Indian Geotechnical Journal, 38(3), 2008, 334-344

TECHNICAL NOTE

Dynamic Properties of Dry Sands

T. G. Sitharam*, B. V. Ravishankar and J. S. Vinod*****

Introduction

The dynamic soil analysis to evaluate earthquake effects on soil deposits, slopes and overlying structures were at one time rarely considered, but due to the frequent occurring of earthquakes around the world the dynamic soil analysis has become important for all classes of geotechnical engineering problems. A major requirement for these analyses is dynamic soil properties, usually presented as shear modulus and damping values. In the recent past researchers (Hardin and Drnevich, 1970; Silver and Park, 1975; Sherif et al., 1977; Lin, M and Huang,1996 to name a few) have shown the influence of parameters such as amplitude of cyclic strain, confining pressure and relative density on the dynamic properties of dry sands. As the dynamic properties are strongly affected by the magnitude of the cyclic shear strain amplitudes induced in the soil deposits during the ground motion, it is necessary to evaluate the dynamic properties of soils for wide range of shear strain amplitudes.

In addition, the recent developments in the numerical analysis for the non-linear dynamic responses has increased the demand for the dynamic properties corresponding not only at small shear strain levels but also at large shear strain levels. Furthermore, due to the increase in the rate of occurrence of earthquakes, the dynamic properties are finding increased application in the design of all classes of civil engineering structures.

In the present investigation, a comprehensive study has been undertaken to evaluate the strain dependent dynamic properties of the dry sand samples collected from the earthquake affected area of Ahmedabad of Gujarat state in India. The city of Ahmedabad in Gujarat, situated on the bank of river Sabarmati, suffered severe damages despite being at 250 km away from the epicenter of Bhuj earthquake 2001. A number of residential apartments having ground plus three to four floors and some with ground plus eight to ten floors suffered extensive damage and collapse. To the authors' knowledge, no attempt has been made to understand the dynamic properties of dry sands of earthquake effected areas of Ahmedabad city. Keeping this in mind, in the present investigation, a series of strain controlled cyclic triaxial tests were carried out on natural dry sand samples to determine the dynamic properties

* Professor, Indian Institute of Science, Bangalore, India,
Email: sitharam@civil.iisc.ernet.in

** Professor, B. M. S. College of Engineering, Bangalore, India,
Email: ravishankar.bv@gmail.com

*** Research Fellow, University of Wollongong, NSW, Australia,
Email: vinod@uow.edu.au

such as shear modulus and damping ratio. The influence of amplitude of cyclic strain, confining pressure and frequency of loading on the dynamic properties of Ahmedabad sand has been investigated and presented.

Testing Programme

In the present study experiments were carried out on dry sands derived from the representative natural sand samples collected from earthquake affected area of Ahmedabad city of Gujarat state in India. The gradation of the original sand particles determined by dry sieve analysis is shown in Figure 1. The index properties were determined and presented in Table 1.

Table 1 Index Properties of Dry Sand

Property	*Value*
Specific Gravity	2.65
Medium Sand	37%
Fine Sand	53.8%
Silty Sand	9.2%
Clay	Nil
Liquid Limit	-
Plasticity Index	-
Coefficient of curvature (C_c)	0.82
Coefficient of Uniformity (C_u)	4.48
Median GrainSize (D_{50})	0.28 mm
Maximum void ratio (e_{max})	0.67
Minimum void ratio (e_{min})	0.38

