ANNUAL PROJECT SUMMARY
TECHNICAL REPORT

Development of a Piezovibrocone Penetrometer for In-Situ Evaluation of Soil Liquefaction Potential: Collaborative Research with Virginia Tech and Georgia Tech, March 1998 to October 1998

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I. Non-technical Summary

The objective of this research is to develop new instrumentation, test methods, and evaluation procedures for the direct and in-situ assessment of the liquefaction potential of soil deposits by cone penetration testing. This objective will be obtained through the development of a vibrating piezocone penetrometer, laboratory calibration testing, cyclic triaxial and simple shear laboratory testing, and analytical modeling. This project is a collaborative effort between the geotechnical engineering departments of Virginia Tech and Georgia Tech.

II. Summary of July 1998 Progress Report

Work on the project documented in the July 1998 Progress Report first involved the modification of the sampling sealing procedure. The resulting sealing procedure involves the use of a natural rubber gasket at the top plate / chamber lid interface. This gasket replaces the silicon that had been used to seal the membrane to the top plate and chamber lid and removes the drying and cleanup time delays associated with the use of silicon as the sealant. This allows for the reduction of the calibration chamber testing time by over 30%.

The cone penetrometer used for the calibration chamber testing is a Fugro 15 cm^2 triple element piezocone. The locations of the pore pressure transducers on the cone have been included on Figure 1 below.

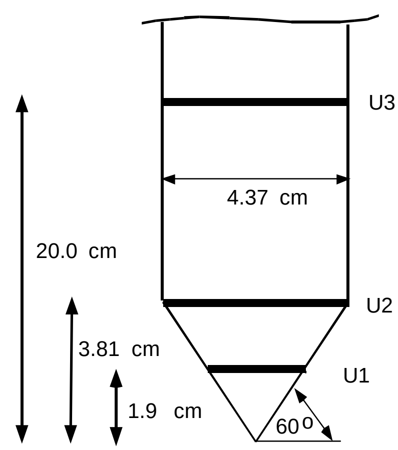


Figure 1. Schematic of Triple Element Cone Penetrometer Used in Calibration Testing

Work then focused on repairing the U_3 pore pressure element by obtaining cable wiring diagrams from the manufacturer (Fugro Geotechnical Engineers, B.V.) and then modifying the power supply / penetrometer pin connections so that electrical communication was made between the power supply and the cone penetrometer. The electrical problems were corrected and pore pressure readings are now available at the U_3 location.

Subsequent work then focused on the continuation of static penetration tests in dry and saturated Light Castle sand. Penetration tests were performed until concerns arose regarding to the validity of the pore pressure measurements. Induced positive pore pressures were recorded at the U_1

location during penetration tests in dry sands. As expected, no induced pore pressure readings were recorded at the U_2 location. After much investigation, the source of the anomalous U_1 values was determined to be thermal instability of the 200 Bar pore pressure transducer located at the U_1 location. This conclusion was reached after reviewing the results of a series of tests involving the submergence of the cone penetrometer in a water bath of varying temperatures and measuring the voltage output of the U_1 transducer with time. The results of these tests are shown in Figure 2 below. Also included in Figure 2 are the results of a calibration chamber test conducted in a dry Light Castle sand at a relative density of 25% and vertical and horizontal stress conditions of 101 and 51 kPa, respectively.

