SAND LIQUEFACTION DURING SHAKE TABLE VIBRATION

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SYNOPSIS

A laboratory study on sands obtained from Ukai, Obra, Tenughat dam sites and Solani river was performed on steady state horizontal vibration table. The grain size of sands varied from fine to very coarse. Effect of initial density, initial effective surcharge number of cycles of motion and acceleration have been studied. Dense sands developed negative pore pressure during vibration on shake table. Two types of surcharge devices were used. One air pressure surcharge device and second dead weight surcharge device. Pore pressure developed under dead weight surcharge was observed to be very high in comparison to that when surcharge due to air pressure was used.

INTRODUCTION

In case a foundation soil is liable to liquefy during an earthquake any amount of safety taken in design of structures is not of any help in the event of an earthquake. Catastrophic damage to structures resulting in loss of life and property have emphasized the need for reliable procedures for predicting the possible development of this phenomenon. Two types of laboratory tests are usually current for studies on liquefaction of sands, i) Triaxial or simple shear tests. ii) Vibration table tests. Analytical procedures for predicting the possibility of liquefaction of sand deposits has been made available which uses the quantitative data from small sample tests under triaxial or simple shear conditions. One of the important aspect is the consideration of progressive development of liquefaction and spreading of liquefying zone to deep layers during the duration of earthquake on account of liquefaction of any zone in first few cycles of an earthquake. In the analysis as proposed by Seed and Idriss, this aspect of the problem is not considered. The equivalent number of cycles concept used in the above process can not take care of this phenomenon which is expected to occure in field during an actual earthquake.

There is a need to evolve some method which can take care of the above limitation. Since no uniform agreement could be achieved by different investigators on small sample tests and the test results are effected by the method of test and test equipment used, it would appear to be necessary to carry out further investigations on different types of equipment and develop a more rational analysis. Vibration tables have been used to study the liquefaction behaviour of sands. But a systematic investigations has not been done so far on vibration tables. It was for those purposes that the investigations described here in were conducted.

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The present investigations were carried out on vibration table which can be excited in horizontal direction under steady state vibrations. The frequency and amplitude of the vibration table can be independently controlled. The size of the tank mounted on the table is 105cm x 60cm x 40cm high. Increase in pore water pressure was observed in the centre of the tank at 6cm, 15.5cm and 25cm depths from the surface. 26cm being the height of the saturated sample. Tests were carried out under three types of surcharge conditions at a frequency of 5 cycles per second. i) Zero surcharge condition ii) Air pressure surcharge condition iii) Dead weight surcharge condition. The details of the test set up and procedure are presented elsewhere(2).

Tests were run on Ukai, Obra, Tenughat and Solani sand representing a fairly wide variation in grain size with the maximum and minimum void ratios as given below. The initial relative densities for these sands which could be obtained in loosest condition in test tank are also listed below:

Sand	Ukai	Obra	Tenughat	Solani
Grain size D_{50}	1.8mm	1.00mm	0.47mm	0.15mm
Maximum void ratio	0.57	0.68	0.79	0.86
Minimum void ratio	0.34	0.40	0.49	0.48
Initial relative density	40%	28%	21%	20%

Solani sand is a fine sand while the other three are coarse sands.

TEST RESULTS

In case of relatively loose sands no increase in porewater pressure was observed in first three cycles. It gradually increased to about 60% of maximum pore pressure in next three to five cycles and then suddenly it increased to the maximum value in next one or two cycles. In case of fine sand the maximum pore pressure remained constant for about 35 seconds before it started dissipating and total time for dissipation being about 2 minutes. In case of coarse sands the maximum pore pressure developed in about 6 to 7 cycles and started dissipating immediately on attaining a maximum value. The total time for dissipation being about 20 seconds for Obra and Tenughat sand and about 8 seconds for Ukai sand which is a very coarse sand. It can be observed that the pore pressures dissipated quickly with increased coarseness while it lasted longer in case of fine sand. Therefore the chances of large movements are less in coarse sands and the problem of liquefaction with coarse sands may not be that severe in comparison to fine sands.

