LIQUEFACATION OF FINE GRAINED SOILS

Shamsher Prakash[1] and Vijay K. Puri[2]

ABSTRACT

The liquefaction behavior of silts and silt clay mixers was investigated over a range of plasticity index values of interest by conducting cyclic triaxial tests and was compared with that of sand. It was found that saturated silts with plastic fines behave differently from sands both with regard to rate of development of pore water pressure and axial deformations with number of load cycles. The results also showed that liquefaction susceptibility of silts shows a marked change with change in the plasticity index values. For a PI range of 2-4%, the liquefaction resistance of silt was fond to decrease with an increase in plasticity. The results of the investigation were compared with available information and reasonable agreement was noted.

Key Words: Liquefaction, Soils, Fine Grained, Silt, Clay, Plasticity

Introduction

Most earlier studies on liquefaction were devoted to sands. The present state of the art on liquefaction of sands has progressed to a stage that reasonable estimates of liquefaction potential can be made based on laboratory investigations or on simple in-situ test data such as standard penetration values (N_1 or $(N_1)_{60}$) or on cone penetration data, and the experience during the past earthquakes,(Arulanandan et al.1986, Mitchell and Tseng 1990, Robertson 1990, Seed 1976,1979 Seed and Idriss 1981, Seed and DeAlba, 1986, Seed and Harder 1990, Idriss 1991,Youd and Idriss ,2001 and Youd et. al, 2001).

The cyclic stress approach (Seed and Idriss 1981) and the cyclic strain approach (Dobry et al 1982) are commonly used for evaluation of liquefaction potential of sands and fine grained soils such as silts, clayey silts and sands with fines and silty soils were considered non-liquefiable. However, the observations following the Haicheng (1975) and Tangshan (1976) earthquakes indicate that many cohesive soils had liquefied. These cohesive soils had clay fraction less than 20%, liquid limit between 21-35%, plasticity index between 4% and 14% and water content more than 90% of their liquid limit. Kishida (1969) reported liquefaction of soils with upto 70% fines and 10% clay fraction during Mino-Owar, Tohankai and Fukui earthquakes.

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[1] Emeritus Professor, Civil, Environmental and Architectural Engineering, University of Missouri, Rolla, MO 65401

[2] Professor, Civil and Environmental Engineering, Southern Illinois University, Carbondale, IL 62901

Tohno and Yasuda (1981) reported that soils with fines up to 90% and clay content of 18 % exhibited liquefaction during Tokachi –Oki earthquake of 1968. Soils with up to 48 % fines and 18 % clay content were found to have liquiefied during the Hokkaido Nansai –Oki earthquake of 1993. Gold mine tailings liquefied during the Oshima- Kinkai earthquake in Japan (Ishihara, 1984). These tailings had silt sized particles and liquid limit of 31%, plasticity index of 10 % and water content of 37 %.

Seed et al (1983) found that some soils with fines may be susceptible to liquefaction. Such soils (based on Chinese criteria) appear to have the following characteristics:

Percent finer than 0.005 mm (5 microns) ‹15%
Liquid limit ‹ 35 %
Water content › 90 % of liquid limit

Seed et al., (2001) observed that there is significant controversy and confusion regarding the liquefaction potential of silty soils (and silty /clayey soils), and also coarser, gravelly soils and rockfills. Finn et al., (1994), Perlea et al., (1999) and Andrews and Martin (2000) have provided general criteria about liquefaction susceptibility of soils with fines. The findings of Andrews and Martin (2000) are summarized in table 1 below. For use of table 1, the clays refers to fraction finer than 2 μm and liquid limit should be determined by Cassagrande- type percussion equipment.

