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Effects of Silt Content on Dynamic Properties of Solani Sand

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EFFECTS OF SILT CONTENT ON DYNAMIC PROPERTIES OF SOLANI SAND

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ABSTRACT

In the present article, the results of cyclic triaxial tests conducted on Solani sand, collected from the bed of Solani River near Roorkee, are presented. Results of strain controlled undrained tests carried out as per ASTM D3999 for determinations of dynamic soil properties are presented. The variations of shear modulus with shear strain are reported. Remoulded samples were prepared with different percentage of silt contents and tested. The effects of silt content on shear modulus of Solani sand at different shear strain are evaluated. This effect is studied at two relative densities. It was found that the effect of silt content is significant on both shear modulus and damping ratio.

INTRODUCTION

In literature the results of many investigations were reported for understanding the influence of different parameters such as cyclic strain amplitudes, effective confining pressures, soil types, plasticity index, density, frequency of loading, number of loading cycles, overconsolidation ratio, degree of saturation and grain characteristics on the dynamic properties of soils (Seed & Idriss 1970; Hardin & Drnevich 1972a; Iwasaki et al. 1978; Kokusho et al. 1982; Seed et al. 1986; Vucetic & Dobry 1991; Maheshwari et al. 2012).

Increasing fines content are known to lead increasing cyclic shearing strength of granular soils. However, information on this form of behavior is apparently scarce in the literature possibly because of the difficulty in testing samples with the same relative density at different fines contents. Most research efforts in this area is on liquefaction (Chang et al. 1982; Guo and Prakash 1999; Polito and Martin 2001; Sitharam et al. 2004; Maheshwari and Patel 2010; Muley et al. 2012). The only documented work on the behavior of fine contents on dynamic properties of soils (Sitharam et al. 2004; Yamada et al. 2008a, b; Zhang and Sun 2011). Seed and Idriss (1970) suggested that dynamic shear modulus ratio G/G_{max} of silty soil is higher than that of general saturated sand while its damping ratio is lower than the saturated clay.

This paper presents the experimental results on the influence of silt contents on shear modulus and damping ratio of Solani sand. A number of strain controlled undrained cyclic triaxial tests were conducted varying the silt content and relative density. Shear modulus at different strain levels have been determined and compared with that of sand specimen.

EXPERIMENTAL INVESTIGATIONS

Material Used

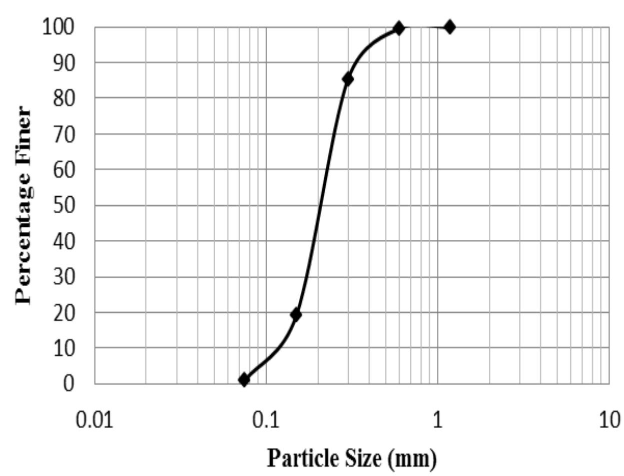

Fig. 1. Grain size distribution for Solani sand

The sand used in this study was collected from the bed of Solani 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 (IS 2720 Part 4-1983), the soil has been identified as Poorly Graded sand (SP) and silt as low plasticity silt (ML). Grain size distribution for Solani sand is shown in Fig. 1. The properties of Solani sand and silt are presented in the Table 1 and Table 2, respectively.

Table 1. Index Properties of Solani Sand

S. No.	Particulars	Notations	Value
1	Soil Type	SP	Poorly Graded Sand
2	Specific Gravity	G_s	2.68
3	Uniformity Coefficient	C_u	1.96
4	Coefficient of Curvature	Cc	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. Properties of Silt

S. 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
7	Maximum void ratio	e_{max}	1.27
8	Minimum void ratio	e_{min}	0.34

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. Axial strain on which samples were tested is 0.75%. Total 10 numbers of tests were conducted in this study.

