Studies on Development of Pore Water Pressure and Liquefaction using Shake Table Test

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***Abstract*—Earthquake induced Liquefaction in saturated granular soil is an important phenomenon causing severe damages. Under dynamic loading, pore water pressure develops and soil loses its shear strength. There are various parameters that affect liquefaction of sand deposits. In order to minimize the ill-effects due to liquefaction, various lab tests as well as field tests are being used for assessing the liquefaction potential. In the present study shake table test has being used to assess the liquefaction of loose saturated cohesionless sand by simulating earthquake condition in the laboratory. This report presents the results of shake table experiments conducted on three types of saturated sand subjected to sinusoidal shaking at three different relative densities 30%, 40% and 50% each. The studies were conducted by using a uniaxial shake table producing 0.33g acceleration. A total of 15 pore water pressure sensors are placed in different locations and at different levels inside the sand bed.**

The results shows that liquefaction decreases with the increase in relative density as expected. The criterion adopted for liquefaction is pore water pressure ratio ru = 1. Liquefaction behavior of Puthu Vypin sand was more than Chertala and Aluva sand

Keywords—Liquefaction, Excess Porewater pressure, Shake table test.

I. INTRODUCTION

Earthquakes are among the most severe natural disaster causing significant damages such as failure of earth structure, settlement or tipping of buildings, lateral spreading of sloping ground and densification causing vertical settlements. The reasons for these failures can be either due to the compaction of loose deposits of soils or by a phenomenon called liquefaction.

Earth quake is the most destructive natural hazard in the world, manifest themselves in the form of vibrations of the earth which are caused by the abrupt release of strain that has accumulated overtime. Several approaches to evaluate the potential for liquefaction have been developed. The commonly employed are cyclic stress approach and cyclic strain approach to characterize the liquefaction resistance of soils both by laboratory and field tests. The field study mainly deals with SPT and CPT data. The laboratory methods include direct shear test, Triaxial shear test, Centrifuge shear tests, Ring shear test, Torsion shear test and shake table test. In these types of tests, the stresses conditions and deformation in the soil elements are significantly affected by the boundary conditions, and the loading conditions are generally not the true field conditions. Therefore it is believed that large soil specimen can reproduce the actual seismic ground shaking (Seed et al). Since Shake table test can simulate actual seismic conditions, among the various laboratory tests, focus is given on shake table test in the present study.

As per IS code Kerala is included in earthquake zone III. Previous studies shows that the maximum earthquake occurred in Kerala are of magnitude 5.5. It is not necessary that all parts of Kerala should experience an earthquake of this magnitude. It is observed that Pathanamthitta, Kottayam, Alapuzha and Ernakulam districts shows highest value of peak ground acceleration ranging from 0.234g to 0.278g (Sajudeen et al). In this series of shake table test by giving an input acceleration of 0.33g, an attempt to study the liquefaction behavior three types of soils is made here.

II. EXPEREMENTAL PROCEDURE

A. *Shake Table*

For the present experimental investigation, shake table is used. It consist of a rigid rectangular box made of steel and perspex glass mounted on a one dimensional shake table . This table is connected through a pulley system to an AC motor. The setup can create acceleration 0.1g to 1g. The box is 1.50m long, 0.50m wide and 0.60m deep. The bottom portion of box is provided with baffle walls for regulating water uniformly to saturate sand. A small orifice is provided at the bottom to introduce as well as drain water. A filter media is provided above the baffle wall to restrict the entry of sand in to the baffle wall portion, which could be easily removed and placed back.

B. *Pore Water pressure sensors*

Acceleration is measured by using ADXL335 three axis sensor and Pore-water pressure is measured using FreeScale MPVX7007DP analog piezoresistive differential pressure sensor. The sensor is used to measure pressure in the range of -7kPa to 7kPa.. A total of 15 pore water pressure sensors are placed inside the soil bed at 10, 20 and 30 cm depth.

Fig.1 shaking table with transducer and computer

C. Sample

In the present study , three types of soil samples are procured from different places in Kerala as mentioned earlier. The sands are designated with respect to the place from which it was collected and accordingly they are named as Chertala sand, Puthu Vypin beach sand, and Aluva river sand. Chertala sand was procured from Alapuzha district, Puthu Vypin beach sand and Aluva river sand are from Ernakulam district. To know the soil properties, the following tests were conducted Sieve analysis, Specific gravity, Maximum and minimum density and Falling head permeability test.