Table1. Liquefaction susceptibility of silty and clayey sands (Andrew and Martins, 2000)

	Liquid limit < 32	Liquid limit ≥ 32
Clay content < 10 %	Susceptible	Further studies required (Considering plastic non-clay sized grains such as Mica)
Clay content > 10 %	Further studies required (Considering non-plastic clay sized grains such as mine and quarry tailings	Not susceptible

It may be mentioned here that in soils in which the fines content is sufficient to separate the coarser particles, the nature of the fines controls the behavior (Ishihara 1993). Low plasticity or non-plastic silts and silty sands may be highly susceptible to liquefaction. This will be the case when PI is less than 10. For soils with moderately plastic fines (fines content more than about 15 % and $8 \leq$ PI ≤ 15), the liquefaction behavior may be uncertain and may need further investigation. It is obvious that it is still not possible to evaluate the likelihood of liquefaction of silts or silty clays with the same confidence as for clean sand.

Present Investigation

Dynamic triaxial tests were conducted on 73.65 mm (diameter) and 147.3 mm (high) samples of two different types of silts (A and B) to determine the effect of plasticity index on susceptibility to liquefaction. The index properties of these silts are given below:

	Soil A	Soil B
Percent finer than 75 μ (0.075 mm)	93-98	96-98
Natural water content %	18-26	---
Liquid limit	32.0 -36.0	24.2-26.6
Plastic limit	21.5-25.0	22.5-23.0
Plasticity index	9 -14 (mostly ≈ 10)	1.6-1.8
Clay content (‹ 2μm)	2.0 – 7.2 %	
Specific gravity of soil particles	2.71	2.725
Particle size D_{50} mm	0.06	0.022

Soil A is a naturally occurring silt. The PI of this silt was altered by adding the clay fraction obtained from this soil itself (Puri, 1984). The tests on silt A were conducted at PI = 10, 15 and 30. The PI of silt B was varied in the low plasticity range by adding kaolinite. The tests on silt B were conducted at PI = 1.7, 2.6 and 3.4 (Sandoval 1989)

A typical data for the tests for one test on silt A is shown in figure 1. It is seen form this figure that for the case of silt samples tested the failure defined by 5 % or 10 % double amplitude axial strains occurs before the condition of initial liquefaction defined by u $=\overline{\sigma}_3$ occurs. Similar trend has been observed by other investigators also during cyclic strength tests on silt samples (Singh 1994)

Figure 2. shows the effect of plasticity index on cyclic stress ratio inducing 5% DA strain in a given number of load cycles. Increase in PI value is seen to increase the cyclic stress ratio. The trend of the data from other tests was similar with the exception that that for the case of PI=20, the condition u$=\overline{\sigma}_3$ did not develop within the range of cyclic load applications used in this study.

Typical results of the investigation on samples of silt B showing the effect of plasticity index (PI = 1.7%, 2.6% and 3.4%) on the cyclic stress ratio causing initial liquefaction in any given number of cycles are shown in Fig. 3. It is clear from this figure that the cyclic stress ratio causing liquefaction in a given number of cycles decreases with the increase in plasticity index. It was observed during the testing phase that cyclic loading of plastic silts results in pore pressure build up which becomes equal to the initial effective confining pressure resulting in development of the initial liquefaction. This is just opposite the case when PI of 10% or greater (Silt A).

