LIQUEFACTION CHARACTERISTICS OF SATURATED SAND-GRAVELS UNDER VIBRATION AND CYCLIC LOADING

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SUMMARY

This paper presents some experimental results of the liquefaction characteristics of three saturated sand-gravel samples taken from embankment dams and borrow pits in the earthquake region of China. The cross interrelationships among the liquefaction potential, volumetric compressibility, coefficient of permeability, relative density and grain size distribution of the sand-gravels are studied. The findings are interesting and have practical importance in the aseismatic design of embankment dams.

INTRODUCTION

Several upstream saturated sand-gravel slopes of embankment dams in China have shown flow slides at earthquakes in regions of moderate earthquake intensities as low as VI to VII degree according to the Modified Mercalli Scale. The liquefaction characteristics of three different types of saturated sand-gravel have been investigated. The experimental work has been performed both on a shaking table and in a medium sized cyclic triaxial testing mechine with drained and undrained conditions respectively. The cross interrelationships amo the grain size distribution, relative density, coefficient permeability, volumetric compressibility and liquefaction characteristics of those sand-gravels under vibration and cyclic loading with various intensities of dynamic actions have been studied.

DESCRIPTION OF TESTING SAMPLES

Three different type of sand-gravel samples have been used in testing. Their grain size distribution curves are shown in Fig. 1. Sample I is taken from an earth dam which is a region of prospective earthquake intensity of IX MM. Sample II is taken from the upstream slope of an earth dam where flow slide has occurred at an earthquake of intensity VI MM. Sample III is a proposed material for new embankment dam under planning in a region of prospective earthquake intensity of VIII. It can be noted from Fig. 1 that sample I and sample II are poorly graded and lack in intermediate sizes in

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regions of 0.25-2.00 mm and 1-5 mm respectively. Sample III is well graded. In cyclic triaxial tests, grains over 20 mm in size have been replaced by grains of sizes between 5 and 20 mm for samples II and III as also shown in Fig. 1.

TYPES OF TESTS

Two different kinds of apparatus have been used for two different types of tests.

Drained Vibration Tests

Drained vibration tests have been performed on a vertically shaking table. Saturated sand-gravel samples are put in transparent cylindrical containers of sizes 12 and 40 cm in diameters and 20 and 40 cm in heights respectively. The containers are fixed on the shaking table which may be operated with prescribed frequencies and amplitudes to produce sinusoidal motions with different amplitude of acceleration. Pore water pressure measurements device is attached to the bottom of the container. The ratio of maximum (peak) pore water pressure created during vibration to what should be created when full liquefaction commences is defined as "degree of liquefaction" and denoted by K_t. The height of sample in the container can be measured directly on a scale sticked on the transparent wall of the cylindrical container. The ratio of settlement of the sample after vibration to its original height gives the quantity of volumetric compressibility of the sample dur to vibration as M_v.

Consolidated Undrained Cyclic Triaxial Tests

A medium sized cyclic triaxial testing mechinc has been used. The size of testing specimens is 10 cm in diameter and 23 cm in height. All testing specimens were saturated and consolidated under static stresses (σ_1' , σ_3') before application of cyclic stress $\Delta\sigma_1$. The ratio of cyclic shear stress $\Delta\tau = \sigma_1/2$ to $\sigma_o' = (\sigma_1' + \sigma_3') / 2$ is called cyclic shear stres ratio $R_c = \Delta\tau/\sigma_o'$. Measurements were made for pore water pressure changes and axial strain of the specimens by appropriate transdusers. When the increase in pore water pressure reached σ_3' , the specimen was considered to be in liquefaction state. The corresponding number of cycles is denoted by N.

COMMENTS ON RELATIVE DENSITY TESTS

The maximum and minimum void ratios of samples II and III were determined by stantard testing procedures (Ref. 1) with air dried samples in a container of 279,4 mm inner diameter and 230.1 mm height, which gives a volume of testing specimen to be 14156 cm^3.

The maximum void ratio of sample I was determined by pouring dry particles into water in a cylindrical container of 120 mm inner diameter and 240 mm height. The minimum void ratio of sample I was also determined on a shaking table in the same water container.

