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BEHAVIOR OF A DENSE NONPLASTIC SILT UNDER CYCLIC LOADING

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ABSTRACT

Density of granular soils is increased after being subjected to seismic loading, leading to settlements in deeper layers. Foundation systems and shallow buried structures are affected from possible damage due to settlements induced by seismic action. Since studies on liquefaction behavior of silts is limited, it was considered to carry out an experimental study for evaluation of strength behavior of dense silts under cyclic loading conditions. All the tests were performed on specimens at a relative density of 80%, by application of constant level sinusoidal stresses under a frequency of 0.1 Hz. As a consequence, cyclic behavior of a dense silt is experimentally determined and evaluated by application of ten different cyclic stress ratio values.

Keywords: Nonplastic silt, Cyclic triaxial tests, Liquefaction

1. INTRODUCTION

During seismic excitations, propagation of shear waves cause undrained shear stresses under certain conditions. Formation of undrained shear stresses during shear wave propagation leads to deformations along with increase in pore water pressure. Increasing pore water pressure is accompanied with a decrease in soil rigidity by initiating a vicious circle comprising increasing levels of shear deformation and pore water pressure. When the total stress is equal to the pore water pressure at a certain point, soil liquefaction occurs. In this regard, many studies concerning the evaluation and modeling of liquefaction induced settlements were performed in the last thirty years, however, it is hard to include a comprehensive literature survey within this limited space. While a number of studies were concentrated on assessment of liquefaction susceptibility based on field research and observations [1-6] theoretical & experimental studies were also carried out [5, 7-10].

Experimental results revealed that, post-liquefaction volumetric strains control change in unit weight of soil, maximum shear deformation and excess pore pressure along dynamic loading. Past studies confirm relationships among post-liquefaction volumetric strain, relative density and maximum shear strain [11]. Seed et al. [12] formerly established a relationship among between corrected SPT-N and cyclic stress ratio. Unifying the results of two studies, a method for predicting post-liquefaction settlement was proposed by Tokimatsu and Seed [13]. The study presents a practical method for prediction of volumetric strains by use of cyclic stress ratio and SPT-N, when saturated sands are exposed to an earthquake of magnitude M=7.5 (Figure 1).

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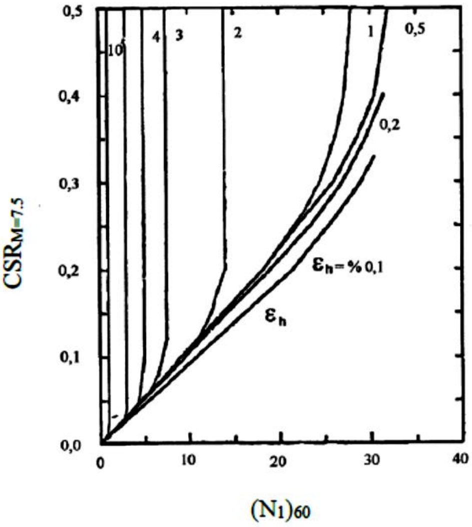

Figure 1. Volumetric strain values by using cyclic stress ratio and SPT on saturated sands (Tokimatsu and Seed, 1987)

Later, a practical procedure for prediction of surface settlements in clean sands was proposed by Ishihara and Yoshimine (1992) [3]. The method presents the plot of factor of safety against liquefaction, maximum cyclic shear deformation, relative density and SPT-N to predict post-liquefaction volumetric strain (Figure 2).

