27 May 2010, 4:30 pm - 6:20 pm

A Note on the Effect of Non-Plastic Fines on the Liquefaction and Reconsolidation Volumetric Strain Behaviour of Sands

T. G. Sitharam
Indian Institute of Science, India

B. V. Ravishankar
B.M.S. College of Engineering, India

J. S. Vinod
University of Wollongong, Australia

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

A NOTE ON THE EFFECT OF NON-PLASTIC FINES ON THE LIQUEFACTION AND RECONSOLIDATION VOLUMETRIC STRAIN BEHAVIOUR OF SANDS

T G Sitharam
Indian Institute of science
Bangalore, India

B V Ravishankar
B M S College of Engineering
Bangalore, India

J S Vinod
University of Wollongong
Australia

ABSTRACT

This paper discusses the influence of non- plastic fines on the liquefaction and reconsolidation volumetric strain behaviour of sand based on the strain controlled cyclic triaxial experimental results. The investigations were carried out on sand samples collected from earthquake-affected area of Ahmedabad city of Gujarat state in India. Laboratory investigations were conducted on clean sand (prepared from the natural sand) samples with varying amount of non-plastic fines. Experimental results highlight a considerable influence of non-plastic fines on the resistance to liquefaction and reconsolidation volumetric strains behaviour during cyclic loading.

INTRODUCTION

In the recent past numerous researches have been carried out to understand the influence of non-plastic fines on the influence of liquefaction behaviour of sands (e.g. Law and Ling, 1992; Koester, 1994; Polito and Martin, 2001, Sitharam et al, 2008). However, till now there is no clear consensus in the literature on the influence of fines has upon the liquefaction behaviour of sand. Both field and stress controlled cyclic tests have indicated that with increase in the non-plastic fines content in a sand will either increase or decrease the liquefaction resistance of the sands. The recent research study on the influence of non-plastic fines on liquefaction resistance at Indian Institute of Science, using strain controlled cyclic triaxial test have shown that resistance to liquefaction decreases with increasing fines until some limiting value and thereafter the resistance to liquefaction increase with increase in non-plastic fines. This kind of behaviour is similar to the results highlighted based on stress controlled tests (e.g. Shen et al, 1977; Vaid, 1994 Polito and Martin, 2001). After liquefaction, the pore water generated will eventually dissipate along some drainage route following the earthquake and this excess pore water pressure dissipation will be accompanied by some volume change of the sand deposits due to reconsolidation (Lee and Albaisa 1974). The volume change during reconsolidation was considered to represent the characteristics of the sand directly related to the settlements of in-situ sand deposits which take place following liquefaction during earthquakes. The settlement of the ground surface in turn will results in damage to engineering structures, pavements and other utilities. Hence, it is important to evaluate the settlements in terms of volumetric strain of sands due to dissipation of pore water pressure induced by undrained cyclic loading. In the literature, very few studies (e.g. Tatsuoka et al 1984; Ishihara and Yoshimine, 1992; Sento et al 2004) have been carried out to understand the influence of non- plastic fines on the reconsolidation volume change behaviour of sands during cyclic loading. This paper discusses non-plastic fines on the liquefaction and reconsolidation volumetric strain behaviour of sands during strain controlled cyclic loading.

LABORATORY EXPERIMENTS

Laboratory experiments were carried out on clean derived from the representative natural sand samples (base sand which contains about 9.2% of silt content) which are collected from earthquake-affected area of Ahmedabad city of Gujarat state in India. The clean sand (particle size >0.075mm) was prepared by removing the silt portion by washing from the base sand using 75-micron sieve. Figure 1 show the ranges of grain size distribution for liquefaction susceptible soils as proposed by Tsuchida [1970] and Xenaki and Athanasopoulos [2003] along with grain size distribution plot of clean sand samples considered for the current investigation. Fig. 1 clearly highlight that sand samples falls with in the range of most liquefiable soils. The sand samples with non-plastic fines were prepared by adding the non-plastic fines derived from the natural sand in different percentage (15%, 30% and 45%) by weight to the clean sand. Samples of size 50 mm diameter and 100 mm height were prepared by dry pluviation through a funnel by raising it along the axis of symmetry of the specimen in the membrane lined split mould and tapping gently to the sides of the mould to achieve the desired density. These samples were saturated with de-aired water using back pressure saturation. After saturation (B>0.98), samples were subjected to different amplitudes of cyclic loading using strain controlled cyclic triaxial tests at 1 Hz frequency up to initial liquefaction, which is defined as the state in which the pore water pressure builds up to a value equal to the initially applied confining pressure.