TEST RESULTS

Results of Drained Vibration Tests

Drained vibration tests have been performed on samples I and III. Test results for sample I are given in Figs. 2, 3 and 4. The interrelationships among peak K_t, Dr. maximum M_v and percentcge of coarse grained portion (P_2 for d>2 mm or P_5 for d>5 mm) are obvious as shown in the Figs. 2 and 3. For Dr>80% and P_2>60%, peak K_t and maximum Mv approach zero in Fig. 2 and become less than 10% and 0.5% respectively in Fig. 3. Examples of change of K_t with N are shown in Fig. 4. They are also effected by Dr and P_2. These results clearly tells that, the increase of coarse grained portion in the sand-gravel will reduce the volumetrical compressibility of the material so to reduce the degree of liquefaction.

Test results of sample III with vertical acceleration amplitude of 1960 mm/sec^2 are given in Fig. 5. Besides peak K_t and maximum Mv, coefficients of permeabilty of the testing specimens are also plotted with Dr and P_5 (and P_2). The interrelationships among peak K_t, Dr. maximum Mv and P_5(or P_2) are similar to Figs. 2 and 3. An additional influential factor k, coefficient of permeability has been found to be important in drained cases. It can be seen clearly from the Fig. 5 that, as P_5 becomes greater than 60%, k increases rapidly and peak K_t diminishes.

Another fact may be noticed is that the values of peak K_t shown in Figs. 2 and 3 are much igher than those given in Fig. 5. It is felt that the poor gradation of the sample I might play some role in worsening the stability condition of the soil skeleton against vibration and consequently leading to liquefaction.

A similar result of drained vibration tests on sample II with vertical acceleration amplitude of 1980 mm/sec^2 reported by Liu, Li and Bing is given in Fig. 6 (Ref. 2). Sample II also has poor gradation and higher peak K_t as sample I. But the data given in Fig. 6 are not based on a definite relative density but rarious between 20 to 60%.

Consolidated Undrained Cyclic Triaxial Tests

Consolidated undrained cyclic triaxial tests have been performed for saturated samples II and III. The results are given in Figs. 7 and 8 respectively by plots of stress ratios causing initial liquefaction versus numbers of cycles. It can be seen that the two smaples show almost same liquefaction characteristics regardless of the difference between their gradations. The coarse grained portion (d>5 mm) has some effect on Rc, but, even with high percentage of coarse grain content, the saturated sand-gravel still can liquefy under cyclic loading in undrained condition.

CONCLUSIONS

1. Coarse grained portion (d>2 mm or d>5 mm) has noticeable effect on the liquefaction characteristics of the saturated sand-gravel. This can be attributed to the reduction of volumetric compressibility and increase of coefficient of permeability of the sand-gravel mass with increase of porcentage of coarse grained portion.

2. The gradation of sand-gravel has less effect on liquefaction characteristics in undrained condition, but it shows significant effect in drained condition. Sand-gravels of poor gradation shows to be more venerable to liquefaction than the well gradated ones in drained condition.
3. The relative density still plays the important pole in the liquefaction characteristics of sand-gravels. It is felt that any sand-gravel fill in the saturated zone of embankment dams should be compacted by vibratory roller to a relative density of 80% and over.

REFERENCES

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2. Liu, L., Li, K. and Bing, D. (1979), "Earthquake Damage of Baihe Earth Dam and Liquefaction Characteristics of Sand and Gravel Materials", Research Institute of Water Conservancy and Hydroelectric Power, Beijing, P.R.China.

