Undrained shear strength and liquefaction potential of loose silty sand treated with micro-fine cement

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Undrained shear strength and liquefaction potential of loose silty sand treated with microfine cement.

La force de cisailles de Undrained et liquefaction potentiels de sable de silty détaché ont traité avec le ciment de microfine.

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ABSTRACT: The objective of present paper is to evaluate the effect of cement grouting on undrained shear strength and liquefaction potential of silty sand. For this purpose, triaxial undrained compression tests are performed on silty sand sample with different amount of silt content (0 – 30 %), treated with microfine cement. The results indicate that, cement grouting significantly improves the physical and engineering properties of soils, which can result in increased shear strength of silty sand.

RESUME: L'objectif de papier actuel sera obligé à évaluer l'effet de ciment mastique sur la force de cisailles de undrained et liquefaction potentiel de sable de silty. A cet effet, les tests de compression de undrained de triaxial sont exécutés sur l'échantillon de sable de silty avec la quantité différente de contenu de silt (0 – 30 %), traité avec le ciment de microfine. Les résultats indiquent cela, le ciment mastique significativement améliore les propriétés physiques et construisant de sols, qui ont pour résultat de la force de cisailles augmentée de sable de silty.

1 INTRODCTION

During earthquake, the shaking of the ground may cause saturated silty soils to lose their resistance and behave like a liquid. This phenomenon is called soil liquefaction and will cause building settlement or tipping, sand boils, landslides and other failures. Many ensuing studies were concentrated on clean sands with assumption that, The behavior of silty sand is similar to that of clean sands. Recent researches made by (Zlatovic and Ishihara 1995, Lade and Yamamuro 1992, Thevanayagam et al 1997, Yamamuro and Lade 1998, Naeini 2001) indicate that sands deposited with silt content are much more liquefiable than clean sands.

In – situ ground improvement has been used extensively in recent years to mitigate liquefaction risk. Mitchell and Wentz (1991) evaluated a number of sites where ground improvement had been used prior to the earthquake. The improvement methods used included vibro–replacement, sand compaction piles, non-structural timber displacement piles, deep dynamic compaction, compaction grout and chemical penetration grouting. The study concluded that no damage was observed due to liquefaction to either the improved ground or the facilities built upon it in the cases studied. Among the treatment methods used for reduction of liquefaction potential, cement grouting may be the most effective in cases where the soil to be treated is difficult to reach as in the case of soils under existing foundations.

In general, cement grouting significantly improves the physical and engineering properties of soil, which can result in reduced liquefaction (Frydman et al. 1980, Red and Clough, 1982, Saxena et al. 1988, Maher et al. 1994, Mitchell 1981). The existing knowledge on the liquefaction potential of cement grouted silty sand is very limited and most of the research activity in this area has been concentrated on the sandy soils.

This paper describes the behavior of cement grouted silty sand under undrained monotonic loading conditions. The objective of the paper is to evaluate the effect of cement grouting on undrained shear strength (Sus) and liquefaction potential of silty sands.

2 MATERIALS TESTED

Ardebil sand was used in all tests performed in this study. Individual particles are sub-rounded and predominant minerals are feldspar and quarts. The fines used in this study was the particles passing through the No. 200 sieve, collected from the natural Ardebil sand resources. The particle size distribution curve and physical properties of the samples are shown in Figure.1 and Table 1.

The microfine cement (MC - 500) was used for grouting. The chemical composition and the physical properties of MC - 500 are presented in Table2. The water - cement ratio used is % 25 (Maher et al. 1994). The final set time for the water - cement ratio considered 24 hours. This time interval was estimated from the results of the study conducted by Schwarz and Krizek (1992).

3 SAMPLE PREPARATION AND TEST PROCEDURES

All test specimens were prepared by under-compaction method which had an initial water content of 9 % and were compacted with 4 % under-compaction value (Uni = 4 %) in six layers (Ladd 1978). The sample preparation procedure used was based on ASTM Test Method for Laboratory Preparation of chemically Grouted Soil Specimens for Obtaining Design Strength Parameters (D - 4320).