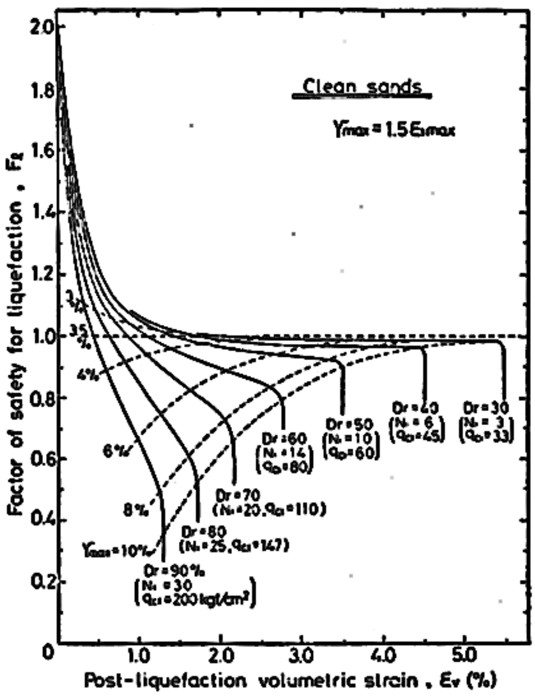

Figure 2. The relationship between post liquefaction volumetric strain and factor of safety (Ishihara and Yoshimine, 1992).

The literature survey revealed that number of studies concerning prediction of post-liquefaction volumetric settlements of silts are not expectedly high. Therefore, a set of dynamic triaxial compression tests were performed to analyze the above-mentioned behaviour of a very dense silt by evaluation of cyclic stress, double amplitude axial strain level and pore water pressure. The results are discussed in detail.

2. MATERIAL AND METHODS

Non-plastic silt was obtained from a construction site in Izmir. Specific gravity of silt is 2.68. The maximum and minimum void ratios in accordance with related ASTM standards [14-15] were determined as 1.352 and 0.894, respectively. An experimental program was established to investigate interrelationships among cyclic stress ratio (CSR), pore water pressure and double amplitude of axial strain (DA).

Experiments were repeatedly performed to verify the sample preparation method. Height and diameter of specimens were selected as 100 and 50 mm, respectively. We tamping method was used to specimen preparation, in accordance with JGS 0520-2000 standard [16]. Cyclic triaxial compression testing equipment used in this study is shown in Fig. 3. Skempton value, $B=\Delta u/\Delta\sigma$ was checked after saturation of specimens, a minimum value of 0.96 was selected to proceed to consolidation stage. Later on, specimens are consolidated isotropically. All cyclic triaxial experiments were performed by stress-controlled cyclic loading, in accordance with related Japanese standards [17-18]. Confining pressure is selected to be 100 kPa. In liquefaction tests, the loading sequence involved 20 cycles of loading under a frequency of 0.1 Hz.

3. RESULTS AND DISCUSSION

In the literature, there are many studies concentrated on evaluation of stress strain or liquefaction behavior of sands including non-plastic fines at rates of 10% to 50%. Ishihara et al., (1980) [19], found that non plastic soils have much smaller cyclic strength ratios than those of low plasticity soils. In this study, a constant value of 20 loading cycles were applied. Figure 4 to 10 illustrate representative results of tests carried out on silts. From Figure 4, it can be inferred that, for the silt soil at a relative density (D_r=80%), the pore water pressure develops slowly under a CSR of 0.069 and liquefaction was not observed. Figure 5 shows that double amplitude of axial stain reaches 0.1% after 20 cycles. It is concluded that, if the CSR small enough, the effective stress does not reach the zero. As can be seen in Fig. 4, the pore water pressure and strain is also limited. The stiffness of the soil is higher.

