Shear strength behavior of sand stabilized with cement.

Naeini, S, A.

Associate Professor, Civil Engineering Department, Imam Khomeini International University Qazvin, Iran.

Malek Avrzamani, H

Graduate Student, Civil Engineering Department, Imam Khomeini International University, Qazvin, Iran.

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ABSTRACT**:** One of the prevalent methods for increasing the shear strength of soil is to mix additives as stabilizer to the soil .This study presents the test results on the shears stress – displacement and shear strength parameters of sand stabilized with Portland cement. Direct shear tests was performed on series of sand and cemented sand samples with different normal stresses ranged from 55 kPa to 218 kPa. The cement content values used in the experiments ranged from 0 to 5 percent by dry weight of sand. The results show an increase in shear stress level with increasing normal stress. For sand stabilized with cement, the results show stiffening of material response and a decrease in contraction and internal angle of friction with increasing cement content. Also, the values of cohesion increased with increasing cement content.

1 INTRODUCTION

Cement can be used for soil stabilization . The term stabilization is adopted for improvement in mechanical behavior of cement treated soils. The use of cement has certain advantages over other stabilization agents .Cement stabilization is quick, does not need mellowing time, and provides a non-leaching platform. Cement can also be used for stabilization of wide range of soils. The best results of cement have been observed on silt as well as coarse-grained materials (Currin et al 1976).The beneficial of cement treatment on the performance of a broad range of soils have been widely investigated by Michell (1976),Uddin etal. (1997), Lo & Wardani (2002), Lorenzo& Bergado (2004), The addition of a few percentages by weight of cement has shown its effectiveness towards better control of workability during compaction and significant cost savings over removal and replacement of fill material in some projects (Lowell,2005). The improvement of sandy soils by adding cement have also documented by Wany & Leung (2008) and Consoli et al. (2011). The effects of the addition of cement on three different soils on their solidification, plasticity limit, compaction characteristics, unconfined compressive strength, and undrained triaxial shear behavior was investigated by Sariosseiria and Muhunthanb(2009).The results showed significant improvement in drying rate, workability, unconfined compressive strength and shear strength. Uchaipichat and Limsiri (2011) studied the shear strength characteristics of cemented loose sand. The results of direct shear tests on loose sand stabilized with cement shows that with increasing cement content, the value of the angle of friction increased while the cohesion are zero. However, the effectiveness and improvement of engineering properties needed to be examined systematically for future design and construction purposes. The purpose of this study is to investigate the shear –

displacement and shear strength parameters of sand and sand stabilized with different percentage of Portland cement through results of direct shear test.

2 TESTED MATERIALS

The materials used in this study were sand and Portland cement. A clean oven –dried sub-angular sand with relative density of %80 was used in the test. The clean sand is poorly graded and classified as SP according to the unified soil classification system (USCS) with coefficients of uniformity (C_u) and curvature (C_c) of 5.3 and 1.2 respectively. The grain-size distribution of the sand is presented in Figure1.Some properties of the sand are given in Table 1.

A Portland cement type 2 was used as a stabilization agent. A Portland cement particles is heterogeneous substance, containing minute tri-calcium silicate (C_3S), dicalicum(C_2S),tricalcium(C_3A), and solid solution described as tetra calcium alumino- ferrite (C_4A).When the water encounters with cement ,hydration of the cement occurs rapidly and the major hydration (primary cementation) produces hydrated calcium silicates (C_2SHX,C_4AHX),and hydrated lime $Ca(OH)_2$. Different percentages of Portland cement ranging from 1 to 5% were added to stabilize the sand. The properties of Portland cement used in all tests are given in Table2.