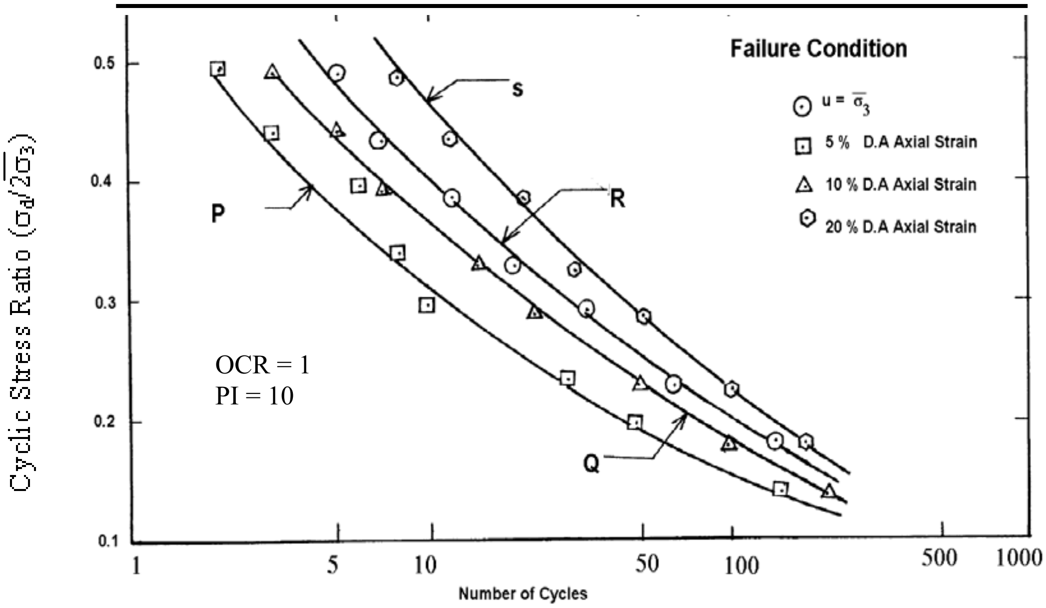

Figure 1. Cyclic Stress Ratio versus Number of Cycles for Reconstituted Saturated Samples, silt A, For $\bar{\sigma}_3$ = 15 psi

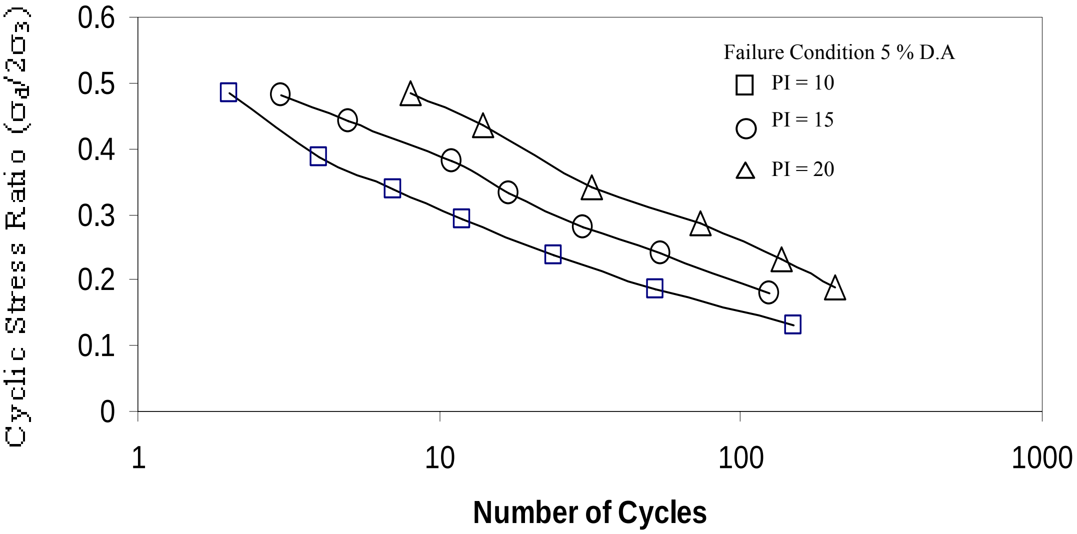

Figure 2. Cyclic Stress Ratio versus Number of Cycles for Reconstituted Saturated Samples, silt A, For $\bar{\sigma}_3$ =10 psi

Combining results for silts A and B with CSR normalized at void ratio of 0.74, (Prakash and Guo, 1998) leads to results as shown in Fig. 4. It is observed from this figure that for PI values of less than about 4% the cyclic stress ratio causing liquefaction in any given number of cycles decreases with an increase in PI values. For PI values beyond about 4%, the cyclic stress ratio causing initial liquefaction in any given number of cycles increases with an increase in the PI values. Based on these results, it may