SAMPLE PREPARATION

In the present 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

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \tag{1}$$

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

$$e = e_{\max} - D_r(e_{\max} - e_{\min}) \tag{2}$$

The values of e_{max} and e_{min} are given in Tables 1 and 2 for sand and silt, respectively.

c) Knowing the value of void ratio (e) obtained, dry unit weight of sand (γ_d) was determined as

$$\gamma_d = \frac{G_s}{1+e}\gamma_w \tag{3}$$

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, $S_r = 1.0$ was determined by

$$w = \frac{e \times S_r}{G_s} \text{ i.e. } w = \frac{e}{G_s} \tag{4}$$

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

$$W_d = \gamma_d \times V \tag{5}$$

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

$$W_W = w \times W_d \tag{6}$$

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. 6.

i) The quantity of dry sand (W_d) obtained in step (e) and the specified weight of silts (as percentage of dry weight of sand) was distributed over the sand and mixed uniformly. The silt-sand 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. Filter paper and porous stone was placed on top of the sample.

k) 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. 2 shows a sample of sand ready for testing.

Fig. 2. A sample ready for testing on cyclic triaxial

FORMULATION USED

The shear modulus is evaluated as the slope of a secant line that connects the extreme points on a hysteresis loop at a given shear strain, as shown in Fig. 3. As the cyclic strain amplitude increases, the shear modulus decreases. From cyclic triaxial test results, a hysteresis loop is obtained by plotting the deviator stress (σ_d) versus axial strain (ε). The slope of the secant line connecting the extreme points on the hysteresis loop is the young modulus (E) (Towhata 2008).

$$\gamma = (1+\mu)\varepsilon \tag{7}$$

$$E = \frac{\sigma_{d\max}}{\varepsilon_{\max}} \tag{8}$$

$$G = \frac{E}{2(1+\mu)} \tag{9}$$

where, G is the shear modulus, γ is the shear strain and μ is the Poisson's ratio that may be taken as 0.5 for saturated undrained specimen (Towhata, 2008). The damping ratio D, is a measure of dissipated energy versus elastic strain energy and is computed by

$$D = \frac{1}{4\pi}\frac{A_L}{A_T} \tag{10}$$

where, A_L = Area enclosed by the hysteresis loop and A_T = Area of the shaded triangle

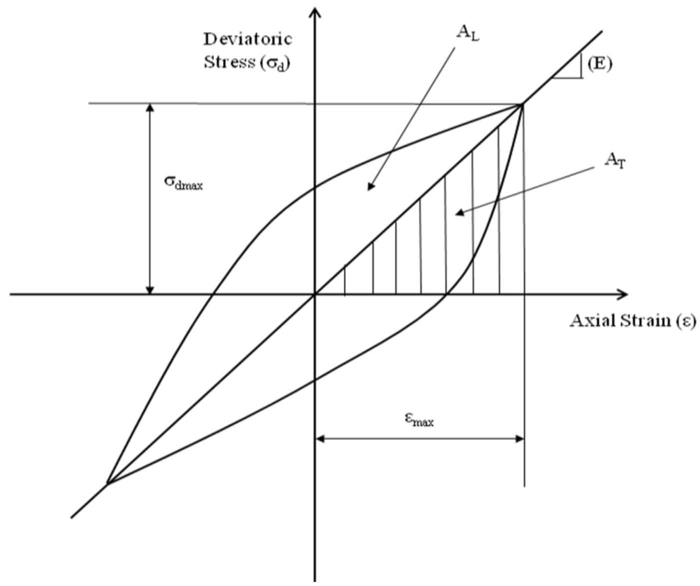

Fig. 3. Hysteretic stress-strain relationship

The maximum shear modulus (G_{max}) has been calculated by the following equation (Kramer 1996).

