Effect of Geotextile on the Liquefaction Behavior of Sand in Cyclic Triaxial Test

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Abstract— **Liquefaction is one of the most important phenomena related to the earthquake that decrease the resistance of saturated soils. The problem of liquefaction of sand is nowadays a classical soil mechanics subject. Since loading due to earthquake is very fast and there is not drainage possibility in loading time, so study of sands shear behavior is performed under undrained and saturation conditions. Using a cyclic triaxial test apparatus, we use non-woven geotextile reinforcement to improve the liquefaction resistance of sand. The layer configurations used are zero, one and two horizontal reinforcing layers in a triaxial test sample. The influences of the number of geotextile layers, and cyclic stress ratio (CSR) were studied and described. Tests were performed on samples with diameter of 70 mm and a height of 140 mm. Only one type of soil and one type of geotextile were used in all tests. The results illustrated that the geotextile inclusion increases liquefaction resistance.**

Keywords— Geotextile; liquefaction resistance; sand; cyclic triaxial test; cyclic stress ratio;

I. INTRODUCTION

Liquefaction is one of the most important phenomena related to the earthquake that decrease the resistance of saturated soils. Castro [1] found that sudden increases of pore water pressure, induced by monotonic shearing under undrained conditions, lead to the liquefaction of sand layers. Krishnaswamy and Isaac [2] performed a series of cyclic triaxial test to evaluate the liquefaction potential of sand with and without reinforcement. The results were shown that the reinforced sand can be a promising solution for increasing the safety against liquefaction potential of sand.Vercueil et al. [3] presented various tests using a cyclic triaxial instrument, on samples of saturated Hostun RF sand, reinforced with circular sheets of geosynthetic material. Tests were performed with different types of geosynthetic of different compressibility, rigidity and roughness characteristics indicate a significant increase in liquefaction resistance for samples reinforced with compressible, non-woven geotextile. The undrained behavior of saturated Hostun RF sand reinforced with non-woven geotextile is analyzed on the basis of different test series. This analysis highlights the influence of reinforcement compressibility on interstitial pressure distribution in the sample, thus showing the role of this type of inclusion in the increase in liquefaction resistance.

A series of stress controlled cyclic triaxial tests were carried out on fly ash samples reinforced with randomly distributed fiber and mesh elements (Boominathan and Hari, [4]).Test results indicate that the addition of fiber/mesh elements increases the liquefaction strength of fly ash significantly and arrests the initiation of liquefaction even in samples of loose initial condition and consolidated with the low confining pressure.

Haeri et al. [5] carried out monotonic triaxial compression tests in order to study stress-strain and dilation characteristics of geotextile-reinforced dry beach sand. The results illustrated that geotextile inclusion increases the peak strength, axial strain at failure, and ductility.

As well as numerous other papers have studied the beneficial effects of soil reinforcement to increase the strength (McGown et al. [6] Gray and AL-Refeai [7], Athanasopoulos [8], Chandrasekaran et al. [9], Latha and Murthy [10], Xie [11], etc) using triaxial, direct shear and plane strain tests.

In the Current research, reinforced and unreinforced soil aggregate systems were prepared in the laboratory. The reinforcing materials were placed at the interface of soil aggregate system. Experiments were conducted to study the effect of reinforcement and cyclic stress ratio (CSR) on the liquefaction resistance of sand.

II. TEST MATERIAL

The Firoozkuh sand is used in the current study. Some of the physical properties of Firoozkuh sand are shown in Table I and the sand particle size distribution curve is depicted in Fig. 1. As it is shown, the sand can be considered as fine sand.

TABLE I. PHYSICAL PROPERTIES OF FIROOZKUH SAND

Firoozkuh	e_{min}	e_{max}	*Gs*	*Cc*	*Cu*	*F%*
Sand	0.56	0.877	2.658	0.93	1.7	0

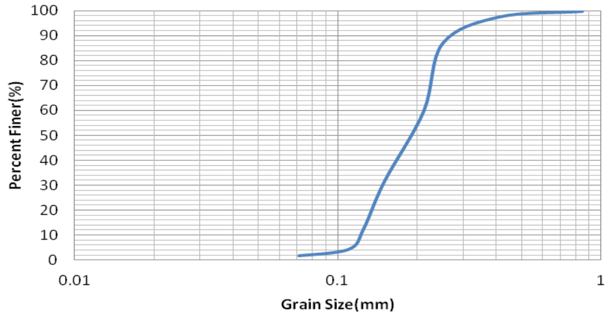


Fig. 1. Grain size distribution of Firoozkuh sand.

