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THE LIQUEFACTION POTENTIAL OF LARGE SCALE SAND SAMPLES SUBJECTED TO IRREGULAR LOADING

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SUMMARY

The results of shaking table tests conducted on saturated sand samples are presented. The samples were constructed in a chamber surrounded by a rubber membrane to which was applied the confining pressure. The build-up of porewater pressures was monitored using transducers placed at different locations within the sample. The results obtained are compared with test data reported by other investigators. General agreement on the shape of the curves depicting the cyclic stress level versus cycles to liquefaction was found, however, the actual number of stress cycles required to reach liquefaction is markedly different. Possible explanations for these differences are given.

INTRODUCTION

Historically, laboratory studies into the behavior of saturated sands under cyclic stress conditions have played an important role in the determination of liquefaction potential. Various test devices (e.g. the cyclic triaxial, cyclic simple shear, torsional shear, shaking table and centrifuge) have been designed or modified in an attempt to provide an accurate representation of the stress state generated in-situ by ground motion. Detailed reviews of these experimental programs and design methods based upon results obtained from them, can be found in several state-of-the-art reports. In particular, those reviews by Seed (Refs. 1,2), Casagrande (Ref. 3), Finn (Ref. 4), and the U.S. National Research Council (Ref. 5) should be noted.

It has been well documented (Refs. 3,6,7,8) that the small scale devices currently in use in the laboratory introduce non-uniform stress and strain fields in the sample being tested. Since the onset of liquefaction is strongly dependent on local conditions, the determination of liquefaction resistance of a saturated sand would obviously be affected by the resulting stress and strain concentrations. The result of such irregularities should be an under-prediction of the actual liquefaction resistance.

The shaking table offers several advantages over cyclic triaxial and simple shear devices. Chief among these advantages are: (1) a comparatively large sample size; (2) embedded instrumentation can be used, which due to size of the sample, has only a negligible effect on sample response; (3) because the instrumentation can be embedded, the spatial distribution of the measured quantity over time can be monitored; (4) the uniform accelerations developed in the plane strain specimens more closely correspond to actual field conditions.

Although the shaking table is not as widely used as the other laboratory devices, since it does more closely simulate field conditions, several investigators have made it the basis of their experimental liquefaction studies (Refs. 9,10,11,12). Sasaki and Taniguchi (Ref. 11) conducted a series of shaking table tests in which measurements of cyclically induced increases in pore pressure were made at a total of 35 locations within the sample both in the free field and in the vicinity of an embedded concrete box. The increases in pore pressure that they measured immediately beneath the box were an order of magnitude greater than those measured in the free field. Clearly the rate of pore pressure increase during shaking is very sensitive to the presence of local irregularities, in this case a rigid inclusion. O-Hara (Ref. 10) conducted shaking table tests on two different uniform sands. He also performed cyclic triaxial and cyclic simple shear tests on the same sands, and observed that the samples tested on the shaking table typically showed an increased resistance to initial liquefaction compared with the behavior of the same materials tested in either of the two small scale devices. Seed, Mori and Chan (Ref. 12) observed a dramatic increase in the number of cycles required to induce liquefaction in samples which had previously been subjected to cyclic motions large enough to raise pore pressures but not large enough to cause liquefaction. They attributed the observed increase in cyclic strength to grain rearrangement. They pointed out that there is substantial evidence that these higher values of liquefaction resistance are more representative of the actual performance of natural sand deposits which have been subjected to past cyclic motions.

EXPERIMENTAL PROGRAM

Laboratory facilities The shaking table and test chamber used to load the sand samples in the study described herein are shown in Photo 1. The chamber was designed to provide reproducible results in which the stresses and strains at the sample boundaries were well understood and could be modelled accurately in a numerical code. It consisted of a box with moveable inner walls which provided the required lateral support to the sample during construction, and could then be withdrawn prior to shaking so that the Ottawa sand samples could deform under plane strain conditions. The sample was confined within a molded rubber membrane, allowing the top, front and back boundaries of the specimen to be subjected to constant confining pressures while the bottom and sides could be made constant (zero) displacement boundaries. A diagram of the test chamber is shown in Fig. 1. The instrumentation to monitor sample behavior consisted of embedded pressure transducers and accelerometers.