Effect of coarseness on liquefaction characteristics is shown in Figure 1. The maximum increase in pore pressure is plotted versus acceleration of vibrations at 25cm depth under zero surcharge for all the four sands. With increase in acceleration pore pressure has been observed to increase initially for all the sands. The maximum pore pressure required to cause complete liquefaction in the test is 29.4cm, 25cm, 24cm and 22.2cm for Ukai, Obra, Tenughat and Solani sand respectively. It can be seen that Solani sand liquefied completely even at low accelerations which could be observed visually also while coarse sands did not completely liquefy. The maximum pore pressure remained constant with increase in acceleration for fine sand, while in case of coarse sands the maximum pore pressure started decreasing with increased acceleration after attaining a maximum value.

Figure 2 shows the effect of initial relative density. It is observed that with increase in relative density, the pore pressure decreases under vibrations and chances of liquefaction are reduced. In case of dense sands negative pore pressures were observed at relative densities of more than 65% and a dilation of sand mass could be observed visually, however no measurement of volume changes during vibration could be taken during the tests. Casagrande also observed dilation in case of medium dense to dense sands on small sample studies under cyclic loading triaxial tests and concluded that if sand is at relative density of more than 50% it may not liquefy (1). From shake table studies it is concluded that sand may not liquefy if a sand is at relative densities of more than 65%.

Effect of air pressure and dead weight surcharge is shown in Figure 3 which is aplot between maximum pore pressure and surcharge at 20%g. for Solani sand. It can be seen that the pore pressure developed are very small in case of air pressure surcharge device in comparison to case where surcharge was applied by means of dead weights. Air pressure surcharge device increases the initial effective- over-burden pressure but during vibrations it can not give rise to the inertial stresses caused by the vibration of overburden mass. As can be seen from the results of dead weight surcharge device the effect of overburden is very significant and cannot be neglected. Therefore laboratory tests with air pressure surcharge are not suitable for liquefaction studies.

In the tests with dead weight surcharge device the pore pressure developed increased with increase in surcharge initially and the sand liquefied completely (figure 3). Complete liquefaction is represented by line AB which represents pore pressures equal to initial effective stress. After a certain value of surcharge the increase in pore pressure started decreasing with increase in surcharge. At this stage the intergranular stress were large enough to provide resistance against shear of sand particles and causing less pore pressure increase.

LIQUEFACTION DURING AN EARTHQUAKE

Liquefaction may develop at any zone of a sand deposit where the necessary combination of in situ density, surcharge and vibration conditions occur. Such a zone may be at the surface or at some depth below the ground surface, which may liquefy in first few cycles of an earthquake and the over burden pressure on the underlying layers would be reduced. This may cause favourable conditions for liquefaction to occur in the underlying layer in the next few cycles of earthquake motion, thereby further reducing the over burden pressure on deeper layers. In this way the liquefaction may travel to sufficient deep layers during the earthquake.

The method used here involves an estimate of loss of effective overburden on the deeper layer during initial few cycles of motion and causing the favourable conditions for that layer to get liquefied in next few cycles using the data obtained from shake table tests. For example a saturated fine sand deposit is considered here having a relative density of 24 percent to depth of 3m and then 36 percent upto a depth of 10m. Initial effective overburden pressure is represented by line OA in figure 4. The details of earthquake acceleration peaks are assumed as given below:

Acceleration g	.035	.1	.2	.13	.1	.20	.25	.2	.1	.3	.2	.15	.05	.1	.05
No. of peaks	20	3	2	3	6	1	1	1	5	1	1	1	5	5	10

Now it has been assumed that maximum pore pressure may develop in 10 cycles and the above earthquake is regrouped to consider it in step by step. Effect of 10 cycles of 0.035g acceleration at 24% relative density is plotted on OB in figure 4 with the help of laboratory tests. The maximum of this is a loss in effective overburden on lower layers. Proceeding in a similar way it could be seen that liquefaction will penetrate to a depth of 5.3 meters in this case (Ph.D. thesis under submission). The accuracy of this method will depend on representable of field condition by i) Dead weight surcharge test - In these tests there is a possibility of presence of confining effect provided by the rigid walls of the tank which could under estimate the increase of pore pressure ii) Minimum number of cycles required to cause maximum pore pressure.

