Paper No. 1079. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

LIQUEFACTION OF SILTS AND SILTY SANDS

S. SINGH

Department of Civil Engineering, Santa Clara University
Santa Clara, California, 95053 USA

Abstract

The paper critically examines the influence of non-plastic fine contents on the liquefaction behavior of sands. The studies reported in the literature are reviewed. It appears that it is not easy to clarify the influence of fines using parameters such as relative density and void ratio currently used for sands. The affects of fines beyond about 20% on liquefaction behavior of sand are more complex than previously thought.

Keywords

Liquefaction; silts; silty sand; non-plastic fines; relative density; void ratio.

Introduction

Research on the liquefaction susceptibility of silt is a relatively recent undertaking and it appears that liquefaction behavior of silt and silty sand has not yet been completely understood. While studies by Finn (1991) and Chameau and Sutterer (1994) indicate that the increase in fine content (silt) increases resistance to liquefaction of a soil, laboratory studies by Kuerbis et al (1988), Zlatovic and Ishihara (1995) and others indicate that the presence of silt in sand decreases the resistance to liquefaction. Often attempts have been made to understand the liquefaction behavior of silts and silty sands in terms of parameters used for sands. For example, relative density has been found to be not a suitable parameter for silty sands (Ishihara et al 1980; Kuerbis et al, 1988; and Singh, 1994). Vaid (1994) encountered difficulties in comparing the densities of sands and sand-silt mixes. Singh and Chew (1988) tested undisturbed samples of silts and silty sands and found that the pore pressure generation and deformation characteristics of silty samples were different than that of sand samples. Clearly the effects of fines (non-plastic silts) on the liquefaction behavior of sands are more complex than it has been previously thought. Accordingly, this paper attempts to critically examine the studies reported in the literature in light of the recently reported studies made by the author on the cycle strength behavior of laboratory prepared samples of pure silt and samples of sand containing 10, 20, 30 and 60 percent silt.

Investigation of the Influence of Fine Contents

Laboratory controlled studies on the influence of silt content on cyclic strengths of clean sands have been reported by Ishihara et al., (1980), Chang et al., (1982), Kuerbis et al., (1988), Singh (1994), Vaid (1984), Chien et al., (1995), Zlatovic and Ishihara (1995), Pradhan et al., (1995) and others. Test results from Zlatovic and Ishihara (1995) indicate that cyclic peak and residual strength of sands is very sensitive to the silt content; and that while the void ratio decreased and relative density increased with an increase in silt content up to 30%, specimens at the same time became more contractive. Chien et al (1995) studied the influence of fine content on the shear modulus and concluded on the basis of experimental results that for 10% of fines content, there is the greatest value for the shear modulus; and that for fines contents of 10%, 16%, 20% and 30%, the shear modulus decreases. Chien et al argued that this is due to the contact surfaces among soil aggregates; and that when the fines content is 10%, the voids were filled with fines but the contact surfaces among the soil aggregates were not reduced. Kuerbis et al (1988) had suggested similar explanation by using the concept of sand skeleton, according to which silt merely acts as a filler up to about 20% of silt. Pradhan et al (1995) carried out laboratory tests on sands and found that liquefaction potential is not affected significantly due to presence of fines up to 15%. From the foregoing, it appears that the behavior of silty sands with about 15% fines is dominated by sand.

Author used Flint Shot #4 sand, a uniform sand and a uniform non-cohesive silt to study the influence of fines content. All samples were tested under cyclic triaxial testing conditions. Moist tamping method was used for sample preparation. Preparation of silt samples was a challenge. In all of the test series involving silt, it was found that the results were very sensitive to the mixing moisture and tamping procedure for sample preparation. Consistencies in all aspects such as mixing, tamping and handling were very important to achieve consistent results. The presence of a somewhat weaker layer was readily evident from the manner in which the sample would fail. Further details of sample preparation are given in Singh (1994). Figure 1 shows the relationship between cyclic stress ratio and number of cycles to initial liquefaction for reconstituted samples of pure sand, pure sit and silty sand.

