Effect of Degree of Saturation on Dynamic Properties of Solani Sand in Small Strain

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Abstract. This paper comprises of tests conducted on Resonant Column Apparatus (RCA) to find the dynamic soil properties in low strain range for different relative density, confining pressure and the effect of degree of saturation is observed. Sand used for testing is collected from the local Solani River near Roorkee. Dynamic soil properties such as shear modulus, Young's modulus, Poisson's ratio and Damping Ratio. The tests were conducted on a cylindrical samples of diameter 50mm and height 100 mm. Dynamic Soil Properties is studied for different Relative density (40%, 60% and 80%), confining pressures (100kPa, 200kPa and 300kPa) and degree of saturation (0%, 25%, 50%, 75% and 100%). It has been observed that the shear modulus is decreases with the increase of degree of saturation and damping ratio is increases.

Keywords: Shear Modulus, Young's Modulus, Damping Ratio, Degree of Saturation.

1 Introduction

Several researchers have been studied the behavior of soil in different loading conditions i.e. static and dynamic. Response of soil under dynamic loading is governed by its dynamic properties. The dynamic soil properties such as stiffness properties (G=Shear modulus & E= Young's Modulus), damping properties (D= Damping Ratio) are required for investigation. Dynamic soil properties are more important as it is observed that the damage is more in dynamic loading e.g. liquefaction of sand during earthquake leading to subsidence of ground. Damping property of soil is also affected by different stress conditions, plasticity, void ratio etc. [1-4]. Damping ratio decreases with increase in confining pressure, so as we go deeper in soil damping ratio decreases. Poisson's ratio is also an important parameter, it is very important in case of drilling wells, hydraulic fracturing, well instability etc. The value of Poisson's obtained from resonant column apparatus can be used for numerical modeling [5].

The low strain Young Modulus, Shear Modulus, damping ratio and Poisson's ratio are important properties that are needed for the evaluation of dynamic response of soils. As the influence of water in case of sand is significant due to capillary action, significant differences has been observed in the behavior of unsaturated, partially saturated and fully saturated soils. The behavior of soil changes as the degree of saturation increases, its damping ratio increases and stiffness decreases. Degree of saturation can be simulated to the condition where the water starts coming in the soil or being removed and in any stage between the soil is subjected to dynamic loading. So, it is important to study the behavior of soil in different saturation condition.

Seed et al. [6] have evaluated the response of soil deposits, and determined the variation of shear modulus and damping ratio with shear strain. Also studied the effect of confining pressure, void ratio and strain levels. Zhang and Aggour [7] have conducted tests in RCA using three different types of loading (random, impulse and sinusoidal) under different confining pressures. Main objective was to evaluate the effect of coupling vibrating of compressive waves and shear waves on dynamic properties. The resonant frequencies are obtained from digital frequency meter in longitudinal and torsional directions, using these frequencies the young modulus, shear modulus and damping in flexure and torsional mode has been calculated. Used resonant column tests in flexural mode for dynamic characterization of Bangalore Sand [8]. They reported that material damping is sensitive to the mode of vibration and flexural damping is higher in magnitude that shear damping. This trend was more pronounced at an increasing confining pressure. Many researchers studied the dynamic properties of sand in dry as well as saturation conditions [9-12].

2 Experimental Study

In the present study a series of small strain based RCA tests has been performed under different confining pressure and relative density. Test samples preparation and test procedure has been discussed in the sub section.

2.1 Sample Preparation and Test Procedure

The cylindrical sample of diameter 50mm and height 100 mm is prepared for the present study. The samples were prepared in five layers and each layer is tamped after pouring the sand to maintain the height. Dry samples are prepared by pouring sand and tamping to get the required relative density. For partially and fully saturated samples, the amount of water required for that particular degree of saturation is calculated and is divided in five equal parts, for each layer prepared that amount of water is added to prepare the sample for required degree of saturation.

To determine the shear and young's modulus the resonant test is conducted to determine the resonant frequency and at that resonant frequency corresponding strain is observed. For the damping test, the damping test is performed at the resonant frequency and for 20 no of cycles the damping ratio is noted. All the tests were conducted under different relative density (40%, 60% and 80%), confining pressures (100kPa, 200kPa and 300kPa) respectively. The degree of saturation is varied from 0%, 25%, 50%, 75% and 100%subsequently. The test was performed at input voltage from 0.001V to 0.3 V. While conducting the resonant test firstly the broad sweep is done to find the range were the resonant frequency will occur then in that range fine sweep is done to find the resonant frequency. For damping test, the no of cycles at which damping is to be observed at which the logarithmic decrement curve is almost a straight line.

