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Dynamic Soil Properties of Clayey Sand using Cyclic Triaxial tests

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Abstract. Site response analysis heavily weighs dynamic soil characteristics including liquefaction potential, shear modulus, and soil damping ratio. The current work studies the response of clayey sand owing to dynamic loads. Saturated undrained cyclic triaxial tests have been conducted using strain controlled loading at different relative densities (50-80%) representing the field conditions and by varying shear strain amplitudes and confining pressure under 1 Hz loading frequency. Test results have shown that, soil's ability to liquefy is reduced when confining pressure and relative density increased. For higher shear strains liquefaction susceptibility, damping ratio increased significantly and shear modulus reduced.

Keywords: Dynamic soil properties, cyclic triaxial test, loading frequency, Shear strain.

1 Introduction

Dynamic soil parameters such as shear modulus and damping ratio impact the behavior of soils exposed to dynamic stresses. Numerous geotechnical engineering problems involving dynamic loads and soil response analysis depend on dynamic soil properties. The dynamic soil properties are mainly responsible for the performance of soils subjected to the dynamic loading.[1,2] Lot of research is going on this aspect, but, soil properties changes from place to place, test results from one place not relates to another. Many parameters such as relative density, shear strain amplitude, type of soil, no of loading cycles and frequency affect dynamic soil properties during dynamic loading [13]. Based on test results, this paper presents the experimental study of effects of cell relative density, cell pressure and shear strain amplitude on dynamic properties of clayey sand.

2 Materials used

Locally available sand around Warangal was collected in this present study. To identify the fundamental index properties as specified by the IS code, experiments on sandy soil were carried out. In Fig 1 and table 1, the particle size distribution curve and soil properties are depicted, respectively. The properties state clearly that the sand under study is SP.

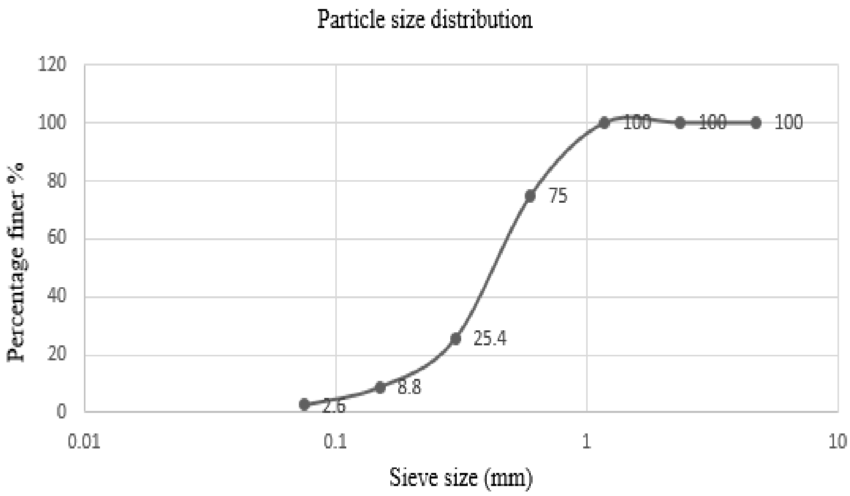

Fig. 1. Particle size distribution of sand

Table 1. Index properties of sand used

Index property	Value
Specific Gravity (G)	2.66
Maximum void ratio(e_{max})	0.98
Minimum void ratio(e_{min})	0.49
D_{10}(mm)	0.16
D_{30}(mm)	0.34
$D_6$0(mm)	0.49
Coefficient of uniformity (C_u)	2.97
Coefficient of curvature(C_c)	1.44
Maximum dry density(kN/m^3)	17.5
Minimum dry density(kN/m^3)	13.15
Soil classification	SP

