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Liquefaction Resistance of Sand by Varying the Silt Content Using Horizontal Shake Table Test

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Abstract:- The effect of silt particles on the saturated sand under earthquake loads is controversial issue from few decades. Liquefaction phenomenon was observed in the silty soils during many past earthquakes and also there sever damages. The present study is carried out in order to understand the effect of silt content on the liquefaction resistance of the silty sand using relative density approach. The study is carried out by keeping the relative density constant as 30% and varying the amount of silt from 0% to 50% for different frequency values 2Hz, 3Hz, 4Hz, and 5Hz using small scale uniaxial, horizontal shake table instrument. From the present study it is observed that amount of silt content and frequency of vibration significantly influence the liquefaction resistance of soil. There is a decrease in liquefaction resistance up to 30% of silt content beyond this it reverse its trend and liquefaction resistance decreases with increase in the frequency of vibration. The variations of pore water pressure and sand bed settlement are also studied. Results of this work will give some contributions to understand the behavior of silty sand, with respect to silt content and frequency on its liquefaction resistance.

Keywords:- *Liquefaction Resistance, Horizontal Shake Table, Silt Content Effect, Effect of Frequency of Vibration, Pore Water Pressure, Sand Bed Settlement.*

I. INTRODUCTION

Dynamic liquefaction has long been considered as a serious issue because of its most damaging nature. ‘Liquefaction’ in generally used to describe the sudden and considerable strength loss of saturated sand when it is subjected to dynamic loading. For many years, liquefaction related phenomenon was considered to be limited to clean sands because of the assumption that poorly graded sands were most susceptible to liquefaction and fines present in the sand would increases the liquefaction resistance. However, later it was observed that silty soils were also experience liquefaction and causes tremendous damages during the some earthquakes (Saguenay earthquake (1988), Chi-Chi earthquake (1999) and Bhuj earthquake (2001) [2]. These post-earthquake studies draw the attention towards the occurrence liquefaction process in sands with some percentage of silts. Table 1.1 shows the characteristics of liquefied soil during earthquakes.

TABLE 1.1: Type of liquefied soil in the past earthquakes [1] [5]

Year	Earthquake	Characteristics of liquefied soil
1964	Niigata	70% silt and 10% clay fraction
1968	Tokachi	90% silt and 18% clay fraction
1971	San Fernando	Silty sands
1983	Idaho	70% silt and 20% clay fraction
1999	ChiChi	Silt content as high as 36% to 53%
2001	Buhj	Silty sand
2010	Christchurch	Gray fine silty sands
2011	Great East Japan earthquake	Reclaimed silty sand

Many laboratory and field tests have been used to understand the liquefaction behavior of silty sands. Some numerical methods are also available,

- Investigation of sites damaged by liquefaction, i.e. post-earthquake studies.
- Laboratory tests using undrained cyclic Triaxial devices.
- Field tests like standard penetration test, cone penetration test and shear wave velocity tests.
- Numerical analysis by using software like Geo-Studio, FLAC or PLAXIS.
- Vibration or Shake table tests.

This paper deals with the liquefaction study using uniaxial, horizontal shake table test. Many authors [8], [10] concluded that testing of large samples by using horizontal shake table may provide better representation of field deposits during liquefaction. This experimental study also focuses on the pore water pressure variation and the sand bed settlement.

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II. LITERATURE SURVEY

Many research works have been carried out to understand the liquefaction resistance of sand mixed with different percentage of silt content. Tianqiang Guo and Shamsher Prakash (1999) studied the effect of silt and silt-clay on the liquefaction potential of sand. They concluded that lowest liquefaction resistance will develop between 20% to 30% silt content whereas silt-clay mixtures liquefaction resistance increased by the addition of silt. Liquefaction studies have been conducted using cyclic triaxial tests by varying silt content. Carmine P. Polito and James R. Martin (2001) studied the effect of silt ranging from 0% to 100% and they found that 35% silt content is the limiting silt content. K. Rangaswamy et al. (2009) this paper discussed the comparative study on cyclic behavior of sand and silty soil of 50% fines and concluded that liquefaction resistance of clean sand decreases by the addition of silt. B. K. Maheshwari and Akhilesh K. Patel (2010) conducted the cyclic triaxial tests to clarify the effect of nonplastic silts on liquefaction potential of solani sand and also on the pore water pressure development. . The tested range of silt content was 0% to 25% and concluded that critical silt content was different for different amplitude values. Pradeep Muley et al. (2012), He tested the sand with 0%, 5%, 10%, 15% and 20% silt content at two relative densities 35% and 50%. . Based on the test results they concluded that liquefaction resistance increases with increase in the silt content upto 15% then it starts to decrease. The test results of this work shows that pore water pressure decreases by the addition of silt upto limiting silt content. Mohammad Emdadul Karim and Md. Jahangir Alam (2014), they conducted about 60 undrained cyclic triaxial tests for a constant relative density 60% with frequency of 1 Hz. They concluded that the threshold silt content was 30% upto which the liquefaction resistance of sand-silt mixture decreases beyond this value there was increase in the resistance. S.R. Pathak et al. (2016) conducted shake table tests on silty sands to study the effect of silt content. They tested the range of silt content from 0% to 20% at different relative densities, 30%, 40%, 50% and 60%. . Based on the test results they concluded that liquefaction occurs even the value of pore pressure ratio less than one and CSR decreases with increase in the fines content for relative density >40%.