3 Experimental Test Results

The laboratory test has been performed for the estimation of index properties of sand as per Indian Standards. The index properties of the sand presented in Table 1.

Table 1. Index properties of Solani Sand

Particulars		Value
Specific gravity (G)		2.68
Uniformity coefficient (C_u)		1.96
Coefficient of curvature (C_c)		1.15
Grain size	D_{10}	0.120 mm
	D_{30}	0.180 mm
	D_{50}	0.210 mm
	D_{60}	0.235 mm
Maximum Void Ratio (e_{max})		0.850
Minimum Void Ratio (e_{min})		0.540

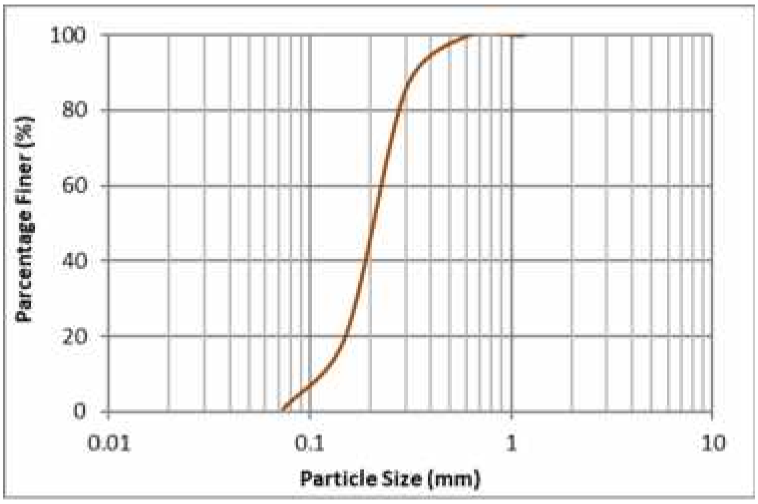


Fig 1. Grain size distribution for Solani Sand

The RCA test has been carried out for determining the shear modulus, young modulus and damping ratio at different conditions. For the validation, the results obtained from the present study using flexure test are compared with that of Madhusudhan and Senetakis [8] in Fig 2. It can be observed that the trend of the results is similar. It shall be noted that the results presented by Madhusudhan and Senetakis (2016) are for Bangalore sand while the result of present study are of Solani sand. It can be observed that the index properties of both the sands are comparable therefore the results are compared and found in good agreement. Though comparison is not in the same order at both the confining pressure.