$$G_{\max} = 625F(e)(OCR)^k p_a^{(1-n)}(\sigma_m')^n \tag{11}$$

where, F(e) = a function of the void ratio (e), OCR = over consolidation ratio, σ_m' = mean principal effective stress, n = stress exponent which is often taken as 0.5, p_a = atmospheric pressure in the same unit as σ_m' and G_{max}; k = constant which depends upon the PI of clay, its value of may be taken as zero for sand (Hardin and Drnevich, 1972b). The value of p_a may be taken as 98 kPa). The value of function F (e) has been evaluated by the following equation

$$F(e) = \frac{1}{(0.3+0.7e^2)} \tag{12}$$

Substituting Eq. 12 in Eq. 11 and simplifying leads to

$$G_{\max} = 625\frac{1}{(0.3+0.7e^2)}\sqrt{p_a \times \sigma_m'} \tag{13}$$

EFFECTS OF DIFFERENT SILT CONTENTS

To show one typical test result, a sample calculation is shown for the case of sand with 0% silt i.e. plain sand at 0.75% axial strain i.e. at shear strain 1.125 %. Fig. 4 show the typical deviatoric stress versus the axial strain plot for the first cycle of loading obtained from the strain controlled cyclic triaxial test for plain sand at 35% relative density and 0.75 % axial strain. The test was conducted at a frequency of 1 Hz and the data was collected at every 5 millisecond i.e. 200 points for one cycle. Fig. 5 shows shear stress versus shear strain plot derived from Fig. 4

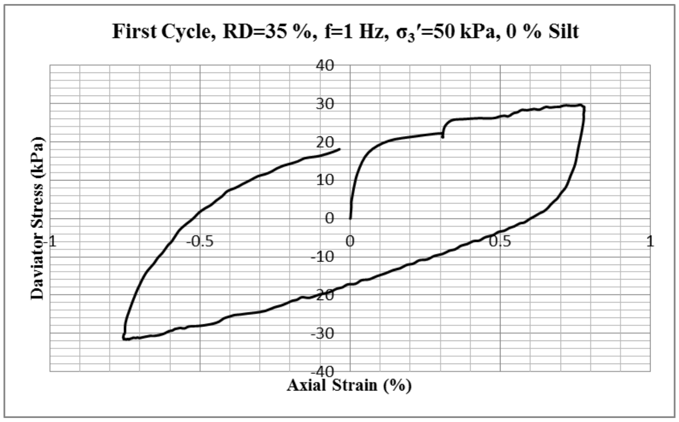

Fig. 4. Deviator stress vs. axial strain relationship at first cycle for 0.75 % axial strain

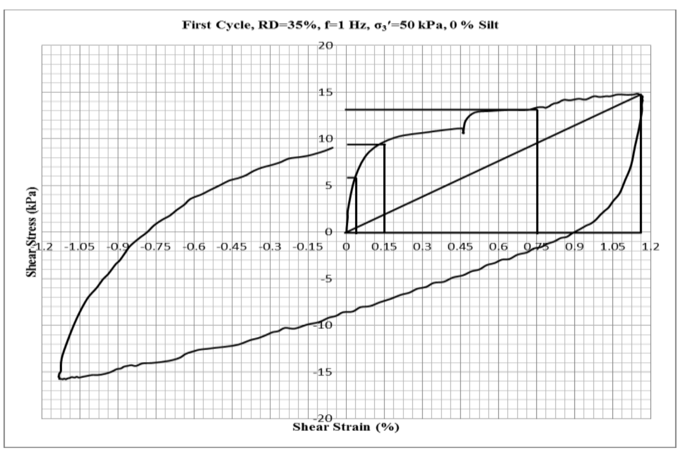

Fig. 5 .Shear stress vs. shear strain relationship at first cycle for 1.125 % shear strain

