Both stress-controlled and strain-controlled cyclic triaxial tests were conducted on samples of Monterey No. 0 sand of 30 percent relative density to assess the frequency effect on its liquefaction potential. The result indicated that the liquefaction potential of a loose sand was affected significantly in the stress-controlled cyclic triaxial test with stress reversal and the cyclic triaxial extension test when the frequency is greater than 0.01 Hz. The effect increases with the frequency. In a low frequency cyclic triaxial test, a sample was allowed to undergo severe contraction in the extension phase of the test. As a result, the sample was substantially weakened due to the generation of a large excess pore water pressure. Thus, the extension phase of a stress-controlled cyclic triaxial test was found to be more damaging and responsible for the strength reduction and liquefaction of a loose sand than the compression phase. As the frequency increases from one-hundredth of a hertz, the amount of damage per cycle of loading reduces, and the number of cycles required to cause liquefaction also increases. In a strain-controlled cyclic triaxial test, however, the above effect was found to be negligible.

INTRODUCTION

Stress waves produced by an earthquake are random waves of irregular frequencies and stress amplitudes. Both the frequency content and stress amplitude are earthquake dependent. Thus, the ground response is different from one earthquake to the other. To predict the ground response, it is ideal to conduct a dynamic test using an actual seismic history. However, the complication of data analysis has led to the adoption of the cyclic triaxial test with a uniform stress amplitude (Annaki
and Lee, 1977). In this method, it was assumed that the sample damage inflicted in a cyclic triaxial test is frequency independent. In current practice, a convenient frequency ranging from 0.5 to 2 Hz is used in conducting a cyclic triaxial test.

Lee and Fitton (1969) performed a series of cyclic triaxial tests on a uniform medium sand with the mean diameter of 0.68 mm at frequencies ranging from 0.17 to 1 Hz and found that the cyclic strength under a low frequency excitation is slightly lower than that under a high frequency excitation. Peacock and Seed's tests with the frequency range of 0.17 to 4 Hz showed that the cyclic strength scattered within ±10% of the mean without a definite trend. Seed, Wong and Chan (1975) found the frequency effect on gravelly soils to be negligible in the frequency range of 1 to 20 Hz. Lee and Focht (1975) investigated the cyclic strength of a fine foundation sand from the Ekfish Tank in the North Sea. Vernese and Lee (1977) studied the cyclic strength of Monterey No. 0 sand. Both studies indicated a negligible frequency effect on the cyclic strength of sands. With an increasing interest in off-shore structures which are subjected to the dynamic load of a wide range of frequency, it becomes necessary to re-examine the frequency effect on the liquefaction potential of sand.

This paper presents the result of the study on the frequency effect on the behavior of loose Monterey No. 0 sand. Both stress-controlled and strain-controlled cyclic triaxial tests were conducted at frequencies of 0.0001 to 1 Hz. It was found that, in the stress-controlled cyclic triaxial test with stress reversal, the cyclic strength increases with frequency at the frequency higher than 0.01 Hz. Below 0.01 Hz the above frequency effect no longer exists.

BOUNDARY SURFACES

The boundary surface (or failure envelope) is the locus of all failure stress states. It also serves as the dividing line between the possible and the impossible stress states and bounds the effective stress path of a soil. The surface is generally nonlinear and can be located experimentally. However, within a certain range of stresses, it can be approximated by a straight line.

According to the study conducted by Ishihara, Tatsuoka and Yasuda (1975), there exists a phase transformation line just below the boundary surface as shown in Figure 1. The phase transformation line is the loci of the abrupt curvature and direction changes of the effective stress path. The boundary surface line and the phase transformation line are usually steeper in compression than in extension. It is especially so for sandy soils. Ishihara, et al. (1975) also indicated that the liquefaction is initiated when the effective stress path