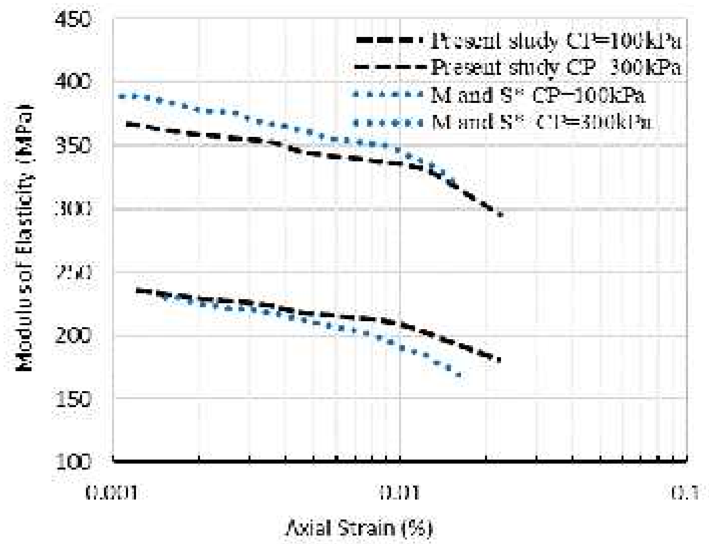


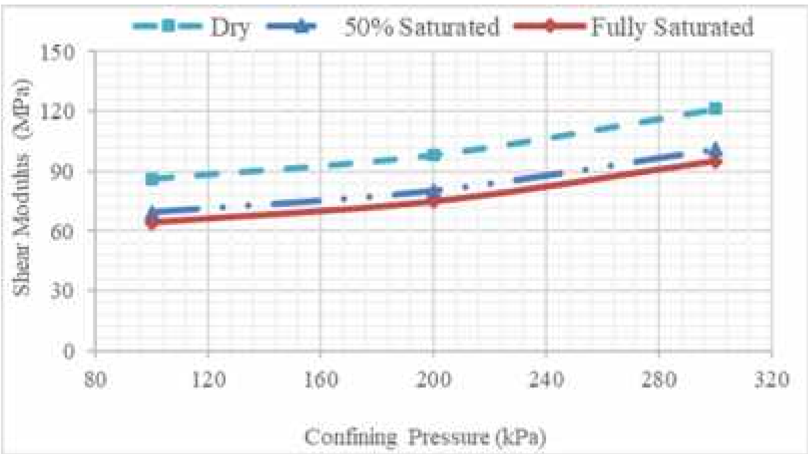
Fig. 2. Comparison of Present Study with literature
(*M and S= Madhusudhan and Senetakis, 2016)

3.1 Dynamic properties of sand

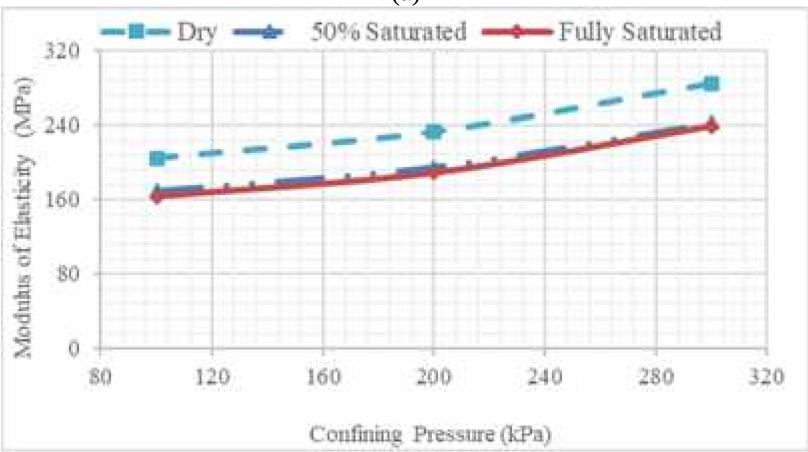
In the Fig 3, a-b and 3, c, the variation of shear modulus, modulus of elasticity and damping Ratio with confining pressure at different saturation condition has been presented. As observed from the test results, with increase in confining pressure the shear modulus and elastic modulus increases. With increase in confining pressure, the grain contact within the soil mass increases which leading to more strength development. Shear modulus and modulus of Elasticity is approximately similar for 50% saturation and 100% saturation condition.

For a given density, with increase in pressure there is decreases in damping, this is due to faster wave propagation path and less attenuation of waves as with increase in confining pressure this is due to the increase in grain contacts.

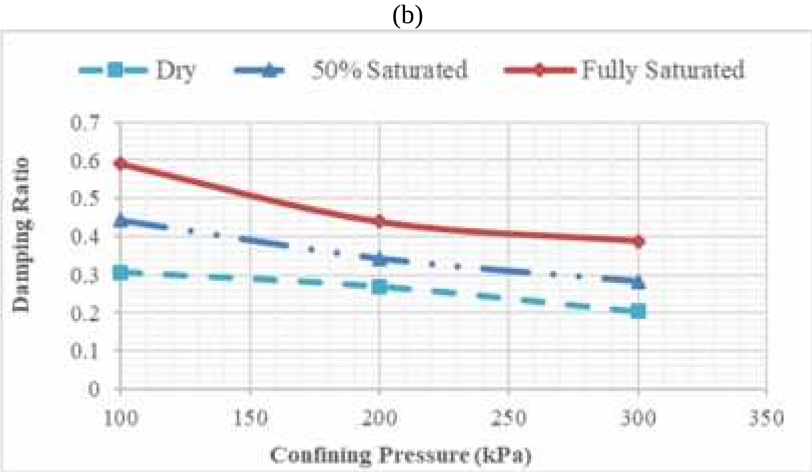
Fig 4, a-b and 4, c represents the variation of shear modulus, modulus of elasticity and damping ratio with relative density respectively for different saturation condition. The shear modulus and modulus of elasticity seems to be approximately similar for 50% and fully saturated condition for relative density increment. From the test results, with increase in relative density the shear modulus and modulus of elasticity increases as with increase in relative the amount of sand increases for the same volume thus strength increases as the void reduces with increases relative density. The changes of damping ratio is less in small strain conditions.