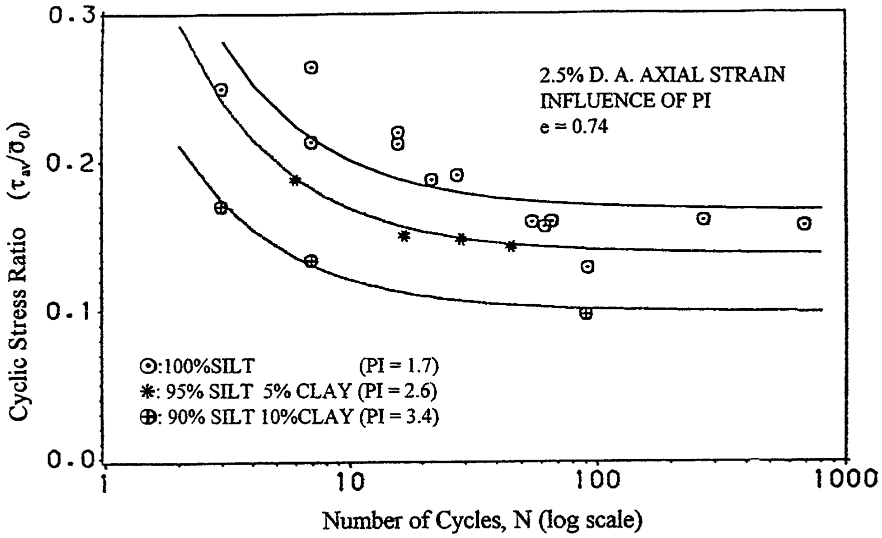

Figure 3 Cyclic Stress Ratio versus Number of Cycles for Low Plasticity Silts for Inducing Initial Liquefaction Condition at 15 psi Effective Confining Pressure; PI = 1.7, 2.6, and 3.4, for Density 97.2-99.8 pcf, and w = 8% (Sandoval 1989; Prakash and Sandoval 1992)