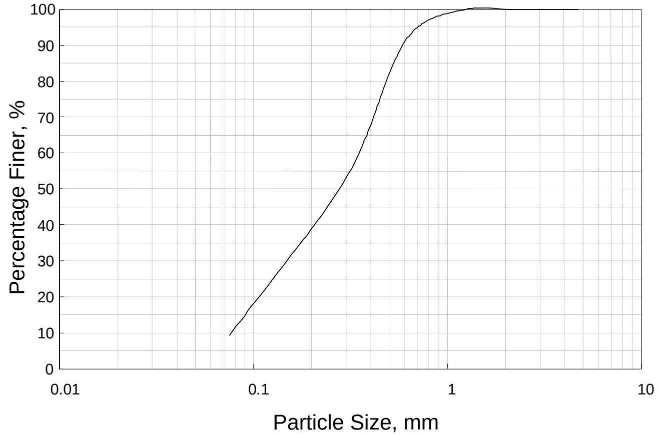

Fig. 1 Particle size distribution curve

A series of strain controlled cyclic triaxial tests were carried out on dry sand samples to investigate the influence of different parameters such as number of loading cycles, confining pressure and frequency on the dynamic soil properties. Present investigations were carried out on specimens having a size 50 mm diameter and height 100 mm prepared by dry deposition technique.

The dynamic properties, shear modulus and damping ratio, have been evaluated from the test data corresponding to the first cycle (ASTM D3999) of the hystersis loop. In the entire testing programme, a harmonic sinusoidal loading was applied and cell pressure, pore water pressure and cyclic loads were monitored by data acquisition system.

Evaluation of Dynamic Properties of Soil

When cyclic triaxial tests are performed on soil specimen, a hysteresis loop similar to the one shown in Figure 2 will be formed in the plot of deviator stress, $\sigma_{d,}$ versus axial strain, ε.

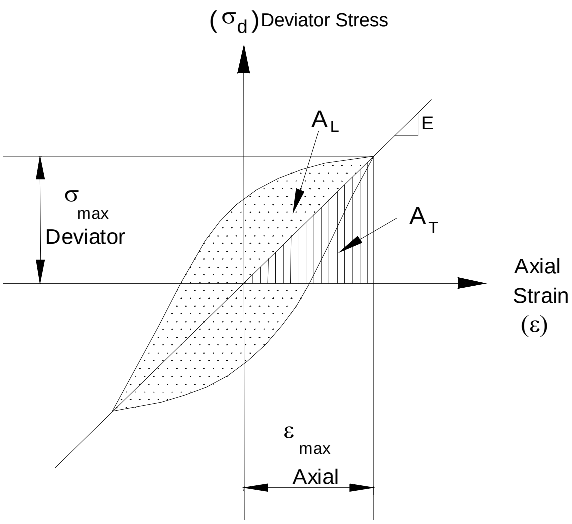

Fig. 2 Hysteretic Stress-Strain Relationship for Cyclic Loading

The slope of the secant line connecting the extreme points on the hysteresis loop is the dynamic Young's modulus, E, which is given by

$$E = \sigma_{max} / \varepsilon_{max} \quad (1)$$

Further,

$$\gamma = (1+ \nu)\ \varepsilon \quad \text{and} \quad G = E / 2\ (1+ \nu) \quad (2)$$

where G is the shear modulus, γ is the shear strain and ν is the Poisson's ratio that may be taken as 0.4 for dry sand specimens (Silver and Park, 1975). The damping ratio, D, is a measure of dissipated energy versus elastic strain energy, and may be computed from the equation,

$$D = \frac{1}{4\pi}\frac{A_L}{A_T} \qquad (3)$$

where A_L = area enclosed by the hysteresis loop; and A_T = area of the shaded triangle in Figure 2.

Results and Discussion

Figures 3 and 4 show the typical deviator stress versus number of cycles for sand samples of relative densities 25%, and 50%.

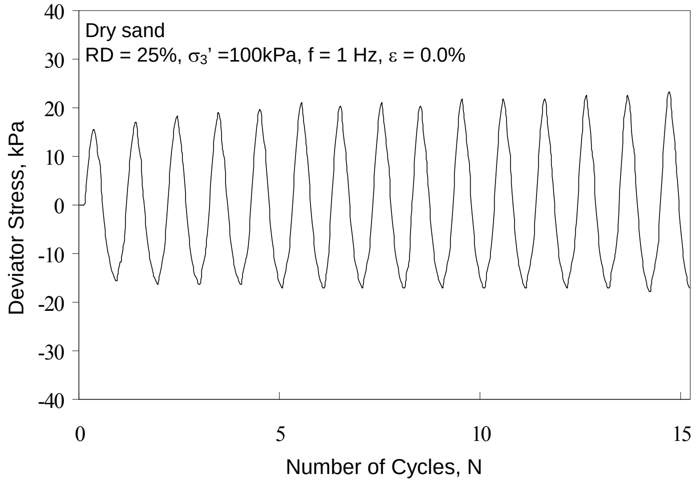

Fig. 3 Deviator Stress Versus Number of Cycles forDry Sand at Relative Density of 25%

