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Experimental Studies on Liquefaction Susceptibility and Effect of Fines (Silt) Using Shake Table Test

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Abstract
Soil liquefaction is a major reason of failure of foundations of buildings and infrastructure during earthquake due to loss of shear strength of soil. Liquefaction resistance prediction of soil is one of important aspect of practicing geotechnical earthquake engineering. An attempt was made herein to evaluate liquefaction resistance of saturated sand under varying cyclic frequencies and acceleration. The tests on saturated sand sample and saturated sand with varying % fines (silt) sample were performed by Shake table. Results of experimental studies shows, as increases base frequency and acceleration resulted increases liquefaction potential. The variation in pore pressure is obtained for varying percentage of silt contents shows that time required for achieving pore pressure value increases with increasing silt content.

Keywords
Liquefaction Assessment, Shake Table Test, Pore Water Pressure, Earthquake, % Fines (Silt)

Introduction

When loose saturate sand subjected to instantaneous load application like cyclic loads, repetitive and vibratory loads due to earthquakes, blasting, repetitive impacts from machines, pile driving etc. Under this instantaneous loads and unable drainage condition, the ability to change in volume results built up pore water pressure, due to trapped water in pores. If the pore water pressure generated up to the point at which it is equal to the total stress hence effective stress becomes zero and that time strength of sand is negligible, this process is known as liquefaction of soil.[4]

Liquefaction resistance prediction of soil is one of important aspect of practicing geotechnical earthquake engineering. [3] Model of shake table test is considered one of the best methods for simulating seismic loading to produce the earthquake loading of field. Many researchers [Vancouver; Boulanger; Maheshwari; Pathak; Verghese] performed shake table tests to evaluate liquefaction resistance of sand. [8]

Testing Material

Property	Values	Property	Values
Unit weight (kN/m^3) ϒmax	17.76	Coefficient of uniformity, Cu	1.91
Unit weight (kN/m^3) ϒmin	15.02	Coefficient of curvature, Cc	1.24
Specific gravity (G)	2.64	D10	0.24
Maximum void ratio e max	0.724	D30	0.37
Minimum void ratio e min	0.458	D60	0.46

Table 1: Test Sand Properties

Experimental Set Up

Shake table is specifically designed to perform the tests for study of liquefaction process by simulating ground shaking during Earthquake in laboratory.[1] Tests on sand bed model were conducted using uniaxial shake table capable by applying shaking of horizontal base. The maximum amplitude is 10 mm & Frequency 25 Hz for shake table. It's composition of mainly three main components, a vibrating platform of size 400 mm × 400 mm made up of cast iron ,mounted with circular silver plate (400 cm= Dia. of silver plate), through which excitation is given to attached model containing soil/sand. A model (Liquefaction tank) made of Acrylic sheet of 8.00 mm thickness with size 220 x 220 x 300 mm (length × width × height) is used. One dimensional sinusoidal excitation is used and the arrangement is shown in Figure No. 2 a. [5] Position of Pore Water Pressure Measure transducer is from base of (1/3) Height of Sample i.e. (8cm) and Attached to Vertical Stand Pipe (Burette). Pluviation technique is used for Sand beds preparation with funnel was used to achieve uniform density of sand layer [7]. The calculated amount of sand is poured in liquefaction tank using pluviation technique in equal 4 layers (6 cm each layer). All tests were carried out at 34% relative density of sand with height of saturated bed is 240mm [9].

Fig.2a: Shake Table Experimental Setup

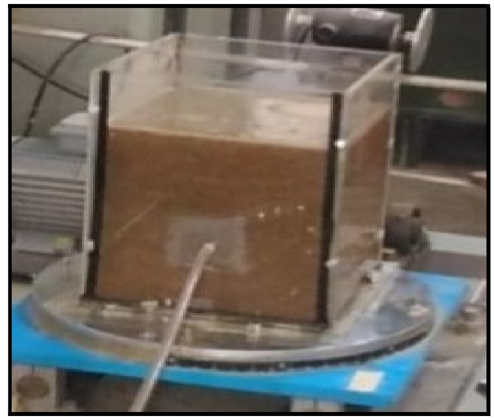

Fig.2b: Shake Table Mounted With Liquefied Sample

Methodology for Experimental Testing Program

To understand and study the effect of various ground motion parameters, the tests series ae carried out on free field liquefaction studies and addition of varying percentage of fines (silt) and properly mixed with sand, density (34 %) of the layer were kept same.[2] The percentage of fines was maintained by weight of the dry sand. The effect of varying percentage of fines was varied from 5 % to 10 % in this series.[6]