3 Test procedure

In the current study, cyclic triaxial test apparatus has been used to conduct the set of experiments. A series of strain-controlled undrained tests (ASTM D3999) and stress-controlled undrained tests (ASTM D5311) are carried out to determine the strain-dependent and stress-dependent dynamic response. The four factors indicated (Dr, r'c, c, and CSR) are significantly modified in order to analyze the dynamic soil characteristics. Dr stands for the cohesionless soil's relative density. The effective confining stress on the specimen under field conditions is represented by r'c. The soil specimen was exposed to a maximum shear strain value of c during the shaking motion of excitation. The index value known as CSR is utilized to reveal the soil strength under cyclic stress. The number of loading cycles is altered in addition to the previously specified parameters to assess the formation of extra pore-water pressure, which is utilized to identify the different liquefaction phases. According to Kramer (1996), the aforementioned criteria serve as indications of a soil's ability to liquefy, and the variance of these parameters is noted in the research at hand [12]. It might be challenging to choose a certain frequency value for strain-controlled cycle tests and stress-controlled cyclic testing when the ground motion of an earthquake encompasses a range of frequencies. The frequency of 1 Hz was selected for the applied harmonic regular excitations for the experiments performed in this research based on studies that are currently available on the fluctuation of dynamic soil behavior as well as soil liquefaction with reference to frequency.

4 Results and discussions

In this experiment, moist tamping method is used to prepare the sample. The dimensions of the sample are height 15 cm and diameter 7.5 cm. By raising the back pressure to a minimum B-value of 0.96, saturation was attained [4,5]. Specimens were allowed to consolidate to the necessary net effective stress prior to loading by increasing the cell pressure and letting water to flow through. Samples were then exposed to strain-controlled cyclic loading in an undrained state. A series of strain-controlled undrained experiments using cyclic triaxial test equipment were carried out to assess the sand's dynamic soil qualities. A test was performed on a specimen that had gone through 40 cycles of 0.5% strain, as can be shown in Fig. 2.1(a). According to test findings, shear stress reduces as the number of cycles increases, as shown in Fig. 2.1. (b). It results from an increase in the surplus pore water pressure that is seen in Fig 3.1. (c). It should be noted that a rise in excess pore pressure causes the hysteresis loop to flatten, which reduces the specimen's stiffness (shear modulus). This is shown in Fig. 2.1. (d). As shown in Fig. 2.1.(c), when the pore water pressure ratio is nearly 0.9 after 10 cycles, the sample only shows about one-fifth of the original shear strength value. The shear stress was lower after 12 cycles, and the pore water pressure was about equivalent to the cell pressure. Beyond this, the sample is considered to have liquefied. It should be emphasized that the rise in pore pressure serves as the primary determinant of the specimen's shear strength at any given cycle.

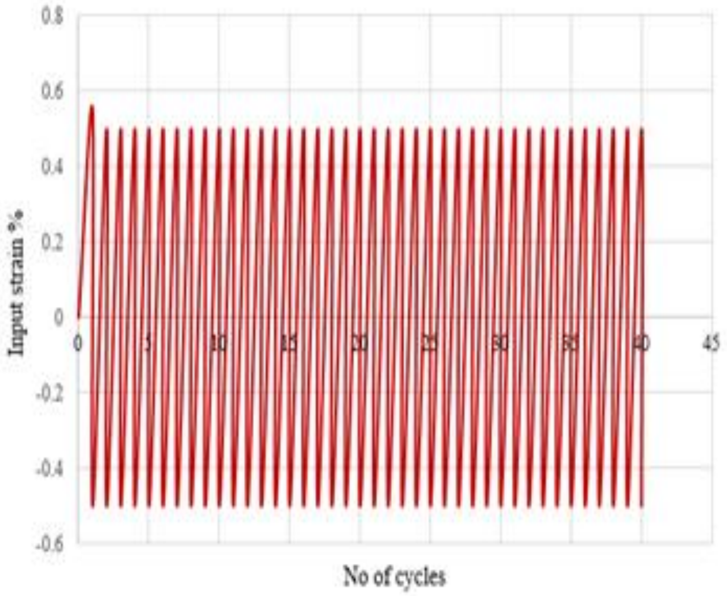

Fig.2.1 (a): Shear strain vs. No. of loading cycles.

