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Results of Seismic Piezocone and Flat Plate Dilatometer Tests Performed at the I-155 Bridge in Caruthersville, MO



Interim Report
MAEC Project No. GT-3
GTRC Project No. E20-677

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1 INTRODUCTION

This report documents the results from four piezocone penetration tests (CPTu) and two flat plate dilatometer tests (DMT) conducted for the purpose of site characterization and assessment of soil liquefaction potential on the Missouri side of the I-155 bridge. For two of the piezocone soundings, downhole geophysics were performed at rod breaks (approximately 1-meter intervals) in order to obtain discrete determinations of seismic shear wave velocity with depth. The hybrid test is known as the seismic piezocone penetration test (SCPTu).

A brief overview of the cone penetration test (CPT) equipment and DMT equipment used for this study will be discussed, followed by descriptions of the site and presentation of the data.

2 IN-SITU PENETRATION TESTS

2.1 Seismic Piezocone Equipment

Two electronic cone penetrometers, each manufactured by Hogentogler, were used during the investigations. Cones used for each test are listed on the applicable graph as well as in Table-1. A cone penetrometer with a 60° apex at the tip, 10-cm^2 projected tip area, 150-cm^2 sleeve surface area, a pore pressure element located at the mid-face (u_1), and a maximum capacity of 10 tons was used for two soundings. A cone penetrometer with a 60° apex at the tip, 15-cm^2 projected tip area, 225-cm^2 sleeve surface area, a pore pressure element located behind the tip (u_2), and a maximum capacity of 15 tons was used for two soundings. The piezocones were vertically advanced at the standard rate of 2 cm/sec (Lunne et al., 1997). Readings of tip resistance (q_c), sleeve friction (f_s), inclination (i), and pore pressure (u_m) were taken every 5-cm (2.5-sec).

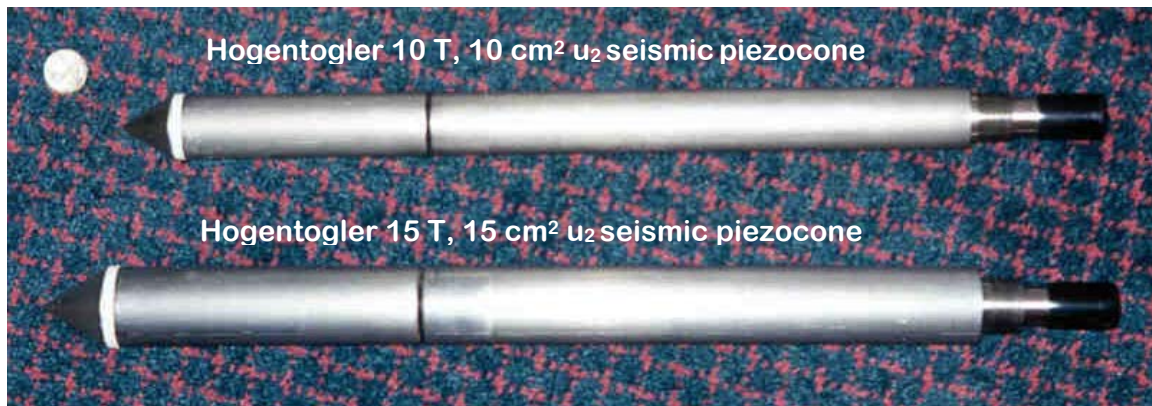


Figure 1. Seismic piezocones used in this study (quarter for scale)

The tip resistance (q_c) is obtained by measurement of the maximum force over the conical tip area of 10-cm^2 or 15-cm^2 . It is a point stress related to the bearing capacity of the soil. The measured q_c must be corrected for pore water pressures acting on the cone tip geometry, particularly in clays and silts, thus obtaining, q_t (Lunne, et al., 1997). The sleeve friction (f_s) is determined as the load over a 150-cm^2 , or 225-cm^2 , sleeve area. The sleeve friction can be

expressed as the Friction Ratio, $FR = f_s / q_t \times 100$, that relates approximately to soil type. The penetration porewater pressures are monitored using a transducer and porous filter element. The filter element position can be located mid-face on the cone (u_1) or behind the cone tip at the shoulder (u_2), with the latter required for the correction of tip resistance. These readings represent the fluid pressures between the soil particles. At the shoulder position, the pressures are near hydrostatic in sands whilst considerably higher than hydrostatic in soft to firm to stiff clays. The pore pressure parameter, $B_q = (u_2 - u_o) / (q_t - \sigma_{vo})$, has been developed to better define soil parameters when using piezocone penetrometers. In this study it has been used in soil classification (Robertson et al., 1986; Lunne et al., 1997) for developing general soil profiles

Inside the penetrometer, approximately 25-cm behind the tip, are a velocity geophone and an inclinometer. The inclinometer is used to assess the verticality of the sounding to warn against excessive drift. The geophone detects vertically-propagating, horizontally-polarized shear waves generated at the ground surface at intervals of approximately 1-meter, corresponding to successive rod additions.

The filter elements consisted of high-density polypropylene that was saturated with glycerin in a small vacuum chamber prior to testing. Filter elements were changed to minimize clogging, and the cone was re-saturated between each test to ensure accurate pore pressure data. The data acquisition system used during testing was a commercial Hogentogler field computer unit interfaced with the GT - GeoStar cone truck. A 10-pin electronic cable connects the penetrometer through the rods to the computer. Depth readings were taken using a gear system attached to the hydraulic rams, and a proximity switch to trigger readings every 5-cm.

The GeoStar truck-mounted rig has a set of hydraulic rams attached to the rear of a 6.7 tonne Ford F-350 Super Duty truck chassis. The unit has a reaction mass of approximately 4 tonnes without anchoring and an additional 20 tonne reaction with earth anchoring. All soundings utilized the earth anchoring system.

2.2 Seismic Piezocone Testing Procedures

Cone penetration tests (CPT) were performed in general accordance to ASTM D-5778 guidelines using an electronic cone penetrometer and computer data acquisition system. The test site was located under the I-155 bridge on the Missouri side of the Mississippi river. A detailed site location and sounding location maps are provided in Section 3 (SITE LAYOUT).