CONCLUSIONS

The following conclusions may be derived based on the study of fine to coarse sands on shake table.

1. The problem of liquefaction with coarse sands may not be that severe in comparison to fine sands.
2. The saturated sands may not liquefy if the relative density is more than 65%.
3. Laboratory tests with air pressure surcharge device are not suitable for liquefaction studies.
4. Possibility of liquefaction during an earthquake can be evaluated in a more rational manner from shake table tests.

REFERENCES

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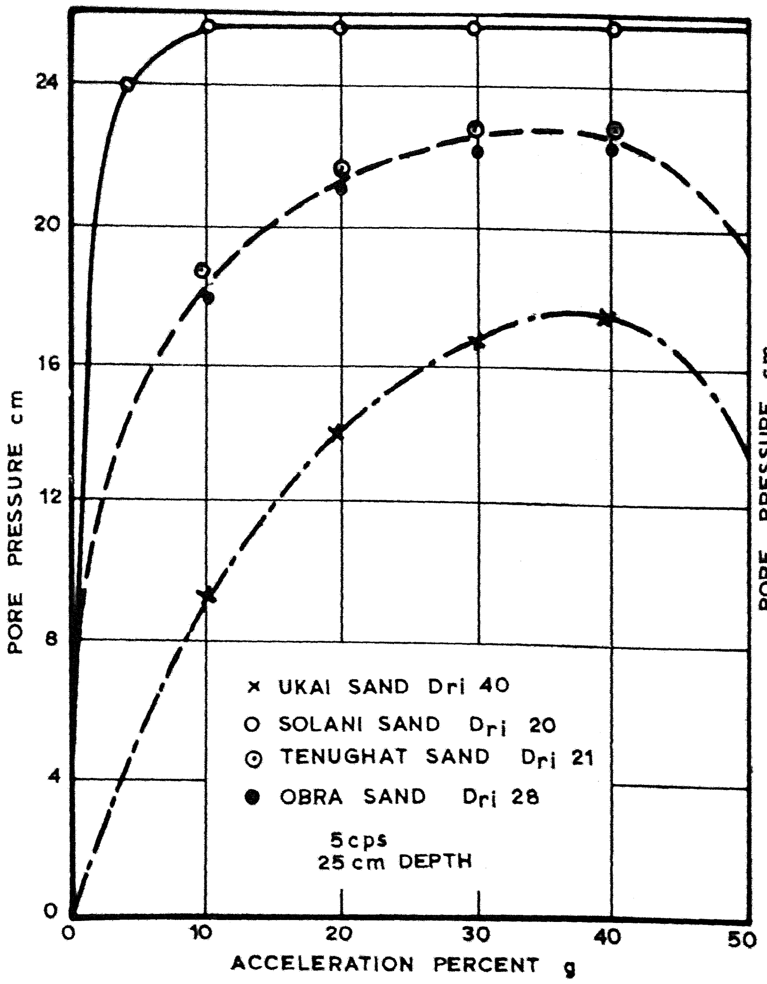

