Liquefaction Potential of Impounded Class F Fly Ash

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Abstract

The susceptibility of Class F fly ash in retention ponds to earthquake induced liquefaction is a concern of both regulators and facility owners. Procedures for determining the stability of soil structures during seismic events rely on experimentally obtained material properties. Test programs (both in-situ and laboratory) to provide the necessary data are well established for natural soils, however, it is not clear that existing test data collected on these materials, even with similar grain size distributions (fine sands, silty sands, silts) are appropriate for coal combustion residues such as fly ash. In order to generate appropriate data sets an extensive laboratory program of cyclic triaxial tests was conducted on samples of saturated fly ash taken from storage ponds at seven Midwest US facilities.

Test specimens were constructed in the laboratory by fluviation. Each specimen was consolidated to a confining pressure representative of pressures existing in utility ash ponds. After saturation was verified, a cyclic shear stress was applied. Induced pore pressures and strains were measured throughout the test. Results of the tests are presented in graphical form as the number of cycles required to induce liquefaction versus the ratio of applied cyclic stress to confining pressure.

The results of the test program show that, while the main trend of increased number of stress cycles with decreased cyclic stress well documented for natural sands and silts is typically observed, the cyclic behavior of ponded fly ash is not adequately characterized by published data obtained from natural soils.

1. Introduction

At a number of facilities in the Midwest, the disposal of coal combustion residues has been accomplished by impounding the material in on-site reservoirs. With the increasing environmental concerns and restrictions, a number of these impoundments are being scheduled for closure. However, as the cost of siting and preparing new areas for land-fills rises, these existing impoundments are being considered for locations for construction landfills. Before the impoundments can be used for this purpose, the stability of the impounded material must be determined. The potential for liquefaction of the material in these impoundments (typically Class F fly ash) during an earthquake is a concern for the design of superimposed monofills. Many studies have been completed on the liquefaction potential of sands and clayey soils, but little is known about the liquefaction potential of fly ash. To understand in greater detail the liquefaction potential of fly ash, an experimental study was performed on reconstituted fly ash samples from seven power plant impoundments to further expand on the fly ash pond dataset presented by Zand et. al., 2009. The cyclic strength of the fly ash was determined by performing cyclic triaxial tests on a number of representative fly ash samples collected at several sites in the US Midwest.

2. Testing Procedures and Specimen Preparation

As intact specimens could not be retrieved from the ash ponds, laboratory samples were reconstituted from the provided fly ash at the OSU Soil Mechanics Laboratory, using a wet depositional process to simulate the method employed at the power plants to place the fly ash into on-site impoundments. Laboratory dry densities were compared with the values recorded in the field. Specimens were consolidated under effective stresses of 10, 20, 30, 40, and 50 psi.

The specimens underwent cyclic triaxial testing with cyclic stress ratios (CSR) ranging from 0.075 to 0.400.

2A. Specimen Preparation

A bulk sample was created in six to eight pour lifts of 500g of Class F fly ash mixed with de-aired and distilled water to create a slurry. Each sample was cured for a minimum of 24 hours. In some instances the sample was consolidated under an additional axial load to create a higher density. Specimens were then extruded from the bulk sample. Specimen weight, diameter, and height were measured. A representative specimen was taken from each bulk sample to measure moisture content and dry density. Specimens were then placed in a triaxial test chamber.

Saturation of the specimens was achieved by applying a pressure of approximately 48.5 psi to the top and a pressure of 49 psi to the bottom, creating a pressure differential allowing water to flow throughout the specimen. Effective pressure during time of saturation was 1 psi. Saturation was determined by measuring the B-value. Once a specimen reached a B-value of 95% or higher the cyclic triaxial test was performed. However, if the B-value did not reach this criterion within two weeks, the specimen was tested due to time constraints.