(a)

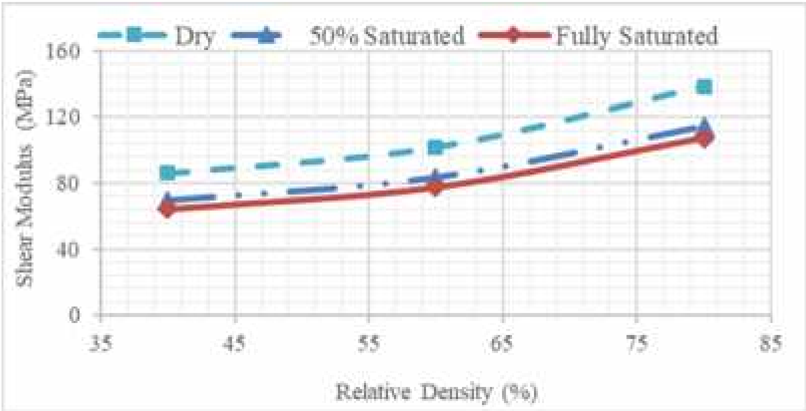


(b)

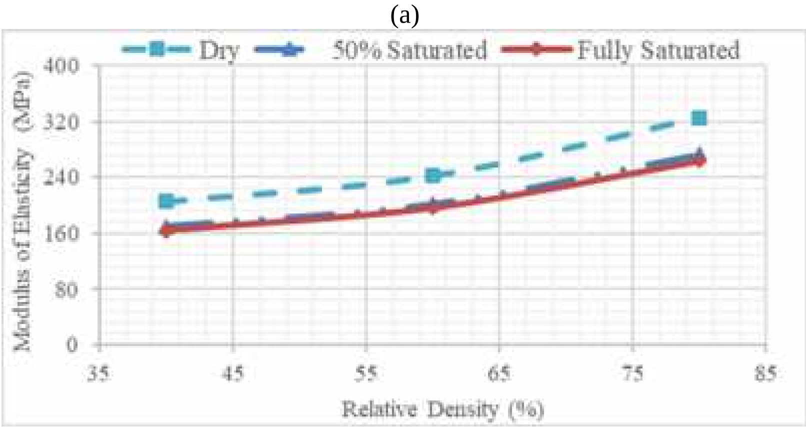


(c)

Fig. 3. Effect of confining pressure on dynamic properties of sand at RD=40%



(a)



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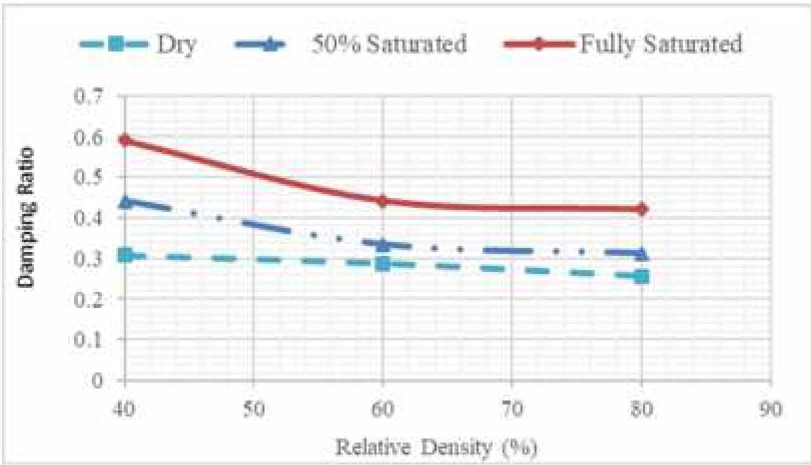
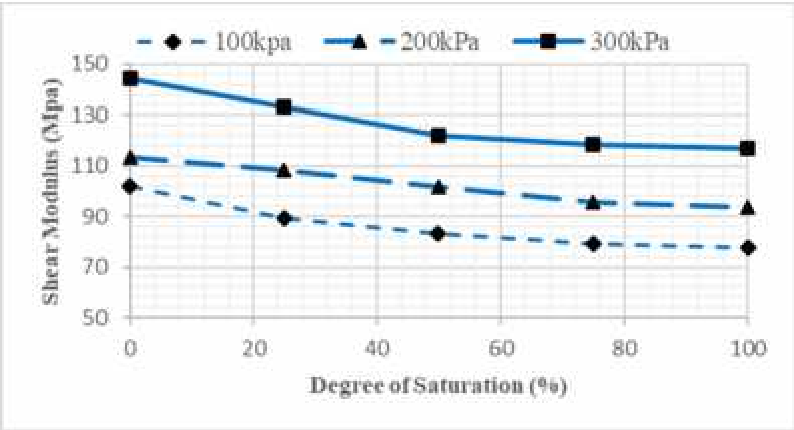