In each of the 15-ton cone soundings, shear wave arrivals were measured at regular intervals of approximately 1-meter. A special instrumented hammer was used to trigger a surface source rich in shear waves from a horizontal steel beam. The steel beam was coupled to the ground by the weight of the GeoStar cone truck, under a hydraulic outrigger. A single horizontal velocity geophone located within the penetrometer served as a receiver for the signal, which was displayed on the Hogentogler computer screen. At least four separate wave records were generated at each depth utilizing left-strike and right-strike polarization. Two waves were taken, compared for repeatability, and then averaged if an acceptable match was recorded. The process was repeated for an additional pair of waves, which were used to determine the first crossover

pseudo-interval shear wave velocity (V_s). Pseudo-interval V_s is obtained from incremental measurements between successive wave time arrivals and the incremental distance to the geophone (Campanella et al., 1986). For the initial depth interval, shear wave first arrival times were utilized to calculate the shear wave velocity. Thereafter, an iterative process of analyzing the difference between successive peak, trough, and first-crossover points on each shear wave was utilized to provide repeatable velocities. First crossover velocities are presented on the figures and in the data.

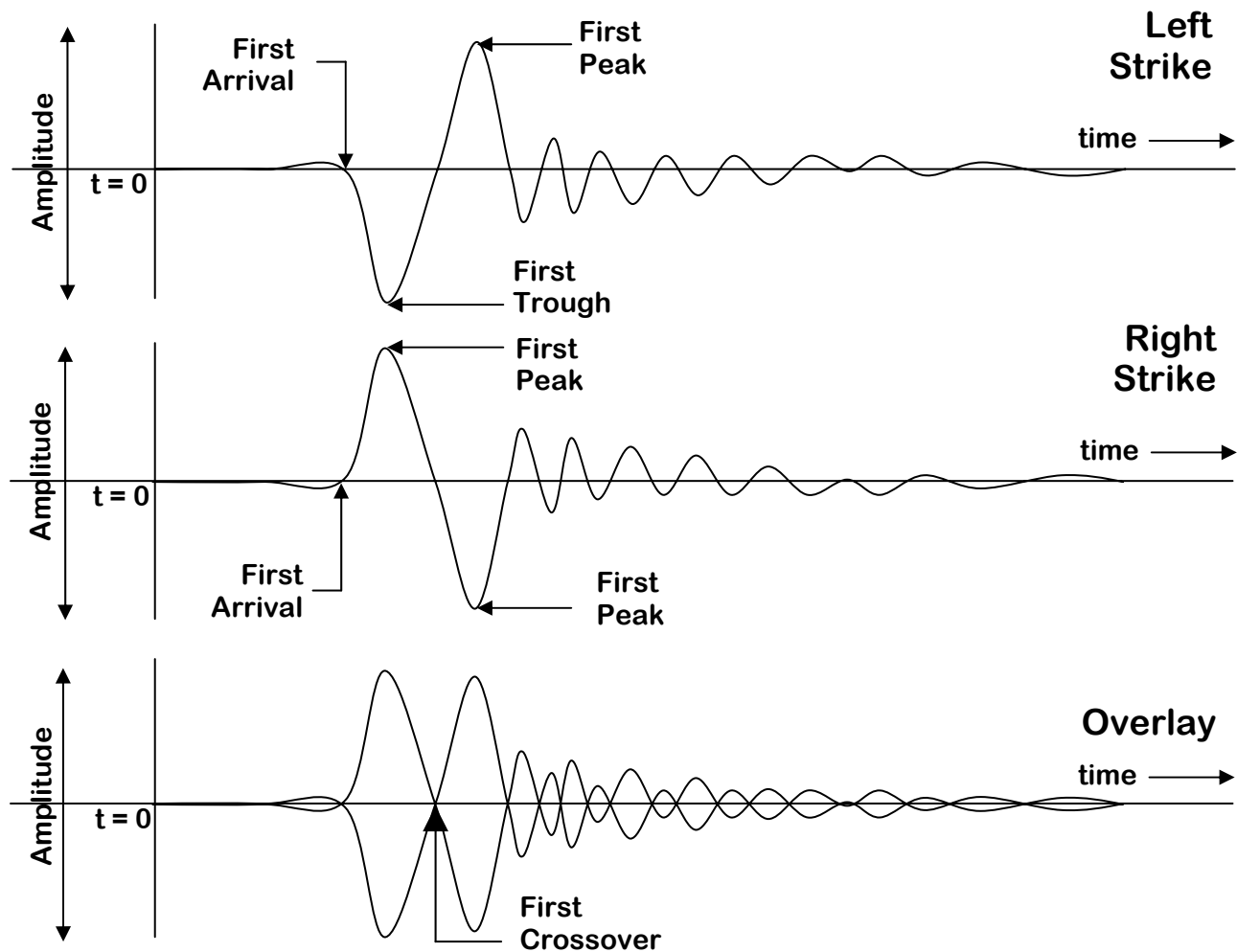


Figure 2. Shear wave arrival time analysis procedure

2.3 Flat Plate Dilatometer Test

The flat plate dilatometer system consists of a high strength steel blade, tubing, pressure gauge readout unit, and a nitrogen gas tank. Two blades, manufactured by GPE of Gainesville, FL, were used in this study. The tapered steel blade is approximately 240-mm long, 95-mm wide, 15-mm thick, with an 18° wedge tip. The blade is pushed into the ground at 20 mm/sec utilizing the same truck and hydraulic system as described in Section 2.1. Discrete tests were performed at approximately 200-mm intervals using a marking system on the hydraulic rams to determine

depth. At each interval, a 60 mm diameter flexible steel membrane on the face of the blade is horizontally inflated with nitrogen pressure to provide two readings: (A) lift-off pressure ($\delta=0$); and (B) expansion pressure ($\delta=1.1$ mm). The A- and B- readings are taken within about one minute after penetration.

Membrane stiffness correction factors are necessary due to the initial stiffness of the membrane. Original correction factors are presented in Marchetti (1980) as:

$$p_0 = A + \Delta A$$

$$p_1 = B - \Delta B$$

where ΔA and ΔB are the applied suction and expansion of the membrane in air, respectively. A more accurate correction has been determined by Schmertmann (1986):

$$p_0 = 1.05(A + \Delta A - z_m) - 0.05(B - \Delta B - z_m)$$

$$p_1 = B - \Delta B - z_m$$

where z_m is the gage offset zero reading. For the data presented in this report, the Schmertmann (1986) membrane stiffness correction factors have been used.