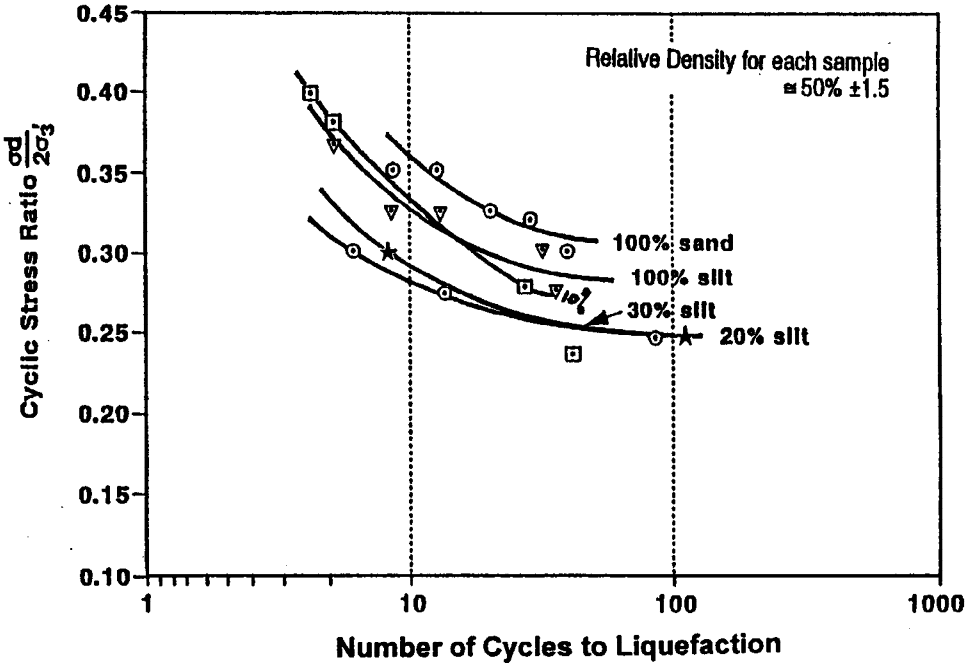

Fig. 1 Relationship Between Cyclic Stress Ratio and Number of Cycles to Initial Liquefaction for Reconstituted Samples of Sands and Silts.

It may be noted from Figure 1 that sands containing 10, 20 or 30 percent of silt have lesser cyclic strength than that of 100 percent sands. These samples were prepared to approximately the same relative density of 50%. It has been suggested that relative density is not a suitable index for characterizing behavior of silty sands (Ishihara et al., 1980). Chang et al. (1982) used void ratio as the basis for comparison and tested silty sand samples at the same void ratio as the 100 percent sand samples, and concluded that the cyclic resistance increases as the silt content increases; that the increase is slight, up to 10% silt content, and begins to develop more as the silt content increases to 30% silt. Chang et al. explains this behavior in terms of sand grain to sand grain contact in the soil structure. But it appears to be due to the increase in relative density as the more silt is added and the samples are prepared at the same void ratio. Studies by Kuerbis et al. (1988) suggest that the higher the silt content, the lower the cyclic resistance for given relative density. Studies reported herein indicate similar results (Figure 2). Kuerbis et al. also reported that over the range of overlapping void ratios of various silty sands, the cyclic resistance at a given void ratio decreases with increase in silt content. Kuerbis et al. used the concept of sand-skeleton void ratio to explain the results and concluded that the rather small change in behavior with increasing silt can be explained by the fact that the sand skeleton void ratio remains virtually unaltered with the addition of silt. Silt merely acts as a filler of sand skeleton voids and hence behaves as an inert component (up to about 20% of silt). Tokimatsu and Yoshimi (1984) and Seed et al. (1985) suggested on the basis of field performance of sandy soils with fines that soils containing more than 20% clay (finer than 5 μm) would hardly liquefy unless their plasticity indexes are low.