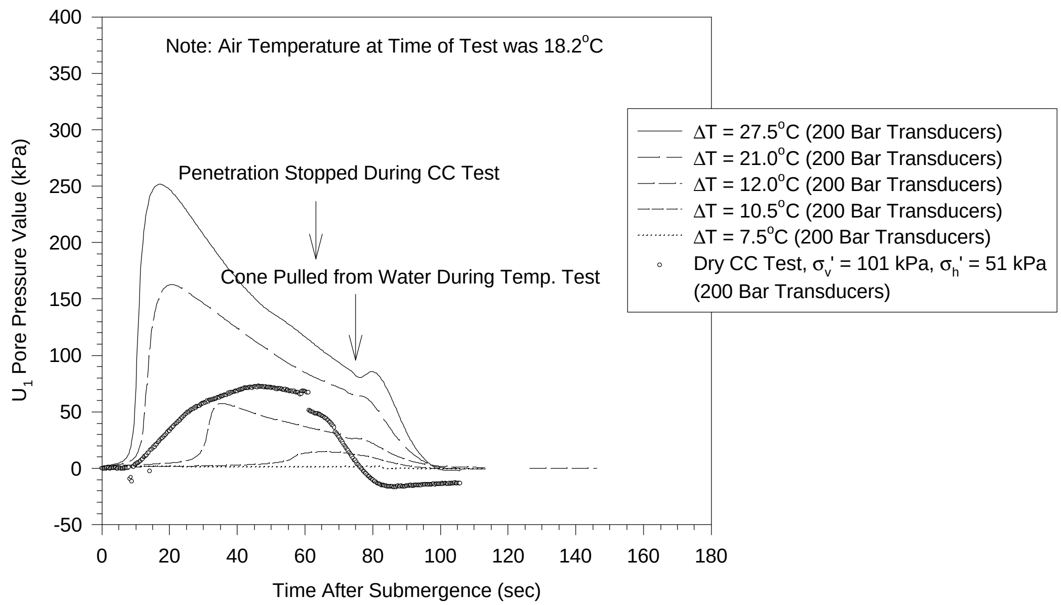


Figure 2. Comparison of the Effects of Temperature on the 200 Bar Pore Pressure Transducer at the U_1 and U_2 Locations

Corrective measures to account for this thermal shock behavior required replacing the pore pressure transducers. Due to the proprietary nature of the cone, this was done at the Fugro Geotechnical Engineers, B.V. office in the Netherlands.

III. <u>Work Performed from July 1998 to October 1998</u>

The 15 cm^2 cone penetrometer was sent to the Fugro Geotechnical Engineers, B.V. office in the Netherlands in July, 1998 and returned to Virginia Tech in September, 1998. The repair work performed by Fugro personnel involved replacing the 200 Bar transducers at the U_1 and U_2 locations with 20 Bar transducers. These transducers were reported to be thermally compensated to account for thermal shock and are more accurate for the lower stress range conditions encountered in the calibration chamber tests and proposed stresses encountered during the field liquefaction trials.

A series of calibration and water bath tests were performed on the cone penetrometer prior to performing additional calibration chamber tests to confirm the accuracy and stability of the modified cone. The results of the water bath tests have been presented as Figure 3 below. The maximum temperature increase (ΔT) reached in the test was set at approximately 27°C, which corresponds to the maximum measured temperature increase noted by Zuidberg (1988). For comparative purposes, also included in this figure are the induced pore pressure measurements recorded in a dry calibration test when the 200 Bar transducers were present in the cone.

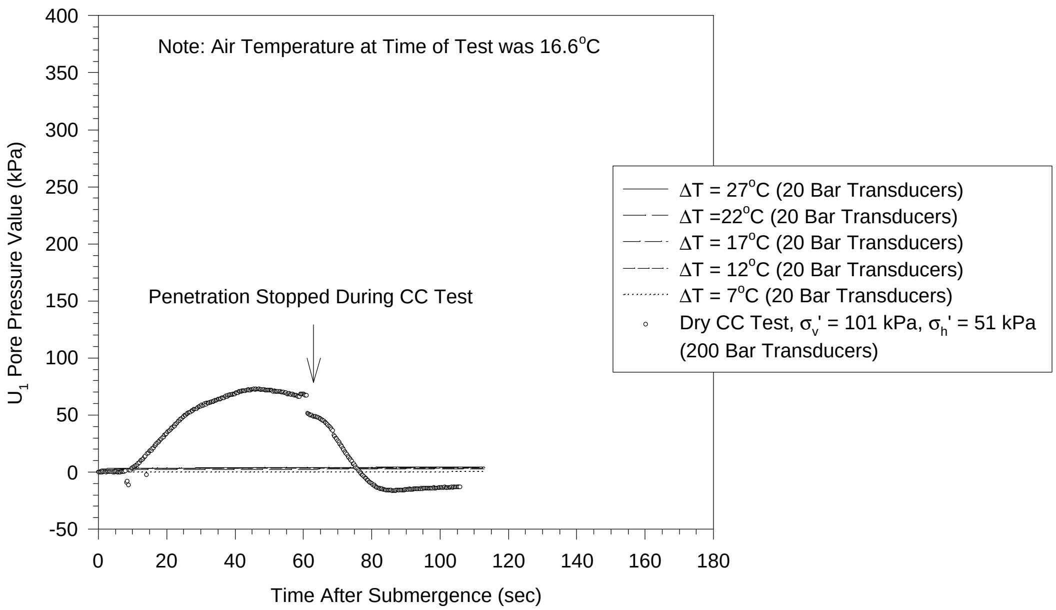


Figure 3. Comparison of the Effects of Temperature on the 20 Bar Pore Pressure Transducer at the U_1 and U_2 Locations.

