A RE-EXAMINATION OF THE EFFECT OF PRIOR LOADINGS ON THE LIQUEFACTION OF SANDS

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SYNOPSIS

It is now well accepted that the liquefaction characteristics of sands are influenced by the seismic history to which they previously have been subjected. This paper reports studies which have been carried out to investigate the extent of this strength increase. These have shown that conditions can be developed such that the beneficial effect of prior shaking can be destroyed. It was found that if the excess pore pressure increase developed during seismic shaking was approximately 0.6 of the overburden pressure, then the beneficial effects of any prior low level shaking were effectively lost. The significance of these results is important in two areas. The possible beneficial effect of events prior to a large event should be considered with caution and the possible significance of aftershocks may be increased.

INTRODUCTION

The influence of prior seismic history has been recognized as a significant factor affecting the liquefaction or the cyclic strength characteristics of soils. Laboratory studies by Finn et al. (1970) and Seed et al. (1977) conclusively demonstrated that samples which had been previously subjected to small levels of shaking (straining causing almost no volume changes in the samples) and allowed to drain developed greater resistance against a future liquefaction failure. However, the extent of this phenomenon and limitations in terms of possible upper and lower bounds or its effectiveness have not been fully examined. Studies carried out by

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Finn et al. (1970) to investigate the influence of prior cyclic strain history in the range of 0.5 to 2 percent on liquefaction resistance found that the threshhold value at which the cyclic shear strain weakens the resistance to liquefaction probably depends on the number of times the shear strain is cycled. They were unable to define the boundary between shear strains that lead to an increase and those that lead to a decrease in resistance to liquefaction. Subsequent studies by Seed et al. (1977) of the influence of prior seismic history on liquefaction characteristics were carried out in terms of the influence of a low level of shaking causing a build-up of an excess pore pressure ratio to about 30 percent. The validity of this increase in resistance to liquefaction when larger pore pressure ratios are developed was examined. This was done to see if there is a threshhold value of developed pore pressure ratio above which the beneficial effects of prior shaking will not be realized. Studies were undertaken to examine this effect on two sands with different gradation using cyclic triaxial equipment.

TEST PROGRAM

Monterey #0 and #20 were used in this investigation. Monterey #0 sand has been widely used to study different aspects of liquefaction behavior which are now well documented in the literature. Quartz and colored feldspars are the predominant minerals. The maximum and minimum densities respectively are 105.3 pounds per cubic foot and 89.5 pounds per cubic foot for Monterey #0 sand and 106.9 pounds per cubic foot and 93.9 pounds per cubic foot for Monterey #20 sand. Figure 1 presents the gradation curves for the two sands.

Monterey #0 sand samples were prepared by tamping at a relative density of 48 percent and Monterey #20 sand samples were prepared by pluviation at a relative density of 40 percent.

Three series of tests were conducted for each sand. The first two series were designed to obtain what could be called the baseline characteristics. For the first series, a set of specimens was prepared to the same relative density. They were then saturated and consolidated under the same effective confining pressure. These specimens were then subjected to cyclic triaxial tests until a pore pressure ratio of 100 percent was reached. A virgin line or baseline for samples with no prior strain history effects was obtained in this way. Another set of specimens was first subjected to a known seismic history and then tested using procedures described by Seed et al. (1977). Each specimen was subjected to a series of low level stress ratios representing small magnitude earthquakes. After each series, the developed pore pressure was allowed to dissipate. After five or six such small events, each sample was cyclically loaded to the 100 percent pore pressure ratio conditions representing a large event. In this way cyclic loading curves influenced by different levels of prior seismic history were established. These two curves when shown on a typical stress ratio versus number of cycles plot are referred to as the "virgin" and the "history" lines respectively. These relationships provide the framework or the basis for evaluating the influence of pore pressure ratio on the liquefaction characteristics. It may be noted that the history lines were established with only a small pore pressure ratio of about 25 to 30 percent.

Finally, to study the effects of higher developed pore pressure ratios, a set of virgin specimens was prepared and the seismic history effects were similarly introduced. After the seismic history effects were introduced the specimens were subjected to somewhat higher levels of cyclic stress to cause development of excess pore pressure ratios ranging from 45 to 80 percent. Again, the developed pore pressure was allowed to dissipate and each sample was subjected to cyclic load until the 100 percent pore pressure ratio was reached. The results of these tests are shown on Figures 2 and 3. It can be seen that the development of an excess pore pressure ratio which subsequently dissipated before final testing causes the specimen to lose some or all of the beneficial effects of the seismic history previously given to the specimen. The boundary appears to be the 50 percent of excessive pore pressure ratios, indicating that the influence of a moderate level of shaking in affecting the resistance to liquefaction may be interpreted with caution.