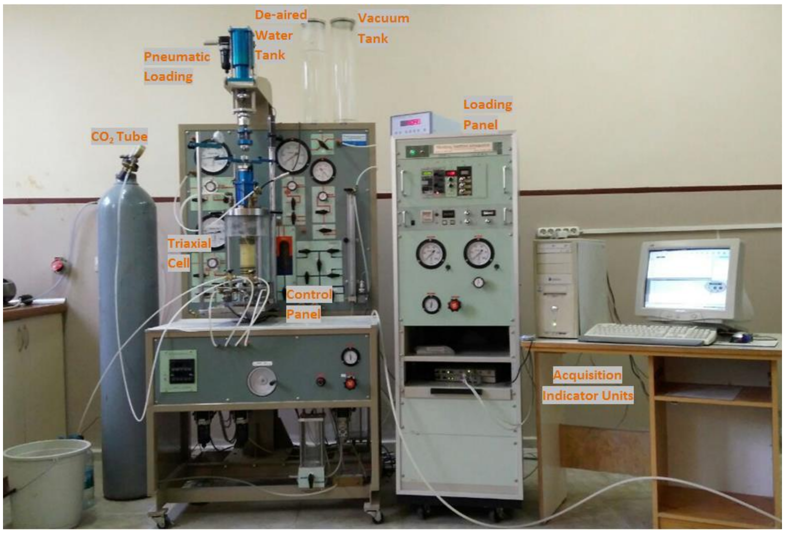

Figure 3. Dynamic Triaxial Test System

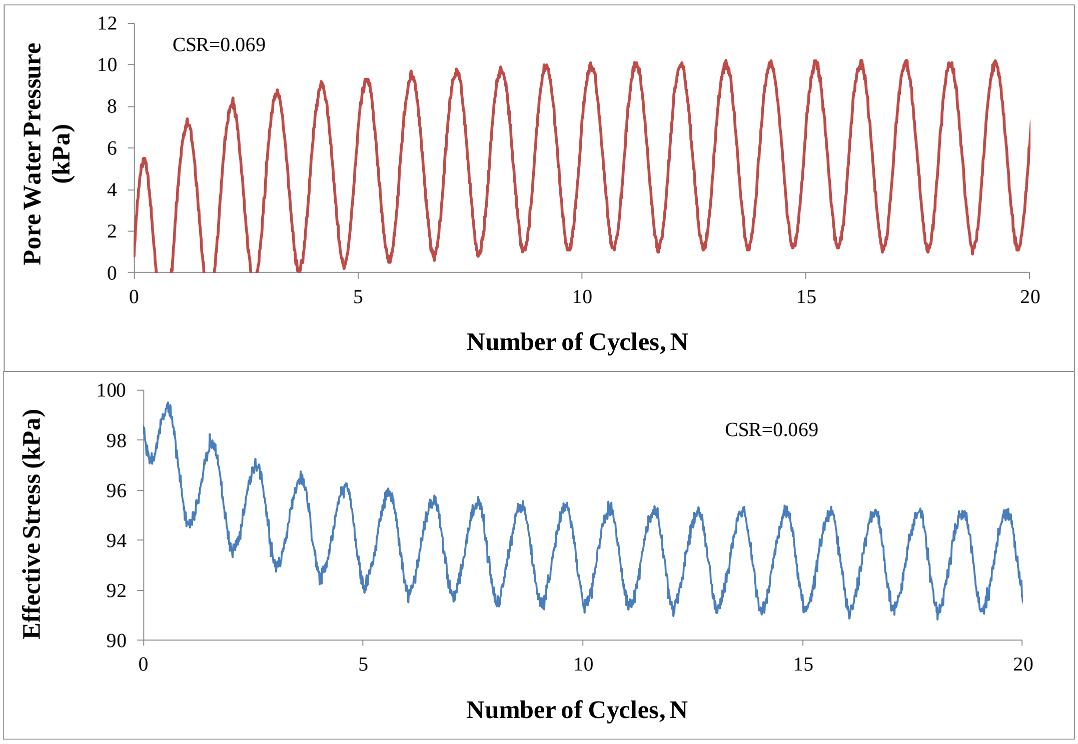

Figure 4. The change of pore water pressure and effective stress for D_r=80 % and CSR=0.069 with number of cycles.