A. Geotextile

The geotextile used in this research, was made by an Iranian company. This type of geotextile is non-woven with mass of 400 mgh; nominal thickness of 3.2 mm and effective opening size of 0.15mm. Figure 2 shows arrangement of geotextile in cyclic tests.

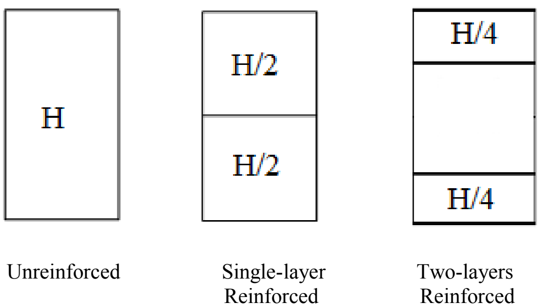


Fig. 2. Geotextile arrangement for cyclic tests

B. Test equipment

A cyclic triaxial device was used. Figure 3 shows this apparatus. The cyclic tests were performed at Laboratory of Imam Khomeini International University.

Fig. 3. An overall view of the cyclic triaxial apparatus.

III. Sample Preparation

The preparation of the soil sample is of great importance for laboratorial research. . samples were prepared using a moist tamping technique. This technique is commonly used in laboratory studies of sand and allows the control of sample density. The soils were mixed with water so that moisture content (w) of soil is 5% and then placed within five layers. After compacting and leveling each layer of soil, the geotextile layer (with a diameter slightly less than the sample) was placed horizontally on the surface of layer. For all of the samples a relative density of RD = 30% is used.

IV. Test Procedure

Samples with 70mm diameter and 140mm height were prepared. The test results are given in Table II. The main purpose of these tests was to find out the failure stress of each sample, which was later used for conducting repeated triaxial tests. Typical results in the form of stress–strain plots of these tests are given. After the sample was formed, it was saturated using carbon dioxide (CO_2) and de-aired water. Firstly, CO_2 was percolated through the sample to expel the air in the sample pores. Then, deaired water was infiltrated into the sample to expel the CO_2 as completely as possible. After that, the degree of saturation was checked using the parameter $B_D = \Delta u/\Delta \sigma$, where Δu is an increment of pore pressure and $\Delta\sigma$ is an increment of normal stress.

In this study, the sample was first consolidated under a normal stress of 30 kpa at the drained condition. An increment of normal stress, $\Delta\sigma$= 30 kpa, was then applied in the undrained state, and the resultant excess pore pressure increment Δu was measured. Finally the saturation degree B_D was indirectly given by $\Delta u/\Delta\sigma$. Values of BD of at least 0.96 were deemed to indicate sufficient water saturation for all the undrained tests.

After checking the B_D, the saturated sample was consolidated under selected values of normal stress 100 kpa in a drained condition until the axial strain was constant. Thereafter, the drainage valve was closed and then finally a cyclic deviator stress was applied in both compression and extension side. The frequency was about 2 Hz.

V. Definitions

The definition of the CSR is normally given as:

$$CSR = \frac{\sigma_{dcy}}{2\sigma'_{3c}} \tag{1}$$

Where, σ_{dcy} is the applied cyclic stress.

A direct comparison of the cyclic resistance using the CSR versus the number of cycles to failure for a standard suite of stress-controlled cyclic tests requires a cyclic stress ratio.

VI. Test Results and Discussions

In this part results of the experimental investigation are presented. Total number of 9 cyclic triaxial tests is conducted on the pure Firoozkuh sand with and without geotextile. Therefore the presented discussion is focused on the behavior of unreinforced and reinforced sand.

A. Changes in pressures during cyclic loading

Figure 4 shows the pressure changes during cyclic loading. At the shear stage, cell pressure is constant but pore water pressure increases and effective confining pressure decreases until the pore water pressure is equal to the initial confining pressure and effective confining pressure reaches to zero.