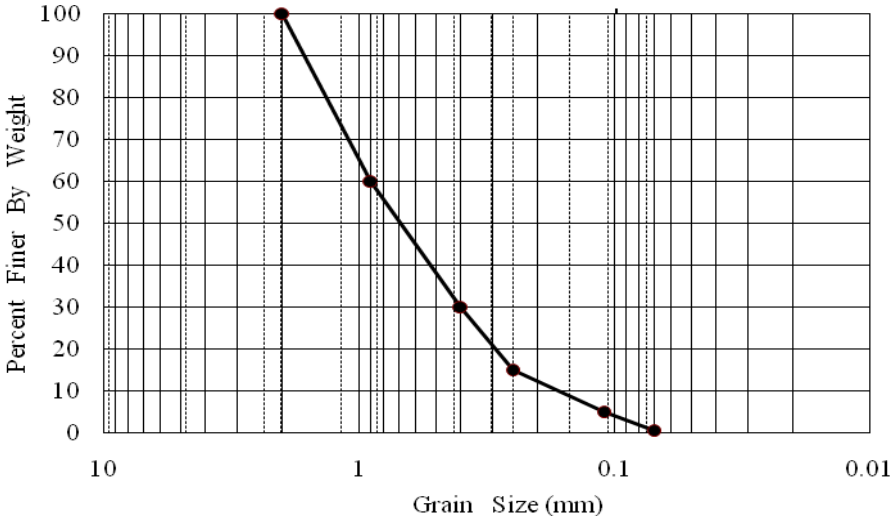

Figure 1. Grain-size distribution of the sand

Table1. Properties of sand

Property	Value
Specific gravity	2.66
D_{50}(mm)	0.70
D_{10}(mm)	0.17
Relative density (%)	80
Dry unit weight(KN/m^2)	16
Maximum dry unit weight (KN/m^2)	16.8
Minimum dry unit weight(KN/m^2)	13.3
Void ratio	0.69
Maximum void ratio	1.03
Minimum void ratio	0.61
Uniformity coefficient	6.6
Gradation coefficient	1.2
USCS	SP

Table2. Portland cement properties

Portland Cement	
Minimum(SiO_2)	26%
Maximum(Al_2O_3)	6%
Maximum(Fe_2O_3)	6%
Maximum(Mgo)	5%
Maximum(So_3)	2.5%
$3CaO,Al_2O_3$	8%

3 PREPARATION OF SAMPLE AND TEST PROCEDURE

For the cement admixed sand, the designed quantity of each cementing agent (1 to 5% by weight of sand) was added to the sand and properly mixed by hand while dry. Water (8% by weight of sand) was slowly added and the material was thoroughly mixed for about 10 minutes using mechanical mixer. The 8% water was used to provide enough water for the hydration. The specimens were statically compacted in three equal layers in the shear box of 60mm×60mm in plan and 25mm in depth with relative density of 80%. The compacted specimens were then cured in the sealed plastic bags for the hydration reaction for curing time period of 7 days.

The conventional direct shear apparatus used to investigate the effect of cementation on stress-displacement and shear strength characteristics of sand and cemented sand. The tests were performed on series of dry sand and cemented sand samples at different normal stresses of 55,109 and218 kPa. Prior to each test, the shear box containing the cured samples was removed from the sealed plastic bag and placed in the testing container with the porous disks on the top and bottom of the sample. The samples sheared under constant rate of 0.9mm/min. During shearing, the shearing force and the horizontal displacements were recorded. Using this information, the shear stress –displacement and shear strength parameters of sand and cemented sand were discussed.

4 RESULTS AND DISCUSSION

A series of direct shear tests were performed to investigate the stress-displacement and shear strength characteristics of sand and cemented sand samples with different cement content at different normal stresses. The test results in term of shear stress versus horizontal displacement for different normal stresses are presented in Figure 2. The results show an increase of shear stress level and stiffness with increasing normal stress. The effect of cement treatment on stress-displacement behavior of sand is shown in Figure 3. It is observed that, the peak axial stress increases significantly due to cement treatment, but the corresponding displacement decreased. Thus, cement treated sand exhibit much more brittle behavior than non-treated sand. The shear strength parameters of the samples with different cement contents are given in Table 3.

Table3. Shear strength parameter of the with different cement contents

Soil	Shear strength (Kpa) Normal stress (Kpa)			Cohesion (Kpa)	Angle of friction (deg)
	55	109	218		
Sand	60.2	94.6	185.9	0	41.7
Sand+2%cement	57.2	84.4	169.0	8.5	35.1
Sand+3%cement	87.1	114.6	200.1	58.6	33.4
Sand+4%cement	112.3	128.4	218.7	79.6	32.8
Sand+5%cement	96.2	112.3	198.6	83.1	28.3

As seen in Figure 4 and Table 3, when the cement content increases from 0 to 2 percent, the shear strength decreased. By increasing the cement content to 4 percent, the increase in the shear strength becomes more noticeable. According to this figure, the effectiveness of cemented bonds is

