International Journal of GEOMATE, Feb., 2019 Vol.16, Issue 54, pp.170 - 175
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.54.8325
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

EFFECT OF NON-PLASTIC FINES ON UNDRAINED RESPONSE OF FINE SAND

*M Akhila, K Rangaswamy and N Sankar

Department of Civil Engineering, National Institute of Technology, Calicut, India

*Corresponding Author, Received: 15 Oct. 2018, Revised: 28 Nov. 2018, Accepted: 17 Dec. 2018

ABSTRACT: Silty soils are widespread in many countries, particularly in the United States, China, and India; hence it is essential to get an idea of the response of such soils under different forms of loading. In this paper, the results based on undrained triaxial tests, under static as well as cyclic loading, which were carried out on the silty sands (fine sand mixed with non-plastic fines at different percentages) are presented. The samples were prepared at the required unit weight (D_r = 50%), saturated by using back pressure and cell pressure increments and consolidated isotropically. Each consolidated sample is then subjected to static/cyclic loading. The results of the static triaxial testing showed that the non-plastic fines have a significant influence on the behaviour of fine sand. The dilation tendency decreases with the addition of fines. In the case of cyclic triaxial testing, as the fines content increases, the rate of generation of excess pore water pressure and axial strain on cycles of loading was found to increase and hence the liquefaction susceptibility.

Keywords: Liquefaction, Silty sands, Triaxial test, Undrained response

1. INTRODUCTION

The liquefaction may occur in fully saturated sands, silts and low plastic clays. When the saturated soil mass is subjected to seismic or dynamic loads, there is a sudden build-up of pore water pressure within a short duration. If the pore water pressure could not dissipate, it leads to reduction of the effective shear strength of soil mass. In this state, the soil mass behaves like a liquid and causes large deformations, settlements, flow failures, etc. This phenomenon is called soil liquefaction. As a result, the ability of soil deposit to support the foundations of buildings, bridges, dams, etc. are reduced.

Since the 1964 Niigata and Great Alaska earthquakes, numerous research studies have been performed on liquefaction of sand. It was believed that only “clean sand soils” with few amounts of fines could liquefy, and cohesive soils were considered to be resistant to cyclic loading due to cohesion component of shear strength. The researchers have not realised about the liquefaction susceptibility of clay soils until the 1994 Northridge, 1999 Adapazari and Chi-Chi earthquake events. In series of 1999 Chi-Chi earthquake, a lot of evidence on liquefaction failures in cohesive soils were observed, indicating that the soils with fines may liquefy. Hence recent research works are mainly focused on liquefaction susceptibility of silt and clay soils.

Many researchers have studied the effect of fines on liquefaction potential of soils. An increase of liquefaction potential with the increase in fine content was observed by [1] and [2]. An inverse relation was suggested by [3], [4] and [5]. But [6] and [7] put forward an inverse proportion at low fines content and direct proportion at high fines content. (Note: All the fines were non-plastic, except for the studies by [2]).Even though these studies indicate the cyclic loading mechanism, the mechanism under static and cyclic loading are strongly related.

Significant findings from the recent literature papers are proven that the fine-grained soils (soils with considerable amount particles less than 75 microns) are more susceptible to liquefaction. But, the state criteria on liquefaction of cohesive soils are not yet conclusive and a lot of contradictory results are reported. Therefore, more research efforts are needed for a good understanding of the liquefaction behaviour of fine-grained soils. Hence, the current research study is mainly focused on the undrained response of fine-grained soils contains the non – plastic fines content up to 40%.

2. METHODOLOGY

It contains sequential stages of materials collection, processing the soil combinations, testing for index properties and carry out the triaxial tests to analyze the effect of fines content on the undrained response of fine sands under both static and cyclic loading. The soil materials, fine sand and crushed stone powder, are collected from various locations of Kerala state. Totally five soil combinations were prepared after mixing the non-plastic silty fines in different amounts into the fine sand. All the basic properties tests were performed on the soil combinations, and the properties are listed in table 1. A combined dry sieve and hydrometer analysis were performed to obtain the particle size distribution of various soil combinations. The gradation curves of all the soil combinations are shown in fig.1.