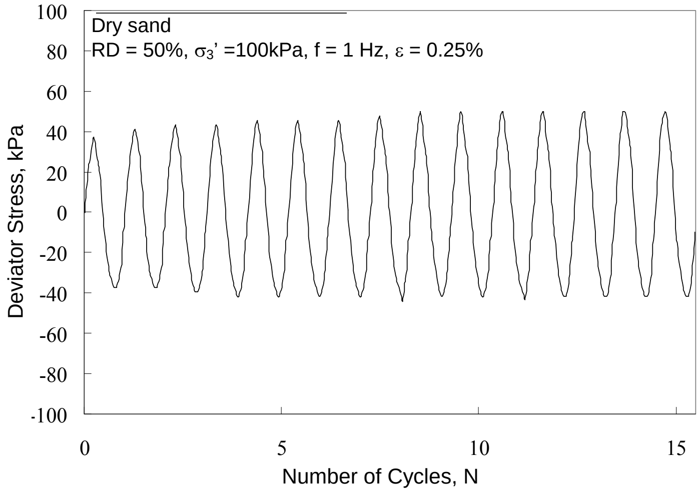

Fig. 4 Deviator Stress Versus Number of Cycles for dry Sand at Relative Density of 50%

As it can be observed from the figures that the increase of deviator stress occurs only for very first few number cycles of loading and thereafter the deviator stress almost remains constant with number of cycles. This clearly highlights the fact that the dry sands densifies with in first few cycles and thereafter the increase in number of cycles has no influence on the deviator stress. Similar behaviour of variation of deviator stress with number of cycles for dry sands has been reported by Silver and Park (1975). Figure 5 shows a typical hysteresis loop of first cycle of loading obtained from a strain controlled cyclic triaxial testing for dry sand sample of relative density 50%.

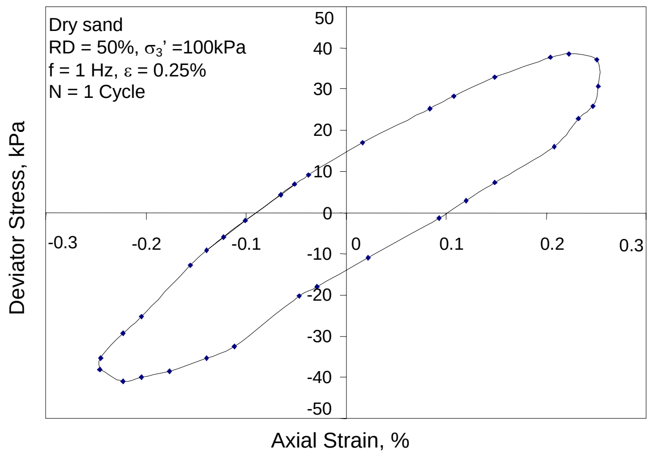

Fig. 5 Deviator Stress Versus Axial Strain Relationship at First Cycle for Sand Sample at Relative Density of 50%

Figure 6 shows the effect of number of cycles on shear modulus in the strain controlled triaxial testing on reconstituted dry sand samples at 25% relative density under a confining pressure of 100 kPa at 1 Hz frequency.