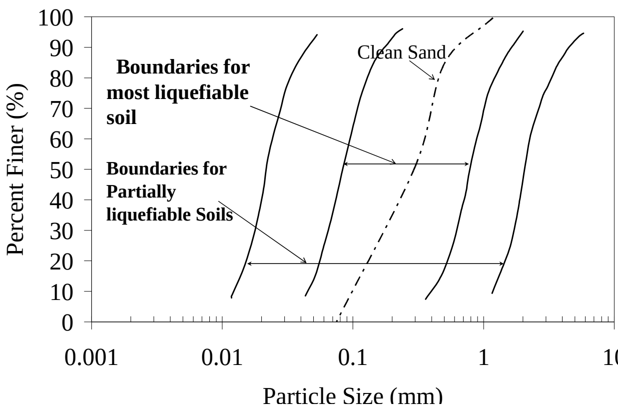

Fig.1 Particle size distribution curve

After initial liquefaction, the drainage line was opened and the excess pore water pressure generated during the undrained cyclic loading was allowed to dissipate from the sample against the same back pressure originally used during isotropic consolidation process (i.e., the mean effective stress returned to the initial mean effective stress). The amount of out flow of pore water was taken as the volume change of the sample caused by reconsolidation following the cyclic loading and the corresponding volumetric strain is presented as the reconsolidation volumetric strains. Influence of non-plastic fines on the reconsolidation volumetric strain of liquefied sand was investigated.

RESULTS

Effect of Non-Plastic Fines on Liquefaction Potential of Sands

Fig. 2 illustrates the liquefaction susceptibility of sands with varying percentage of non-plastic fines at a constant dry density of 1.69g/cm^3. It is evident from Fig.2 that the liquefaction potential is influenced by the non-plastic fines. This clearly indicates that the percentage of non-plastic fines in the sand samples has a significant effect on the liquefaction potential. Moreover, the liquefaction potential of the sand sample increases with increase in the addition of non-plastic fines up to 30%. However, with further increase in non-plastic fines (FC>30%) the liquefaction potential is found to be decreasing.

Fig. 3 shows the effect of non-plastic fine content on the pore water generation with number of loading cycles for a constant dry density of 1.69g/cm^3 at 1Hz frequency under an effective confining pressure of 100 kPa. It can be noticed that the pore water pressure ratio is increasing with the increase in the non-plastic fine content up to 30%. There after pore pressure ratio decreases with increase in the non- plastic fine content.

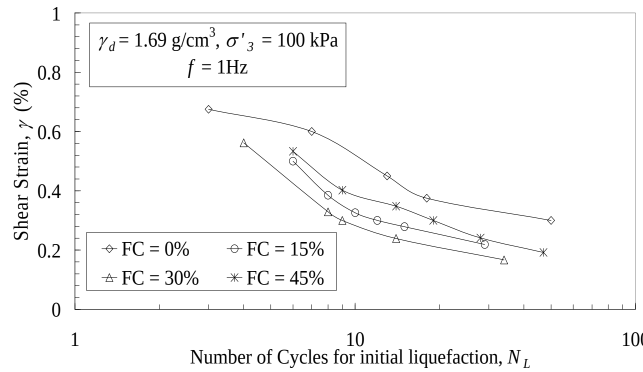

Fig. 2 Influence of non-plastic fines on the shear strain versus number of cycles for initial liquefaction curve (Sitharam et al, 2008)

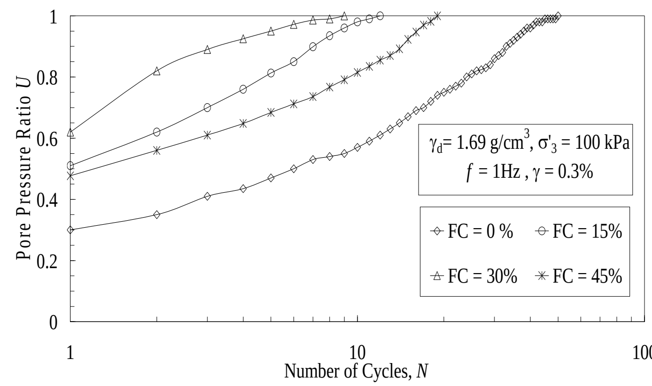

Fig. 3 Variation of pore pressure ratio with number of cycles of different percentages of non-plastic fine (Sitharam et al, 2008)

Fig. 4 presents the liquefaction potential of sand in the form of cyclic shear strain required for 20 numbers of loading cycles for clean sand samples mixed with varying percentage of non-plastic fines at constant dry density under of 1.69 g/cm^3. It is evident from the Fig.4 that the cyclic shear strain at 20 numbers of cycles decreases with increase in the percentage of non-plastic fine content up to 30% and thereafter the shear strain amplitudes corresponding to 20 number of cycle is increases with increase in the non-plastic fine content. The experimental results of the current study indicate that this threshold value (limiting value) of fines content is, approximately, equal to 30%.

