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SYNOPSIS Stress controlled undrained cyclic triaxial tests have been conducted on undisturbed sandy and silty soil samples obtained by special sampler in order to minimize the effect of disturbance. The influence of fines content on liquefaction - induced volumetric strains have been studied. The results indicate that cyclic mobility of sands is affected by non - plastic fines content. As fines content increase, cyclic shear strength decreases. Volumetric strain is influenced by fines content as well as shear strain and cyclic stress. At large shear strains amplitudes, an increase in percentage of fines causes more volumetric strains. Volumetric strains of silt samples are affected by cyclic shear stress more than sands.

INTRODUCTION

During earthquakes, pore water pressure generated in saturated sand deposits cause differential settlements at the ground surface as well as loss of shear strength due to liquefaction. Following an earthquake, induced pore pressure dissipates towards the ground surface resulting in reconsolidation and volumetric strains. These settlements may cause damage on structure located on the ground surface. Up to the present, only clean, reconstituted sand samples have been studied and the effect of fines has not been considered (Lee et al., 1974; Tatsuoka et al., 1984; Nagase et al, 1988; Chang et al., 1988; Ishihara et al., 1992). Whereas, field observations of earthquake induced settlements have shown that sands contain fines varying within a wide range (Tokimatsu et al., 1987). The results have shown that the shear strain and relative density strongly affect volumetric strain, while consolidation pressure has a limited influence (Lee at al., 1974 ; Tatsuoka et al., 1984).

The aim of this study is to evaluate the liquefaction-induced settlement of undisturbed sandy and silty soils as well as to assess the liquefaction potential. Cyclic triaxial tests have been conducted on undisturbed silt samples and sand samples containing different percentage of fines. The observed results indicate that the fines content in addition to shear strain is one of the important factors influence by the volumetric strains.

TEST SAMPLES

The sampling sites are located on the south coast of Turkey. In the first site, subsurface soils consists of sand and silt layers. The sand layer with the field SPT, standard penetration test values ranging between 10 to 20 lies about 18 m below the ground surface. This layer contains different percentage of fines. Following the sand layer, non-plastic silt layer dominates. The field SPT values for 10 m of thickness of the silt layer are about 18. In the second site, the sand layer containing different percentage of fines also lies 18 m below the surface. The field SPT values vary from 13 to 17 with increasing depth. Ground water table is below about 1.0 m from the ground surface at both sites. Undisturbed soil samples were taken from the deposits below ground water table with piston samplers and shelby tubes. Water in the pores of saturated sands and silts were drained and the capillary tension within the pores becomes effective in developing a temporary strength necessary for sample handling. In order to prevent disturbance of the samples, shelby tubes were frozen before transportation and were kept frozen at -10° C in a deep freezer until they were used in test. Figure 1 shows the grain size distribution of the tested sand samples. There is no significant difference among the curves. The fines content is in the range of 16 % to 35 %. The mean diameter is around 0.14 mm. The samples can be classified as silty fine sand. The field SPT values were corrected by the method proposed by Liao and Whitman (1986).