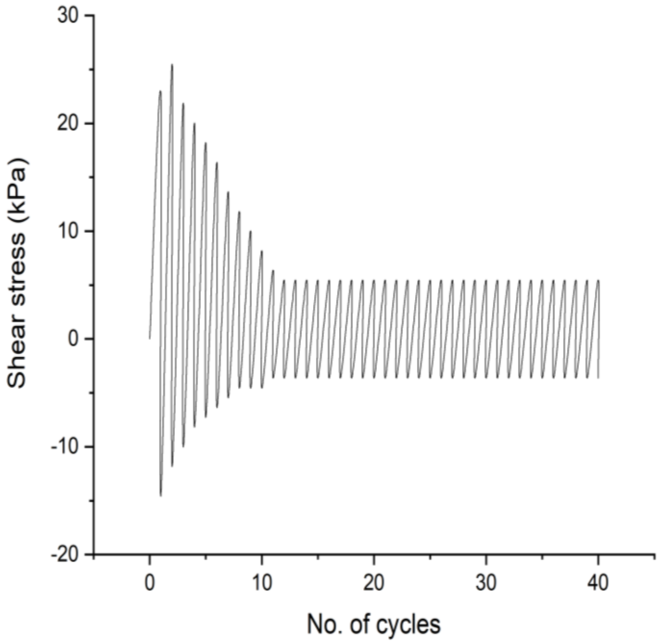

Fig.2.1 (b): Shear stress vs. No. of cycles.

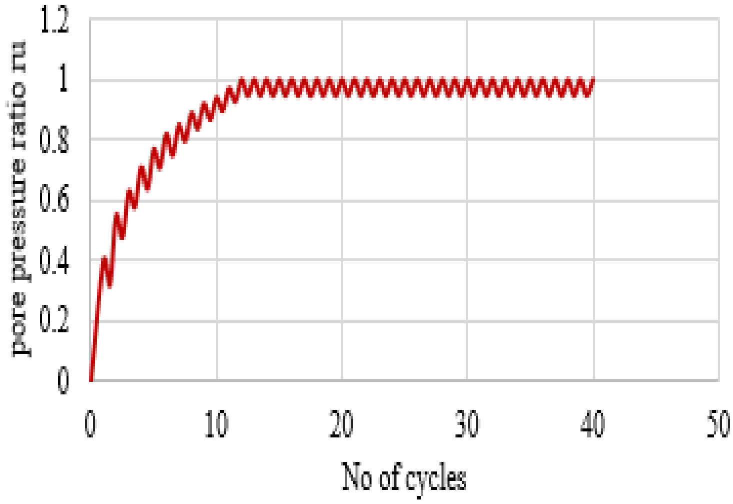

Fig.2.1(c): Pore water pressure ratio vs. No. of cycles.