It can be seen from the water bath tests presented as Figures 2 and 3 that the pore pressures induced through thermal fluctuations in the 20 Bar transducers are negligible when compared to those induced using the 200 Bar transducers for normal ranges of measured pore pressure values. Similarly, as shown in Figure 3, the pore pressures induced by the 20 Bar transducers in the water bath tests are negligible when compared to those induced during the calibration chamber penetration tests using the 200 Bar transducers.

Modifications were then made to the calibration chamber to allow for a backpressure to be applied to the sample so that the sample water pressure simulated the hydrostatic water pressure at the depth corresponding to the testing effective stress. These modifications involved the fabrication of a chamber lid cap that served as a seal when the cone penetrometer penetrated into the sample.

Calibration chamber tests were performed in both dry and saturated Light Castle sand samples at a relative density of 25% and under vertical and horizontal effective stresses of 101 kPa and 52 kPa, respectively. A back pressure of 123 kPa was used in the saturated test to simulate the hydrostatic water pressure at the depth corresponding to these effective stress conditions. A comparison of the penetration resistance measurements from these tests has been presented in Figure 4 and a comparison of the pore pressure measurements at the U_1 and U_2 locations is presented in Figure 5.

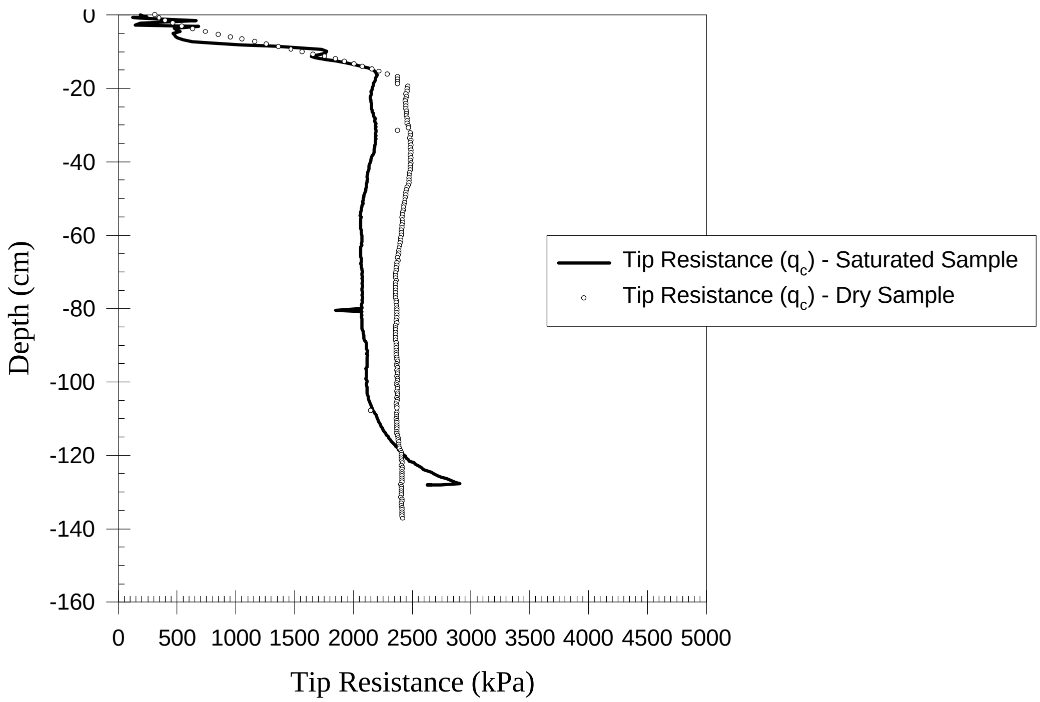


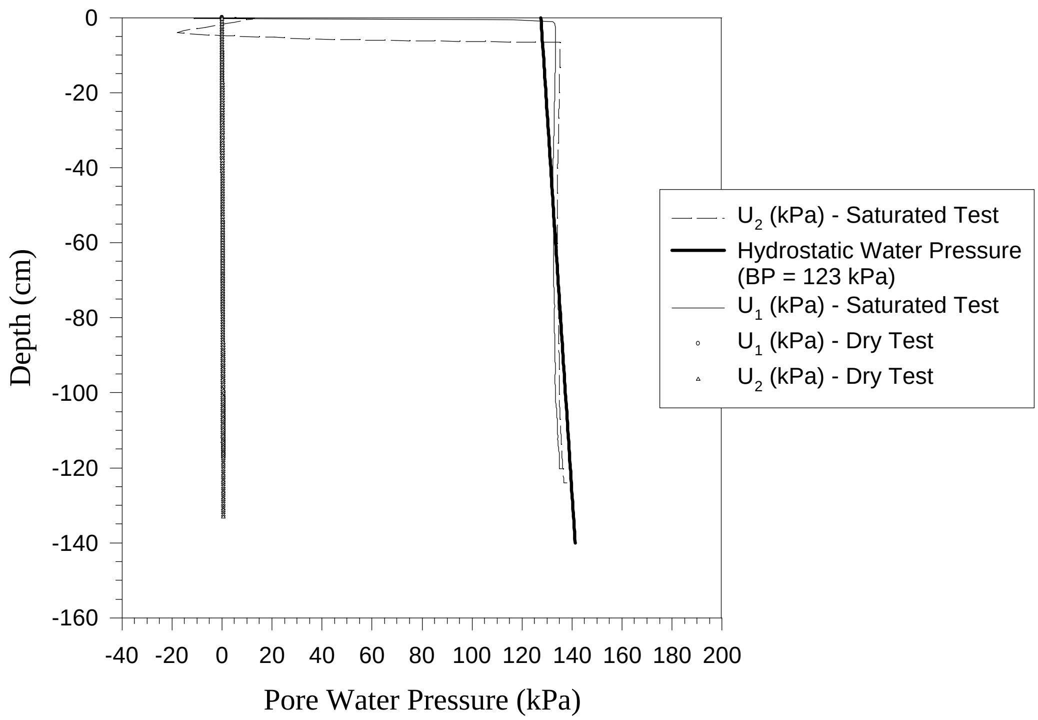
Figure 4. Comparison of Penetration Resistance During Calibration Chamber Tests in Dry and Saturated Sands at Dr = 25% and σ_v ' 101 kPa, σ_h' = 52 kPa

It can be seen from Figures 4 and 5 that the penetration resistance of the saturated sample is slightly lower than that of the dry sample. This may be due to induced positive pore pressures at the U_1 location in the upper portion of the sample or to a slightly lower strength in the saturated sand. It can also be seen in Figure 5 that the induced pore pressures at the U_1 and U_2 locations are negligible for the test in the dry sample. These results suggest that the thermal shock effects have been eliminated by replacing the 200 Bar transducers with the 20 Bar transducers.

IV. <u>Concurrent Research at Georgia Tech</u>

This research program is a collaborative effort between Virginia Tech and Georgia Tech. Project meetings between the Georgia Tech and Virginia Tech is an on-going process. The meetings consist of Professors James Mitchell and Thomas Brandon of Virginia Tech, Paul Mayne of

