Effect of Fines on Liquefaction Resistance of Solani Sand

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ABSTRACT:
The purpose of this study is to investigate the effect of non-plastic silts on liquefaction susceptibility of Solani sand using cyclic triaxial test. For this, soil samples were prepared by varying silt contents and the initial relative density. The results of the study performed are used to clarify the effects of fines on the Solani sand. As the fine contents increases, the number of cycles required to produce pore water pressure causing liquefaction changes. It is observed that critical silts contents to generate pore water pressure initiating liquefaction are different for different relative density. Effects of fine content were very much dependent on relative density.

Keywords: Solani Sand, Fines, Liquefaction, Pore Pressure and Cyclic Triaxial tests.

1. INTRODUCTION

Liquefaction of soils is a complex problem on which a great deal of research has been done both experimentally and numerically. Liquefaction may be defined as a phenomenon associated with rise of pore water pressure and loss of shearing resistance in soils (Kramer 1996, Towhata 2008). Loose saturated cohesionless soils are most susceptible to liquefaction (Prakash 1981); however there are strong historical evidence suggesting that soils containing fines are also prone to liquefaction during earthquakes. The liquefaction of silty sands has been observed in a number of studies. Initial relative density is major governing parameter for the development of pore water pressure.

Maheshwari and Patel (2010) studied the effect of fine content and suggested that liquefaction resistance increases when fine contents are in the range of about 12% to 15%. Further with a certain N value, a soil with fine content 30% would have no more additional resistance to liquefaction than sand with 15% fine content Liao (1986).

For the same SPT N value, liquefaction resistance decreases with percentages of fines increases Tkoimatsu and Yoshimi (1983). A numbers of researchers have done study on effects of fines on liquefaction resistance based on laboratory tests e.g. Prakash *et al.* (1992), Erten and Maher (1995), Guo and Prakash (1999), Polito and Martin (2001), Xenaki and Athanasopoulos (2003), Sitharam et al. (2004), Hazirbaba (2005), Patel (2006), Derakhshandi et al. (2008), Singh (2009) and Maheshwari et al. (2012) studied the liquefaction resistance of composite material. However, the conclusions drawn in literature about effect of fines on liquefaction resistance are contradictory and it is not clear whether the fines increase or decrease the liquefaction resistance.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Material Used

The sand used in this study was collected from Solani River bed near Roorkee, India and the silt was collected from the Dhanauri River bed near Kaukheda village, about 10km from Roorkee India.

According to the Indian Standards specifications (IS 2720 Part 4-1983) for classification of soils for engineering purpose, the soil has been identified as Poorly Graded sand (SP) and silt as low plasticity silt (ML). The properties of Solani sand and silt are presented in the Table 2.1 and Table 2.2, respectively.

Table 2.1. Properties of Solani Sand

Sr. No.	Particulars	Notations	Value
1	Soil Type	SP	Poorly Graded Sand
2	Specific Gravity	G_s	2.68
3	Uniformity Co-efficient	C_u	1.96
4	Co-efficient of Curvature	C_c	1.15
5	Grain Size	D_{10}	0.120 mm
		D_{30}	0.180 mm
		D_{50}	0.210 mm
		D_{60}	0.235 mm
6	Maximum Void Ratio	e_{max}	0.850
7	Minimum Void Ratio	e_{min}	0.540

Table 2.2. Properties of Silt

Sr. No.	Particulars	Notations	Value
1	Soil type	ML	Low Plasticity Silt
2	Specific gravity	G_s	2.54
3	Liquid limit	LL	30%
4	Plastic limit	PL	24%
5	Plasticity index	PI	6%
6	Grain size	D_{10}	0.001 mm
		D_{30}	0.006 mm
		D_{50}	0.018 mm
		D_{60}	0.026 mm
9	Maximum void ratio	e_{max}	1.27
10	Minimum void ratio	e_{min}	0.34

2.2 Details of the Tests Conducted

In the present study, strain controlled cyclic triaxial test were performed according to ASTM 3999-11, on Solani sand with different percentages of silt content (0%, 5%, 10%, 15% & 20%), at 2 relative densities 35% & 50% at constant effective confining pressures of 50 kPa and frequency of 1 Hz. In this study adopted a strain approach because excess pore water pressure generation is controlled mainly by the level of induced shear strains. This approach was first proposed by Dobry et al. (1982). Axial strain on which samples were tested is 0.75%. Total 10 numbers of tests were conducted in this study.

3. SAMPLE PREPARATION

Moist placement method (wet tamping), dry deposition method and water sedimentation method these are three types of methods widely used for the sample preparation for triaxial testing of saturated sands samples.

