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LIQUEFACTION AND SETTLEMENT CHARACTERISTICS OF UKAI DAM SAND

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INTRODUCTION

Ukai Dam Site is on Tapti River, Surat District, Gujarat. The proposed dam is to be about 81 m high earth dam in river portion. There remains a standing pool of water created by the back water of the existing Kakrapar pickup weir. Artificial sandy platform having a maximum depth of 6.7m, is constructed by depositing the sand under water. This forms a part of the foundations of the main dam. This is in loose state and site of this dam lies in seismically active region. A seismic coefficient ot 0 05 g has been adopted for the design of the dam and the site may experience peak ground shocks of about 0.3g. It was therefore necessary to assertain the suitability of the deposited foundation sand to withstand the anticipated ground shock without undergoing liquefaction.

If the saturated sands are subjected to dynamic forces, the pore pressure increases and the shear strength decreases. The dynamic strength of sand is given by the following expression :

$$S_{dyn} = (\sigma_1 - U_{dyn}) \tan \phi$$

where S_{dyn} = dynamic shear strength

σ_1 = initial effective stress

U_{dyn} = dynamic pore pressure increase.

If increase in pore pressure is such that it is equal to initial effective stress, the complete transfer of stress to pore water takes place and *complete liquefaction* occurs. When the transfer of stresses to pore water is smaller than the initial intergranular stresses, *partial liquefaction* occurs. As soon as liquefaction, partial or complete, occurs the process of consolidation starts followed by surface settlement.

To recognize the factors that govern the liquefaction of sand, the work done on the problem so far is examined critically. The theory of 'critical void ratio' was put forward by A. Casagrande and I.V. Yaropolsky in late thirties[1] i.e. if the void ratio of soil is above critical, the structure of sand becomes unstable. Later investigations showed however, that the critical void ratio is not a unique property of a particular soil. In dynamic cases, liquefaction occured at much lower void ratios than those at which the phenomenon occurred in static case.

There is a 'critical acceleration' beyond which the increase in pore pressure is high enough to decrease shear strength to the state of liquefaction[4]. The value of critical

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acceleration depends upon the initial density of sand. If the sand was subjected to shock loading, the whole stratum got liquefied at the same time while under steady state vibrations the process started from top and proceeded downwards[2]. It is believed that the effect of liquefaction on structures founded on soil which liquefy also depends on the duration for which the sand remains in liquefied state. This duration reduces with increase in grain size of the soil. Also with increasing surcharge, the chances of complete liquefaction are reduced.

From the tests carried on triaxial sample in the triaxial apparatus under pulsating stresses[3,8] it was concluded that the susceptibility of a sand to liquefaction is determined by complex relationship between void ratio, confining pressure, cyclic stress and number of stress applications. The higher the void ratio the more easily liquefaction occurs. The lower the confining pressure the more easily liquefaction develops The large the stress the smaller the number of cycles required to induce liquefaction. However it is reported that dense sands could also be liquefied in such a set up Similar qualitative conclusions have also been drawn by Peacock and Seed based on tests data obtained under simple shear cyclic loading conditions[5]. However, large difference was found in quantitative values in the two cases.

It was observed from the tests carried in tank mounted on steady state horizontal vibration table[6] that maximum pore pressure is observed only after certain number of revolutions are imparted to the deposit Both settlement and pore pressures are reduced considerably during vibration with increase in initial relative density and also with increase in confining pressure. Frequency of dynamic loading is also an important factor for liquefaction and settlement characteristics of sand.

In this paper problem of liquefaction of Ukai sand under dynamic loads has been discussed on the basis of tests performed on Ukai dam sand on a horizontal steady state vibration table.

SEISMICITY OF THE AREA

Satpura region is known to be a seismically active zone. The seismic coefficient of the design of the dam for the overall stability of the structure recommended is 0.05 g. Further the occurrence of the Koyna earthquake in December 1967 indicates possibility of increased activity in the region of this project. The peak horizontal acceleration of the ground during Koyna earthquake was 63% g in one direction and 49% g in the other. However it is felt that a maximum acceleration 30% g could be expreted at the Ukai Dam Site.