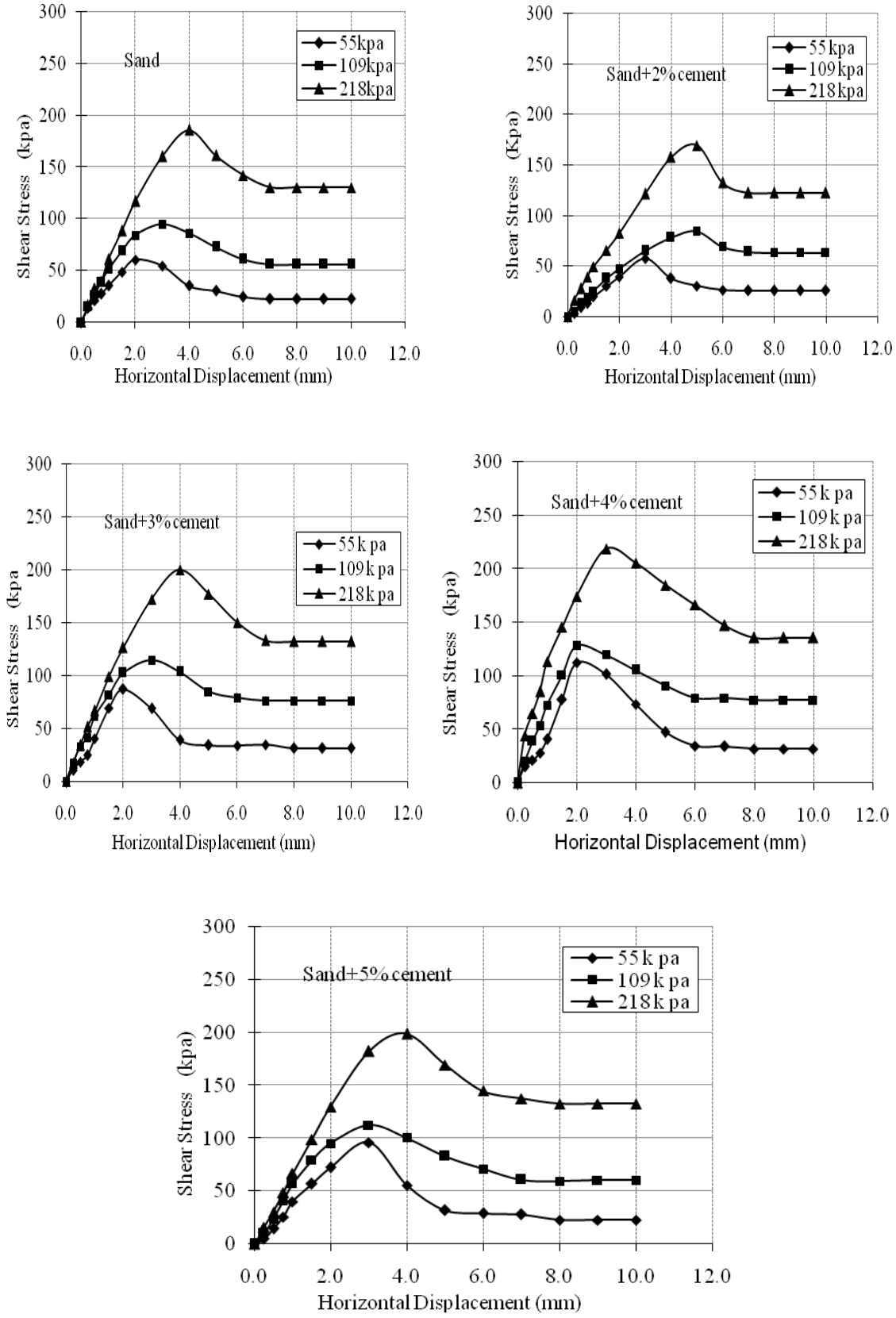

Figure 2.Shear stress versus horizontal displacement for different normal stresses