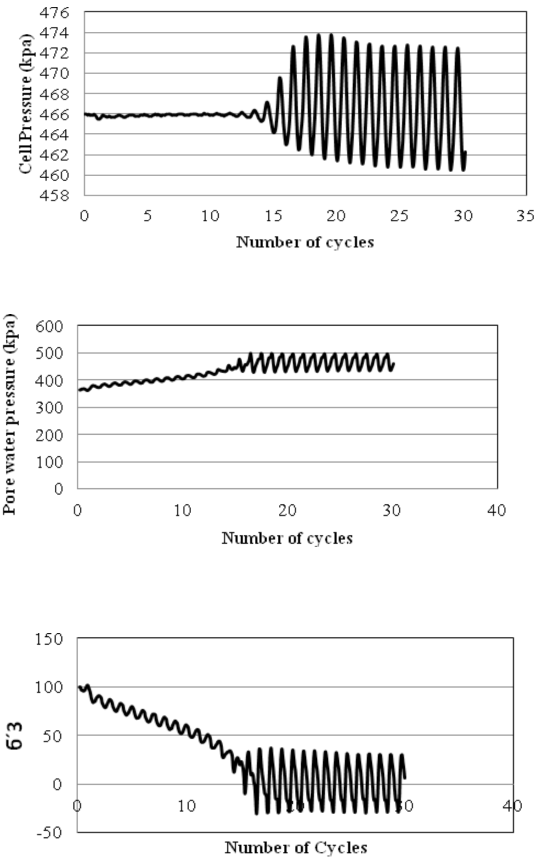


Fig. 4. Changes in pressures during cyclic tests
(P'0=100kPa, CSR=0.16, Dr=0.30)

B. Deformation pattern in cyclic compression modes

The resistance of sand to soil liquefaction is evaluated by performing cyclic undrained test on sand specimen using cyclic triaxial apparatus. In the tests, samples of unreinforced and reinforced sand are consolidated under a specified confining pressure and subjected to cyclic stress until the specimen either deforms to a certain amount of strain, or the excess pore water pressure reaches a value close to the initial confining pressure.

At this stage, it can be considered that the specimen is in a state of cyclic instability, and liquefaction has occurred. In essence, liquefaction can be defined in two ways: (a) development of high pore water pressure, the pore pressure ratio (r_u) of 1; or (2) development of high strain, typically expressed as 2.5% double amplitude axial strain for triaxial tests.

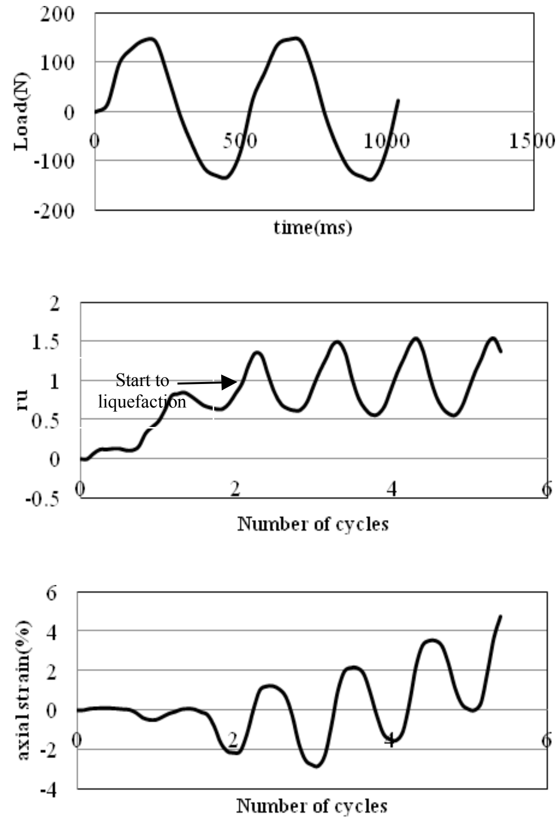


Fig.5. Behavior of Unreinforced sand during cyclic tests
(Unreinforced sand, P'_0=100kPa, CSR=0.19, Dr=0.30)

Typical results of cyclic tests on the saturated pure sand with and without geotextile are shown in Figure 5 and 6. The extensional and compression deviator stresses are equal during each loading cycle. In other word a symmetric stress history was applied to the soil samples. As shown in Fig. 5 and 6, in constant cyclic stress ratio (CSR=0.19), liquefaction of unreinforced sand occurs in 2 cycles but liquefaction of reinforced sand occurs in 5 cycles. So, geotextile inclusion decreases liquefaction potential.