The topic of resistance of silty sand to liquefaction has become one of the most controversial issue in the recent days. All the available research studies provide the conflicting opinion and conclusion that are contradictory in nature.

III. EXPERIMENTAL STUDY

A. Materials used

Tests were conducted on the clean sand (Sand+0% silt), collected from the Bagalkot district. The properties of the sand and Silt are tabulated in the table 3.1. The grain size distribution curve of sand as shown in figure 3.1. It was observed that the grain size distribution curve of collected sand falling within the range of gradation of liquefiable sand provided by V. C Xenaki and G. A Athanasopoulos (2003) [7].

TABLE NO.3.1: PROPERTIES OF SAND

Particulars	Notation	Value
Soil type	SP	Poorly Graded sand
Specific gravity	Gs	2.68
Grain size (mm)	D10	0.38
	D30	0.59
	D60	0.85
Uniformity coefficient	Cu	2.24
Coefficient of curvature	CC	1.07
Maximum void ratio	emax	0.73
Minimum void ratio	emin	0.52
Maximum dry unit weight (kN/m3)	γ_{max}	17.25
Minimum dry unit weight (kN/m3)	γ_{min}	15.20
Angle of internal friction in dense state	Ømax	37°
Angle of internal friction in loose state	Ømin	34°

TABLE NO. 3.2: PROPERTIES OF SILT

Particulars	Notation	Value
Specific gravity	Gs	2.53
Liquid limit	WL	14
Plastic limit	Wp	12
Plasticity index	Ip	2
Soil type	ML	Low plastic silt
Maximum void ratio	emax	1.12
Minimum void ratio	emin	0.702
Maximum dry unit weight (kN/m3)	γ_{max}	14.58
Minimum dry unit weight (kN/m3)	γ_{min}	11.67

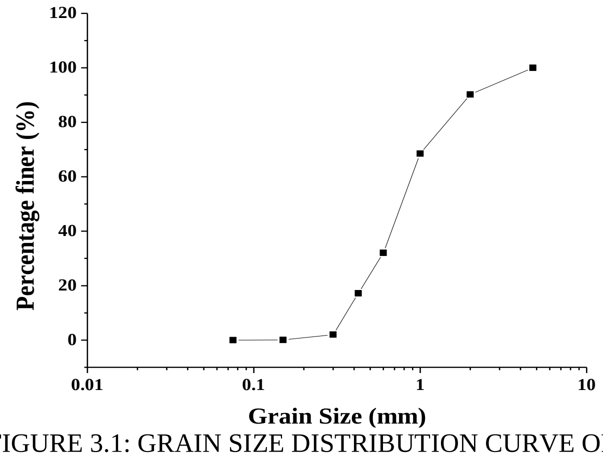

FIGURE 3.1: GRAIN SIZE DISTRIBUTION CURVE OF TESTED SAND

B. Horizontal Shake Table

Figure 3.2 shows a shake table with control units. Using shake table it is possible to stimulate earthquake field conditions by providing known frequency and amplitude of vibrations. In the present work electronic cam type horizontal shake table instrument is used to produce the earthquake field condition. The horizontal shake table instrument mainly consists of Eccentric cam unit, Drive unit, Shake table and Control unit. Required frequency can be set in the frequency drive of control unit which is having ON and OFF indicators. The flywheel consists of radial scale which is used to fix desire amplitude.