2B. Cyclic Triaxial Test

Once saturated each specimen was consolidated under the desired effective confining pressure. Cyclic triaxial tests were performed using an MTS load frame at a loading rate of 1Hz. During the cyclic test cell pressure remained constant under undrained conditions. Pore water pressure, axial deformation, and axial load were recorded continuously at a sampling rate of 100 Hz. A range of effective confining pressures and cyclic stress ratios were tested. The number of cycles to liquefaction was identified as the location in which the axial load deviated by more than 5% of the programmed load, or at the point the pore pressure equaled the confining stress (effective stress reached zero). Whichever of these events occurred first in testing was taken as the point of liquefaction. These conditions typically coincided with the onset of large axial deformations. An example of the identification of liquefaction can be seen in Figures 1 and 2. Figure 1 displays the number of cycles vs. recorded axial stress. The vertical line identifies the point where liquefaction occurred. Figure 2 displays number of cycles vs. ratio of excess pore water pressure to effective pressure and axial strain. The vertical line also identifies where liquefaction has occurred. It can be seen that liquefaction occurs as axial stress deviates from the programmed stress and strains begin to increase dramatically.

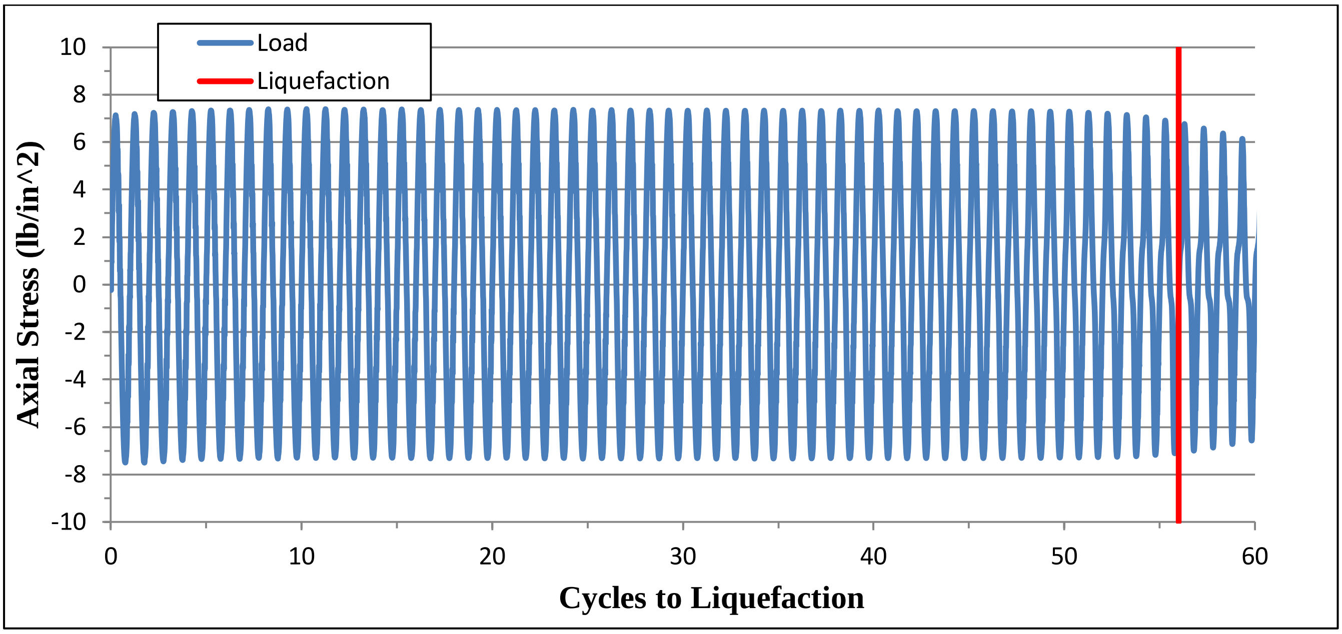

Figure 1: Identification of Liquefaction on Cycles vs. Axial Stress Plot

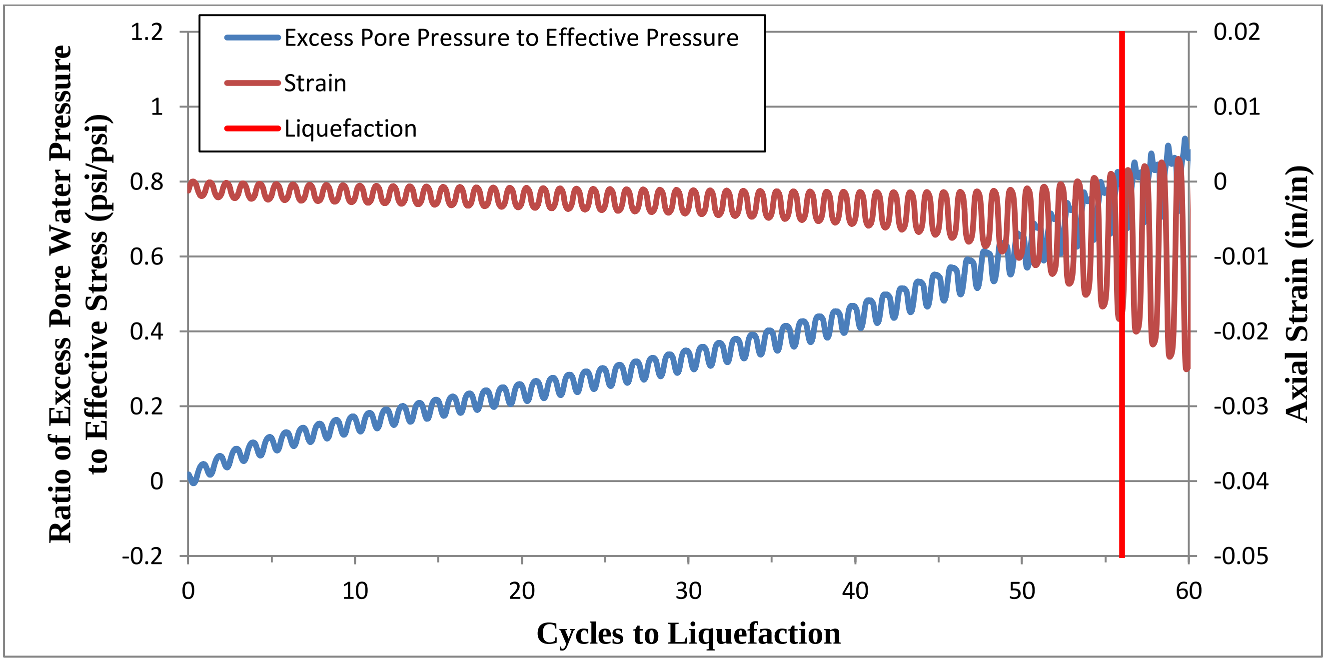

Figure 2: Identification of Liquefaction on Cycles vs. Ratio of Excess Pore Water Pressure to Effective Stress and Axial Strain Plot

3. Results and Discussion

Figure 3 is a summary of the test results on the fly ash samples obtained from seven Midwest US power plants including the one presented earlier by Zand et. al., 2009. The number of cycles to liquefaction at a 1 Hz frequency is plotted against CSR for each plant. Test limit is at 500 cycles, i.e. the test was terminated if the specimen had not liquefied in 500 load cycles. It is apparent from the results that as CSR increases the number of cycles to liquefy the specimen decreases.