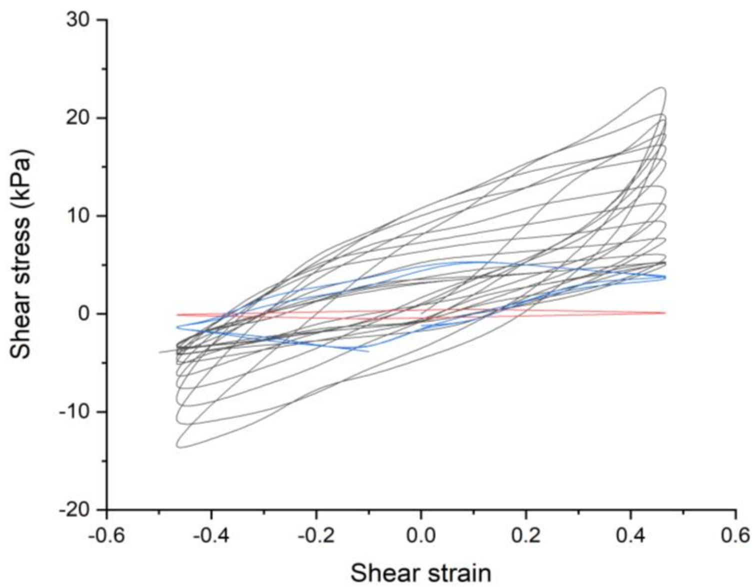

Fig.2.1 (d): Shear stress vs. Shear strain

Fig.2.1 Results of the strain-controlled tests of sands at f = 1 Hz, σ'_c = 100 kPa and axial strain = 0.5% and D_r = 70%.

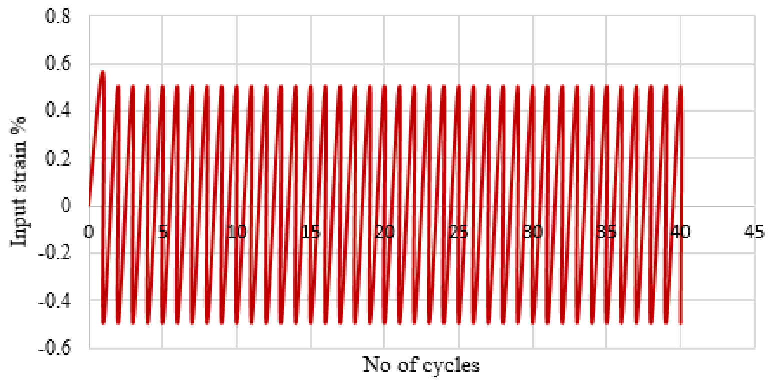

Fig.2.2 (a): Input shear strain vs. No. of cycles.

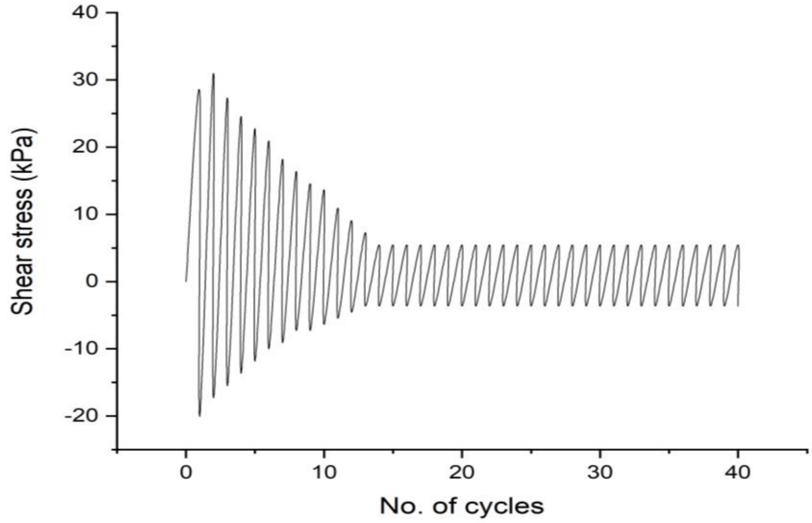

Fig.2.2 (b): Shear stress vs. No. of cycles

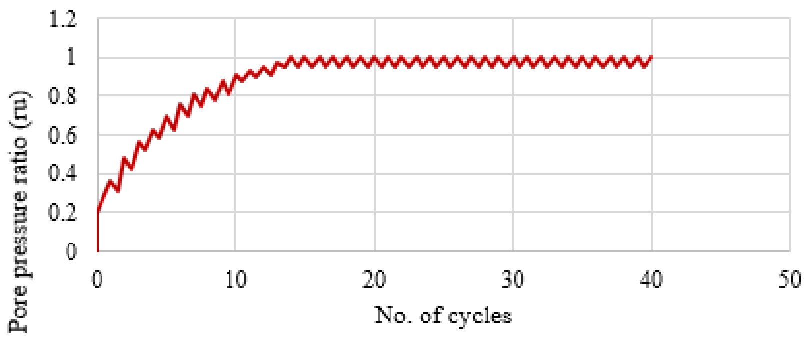

Fig.2.2(c): Pore water pressure ratio vs No. of cycles.

