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Reinforcement Effect on Dynamic Properties of Saturated Sand

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***Abstract*—**Dynamic behavior of soil are evaluated relative to a number of factors including: strain level, density, number of cycles, material type, fine content, geosynthetic inclusion, saturation, and effective stress .This paper investigate the dynamic behavior of saturated reinforced sand under cyclic stress condition. The cyclic triaxial tests are conducted on remolded specimens under various CSR which reinforced by different arrangement of non-woven geotextile. Aforementioned tests simulate field reinforced saturated deposits during earthquake or other cyclic loadings. This analysis revealed that the geotextile arrangement played dominant role on dynamic soil behavior and as geotextile close to top of specimen, the liquefaction resistance increased.

***Keywords*—**Dynamic Behavior, Reinforced Sand, Triaxial Test, Non-woven Geotextile.

I. Introduction

THE phenomenon of the loss of strength of saturated uniformly graded sand and gravel is generally referred to as liquefaction. Liquefaction may be caused by cyclic or monotonic undrained loading. The process of liquefaction transforms an element of soil from a solid to a liquid state, which eventually leads to the development of instabilities in large masses of soil, bringing about extensive damage to supported structures. The devastating nature of this type of failure attracted the attention of researchers in this area and considerable work has been done to evaluate the susceptibility to liquefaction. Improving site conditions to eliminate liquefaction is one area that received considerable attention from practicing engineers. The methods commonly adopted include installation of gravel drains, compaction of the existing soil with piles using coarse backfill [1], replacement of the loose site soil with a more acceptable material [2], installation of dewatering systems, stabilization using suitable chemicals, blast densification, deep dynamic compaction, surcharge, vibrofloatation, and a combination of the aforementioned methods. The time has long since passed when, in the 1960s, this type of material was used essentially to facilitate locomotion or to improve soft soil bearing capacity. Reinforced soil has gained popularity due to its extensive application in various problems such as retaining walls, port structures, embankments, and so on. Krishnaswamy and Isaac (1994) conducted cyclic triaxial tests on reinforced soil specimens and concluded that the deployment of reinforcement has a significant effect on increasing the liquefaction resistance of sand [3]. Ling and Tatsuoka (1994) conducted a study on silty clay reinforced with three types of geosynthetics, two geotextiles, and a geogrid under plane strain conditions [4]. Taha et al. (1999) demonstrated the behavior of georeinforced residual soil using drained triaxial samples, shown that the reinforced systems increased strength-deformation properties in a significant manner [5]. Ashmawy et al. (1999) reported that reinforced soils exhibit an improvement in strength-deformation characteristics under monotonic loading conditions, due to the additional "pseudo" confinement caused by the lateral restraint and shear mobilization [6]. In view of the varied hydraulic and mechanical properties of these materials, para-seismic engineering specialists are showing increasing interest in them [7], [8]. This study included a number of cyclic triaxial tests on Firouzkuh #161 sand samples reinforced with different arrangement of geotextile, to characterize the role played by these inclusions on dynamic behavior.

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II. Experimental Apparatus and Material Used

A. Cyclic Triaxial Setup

Specimens were tested in a cyclic triaxial device (Wykeham Farrance31-WF7008). The device is instrumented with LVDT, a load cell, pore pressure and a cell pressure transducer and a computer controlled data acquisition system (Fig. 1).

Fig. 1 Cyclic triaxial device set

B. Material Used

1. Sand

The sand used in this study is Firouzkuh #161 crushed silica sand. This type of sand has a golden yellow color and has a uniform aggregation, which henceforth briefly named Firouzkuh Sand (Fig. 2). Firouzkuh sand has recently been used in studies in laboratory stress-strain tests and studies on cyclic loading and liquefaction behavior in the University of Tehran and Amirkabir University of Technology and defined as a standard sand in Iran [9], [10]. Toyoura and Sengenyama standard sands that their characteristics are described in this paper were compared to Firouzkuh sand (Table I). Grain size distribution curves of the last two mentioned sands are presented in Fig. 3.