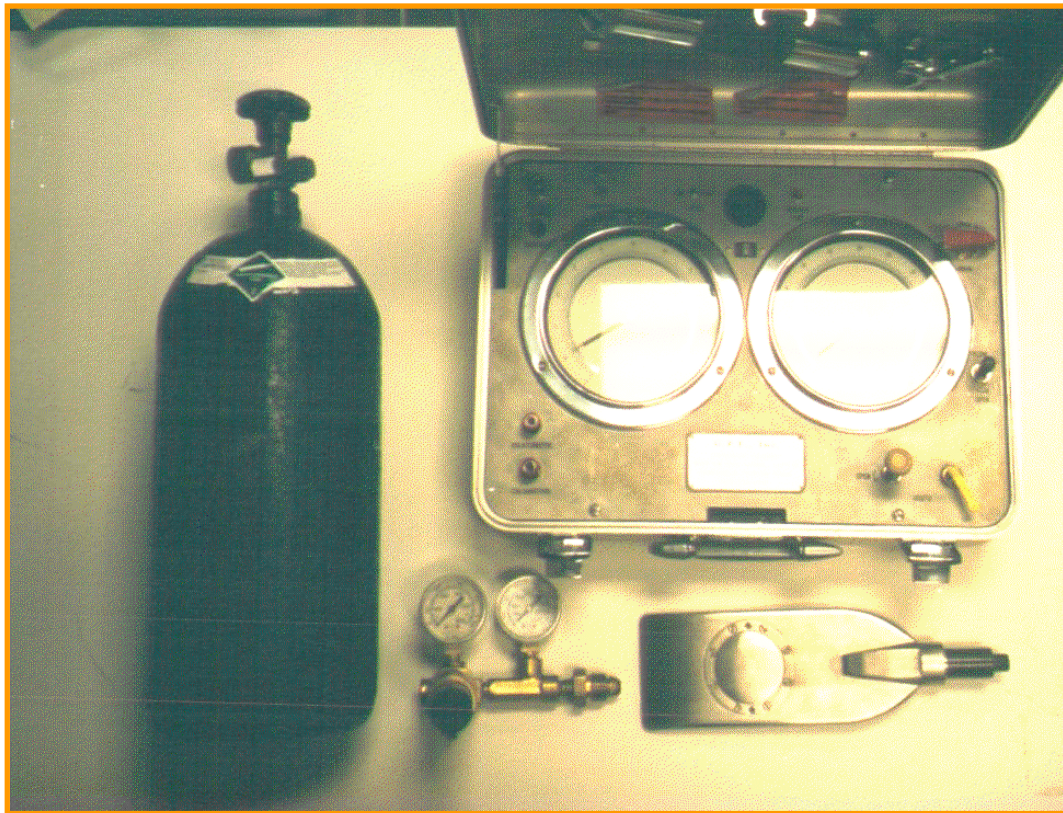


Figure 3. Flat plate dilatometer and associated equipment

The two dilatometer readings, p_o and p_1 , are combined to provide three index parameters developed by Marchetti (1980). The material index, I_D , is related to the soil classification and is presented as:

$$I_D = (p_1 - p_o) / (p_o - u_o)$$

The dilatometer modulus, E_D , is related to the compressibility of the soil. The equation for this parameter is based on elastic theory and is presented as:

$$E_D = 34.7 (p_1 - p_o)$$

The horizontal stress index, K_D , is related to the in-situ horizontal stress-state of the soil. The index K_D will always be greater than K_o due to disturbance caused during insertion. This parameter is presented as:

$$K_D = (p_o - u_o) / \sigma_{vo}'$$

A soil classification and consistency scheme has been developed utilizing the material index, I_D , and Dilatometer Modulus, E_D , and is presented in Schmertmann (1986). The mass density has been estimated by relating these two parameters, and has been presented as:

$$\rho \sim 1.12 (E_D / p_a)^{0.1} I_D^{-0.05}$$

where p_a is the atmospheric pressure in the same units as E_D . While this density is only approximate, it provides a reasonable estimate when determining overburden stresses for additional parameters, such as K_D . This correlation was used to determine mass densities and overburden stresses when performing data analysis during this study.

The hydrostatic water pressure, u_o , is another necessary parameter for analyzing dilatometer results. The pore water pressure can be determined by bleeding off pressure after taking the B-reading, until the membrane is flush with the blade surface. This reading is termed the C-reading. In soft intact clays, the penetration and membrane expansion is undrained, and the C-reading will be near the excess pore water pressure. In sands, the penetration and membrane expansion is drained, and the C-reading will be equal to the hydrostatic pore water pressure, u_o . For this study, the approximate water table depth was estimated from CPT soundings.

The nitrogen gas regulator used during this study could only deliver 19 bars of pressure. Due to the high pressures required to reach the B-reading in medium dense to dense sands, approximately 25 percent of the B-readings were at higher pressures than could be delivered by the regulated nitrogen tank. At these 39 depths, A-readings were taken, and B-readings were estimated from Mississippi Valley soil type specific correlations developed from this testing and other testing in the Blytheville, AR, Steele, MO, and Shelby County, TN areas (Schneider & Mayne, 1998). The estimated B-readings are italicized in Appendix III.

A study of the relationship between initial liftoff pressures and extended pressure readings of the dilatometer was performed by Garcia (1991) using calibration chamber and field test data. This

study found linear relationships between p_0 and p_1 to be dependent upon soil type, but to be independent of relative density and OCR. Previous studies by Konrad (1988) found the slope of the relationship between p_0 and p_1 in granular soils to be dependant upon relative density, but that study of calibration test data only did not install the dilatometer vertically or in a typical manner. Since the $p_0 - p_1$ relationship appears to be primarily dependent upon soil type, and is somewhat site specific, correlations were developed using individual sites, as well as all data collected from three sites in the Mississippi Valley. These correlations are presented in Figure 3. The intercept for each trend was set to zero, since p_1 should be zero if p_0 is zero.

Upon analysis of the I_D equation and re-arrangement of terms, it appears that p_1 should be a function of u_0 as well as p_0 . A number of relationships were evaluated using p_0 , p_1 , and u_0 data from tests in the Mississippi Valley, but an increase in the correlation coefficient, R^2 , was not obtained. This most likely occurred since the $p_0 - p_1$ relationship was already quite good ($0.90 < R^2 < 0.99$), additional uncertainty resulted from estimates of the water table depth, and since u_0 values were much smaller than p_0 values in dense sands they did not have much effect.

