Dynamic Properties of Solani Sand Reinforced with Coir Fibers

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SUMMARY:
In the present article, the results of the cyclic triaxial tests conducted on cylindrical reinforced and unreinforced sand samples are reported. The sand is collected from the bed of Solani River near Roorkee, India. Results are presented for strain controlled undrained cyclic triaxial tests carried out as per ASTM D3999 for determination of dynamic soil properties (i.e., shear modulus and damping ratio). Remoulded samples were prepared with randomly distributed coir fiber at different percentage of fiber contents and tested. The effect of fiber inclusion is evaluated as a function of shearing-strain amplitude, confining stress and fiber content. It was found that the effect of fiber content is significant on both shear modulus and damping ratio particularly at high shear strain amplitude. Thus effect of fibers in the improvement of dynamic properties of Solani sand is investigated and feasibility of coir fibers for ground improvement is explored.

Keywords: Dynamic Soil Properties, Solani Sand, Coir Fiber.

1. INTRODUCTION

Significant work has been reported on the cyclic response of soils (e.g. Vucetic and Dobry 1991; Kokusho 2004). However, most of the reported work is for unreinforced soil. Use of natural fiber in geotechnical earthquake engineering may be beneficial as they are cheap, locally available, biodegradable, and eco-friendly. Existing knowledge on the behaviour of fiber-reinforced soil composites under dynamic loads is very limited. Thus far, most of the research activity in this area has been concentrated on the behaviour of these composites under static loads (Gray and Ohashi 1983; Gray and Al-Refeai 1986; Gray and Maher 1989; Michalowski and Cermak 2003; Consoli et al. 2005). The only documented works on the behaviour of fiber-reinforced sand under dynamic loads are presented by Maher and Woods (1990); Shewbridge and Sousa (1991); Li and Ding (2002); Singh (2009); Maheshwari et al. (2012). The use of coir fiber for improvement of strength of soils for static loads has been explored up to certain extent (Sivakumar Babu and Vasudevan 2008). However, its utility for dynamic and cyclic loads is not explored yet.

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

2. PROPERTIES OF SOLANI SAND AND COIR FIBER

Grain size distribution (determined according to IS 2720 Part 4-1983) for Solani sand is shown in Fig. 2.1. It can be observed that the 95 % of the particle size falls in range of fine sand and less than 2 % is passing through 0.075 mm sieve. Therefore as per Unified Soil Classification System, Solani sand can be classified as poorly graded sand i.e. SP type. Other index properties of Solani sand are listed in

Table 2.1. Coir fibers of random diameters varying from 0.1 mm to 0.3 mm were taken from the local market (Roorkee, India) and were used in this study. The average length of coir fiber was about 20 mm. Fig. 2.2 shows a typical sample of coir fibers used in the study.

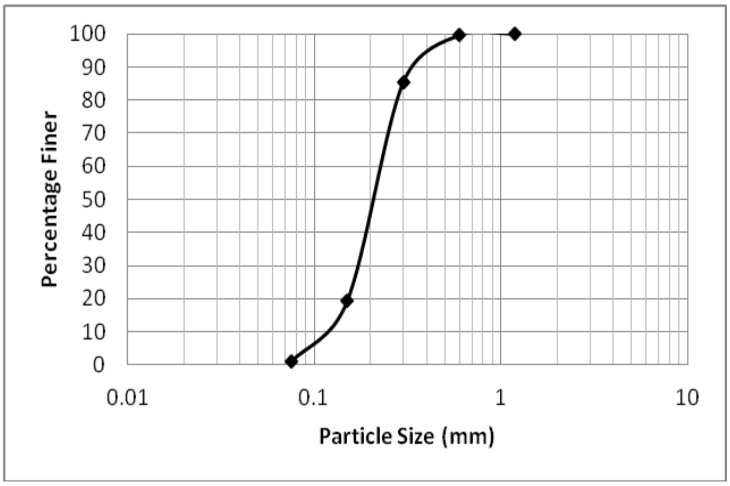

Figure 2.1. Grain size distribution for Solani sand

Table 2.1. 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 Co-efficient	C_u	1.96
4	Co-efficient 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