Acrylic Liquefaction tank with the sand bed is subjected to sinusoidal base shaking of different acceleration and frequency is carried out to understand the liquefaction susceptibility in the tests at the laboratory of earthquake engineering.

Sr. No.	Acceleration (g)	Frequency (Hz)	%Fines (Silt)	Test Code
1	0.10 g	1.6	0	S1a.1f1.6
2	0.25 g	2.5	0	S1a.25f2.5
3	0.36 g	3.0	0	S1a.36f3
4	0.50 g	3.5	0	S1a.5f3.5
5	0.50 g	3.5	5%	S4a.5f3.5F.05
6	0.50 g	3.5	10%	S4a.5f3.5F.1

Table 2: Experimental Testing Programs

Results and Discussion

Study of Free Field Liquefaction at Different Acceleration and Frequencies and Effect of Varying % Fines (Silt): The tests were performed to find out the minimum base frequency and acceleration for determination of liquefaction. The shake table tests, at an acceleration of 0.5g and frequency 3.6 Hz, the liquefaction of sand bed were observed. In this test, physically Liquefaction as the flow of sand bed like liquid was observed. Less than specified acceleration and frequency, complete flow was not observed. As the acceleration and frequency are increased, the pore water pressure increases and it is reported in terms of number of cycles.

Changes of pore water pressure ratio with number of cycles for these tests are plotted in Fig. No.3 graph here we can clearly observe that the pore water pressure ratio is suddenly increased to one, and sand bed was liquefied within 35 cycles at a base frequency of 3.5 Hz and acceleration of 0.5g. This frequency is known as threshold frequency. The 35 number of cycles necessary to increase the pore water pressure ratio from zero to one represents the liquefaction potential of the sand. However no liquefaction is observed below this Frequency and Acceleration even after 75 numbers of cycles. It was clearly observed that small variations in acceleration amplitude and frequency affect the behavior of sand considerably.

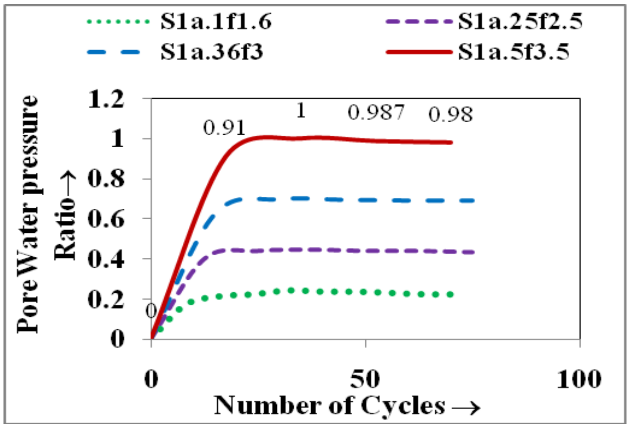

Fig.3: Changes in Pore Water Pressure Ratio with Frequency and Acceleration

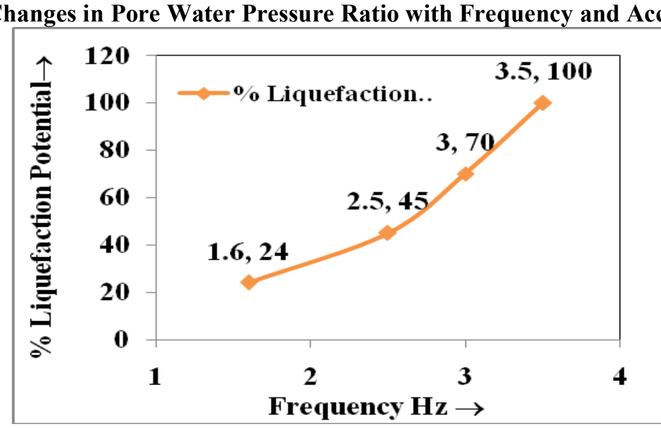

Fig.4: Percentage Variation of Liquefaction Potential with Frequency

Here we can observe from Fig. No.4 that % liquefaction potential increases with increased frequencies and the liquefaction potential reaches to 100 % with frequency 3.5 Hz. From test, it is observed that the pore pressure is very small below this accelerations and frequencies, without showing any signal of failure associated at the particular accelerations and frequencies.