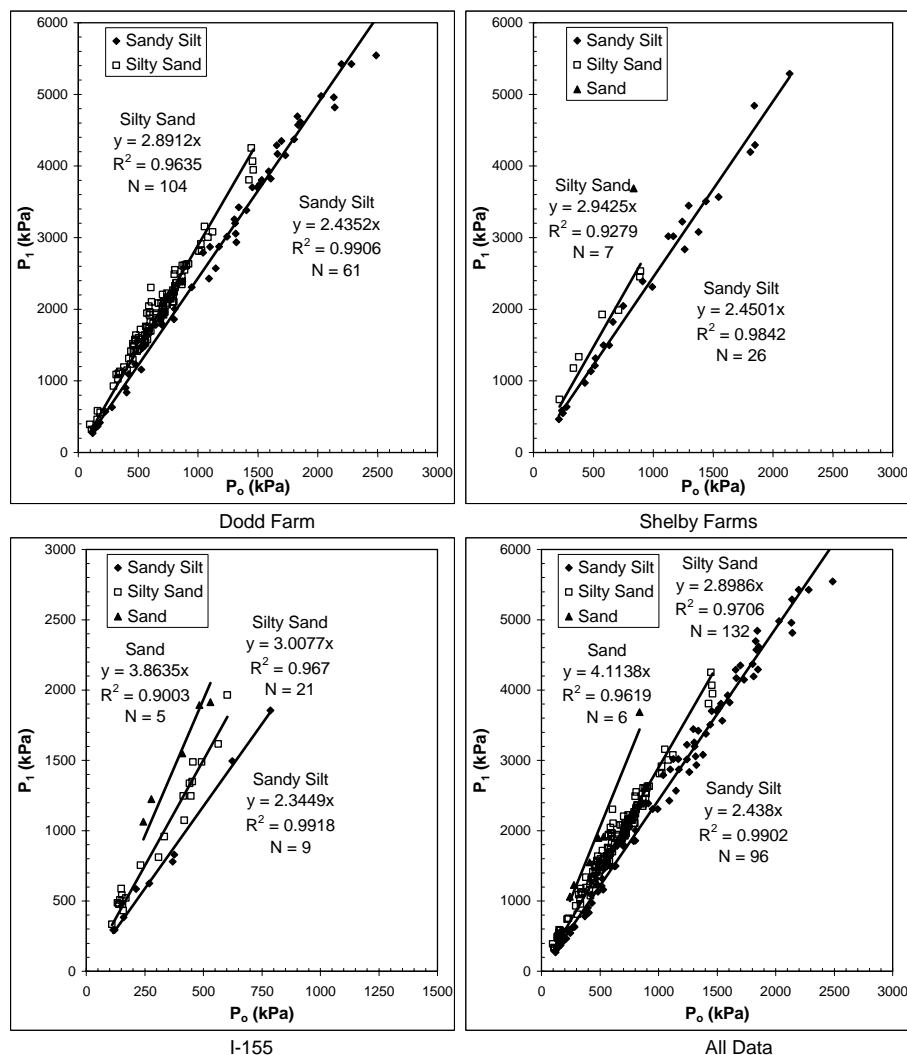


Figure 4. Relationships between p_0 and p_1 in Mississippi Valley Soils

3 SITE SETUP

Six soundings were performed below the I-155 Bridge on the Missouri side of the Mississippi River. Figure 5 shows the approximate site location with reference to pertinent landmarks.

