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Liquefaction Characteristics of Undisturbed Soils

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SYNOPSIS Undrained cyclic triaxial tests were performed on undisturbed samples of natural soil deposits in order to investigate some of the factors affecting its liquefaction characteristics. It was shown that when the cyclic deviator stress is normalized with respect to major principal effective stress the number of cycles to liquefaction is not affected by sample size, consolidation stress, anisotropic consolidation, and grain size and density variations. However, liquefaction resistance was markedly increased by increasing over-consolidation ratio and aging. Also, sample disturbance of loose soils results in an increase, or unconservative measurement, of liquefaction resistance.

INTRODUCTION

In recent years, considerable advances have been made in the understanding of the phenomenon of soil liquefaction. The mechanism of liquefaction has been described to some extent by Martin,Finn and Seed (1975), and Seed (1979). It is now recognized that some of the most significant factors affecting the liquefaction and cyclic mobility characteristics of any given soil are (1) the density or relative density; (2) the grain structure or fabric; (3) the length of time the soil is subjected to the consolidation pressure; (4) the value of the lateral earth pressure coefficient which is governed by the state of overconsolidation of the soil; and (5) prior seismic or other shear strain to which the soil may have been subjected.

It is also observed in the experimental work on reconstituted soil samples that the liquefaction characteristics of these samples are affected by the methods of sample preparation (Mulilis,Seed, Chan,Mitchell,Arulanadan, 1977) sample size (Murphy, Koutsoftas, Covey, Fischer, 1978) and to a lesser extent by the grain size and gradation.

In order to assess how these factors might affect the liquefaction characteristics of natural soil deposits, two series of cyclic triaxial tests were carried out on undisturbed soil samples at the University of British Columbia. All undisturbed soil samples were obtained by shelby tube sampling methods. The results of the experimental program are briefly described in this paper. For a more detailed description, the readers are referred to the thesis presented by B.S. Lim (1981).

TEST APPARATUS

The test apparatus used in this experimental program is essentially similar to those used in conventional static triaxial shear testing. The confining pressure and back pressure are supplied by means of precision air pressure regulators. The cyclic axial loads are controlled by a pneumatic system which is actuated by a pulse generator. Because of the limitation of the system, the loading waveform is essentially a degraded square wave. The cyclic axial load is monitored by a load cell; axial deformation by a displacement transducer (DCDT); and the pore pressure by a pressure transducer. These measurements are in turn recorded on a light beam oscillograph recorder as a function of time.

TEST PROCEDURE

The soils were tested as both a full-size shelby tube sample (85.7 mm dia. and 73.0 mm dia.) and trimmed cylindrical samples (35.6 mm dia.) from shelby tube samples. In order to minimize sample disturbance during sample preparation, full size shelby tube samples were prepared by either of the two following methods:

1) The tube was first cut with a band saw to the desired test length and then clamped at the ends, sawn longitudinally, relaxed and extruded by hand pressure.
2) The sample tube was cut with a rotating tube cutter to the desired test length, the folded-in edges were peeled back and the sample extracted by hand pressure.

For the samples trimmed from shelby tube samples the soil samples were first extracted from the tube and then trimmed with a wire saw to the desired test size.

After extrusion or trimming, the test sample was placed in the test chamber and surrounded with a single 0.3 mm thick rubber membrane with O-ring seals. A slight vacuum of about 10 kPa was then applied to the test sample in order to provide some support. The test sample was then measured and the test chamber assembled and filled with water. The whole assemblage was then connected to the back pressure system. To ensure a quick and full saturation of the test sample, a vacuum of about 85 kPa was first applied to both ends of the test sample until pore air expulsion was completed (about ½ to 1 hour). This was followed by the application of a relatively high back pressure of 295 kPa. Normally, the sample was allowed to stabilize at an effective stress of about 50 kPa for 24 hours. The degree of saturation was checked by means of Skempton's pore pressure parameter "B" when the cell pressure was brought in stages to the desired level prior to consolidation. In most cases, a "B" value of 0.98 or greater was obtained after 24 hours. The drainage valves were then opened to initiate consolidation. The sample was cyclically loaded at a frequency of 1 Hz. after consolidation was completed.

The failure criteria used in the experimental program was defined as the state when the excess pore pressure generated during the cyclic loading phase becomes equal to the effective confining pressure; or when the double amplitude cyclic strain exceeds 5%. In most cases, the two criteria gave a failure state within one cycle of each other.