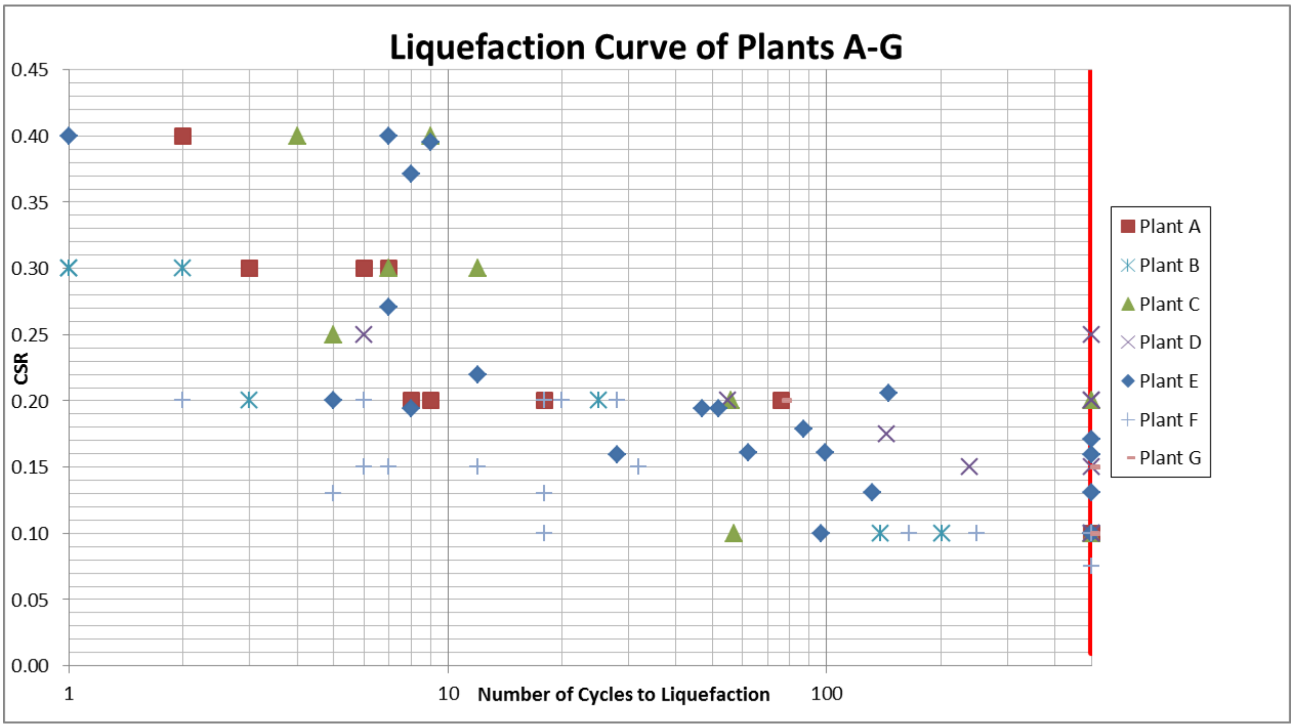

Figure 3: Liquefaction Curves of Plants A-G

Figure 4 presents the Figure 3 data with the liquefaction potential curve as a function of effective stress identified. It appears that over the tested stress range of 10 to 50 psi, higher imposed effective stress resulted in lower CSR at liquefaction.