Table 1 Basic properties of various soil combinations

Notation	FS	SS10	SS20	SS30	SS40
Sand, %	100	90	80	70	60
Silt, %	0	10	20	30	40
G	2.62	2.66	2.71	2.72	2.69
D_{50}, mm	0.28	0.26	0.23	0.20	0.15
C_u	2.36	4.00	4.67	6.25	7.33
C_c	0.87	1.28	1.17	0.72	0.74
e_{max}	0.858	0.847	0.831	0.789	0.768
e_{min}	0.578	0.554	0.497	0.462	0.423

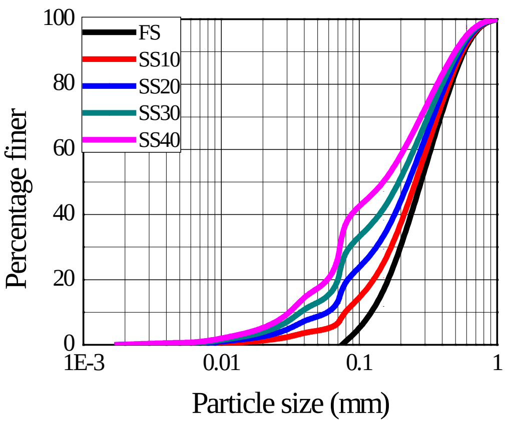


Fig. 1 Particle size distribution curves

A series of undrained static and cyclic triaxial tests were performed using a servo-controlled computerised cyclic triaxial testing device (Make: HEICO Pvt. Ltd, New Delhi, India), which is fully automated and controlled by a data acquisition system and test software (see fig. 2). The testing was conducted in sequential stages of triaxial sample preparation, assemble into the triaxial chamber, saturation of soil, consolidation, and application static/cyclic loading in the undrained state of the soil sample. For the present study, the cylindrical soil samples with 50 mm in diameter and 100 mm in height are prepared at 50% relative density to constitute a medium dense state of field soil. The cylindrical samples were moulded in the split spoon sampler by using moist tamping method with the under-compaction procedure, as suggested by [8]. A schematic of the triaxial cell with the sample is shown in fig. 3 and a photograph is given as fig. 4.

Fig. 2 Photographic overall view of the cyclic triaxial system at CED, NIT Calicut

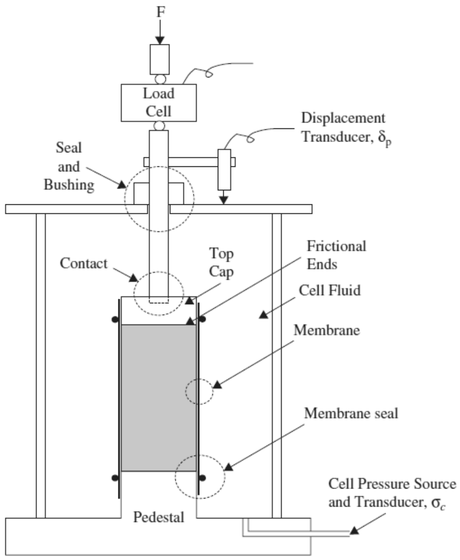


Fig. 3 Test schematic representation

Fig. 4 Soil sample in the triaxial cell

Saturation of the samples was accomplished in two stages: initial saturation and back pressure saturation. After completion of the saturation stage, all the samples were isotropically consolidated to the desired effective consolidation pressure. The sample was allowed to consolidate in drained condition until there is no further significant volume change occurred. The undrained stress controlled cyclic triaxial tests were performed on the consolidated samples as per ASTM d 5311-92 testing procedures. More detailed description of each stage is given in

[9]. In the case of static testing, tests were conducted on each soil combinations according to standard procedures adopted by [10]. The strain rate of 0.625 mm/min was maintained throughout the test.