TEST SET-UP

Figure 1 shows the photograph of horizontal shaking table and surcharge device for the study of Ukai Sand. It consists of a tank 105 cm × 60 cm mounted on 4 wheels and it can be excited in horizontal motion with a suitable drive mechanism. The range of frequencies and amplitudes that can be attained are 0 to 20 cps and 0 to 10mm respectively. Figure 2 shows the surcharge device for applying the effective surcharge on the sample for drained conditions, both during surcharge application and during shaking. The surcharge is applied through a 1cm thick bottom plate having holes. On this plate an air tight air chamber having top plate 3/8" thick and bottom plate 1/8" thick is fitted through angle irons to provide a hollow space. The whole assembly is tied together by means of four bolts which passes freely into the top plate This arrangement enabales the device to get adjusted in the tank to make the bottom plate rest all the time on the soil deposit[7]. The frequency of vibration is measured by noting time for 500 revolutions with the help of a revolution counter and stop watch.

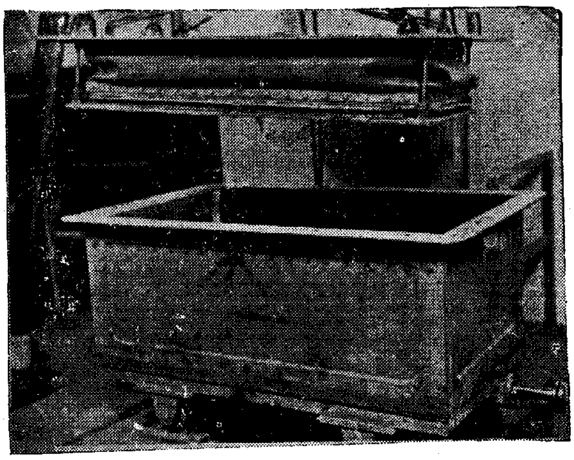

Figure 1. Shaking Table

1-Hollow space 2-Angle irons 3-Bottom plate with holes 4-Rubber chamber 5-Pressure gauge 6-To com pressure 7-Top plate to be bolted with tank·

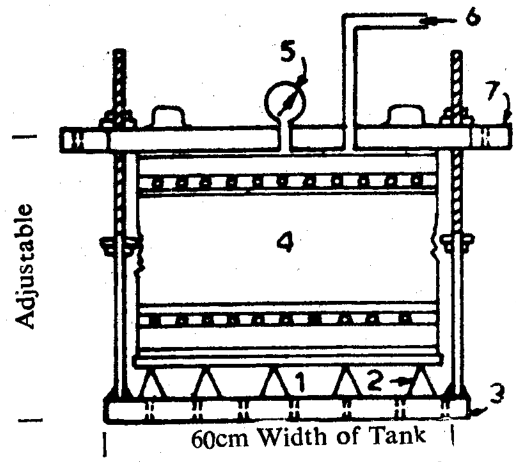

Figure 2. Surcharge Device

Iron pieces were placed on the top of the sand deposit. The depth by which these pieces would settle indicates whether the soil has completely liquefied in that portion.

PROPERTIES OF SAND USED

The grain size curve of the sand is shown in Fig. 3 other properties of this sand are as under :-

		Ukai sand	Tenughat sand
Specific gravity of grains	S_s	2.76	2.62
Uniformity coefficient	C_u	5.7	2.27
Maximum void ratio	e_{max}	0.57	0.79
Minimum void ratio	e_{min}	0.34	0.49
Effective grains size	D_{10}	0.42 mm	0.23 mm

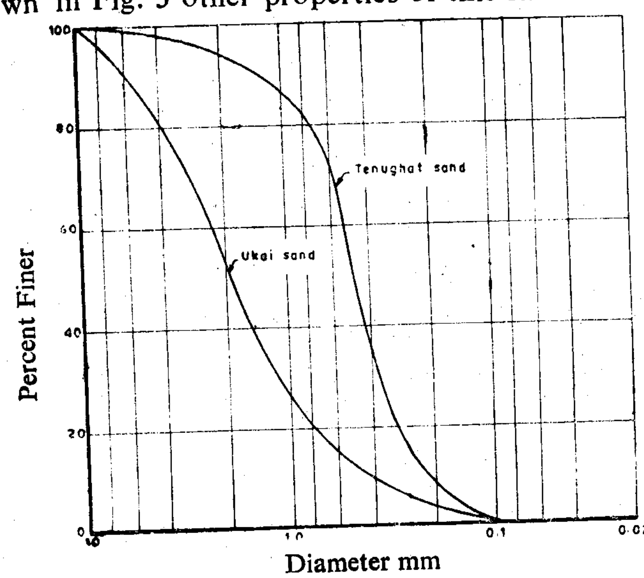

Figure 3. Grain Size Curve of Sand Tested

Data on Tenughat sand has been included for the sake of comparison.