FIG. 1 _ PORE PRESSURE VS ACCELERATION

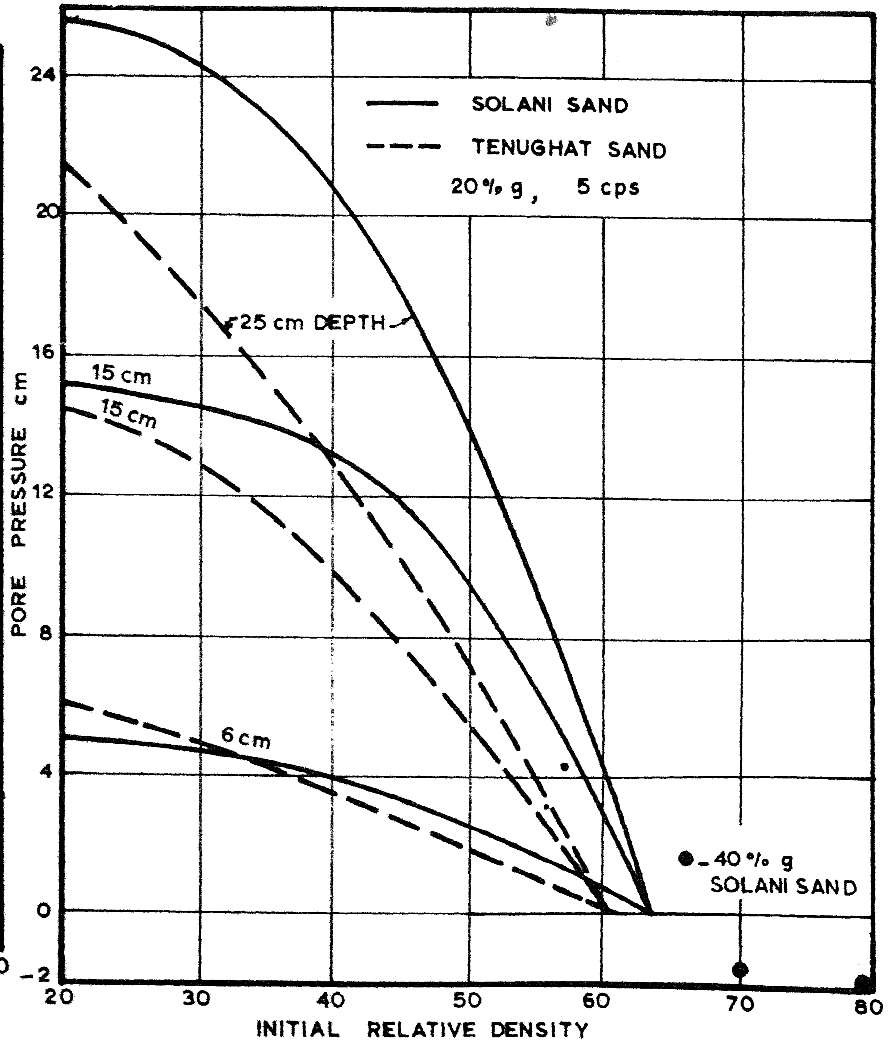

FIG. 2 _ PORE PRESSURE VS INITIAL RELATIVE DENSITY