TABLE I
FIROUZKUH SAND PHYSICAL CHARACTERISTICS AND COMPARING WITH TOYOURA AND SENGENYAMA SANDS

Sand type	Firouzkuh #161	Toyoura	Sengenyama
Gs	2.685	2.65	2.72
emax	0.94	0.97	0.91
emin	0.60	0.597	0.55
D_{50} (mm)	0.27	0.17	0.27
C_u	1.87	-	-
C_c	0.88	-	-

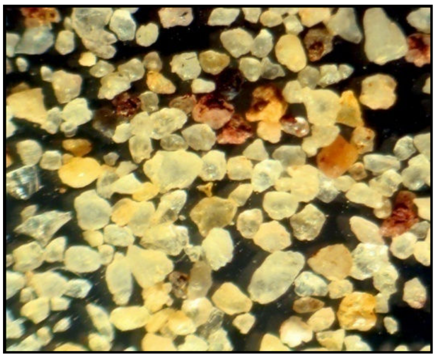

Fig. 2 Magnified picture of Firouzkuh sand grains

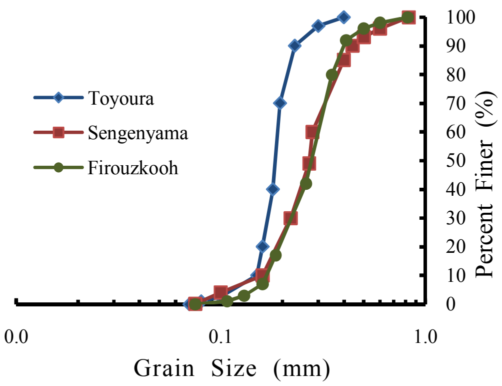

Fig. 3 Grain size distribution curve of Firouzkuh sand compared with other famous sands

2. Geotextile

Table II presented properties of this non-woven PET geotextile. Picture of geotextile are shown in Fig. 4.

TABLE II
GEOTEXTILE PROPERTIES

Properties	ASTM METHOD	Quantity
Unit weight	D-5261	500 gr/m^2
Thickness	D-5199	3.5 mm
Puncture strength	D-4833	1100 N
Wide width tensile	D-4595	23.1 kN/m

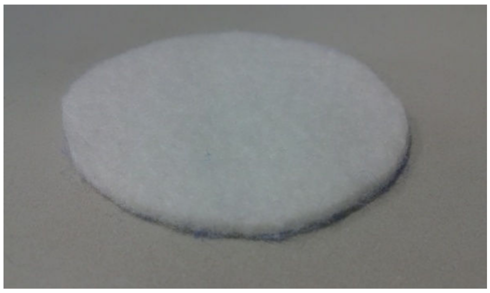

Fig. 4 Geotextile used

III. EXPERIMENTAL PROCEDURE

A. Sample Preparation

The tests were performed on samples with a slenderness coefficient of 2, and a height of 14cm. With a density of 13 kN/m^3, corresponding to a relative density of 27%, the dry sand specimens were prepared by pouring the sand through a funnel in a mould by maintaining a constant funnel height above the sand surface. Geosynthetic inclusions of 7 cm diameter are placed horizontally in the sample as each of the sand layers is formed. The specimens with different geotextile arrangement are shown in Fig. 5. After the specimen has been formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 35 kPa (ASTM D5311-92) is applied to the specimen to reduce the disturbances. Tubing connections to the top and bottom specimen platens permit flow of water during saturation, consolidation and measurement of pore water pressure during cyclic loading.

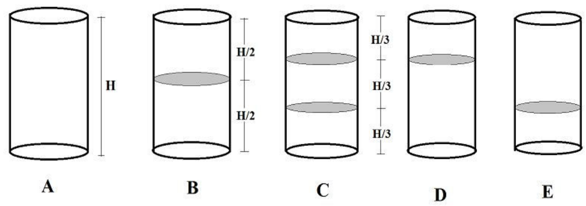

Fig. 5 The different geotextile arrangement in specimens

B. Saturation and Consolidation

When the triaxial cell is assembled and filled with water, an isotropic pressure of 10 kPa is applied. After circulating a flow of carbon dioxide (CO_2) under a low-pressure gradient (5kPa) through the sample for 7min, water is circulated about 30 min until the total quantity of water passing through the sample is at least equal to twice the initial volume of the sample. After this water percolation period, the effective stress acting on the sample is kept constant by a parallel increase in the backpressure and cell pressure. The backpressure used varies from 10 to 90 kPa, which is sufficiently high to dissolve the carbon dioxide and to obtain Skempton B coefficients greater than 0.95 [11].