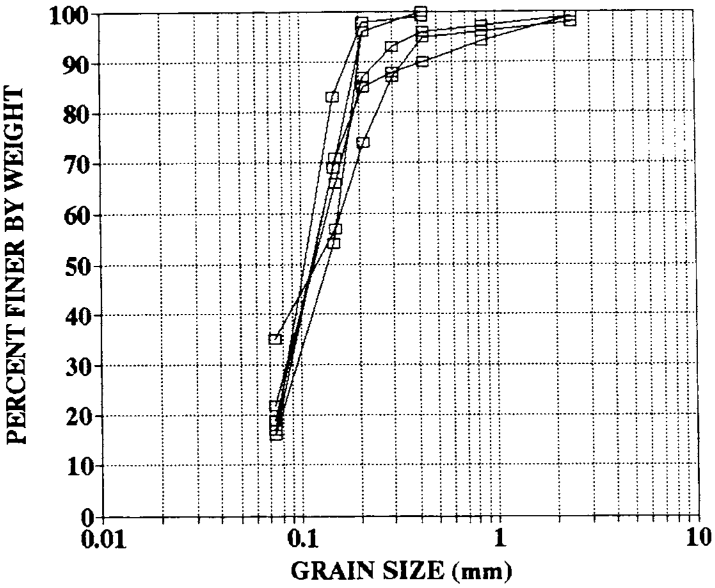

Figure 1. Grain size distribution curves

TEST APPARATUS

In this study, the cyclic triaxial testing system has been used. The system is composed of four units; the triaxial cell; the air pressure, water pressure and vacuum systems; cyclic axial load generator; and the measuring and recording units. The confining, vertical and back pressures are applied to the sample by means of one regulator. Stress controlled loads as well as strain controlled loads can be applied on cylindrical samples with 5 cm and 7 cm in diameter with different amplitudes and frequencies.

TEST PROCEDURE

The aim of this study is to determine settlement behavior of undisturbed silty sand and silt samples following initial liquefaction. Soil samples were taken from shelby tubes. The frozen shelby tubes with 75 mm and 85 in diameter were cut with an electrical saw to the desired length and the samples were trimmed as cylindrical samples with a diameter of 70 mm and a length of 140 mm. After the test sample were placed in the test chamber, a vacuum of about 90 kPa was applied to both ends of the samples to completely thaw and to allow the circulation of deaired water in the pores. Dimensions were measured. The test chamber was assembled and filled with water. The vacuum was gradually decreased to zero while cell pressure was simultaneously increased to a value of 90 kPa. The samples were isotropically consolidated to overburden pressures of 100 to 200 kPa for 24 hours. It was considered that the effect of consolidation pressure within the limit of the σ_C values in this study, has no significant influence on cyclic shear strength and volumetric strain. Saturation with a B value of 0.98 or higher was obtained by using deaired water and high back pressure. Stress control tests have been performed at a frequency of 1 Hz.

TEST PROGRAM

In order to study the effect of fines content on generated volumetric strain due to liquefaction, the cyclic triaxial tests were conducted on sand samples containing fines in the range of 16 % to 35 % and silty samples. After isotropic consolidation, stress controlled cyclic axial loads in a wide range were applied until initial liquefaction can be observed. As the initial liquefaction was observed, tests were terminated. The generated pore water pressures were allowed to dissipate. The volume changes due to reconsolidation were measured. In some tests, the applied cyclic stress was kept low not to cause liquefaction. After generated pore water pressure was constant, tests were also terminated and volume changes were measured. During tests, cyclic stress, pore pressure and axial strain were measured. The axial strain, ε_1 has been transformed into the strain in the simple shear, γ with the relation,

$$\gamma = 1.5\, \varepsilon_1 \qquad (1)$$

DISCUSSION OF TEST RESULTS

Liquefaction Resistance of Undisturbed Sands

In order to determine both cyclic strength and liquefaction - induced settlement of sands and silts, a series cyclic triaxial test were conducted on sands samples in a range of relative density varying between 35 % to 41 % and silt samples with a relative density of 34 %. In this study, the main reason of using relative density for silts is to eliminate the influence of the density to compare them with sand samples. Figure 2 presents the behavior between $\pm\, \sigma_d/2\sigma_c$, cyclic shear stress ratio and N_C, number of cycles. As shown, the liquefaction resistance of sand samples containing non-plastic fines decreases as the fines content increases (Erken et al, 1993, 1994). A similar trend has been observed in the research reported by Kuerbis and Vaid (1989) and Troncoso and Verdugo (1985). Whereas, the cyclic strength of silts is not dependent on sand percentage. As can be seen, there is only one strength curve for silt samples with varying silt content of 59% to 92%.