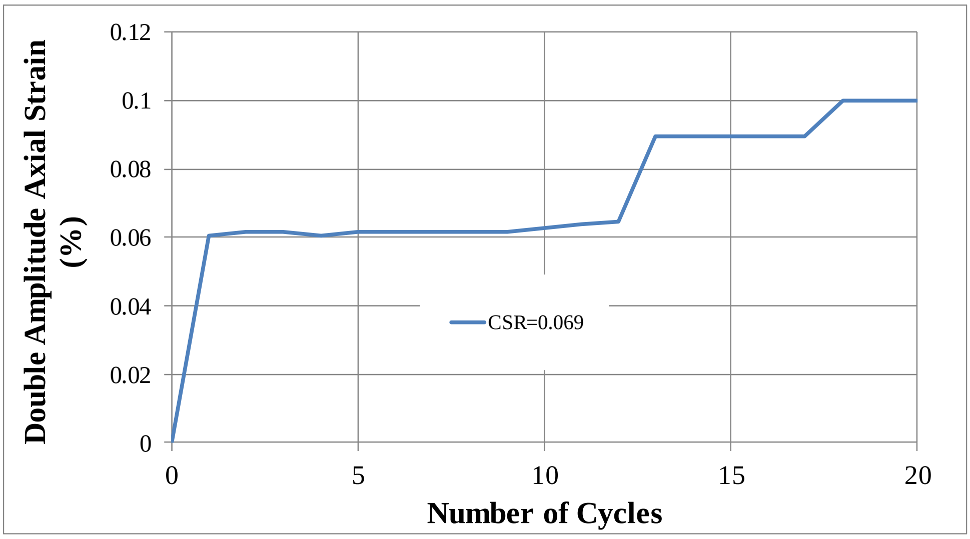

Figure 5. The change of DA with number of cycles for D_r=80 % and CSR=0.069.

Moreover, Fig. 6 shows that, for the silt specimen prepared at a relative density of D_r=80%, the pore water pressure builds up continuously under a CSR of 0.111 and as a result, the pore water pressure reaches 100 kPa in 20 cycles. When the pore water pressure builds up steadily, at the same time, effective stress drastically decreases down to zero. So, the pore water pressure is equal to effective stress. (Fig. 6). In this case, the silt specimen reaches 6.5% double amplitude axial strain (Figure 7). So, the liquefaction occurrs and the soil stiffness completely disappears. When CSR is equal to 0.111, for the first 18 cycles, the double amplitude of axial strain is smaller than 1%, but after the last 2 cycles it reaches 6.5%. After 18 cycles, pore water pressure (PWP) ratio is at around 0.65, eventually, after application of the last 2 cycles of loading, PWP ratio reaches to 1.