In this study water sedimentation method has been used for sample preparation. For the preparation of saturated sand sample of relative density (D_r), the following steps have been evolved.

a) The relative density (D_r) of sand is defined by a mathematical equation given by

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \tag{3.1}$$

Where D_r. is the relative density, e_{max} is the maximum void ratio, e_{min} is the minimum void ratio and e is the desired void ratio at a particular relative density of sand.

b) The void ratio (e) corresponding to a relative density (D_r) of sand was calculated as

$$e = e_{\max} - D_r (e_{\max} - e_{\min}) \tag{3.2}$$

The values of e_{max} and e_{min} are given in Tables 2.1 and 2.2 for sand and silt, respectively.

c) Knowing the value of void ratio (e) obtained, dry unit weight of sand (γ_d) was determined by the following equation:

$$\gamma_d = \frac{G_s}{1+e} \gamma_w \tag{3.3}$$

Where γ_w is the unit weight of water (taken as10 kN/m^3) and G_s is the specific gravity of solids.

d) Water content (w) required for 100 % saturation i.e. $S_r = 1.0$ was determined by

$$w = \frac{e \times S_r}{G_s} \text{ i.e. } w = \frac{e}{G_s} \tag{3.4}$$

e) Knowing the values of γ_d and V, the dry weight of sand (W_d) was determined by the equation:

$$W_d = \gamma_d \times V \tag{3.5}$$

Where, V is volume of the sample.

f) Quantity of water (W_w) required for saturation was determined from

$$W_W = w \times W_d \tag{3.6}$$

g) Mould of desired size was fixed to the base pedal of corresponding triaxial cell with rubber membrane attached tightly to it, porous stone and wet filter paper was placed at the bottom of the mould.

h) The amount of water required to achieve saturation is added into the mould. Quantity of water required for the particular D_r can be determined by Eqn. 3.6.

i) The quantity of dry sand (W_d) obtained in step (e) and the specified weight of Silt content (percent by dry weight of sand). The Sand-Silt mixture was poured into the water through funnel with a plastic tube attached to the end, keeping the tip of the funnel at a constant height from the water surface.

j) The sample was prepared in three layers and tamped gently at each layer.

k) Filter paper and porous stone was placed on top of the sample.

l) Top cap with vacuum ring was placed on porous stone and rubber membrane is pulled over this assembly. Then rubber membrane was sealed with O-ring. Fig. 3.1 shows a sample of sand ready for testing.

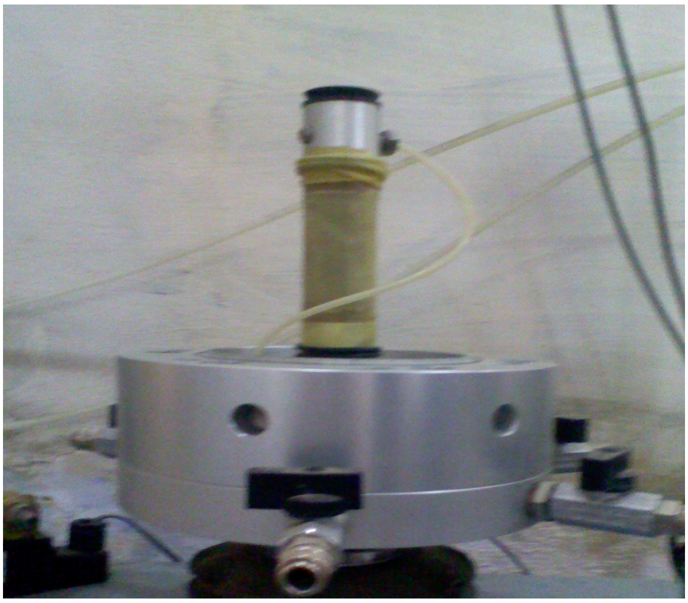


Figure 3.1. Sample ready for testing

4 ANALYSES OF TEST RESULTS

All experiments were conducted using cyclic triaxial testing system. Figs. 4.1 and 4.2 show the variation of shear stress, shear strain and pore pressure ratio with number of cycles at high strain level (0.75%) for relative density (RD) equal to 50% for plain sand and sand with 0.75% silts, respectively. When the specimen is liquefied, there is complete loss of shear strength. To measure the liquefaction resistance, a parameter r_u is defined as the ratio of excess pore water pressure due to shaking to effective confining pressure.

All tests were performed under strain controlled condition. As evident from Figs. 4.1 and 4.2, value of shear stress decreases with the number of cycles and then finally becomes constant at a small value. The increase in pore water pressure results in a corresponding decrease in the effective stress, which finally reduces to zero when excess pore water ratio (r_u) is equal to 1 (a condition for liquefaction).