CONCLUSIONS

The results of this study show that prior seismic loading can have a marked effect on the resistance of a sand to liquefaction in a future seismic event. These effects are:

1) For repeated loadings where small pore pressure ratios are developed the resistance to liquefaction is increased. This increase reaches a maximum value for pore pressure ratio increases of 30 to 40 percent.

2) Where higher pore pressures are developed in an event subsequent to smaller prior loading the increased resistance will be reduced. This reduction increases with increasing pore pressure ratios and the effects of prior history are almost eliminated for pore pressure ratios of 60 percent or greater.

3) The increasing recognition that major earthquakes are cyclic in nature with long intervals between recurrences suggests that the prior history effect and its possible destruction could be completely offset by the continuing increased resistance to liquefaction resulting from the aging effect (Seed, 1976; and Donovan and Singh, 1976).

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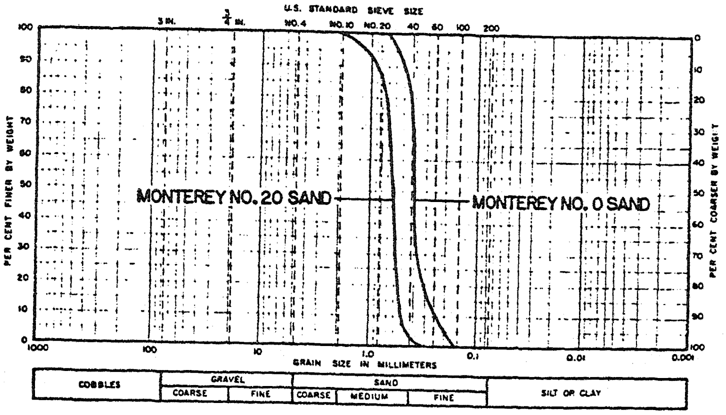

Figure 1. Grain Size Distribution Curve

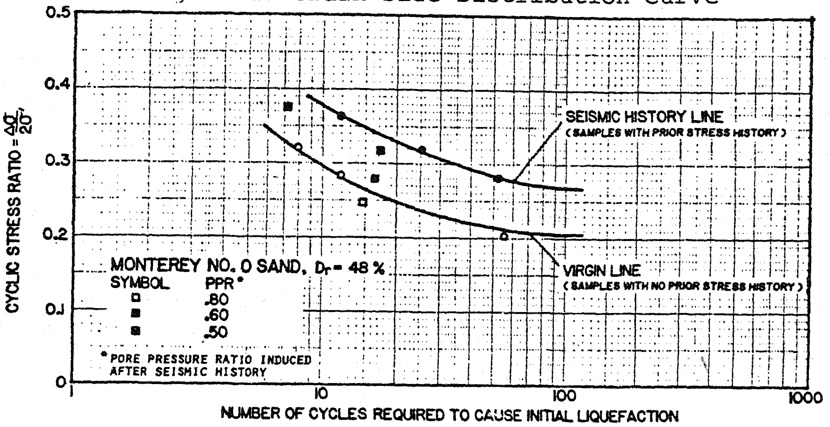

Figure 2. Cyclic Triaxial Test Results Showing the Effect of Pore Pressure Ratio Equivalent to Prior Seismic History on the Liquefaction Characteristics for Monterey No. 0 Sand.

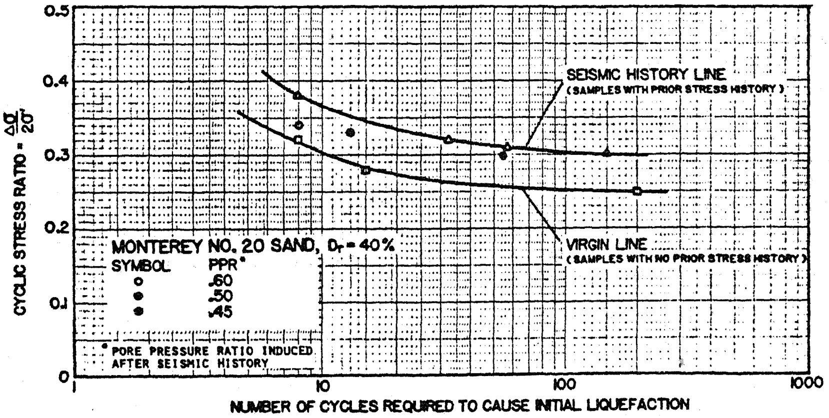

Figure 3. Cyclic Triaxial Test Results Showing the Effect Pore Pressure Ratio Equivalent to Prior Seismic History on the Liquefaction Characteristics for Monterey No. 20 Sand.