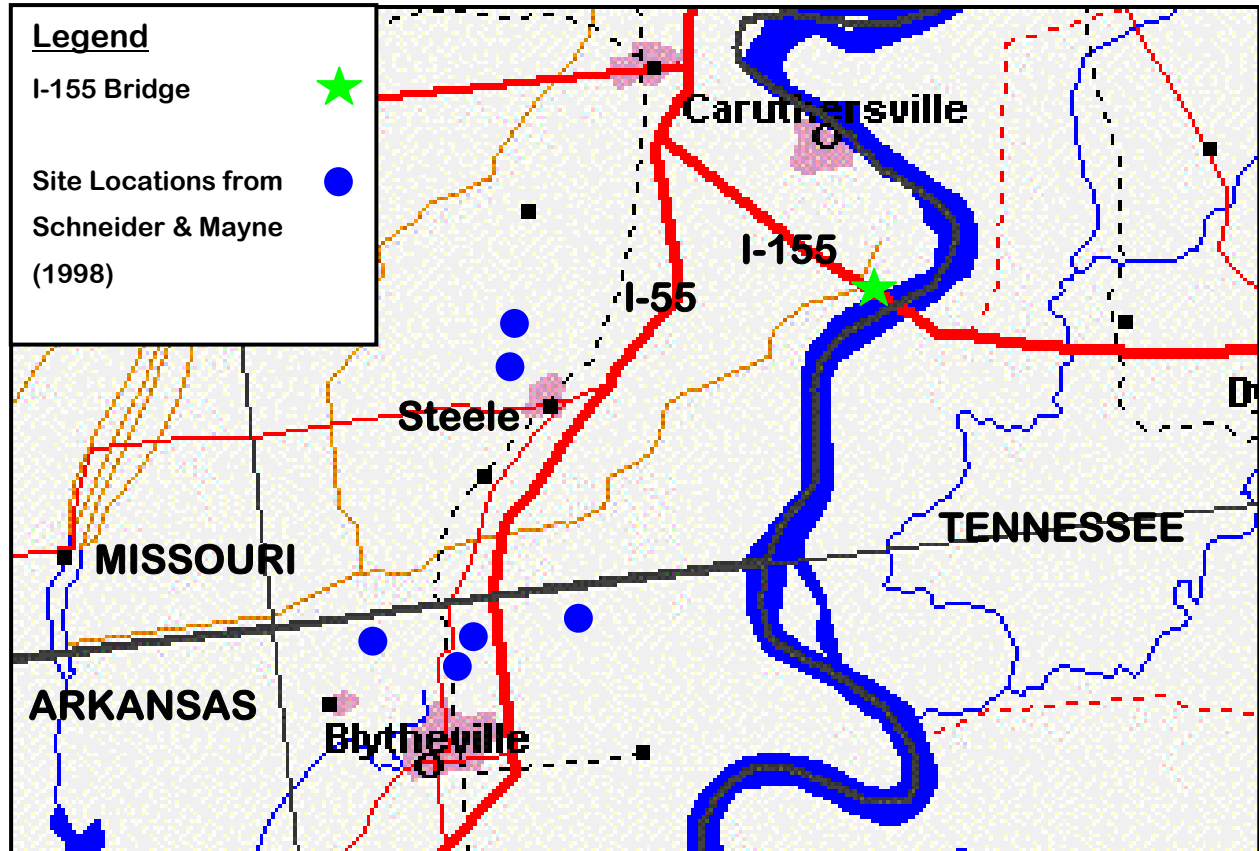


Figure 5. Location of Test Site

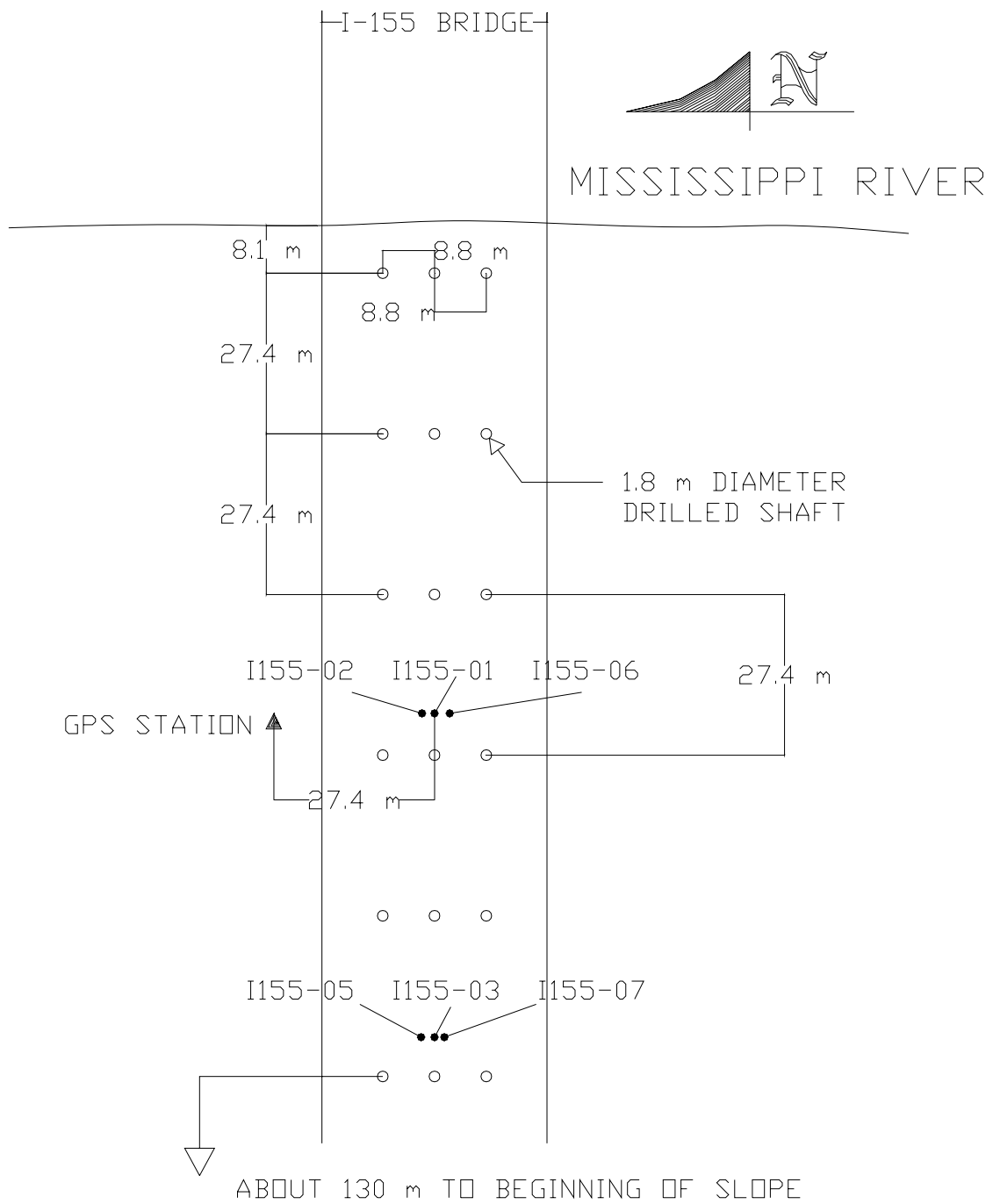


Figure 6. Layout of all tests performed under the I-155 bridge

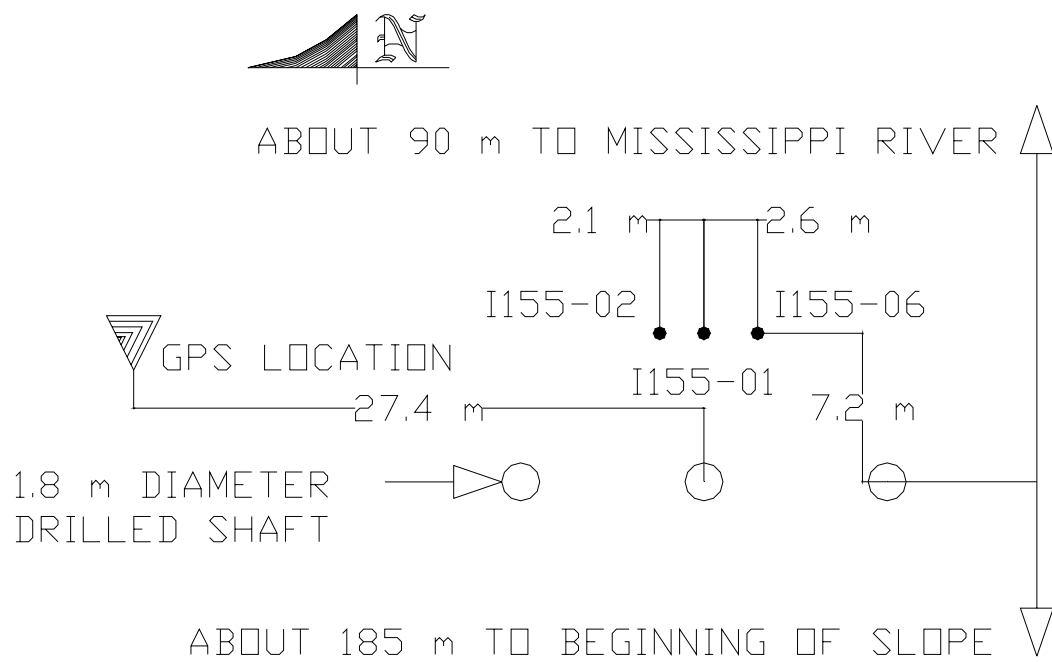


Figure 7. Detailed layout of tests between third and fourth column set



Figure 8. Photograph of GT GeoStar Truck set up under I-155 Bridge

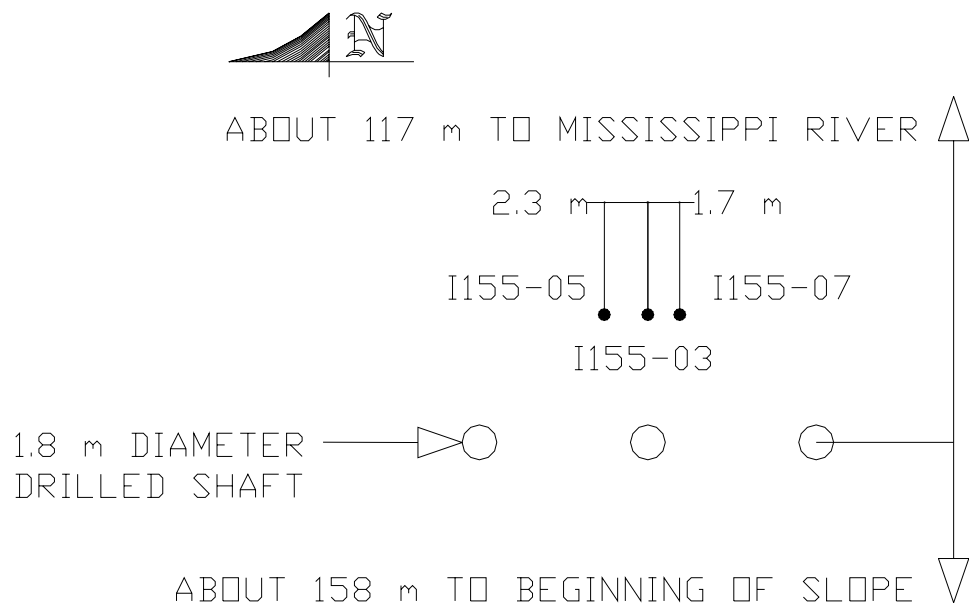


Figure 9. Detailed layout of tests between fourth and fifth column set



Figure 10. Photograph of setup for Dilatometer Testing

4 RESULTS

Four piezocone soundings and two dilatometer soundings were performed at the I-155 bridge site described in the previous section. Table 1 displays pertinent information for each sounding performed. Figures 12 through 17 display the results of each sounding. An interpreted soil profile was determined using a combination of the Robertson et al. (1986) Friction Ratio and Pore Pressure Parameter (B_q) charts for the CPT soundings, and from the Material Index, I_D , defined in Marchetti (1980). Figure 11 