Figure 2.2. A typical sample of coir fibers used in the study

3. SAMPLE PREPARATION AND TESTS CONDUCTED

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

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

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. After evaluating the value of void ratio e, dry unit weight of sand (γ_d) was determined by the following equation.

$$\gamma_d = \frac{G_s}{1+e}\gamma_w \tag{3.2}$$

where γ_w is the unit weight of water (taken as 10 kN/m^3) and G_s is the specific gravity of solids. The required quantity of dry sand and the specified weight of fibers (as percentage of dry weight of sand) distributed randomly over the sand. Then dry sand and fibers mixed uniformly. The fiber-sand mixture was poured into mould filled with 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. 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. Top cap with vacuum ring was placed on porous stone and rubber membrane was pulled over this assembly. Then rubber membrane was sealed with O-ring. Fig. 3.1 shows a sample ready for testing.

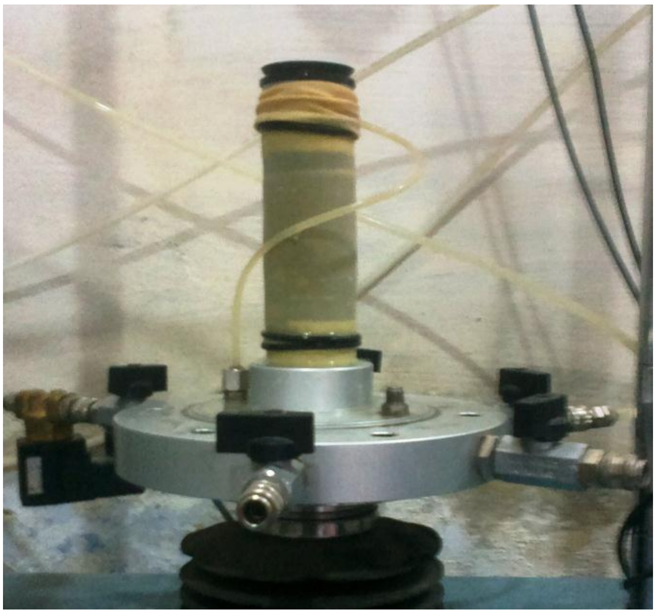

Figure 3.1. A sample ready for testing on cyclic triaxial

Cyclic triaxial test were carried out as per ASTM D3999 (2011) on Solani sand samples and sand-fiber samples of 50 mm diameter and 100 mm height with relative density 35%. The samples were prepared with 3 fiber contents viz. 0.25 %, 0.5 % and 0.75 %, and all tested at an effective confining pressure 50 kPa. To examine the effect of confining pressures, sample with 0.25% fiber content was also tested at an effective confining pressure 100 kPa. Each sample was tested at 3 levels of axial strains. All the tests were undrained strain controlled at a loading frequency of 1 Hz with sinusoidal wave. Axial strains for each sample testing were 0.025%, 0.1% and 0.75% and corresponding shear strain were 0.0375%, 0.15% and 1.125%, respectively. The combinations are given in Table 3.1, a total of 15 samples were tested.

Table 3.1. Combination of Parameters for Testing at 35 % Relative Density and 1 Hz Frequency

Test No.	Fiber contents (by weight)	Shear Strain	Effective Confining Pressure
1 to 12	0 %, 0.25 %, 0.50 % and 0.75 %	0.0375%, 0.15 % and 1.125 %	50 kPa
13 to 15	0.25 %		100 kPa

4. 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. 4.1. As the cyclic strain amplitude increases, the shear modulus decreases.