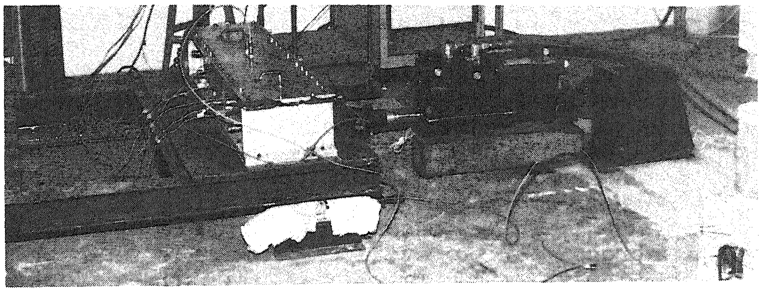


Photo 1 Shaking Table and Test Chamber

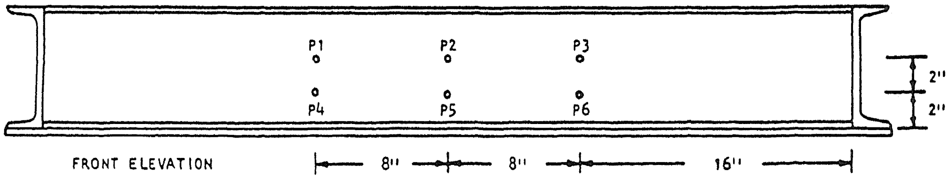


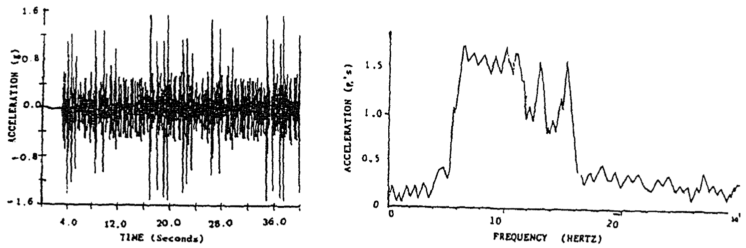
Fig. 1 Sample Test Chamber

Input motion Earthquake excitations do not repeat themselves although they are oftentimes similar in frequency content. To investigate the effects of similar but not identical ground motions on liquefaction potential, three artificial earthquakes were generated. These "earthquakes" resulted from the passing of three randomly generated acceleration time histories through a 6 to 15 Hz. band pass filter. The filter frequencies were chosen to allow the application of large accelerations (± 2g's) while keeping the displacements well within table limits. This procedure resulted in three different base motions each with essentially the same spectral content. A typical time and frequency record of table excitation is given in Fig. 2.

RESULTS

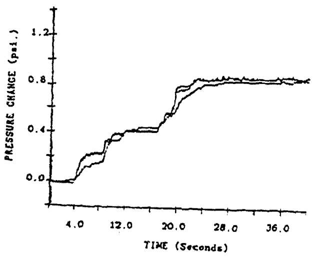
Also shown in Fig. 2, is the pore pressure build-up measured at three locations in the sample subjected to the depicted acceleration time history. It can be seen that the increased pore pressure reached the initial confining pressure at approximately the same time at all three locations. Also, it is apparent that the jumps in measured pore pressure correspond to the peaks in the table motion. Further it should be observed that although the three pressure time histories are similar in shape, they are not identical, clearly demonstrating that increases in pore pressure do not take place uniformly throughout a sample. In Fig. 3, a plot of the ratio of peak shear stress to normal stress versus the time to the onset of liquefaction is given for the random motion tests as well as for a series of harmonic tests performed at the same facility (Ref. 13) and for the test results obtained by DeAlba et. al. (Ref. 14). Two observations can readily be made. First, although the overall shapes of the curves are similar, the samples tested in the facility described in this paper exhibit a significantly larger resistance to liquefaction than do the samples tested by DeAlba. Second, within the test data obtained during this test program, there is some effect on the measured liquefaction potential of the particular random motion used. These results indicate that the use of the maximum shear stress during cyclic loading is not by itself an appropriate method with which to characterize the effects of ground shaking on liquefaction potential.

