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Cyclic behaviour of dry silty sand reinforced with a geotextile

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ABSTRACT

Recent studies on construction material technology have indicated that soil reinforcement improves resistance of soil against compression and tension. Due to the wide use of geotextile reinforcement in road construction, the potential benefit of geotextile reinforcement in cyclic loading should be investigated. In this study we performed a series of cyclic triaxial tests to examine dry silty sand reinforced with geotextile when subjected to dynamic loading. These tests were conducted on reinforced and unreinforced dry sand and sand mixed with varying amounts of silt (0–50%). The main factors affecting the cyclic behaviour, such as the arrangement and number of geotextile layers, confined pressure and silt content are examined and discussed in this paper. The results indicate that geotextile inclusion and increased confining pressure increase the axial modulus and decreased cyclic ductility of dry sand for all silt contents examined. Also, it was found that by increasing the silt content by up to about 35 percent the axial modulus in reinforced and unreinforced sand is decreased and cyclic ductility increased. With further increases in silt content, these values are increased for cyclic axial modulus and decreased for cyclic ductility.

1. Introduction

If the stability of the soil in a civil project is not adequate for supporting applied loads, the properties may be improved by soil reinforcement techniques. The acceptance of soil reinforcement can be attributed to a number of factors, including low cost, reliability, simple construction techniques, and the ability to adapt to different site conditions. Since 1970's, the use of geotextile as reinforcement has become more popular due to a more satisfactory performance compared with metal reinforcement, which has been reported in several instances (Gray and Ohashi, 1983; Joseph and Fluet, 1986; Leschinsky et al., 1986; Raymond, 1999; Tarafder, 2008). The reason for this performance is that geotextile or synthetic fabrics have relatively low stiffness compared to that of steel reinforcements. Geotextile, as a reinforcing material, in both forms of planner and fiber, not only increases shear strength but also improves static liquefaction resistance, ductility and provides less post-peak strength reduction in reinforced sand in comparison with unreinforced sand. Such results were obtained from the studies of Al Refeai (1991), Ranjan et al. (1994), Yetimoglu and Salbas (2003), Consoli et al. (2009), Ibraim et al. (2010), Liu et al. (2011) and Hamidi and Hooresfand (2013), all of which mostly focused on evaluation of the behaviour of soils reinforced with distributed fibers. Over the past few decades, the beneficial effects of using planner reinforcement to increase the strength of sand at failure and the factors affecting these beneficial effects such as type and material of reinforcement, soil particle size and arrangement of reinforcements have been evaluated by some researchers in monotonic conditions (McGown et al., 1978; Chandrasekaran et al., 1989; Kothari and Das, 1992; Athanasopoulos, 1993; Haeri et al., 2000; Latha and Murthy, 2007; Moghaddas Tafreshi and Asakereh, 2007; Sadoglu et al., 2009; Subaida et al., 2009; Khoury et al., 2010; Tuna and Altun, 2012; Abu-Farsakh et al., 2013; Vieira and Lopes, 2013; Altalhea et al., 2013).

Compared to the studies performed in static loading, fewer investigations have been carried out for cyclic loading. Among such studies are Maher and Woods (1990), Kothari and Das, 1994, Krishnaswamy and Isaac (1994), Vercueil et al. (1997), Feng and Sutter (2000), Boominathan and Hari (2002), Shahnazari et al. (2009), Moghaddas Tafreshi and Dawson (2009, 2012), Palmeira and Antunes (2010), Wang et al. (2011), Sreedhar and Kumar (2011), El Sawwaf and Nazir (2012), Koseki (2012), Vieira et al. (2013) and Srilatha et al. (2013), which mostly concentrated on the evaluation of the dynamic behaviour of soils reinforced with plane elements and distributed fibers using the cyclic triaxial test,

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torsion shear tests, shaking table tests and resonant column tests. Ravi Shankar and Sitharam (2005) evaluated the dynamic properties of Ahmedabad sand at large strains by performing a strain controlled cyclic triaxial test on dry and saturated soil samples at medium to large shear strain levels. The results of the study highlighted that the dynamic properties of sands are not very much influenced by the dry or saturated condition of samples, further the effect of frequency of loading is not significant on shear modulus but has some influence on the damping ratios of the soils for the range of frequencies tested. Bhandari and Han (2010) investigated the geotextile–soil interaction under a cyclic wheel load using the Discrete Element Method (DEM). The DEM results showed that the depth of the geotextile significantly affected the degree of interaction between the geotextile and the soil. Under the applied cyclic vertical load, the geotextile developed a low tensile strain. The effect of the stiffness of the geotextile on the deformation was more significant when the geotextile was placed at a shallower depth than when placed deeper. Shuai-dong and Xiang-juan (2011) investigated the dynamic behaviour of reinforced silty sand by using consolidated-undrained dynamic triaxial tests and found that the dynamic elastic modulus of reinforced soil increases due to reinforcement and increase of confining pressure or consolidation stress ratio, in comparison with the unreinforced soil.