Here the test has been conducted only at 0.75% axial strain (i.e. at 1.125% shear strain). The results at other shear stains are derived by interpolating Fig. 5. Slope of the line connecting maximum and minimum point of the loop shown in Fig 5 gives shear modulus for the first cycle of the test

$$G= (14.9+15.8)/ (0.0115+0.01125) = 1349 \text{ kPa}$$

G at 0.0375 % Shear Strain

$$G=6/0.000375 = 16000 \text{ kPa}$$

G at 0.15 % Shear Strain

$$G=9.6/0.0015 = 6400 \text{ kPa}$$

G at 0.75 % Shear Strain

$$G=13.4/0.0075 = 1786 \text{ kPa}$$

To investigate the effects of silt contents, the results have been presented in Figs. 6 and 7. Fig. 6 shows variation in shear modulus (G) with shear strain. Fig. 7 shows variation in normalized shear modulus (G/G_{max}) with shear strain, where maximum shear modulus (G_{max}) is found using Eq. 13. It can be observed that the values of (G/G_{max}) shown in Fig. 7 for plain sand is in the range of that reported by Kokusho (2004). Further, it can be observed that as the shear strain increases, the normalized shear modulus decreases. The trend of results is similar to that for sand (Kramer 1996). Variation of silt content had a significant effect on normalized shear modulus (G/G_{max}).

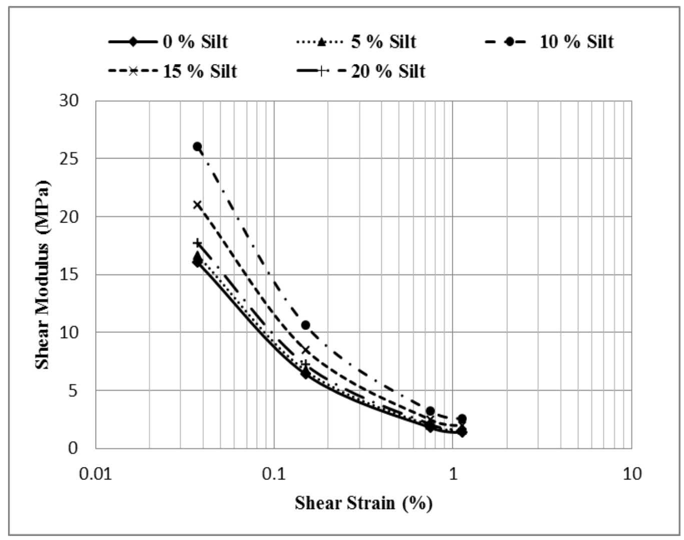

Fig. 6. Influence of silt content on shear modulus versus shear strain at 35 % RD

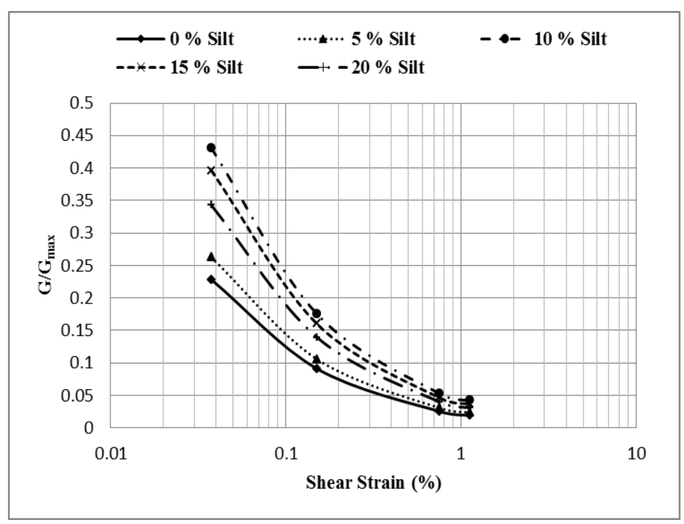

Fig. 7. Influence of silt content on normalized shear modulus versus shear strain at 35 % RD

From Fig. 7, it can be observed that the maximum value of ratio (G/G_{max}) is obtained at 10% silt contents at all shear strains. Figs. 8 and 9 repeat the results shown in Figs. 6 and 7, but for 50% relative density. The trend of results is also similar i.e. at 50% relative density too, optimum value of silt content is 10%.