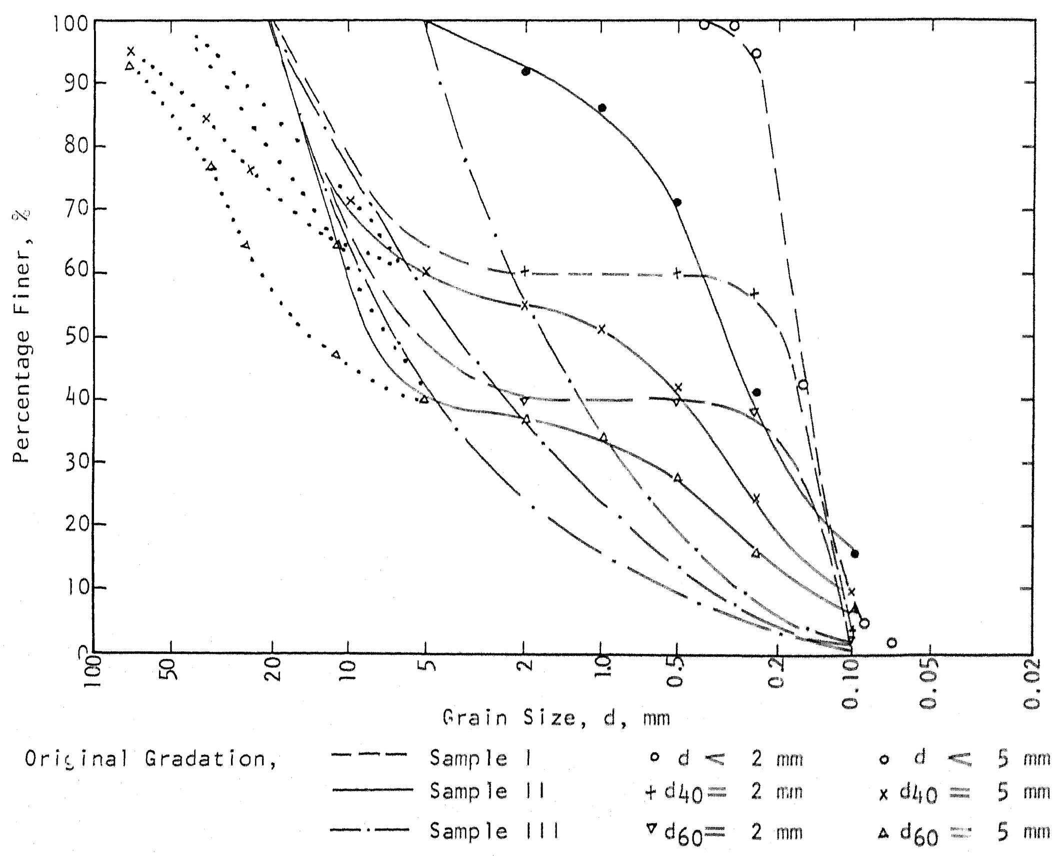

Fig. 1. Grain Size Distribution Curves of Testing Samples.

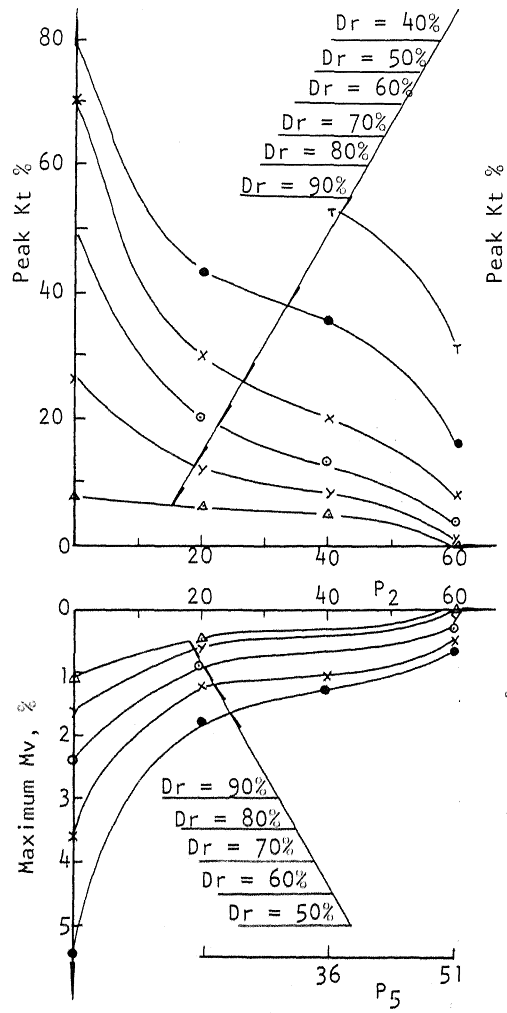

Fig. 2 Results of Drained Vibration Tests on Sample I with Vertical Acceleration Amplitude of 734 mm/sec^2