Inclusion of silt in sand leads to changing soil grain size distribution and consequently reduction in its strength properties. Due to development of civil projects, such as road construction and rail way in areas with silty sand foundation soils, and existence of repeated and dynamic loads in these projects, the investigation of the effects of geotextile reinforcement on behaviour of silty sand under dynamic loading which is not adequately considered by other researchers has become important and necessary. The objective of this investigation is to present the results of cyclic triaxial tests on reinforced dry sand and sand mixed with varying amounts of silt and nonwoven geotextile. In this study, in addition to describing the influence of confining pressure, the number of geotextile layers, geotextile arrangement and silt content on the cyclic axial modulus, cyclic ductility and damping ratio are illustrated.

2. Test materials

2.1. Soil

Relatively uniform, clean sand with subrounded particles from the shores of the Barajin River in the north of Qazvin, Iran was used

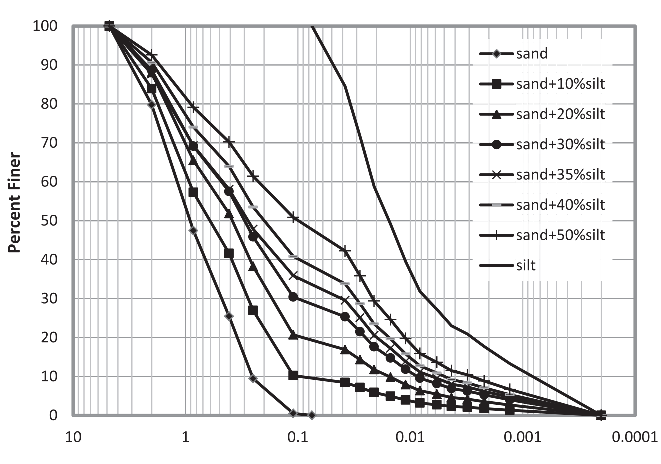

Fig. 1. Grain size distribution curve for sand, silt and sand-silt mixtures.

Table 1
Physical and mechanical properties of Barajin River sand.

Properties	Value
Coefficient of uniformity, C_u	4.23
Coefficient of curvature, C_c	0.81
Unified soil classification	SP
Specific gravity, G_s	2.75
Angle of internal friction (degree) (Triaxial test, Relative density, $D_r = 50\%$, Moisture content, $\omega = 0\%$)	33
Maximum void ratio, e_{max}	0.862
Minimum void ratio, e_{min}	0.629
Effective grain size, D_{10} (mm)	0.24
Medium grain size, D_{50} (mm)	0.93

in this study. The grain size distribution of this sand is shown on Fig. 1. The properties of the sand, which is classified as SP in Unified Soil Classification System, are presented in Table 1. The silt was obtained from the same region as the sand. The grain size distribution of the silt that was obtained by performing a hydrometer analysis is also shown on Fig. 1.

2.2. Geotextile

The reinforcement consisted of a commercially available nonwoven geotextile. The physical and mechanical properties of this geotextile as obtained from data sheets attached to soled geotextile from the company are presented in Table 2.

3. Sample preparation and testing procedure

To investigate the dynamic behaviour of unreinforced and reinforced dry sand and silty sand, a series of stress-controlled cyclic triaxial tests were conducted. These tests were performed to evaluate the effects of silt content and reinforcement on the cyclic stress-strain curve, cyclic axial modulus, cyclic ductility and damping ratio in different confining pressures. The tests were conducted according to ASTM D 5311 by applying a constant cyclic loading with the frequency of 6 Hz which was applied in 12 cycles. This frequency is in the range of dominant frequency of the Bam Earthquake which is between 5.8 and 7.4 Hz. This earthquake occurred in the Bam located at the South-East of Iran on December 26, 2003 with a moment magnitude of 6.6. The values of peak loads in compression and extension (± 165 N) were obtained from simulating of shear stress hysteresis of the Bam earthquake with equal axial load and number of loading cycles in cyclic triaxial tests (Kramer, 1996).

The tests were performed by using Dynatirax cyclic triaxial set (See Fig. 2). The pneumatic loading system of the device was provided by a 10 bar air compressor. The vertical load, deformation and

Table 2
Physical and mechanical properties of geotextile.

Properties	Value
Weight (g/m^2)	750
Nominal thickness (mm)	2.4
Effective opening size (mm)	0.12
Maximum tensile strength (kN/m)	
Longitudinal	2.48
Transverse	1.87
Maximum elongation (%)	
Longitudinal	75
Transverse	85
Puncture resistance (kN)	4.22