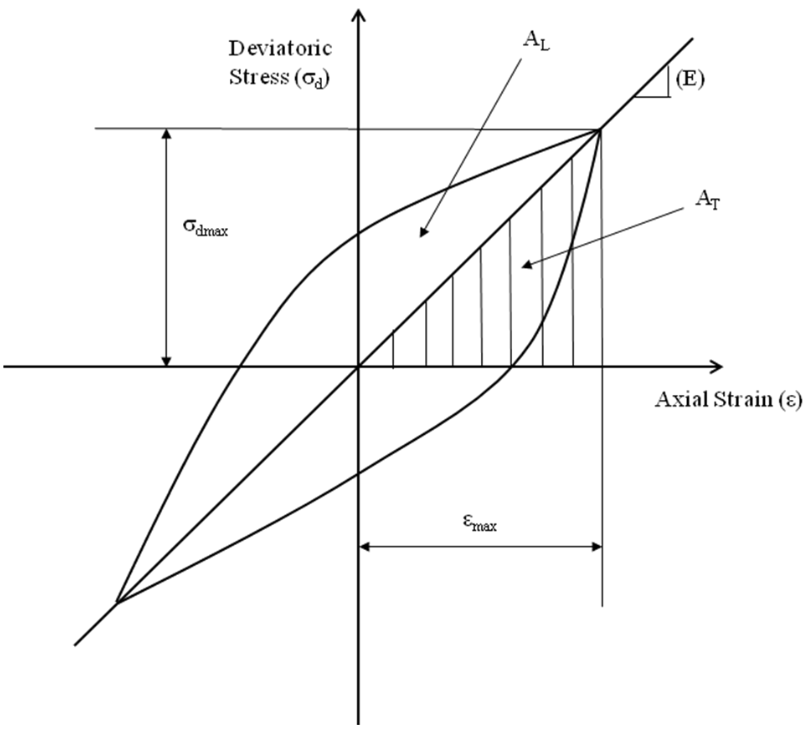

Figure 4.1. Hysteretic stress-strain relationship

From cyclic triaxial test results, a hysteresis loop similar to Fig. 4.1 will be 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).

$$\gamma = (1+\mu)\varepsilon \tag{4.1}$$

$$E = \frac{\sigma_{d\max}}{\varepsilon_{\max}} \tag{4.2}$$

$$G = \frac{E}{2(1+\mu)} \tag{4.3}$$

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

$$D = \frac{1}{4\pi}\frac{A_L}{A_T} \tag{4.4}$$

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

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

$$G_{\max} = 625F(e)(OCR)^k p_a^{(1-n)}(\sigma'_m)^n \tag{4.5}$$

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, 1972). Tthe value of p_a may be taken as 98 kPa (Towhata, 2008). The value of function F (e) has been evaluated by the following equation (Hardin, 1978).

$$F(e) = \frac{1}{\left(0.3 + 0.7e^2\right)} \tag{4.6}$$

Substituting equations 4.6 in equation 4.5 and simplifying leads to

$$G_{\max} = 625\frac{1}{\left(0.3 + 0.7e^2\right)}\sqrt{p_a \times \sigma'_m} \tag{4.7}$$

5. EFFECTS OF DIFFERENT FIBER CONTENTS

To show one typical test result, a sample calculation is shown for the case of sand with 0.25% coir fiber at 0.75% axial strain i.e. at shear strain 1.125 %. Fig. 5.1 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 sand with 0.25% coir fiber with relative density of 35% at 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. 5.2 shows shear stress versus shear strain plot derived from Fig. 5.1.

Slope of the line connecting the maximum and minimum points of the loop shown in Fig. 5.2 gives shear modulus for the first cycle of the test.

$$G = \frac{13.6 + 21.4}{0.0115 + 0.011} = 1555 \text{ kPa}$$

Damping ratio is calculated using Eq. 4.4 for the loop shown in Fig 5.2. The area of the loop and the triangle is determined by using AUTOCAD software

$$D = \frac{1}{4\pi} \times \frac{47.8795}{14.25} = 0.2673 \text{ i.e. } 26.73\ \%$$

Shear modulus and damping ratio for sand with 0.25% coir fiber for 35 % relative density and 50 kPa effective confining pressure at 3 different shear strains are given in Table 5.1.

Table 5.1. Shear Modulus and Damping Ratio for Sand with 0.25% Coir Fiber at 3 Different Shear Strains

S. No.	Fiber Content	Shear Strain (%)	Shear Modulus G (kPa)	G/G_{max}	Damping ratio D (%)
1	0.25 % (G_{max} = 65663 kPa)	0.0375	9804	0.149	15.30
2		0.150	5000	0.076	21.34
3		1.125	1555	0.024	26.73