TEST PROCEDURE AND TESTS PERFORMED

The tank mounted on the table was filled with a known quantity of water (140 kg). Dry sand (300 kg) was poured into the tank with the help of funnel and guide frame. The sand was poured from the same height in all the tests. The funnel was moved along the length of tank on the guide frame, thus depositing the sand in rows along the width of the tank. Overlying water was then removed by siphoning. The relative density thus attained was about 40%. The depth of deposit in all the tests was 25.5 cms.

Table 1 contains particulars of all the tests performed. Tests No. 1–5 were performed with no surcharge. The boundry conditions allowed full drainage of the sample during shaking. After the deposit was laid dawn in the tank, the table was set to desired amplitude and frequency and then it was vibrated for predetermined number of revolutions. After the table is stopped, the water squeezed out was weighed to compute the settlement and final relative density.

TABLE 1

Particulars of Tests Performed

Test	Amplitude mm	Frequency cps	Acceleration % g	Surcharge kg/cm²	Revolution
1	2	3	4	5	6
1	0.5	5	5	Nil	20, 50, 100 200
2	1.0	5	10	Nil	20, 50 100, 200
3	1.5	5	15	Nil	20, 50, 100, 200
4	2.0	5	20	Nil	12, 32, 50, 100, 200
5	5.0	5	50	Nil	20, 50, 100, 200
6	0 5	5	5	0.3	200
7	1.0	5	10	0.3	200
8	1.5	5	15	0 3	200
9	2.0	5	20	0 3	200
10	5.0	5	50	0 3	200
11	0.5	5	5	0.5	200
12	1.0	5	10	0.5	200
13	1.5	5	15	0 5	200
14	2.0	5	20	0 5	200
15	5.0	5	50	0,5	200

In tests 6–10 with initial effective surcharge of 0.3 kg./cm² the surcharge device was placed on the sample after it had been deposited in the tank and then bolted with tank. The air pressure was applied in the chamber. Holes in the lower plate allowed the water to drain out from the sample and it was collected in between the two plates. The table was set at desired amplitude and frequency and then it was vibrated for required number of revolutions. After the table was stopped, the surcharge device was removed and water squeezed out was weighed to compute the settlement and final relative density.

In Tests No. 11–15, the initial effective surcharge was 0.5 kg/cm².

TEST DATA AND INTERPRETATION

Figure 4 is a plot between percent settlement and number of cycles imparted to the deposit. From this figure it is observed that about 200 revolutions are required to complete all the settlement. The settlement is about 2% at anticipated ground acceleration of 5% g and is about 3 to 4% at 10% g. The data were reworked to obtain a plot of relative density Vs number of revolutions Figure 5. The relative density to which the sand with initial relative density of about 40% was compacted at 5% g. was 50 to 55%. These plots were reworked to obtain Figure 6 which is a plot of Initial Relative Density versus Percent Settlement The effect of initial relative density on settlement of deposit, is obvious from this figure. This figure suggests that if initial relative density of the sample were over 62 percent there is no likelihood of any settlement due to ground motion of 10 percent g. The corresponding value of initial relative density is about 52 ± % at 5% g. Also possible settlement reduces considerably with increase in initial relative density.