Figures 4.1(c) and 4.2(c), respectively indicate the pure Solani sand liquefies in 4 cycles and the number of cycles required for liquefaction increases up to 21 cycles for sand with 10% silt content.

Test results are summarized in Tables 4.1 and 4.2 for 35% and 50% relative density, respectively. From Table 4.1, it can be observed that the number of cycles required for liquefaction increases with increase in silt content and reach to a maximum value at 15% silt content. At this silt content, the value of $(r_u)_{max}$ is also minimum. Thus, for 35% R.D., 15% silt content is an optimum value offering maximum liquefaction resistance. Similarly from Table 4.2, the optimum value of silt content for 50% RD is 10%. The results are in close agreement with the result reported by Carraro et al. (2003).

Further, the data of Tables 4.1 and 4.2 are plotted in Fig. 4.3 and 4.4 which also indicate the same trend as discussed above. From Fig. 4.3, it can be observed that at particular silt content, number of cycles required for liquefaction is the same for both 35% and 50% relative density. Thus indicating that at this point effect of relative density is not significant.

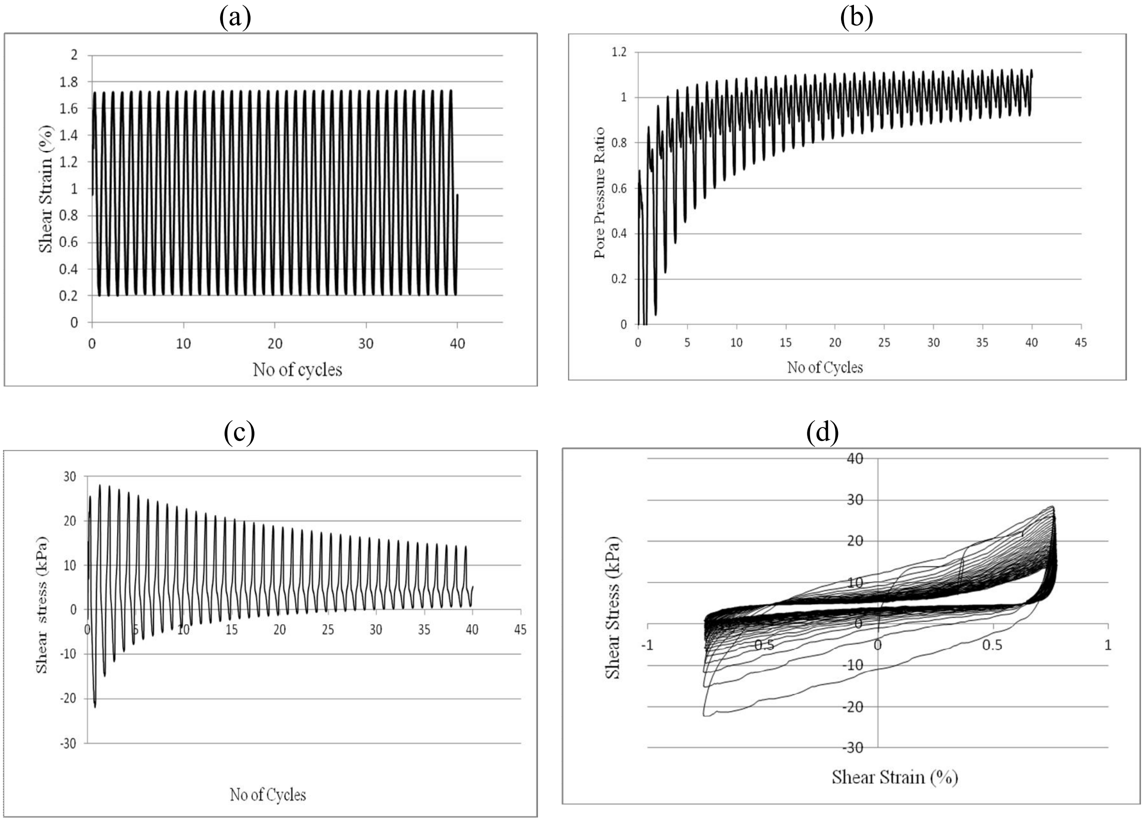


Figure 4.1: Results of a strain controlled test on pure sand (Strain level 0.75%, freq. 1Hz, CP 50 kPa and 50% RD) (a) Shear Strain Vs Number of cycles; (b) Pore water pressure Vs Time in Sec (c) Shear Stress Vs Numbers of cycles (d) Shear Stress Vs Shear Strain.