Several potential causes of the differences between the results obtained in this study and the data reported by DeAlba can be identified. An experimental program conducted by Mulilis et. al. (Ref. 15) showed the importance of the method of sample formation on the liquefaction resistance of the resulting specimen. The samples prepared by DeAlba were made by pluviation through air and subsequent saturation whereas, all the specimens prepared in the present study were saturated by boiling under a vacuum then deposited entirely under water at a constant drop height. In order to induce shear stresses sufficient to induce liquefaction, DeAlba placed a reaction mass on the top of each test specimen. Inclusion of a foreign material into the sample geometry possibly affected the liquefaction potential in much the same way Sasaki and Taniguchi's (Ref. 11) concrete box affected the rate of pore pressure build-up in their tests.



(a). Acceleration Time History

(b). Frequency Spectra of Excitation



(c). Pore Pressure Histories

Fig. 2 Sample Excitation and Pore Pressure Histories

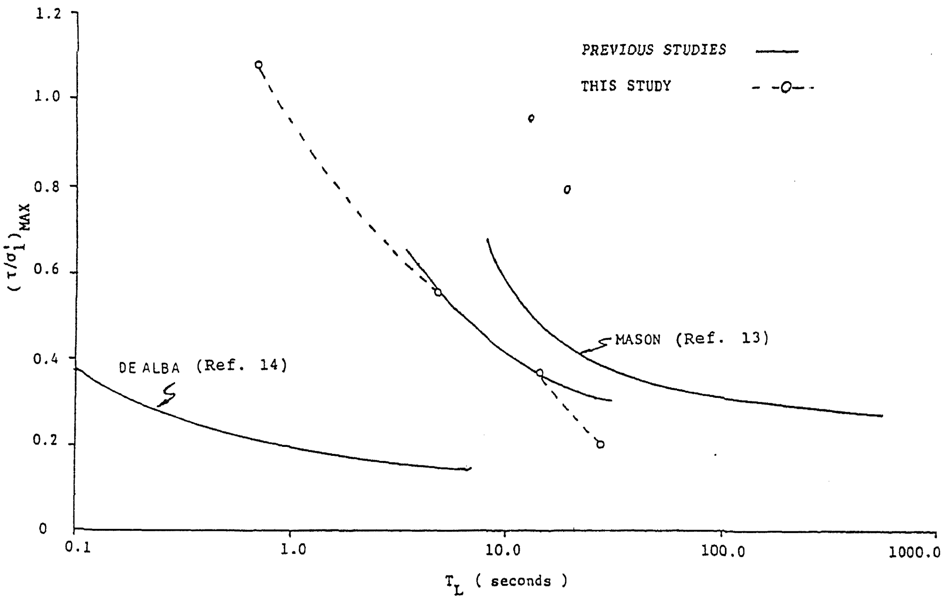


Fig. 3 Comparison of Test Results

CONCLUSIONS

The results of a test program in which saturated sand specimens were subjected to random time histories of base accelerations have been presented. The data show that loose sands can be liquefied using a laboratory shaking table and that the resistance to liquefaction is dependent upon the specific input motion and sample boundary conditions. The test apparatus employed in the program described herein minimized stress irregularities at sample boundaries and should therefore be seen to be an improvement over other laboratory methods for determining liquefaction potential.

ACKNOWLEDGEMENTS

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