LIQUEFACTION POTENTIAL FROM DRAINED CONSTANT VOLUME CYCLIC SIMPLE SHEAR TESTS

by

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SYNOPSIS

A constant volume cyclic shear test has been developed for measuring liquefaction potential of saturated sand using either drained saturated specimens or dry sand. The test is free from many of the difficult and time-consuming features of undrained cyclic loading tests. It is quickly performed, gives results with extraordinarily high reproducibility and leads to a more accurate assessment of liquefaction than current undrained tests.

INTRODUCTION

Laboratory methods currently in use for determining the liquefaction potential of cohesionless soils involve cyclic loading tests of various kinds on undrained saturated samples (2). These tests are difficult and time-consuming to perform. In addition, there is appreciable compliance in each of these test systems which allows significant volume change to occur in the supposedly undrained saturated sample. This volume change, having the same effect as partial drainage would have, decreases the tendency for the porewater pressure to rise during cyclic loading. Therefore undrained tests tend to overestimate the resistance to liquefaction. According to De Alba et al. (1) the overestimation may be as much as 30% of the measured value and a much higher percentage of the true value. The main source of compliance varies from test to test. In triaxial tests it results from membrane penetration; in simple shear tests using rectangular sample cavities with rigid walls it is caused by the membrane expanding into corners and clearances.

The development of a simple shear test to measure liquefaction potential using samples of dry or drained saturated sand is described here. Using dry or drained sands removes the time-consuming and difficult features associated with undrained tests. Furthermore the compliance of the new test system is so small that for all practical purposes it may be considered a constant volume cyclic shear test.

The concept of using constant volume drained tests to study undrained response was first suggested by Taylor (7) for static triaxial conditions and was later advanced by Pickering (4) for cyclic simple shear conditions in which the samples are contained by rigid walls. In the latter circumstances a constant volume condition is maintained by locking the vertical loading head after the required vertical confining

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pressure has been applied. When cycles of shear stress or shear strain are now imposed the tendency of the sand to compact during shaking causes a progressive reduction in vertical pressure on the loading head. This reduction in pressure is equivalent to the increase in porewater pressure in the corresponding undrained test.

DESCRIPTION OF TEST EQUIPMENT

The University of British Columbia simple shear apparatus has been described by Finn et al. (3). Some changes to this apparatus were made in order to carry out constant volume cyclic simple shear liquefaction tests. Fig. 1 shows schematically the necessary additions to the apparatus. A horizontal reaction plate is clamped to four vertical posts which are threaded into the body of the simple shear apparatus. A stiff vertical load transducer is attached to the sample loading head and carries on the upper side a heavy loading bolt which passes through a central hole in the reaction plate. The desired vertical confining pressure is applied to the sample by tightening the loading bolt nut on the underside of the reaction plate. Then the loading head is locked in position by tightening the loading bolt nut on the top side of the reaction plate.

In this so-called constant volume test, the maximum gross volume change (compliance) introduced at liquefaction is very small and arises only as a result of recovery of deformation of the vertical loading components as the load on the system is reduced. The use of a thick reaction plate, heavy vertical posts and loading bolt along with a very stiff load transducer reduces the vertical movement of the clamped loading head to a negligible amount. For liquefaction tests with initial vertical confining stress, $\sigma'_{vo} = 2 kg/cm^2$, this movement amounted to a maximum of 2×10^{-4} inches, which was only 1/20 of that in an undrained liquefaction test in the same apparatus. Thus a more accurate evaluation of liquefaction potential can be made with the new test.

CONSTANT VOLUME CYCLIC LOADING TESTS

All tests were performed on normally consolidated Ottawa sand ASTM designation C-109. This is a natural silica sand consisting of rounded particles with grain sizes between 0.15 and 0.59 mm and $D_{50} = 0.400$ mm. The maximum and minimum void ratios are 0.82 and 0.50 respectively.