displays a legend used for the soil profiles in Figures 12 - 17. The raw digital cone data is contained in Appendix I, and the raw seismic data is contained in Appendix II. The raw digital DMT data is contained in Appendix III. GPS locations were determined using a hand held Garmen GPS III unit. The units averaging function was utilized to provide position error estimations.

Table 1. Piezocone and DMT Soundings Performed at the I-155 Bridge
GPS Location: N: 36° 07.133' ± 33.4 feet W: 089° 36.896' ± 33.4 feet

Sounding	Depth (m)	Notes
I155-01	25.55	15 T, 15 cm ² SCPTu ₂ sounding.
I155-02	22.00	10 T, 10 cm ² CPTu ₁ sounding.
I155-03	23.25	15 T, 15 cm ² SCPTu ₂ sounding.
I155-05	18.00	10 T, 10 cm ² CPTu ₁ sounding.
I155-06	0.2 - 15.85	DMT sounding; I.D. GB67; Blade perpendicular to river; Low pressure for 9 B-readings.
I155-07	0.2 - 15.85	DMT sounding; I.D. GB67; Blade parallel to river; Low pressure for 30 B-readings.

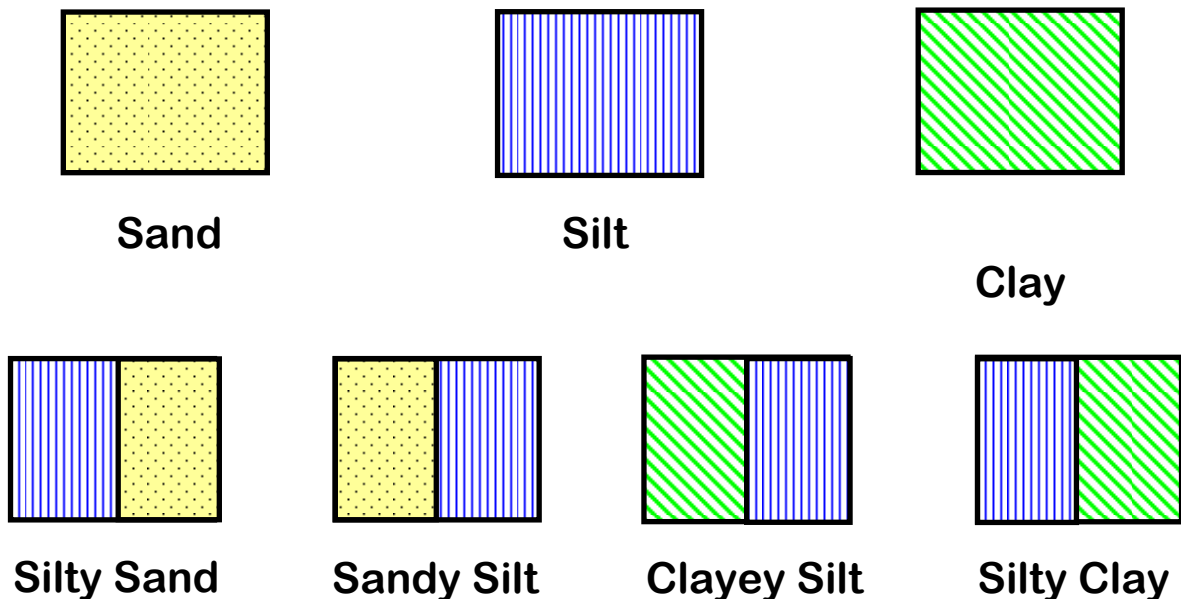


Figure 11. General soil classification legend for profiles depicted in Figures 7 - 12