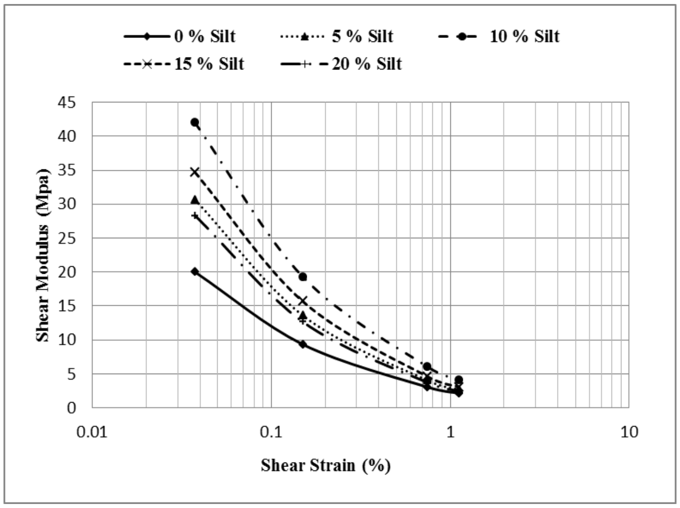

Fig.8 Influence of silt content on shear modulus versus shear strain at 50 % RD

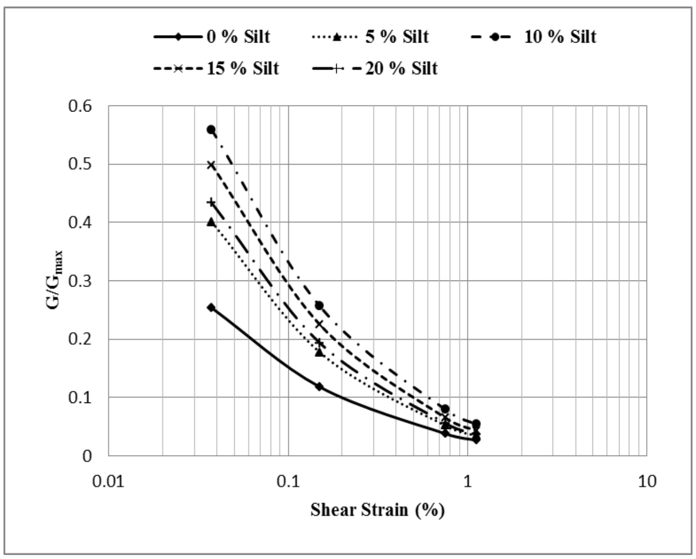

Fig. 9. Influence of silt content on normalized shear modulus versus shear strain at 50 % RD

The percentage increase in shear modulus of sand due to reinforcement can be represented as ratio

$$\% \, Increase = \frac{\Delta G}{G_{sand}}$$

where, $\Delta G = G_{silt} - G_{sand}$. Here G_{silt} and G_{sand} are values of G for sand mixed with silt and sand, respectively, at a particular shear strain considered. Fig. 10 shows percent increase in shear modulus with silt content at different shear strains.

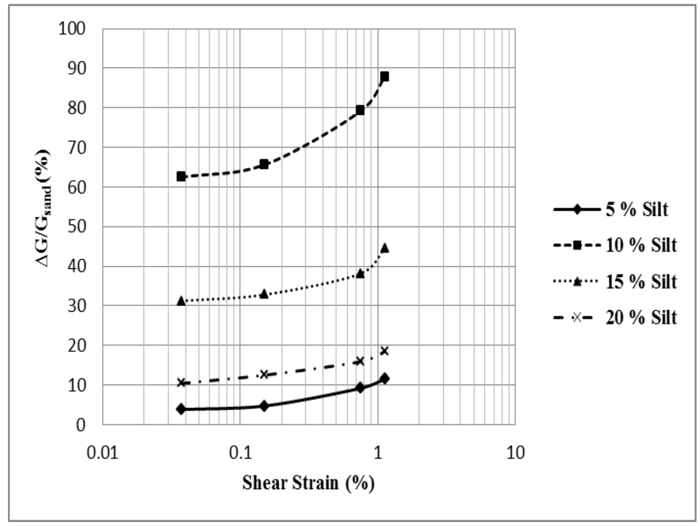

Fig. 10. Percent increase in shear modulus with silt content at different shear strains at 35% RD

From Fig. 10, it can be observed that maximum increase in shear modulus values is for 10% silt content at all shear strains. Further as the shear strain increases, the effect of silt content increases. At 1.125% shear stain, % gain in G value is as high as 90% for 10% silt content which is quite remarkable.