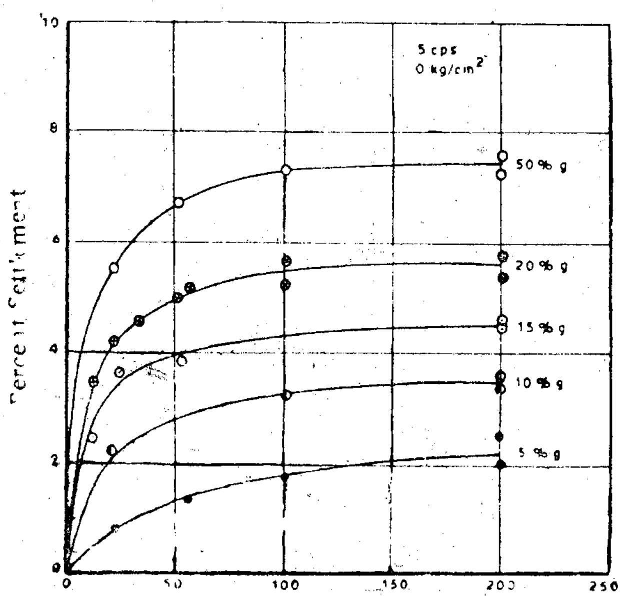

Figure 4. Percent Settlement VS Numbers of Cycles.

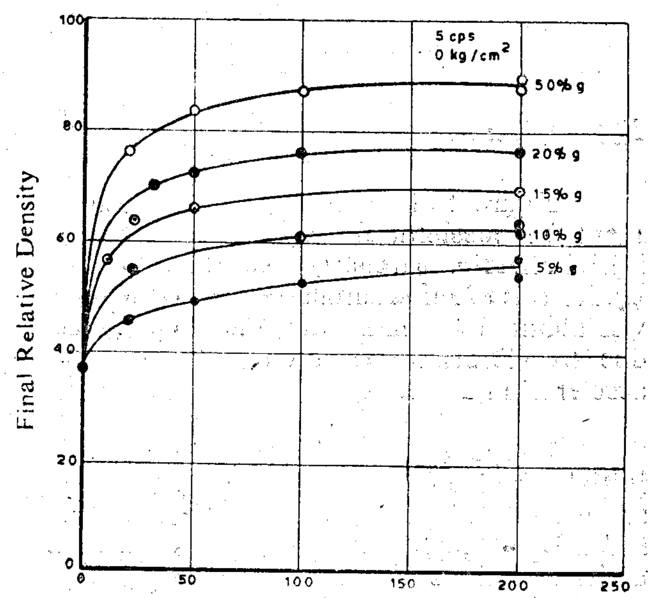

Figure 5. Final Relative Density VS Number of Revolutions

Figure 7 shows plot of acceleration Vs percent settlement for number of revolutions of 10, 20, 50, 100 and 200.