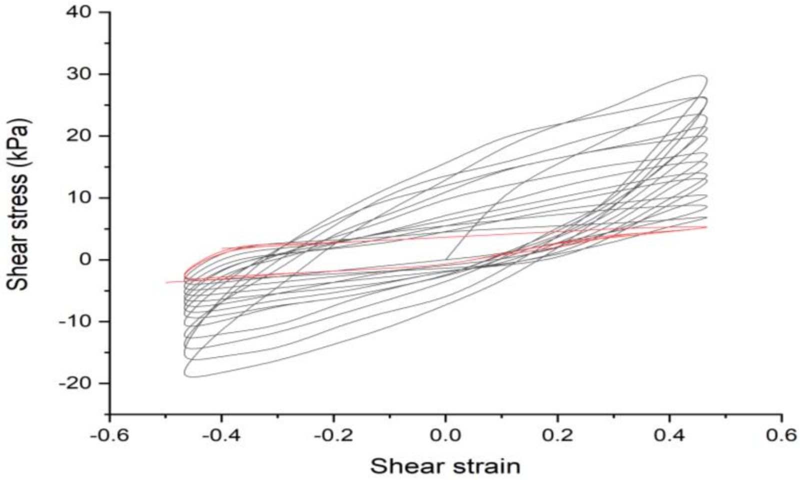

Fig.2.2 (d): shear stress vs. shear strain

Fig.2.2 Results of the strain controlled cyclic tests for clayey sand at f = 1Hz, σ'_c= 100 kPa and axial strain = 0.5% and D_r = 70%.

Sample is reconstituted as similar as to the above sand soil by adding 10% clay to the sand by weight proportion. Saturation and consolidation was done as similar to the above procedure for pure sands and cyclic loading is applied under undrained conditions. Results were presented in Fig 2.2.

Test results revealed that for clayey sand, excess pore pressure ratio reached to liquefaction stage at 14th cycle while for pure sands liquefaction initiated at 12th cycle as shown in 2.2 c. shear stress increases due to adding clay to the sand while comparing with pure sands as shown in 2.2b.

Table 2. List of cyclic triaxial tests performed (strain controlled).

Soil	Dr(%)	σ'(kPa)	F(Hz)	γ (%)
Sand	50	100	1	0.15,0.3,0.5,1
		150		
	70	100	1	0.15,0.3,0.5,1
		150		
	80	100	1	0.15,0.3,0.5,1
		150		
Clayey sand	50	100	1	0.15,0.3,0.5,1
		150		
	70	100	1	0.15,0.3,0.5,1
		150		
	80	100	1	0.15,0.3,0.5,1
		150		

Fig.3. displays the variances in r_u at different values of ɣ with change in number of cycles for D_r = 70%, σ'=100 kPa. Which is an indication of nonlinear growth in number

of cycles and excessive pore pressure. While the ru value for shear strain value of 1 reached 1 at 8 cycles, it took roughly 18 cycles to increase strain value from 0.15 to 1. The figure below show that when the average values of ru rises with shear strain, the cyclic variation of ru at any cycle reduced as the intensity of shear strain is raised. It is evident that when ɣ and N levels increases, then the probability of the commencement of soil liquefaction is more. In other words, the specimen's tendency to liquefy rises with a rise in applied ɣ at any specific ru for identical N. The higher ru causes liquefaction to begin more quickly.