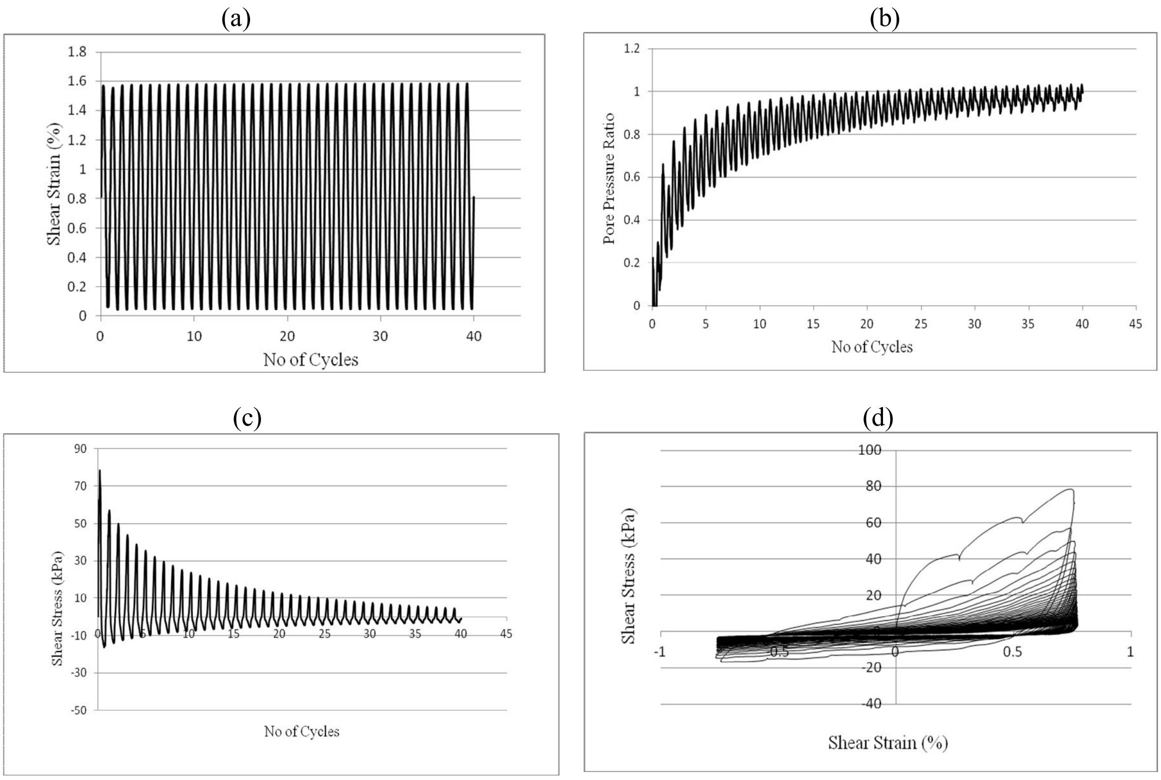


Figure 4.2 Results of a strain controlled test on sand with 10% silts (Strain level 0.75%, freq. 1Hz, CP 50 kPa and 50% RD) (a) Shear Strain Vs Number of cycles; (b) Pore water pressure Vs Time in Sec (c) Shear Stress Vs Numbers of cycles (d) Shear Stress Vs Shear Strain.

Table 4.1. Test results on Solani sand for confining pressure 50 kPa and 35% RD

Sr. No.	Silt Content (%)	No. of Cycle for $(r_u) = 1.0$	$(r_u)_{max}$	G (kPa)
1	0%	4	1.135	1290
2	5%	5	1.097	1494
3	10%	13	1.052	2366
4	15%	15	1.054	2580
5	20%	14	1.064	1935

Table 4.2. Test results on Solani sand for confining pressure 50 kPa and 50% RD

Sr. No.	Silt Content (%)	No. of Cycle for $(r_u) = 1.0$	$(r_u)_{max}$	G (kPa)
1	0%	4	1.123	2123
2	5%	10	1.065	2456
3	10%	21	1.031	4111
4	15%	20	1.051	2822
5	20%	10	1.083	2344