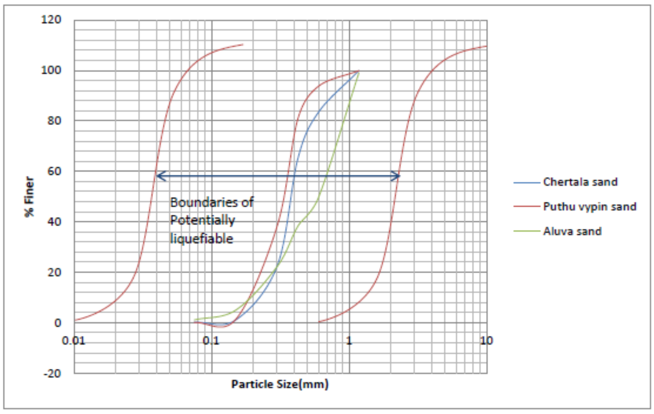

Fig 2. Gradation curve of soil

Table 1 Properties of soil

	Chertala sand	Aluva Sand	Puthuvypin sand
Sp Gravity	2.63	2.6	2.64
Uniformity Coefficient	1.66	1.8	1.6
Coefficient of curvature	1.06	0.9	1.06
emax,emin	0.78, 0.50	0.87, 0.51	0.88, 0.57

D. Sample bed preperation

The sand bed was prepared by pouring the sand loosely into the box using sand pluviation technique with a conical hopper with a 60° base angle to ensure uniform deposition of sand (Renjita et al). Care is taken to drop the sand as close to the bed level as possible without rendering any height to fall, so that the sand is deposited in loose state. The pore water pressure sensors are tied and fixed in exact position before filling the soil so that the relative position of sensor with respect to sand bed remains unchanged. Sand bed in shake table was prepared in four layers. Weight required for each layers is found out and is filled with a funnel to ensure uniform deposition.

Fig 2 shows the grainsize distribution curves for the sand, superimposed on potentially liquefiable ranges of soils proposed by Tsuchida (1970).

The soil was saturated from the bottom of the tank through the channels. Water is allowed to percolate slowly at a very low head so as not to disturb the soil bed. Saturation process took for 6 hours.

The test program consists of 9 tests conducted using shake table apparatus. Three types of sands with varying relative densitiy 30, 40, and 50%. The input acceleration is kept constant and the value is approximately 0.245g throughout the test. Acceleration and excess pore water developed were recorded using data acquisition system.

III. RESULTS AND DISCUSSIONS

Initiation of liquefaction is defined in terms of excess pore water pressure developed during dynamic loading. The ratio of excess pore water pressure to initial vertical effective stress is termed as pore water pressure ratio (ru). When the pore pressure ratio becomes one, sand bed is assumed to have liquefied. The shear strength of soil during liquefaction will be zero due to excess pore water pressure. The vertical stresses at 100mm, 200mm and 300mm depth is calculated. Excess pore water pressure developed is obtained from the graph is divided by the vertical effective stress at that location.

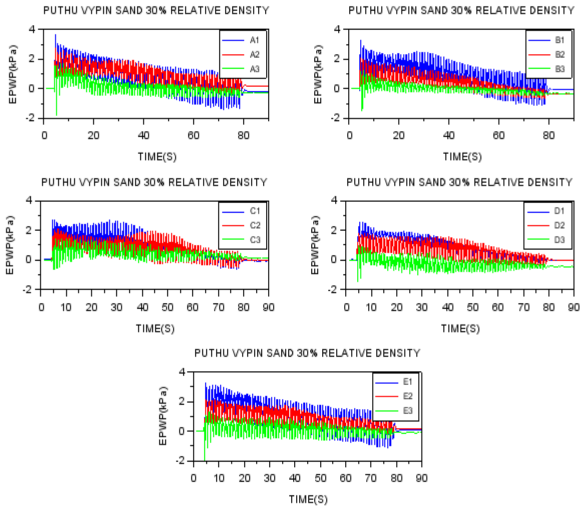

Fig 3 Pore water pressure development of Puthu Vypin Sand 30% relative density.