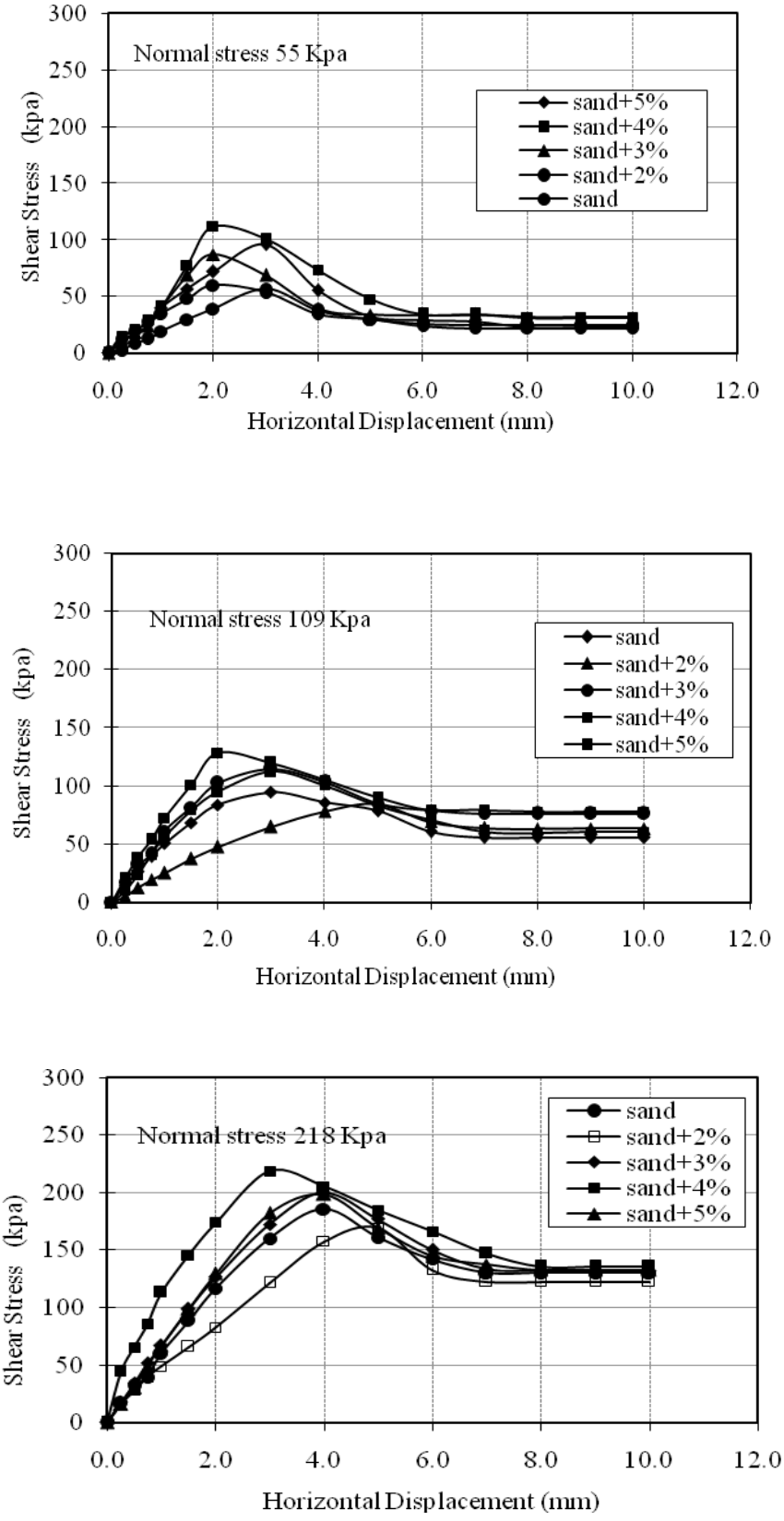

Figure 3.Shear stress versus horizontal displacement for different cement content

greater when the cement content increases from 2 percent to 4 percent than that from 0 to 2 and 4 to 5 percent. It seems that from 0 to 2 and beyond 4 percent cement content, some of the cementing particles act as filler of voids between sand grains rather than an effective bond between contact points of grains. Therefore, adding up to 2 percent cement to sand because of weak bond formation between grains will decreases the shear strength of the cemented sand compared with uncemented sand. Also, the reduction in the shear strength with respect to cement content after 4 percent cement content, suggest a transition of the behavior of cemented sand with cement content.