C. Stress-strain behavior

Figure 7 shows the stress-strain loops for typical test results. As shown in this figure, mean effective stress starts from value equal to effective confining pressure and it found that progress of axial extensional strain in each cycle is larger than compression strain because of inherent anisotropy of sand.

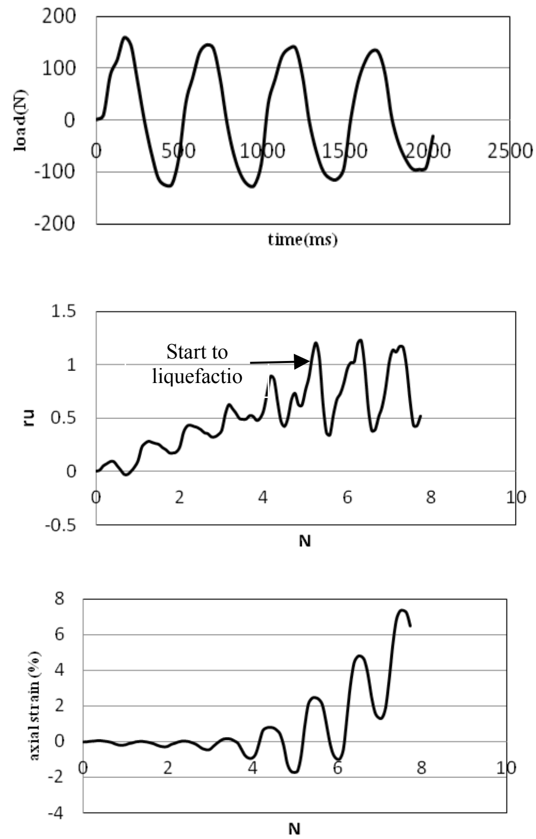
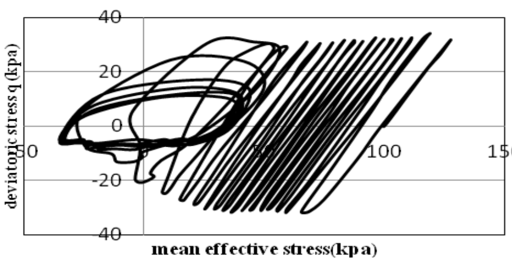
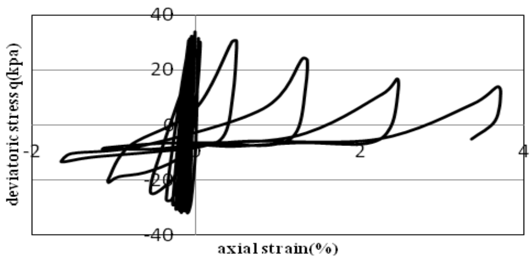


Fig. 6. Behavior of reinforced sand during cyclic tests
(1R, P'0=100kPa, CSR=0.19, Dr=0.30)



(a)



(b)

Fig. 7. Stress-strain diagrams
(Unreinforced, P'0=100kPa, CSR=0.16, Dr=0.30)

The liquefaction potential of any given soil deposit is determined by a combination of the soil properties, environmental factors and characteristics of the earthquake to which it may be subjected to. The testing conditions for the cyclic tests were summarized in Table II.

D. Effect of reinforcement on the liquefaction of sand

The characteristics of tests and their results are shown in Table II.