The tests were performed, maintaining the relative density of sand and fines mixture layer as 34%, acceleration amplitude at 0.50g, and frequency at 3.5 Hz. The % fines were varied from 5% to 10%. Results from these tests for clean sand (S1a.5f3.5) are shown in Fig No. 5 for changes in pore water pressure ratio vs. number of load cycles.

It indicates that increase in percentage of fines increases the liquefaction (flow) resistance of soil and also increases the time required to reach pore water pressure ratio value to unity. It represents that when percentage of fines goes on higher side, the liquefaction potential goes on lower side (liquefaction resistance increases).For the clean sand test (S1a.5f3.5) number of cycles to liquefy soil sample are 35, but the effect of fines we can clearly observe here, Series (S4a.5f3.5F.05) and (S4a.5f3.5F.10) soil get liquefied but the number of cycles required for liquefaction due to addition of fines are increased 47 and 68 respectively.

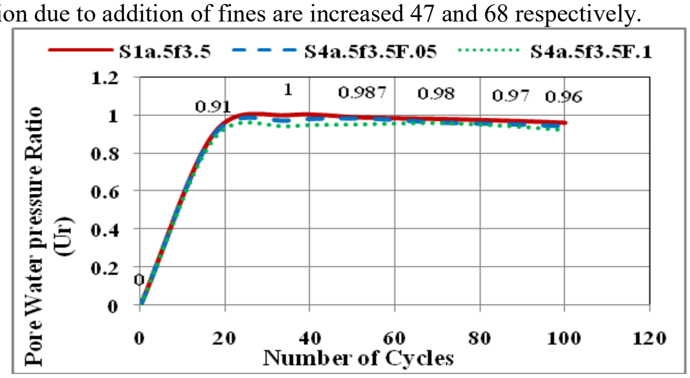

Fig 5: Changes in Pore Water Pressure Ratio with Fines

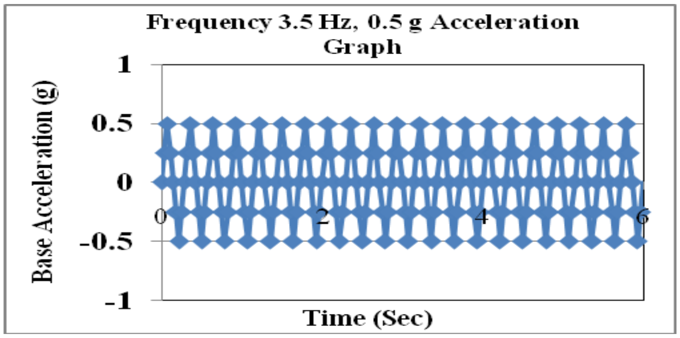

Fig.6: Variations in Acceleration to Time Period with Frequencies

Conclusion

The studies of series of shake table tests deals with the experimental work carried to evaluate the liquefaction response of sand and with varying percentage of fines (Silt) due to ground motion. From free field condition with different input wave parameters, it is clear that the liquefaction potential of soil considerably depends on frequency and acceleration of input wave. As the frequency and acceleration increases the increase in liquefaction potential is observed. The development in pore water pressure also influences the very small change in frequency and acceleration. At frequency (3.5 Hz) and acceleration amplitude (0.5 g) the sand bed got liquefied. Study was carried out to find out the effect of proportions of Fines (Silt) on liquefaction potential of sand. the changes in development of pore pressure for different silt contents is also studied and result shows that time period required for achieve maximum pore pressure value increases with increase in percentage of silt content.

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