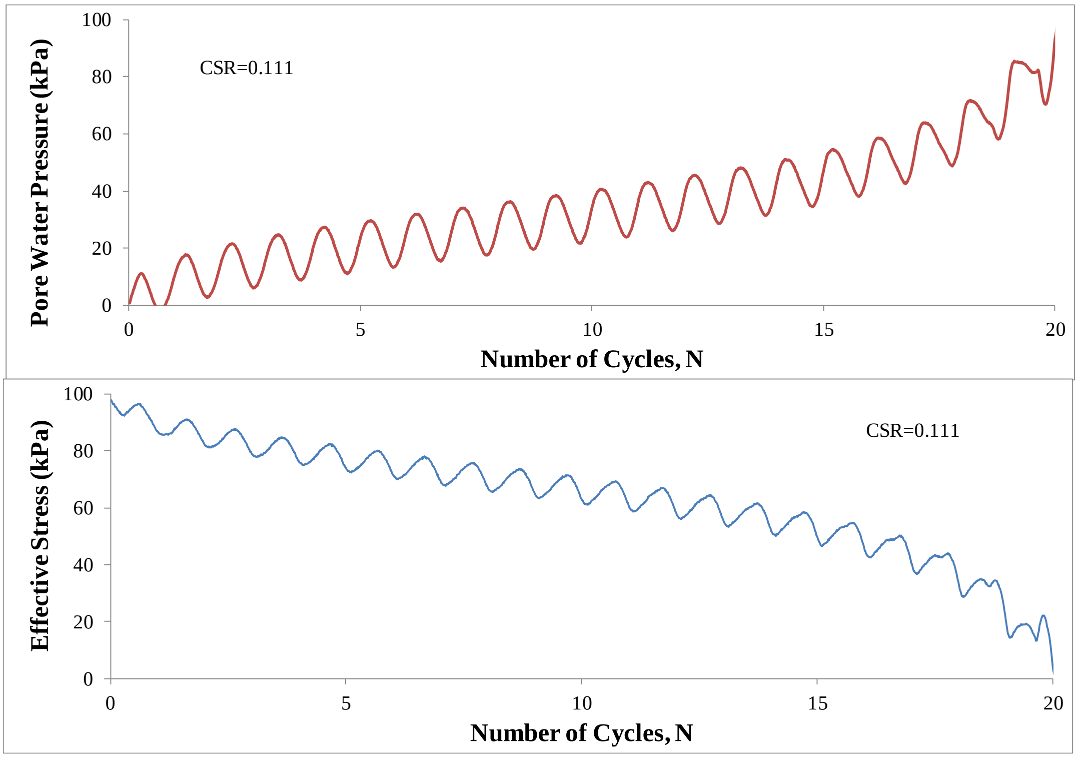

Figure 6. The change of pore water pressure and effective stress for D_r=80 % and CSR=0.111 with increasing number of cycles.

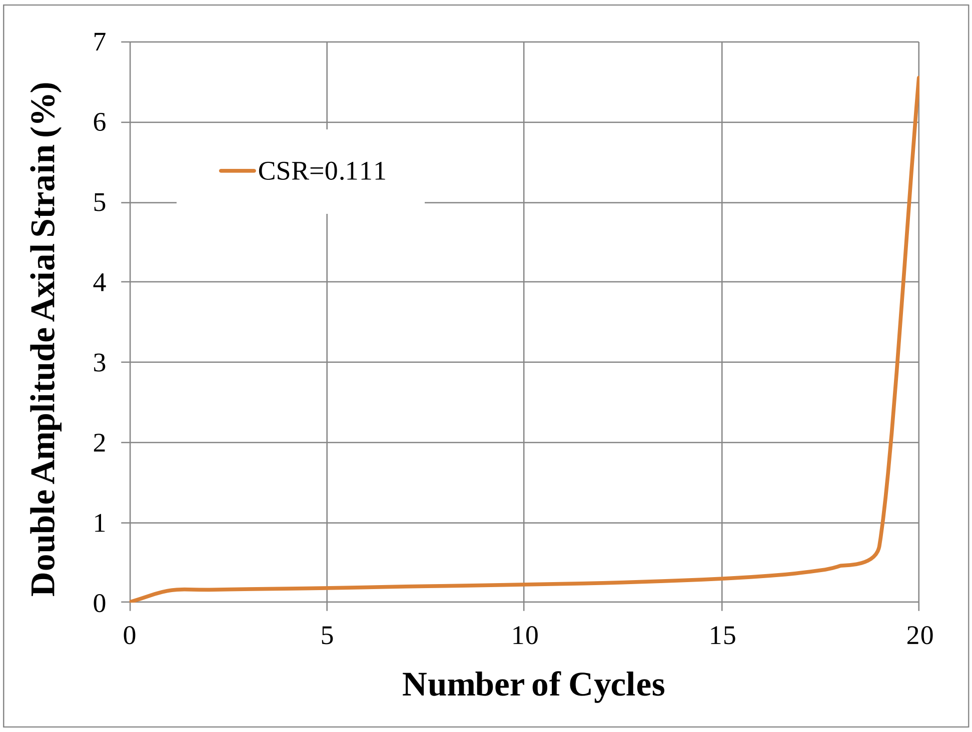

Figure 7. The change of double amplitude axial strain with number of cycles for D_r=80% and CSR=0.111.

Under a higher CSR value of 0.183, pore water pressure is increased up to 90 kPa, while effective stress decreases to 10 kPa, just after two cycles of cyclic loading (Figure 8). For a specific CSR value, increase in axial strain with number of cycles increase to a certain level, as shown in Figure 9. Needless to say, higher the CSR, lower the number of cycles to maximum double amplitude axial strain. The double amplitude of axial strain reaches up to 30% after application of 1 cycle, implying that the magnitude of the cyclic stress is remarkably high. In this situation large deformations occur (Figure 9).