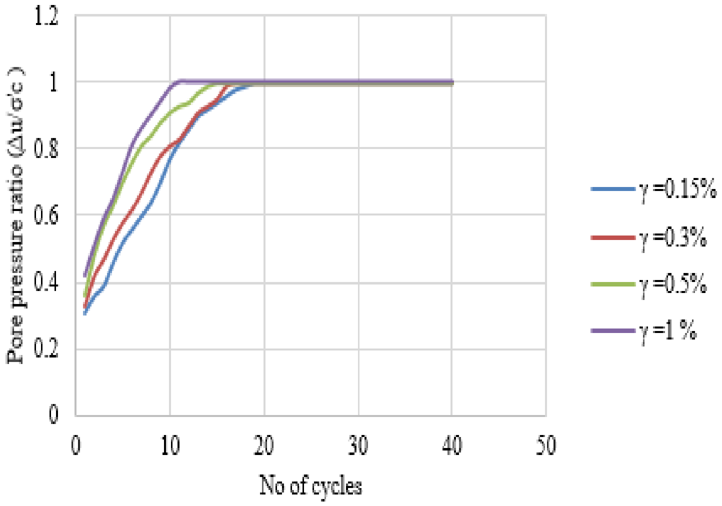

Fig.3. Shear strain effect on pore water pressure ratio (r_u) of clayey sand at relative density 70%.

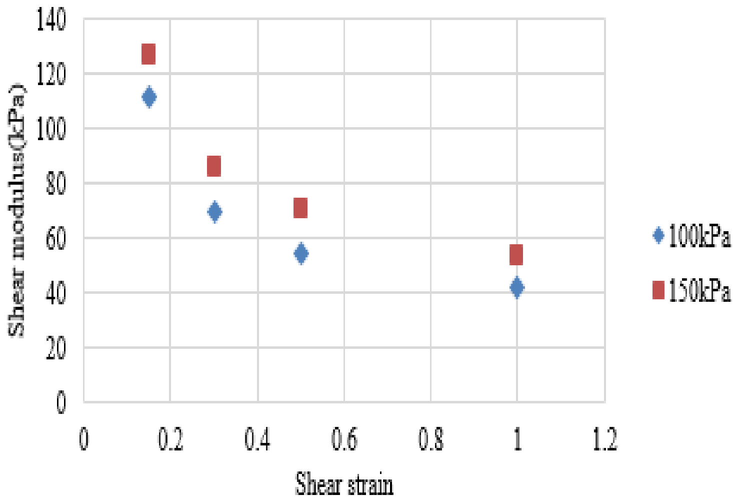

Fig.4. Shear strain effect on shear modulus of clayey sand at relative density 70%

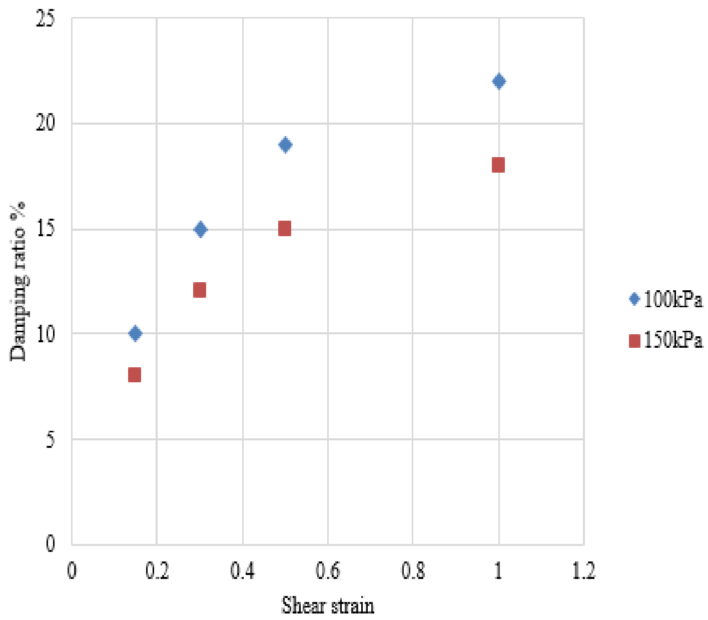

Fig.5. shear strain effect on damping ratio of clayey sand at relative density 70%