Georgia Tech, and the students working on the project from both universities. The focus of the work at Georgia Tech involves the development of a suitable vibratory actuator system for calibration chamber and field use. The vibratory actuator construction is near completion, with prototype versions presently being evaluated in field trials. A complete summary of the vibratory



actuator and field performance evaluation has been submitted by Georgia Tech under a separate document of award number 1434-HQ-97-GR-03128.

Figure 5. Comparison of Pore Water Pressure at U_1 and U_2 Locations During Calibration Chamber Tests in Dry and Saturated Sands at Dr = 25% and σ_v‘ 101 kPa, σ_h’ = 52 kPa

V. Reports Published

None at the present time, but it anticipated that publishable data will be available once the vibrating cone penetrometer tests are performed and evaluated. The induced pore pressure values due to temperature increases in the transducer is also an important topic that has not been significantly explored in the current literature. It is expected that results of our findings regarding this issue will be made available within a few months.

VI. Future Research

Immediate future work on the project will focus on the completion of the calibration chamber tests at a relative density of 25% and then the performance of tests at similar effective stress conditions on samples at a relative density of 65%. Samples will be tested in both dry and saturated conditions. Cyclic simple shear testing will be conducted in our strength testing laboratory concurrently with the calibration chamber testing. Vibratory penetration tests will be performed once the vibratory unit is available from Georgia Tech.

After the calibration chamber and laboratory tests have been completed, the research will be focused on the formulation of an analytical model to simulate the pore pressure/shear strain relationships and strength reduction behavior of liquefiable soils. This model will be used to relate the frequency and force input parameters of the piezovibrocone to cyclic stress ratio and ground accelerations associated with earthquake loading.

Upon completion of the piezovibrocone model development, a field testing program will be implemented at known liquefaction sites, allowing for a comparison of the field behavior to model predictions.

VII. References

Zuidberg, H.M. (1988). "Piezocone penetration testing – probe development". Proceedings of the 2nd International Symposium on Penetration Testing, ISOPT-1, Orlando, Specialty Session No. 13, 24 March, 1988, Balkema Pub, Rotterdam.