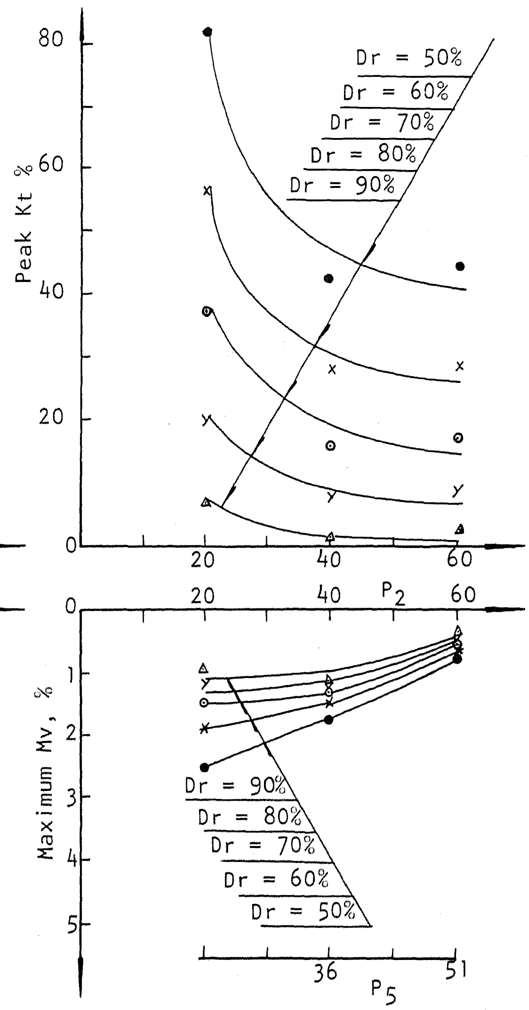

Fig. 3 Results of Drained Vibration Tests on Sample I with Vertical Acceleration Amplitude of 2100 mm/sec^2

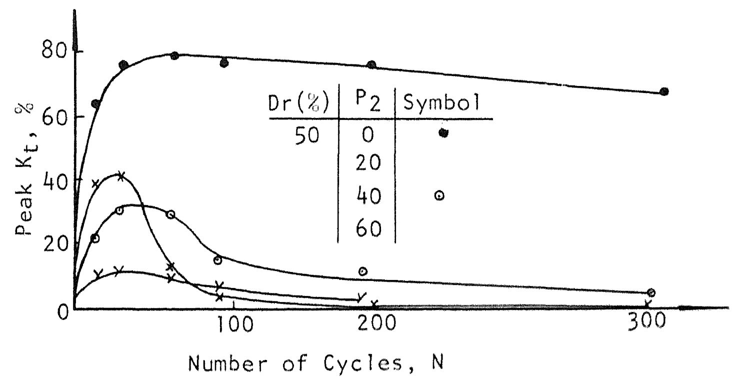

Fig. 4 Examples of K_t - N Curves of Sample I for Dr = 50% With Vertical Acceleration Amplitude of 734 mm/sec^2.

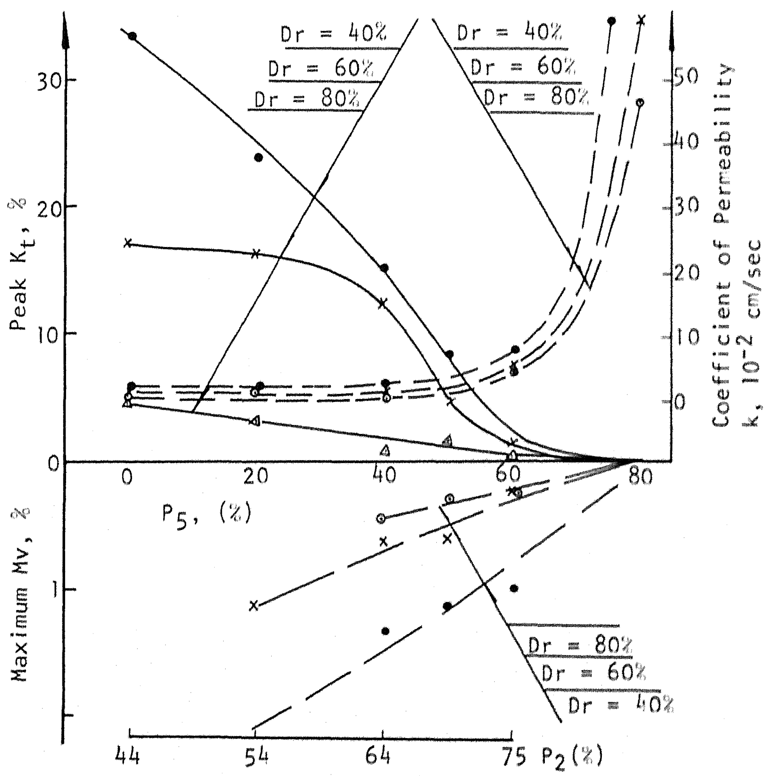

Fig. 5 Results of Drained Vibration Tests on Sample III.