TABLE I

Summary of Physical Properties

Series	I	II
Sample dia (mm)	35.6 & 85.7	73.0
No. of tests	13 & 21	30
Soil Type	Sandy Silt	Clayey Silt
% Sand, 4.7-.07 mm		
mean	29	7
range	7-96	0-48
% Silt, .07-.002 mm		
mean	65	60
range	2-86	10-90
% Clay, <.002 mm		
mean	6	33
range	0-18	6-90
Dry Density, kg/m^3		
mean	1597	1543
range	1454-1784	1459-1715
Moisture Content		
mean	27.4	28.2
range	17.9-37.9	21.5-35.2

TEST PROGRAM

Two series of tests were conducted in order to investigate the effects of various factors on the liquefaction characteristics of natural soil deposits. The physical properties of the two soils tested are summarized in Table I . The two series of tests and their objectives are briefly described as follows:

Series I - The soils tested in this series were predominantly fine sandy silt with a trace of clay. Samples of 35.6 mm (trimmed) and 85.7 mm (full size shelby tube) diameter were tested at consolidation pressures of 980, 1470, 1960 kPa in order to evaluate the effects of sample size and consolidation pressures on the liquefaction characteristics of the soil.

Series II - The soils tested in this series were either clayey silt or silty clay of medium to high plasticity. Full size shelby samples of 73.0 mm diameter were tested in both isotropic and anisotropic consolidation modes, different overconsolidation ratios, and at different ages in order to assess these effects on the liquefaction characteristics of the soil.

DISCUSSIONS OF TEST RESULTS

Factors Affecting Liquefaction Characteristics

Effect of sample size: Wong, Seed and Chan (1975), in their research on the liquefaction resistance of gravelly soils, have reported that 304.8 mm (12 inch) diameter samples are about 10% weaker than 71.1 mm (2.8 inch) diameter samples. Similar observations were also reported by Murphy et. al. (1978) on their work on hard glacial till. The former group of researchers attributed the difference to the effect of membrane penetration which can be quite significant in coarse grained soils. The last group of researchers concluded that the difference was due to the different degree of sample disturbance in the two sizes of samples.

Fig. 1 shows the comparison of the liquefaction resistance of 35.6 mm and 85.7 mm diameter samples of fine sandy silt normally consolidated to pressures of 980, 1470 and 1960 kPa, respectively. As can be seen, for all practical purposes there is no difference of liquefaction resistance between the two sizes signified by the open symbols as opposed to solid symbols.

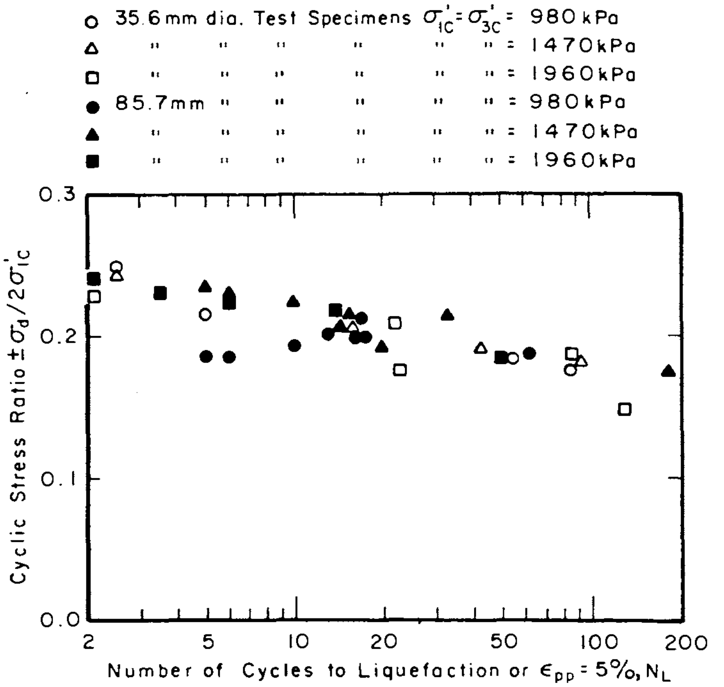

FIG. 1 COMPARISON OF LIQUEFACTION RESISTANCE OF 35.6 mm AND 85.7 mm DIAMETER TEST SPECIMENS AT $\sigma'_{1c}=\sigma'_{3c}=$ 980, 1470 AND 1960 kPa.