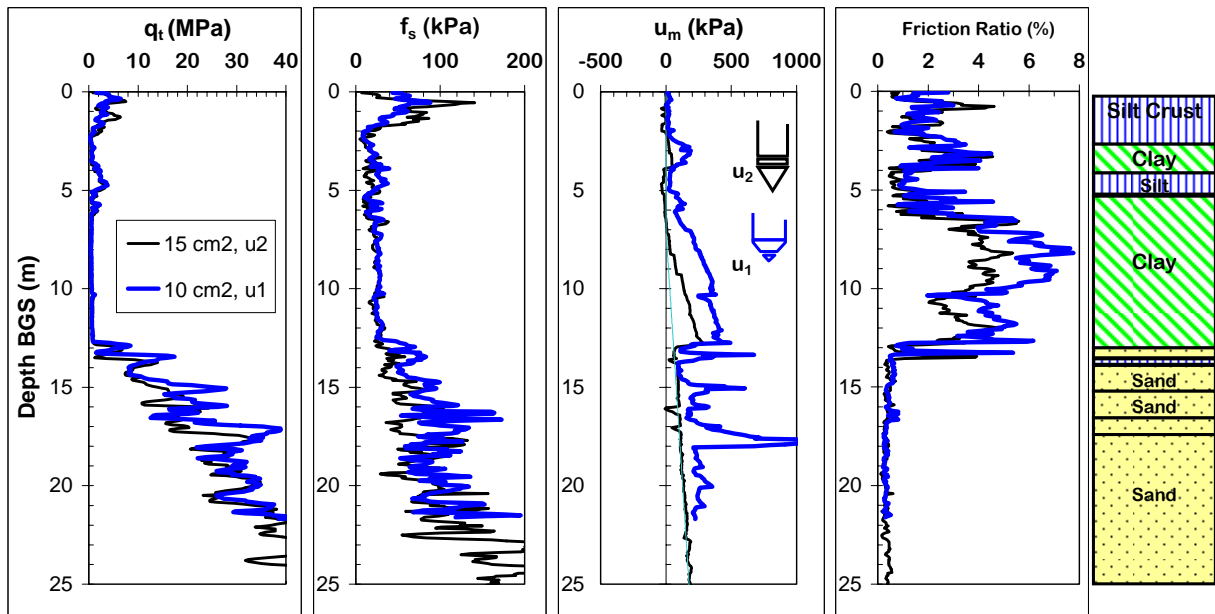
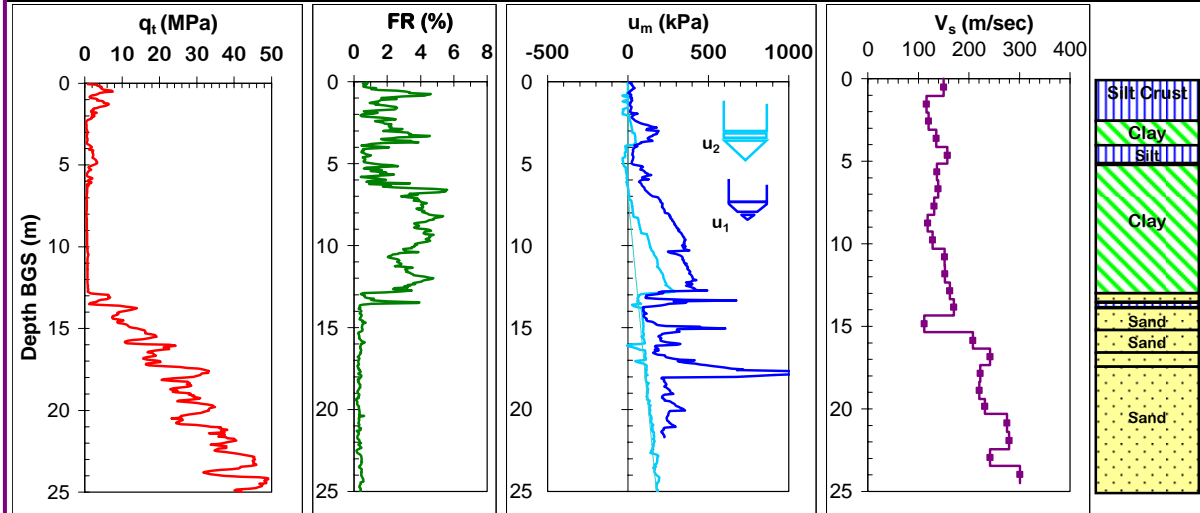
5 ACKNOWLEDGMENTS

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SOUNDING PERFORMED FOR MAEC		GEORGIA INSTITUTE OF TECHNOLOGY	
Date: 10/29/98	Truck: GT GeoStar	Predrill: -	one Type: Hog 15/10 Ton
Test Site: I-155 Bridge	Test No: I15501/02	GWT: 7 m	Filter: Type 2 / Type 1
Location: Caruthersville, MO	Distance to Sounding Axis from Seismic Source: 0.75 m		Operators: James Schneider Ken Thomas



**SEISMIC CONE PENETROMETER DATA
SOUNDING PERFORMED FOR MAEC**

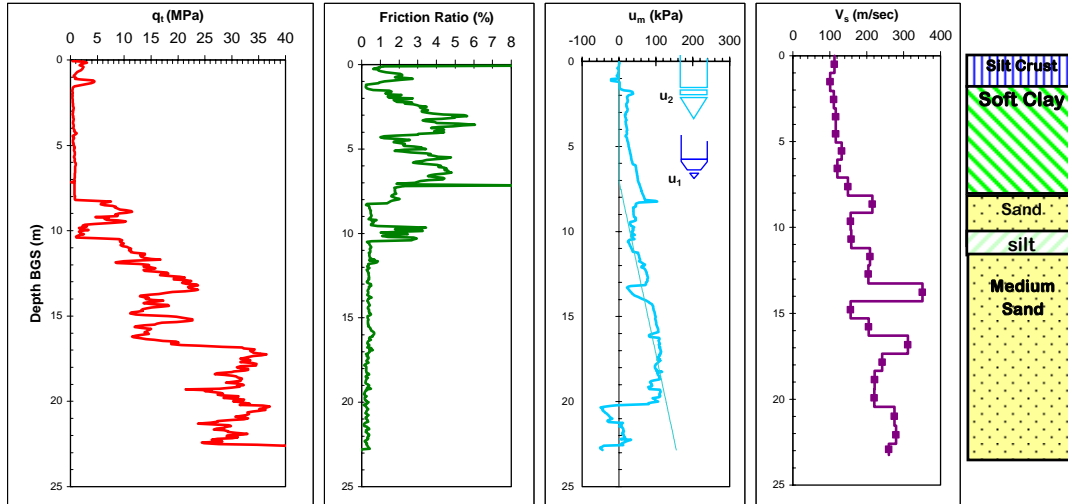
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY**