Following saturation, the specimens are consolidated isotropically (equal axial and radial stress). The specimens were consolidated isotropically at mean effective pressures 100kPa.

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After saturation and consolidation, the specimen is subjected to a sinusoidal varying axial load by means of the load rod connected to the specimen top platen. The cyclic load, specimen axial deformation, and pore water pressure development with time are monitored. The test is conducted under undrained conditions to approximate essentially undrained field conditions during earthquake or other dynamic loading. The cyclic loading generally causes an increase in the pore water pressure in the specimen, resulting in a decrease in the effective stress and an increase in the cyclic axial deformation of the specimen.

The liquefaction tests are performed by applying a sinusoidal stress deviator at a frequency f =2 Hz and by keeping the confining pressure σ_{cell}, constant at 100 kPa. Cyclic Stress Ratio (CSR) is equal to 0.30 for all tests. The Cyclic liquefaction is considered to occur when one of the following conditions is satisfied:

1. Cancellation of effective stress ($Ru = u/\sigma_{cell} = 1$);
2. Axial deformation greater than 5%.

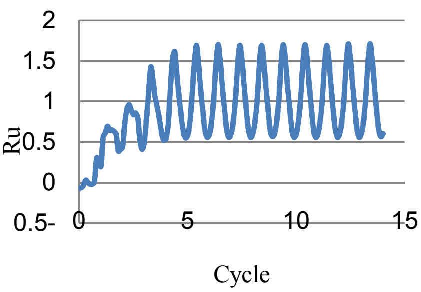
Both of liquefaction criteria considered for specimens.

IV. Result

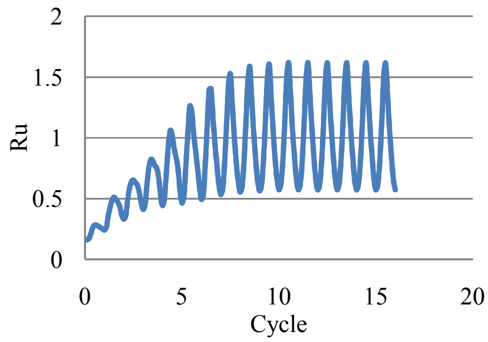
The sand Firouzkuh #161 sand is used to construct the specimens and to study the behavior of reinforced sand. Undrained triaxial tests under dynamic loading condition on unreinforced and reinforced samples are performed with different geotextile arrangement.

The results pore pressure ratio (Ru) and strain of these liquefaction tests on A – E specimens are presented in Figs. 6 and 7 respectively. For each sample tested, the liquefaction resistance tended to drop with increase in the number of cycles. The specimen's liquefaction cycle by two liquefaction criteria are shown in Figs. 8 and 9. As observed from aforementioned figure C-specimen (2 layer geotextile at H/3 and 2H/3 distances from top of sample) presented more liquefaction resistance compared to others.

By Collation of B, D and E arrangement revealed that as geotextile close to top of specimen (load applying part) the liquefaction resistance increased and E (1 layer geotextile at 2H/3 distance from top of specimen) type of reinforcement arrangement tested doesn't lead to an increase in liquefaction resistance of the sand.