EFFECTS OF RELATIVE DENSITY

To investigate the effects of relative density, comparison of results has been carried out for 35% and 50% relative densities. Fig. 11 shows variation in normalized shear modulus (G/G_{max}) with silt content at 1.125 % shear strain. It can be observed that the maximum value of shear modulus ratio is obtained at 10% silt content for both densities.

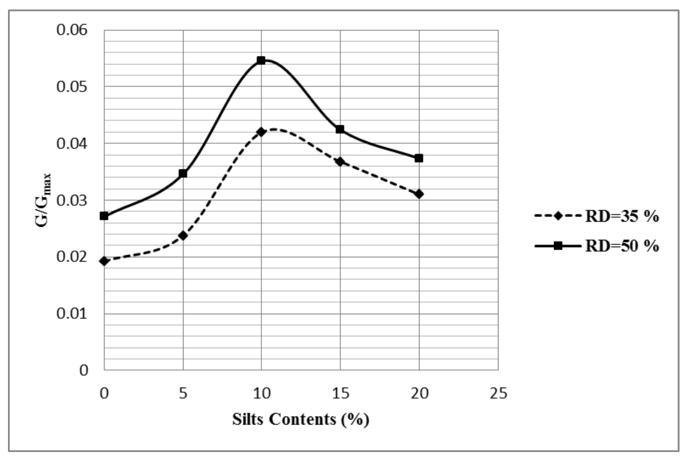

Fig. 11. Influence of relative density on normalized shear modulus versus silt contents at 1.125 % shear strain

Fig. 12 shows variation in damping ratio with silt content. It can be observed that the damping ratio is minimum at 10% silt content for both densities.

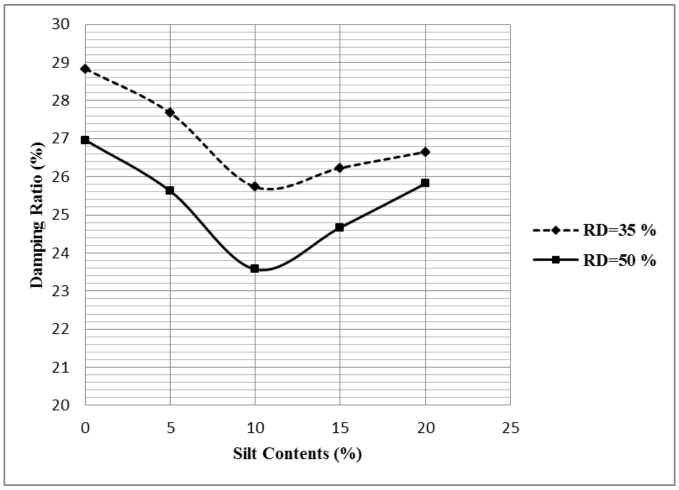

Fig. 12. Influence of relative density on damping ratio versus silt contents at 1.125 % shear strain

CONCLUSIONS

In this paper, the results of cyclic triaxial tests conducted on Solani sand mixed with different silt contents are reported. Effect of silt contents on dynamic soil properties is examined by comparing results with sand.

The following are the major conclusions from this study:

1. For the Solani sand (both sand and sand mixed with silt) as the shear strain increases the normalized shear modulus decreases Thus the basic characteristic of Solani sand remains intact with the silt.
2. There is a optimum slit content where shear modulus ratio is maximum while damping ratio is minimum. In the present study, its value is found to be 10%.
3. It was observed that the silt content is more effective at higher shear strain where its contribution in increasing shear modulus (G) is significant. For example, at 1.125% shear strain, shear modulus increases by a margin of 88% for 10% silt content.
4. Effect of relative density on sand mixed with silt is similar to that on sand i.e. with relative density shear modulus increases while damping ratio decreases.

However authors acknowledge that above results are based on limited test results. For concrete conclusions, more tests need to be conducted which is undergoing.

ACKNOWLEDGEMENT

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