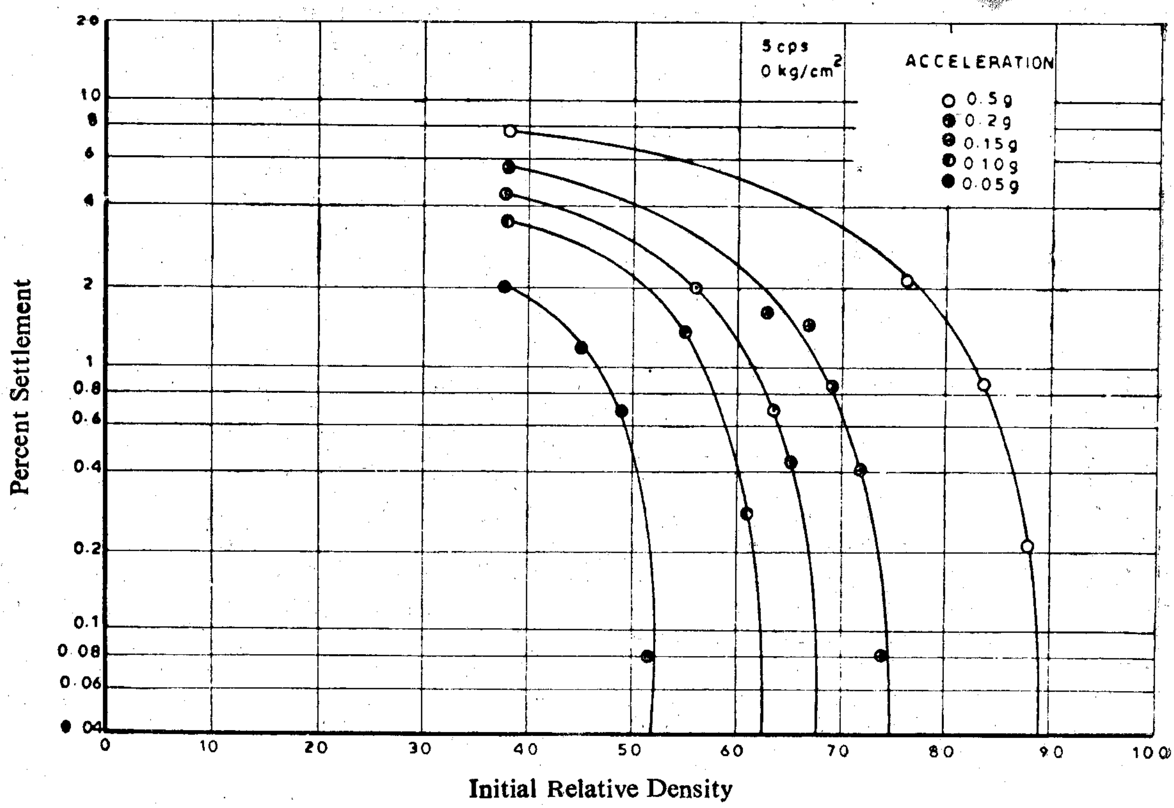

Figure 6. Percent Settlement VS Initial Relative Density.

Effect of Surcharge

Figure 8 is a plot of percent Settlement Vs acceleration for tests in which initial effective surcharge was 0.30 kg/cm². Under this effective surcharge, the settlement was about 0.4% and additional settlement due to vibrations was about 0 2% at 5% of acceleration due to gravity g.

Figure 9 is similar to Figure 8 for initial effective surcharge of 0.5 Kg/cm². The settlement under effective surcharge of 0.5 kg/cm² was 0.6% and additional settlement under vibrations was 0.05 ± % at 5% g. Figure 10, is a plot of Acceleration Vs percent settlement at different initial effective surcharges of 0 to 0.5 kg/cm². It will be noticed that with increase in initial effective surcharge from zero to 0.3 kg/cm² there is a considerable decrease in the settlement. With further increase in surcharge the settlement decreases at a decreasing rate.

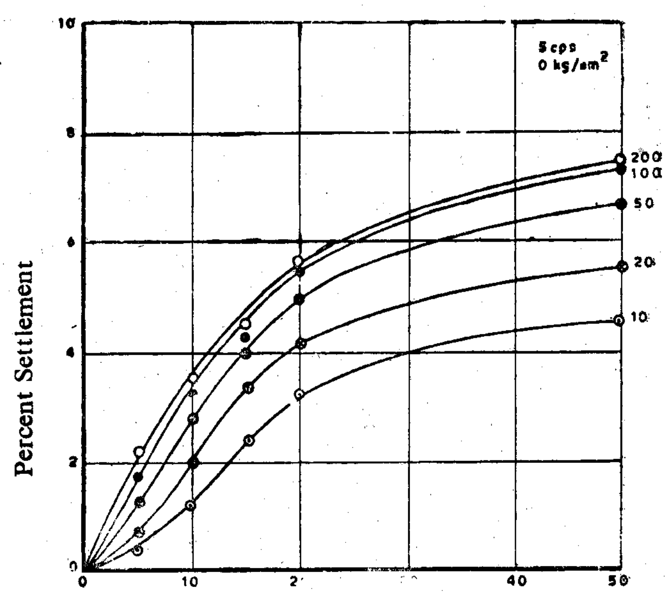

Figure 7. Percent Settlement VS Acceleration.

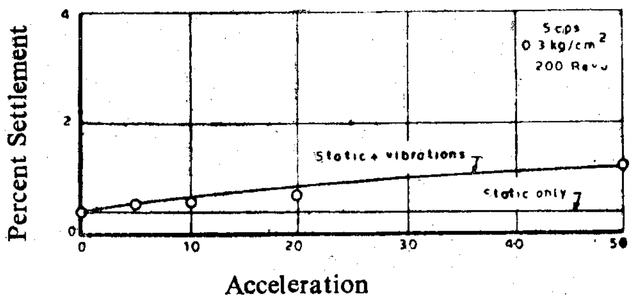

Figure 8. Percent Settlement VS Acceleration.