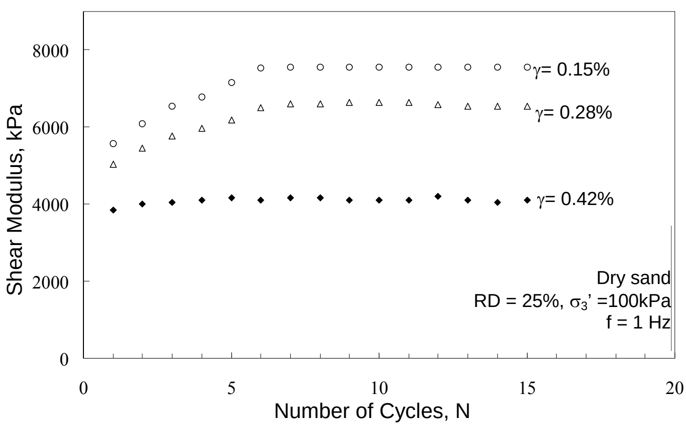

Fig. 6 Relationship Between Shear Modulus and Number of Cycles at 25% Relative Density for Dry Sand

It is evident from the figure that the shear modulus after first cycle of loading increases slightly with increase in the number of cycles up to 6 cycles of loading and thereafter the shear modulus remains constant with further increase in the number of cycles for shear strain levels of 0.15% and 0.28%. Whereas for shear strain level of 0.42 % the shear modulus is almost constant after first cycle of loading, indicating that the soil densifies after first cycle of loading.

The relationship between the damping ratio and the number of cycles for reconstituted dry sand sample at 25% relative density is shown in Figure 7. It can be observed from the figure that except at first cycle of loading the damping ratio remains almost constant with increase in the number of cycles but decreases with increase in the cyclic strain amplitudes. This brings out the fact that the influence of number of loading cycles is not significant on damping ratios of the dry sand samples.

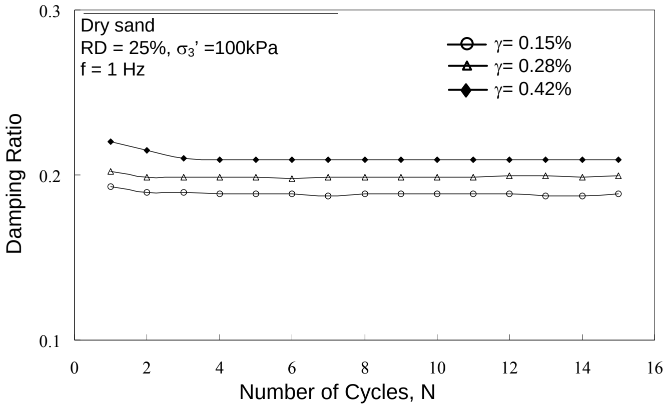

Fig. 7 Relationship Between Damping Ratio and Number of Cycles at 25% Relative Density for Dry Sand

Effect of Confining Pressure

Strain controlled cyclic triaxial tests were carried out on dry sand samples at a relative density of 25% subjected to confining pressures ranging from 25 kPa to 200 kPa. All the tests were carried out under a loading frequency of 1 Hz with uniform sinusoidal wave.

The influence of confining pressure on the shear modulus is shown in Figure 8. It may be noticed from the figure that there is considerable influence of confining pressure on shear modulus. As the confining pressure increases the shear modulus increases significantly, however the shear modulus follows a converging trend towards larger shear strains irrespective of the confining pressure to which the samples are subjected.

Figure 9 shows the influence of confining pressure on the damping ratios. As seen in the figure, the damping ratio increases with increase in the shear strain at a given confining pressure but decreases with increase in the confining pressure. This clearly brings out the fact that the damping ratios in dry sands are influenced by the confining pressure. These results are in close agreement with the results reported by Silver and Park (1975) and Sherif et. al., (1977).