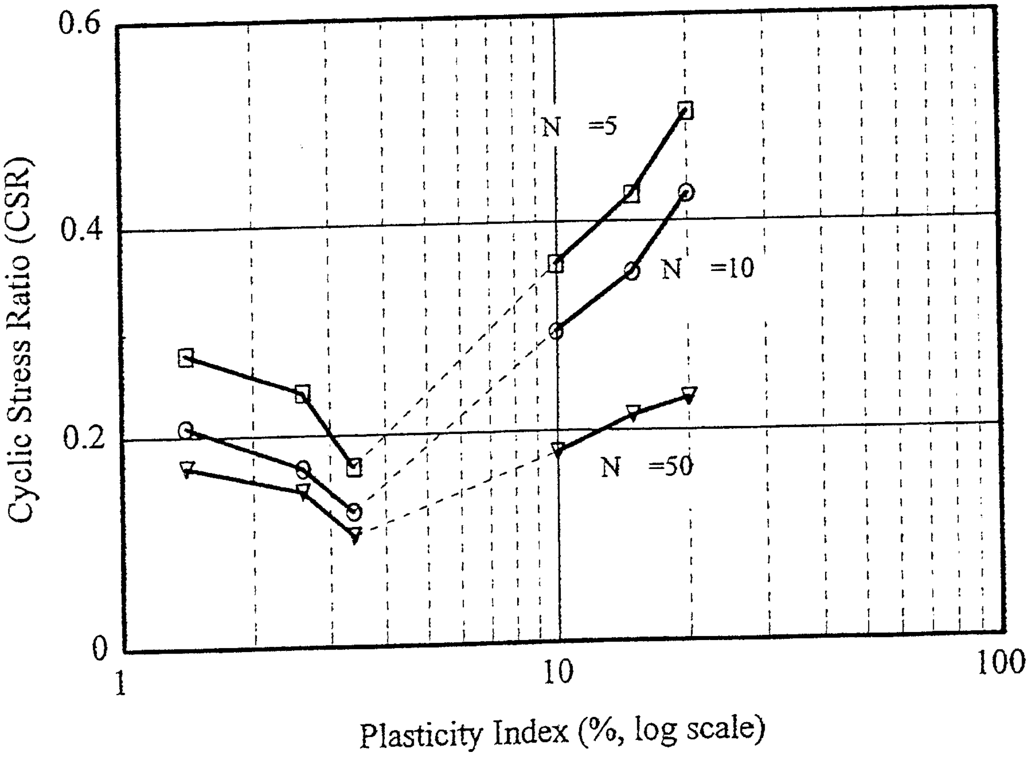

Figure 4 Cyclic Stress Ratio versus Plasticity Index for Silt-Clay Mixtures (CSR Normalized to initial Void Ration $e_0 = 0.74$)

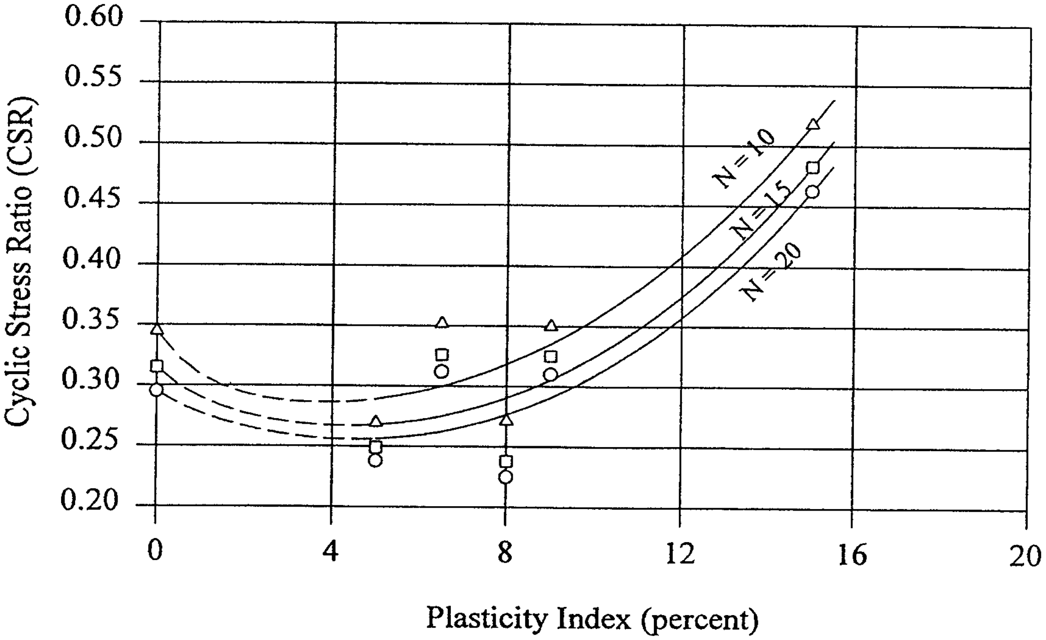

Figure 5 Normalized cyclic Stress Ratio versus plasticity Index on Undisturbed samples (After El Hosri et al 1984)

be inferred that there is a critical value of PI at which saturated samples of silt–clay measured mixtures have a minimum resistance to cyclic loading or highest susceptibility to liquefaction. For PI value below the critical value, liquefaction susceptibility increases with an increase in the PI value. In this case, this critical value of PI is about 4%; the limited nature of the study does not justify any general conclusion. It is worth mentioning here that data of ElHosri et al., (1984) on undisturbed sample Fig.5 also suggests a similar effect of PI on cyclic stress ratio causing liquefaction as observed during the present investigation.

Conclusions

It may be concluded that:

(1)The silts and silt–clay mixtures behave differently from sands, both with respect to development and build up of pore water pressures, and deformations under cyclic loading.

(2)There are several gaps in the existing literature and no guidelines are available and there is no definite criterion to ascertain the liquefaction susceptibility of silts and silt-clay mixtures from simple index properties or simple field tests.

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