The cyclic shear load was applied as the square waveform with periods of zero load described previously by Finn et al. (3) for undrained simple shear liquefaction tests. All tests were run at a loading frequency of 2Hz. The sand is placed in a loose condition and vibrated to the required density. During vibration contact is kept with the loading head by maintaining a very small contact pressure.

Tests were first carried out to determine whether using dry or drained saturated samples resulted in different estimates of liquefaction potential for otherwise identical samples under identical loading conditions. No practical differences were found; the results from both kinds of samples seemed identical. Therefore since preparation of dry sand samples is much easier and less time consuming than preparation of saturated samples all subsequent tests were carried out using dry sand.

Tests on Dry Sand: The resistance to liquefaction of Ottawa sand measured in the new constant volume test is shown in Fig. 2, at four relative densities ranging from loose (D_r = 35%) to dense (D_r = 72%). The data was obtained using identical values of $\sigma'_{vo} = 2$ kg/cm^2. It may be seen in Fig. 2 that the relationship of τ/σ'_{vo} to cycles to liquefaction for each relative density is similar in form to that obtained by undrained liquefaction tests; the cycles to liquefaction decrease as the amplitude of cyclic shear stress increases and the resistance to liquefaction increases with increase in relative density.

These tests were repeated using vertical confining pressures $\sigma'_{vo} = 3$ and 4 kg/cm^2. It was found that, irrespective of the value of σ'_{vo}, identically prepared samples of the same sand required the same number of cycles of shear stress τ to cause liquefaction when the values of τ/σ'_{vo} were the same. This is in agreement with earlier data from tests on undrained saturated samples (5,3).

Comparison between Constant Volume and Undrained Tests: A series of undrained liquefaction tests was also carried out using saturated samples formed to the required density as in the constant volume tests. Constant values of initial confining pressure and cyclic shear stress with τ/σ'_{vo} = 0.13 were used and only the sample density was varied. The results from this series of tests are shown in Fig. 3 which shows the variation of cycles to liquefaction with relative density, D_r, for a constant τ/σ'_{vo} = 0.13. Corresponding results obtained by constant volume liquefaction tests (Fig. 2) are also shown for comparison. It may be seen that at each relative density the undrained test yields a greater number of cycles to liquefaction than the constant volume test.

It may be seen that with τ/σ'_{vo} = 0.13 Ottawa sand at a relative density D_r = 51% will liquefy in 10 cycles in an undrained cyclic load test. The data in Fig. 2 shows that the same sand at the same relative density will liquefy in 10 cycles with τ/σ'_{vo} = 0.107. Therefore, the undrained test because of system compliance overestimates the resistance to liquefaction by about 22% for the case under consideration. For any given apparatus and hence a given amount of compliance, the overestimate in resistance to liquefaction will depend on the type of sand, relative density and the number of cycles to liquefaction under consideration.

The liquefaction resistance of Ottawa sand, represented by a plot of τ/σ'_{vo} ratio vs. cycles to liquefaction, from the new test is compared in Fig. 4 with the resistance of other medium sands in undrained liquefaction reported by Seed and Peacock (6). The comparison is made at a relative density of 50%. The data from the new test agrees reasonably well with that of Seed and Peacock (6). This comparison is useful only in showing that the new test gives results in general agreement with those of other investigators because the Monterey sands used by Seed and Peacock are quite different in their grain size characteristics from Ottawa sand. However, it is probable that a major part of the difference in results is due to system compliance in the undrained tests.

CONCLUSION

A simple shear test has been developed for measuring the liquefaction potential of saturated sands which uses dry sand samples. The volume changes that occur during the test are so small that for all practical purposes the test may be considered a constant volume test. The test is based on the concept that the pressure reduction against the loading head during cyclic loading is equivalent to the increase in porewater pressure that would occur in the corresponding undrained test. Compliance in the constant volume test system is less than 1/20 that of the corresponding undrained test system and consequently the constant volume test gives more realistic estimates of liquefaction potential. In some comparative cases considered in the paper the undrained test overestimated the resistance to liquefaction in 10 cycles by at least 22%.