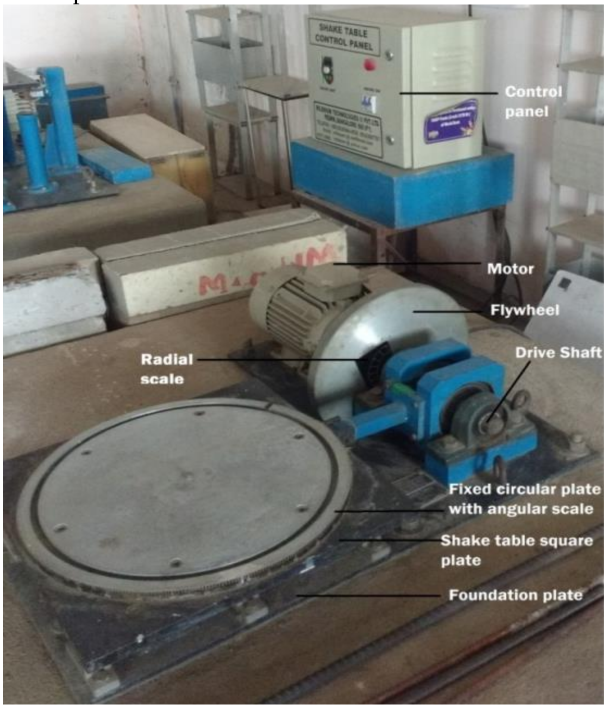

FIGURE 3.2: SHAKE TABLE WITH CONTROL UNIT

C. Perspex container

Transparent Perspex model container of size 30cm×25cm×25cm and having thickness of 6 mm is used to conduct the liquefaction studies. Perspex material is strong enough to resist the vibrations and allow visualization of the saturation level and the liquefaction phenomena during the conduction of test.

D. Methodology

The clean sand was mixed with the different percentage of silt content by manual dry mixing method. The shake table tests were conducted on the Sand-Silt mixtures having 0% to 50% of silt content with an interval of 10%. Transparent Perspex model container of size 30cm×25cm×25cm is used to prepare sand bed in the present study. Conventional rainfall method was used to pour the mixture into the model container. The samples were tested at 30% relative density, amplitude of 4 mm and varying the frequency of vibration, 2Hz, 3Hz, 4Hz and 5Hz. Pore water pressure was measured at 5cm height from the bottom of the container; the readings were recorded at every 5 seconds interval till it reaches the maximum value. The Initiation point of liquefaction was considered at the instant of development of maximum pore water pressure.

IV. RESULTS AND DISCUSSIONS

A. Effect of silt content on liquifaction resistance

Figure 4.1 represents the effect of silt content on the liquefaction resistance of the sand for different frequency values. It was observed that the number of cycles required for the liquefaction of Sand- Silt mixture decreases with the addition of silt upto 30% silt content. Beyond 30% silt content the addition of silt results in the small increase of liquefaction resistance.

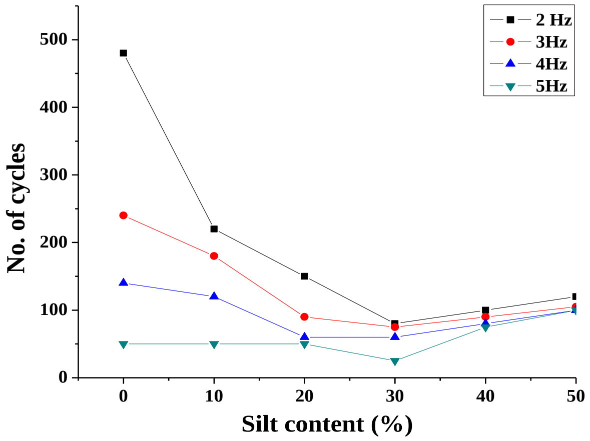

FIGURE 4.1: EFFECT OF SILT CONTENT ON NO. OF CYCLES FOR DIFFERENT FREQUENCY VALUES

The minimum resistance was observed at 30% silt content, hence for the present study 30% silt content is the limiting silt content. The result shows that as the frequency of vibration increses, liquefaction resistance of Sand-Silt mixtures decreases. For all the values of frequency the curve shows the same trend, it indicates that the limiting silt content is same i.e. 30% for the tested frequency range.

The limiting silt content can be calculated by using the following analytical equation [1], from this expression the value of limiting silt content obtained was 26%.

$$LFC = \frac{G_f e_s}{G_f e_s + G_s(1+e_f)} \ldots\ldots (1)$$

where, G_f and G_s are the specific gravity and e_f and e_s are the maximum void ratio of fines and sand respectively.

B. Effect of silt content on the settlement of sand layer for different frequeny values

The settlement of sand bed was measured after the pore water pressure hits the maximum value. Figure 4.2 represents the variations of settlement with the silt content. It was observed that for a particular frequency value the sand bed settlement increases with the addition of silt content upto 30% beyond this settlement starts to decrease. Maximum settlement of 12 mm was observed at 30% silt content for 5 Hz frequency. For particular silt content the settlement increases with increase in the frequency of vibration. At 30% silt content the Sand- Silt mixture shows highly collapsible nature, hence it is clear that the sand – silt mixture forms unstable soil structure at the limiting silt content value. Because of this reason sand with limiting silt content shows minimum liquefaction resistance.