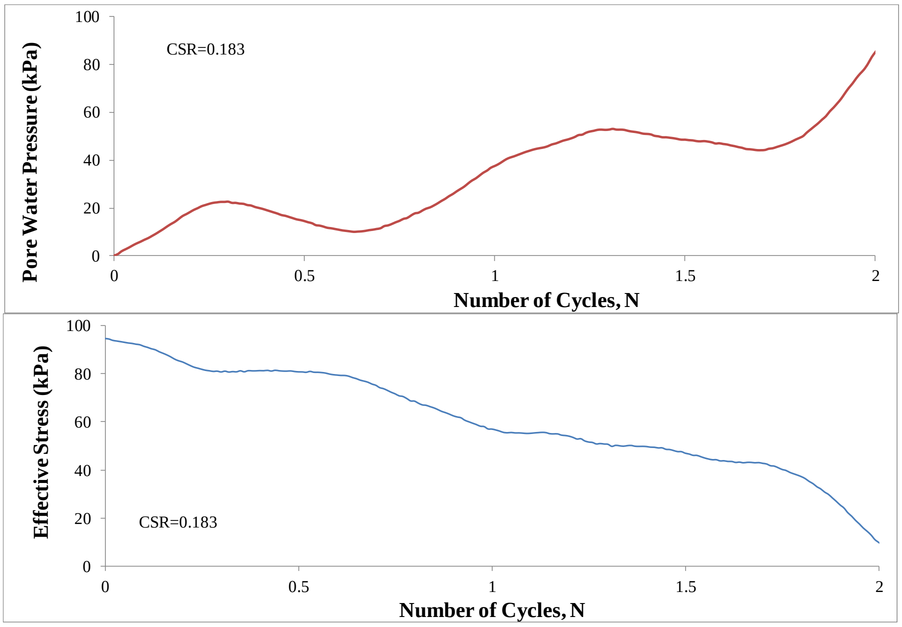

Figure 8. The change of pore water pressure and effective stress for Dr=80% and CSR=0.183 with number of cycles.

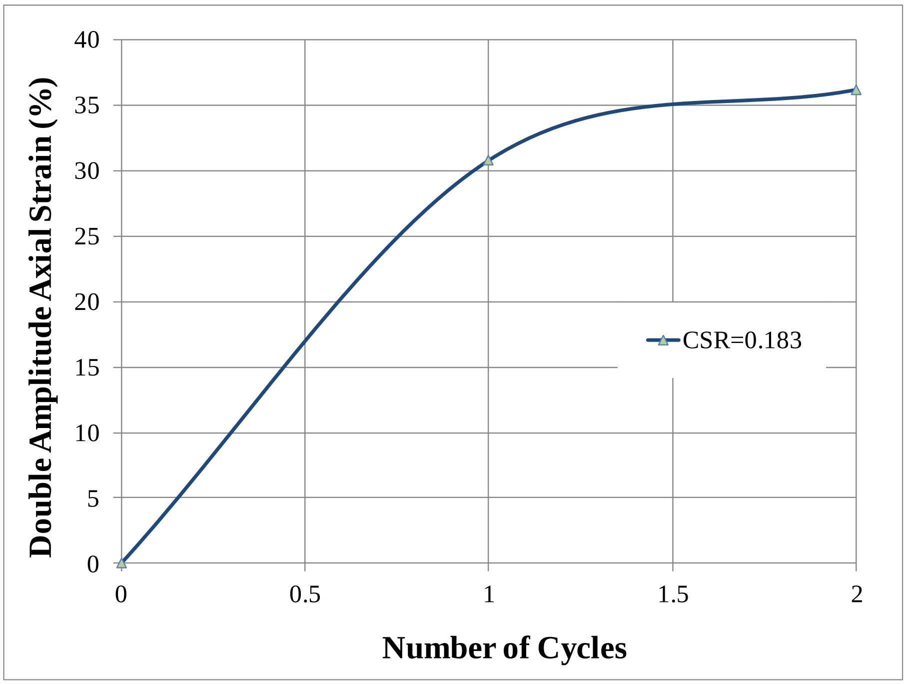

Figure 9. The change of double amplitude of axial strain with number of cycles for D_r=80% and CSR=0.183.