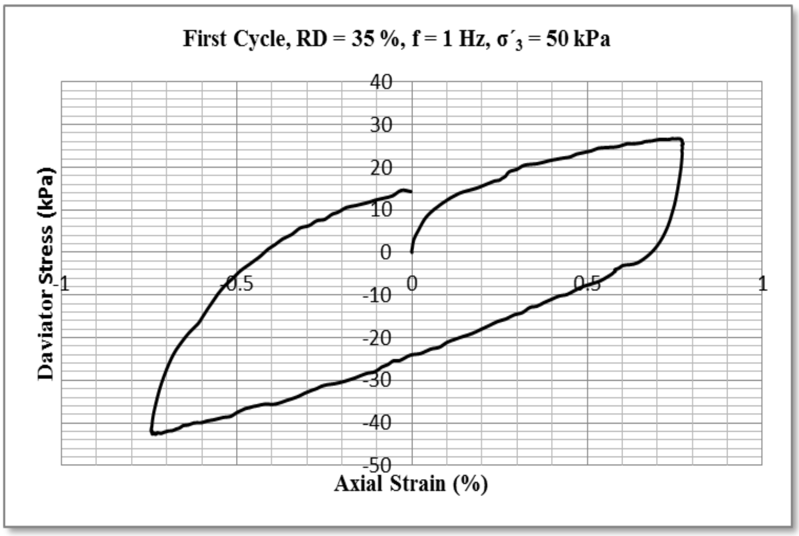

Figure 5.1. Deviator stress vs. axial strain at first cycle for sand with 0.25% coir fiber at 0.75% axial strain

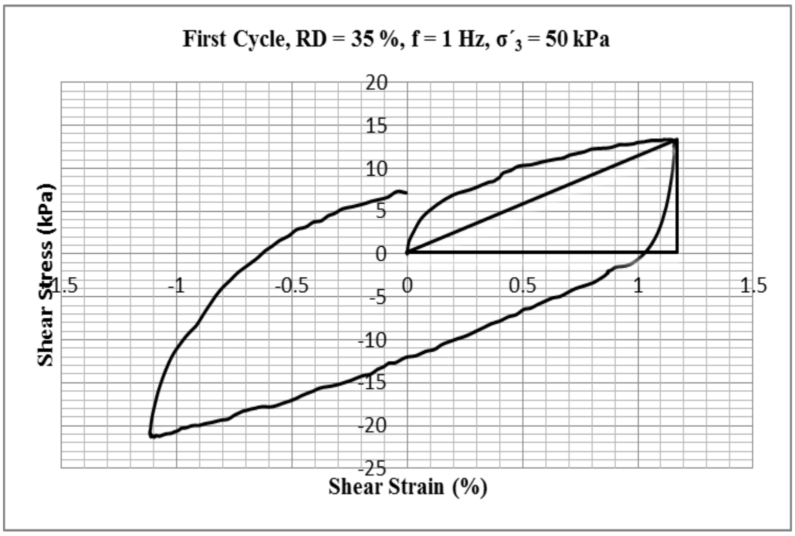

Figure 5.2. Shear stress vs. shear strain at first cycle for sand with 0.25% coir fiber at 1.125% shear strain

To investigate the effects of fiber contents, the results have been presented in Figs. 5.3 and 5.4. Fig. 5.3 shows variation in normalized shear modulus (G/G_{max}) with shear strain, where maximum shear modulus (G_{max}) is found using Eq. 4.7. It can be observed that the values of (G/G_{max}) shown in Fig. 5.3 for plain sand is in the range of that reported by Kokusho (2004).

From Figs. 5.3 and 5.4, it can be observed that as the shear strain increases, the normalized shear modulus decreases and damping ratio increases. The trend of results is similar to that for unreinforced sand (Kokusho 1980, Kramer 1996). Variation of fiber content had a significant effect on both normalized shear modulus (G/G_{max}) and damping ratio (D). Due to inclusion of 0.25% coir fiber in sand there is an increase in shear modulus which further increases with percentage increase of fiber contents. However, the damping ratio decreases due to inclusion of fibers. The trend of the results is similar to that observed by Maher and Woods (1990), which suggested that for dynamic loads as fiber content increases the rigidity of the composite material increases. This increase in rigidity translates into a higher shear modulus at low as well as at high shear strain amplitudes.