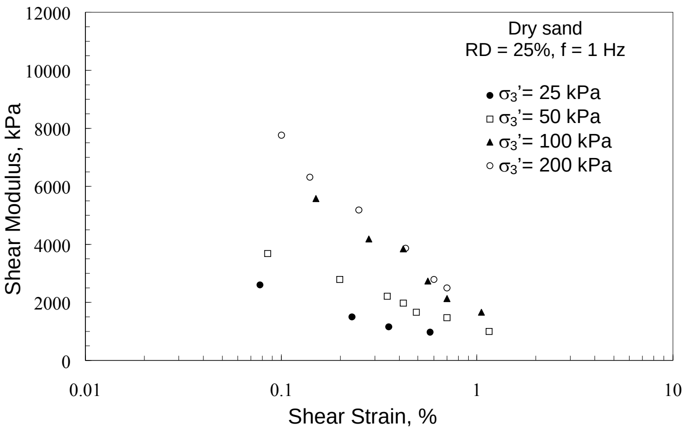

Fig. 8 Influence of Confining Pressure on Shear Modulus for Dry Sands

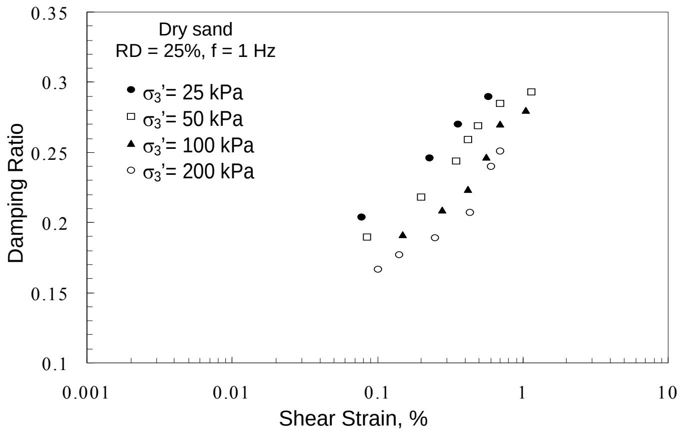

Fig. 9 Influence of Confining Pressure on Damping Ratio for Dry Sands

Effect of Frequency

To study the effect of frequency on dynamic properties, strain controlled cyclic triaxial tests were carried out at a relative density of 25% under a constant confining pressure of 100 kPa. All the samples were subjected to uniform sinusoidal loading frequencies of 0.1 Hz, 0.5Hz, 1 Hz, 1.5 Hz and 2 Hz.

Figure 10 illustrates the effect of frequencies on shear modulus with shear strain. It may be noticed from the figure that the values of shear modulus fall in a very narrow band for the range of frequencies tested. This indicates that for the range of frequencies used in testing, frequency of cyclic loading has no significant influence on the shear modulus. This finding is in close agreement with the results reported for dry sands by Iwasaki et al. (1978) and Lin and Haung (1996).

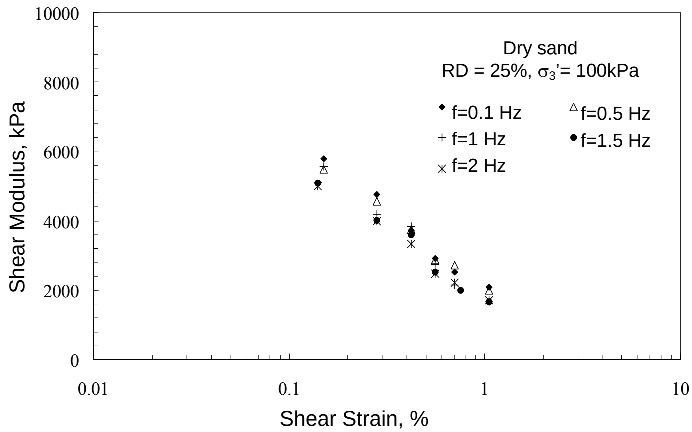

Fig. 10 Influence of Frequency on Shear Modulus for Dry Sands

Figure 11 shows the effect of frequency on the damping ratios for dry sand sample at 25% relative density. It can be noticed that the damping ratio of the dry sands has some influence on the damping unlike as in the case of shear modulus. It can be well noticed that the damping ratio is increasing with increase in the frequency. Lin and Huang (1996) have reported similar behaviour for dry sand samples under constant volume conditions for the frequency range of 0.1 to 20 Hz and at shear strain levels of 10^{-5} to 10^{-4} from cyclic torsion shear testing. GovindaRaju (2005) also reported the influence of frequency on the damping in saturated sands from strain controlled cyclic triaxial testing even at shear strain amplitudes greater than 0.1%.