Plot of CSR against applied number of cycles to liquefaction is given in Fig. 10. Literally, it was observed that for specimens of same relative density, when the CSR is higher, the number of cycles to liquefaction is lower. For instance, when the CSR is equal to 0.205, the number of cycles is 1, however, when CSR=0.110, the number of cycles is increased up to 20.

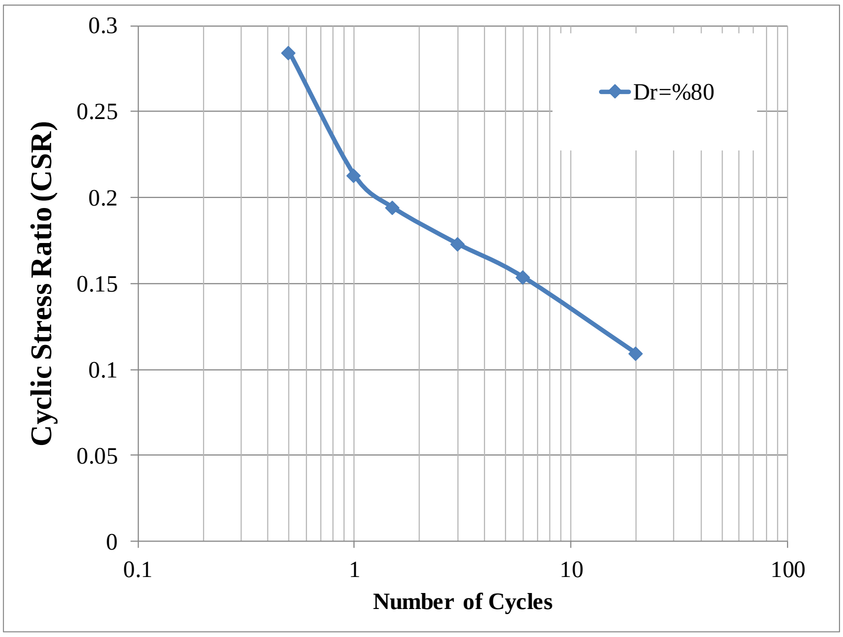

Figure 10. Plot of CSR with number of cycles to liquefaction for D_r=80%

Figure 11 shows the variation of deviatoric stress stress with mean stress. The deviatoric stress changes within ±6 kPa. The stress path starts with a mean stress 100 kPa and zero deviatoric stress. If the CSR is kept constant, when the number of cycles is increased, the mean stress is decreased, so the stress path is directed leftwards. After 20 cycles, the mean stress reaches the zero and the silt specimen liquefies as shown in figure 11.

