considered in sampling process are listed in Table 2.

A computer-controlled triaxial cell was used to test the samples at the confining pressures (CPs) of 50 kPa, 100 kPa, and 150 kPa. The outer surface of samples was soft enough to minimize the effect of membrane penetration. As a result, flexible membranes do not affect pore pressure generation in saturated condition. Membranes with average thickness of 1 mm were used and corrections such as membrane thickness and cross-sectional area were considered according to Bishop and Henkel (1969).

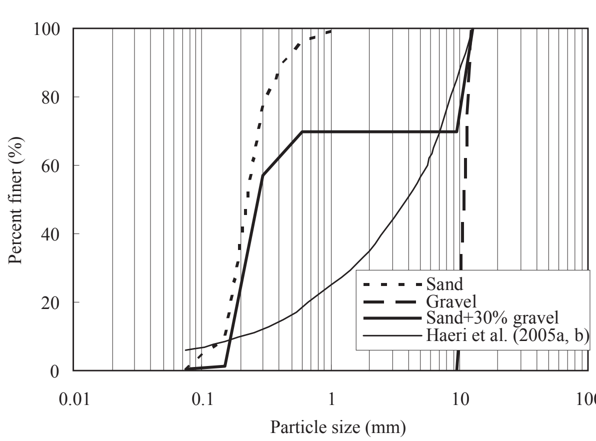

Fig. 1. Gradation curve of tested sand–gravel mixture.

Table 1
Physical properties of the base soil.

Base soil	G_s	D_{10} (mm)	C_U	C_C	$\gamma_{d,\ min}$ (kN/m^3)	$\gamma_{d,\ max}$ (kN/m^3)
Sand	2.74	0.15	1.75	0.89	15.7	18.3
Gravel	2.62	9.82	1.15	0.98	13.36	14.94
Sand + 30% gravel	2.71	0.17	1.88	0.89	17.94	19.1

All samples were fully saturated in two stages prior to shearing. At the first stage, de-aired water was flushed from the bottom of sample under a very low pressure difference of 10 kPa for 24 h. After that both cell and back pressure were ramped simultaneously to 310 kPa and 300 kPa for complete saturation at the second stage. Saturation procedure was considered to be completed until Skempton's B value of 0.9 was reached.

The samples were consolidated up to the desired confining pressures. Shear loading was applied at an axial strain rate of 0.1 mm/min for drained tests and 0.3 mm/min for undrained ones. Cell pressure, volume change, pore pressure, load and displacements were measured during triaxial compression tests by electronic transducers and a calibrated data acquisition system. All the variables considered in testing program are listed in Table 3.

3. Unconfined compression tests

Some specifications of the unconfined compression tests are described in Table 3. Fig. 2 indicates the variation of unconfined compressive strength (UCS) with cement content at different curing times. Peak strength occurred at small strains between 0.2% and 0.7%. It can be observed from Fig. 2 that the UCS increases with increasing cement content and elapsed curing time. The lines intersect horizontal axis at cement content about 0.5%, which is the minimum cement content to mobilize the shear strength of cemented soil and formation of cemented bonds.

4. Analysis of the results

A summary of triaxial test results at failure and residual state is shown in Table 4. Deviatoric stress (q), mean effective stress (p') and specific volume (v) are defined using the following equations:

$$q = \sigma'_1 - \sigma'_3 \tag{1}$$

$$p' = (\sigma'_1 + 2\sigma'_3)/3 \tag{2}$$

Table 2
Summary of samples and test conditions.

Variable	No. of levels	Description of samples
Type of soil	1	Poorly graded sand–gravel mixture
Cementing agent	1	Portland cement (Type II)
Cement content	4	0%, 1%, 2%, and 3% (dry weight) of sand–gravel mixture
Relative density	1	70%
Water content	1	7% (dry weight) of soil–cement mixture
Sample size	1	100 mm in diameter and 200 mm in height, compacted in 8 layers
Curing condition	2	Triaxial test samples cured for 7 d and unconfined compression test samples cured for 7 d and 28 d in (25 ± 3) °C humid room