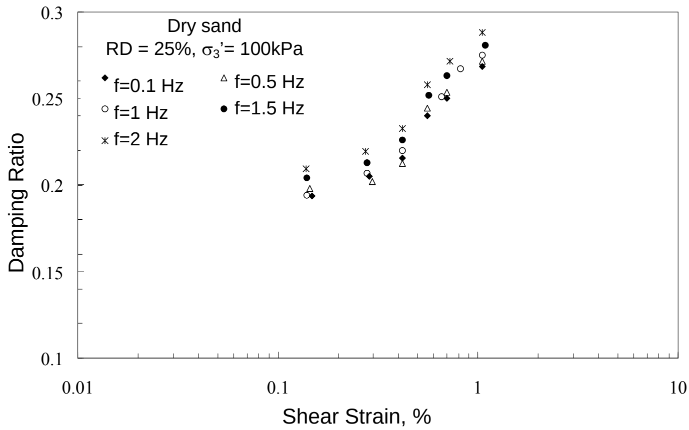

Fig. 11 Influence of Frequency on Damping Ratio for Dry Sand

Figure 12 shows the variation of modulus reduction of dry sands with shear strain for different parameters considered for the present investigation. Also presented in this figure lower and upper bound curve for sands as proposed by Seed and Idriss (1970). G_{max} for dry sands in the present study were established from the shear wave velocity and mass density measurements in Ahmedabad.

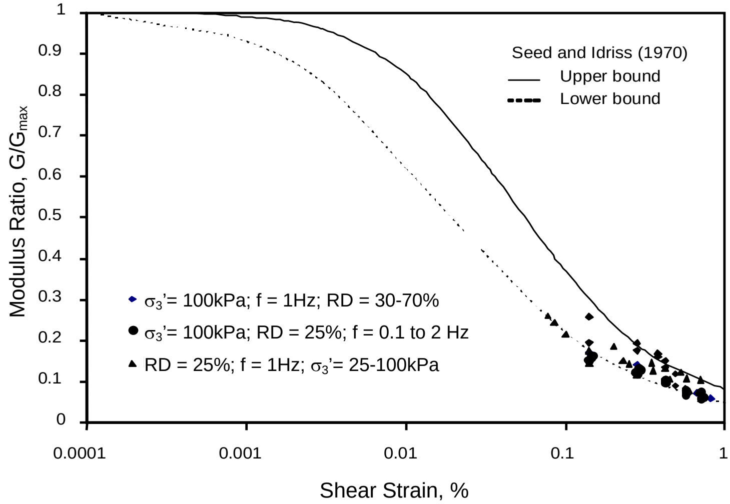

Fig 12. Variation of Modulus Ratio with Shear Strain for Different Parameters Considered for the Present Investigation

According to elastic theory, the small strain shear modulus G_{max} is calculated as

$$G_{max} = \rho V_s^2 \tag{4}$$

where ρ is the mass density of the soil.

The G_{max} value obtained from Equation (4) is used for calculating the modulus ratio (G/G_{max}) in the present study. The normalized modulus was then plotted against shear strain (modulus reduction curve) and is depicted in Figure 12.

It can be observed that, the results of the present study irrespective of different parameters considered for the present investigation fall well within the upper and lower bound for sands as proposed by Seed and Idriss (1970).

Figure 13 shows the variation of damping ratio of dry sands with shear strain for different parameters considered for the present investigation. Also presented in this figure are the lower and upper bound curve for sands as proposed by Seed and Idriss (1970). As it may be seen that the damping values of the dry sand samples from the present study fall well with in the upper and lower bound values of Seed and Idriss (1970).

Conclusions

The dynamic properties such as shear modulus and damping ratio of dry sand collected from earthquake affected area of Ahmedabad of Gujarat state in

India using a series of strain controlled undrained cyclic triaxial tests are presented. The influence of amplitude of cyclic strain, initial confining pressure and frequency on the dynamic properties has been studied.