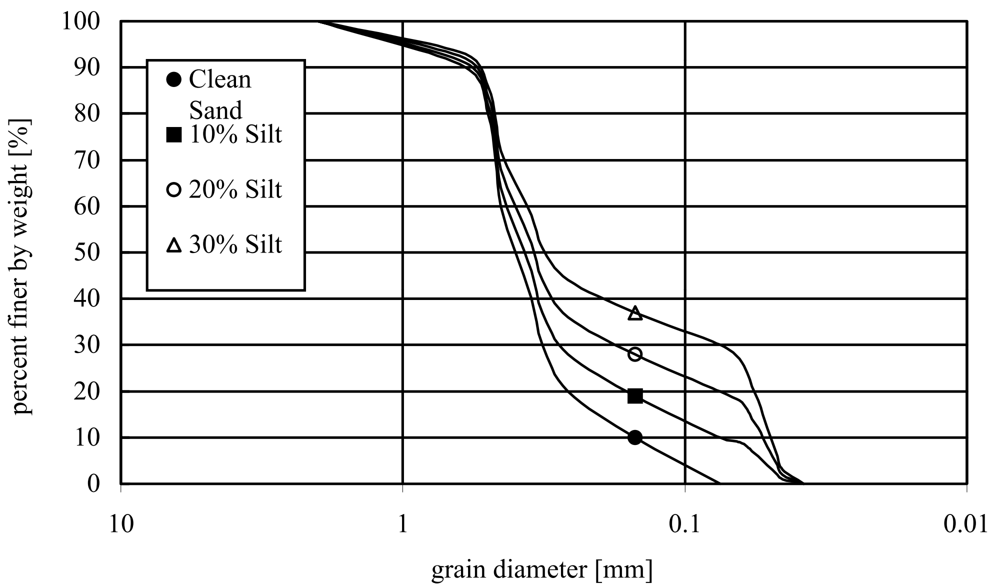

Figure 1. Grain size distribution curves

Table 1. Physical properties of the tested materials.

Material	F.C.*	Gs	D_{50}	Cu	e_{min}	e_{max}
Ardebil sand (AS)	0	2.67	0.19	1.56	.746	1.09
ASF-10	10	2.69	0.18	1.87	.625	1.16
ASF-20	20	2.71	0.14	2.4	.594	1.24
ASF-30	30	2.73	0.10	3.14	.592	1.33

* Cement of grains smaller than 0.074 mm

Table 2. Chemical composition and physical properties of MC-500 (Clark, 1984).

Chemical composition		Physical properties	
Hydration	0.4	Specific gravity	3.0+-0.1
SiO2	30.6	Unit weight (kg/L)	1.0+-0.1
Al2O3	12.4	Odor	Non
Fe2O3	1.1	Appearance light	Gray powder
CaO	48.4	Blaine specific area (cm^2/g)	About 8000
MgO	5.8	50 percent grain size, µm	About 4
SO3	0.8		
Total	99.5		

All samples were 5. 08 mm (2in) in diameter and 101.6 mm (4 in) in height. Purging the specimen with carbon dioxide before adding de-aired water performed saturation. The grout mixture was then injected. The pressure used during the saturation and the injection process were 10 kPa. A minimum of 100 kPa vacuum was used to ensure complete saturation (the vacuum procedure method suggested by Red and Clough, 1982). A minimum B - value of 0.96 was obtained for all specimens. All test specimens were isotropically consolidated at mean effective pressure of 100- 300 kPa. , and then sheared in undrained conditions with a constant strain rate of 1 % per minutes .

4 RESULT AND DISCUSSION

Liquefaction flow failure occurs when a loose, saturated soil loses most of its shear resistance, due to undrained monotonic loading, and flows like a liquid until the shear stresses acting on it are as low as its reduced shear resistance. Based on this approach, liquefaction flow failure is only possible when the steady - state strength of the soil is less then the driving shear stresses.