TABLE II. LIST OF CONDUCTED TESTS AND THEIR RESULTS

No	P'_0 (kpa)	Reinforcement	CSR	N
1	100	unreinforced	0.15	156
2	100	unreinforced	0.16	16
3	100	unreinforced	0.19	1.5
4	100	1R	0.15	239
5	100	1R	0.17	35
6	100	1R	0.19	5
7	100	2R	0.16	246
8	100	2R	0.18	26
9	100	2R	020	3.5

Figure 8 shows effects of cyclic stress ratio (CSR) and number of geotextile layers on the liquefaction resistance. As shown in figure, number of cycles to cause liquefaction dropped significantly when higher cyclic stress ratios were applied. Also results illustrated that, at the constant CSR, increasing the number of geotextile, led to a higher number of cycles leading to liquefaction. So geotextile layer increases liquefaction resistance of sand.

Also as shown in Fig.8, CSR-N curve for reinforced sand is above the curve of unreinforced sand, so geotextile is beneficial to increase resistance to liquefaction.

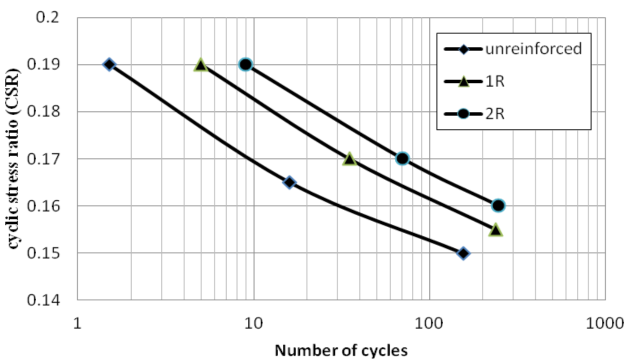


Fig. 8. Effect of reinforcement on the liquefaction of soil.

In liquefaction analyses, usually a reference earthquake of magnitude equal to 7.5, causing the liquefaction at 15 cycles is used. For this reason, the cyclic resistance ratio (CRR15) is used as a measure of the resistance to liquefaction. Figure 9 shows effect of number of geotextile layers on the cyclic resistance ratio (CRR). As shown in figure 9, by increasing the number of geotextile layers, CRR is increased and thus liquefaction potential is reduced.

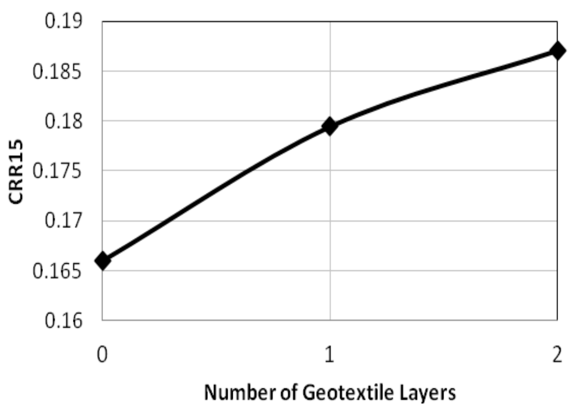


Fig. 9. Effect of geotextile layers on the cyclic resistance ratio (CRR)

VII. Conclusion

Results of 9 undrained cyclic triaxial tests on Firoozkuh sand with and without geotextile were studied. In these tests specimens were tested under isotropic consolidation. To obtain the cyclic resistance of soil samples to liquefaction the cyclic stress was applied with different amplitudes under undrained condition.

In this paper, Effects of cyclic stress ratio (CSR) and reinforcement on the liquefaction resistance of sand are investigated. The followings are the most important conclusions drawn from this study:

In all samples, the number of cycles to cause liquefaction dropped significantly when higher cyclic stress ratios were applied. So, it can be found that increases of cyclic stress ratio (CSR) have a direct impact on the liquefaction potential. In other words, in all circumstances, increase in this ratio increases liquefaction potential or decreases number of cycles that cause liquefaction.

According to CSR curve in terms of number of cycles, at the constant CSR, increasing the number of geotextile, led to a higher number of cycles leading to liquefaction. This issue is caused by increase of confining pressure in the presence of geotextile layer. So, geotextile layer is beneficial to decrease liquefaction potential of sand, and improvement in liquefaction resistance with increasing the number of geotextile layers increases.

With the increasing number of geotextile layers, liquefaction resistance increases, but the rate of increase of resistance is reduced and soil reinforced with 2 geotextile (2R) has the highest resistance to liquefaction.

Acknowledgment

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