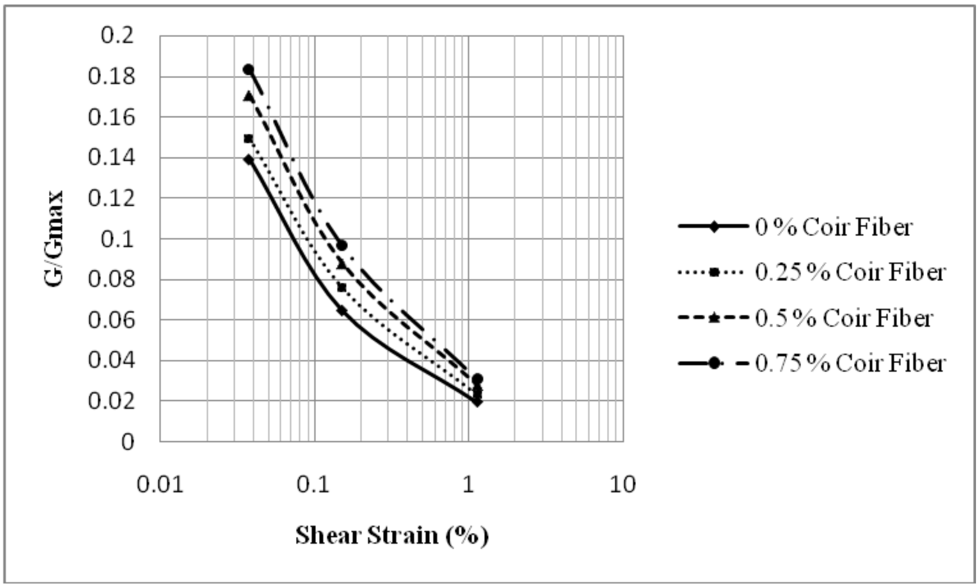

Figure 5.3. Influence of fiber content on normalized shear modulus versus shear strain

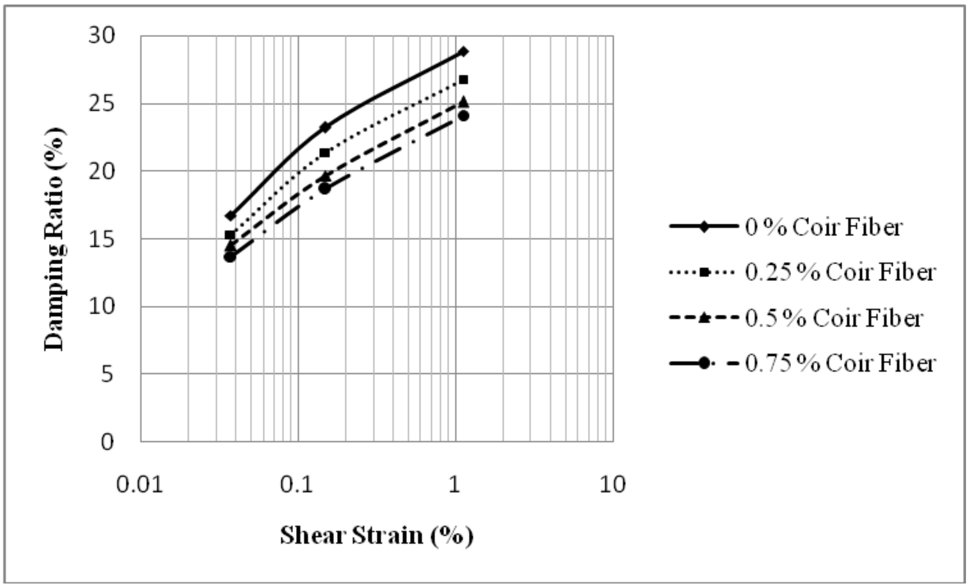

Figure 5.4. Influence of fiber content on damping ratio versus shear strain

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

$$\%Increase = \frac{\Delta G}{G_{sand}} \tag{5.1}$$

where, $\Delta G = G_{fiber} - G_{sand}$. Here G_{fiber} and G_{sand} are values of G for sand mixed with fiber and sand only, respectively, at a particular shear strain considered.