In this investigation, the results from the undrained monotonic tests were used to determine the effect of grouting on the potential for liquefaction flow failure by comparing the peak and residual strength of the sand and silty sand before and after grouting.

The general undrained stress - strain relationship of Ardebil sand and sand containing different percentages of silt before and after grouting with microfine cement at 100 kPa confining pressure is presented in Figure 2. As shown in the figure, peak and residual strength significantly increases and strain at failure reduces for grouted sands. The residual strength is increased from approximately 83 to 138 kPa , which means more than 60 % reduction of liquefaction potential.

It is clear that, as the silt content increases form 0 - 30%, the peak and residual strength decrease and the contractiveness increases. By grouting these silty sands with microfine cement, the peak and residual strength are increased, but the strength of silty sand is less than the clean sand. The same behavior is obtained with 300 and 500 kPa confining pressure.

The results of triaxial tests shown in Figure 3 indicated that, in these series of samples, before grouting, with increase in silt content up to 30 %, the residual strength steadily decrease. It is also concluded that at the same void ratio the clean sand samples have the highest Sus compared with silty sand. Based on the obtained results show in table 3, the residual strength (Sus) increased in grouted sand and silty sand, and increasing rate for clean sand is about 60 % which is more than the increase rate of silty sands.

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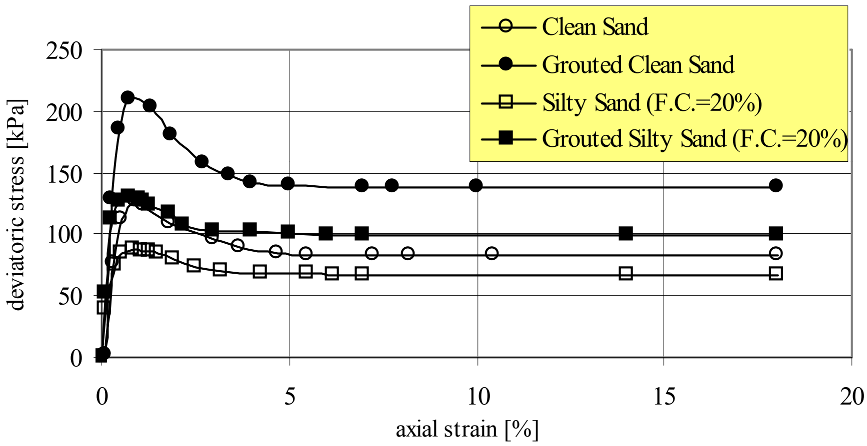

Figure 2. Stress - strain behavior of materials before and after grouting.

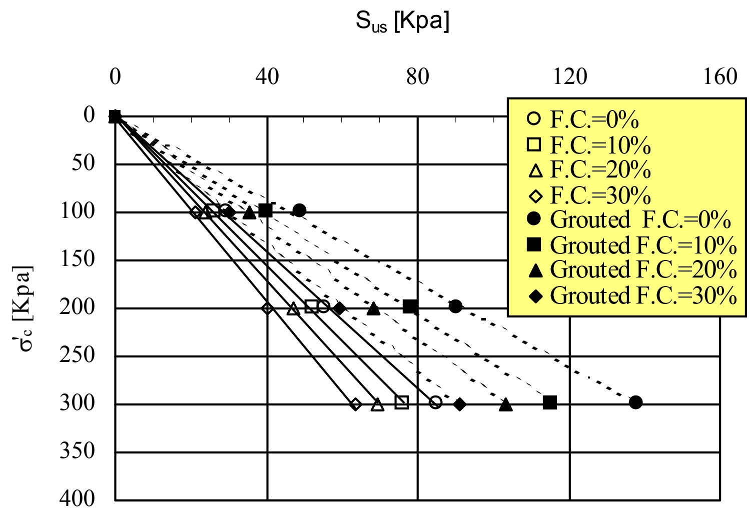

Figure 3. Undrained shear strength versus initial confining pressure

The normalized undrained shear strength in terms of fines content presented in Figure 4, indicate that for the range of 0-30 % fines content, before and after grouting, the following expressions were proposed:

$$Sus / \sigma'c = 0.282 - 0.0025\ (F.C.) \qquad \text{before grouting}$$

$$Sus / \sigma'c = 0.452 - 0.0052\ (F.C.) \qquad \text{after grouting}$$

$$\text{For} \quad 0 < F.C.(\%) < 30\%$$

The results clearly show that cement grouting significantly increase the undrained shear strength of sand and silty sands, which can result in reduced liquefaction potential

Table 3. summery of test result

Test No.	Type of Material	Silt Content (%)	σ' (kPa)	Sus Before grouting (kPa)	Sus after grouting (kPa)
1	Clean Sand	0	100	29.7	49.3
2			200	55.4	90.8
3			300	85.2	138.1
4	Silty Sand	10	100	26.3	40.5
5			200	52.2	78.3
6			300	76.4	115.4
7		20	100	23.9	35.4
8			200	47.2	68.4
9			300	69.2	103.1
10		30	100	21.2	30.2
11			200	36.4	50.9
12			300	63.5	91.2

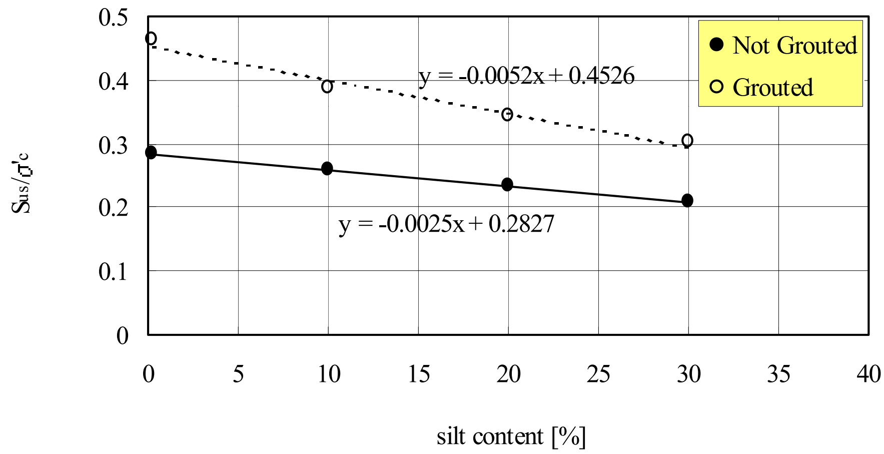

Figure 4. Normalized shear strength versus silt content

5 CONCLUSIONS

Undrained monotonic shear behavior of sand and silty sand before and after grouting with microfine cement were investigated. The effect of grouting on the potential for liquefaction flow failure were studied, the following main conclusions were obtained as a result of this study:

The peak strength and residual strength are sensitive to the silt content. Sand containing 10 to 30 % of silt, has less resistance to liquefaction than pure sands. In fact, residual strength decreases as the content of silt increases.

Improvement of soil properties with cement grouting can reduce the potential for liquefaction - related damage in earthquakes. Although less complicated and more economical densification procedures are the primary methods for limiting liquefaction risk, cement grouting might be the only possible choice where the soil to be treated is difficult to reach (under existing structures or around buried systems) or vibration associated with densification procedures which to be unacceptable .

The results of this investigation and those from past research clearly show that microfine cement grouting significantly increases the peak strength, slightly reduces the strain at failure, and increases the shear strength of the silty sand. Therefore, for liquefaction flow failure to occur in grouted silty sand, a higher load condition is needed to " push the silty sand over the peak ".

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