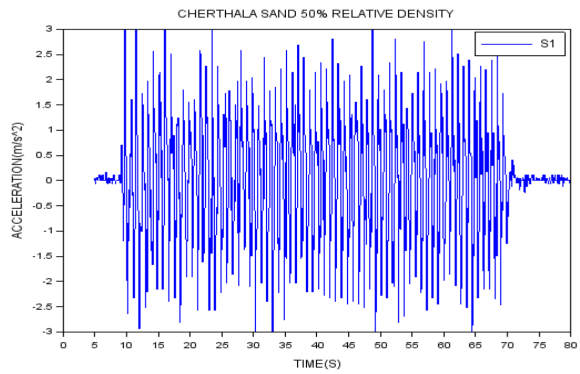

Fig 4 Acceleration time history.

Table: 2 Maximum pore pressure ratio

Description	Location Of sensor	Maximum Pore Pressure Ratio (r_u max)														
		30% Relative Density					40% Relative Density					50% Relative Density				
		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Chertala Sand	Top	1.4	1.4	1.7	1.2	1.4	1.1	1.2	1.3	0.9	1.3	1.3	1.2	1	1.1	1.4
	Middle	1.2	1.1	1.1	0.9	1.2	0.9	1	1.1	1	1.1	1.1	1	1	1.0	1.2
	Bottom	1	1.1	1	0.8	1	0.8	1	1	1	1	1	1	1	0.9	-
P Vypin Sand	Top	1.8	1.2	1.5	1	1.2	1.6	1.1	1.1	1	1.3	1.8	1.5	1.3	1.1	1.3
	Middle	1.5	1.1	1.1	0.9	1.1	1.3	1.1	1.1	1	1.1	1.4	1	0.7	1	1.1
	Bottom	1.1	1	0.9	0.9	1.1	1.3	1.1	1	1	1.1	1	1.1	1.2	1	1.1
Aluva Sand	Top	1.4	1.2	1.1	1	1.3	2.1	1.3	1.1	1.2	1.4	2.1	1.2	1.4	1.15	1.5
	Middle	1.2	0.9	1.1	0.9	1.1	1.3	0.9	1.1	1	1.2	1.3	1	1	1	1.3
	Bottom	1	0.9	1	0.9	1.1	1.1	1	0.9	0.9	1.1	1.7	1.4	1.5	1.4	1.7

Comparison graphs are plotted and found that duration of shaking of Puthu Vypin sand was less and duration was approximately equal to 50 seconds.

Pore pressure ratio of Aluva sand was more and from the graph can analyze that ru value remains 1 for a long time.

It is seen from the above figures that generation of pore pressure is higher at the bottom level as compared to the one at middle and top level, which can be readily traced back to the major fact that the amount of surcharge at bottom level is higher than that at other two levels. Similar trend is observed for test specimens with Dr = 50%, 40% and 30% subjected to acceleration 0.245g.

Thus, (for all the test results) it is clear that pore water pressure first develops at the top of the sample and then proceeds to middle and eventually to the bottom. Thus, liquefaction proceeds in the downward direction for the laboratory shake table apparatusn .We can say that as depth or overburden pressure increases effective stress increases which will decrease the pore pressure ratio. It is observed that in the first 10cm thickness complete liquefaction happens after a few seconds of excitation.

Jiaer W U et al have reported that pore pressure value ratios less than1for the specimens tested in cyclic simple shear tests.

Table 3 Effective stresses at different depths.

Name of sand	Relative Density (I_D)%	Depth in cm from top of the sand bed		
		100mm depth	200mm depth	300mm depth
Chertala	30	1.13	1.99	2.99
	40	1.02	1.96	2.94
	50	0.99	1.93	2.98
Puthu Vypin	30	1.56	1.899	2.85
	40	1.32	1.87	2.798
	50	1.14	1.84	2.75
Aluva	30	1.43	1.809	2.713
	40	1.52	1.847	2.77
	50	0.94	1.886	2.839

The table above shows in some locations, pore pressure ratio is less than 1 especially in the case of Puthu Vypin sand. So that portion can also be considered as liquefied.

This indicates that the excess pore water pressure depends upon the contractive characteristics of sand and inflow/outflow of the pore water. Changes in the pattern of variation of pore pressure ratio reveal the extremely complicated behavior of the pore fluid during the liquefaction process.