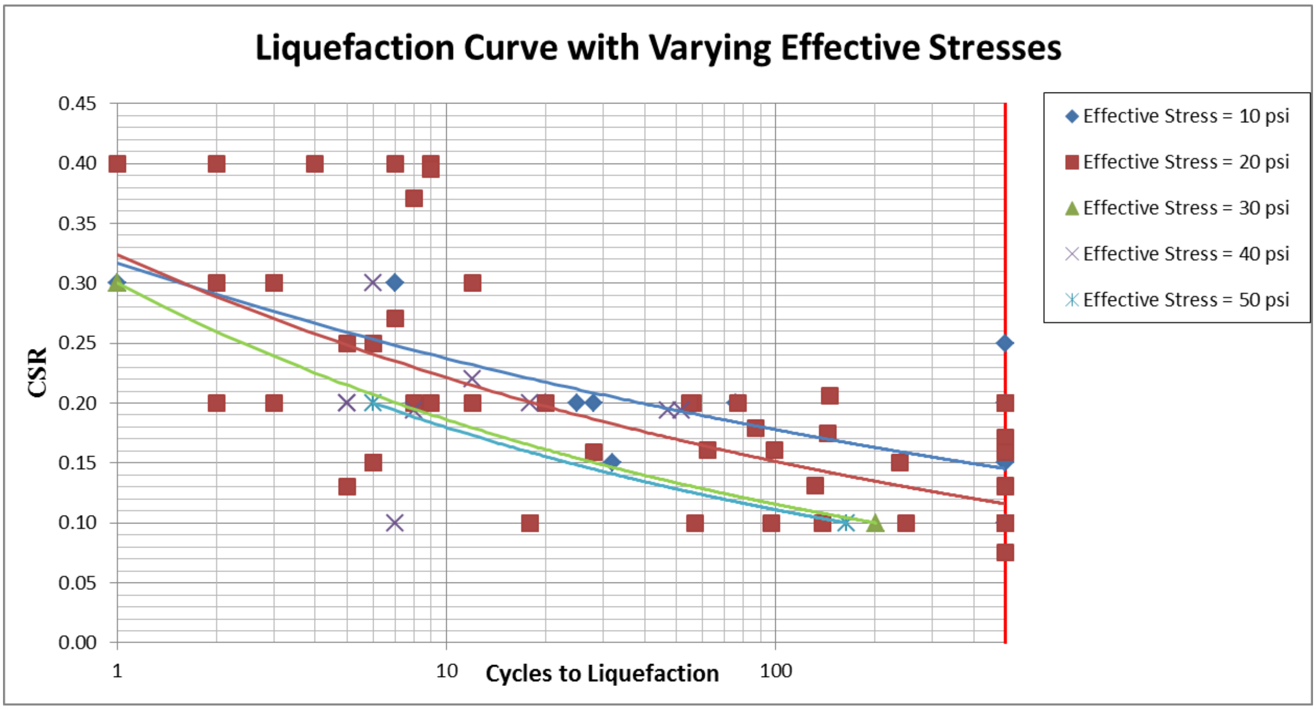

Figure 4: Liquefaction Curve of Plants A-G with Varying Effective Stresses

In order to assess the effect of dry density on liquefaction potential the test data were plotted in Figure 5 as the CSR vs. cycles to liquefaction for each range of dry densities. Similarly, the dry density of the specimens tested at each site is plotted in Figure 6 versus the number of cycles needed to induce liquefaction in that particular specimen. It should be noted that at a specific site, the range of dry density is relatively narrow as it is expected in an ash pond where the fly ash has been fluviated. From the test results collected to date, it appears that density of the specimen has little to no correlation to the liquefaction potential of a specimen.