3. RESULTS AND DISCUSSIONS

3.1 Results of Tests on Fine Sand

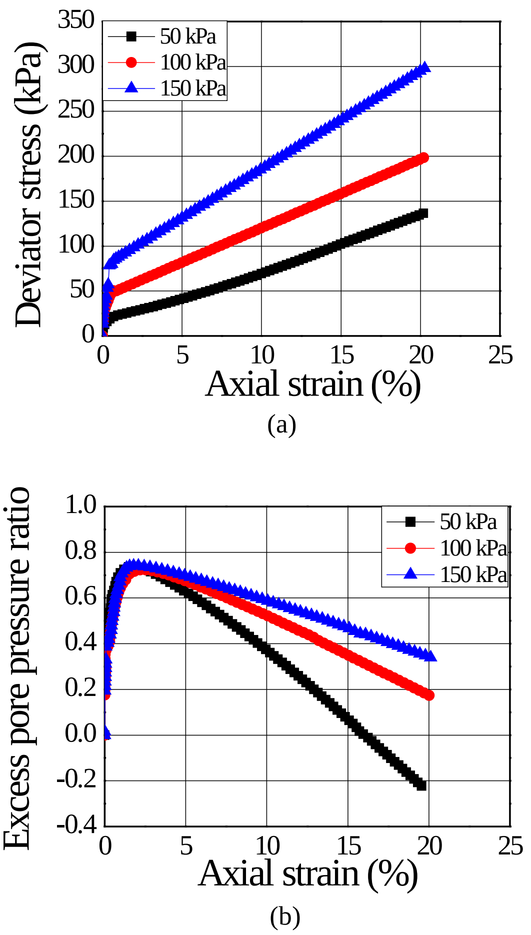


Fig. 5 Undrained response of fine sand under static loading at different consolidation pressures

To study the effect of consolidation pressure on the undrained response of fine sand, static triaxial tests were performed on fine sand samples consolidated at different pressures (50, 100 and 150 kPa). The relative density is fixed at 50%, i.e., the medium dense state. Fig. 5 shows the undrained response in the medium dense fine sand at different consolidation pressures. Fig. 5(a) shows the stress-strain characteristics and Fig. 5(b) shows the pore pressure response of fine sand consolidated at different pressures. The response curves are illustrating that the dilation tendency decreases with increase in consolidation pressures. The fine sand consolidated at low consolidation pressures behave as dilative and vice versa. At a particular density of fine sand, while increasing the consolidation pressures, the state of soil changes from dilative to contraction nature.

The result of the undrained cyclic triaxial test performed on the fine sand sample at CSR =0.178 (D_{ro}=50% and σ_c'=100 kPa) in terms of axial strain propagation, pore pressure build-up and hysteresis loops is shown in Fig. 6. Initial liquefaction occurred at 28 cycles.

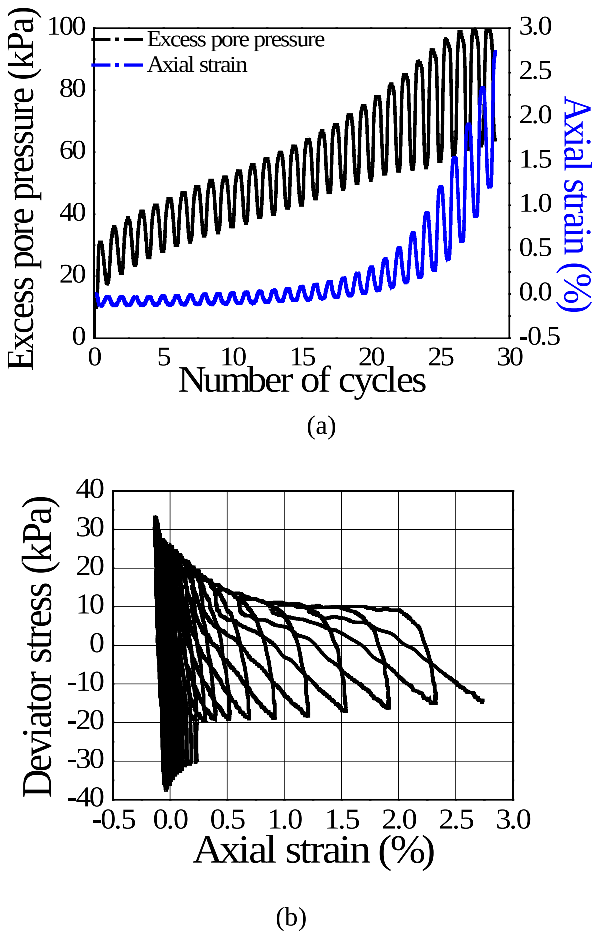
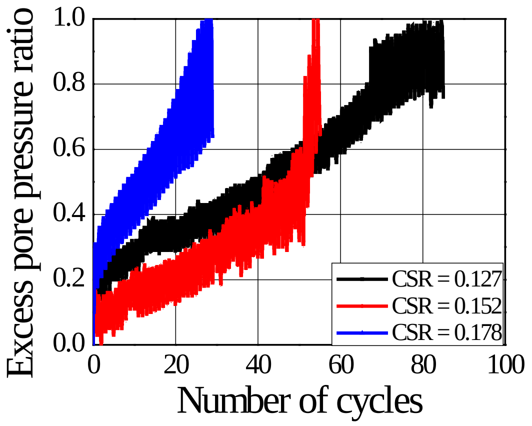
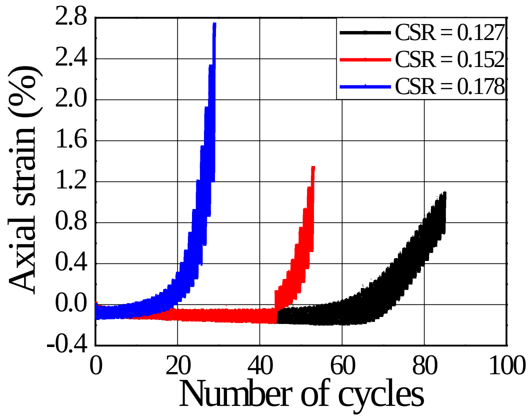