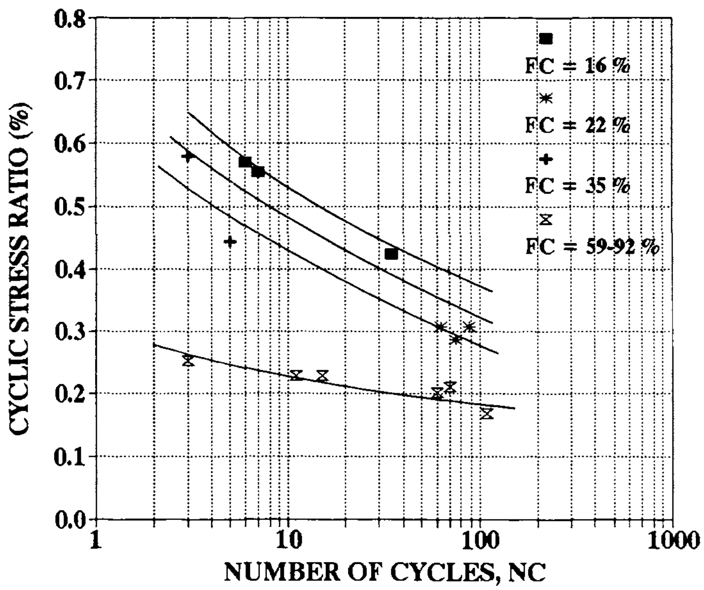

Figure 2. Liquefaction resistance of sands with different non-plastic fines contents

Liquefaction-induced settlements

First, the influence of cyclic shear stress has been investigated. The results have shown that a small amount of increase in cyclic shear stress causes more volumetric changes in silt samples. However, sand samples need a large increase in cyclic stress for the same volumetric strain level. On the otherhand, sands containing fines with different percentages have a unique relationship in terms of cyclic shear stress ratio, $(\sigma_d/2\sigma_c)$ versus volumetric strain, (ε_v) because of the reverse effects of maximum shear strain and relative density (Figure 3). To eliminate the effect of D_r, the volumetric strain has been normalized with the relative density. Eventhough there is some scatter in the data as shown in Figure 4, the increasing trend of ε_v/D_r ratio with fines content is especially visible at certain shear strain level. This behavior can be seen more clearly in Figure 5. At high shear strains, fines content influences volumetric strain more strongly than that at small shear strain levels. Furthermore, the results present good consistency with the obtained results from clean sand samples consolidated to 196 kPa and a relative density of 47 % and loaded irregularly (Nagase and Ishihara, 1988). Figure 6 illustrates the relationship between fines content and volumetric strain normalized with the corrected standard penetration blows, N1 at different maximum strain amplitude level. It may be possible to estimate settlement as a results of liquefaction, according to the expected shear strain level, fines content and corrected SPT blow counts.