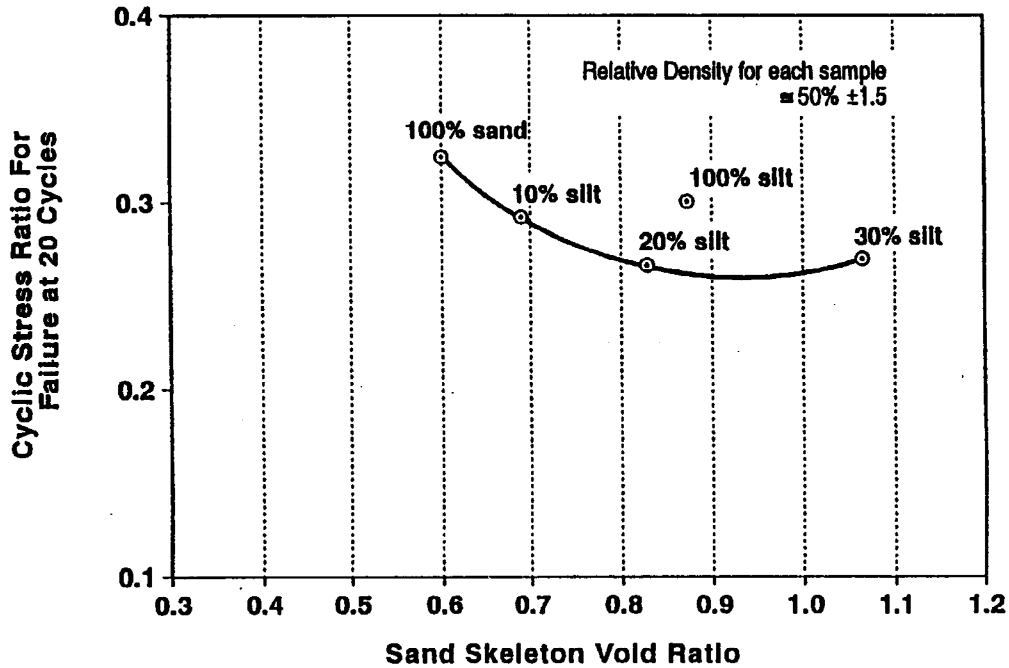

Fig. 2 Relationship between Cyclic Stress Ratio and Sand Skeleton Void Ratio (from Singh, 1994).

From the foregoing, it appears that it is not easy to clarify the influence of fines on the behavior of sands under cyclic loading, and that the liquefaction characteristics of silts may not be estimated on the basis of relative density criteria currently used for sands. In an attempt to explain the behavior in terms of void ratio, Figure 2 was prepared; and it appears that whereas void ratio may be the better index than relative density to explain the influence of fines on sand behavior, the interpretation in terms of void ratio alone may be made with caution. Because, the addition of silt content at a given relative density increases the void rates (of sand skeleton) as shown in Figure 2 and the sample becomes more contractive. Zlatovic and Ishihara (1995) also observed contractive behavior up to about 30% of silt content beyond which the trend changed. Studies reported herein indicate that although the sand skeleton void ratio increases with an increase in silt content, the overall void ratio return of the sample decreases (Figure 3). Beyond about 50% of silt content, the overall void ratio appears to increase and continues to increase till 100% of silt content, and as shown in Fig. 1, though, the samples at 100% silt content are at an increased void ratio than the 10%, 20% and 30% silt samples, the 100% silt samples exhibits higher strengths. This may be because the sand behavior no longer dominates the sample behavior beyond about 30 to 40% silt content, and that at higher silt contents till 100% silt, the behavior is controlled by silt alone. Therefore, the concept of void ratio can also be misleading when applied to silty sands and silts.