Fig. 4 and 5 illustrates how shear strain affected the estimated dynamic properties. The decrease of the shear modulus is seen to follow a common pattern. However, it is discovered that the damping ratio rises up to a particular shear strain. The experiment is conducted with various relative densities and the results of the higher relative densities are presented.

5 Conclusions

1. Applied shear strain amplitude has major impact on excess pore pressure developed during strain controlled test. For higher magnitudes of shear strain, the liquefaction can be achieved with the least cycles.
2. When shear strain increases, damping ratio increases and shear modulus decreases.
3. According to the test results, liquefaction potential of soil is reduced when cell pressure and relative density are increased. Because alternative loading cycles provide smaller surplus pore pressure ratio, more loading cycles are necessary to cause liquefaction.
4. From the results of the first loading cycle, the dynamic soil properties are significantly impacted by confining pressure and shear strain amplitude.
5. Although simple to use, the cyclic strain-based technique tends to produce conservative solutions for regions where site-specific data is not in available.
6. Tests on loose and medium-density specimens show that liquefaction resistance is directly proportional to relative density.

6 References

1. A.Das, P.chakraburthy, K.popescu, “Assessment of lumped particles effect on dynamic behaviour of fine and medium grained sands” Bulletin of Earthquake Engineering (2021).
2. Andrus, R. D., Stokoe, K. H., “Liquefaction Resistance of Soils from Shear-Wave Velocity,” Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 126, No. 11, pp. 1015-1025 (2000).
3. Assimaki, D., Kausel, E., & Whittle, A. “Model for dynamic shear modulus and damping for granular soils”, Journal of Geotechnical and Geoenvironmental Engineering, 126(10), 859-869 (2000).
4. ASTM D3999/D3999M-11e1. Standard test methods for the determination of the modulus and damping properties of soils using the cyclic triaxial apparatus. West Conshohocken, PA, USA: ASTM International; 2011.
5. ASTM D5311M-13, “Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil” pp. 1-11 (2013).
6. Bilham, R., “Earthquakes in India and the Himalaya: tectonics, geodesy and history. Annals of Geophysics”, 47(2-3), 839-858 (2004).
7. Borden, R. H., Shao, L., & Gupta. A, “Dynamic properties of Piedmont residual soils”, Journal of Geotechnical Engineering, 122(10), 813-821 (1996).
8. Bouferra, R., Benseddiq, N., &Shahrour, I. “Saturation and preloading effects on the cyclic behavior of sand. International Journal of Geomechanics”, 7(5), 396-401 (2007).
9. Brennan, A., Thusyanthan, N., and Madabhushi, S. “Evaluation of Shear Modulus and Damping in Dynamic Centrifuge Tests. Journal of Geotechnical and Geoenvironmental Engineering, 131(12), 1488–1497 (2005).
10. Casagrande, A., “Liquefaction and Cyclic Mobility of Sands: a Critical Review”, Harvard Soil Mechanics Series 88, Harvard University, Cambridge, Massachusetts (1976).
11. Castro, G., “Liquefaction and Cyclic Mobility of Sands”, Journal of Geotechnical Engineering Division, ASCE, Vol. 101, No. GT6, pp. 551-569 (1975).
12. Kramer, S. L. 1996. Geotechnical Earthquake Engineering. New Jersey: Prentice Hall.
13. Kumar SS, Krishna AM, Dey A. Evaluation of dynamic properties of sandy soil at high cyclic strains. Soil Dynamics and Earthquake Engineering 2017; 99:157-67.