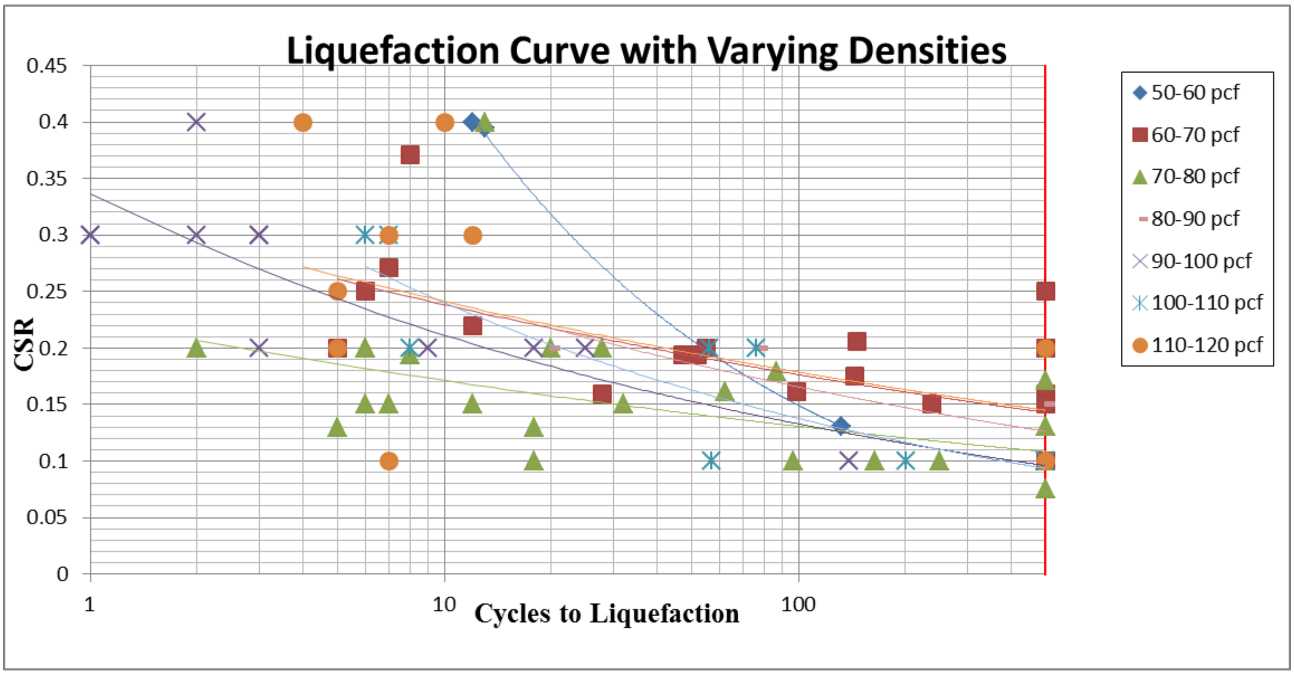

Figure 5: Liquefaction Curve of Plants A-G with Varying Range of Dry Densities

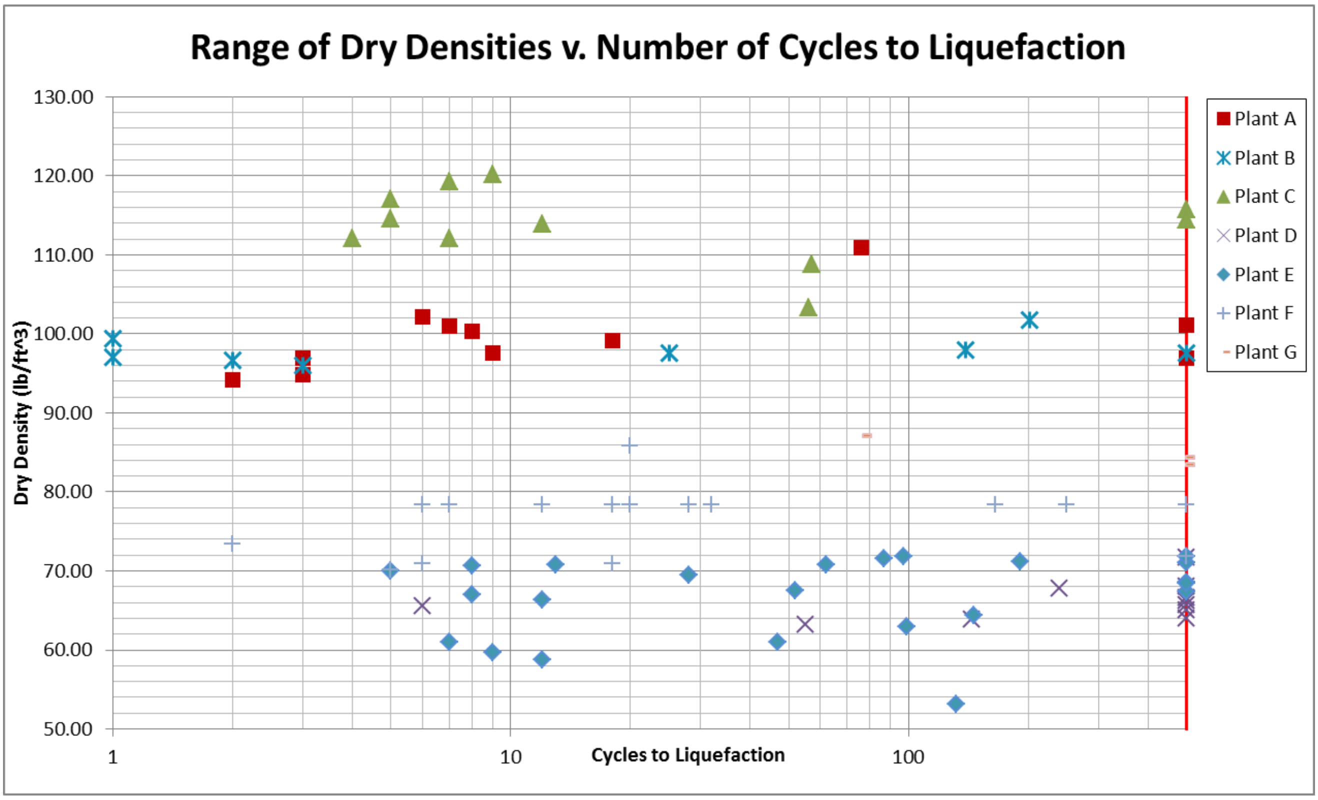

Figure 6: Range of Dry Densities v. Number of Cycles to Liquefaction

4. Summary and Conclusions

The liquefaction resistance of impounded fly Class F fly ash from seven US Midwest burning utility plants was investigated. A total of 84 cyclic triaxial tests were performed with varying densities, confining stresses, and cyclic stress ratios. The cyclic shear strength of the impounded fly ash is presented graphically in terms of cyclic strength curves showing a relationship between cyclic stress amplitude and number of cycles to liquefaction. Graphical plots of CSR and number of cycles to liquefaction were created varying effective pressures and dry densities. The conclusions that were formulated due to this research are as follows:

1. As cyclic stress ratio increases, the number of cycles needed for a specimen to liquefy decreases.
2. Lower effective stresses cause liquefaction to occur at higher CSRs in comparison to higher effective stress specimens.
3. Dry density seems to have little to no correlation to the liquefaction potential of the fly ash specimens.

5. Acknowledgements

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