Date: 10/28/98
Test Site: I-155 Bridge
Location: Caruthersville, MO

Truck: GT GeoStar
Test No: I15501/02
Distance to Sounding Axis from Seismic Source: 0.75 m

Predrill: -
GWT: 7 m

Cone Type: Hog 15/10 Ton
Filter: Type 2 / Type 1
Operators: James Schneider
Ken Thomas



**SEISMIC CONE PENETROMETER DATA
SOUNDING PERFORMED FOR MAEC**

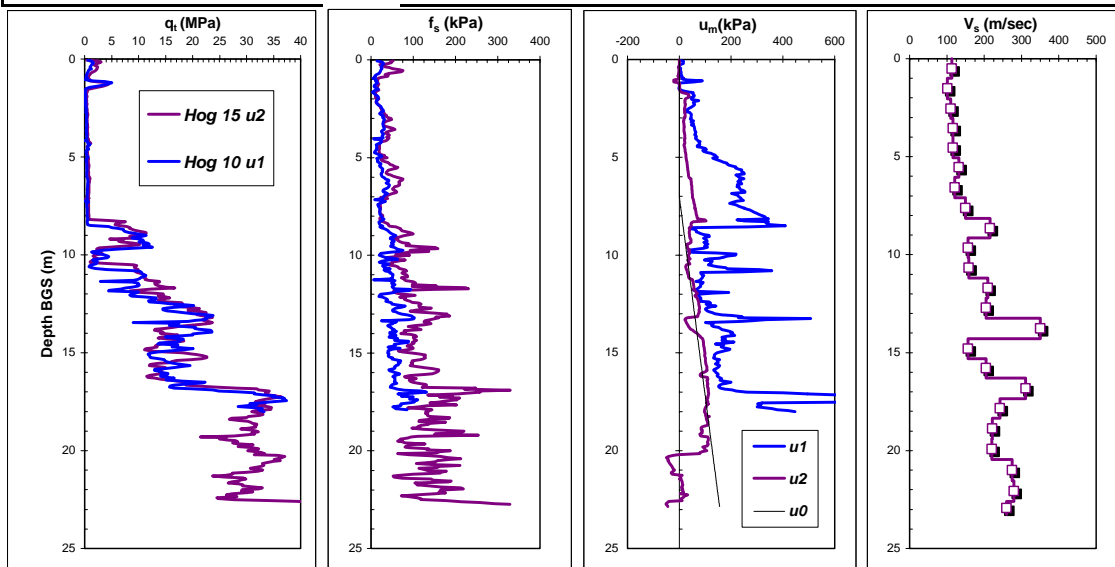
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GEORGIA INSTITUTE OF TECHNOLOGY**

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Location: Caruthersville, MO

Truck: GT GeoStar
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Distance to Sounding Axis from Seismic Source: 0.75 m

Predrill: -
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Cone Type: Hog 15/10 Ton
Filter: Type 2 / Type 1
Operators: James Schneider
Ken Thomas



DILATOMETER TEST DATA
SOUNDING PERFORMED FOR MoDOT

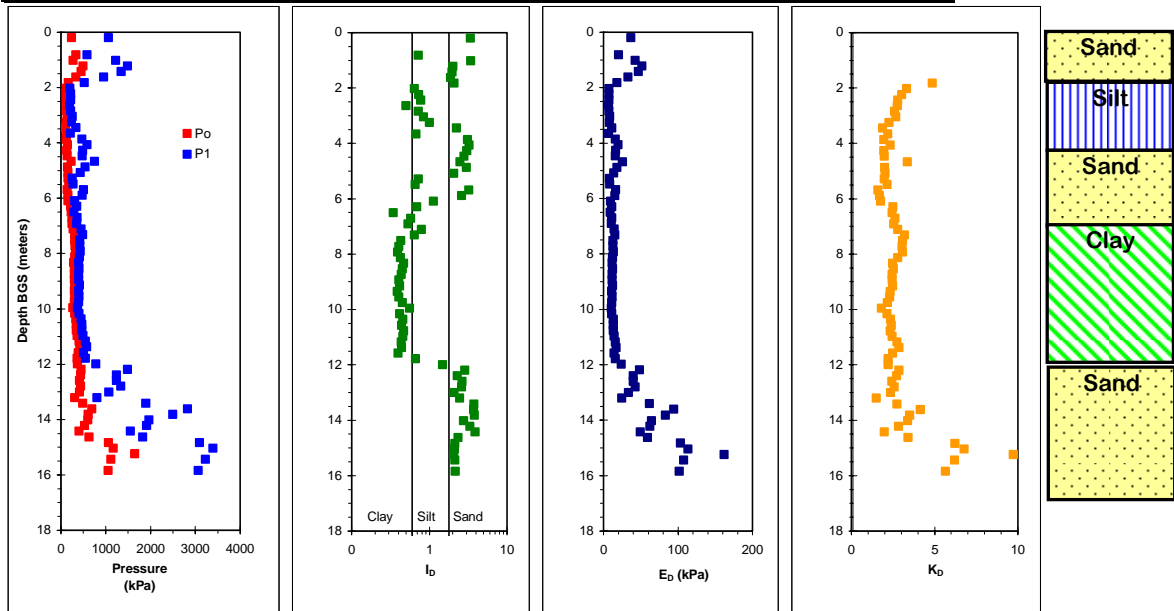
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY

Date: 10/15/1998
Test Site: Caruthersville
Location: DMT I15506

Truck: MDOT Rig
Test No: MDOT-DM1

Predrill: 0
GWT: 2.5 m

Operators:
 James Schneider
 Paul Mayne



DILATOMETER TEST DATA
SOUNDING PERFORMED FOR MAEC

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Date: 10/29/98
Test Site: I-155 Bridge
Location: Caruthersville, MO

Truck: GT GeoStar
Test No: I155-07

Predrill: 0
GWT: 2.5 m

Operators:
 James Schneider
 Paul Mayne