These results agree with other researchers which tend to indicate that the liquefaction resistance of a soil is not influenced by the sample size, and that any difference is most probably due to factors such as membrane penetration or different degrees of sample disturbance.

Effect of Different Normal Consolidation Pressures: Fig. 1 also shows the liquefaction resistance of samples that were normally consolidated to pressures of 980, 1470, and 1960 kPa. As can be seen, there is no trend indicated for the different consolidation pressures at least for the range of pressures from 980 to 1960 kPa. Similar observations were also reported by Castro and Poulos (1977), and Vaid and Finn (1979). Thus, it is concluded that the normalized liquefaction resistance of a soil is not influenced by the consolidation pressure.

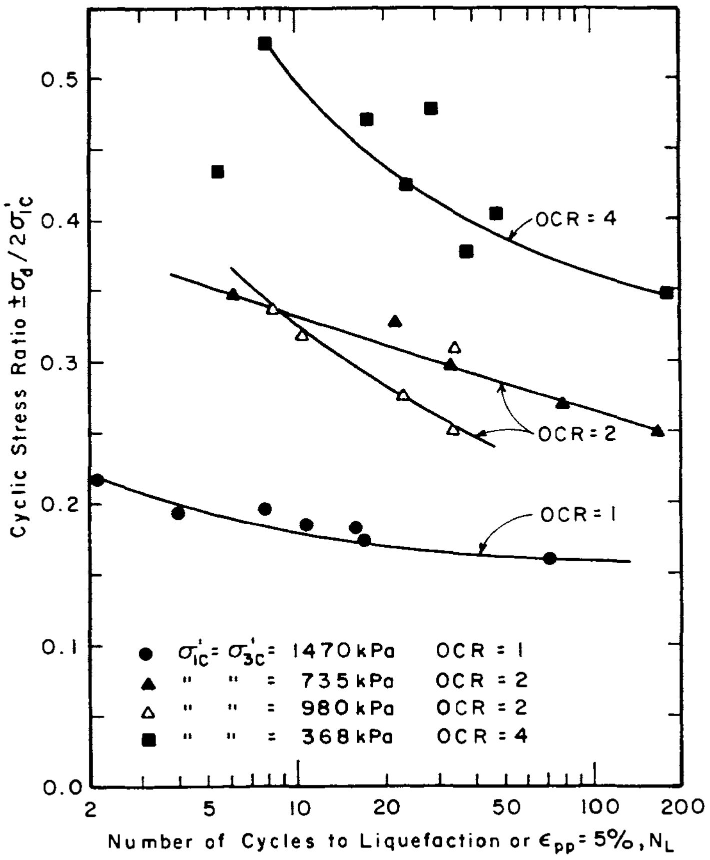

FIG. 2 COMPARISON OF LIQUEFACTION RESISTANCE OF NORMALLY AND OVER-CONSOLIDATED TEST SPECIMENS.

Effect of Overconsolidation: Fig. 2 shows the comparison of liquefaction resistance of normally and over-consolidated clayey silt and silty clay. As shown in Fig. 2, the liquefaction resistance increases by about 75% for an over-consolidation ratio or OCR of 2 and about 150% for an OCR of 4. Similar observations have also been reported by Seed (1979). Of greater interest here is the similar liquefaction resistance of the two series of tests in which the samples were consolidated to the same OCR of 2 but at different consolidation pressures of 735.5 and 980.7 kPa. The slight difference is most probably due to the slight difference in clay content.