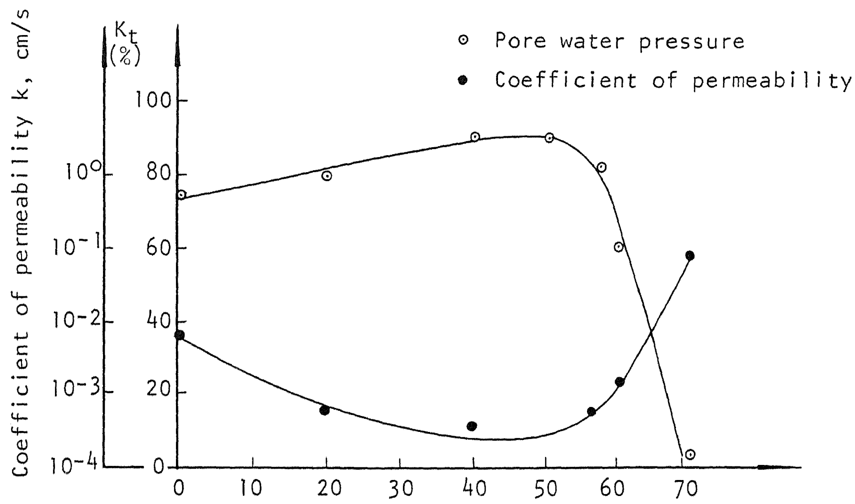

Fig.6 Results of Drained Vibration Test on Sample II (after Liu, Li and Bing)

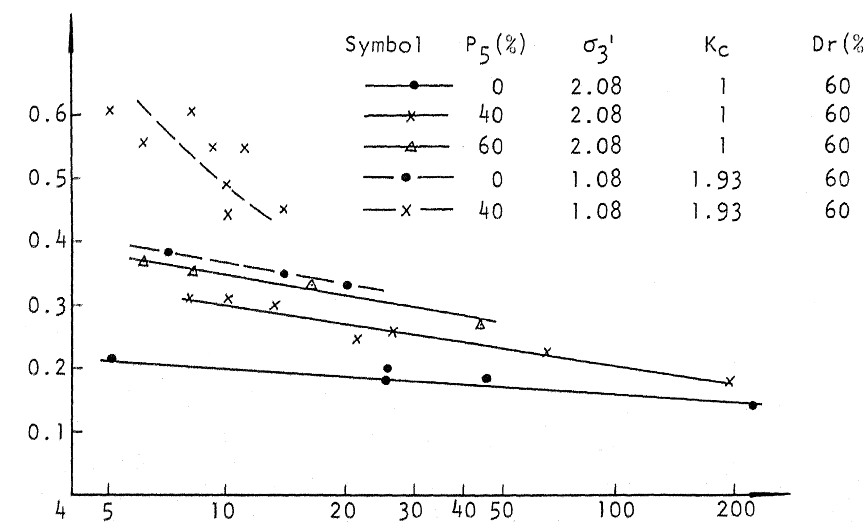

Fig. 7 Results of Cyclic Triaxial Tests of Sample II of Replaced Gradation

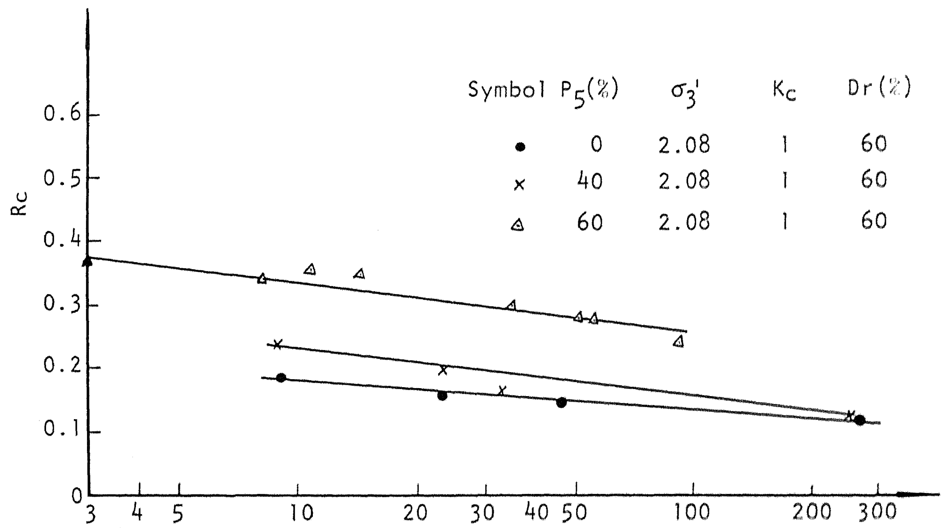

Fig. 8 Results of Cyclic Triaxial Tests of Sample III of Replaced Gradation