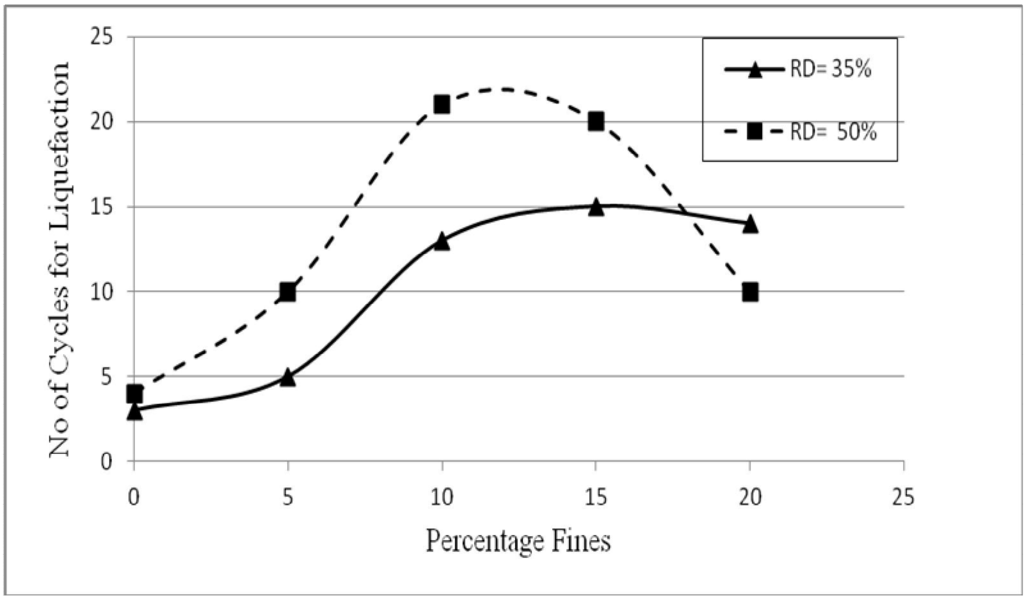
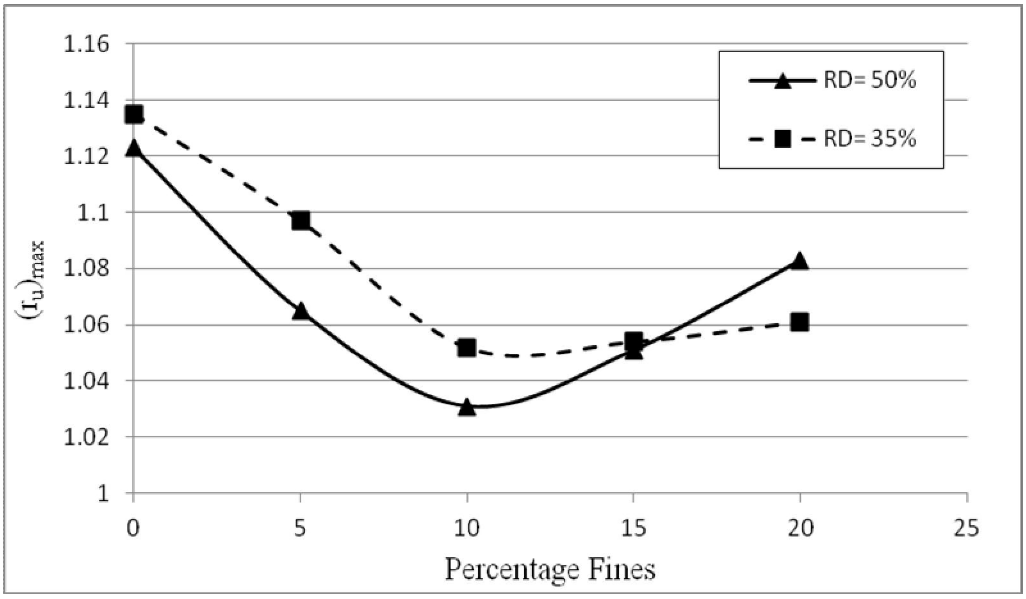


Figure 4.3. Fines Content (%) Vs No of Cycles Required to Liquefaction



Figuure 4.4. Fines Content Vs $(r_u)_{max}$

5. SUMMARY & CONCLUSIONS

In this paper, the effect of non-plastic silts on the liquefaction resistance of Solani sand has been examined. For this, cyclic triaxial tests were conducted at 2 relative densities. Based on the test results, following conclusion may be drawn:

1. Inclusion of non-plastic silt in the pure sand increases liquefaction resistance of sand. The optimum value of silit contents for 35% and 50% relative densities were found to be 15% and 10%, respetively.
2. The number of cycles for liquefaction for the same value of silt content increases when the relative density is incresed. Thus, relative density still play a role but at higher fine contents, its effect decreases.

Authors acknowledge, the above results are based on a limited test data, however more tests are required to arrive at more precise conclusion. Nontheless, the above data indicate the rend of effect of fines content on liquefaction and thus may be used for ground improvement.

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