(a)



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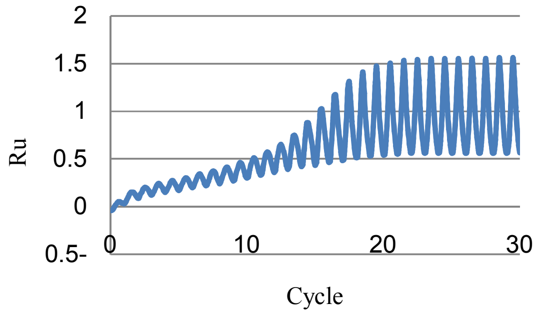

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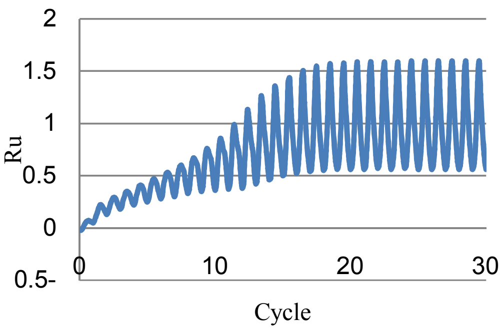

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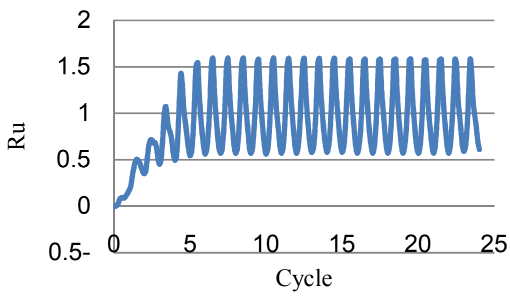
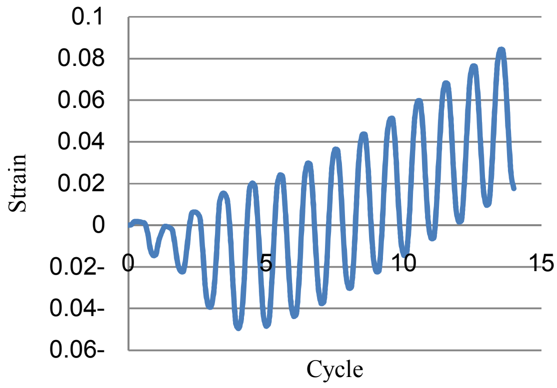
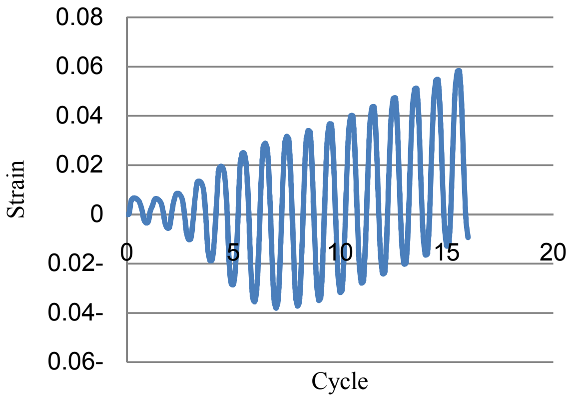


(e)

Fig. 6 Ru with cycles for A-E specimens (a) A sample (unreinforced) (b) B sample (c) C sample (d) D sample (e) E sample



(a)



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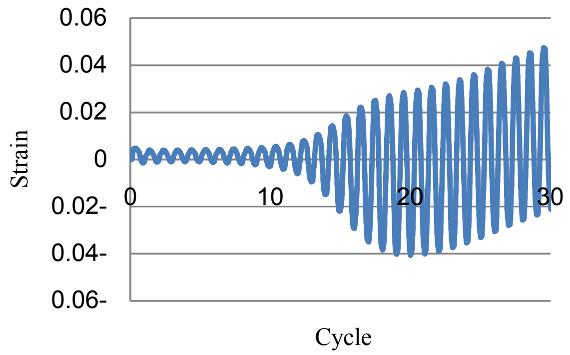

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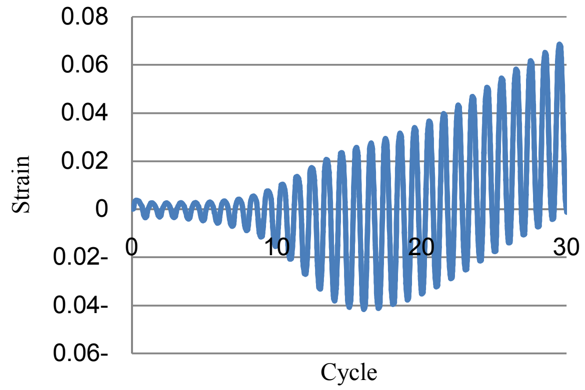