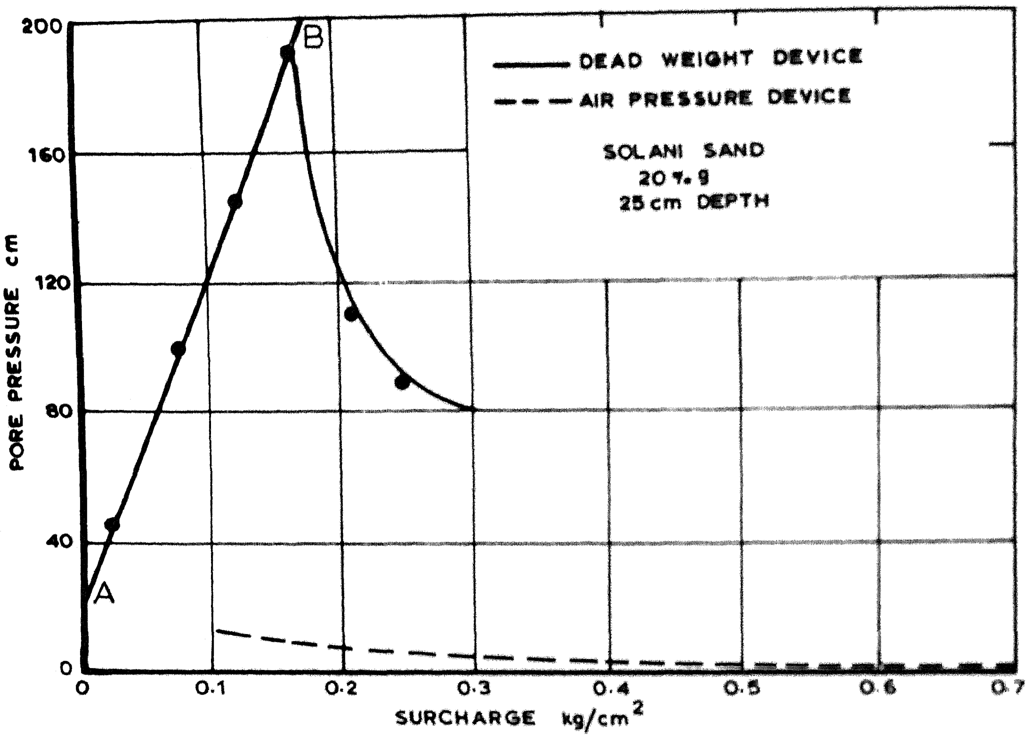

FIG. 3 _PORE PRESSURE VS SURCHARGE

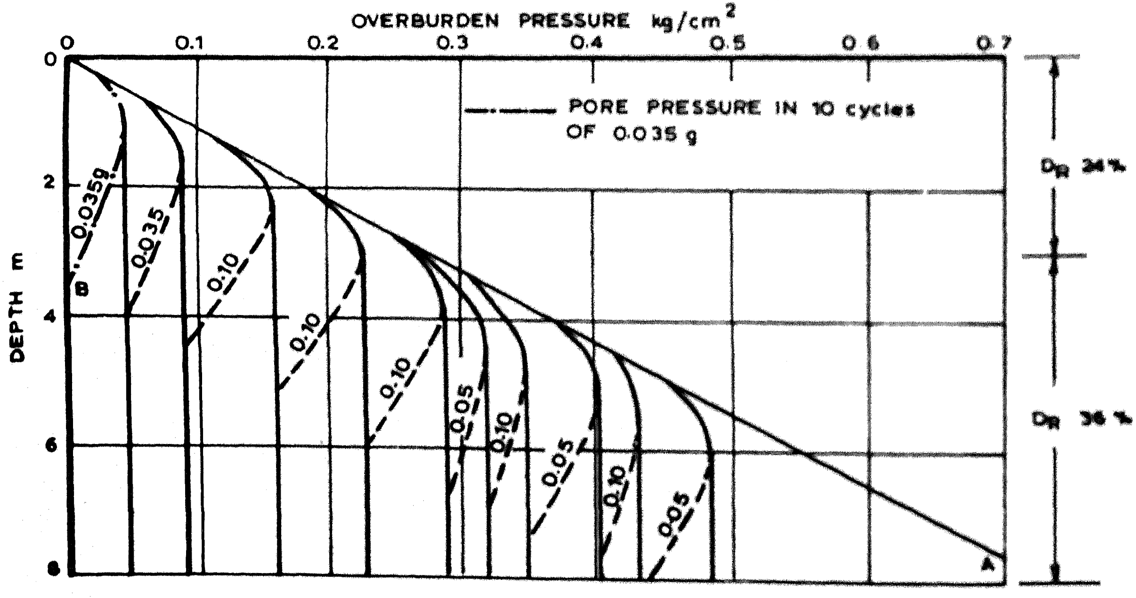

FIG. 4 _ DEPTH VS OVERBURDEN PRESSURE