Fig. 5.5 shows the percent increase in shear modulus with shear strain for different fiber contents. The influence of fiber content is more at high strain level. From Fig. 5.5, it can be observed that the effect of coir fiber on shear modulus is maximum at high shear strain (1.125%). It means fibers are more effective during strong shaking (leading to high strain). Further for 0.5% fiber contents, there is significant increase in ratio ($\Delta G/G_{sand}$). However the increment is not so much when fiber content is further increased to 0.75%. This is because that sand has achieved enough strength with 0.5% fiber content and further increase in reinforcement may not be so effective. The trend of results shown in Fig. 5.5, is similar to that reported by Maher and Woods (1990), Shewbridge and Sousa (1991).

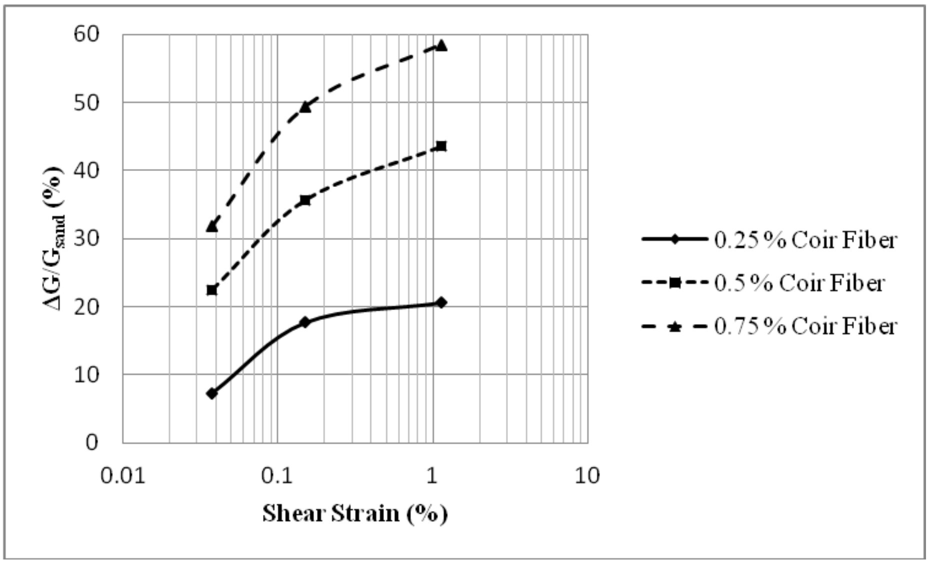

Figure 5.5. Percent increase in shear modulus with coir fiber content at different shear strains

6. EFFECT OF CONFINING PRESSURE

To investigate the effects of confining pressure, the tests were also carried out for 0.25 % coir fiber subjected to confining pressure of 100 kPa. The results have been presented in Figs. 6.1 and 6.2. Fig. 6.1 shows variation in normalized shear modulus (G/G_{max}) with shear strain at 0.25 % coir fiber.
From Fig. 6.1, it can be observed that a considerable effect of confining pressure on the normalized shear modulus can be noticed at low strain level. As the confining pressure increases, normalized shear modulus increases significantly. The influence of effective confining pressure on damping ratio versus shear strain at 0.25 % coir fiber is shown in Fig. 6.2. The damping ratio decreases with increase in confining pressure. Higher values of damping are noticed at lower confining pressure. The results are in close agreement with the result reported by Maher and Woods (1990).

7. SUMMARY AND CONCLUSIONS

In this paper, the results of cyclic triaxial tests conducted on Solani sand reinforced with randomly distributed coir fibers are reported. Effect of reinforcement on dynamic soil properties is examined by comparing results with unreinforced sand.

It was observed that the inclusion of fibers has a significant influence on the dynamic properties of sand, i.e. on normalized shear modulus (G/G_{max}), and damping ratio (D). This influence is primarily a function of percentage of fiber contents, in addition to other parameters like shear strain amplitude and confining stress.