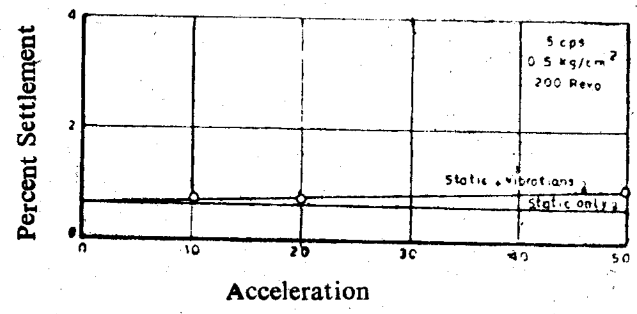

Figure 9. Percent Settlement VS Acceleration.

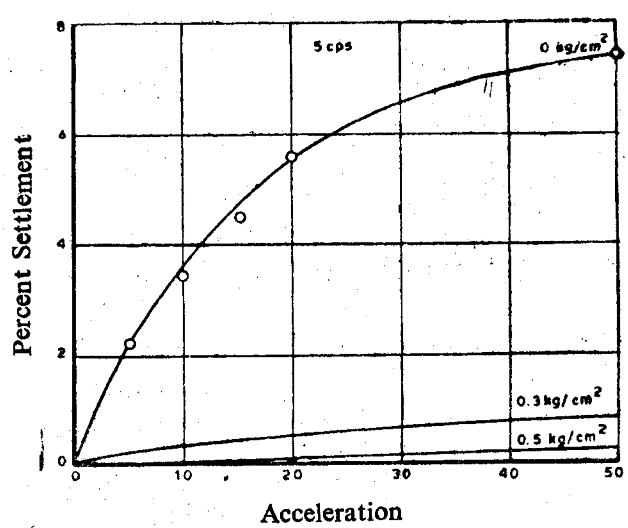

Figure 10. Percent Settlement VS Acceleration.

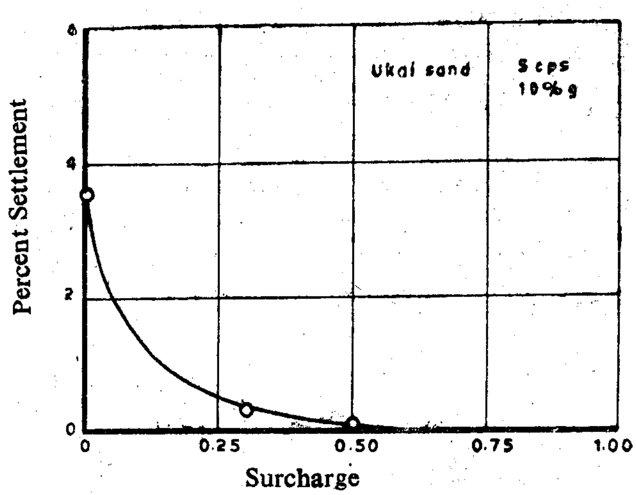

Figure 11. Percent Settlement VS Surcharge:

Figure 11 shows percent settlement Vs Initial Effective surcharge at 10% g. The effect of initial effective surcharge is quite evident from this figure under complete drained boundary conditions.

COMPARISON WITH TENUGHAT DAM SAND

Study of liquefaction of sands is not available on many sands. The effect of grain size on liquefaction and settlement characteristics of sands is being investigated for the first time at the School of Research and Training in Earthquake Engineering, Roorkee. Similar tests were done on Tenughat sand also[6]. A comparison of Ukai dam sand and Tenughat dam sand is done here.

The grain size curve for Tenughat Sand is shown in Fig 3. Figure 12 is a plot of Final Relative Density versus Acceleration with zero surcharge if the initial relative density were zero.

Figure 6 shows the effect of initial relative density on compaction of sand under zero surcharge. This figure suggests that same final relative density will be attained when vibrated at any particular acceleration whatever be the initial relative density of the deposit, provided that the initial relative density of the deposit is less than what can be attained under that particular acceleration as final relative density otherwise no change is expeted to occur. Thus if the initial relative density of the deposit were zero the final relative densities are taken from Figure 5 and plotted in Figure 12 against acceleration. The deposit with zero initial relative density will have zero final relative density under no vibrations. Similar data for Tenughat Sand[6] are also plotted in this figure.