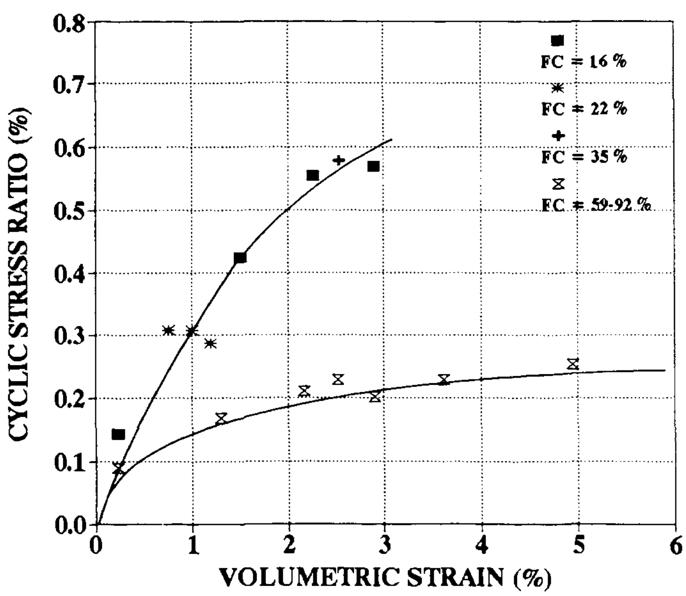

Figure 3. Cyclic stress ratio versus volumetric strain

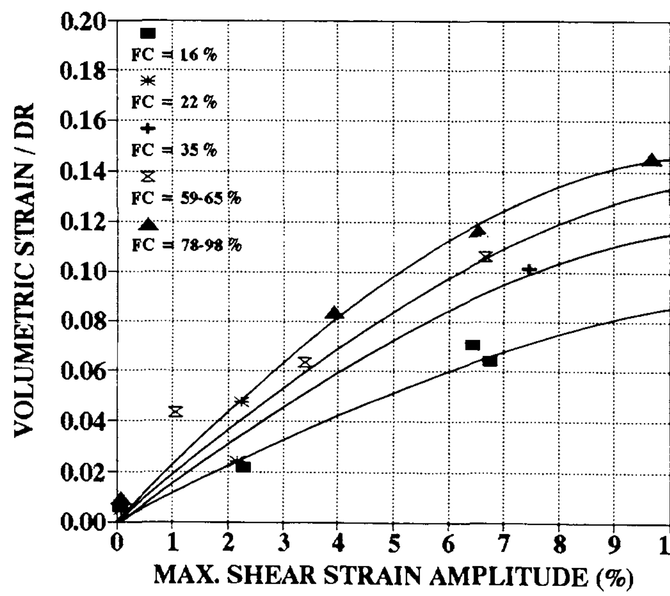

Figure 4. Volumetric strain versus maximum shear strain

CONCLUSIONS

The results of undrained cyclic triaxial tests on undisturbed sandy and silty samples and the volumetric strains due to reconsolidation following cyclic tests indicate the results given below.

1. The liquefaction resistance of undisturbed sands is affected by fines content.
2. The increase non-plastic fines content decreases the cyclic shear strength.

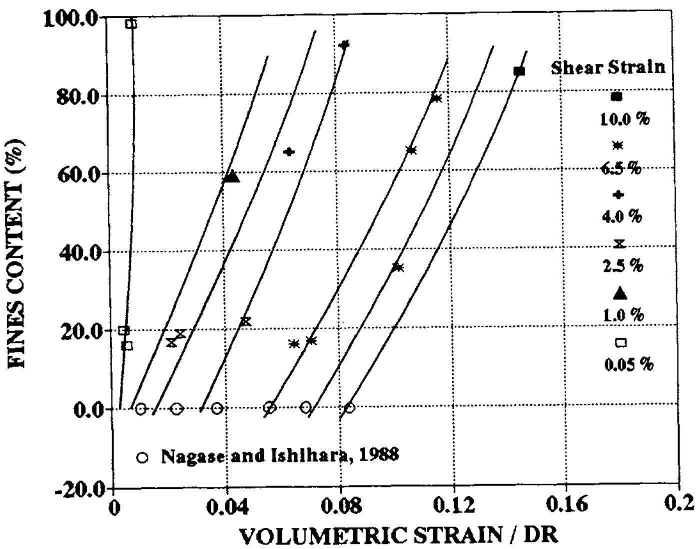

Figure 5. Effect of fines content

4. Volumetric strain induced by liquefaction is affected by shear strain amplitude strongly.
5. Non-plastic fines content strongly affects the volumetric strains at high shear strains.
6. A small increase in cyclic shear stress causes more volumetric strains at silts than sands.
7. Relative density affects volumetric strains induced at sands and silts.

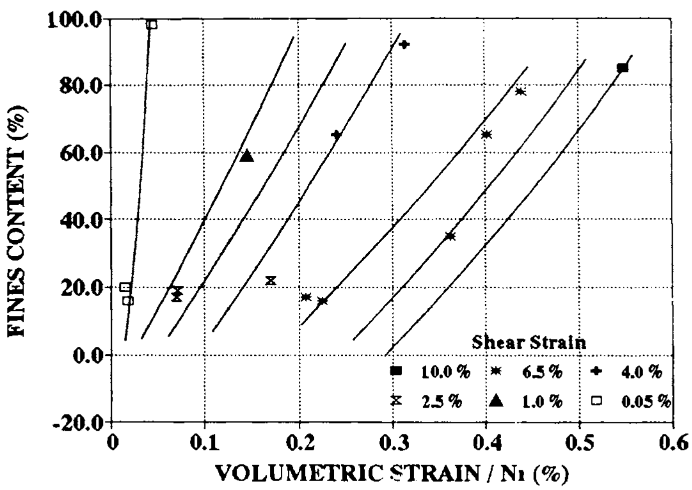

Figure 6. Effect of fines content

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