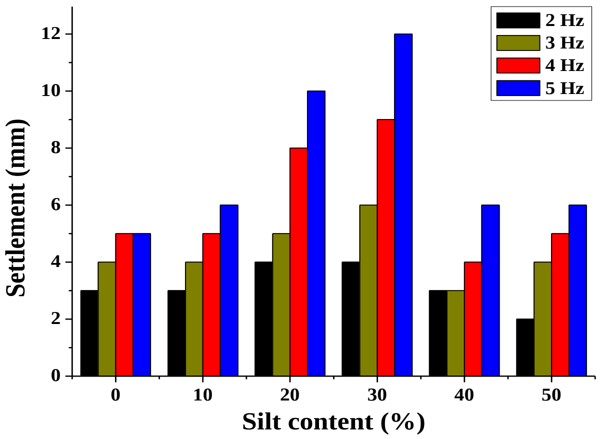

FIGURE 4.2: COMPARISON OF SAND BED SETTLEMENT OF DIFFERENT SAND- SILT MIXTURE

C. Effect of silt content and fequency of vibration on pore water pressure

The effect of silt content on the pore water pressure development for different frequency values is represented in the Figure 4.3 and in Figure 4.4. From the graphs it was observed that clean sand (0% Silt) requires more number of cycles to develop the maximum pore water pressure for any frequency of vibration.

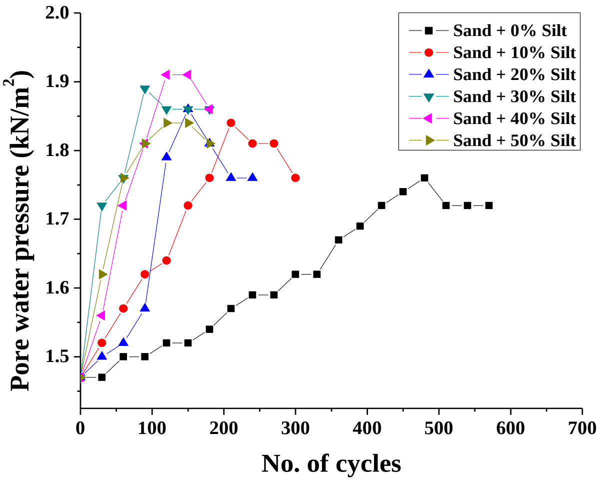

FIGURE 4.3: PORE WATER PRESSURE V/S NO. OF CYCLES FOR 2 HZ

From the result it was also observed that maximum pore water pressure is developed at 5 Hz frequency, hence pore water pressure increases with the frequency of vibration. It was also observed that as the silt content increases the Sand-Silt mixture takes less number of cycles for the development of maximum pore water pressure upto 30% silt content.

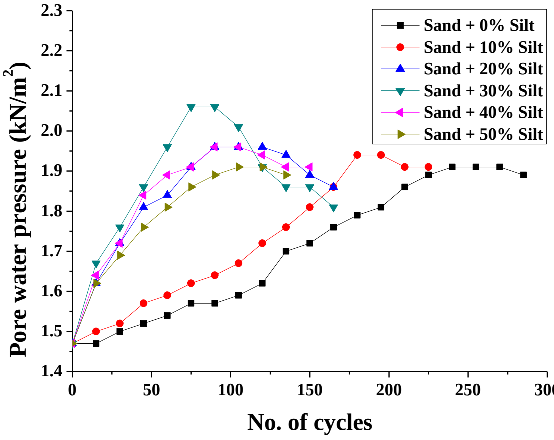

FIGURE 4.4: PORE WATER PRESSURE V/S NO. OF CYCLES FOR 3 HZ

V. CONCLUSSIONS

The following conclusions can be drawn from this experimental work,

1) The increase in frequency of vibration decreases the liquefaction resistance of the Sand –Silt mixture.
2) The increase in the frequency of vibration increases the value of maximum pore water pressure during the liquefaction of Sand- Silt mixture
3) Sand bed settlement increases with increase in the frequency of vibration.
4) Liquefaction resistance of the Sand-Silt mixture decreases upto 30% silt content beyond this there is increase in the resistance. Hence for the present tested sand the 30% silt content is the limiting value.
5) Maximum pore water pressure develops at the limiting silt content, i.e. at 30% silt content.
6) Sand bed settlement is large for the sand-silt mixture having limiting silt content i.e. 30% silt content.
7) Limiting silt content value is same for different frequency of vibration in the tested frequency range.

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