Based on the laboratory investigations following conclusions were made:

The shear modulus of dry sands slightly increases with increase in the number of loading cycles for the first very few cycles and thereafter the shear modulus almost becomes constant with number of cycles. Whereas, the influence of number of loading cycles is not significant on damping ratios of the dry sand samples

The test results related to the influence of confining pressure on dynamic properties of dry sand samples demonstrates that as confining pressure increases, shear modulus increases but follows a converging trend at very large strains, however the damping ratio is seen to be decreasing with increase in the confining pressure for the range tested.

The effect of frequency on the dynamic properties of dry sand samples indicate that the frequency of loading has no significant influence on shear modulus but the damping ratios are influenced to some extent and there is an increasing trend with increase in the frequency for the range of frequencies and strain amplitudes adopted in this study. In addition, dynamic properties evaluated from current investigation fall well within the lower and upper bound values for sands as proposed by Seed and Idriss (1970).

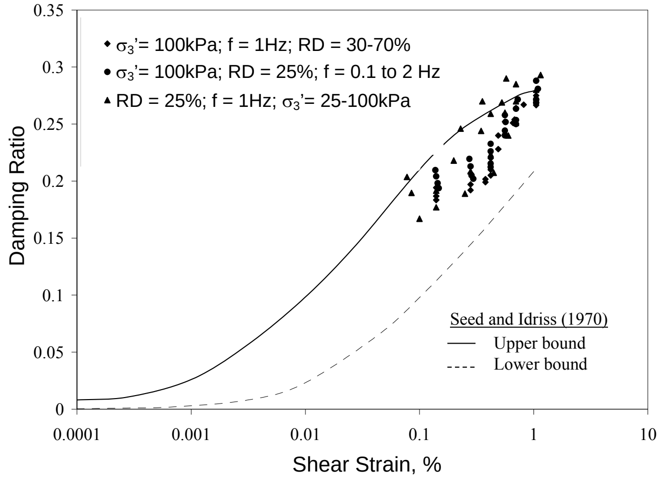

Fig 13. Variation of Damping Ratio with Shear Strain for Different Parameters Considered for the Present Investigation

Notations

RD Relative density

σ_3' Effective confining pressure

f frequency of loading

D Damping ratio

G Shear modulus

G_{max} Shear modulus corresponding to small shear strain

References

ASTM D3999 (1991): *Standard Test Method for The Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus*, American Society for Testing and Materials, pp. 04 -08

Govindaraju, L., (2005): *Liquefaction and Dynamic Properties of Sandy Soils*, Ph. D thesis, Submitted to Department of Civil Engineering, Indian Institute of science*,* Bangalore, India.

Hardin, B. O., and Drnevich, V. P., (1970): 'Shear Modulus and Damping in Soils: Measurement And Parameter Effects', *Journal of Geotechnical Engineering Division, ASCE,* 96(2), pp. 453-469

Iwasaki, T, Tatsuoka, F., and Takagi, Y., (1978): 'Shear Moduli of Sands under Cyclic Torsional Shear Loading', *Soils and Foundations*, 18(1), pp. 39 -56

Lin, M and Huang, T., (1996): 'The Effect of Frequency on Damping Properties of Sand', *Soil Dynamics and Earthquake Engineering*, 15, pp. 269 -279

Seed, H. B., and Idriss, I. M., (1970): 'Soil Moduli and Damping Factors for Dynamic Response Analysis', *Teport EERC 70 -10, Earthquake Engineering Research Centre,* University of California, Berkeley.

Sherif, M. A., Ishibashi, I., and Gaddah, A. H., (1977): 'Damping Ratio for Dry Sands', *Journal of Geotechnical Engineering Division, ASCE*, 103(7), pp. 743 -757

Silver, M. L., and Park, T. K., (1975): 'Testing Procedure Effects on Dynamic Soil Behaviour', *Journal of Geotechnical Engineering Division, ASCE,* 101(10), pp. 1061 -1083