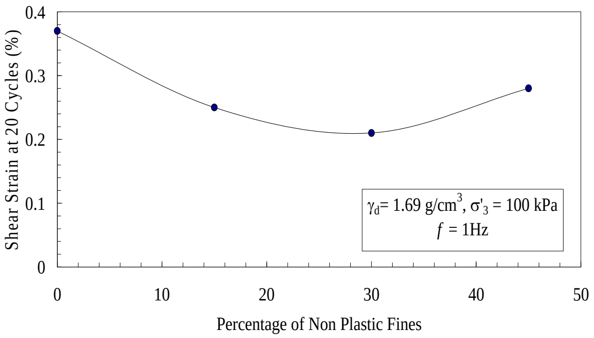

Fig. 4 Cyclic Strength in terms of cyclic shear strain at 20 Number of cycles with different percentage of non-plastic fines (Sitharam et al, 2008)

<u>Effect of Non-Plastic Fines on Reconsolidation Volumetric Strain Behaviour of Sands</u>

The effect of different percentages of non-plastic fines on the reconsolidation volumetric strains for a constant dry density of 1.69g/cm^3 is depicted in the Fig 5. Reconsolidation volumetric strains increases with increase in the shear strain. Moreover, it decreases with increase in the percentage of non- plastic fines.

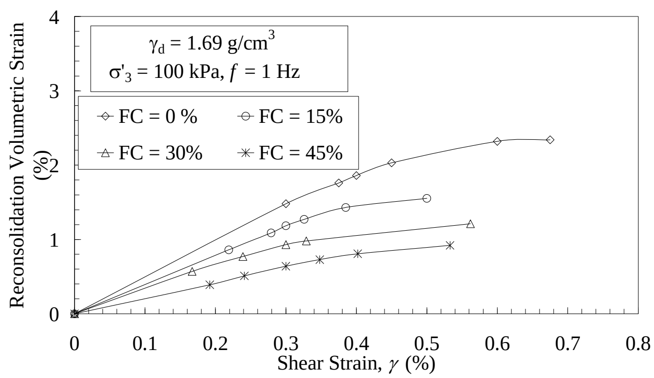

Fig. 5 Influence of non-plastic fines on reconsolidation volumetric strain

Fig. 6 presents the variation of reconsolidation volumetric strain with percentage of non-plastic fines for different amplitudes of shear strains. It is evident from the Fig. 6 that reconsolidation volumetric strain decreases exponentially with increase in non-plastic fines irrespective of amplitudes of shear strain for initial liquefaction. However, the reconsolidation volumetric strain curves tend to converge at higher percentage of non plastic fines. In addition, reconsolidation volumetric strain increases with increase in the shear strain amplitudes for a particular values of non - plastic fines.

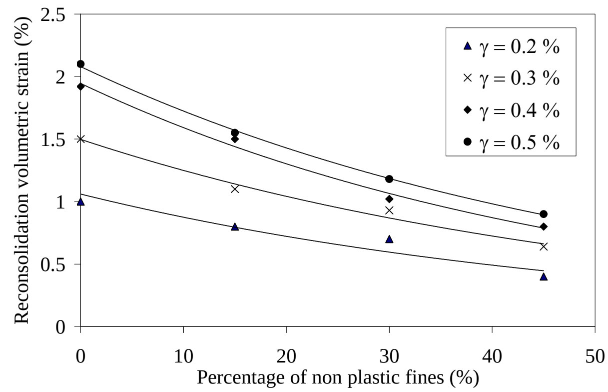

Fig. 6 Relationship between reconsolidation volumetric strain and percentage of non- plastic fines for different shear strain amplitudes