Fig. 6 Undrained response of fine sand under cyclic loading at 100 kPa consolidation pressure

Figure 6(a) shows the insignificant development of axial strain up to 20 numbers of load cycles and further the strain is propagating rapidly towards the initial liquefaction state. The strain was progressed in compression side only and it may be due to the medium dense state of the soil. After triggering the liquefaction state, there is a sudden flow failure with large deformations. The sudden increase of such deformation is due to loss of effective strength of the soil at liquefaction state. Stress-strain hysteresis in the form of loops, as shown in Fig. 6(b), demonstrates that the loops of cycles are close to each other and formed in a thicker band with an insignificant deformation less than 0.5%. Further, the loops are widened with the rapid increase of strain levels in compression side towards the liquefaction state.



(a)



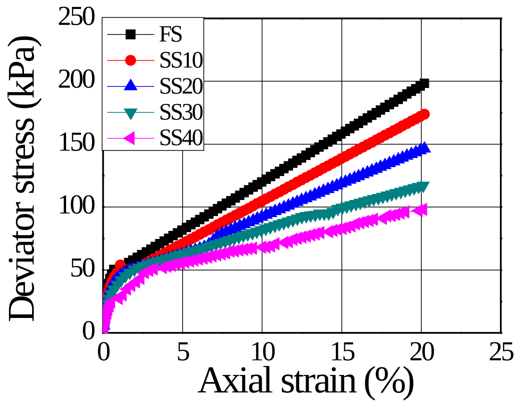
(b)

Fig. 7: Effect of CSR on (a) pore pressure ratio buildup and (b) axial strain propagation in fine sand with load cycles

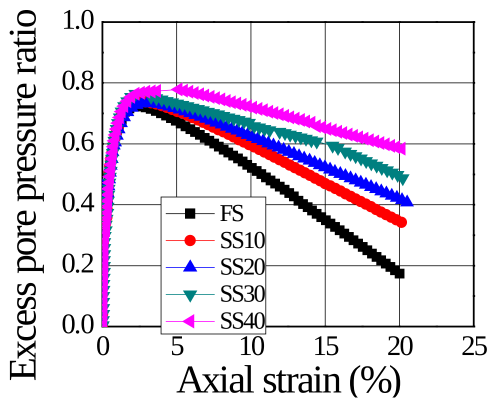
The effect of applied cyclic stress amplitude, the, i.e. cyclic stress ratio (CSR) on the undrained response of fine sand (D_{ro}=50%, σ_c'=100 kPa) is presented in fig. 7. It can be observed from fig. 7 that the pore pressure ratio and axial strains are accumulated gradually under cyclic loading with low CSR levels whereas they develop at a faster rate under cyclic loading with high CSR amplitudes. The large amplitude of strains occurs in the sand subjected the high CSR values and reaches the liquefaction state faster. The pore pressure build-up showed in Fig. 7(a) indicates that the sand sample subjected to high cyclic stress amplitude of 0.178 was liquefied at about 28 cycles of loading, whereas at small CSR of 0.127 the sample liquefied at about 84 load cycles. At 28 cycles of loading, the pore pressure build-up in the sand subjected to CSR of 0.127 is less than 40% only. It can be concluded that the number of cycles is causing liquefaction increases with a decrease in the cyclic stress amplitudes.

3.2 Effect of Fines under Static Loading

To study the effect of fines on the undrained response of fine sand under static loading, static triaxial tests were conducted on the silty sand samples (R_d = 50%) at consolidation of 100 kPa. The results are shown in Fig 8. The non-plastic fines have a major influence on the behaviour of fine sand. From Fig. 8, it is clear that the fine sand is more dilative compared to the sand-silt mixtures. The dilation tendency decreases with the addition of fines. These results are in good agreement with the published literature.