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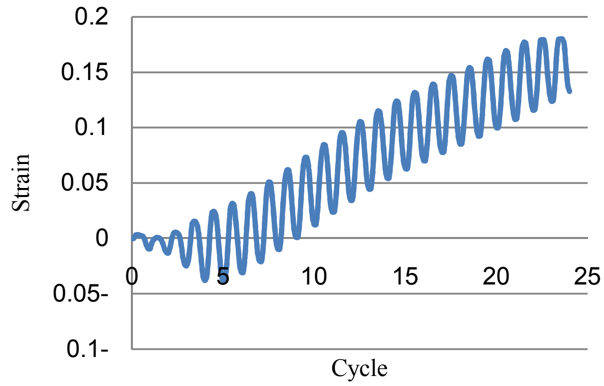

(e)

Fig. 7 Strain with cycles for A-E specimens (a) A sample (unreinforced) (b) B sample (c) C sample (d) D sample (c) C sample (d) D sample (e) E sample

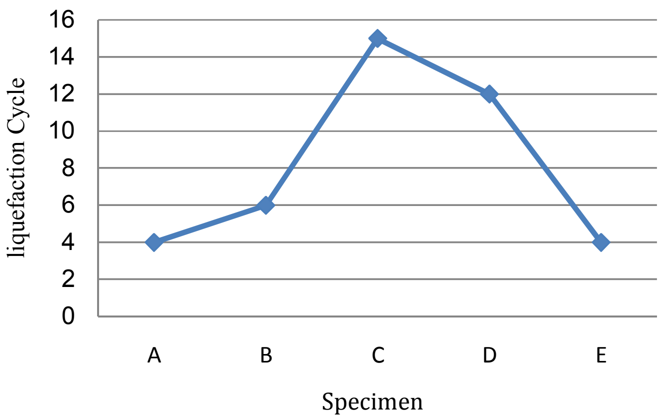

Fig. 8 Specimens liquefaction cycle for Ru=1 liquefaction criteria

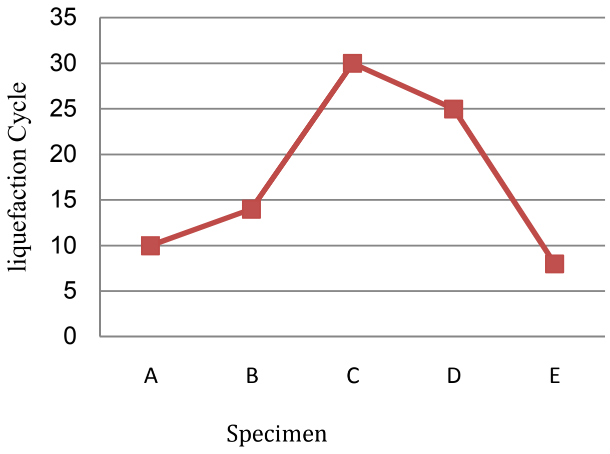

Fig. 9 Specimens liquefaction cycle for axial strain=5% liquefaction criteria

V. Conclusion

A series of cyclic triaxial tests were conducted to investigate the arrangement of geotextile inclusion on dynamic behavior of saturated sand. Based on this experimental study, the following concluding remarks are summarized.

The reinforcement inclusion increases the cyclic strength of soil, thereby making it less susceptible to liquefaction.

As geotextile close to top of specimen (load applying part), the liquefaction resistance increased.

By increasing space between geotextile and cap of sample reinforcement effect on the liquefaction resistance decreases. This indicates that the reinforcement has not significant influence on the liquefaction resistance of soil in the large distance of load applying part (beyond 2H/3). Thus, utilization of geotextile inclusion near the loading part in field is preferable.

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