(c)

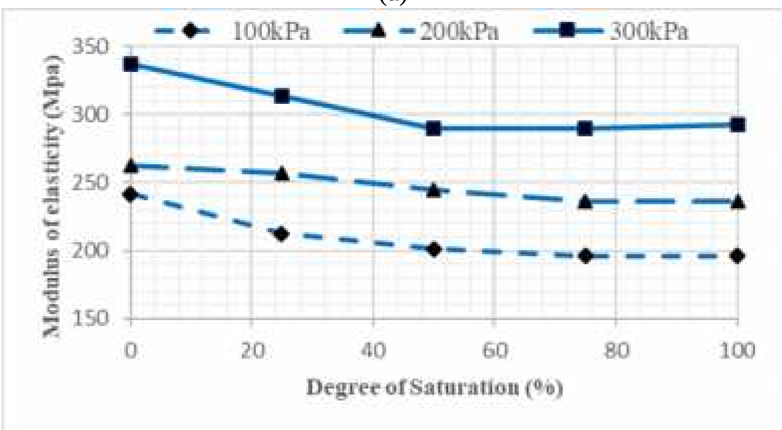
Fig. 4. Effect of confining pressure on dynamic properties of sand at CP=100kPa.

3.2 Variation with Degree of Saturation

Fig 5, a & b shows the variation of shear modulus and young's modulus with degree of saturation for different confining pressure. As there is decrease in degree of saturation causes the outer menisci to be pulled inward, which leads to an increase in both matric suction and effective stress on sample. With increase in degree of saturation the shear modulus decreases. With decrease in degree of saturation matric suction decreases thus inclusion of air takes place in pore water body, thus effective stress increases with decrease in degree of saturation. The reason for this variation is, as the saturation decreases the overall effective area covered by the water droplets for the given cross sectional area of particle results in decrease of net effective stress, which will result in decrease in shear modulus.



(a)



(b)

Fig. 5 Effect of Degree of saturation on *G* and *E* at RD=40%.

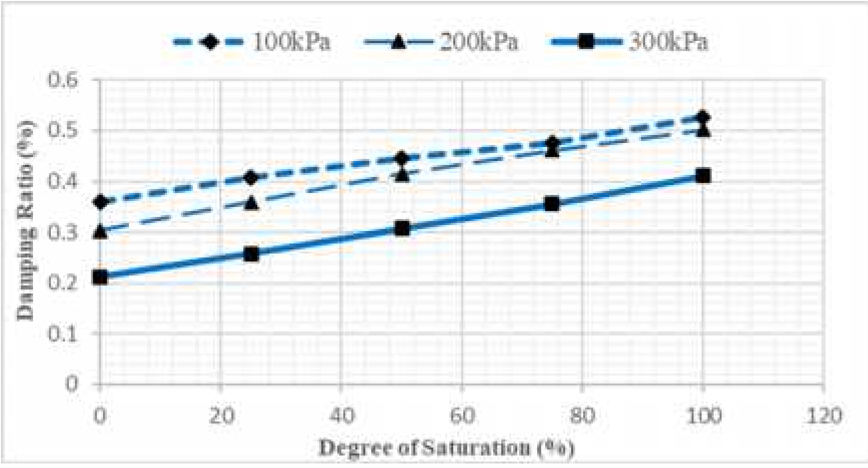


Fig. 6 Effect of Degree of saturation on damping at RD=40%

The Fig 6 shows the variation of damping ratio with degree of saturation for different confining pressure at RD=40 %. Damping ratio is found to be increasing very less with the degree of saturation, although the increase is approximately linear. The damping ratio as observed is increasing very less with degree of saturation, this is due to the presence of more pores filled with water in place of air on increasing the degree of saturation. The damping ratio decreases with increase in confining pressure pressure, the effect is more prominent at higher confining pressure. The difference is less at lower confining pressure. Although with increase in saturation, damping ratio increases.

4 Conclusions

The tests were conducted on Solani Sand using Resonant Column Apparatus. From the above test results the following conclusions can be drawn:

1. With the increase of relative density and confining pressure stiffness increases and damping decreases. Whereas, the shear modulus and young's modulus gets decreases with the increase of shear strain and damping increases.
2. It has been observed that the stiffness decreases more up to 50 % saturation but there is minor difference in 75% and 100% saturation condition.
3. The variation dynamic soil properties with degree of saturations is significant at higher relative density and confining pressure. The variation of damping is less at this small strain level.

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