The constant volume test is very quick and easy to carry out and has none of the difficulties associated with undrained cyclic tests.

ACKNOWLEDGEMENTS

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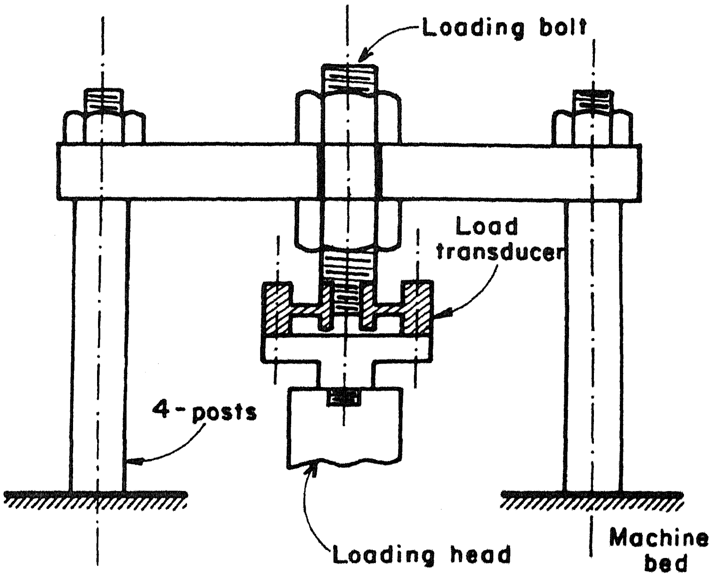

Fig. I Schematic Layout for Constant Volume Simple Shear Liquefaction Tests.

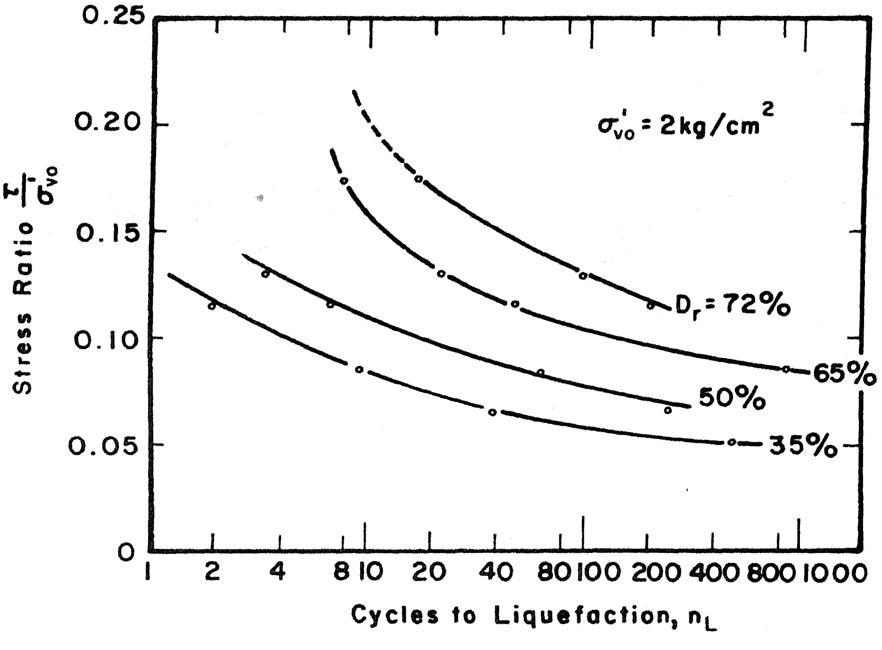

Fig. 2 Resistance to Liquefaction of Normally Consolidated Ottawa Sand.