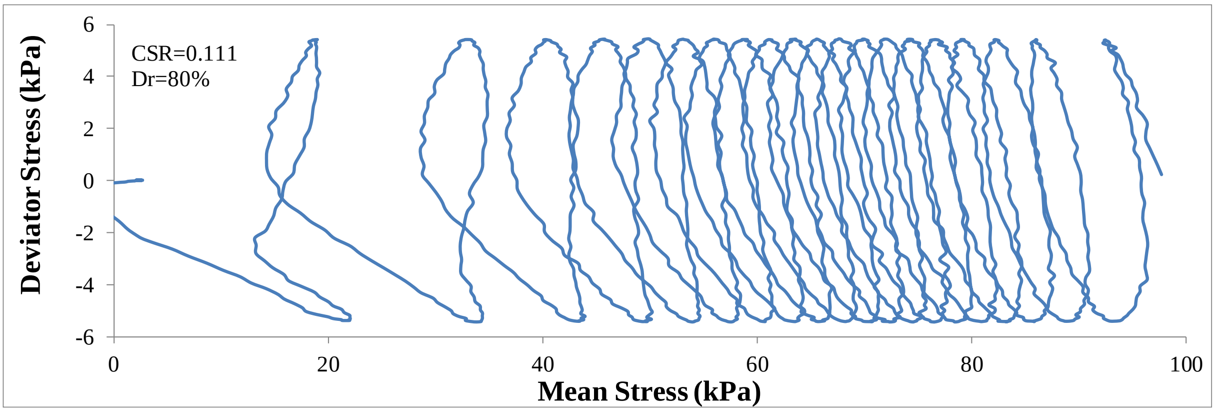

Figure 11. Mean stress versus deviator stress

Figure 12 shows the variation of pore water pressure ratio against cycle ratio necessary to reach liquefaction state, under CSRs ranging among 0.011 and 0.286. At higher CSRs, more drastic increases in pore water pressure is observed, causing a prompt liquefaction occurrence, which causes a sudden loss in shear strength and stiffness of soil. When the pore water pressure ratio increases up to 0.25, the cyclic stress ratio is apparently lower, which is the reason behind the non-liquified state.

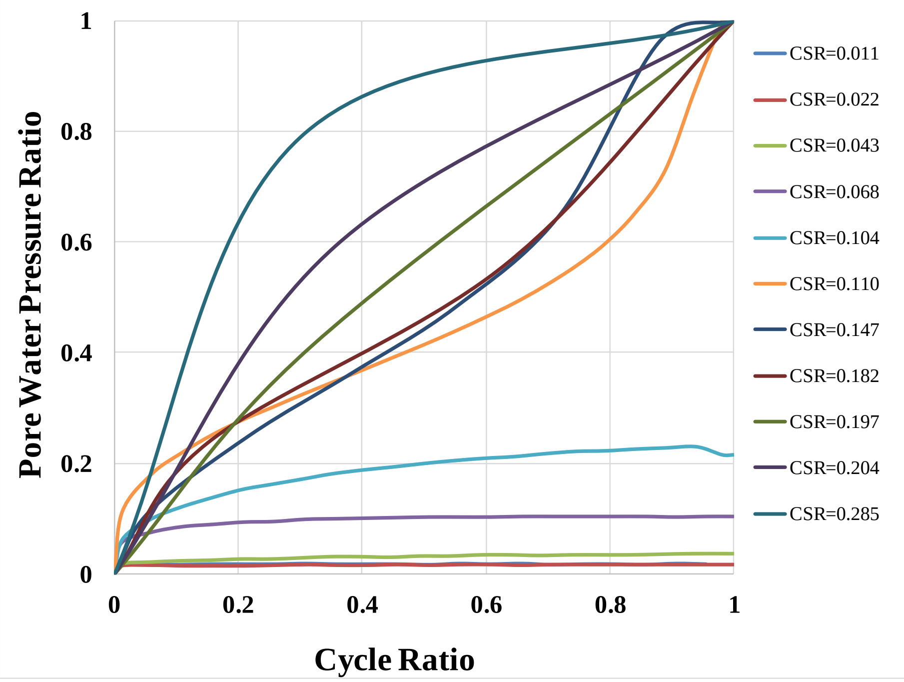

Figure 12. Rate of pore water pressure ratio build up with cycle ratio

4. CONCLUSIONS

In this paper, an experimental study was undertaken for evaluation of the cyclic undrained and liquefaction potential behavior of a dense silt. Cyclic triaxial compression tests were performed for estimation of the liquefaction properties of the dense nonplastic silt undergoing high shear strains ranging among 0.1% to 35%. The pore water pressure ratio increases firmly and levels off at initially applied confining pressure, depending upon the magnitude of CSR. At higher CSRs, high rates of increase in pore water pressure were observed. As a consequence, it was evident that liquefaction in dense silt was triggered at relatively lower number of cycles.

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