(a)



(b)

Fig. 8 Effect of fines on the undrained response of fine sand under static loading

The effect on non-plastic fines on the pore pressure generation at various consolidation pressures is shown in fig. 8 (b). In the early stage of loading, there is an increase in the pore pressure ratio due to initial contraction; but afterwards the pore pressure ratio decreases. The decrease is rapid in the case of fine sand when compared to the silty sand combinations. The slower reduction indicates the contractive nature, and it results in the decrease in undrained strength.

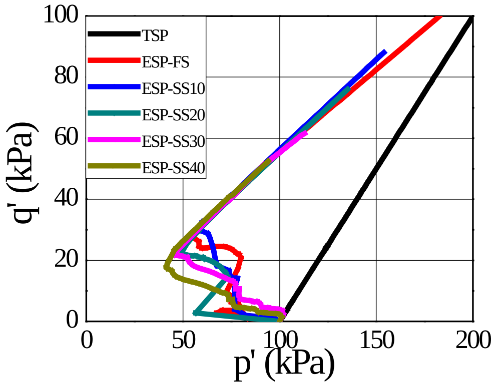


Fig. 9 p'-q' plot

The p'-q' plot of all soil combinations is given in fig. 9. The black line indicates the total stress path of the fine sand sample. From the effective stress paths, it is clear that the samples experience an initial contraction and then becomes dilative. The contraction tendency increases with the addition of fines into the sand sample.

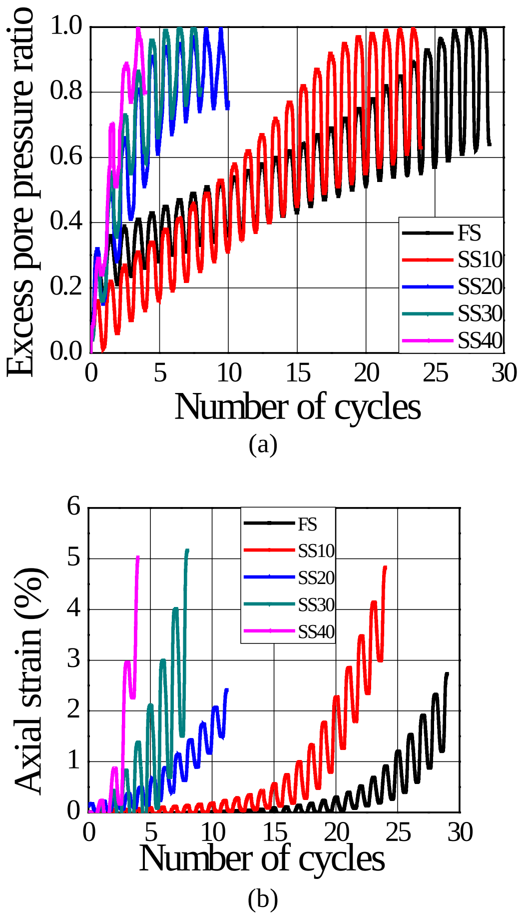


Fig. 10 Effect of silt fines on (a) pore pressure ratio buildup and (b) axial strain propagation during load cycles (CSR=0.178)

3.3 Effect of Fines under Cyclic Loading

To study the effect of fines on the undrained response of fine sand under cyclic loading, cyclic triaxial tests were conducted on the silty sand soil sample combinations at CSR =0.178, 0.152 and 0.127. The results of tests at CSR = 0.178 are shown in fig 10. It indicates that the number of load cycles causing liquefaction at particular cyclic stress level decreases with the addition of silt fraction into the fine sand. It is demonstrated that the silty sands are susceptible to severe liquefaction than the fine sands and causing large deformation at the liquefaction state. Further liquefaction resistance curves are established between the CSR and the number of cycles to initial liquefaction for the fine sand and silty sands as shown in Fig. 11. Similar results have been reported by [11] and [12].