A. EPWP comparison graph of same sand at different relative densities.

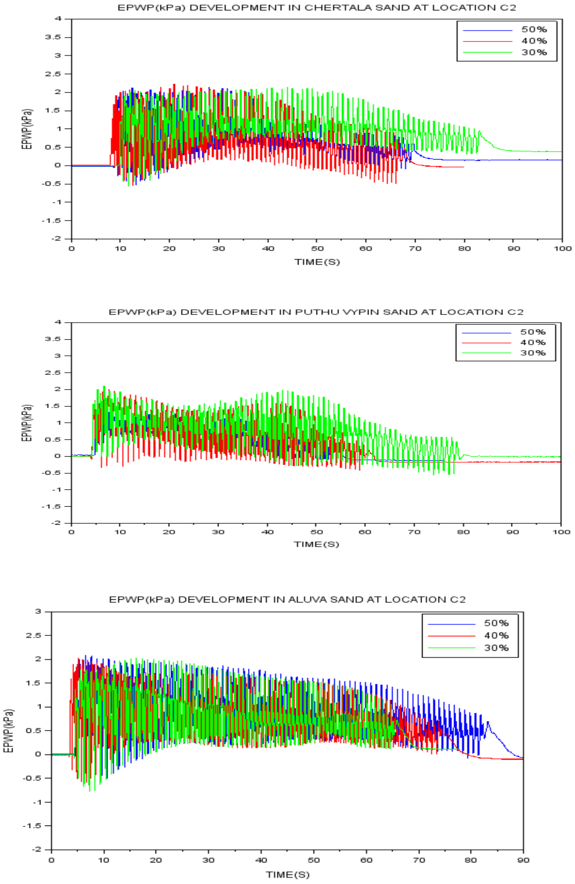

Fig 5 EPWP development of sand at different densities

In all the cases EPWP of sand at 50% relative density is more as expected. EPWP of sand at 40% is slightly less than that of 50%. 30% relative density. Aluva sand shows highest value of EPWP and the maximum value was approximately 3 kPa. Highest Value of Puthu Vypin sand was around 2 kPa. Chertala sand shows low value of EPWP and the value was less than 1.5 kPa.

In all the three graphs we can see that the excess pore water pressure decreases with increase in relative density. Duration of development of pore water increases with increase in relative density in Aluva sand.Duration of development of pore water was more For 30% relative density can be seen in Puthu Vypin and Chertala sand.

B.Effect of permeability on EPWP development

Table 4: Permeability Test Results

Name	Relative Density(I_D)%	Permeability (k) cm/s
Chertala Sand	30	$1.328\text{x}10^{-3}$
	40	$1.107\text{x}10^{-3}$
	50	$0.966\text{x}10^{-3}$
Puthu Vypin beach sand	30	$2.418\text{x}10^{-3}$
	40	$1.729\text{x}10^{-3}$
	50	$1.341\text{x}10^{-3}$
Aluva Sand	30	$3.712\text{x}10^{-3}$
	40	$1.951\text{x}10^{-3}$
	50	$1.3916\text{x}10^{-3}$

Permeability of Chertala sand was less among all the three. Relative density increase permeability decreases. Permeability of 30% density is more in all the three soils and from pore pressure ratio it can be see that increase in pore pressure in 30% density was also more.

Chertala sand did not behave like fluid even when the pore water pressure ratio is greater than 1, reason may be the less permeability of Chertala sand. Liquefaction usually causes a significant increase of the coefficient of permeability, but rapid changes in the pattern of excess pore pressure in the soil during shaking demonstrate that permeability is not a stationary parameter in the liquefaction process and it may either increase or decrease at different depths.

Hence assumption of a constant value of the coefficient of permeability can not be regarded as a suitable approach. Finding a realistic assumption for variation of the coefficient of permeability during liquefaction requires further investigation.

IV. CONCLUSIONS

Shake table test for three varieties of sand samples are conducted and liquefaction behavior was studied at three relative densities. The following conclusions were derived from the present experimental investigation.

- The occurrence of free field liquefaction is almost instant and it could be clearly monitored in a shake table test.
- It is observed that for all the test results, that liquefaction proceeds in the downward direction for the laboratory shake table test.
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- It was observed that the excess pore pressure developed decrease with increase in relative density.
- The coefficient of permeability is not a stationary parameter during shaking as well as during drainage processes during liquefaction and this needs further investigations.
- The magnitude of the excess pore water pressure would be higher at the bottom and lower at the top, causing a pore pressure gradient which results an upward flow .Due to this gradient , the excess pore pressure at the bottom of the sand layer would dissipate as the sand particles at the bottom come into contact with each other.
- If peak ground acceleration of 0.245 occurs in kerala the present study shows that sand will liquefy.
- Among the shake table tests conducted Puthuvypin beach sand with 30% relative density shows more tendency for liquefaction.

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