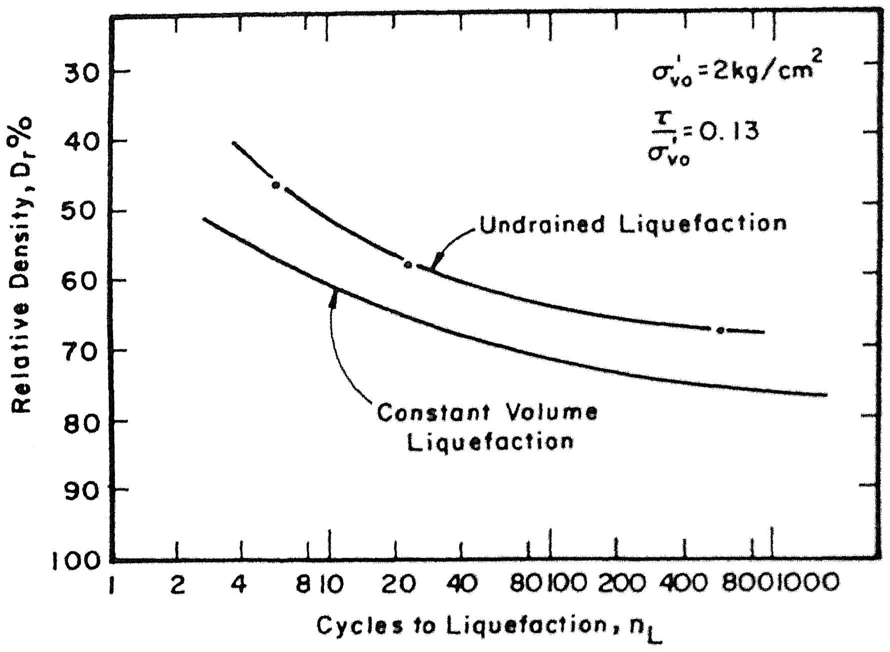

Fig.3 Liquefaction Resistance of Ottawa Sand in Constant Volume and Undrained Simple Shear.

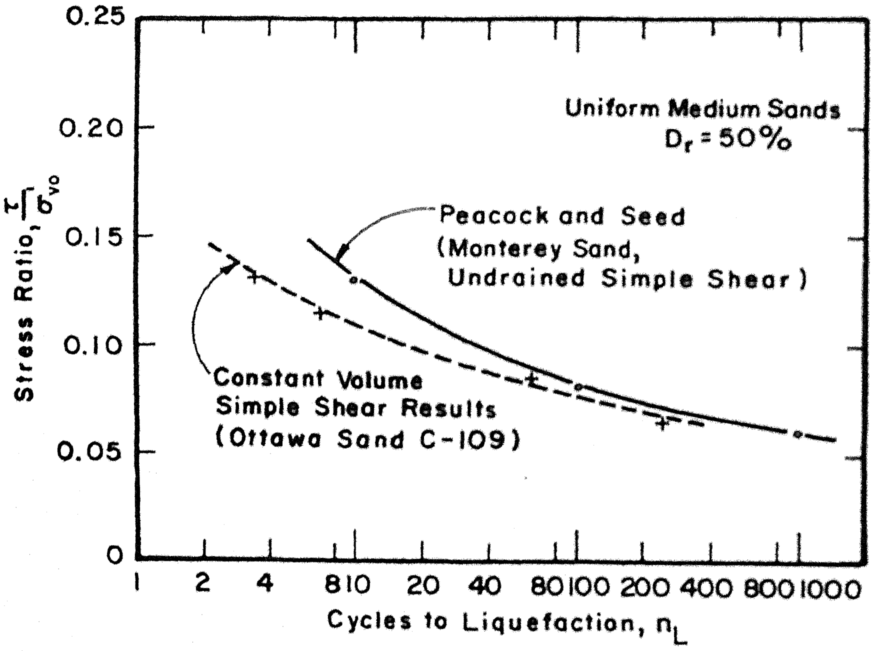

Fig.4 Liquefaction Resistance of Ottawa and Monterey Sands.