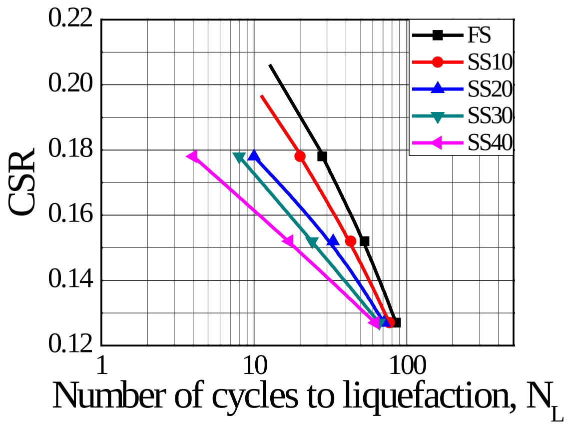


Fig. 11 Liquefaction resistance of fine sand and silty sands

4. CONCLUSIONS

Undrained triaxial tests have been performed on fine sand samples with 0, 10, 20, 30 and 40% fines (Dr = 50% and effective confining pressure = 100 kPa). The following conclusion can be drawn:

Tests on fine sand: From the static triaxial testing conducted on fine sand, it can be concluded that the fine sand consolidated at low consolidation pressures behave as dilative and vice versa. The results of cyclic triaxial testing on fine sand indicate that the pore pressure ratio and axial strains are accumulated gradually under cyclic loading with low CSR levels whereas they develop at a faster rate under cyclic loading with high CSR amplitudes.

Effect of fines under static loading: The non-plastic fines have a major influence on the behaviour of fine sand. The fine sand is more dilative compared to the sand-silt mixtures. The dilation tendency decreases with the addition of fines. The pore pressure response of silty sands also indicates a contractive nature.

Effect of fines under cyclic loading**:** The pore pressure builds up is rapid in last few cycles of the loading. The axial strain development is negligible in initial cycles of loading, and large strains are developed just after the failure. As the fines content increases, the rate of generation of excess pore water pressure on cycles of loading was found to increase. Therefore, it can be concluded that the liquefaction resistance of fine sand decreases with increase in silt content.

5. REFERENCES

[1] Kuerbis, R., Negussey, D. and Vaid, Y. P., Effect Gradation and Fines Content on the Undrained Response of Sand. Geotechnical Special Publication, No. 21, 1988, pp. 330-345.

[2] Amini, F. and Qi, G. Z., Liquefaction Testing of Stratified Silty Sands. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 126, No. 3, 2000, pp. 208-217.

[3] Xenaki, V. C. and Athanasopoulos, G. A., Liquefaction Resistance of Sand-Silt Mixtures: An Experimental Investigation of the Effects of Fines. Soil Dynamics and Earthquake Engineering, Vol. 23, 2003, pp. 183-194.

[4] Papadopoulou, A. and Tika, T., The Effect of Fines on Critical State and Liquefaction Resistance Characteristics of Non-Plastic Silty Sands. Soils and Foundations, Vol. 48, No. 5, 2008, pp. 713-725.

[1] Cubrinovski, M., Rees, S., and Bowman, E., Chapter 6: Effects of Non-Plastic Fines on Liquefaction Resistance of Sandy Soils. Earthquake Engineering in Europe, Springer, 2010, pp. 125-144.

[2] Thevanayagam, S., Liquefaction Potential and Undrained Fragility of Silty Soils. Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 2000, Paper 2383.

[3] Polito, C. P. and Martin, J. R., Effects of Nonplastic Fines on the Liquefaction Resistance of Sands. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 5, 2001, pp.408-415.

[4] Ladd, R.S., Preparing Test Specimens using Undercompaction. Geotechnical Testing Journal, Vol. 1, No.1, 1978, pp. 16-23.

[5] Akhila, M., Rangaswamy, K. and Sankar, N., Undrained Response and Liquefaction Resistance of Sand–Silt Mixtures. International Journal of Geotechnical and Geological Engineering (2018). https://doi.drg/10.1007/S10706-018 00790-0

[6] Bishop, A.W. and Henkel, D.J., The Measurement of Soil Properties in the Triaxial Test. William Clowes And Sons Ltd., London, 1969.

[7] Boominathan, A., Rangaswamy, K. and Rajagopal, K., Effect of Non-plastic fines on Liquefaction Resistance of poorly graded Gujarat sand. International Journal of Geotechnical Engineering, Vol 4, 2010, pp. 241-253

[1] Rangaswamy, K., Bhoominathan, A., and Rajagopal, K., Undrained response and liquefaction behaviour of non-plastic silty sands under cyclic loading. Proceedings of 5th International Conference on recent advances in geotechnical earthquake engineering and soil dynamics, California, 2010, Paper no. 4.21a.