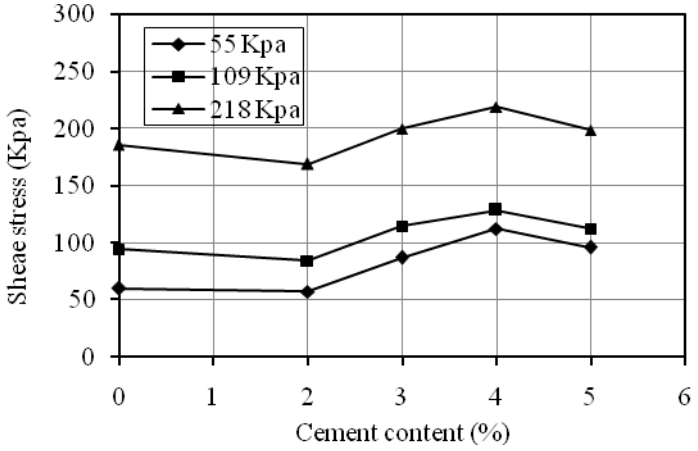

Figure 4. Variation of the shear strength with cement content

Figure 5 shows the shear strength envelopes for samples with different values of cement content. As seen in Figure 5, the values of cohesion increased for all cement content and the values of internal angle of friction decreases with increasing cement content.

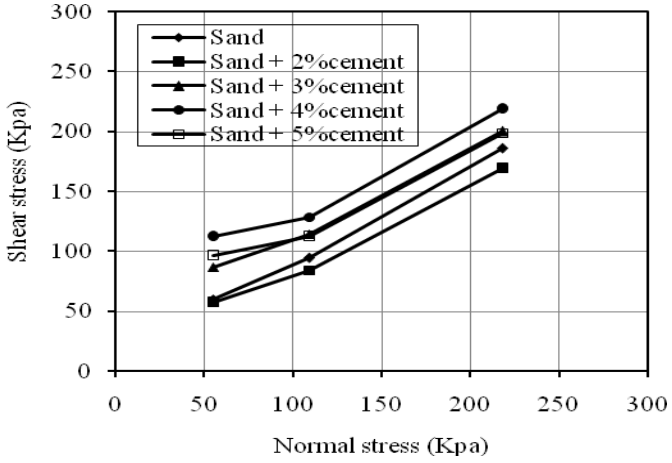

Figure 5. Shear strength envelopes for samples with different values of cement content

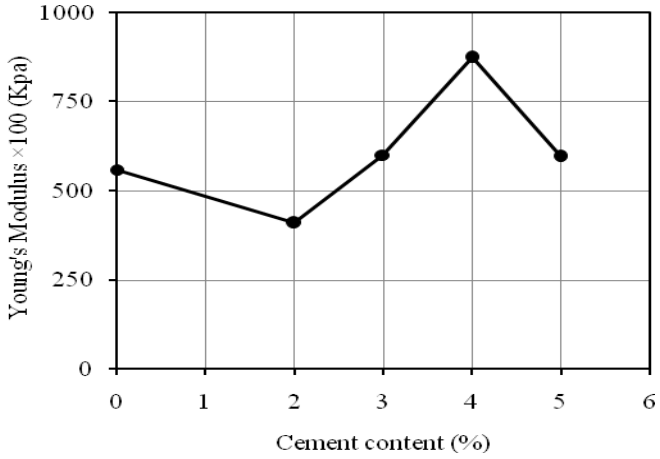

Figure 6. Variation of the Young's Modulus with cement content

The variation in the Young's Modulus computed for different cement content in confining pressure of 218 Kpa presented in Figure 6. According to this figure the Young's Modulus increased with increasing cement content from 2 to 4 percent which shows stiffness and brittle behavior for cemented sand. Increasing cement content to 5 percent reduces the sand stiffness to values lower than that for 4 percent cement.

6 CONCLUSIONS

The effect of the addition of Portland cement to sand was investigated by performing a series of direct shear tests. The results show an increase in shear strength with increasing normal stresses. According to the tests conducted, it was found that the cementation increases the shear strength and stiffness of the sand. The effectiveness of cemented bonds is greater when the cement content increase from 2 percent to 4 percent. The reduction in the shear strength and Young's Modulus with respect to cement content from 4 percent to 5 percent, suggest a transition of the behavior of cemented sand with cement content. The values of cohesion increased for all cement content while the values of internal angle of friction decreased with increasing cement content. The result also shows stiffness and brittle behavior and decrease in contraction for cemented sand.

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