DISCUSSIONS

It is evident from Fig.2 that resistance to liquefaction decreases with increase in percentage of non-plastic fines until some limiting fines (say, F.C =30%) thereafter increases with increase in the non-plastic fines. This behavior is in good agreement with the earlier findings (e.g. Koester 1994; Polito and Martin, 2001). However, numerous studies reported in the literature have produced conflicting answer to the effect the non-plastic fines has upon the liquefaction resistance of sand. Polito and Martin [2001] evaluated the cyclic resistance in terms of sand skeleton void ratio method and concluded that, if the silt content of the soil is below the limiting silt content, the soil can be described as consisting of silt contained in a sand matrix. If the silt content is greater than the limiting silt content, the specimen's structure consists of predominately of sand grains suspended within a silt matrix with little sand grain to sand grain contact. Moreover, the largest amount of silt that can be accommodated in the voids created by the sand skeleton has been called the limiting silt content and generally occurs between 25 and 45%. In this study the limiting silt content was observed to be at 30%. However, it is interesting to note that reconsolidation volumetric strain decreases with increase in non-plastic fine content (Fig.5). In the literature, very little explanation can be found on the behaviour of non-plastic fines on the reconsolidation volume change behaviour of sands. Once the specimen is liquefied there will be a complete collapse of the particle structure and therefore the volumetric strain developed during draining will be totally controlled by the amount of non-plastic fines. During draining (after liquefaction) the coarse particles will settle first and the fines will then take the void space between the coarse grain particles. As the amount of fines increases, it will be then packed on top of the coarse particle after filling void space. These justifications require further support from the detailed micromechanical simulations using Discrete Element Method (DEM).

CONCLUSIONS

From the current study of effect of non-plastic fines on liquefaction and reconsolidation volumetric strains on sand samples collected from earthquake affected area of Ahmedabad the following conclusions are drawn. The potential for liquefaction increases with increase in the non plastic fines up to 30% of fines contents and there after the potential for liquefaction decreases. The threshold fine content (limiting fine content) for Ahmedabad sand was found to be 30%. A significant influence of non-plastic fines on the reconsolidation volumetric strains are observed and the reconsolidation volumetric strains decreases with increase in the non-plastic fines. The current interpretation of these results needs further support from the micromechanical investigation using DEM.

ACKNOWLEDGEMENTS

The Author's wish to thank Ministry of Earth Sciences (MoES), Govt. of India.

REFERENCES

Ishihara, K. and Yoshimine, M., [1992], Evaluation of settlements in sand deposits following liquefaction during earthquakes. *Soils and Foundations*, Vol.32, No.1, pp. 173-188.

Koester, J P [1994], "The influence of fine type content on cyclic resistance," *Ground failure under seismic conditions, Geotech. Spec. Publ.* No.44, ASCE, New York, pp. 17-33.

Law, K T and Ling, Y H [1992]. Liquefaction of granular soils with noncohesive and cohesive fines, *Proceedings, 10th World Conference on Earthquake Engineering*, pp. 1491-1496.

Lee, K.L., and Albaisa, A., [1974], Earthquake induced settlements in saturated sands, *Journal of the Geotechnical Engineering Division, ASCE*, Vol. 100, No.GT4, pp. 387-406.

Polito, C P and Martin, J P [2001], "Effect of nonplastic fines on the liquefaction resistance of sands", *Journal of Geotechnical and Geoenvironmental Engineering*, Vol.127, No.5, pp. 408-414.

Sento, N., Kazama, M., Uzuoka, R., Matsuya, A., and Ishimaru, M., [2004], Liquefaction induced volumetric change during reconsolidation-consolidation of sandy soil subjected to undrained cyclic loading histories. *In proc. of international conf. of cyclic behaviour of soils and liquefaction phenomena*, Ochum, Germany, pp. 199-206.

Shen, C. K., Vrymoed, J.L and Uyeno, C. K [1977], "The effect of fines on liquefaction of sands", *Proc., 9th Int. Conf. on soil mech. And Found. Engrg.*, Vo.. 2 pp. 381-385.

Sitharam, T G, Ravishankar, B V and Vinod, J. S **[**2008]**,** Liquefaction and porepressure generation in sands: A cyclic strain approach**,** *Journal of Earthquake and Tsunami*, Vol.2, No. 3, pp. 227-240**.**

Tatsuoka,F., Sasaki,T. and Yamada,S. [1984], Settlement in saturated sand induced by cyclic undrained simple shear, *Proc. of the 8th World Conf. on Earthquake Eng*., Vol.3, pp.

Tsuchida, H., [1970], "Prediction and counter measure against the liquefaction in sand deposits." *Abstract of the seminar in the Port and Harbor research institute*, pp. 3.1-3.33.

Vaid, V. P [1994], "Liquefaction of silty soils". Ground failures under seismic conditions, *Geotech. Spec. Publ. No. 44 ASCE*, NY pp. 1-16.

Xenaki, V.C., and Anthanasopoulos, G.A., [2003], "Liquefaction resistance of sand- mixtures: An experimental investigation of the effect of fines." *Soil Dynamics and Earthquake Engineering*, pp.183-194.