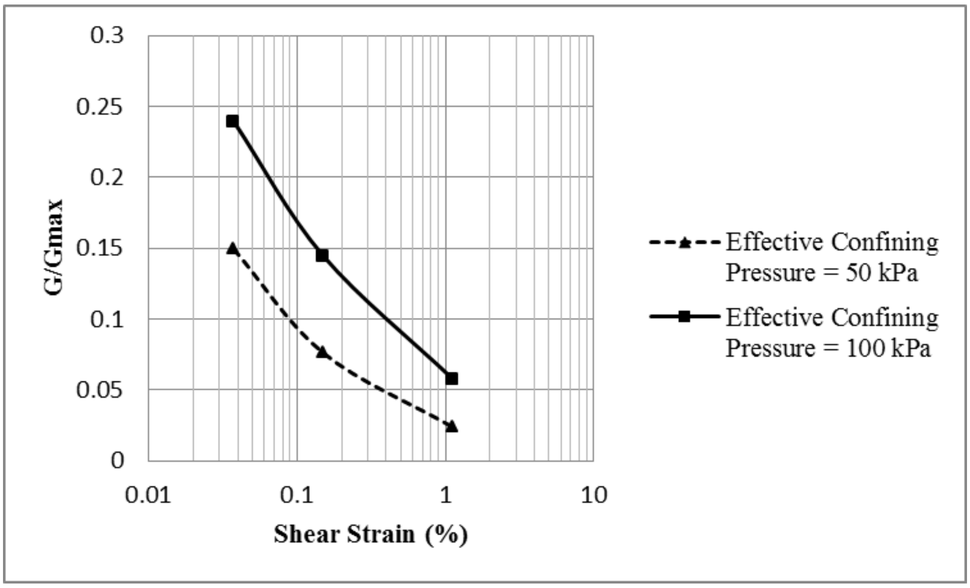

Figure 6.1. Influence of eff. confining press. on normalized shear modulus vs shear strain at 0.25% coir fiber

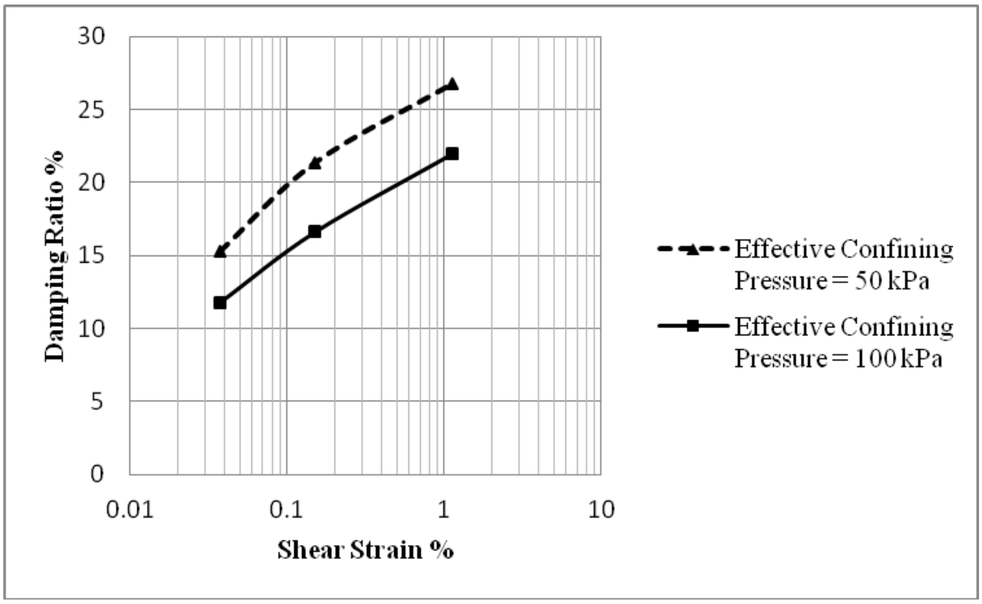

Figure 6.2. Influence of eff. confining press. on damping ratio versus shear strain at 0.25 % coir fiber

The following are the major conclusions from this study:

1. For the Solani sand (both unreinforced and reinforced) as the shear strain increases the normalized shear modulus decreases while damping ratio increases. Thus the basic characteristic of Solani sand remains intact with the reinforcement.
2. It was observed that the coir fiber 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 60% for 0.75% coir fiber contents.
3. Effect of confining pressure on coir-fiber reinforced sand is similar to that on the unreinforced sand. For example, for 0.25% fiber reinforced sand, normalized shear modulus is greater at higher confining pressure.

Authors acknowledge that the above results are based on a limited tests conducted. However, more tests are being conducted. Nonetheless, the tests are clearly indicating that there is significant increase in dynamic strength of Solani sand due to reinforcement.

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