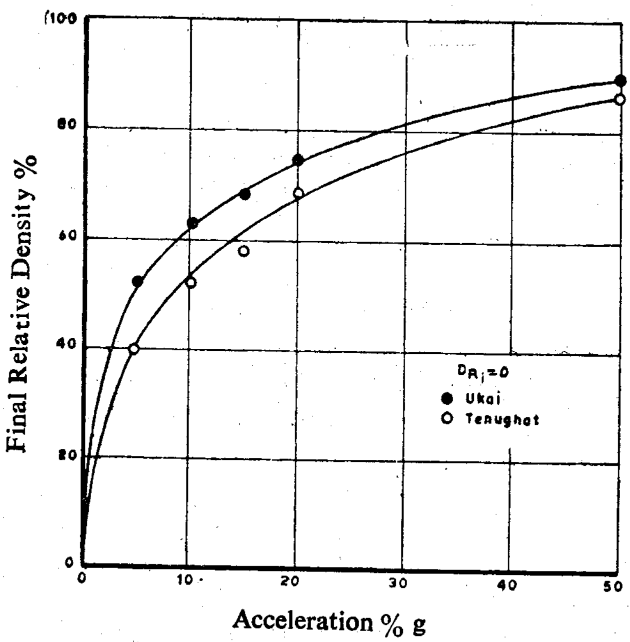

Figure 12. Final Relative Density VS Acceleration.

On comparing the two curves in this figure it is observed that Ukai Sand attains higher relative density as compared with Tenughat sand. under otherwise identical conditions. This can be explained due to the fact that Ukai Sand is much coarse and very well graded as compared to Tenughat sand.

CONCLUSIONS

On the basis of the laboratory study performed, the following conclusions may be drawn :

1. Ukai sand does not undergo complete liquefaction under anticipated ground motion.
2. The maximum settlement of the deposit is of the order of 2.5 percent at 10% g and at 30% g, the settlement is of the order of 7%.
3. The effective surcharge on the sample reduces the settlements in a characterstic manner and is important in determining the behaviour of sands under vibrations.
4. At initial relative density of the order of 45 percent and anticipated ground motion, no liquefaction or excessive settlements is expected which is the case at the site.

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REFERENCES

1. Dalmotov, B. I., "Seismic Effects and Stability of Saturated Sands" Lecture delivered at University of Roorkee, 1962. Unpublished.

2. Florin, V. A and Ivanov, P. L., "Liquefaction of Saturated Sandy Soils", Proc. 5th International Conference on Soil Mechanics and Foundation Engineering, 1961, Vol. I, pp 107–111.

3. Lee, K.L., and Seed, H B., "Cyclic Stress Conditions Causing Liquefaction of Sand", Jour. of the Soil Mechanics and Foundations Div. ASCE, Vol. 93, No. SMI, Proc. Paper 5058, Jan. 1967, pp. 47–70.

4. Maslov, N.N., "Question of Seismic Stability of Submerged Sandy Foundations and Structures", Proceedihgs, 4th International Conf. on Soil Mechanics and Foundation Engineering, London, 1957, Vol. I.

5. Peacock, W. H. and Seed H.B., "Sand Liquefaction Undei Cyclic Loading Simple Shear Conditions, Jour. of Soil Mechanics and Foundations Div., Proc, ASCE Vol. 94, No. SM 3, Proc Paper 5957, May 1968, pp. 689–708.

6. Prakash, S. and Gupta, M.K., "Liquefaction and Settlement Characteristics of Tenughat Sand", Proceedings, 38th Annual Research Session of Central Board of Irrigation and Power, Bangalore, July 1968

7. Prakash, S., Gupta M.K. and Chandrasekaran, V., "Investigation of Saturated Sand Masses for Earthquakes" Proceeding Symposium on Earth and Rockfill dams Talwara Nov. 1968. Vol. I, pp. 241–248.

8. Seed, H. B. and Lee, K L., "Liquefaction of Saturated Sands During Cyclic Loading", Journal of the Soil Mechanics and Foundations Div., ASCE, Vol. 92, No. SM 6, Proc. Paper 4972, Nov. 1966. pp. 105-134.