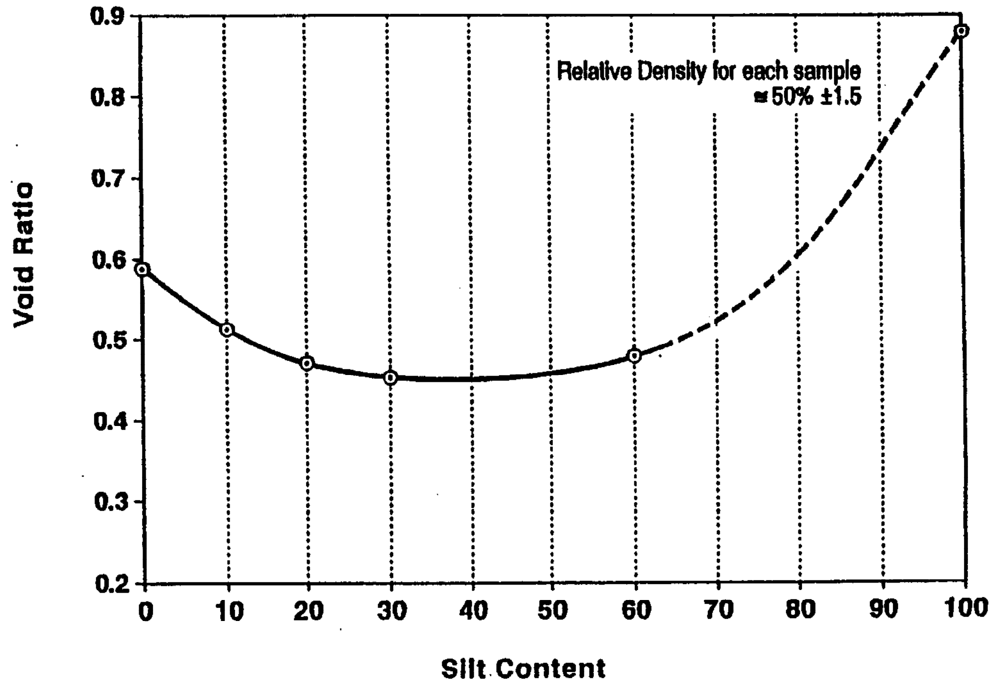

Fig. 3 Effect of Silt content on the Void Ratios of Samples Prepared at 50% Relative Density (from Singh, 1994).

Conclusion

On the basis of the studies reported herein, the following conclusions may be drawn:

1. A review of laboratory test data indicates that it is not easy to clarify the influence of non-plastic fines (greater than 20%) on the behavior of sands in terms of parameters currently used for sands.

2. There is a problem in establishing criteria for liquefaction of silts and silty sands in terms of relative density or void ratio.

References

Chang, N.Y., S.I. Yeh, and L.P. Kaufman, (1982), "Liquefaction Potential of Clean and Silty Sands," Proceedings, *Third International Earthquake Microzonation Conference*, Seattle, Washington, Vol. II, pp. 1017-1032.

Chien, L, Yeh, G. and Oh, Y.,(1995) "To Evaluate Influence of Fine Content on the Dynamic Properties of Reclamation Soil in the Taiwan Nearshore Area," Proceedings, *First International Conference on Earthquake Geotechnical Engineering*, Tokyo, 14-16 November.

Ishihara, K., Troncosco, J., Kawase, Y., and Takahashi, Y. (1980). "Cyclic Strength Characteristics of Tailings Materials," *Soils and Found*, 20(4):127-142.

Kuerbis, R., D. Nequessey, and Y.P. Vaid, (1988), "Effect of Gradation and Fines Content on the Undrained Response of Sand," Proceedings, *ASCE Geotechnical Division Speciality Conference on Hydraulic Fill Structures*, Colorado State University, Fort Collins, Colorado, August.

Pradhan, T. B.S., H. Kiku, and K. Sato (1995), "Effect of Fines Content on Behaviour of Sand During the Process to Liquefaction", Proceedings, *First International Conference on Earthquake Geotechnical Engineering*, Tokyo, 14-16 November.

Prakash, S. and VK. Puri, (1982), "Liquefaction of Loessial Soils," Proceedings, *Third International Earthquake Microzonation Conference*, Seattle, Washington, Vol. II, pp. 1101-1107.

Seed, H.B., K. Tokimatsu, L.F. Harder, and R.M. Chung, (1985), "Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations," *Journal of Geotechnical Engineering Division of ASCE*, Vol. III, No. 12, December.

Singh, S., and R.Y. Chew, (1988), "Dynamic Strain in Silt and Effect on Ground Motions," *Earthquake Engineering and Soil Dynamics II Conference*, American Society of Civil Engineers Division of the Geotechnical Engineering's , Park City, Utah, June 27-30.

Singh, S., (1994) "Liquefaction Characteristics of Silts," Geotechnical Special Publication of Session 27 on Ground Failures under Seismic Conditions (Silty Soils), American Society of Civil Engineering 1994 Annual Convention and Special Exposition, Atlanta, Georgia, October 9-13.

Tokimatsu, K., and Y. Yoshimi, (1984), "Criteria of Soil Liquefaction with SPT and Fines Content," Proceedings, *8th World Conference on Earthquake Engineering*, Vol. III, San Francisco, California, July.

Zlatovic, S., and K. Ishihara (1995), "On the Influence of Nonplastic Fines on Residual Strength", Proceedings, *First International Conference on Earthquake Geotechnical Engineering*, Tokyo, 14-16 November.