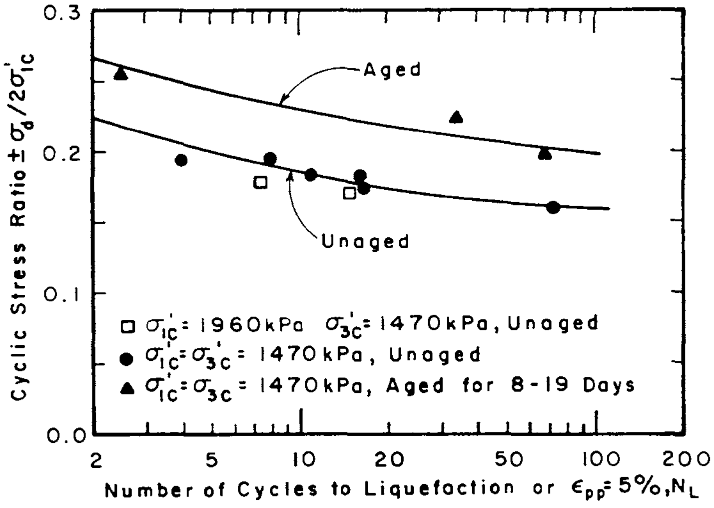

FIG. 3 COMPARISON OF LIQUEFACTION RESISTANCE OF AGED AND UNAGED, ISOTROPIC AND ANISOTROPIC CONSOLIDATED TEST SPECIMENS

Effect of Anisotropic Consolidation: Fig. 3 shows the comparison of liquefaction resistance of isotropic and anisotropic consolidated samples. Though data are rather scant, it tends to indicate that if the liquefaction resistance is normalized with respect to the major principal stress, there is not much difference between the liquefaction resistance of isotropic and anisotropic consolidated samples. Research done by Vaid and Finn (1979) also appeared to indicate a similar observation. Thus, it is concluded that the major principal consolidation stress may be the controlling factor in determining the liquefaction resistance of the soil.

Effect of Aging: Fig. 3 also shows the comparison of the liquefaction resistance of aged and unaged clayey silt samples. It is apparent that the aged samples are about 25% stronger than the unaged samples, even though they have been aged to a maximum of 19 days. Similar observations were reported by Seed (1979). The effect of aging on the liquefaction resistance of soil further illustrate the difficulty in applying laboratory test results to natural soil deposits; are laboratory tests seriously underestimating liquefaction resistance? Also, testing procedures must be standardized so that test results from different laboratories can be readily compared.

Effect of Grain Size Variations: The soils tested in this experimental program range from silty clay to silty fine sand. However, it was noticed that for samples obtained from a deposit, the difference in liquefaction resistance with normalized cyclic stress for a given consolidation condition was quite insignificant despite the variation in grain size composition. For example, the test results plotted in Fig. 1 have the grain size variations given in Table I, Series I. Wong, Seed and Chan (1975) and others have reported that the liquefaction resistance of a soil may be dependent on the grain size, and that coarse grained soil is stronger than fine grained soil. However, as has been pointed out previously the difference may have been due to the effect of membrane penetration which is more significant in coarse grained soil.

Effect of Density: It is interesting that in our experimental work on natural soil deposits, it was observed that even though the density varied by more than ±170 kg per cu m (±10 pcf) the liquefaction resistance of soil from the same deposit was not significantly affected. Literature suggests that density may be a significant parameter but only for lab testing of reconstituted samples. It is believed that in natural soil deposits the liquefaction resistance is mainly affected by factors such as aging, previous strain history and natural grain structure; density per se may be of lesser importance. Furthermore, because of the variation of grain size distribution which greatly affects the values of minimum and maximum densities for the soil, it is difficult to assess the relative density of the soil.

Sample Disturbance: Based on only limited results, it was observed that disturbance of loose sand and silt specimens during preparation resulted in a higher resistance to liquefaction after consolidation. Because of this result, sample preparation method 2) was developed (see test procedure). This method eliminated partial liquefaction of soil while in the shelby tube which was due to either saw blade vibration or excess pore pressure generation when long tube samples are hydraulically extruded.

CONCLUSIONS

The results of undrained cyclic triaxial tests performed on undisturbed samples of natural deposits of sand, silt and clays indicate the following conclusions for the range of stresses investigated.

1) The liquefaction resistance of undisturbed natural soil was not influenced by the size of the test samples for normally consolidated soil.
2) The liquefaction resistance of undisturbed natural soil when normalized with respect to the major principal consolidation stress was independent of the level of the consolidation stress for normally consolidated soil.
3) The liquefaction resistance of isotropic and anisotropic consolidated samples were similar if they are normalized with respect to the major principal consolidation stresses for normally consolidated soil.
4) Overconsolidation increases the liquefaction resistance of silty clay and clayey silt. Furthermore, at the same overconsolidation ratio the liquefaction resistance is similar.
5) Aging increases the liquefaction resistance of silty clay and clayey silt for normally consolidated soils.
6) The liquefaction resistance of sand, silt and clay of the same natural deposit is not affected significantly by variations in grain size and density.
7) Significant disturbance of loose natural soils during sample preparation causes an increase in liquefaction resistance.

ACKNOWLEDGEMENT

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