Comparison of pre-bored and push-in pressuremeter results in Miocene-aged fine grain soil

R. A. Failmezger
In-situ Soil Testing, Morattico, Virginia, USA
J. A. Padgett
GeoServices Corporation, Forestville, Maryland, USA

ABSTRACT: Push-in pressuremeter tests take less time to perform than pre-bored pressuremeter tests because they eliminate hole drilling preparation time. Each push-in pressuremeter test disturbs the soil the same amount, while the amount of disturbance for pre-bored tests depends on the skill of the driller. However, geotechnical engineers use empirical design methods established from large databases of pre-bored pressuremeter test and load test data.

A series of pre-bored and pushed-in pressuremeter tests were performed in a Miocene-aged fine grained soil on the east coast of the USA. The initial modulus, limit pressure, moduli from unload-reload loops and creep factors were compared along with adjacent seismic CPT. The interpreted parameters from the pushed-in pressuremeter tests varied more than those values from the pre-bored tests. The limit pressure from the pre-bored pressuremeter test equaled the tip resistance from the CPT.

1 INTRODUCTION

The objective of this paper is to compare seismic cone penetration test (SCPT) results with both pushed-in (full-displacement) pressuremeter (PIPMT) and pre-bored pressuremeter (PBMT) results at a site composed of Miocene-age fine-grained soils. The site is located in Forestville, Maryland on the east coast of the USA and is composed of approximately 30m of coastal plain, Miocene-age, fine-grained soils. A series of 12 PIPMT and 12 PBMT were carried out from a depth of 6m to 24m in two locations approximately 1.5m apart. SCPT probe was 1 meter below the PIPMT and data from both tests were collected from that same sounding.

2 GEOLOGIC DESCRIPTION OF THE MICOCENE-AGED DEPOSITS

Testing was performed in a relatively thick (30 m [100 ft.±]) and relatively uniform coastal plain soil, a Miocene Age deposit known locally as the Chesapeake Group. At this location the stratum underlies local fills and shallow remnants of Pliocene Age river deposits. Soils in the test stratum classified as poorly graded (fine to very fine) sandy clay, clayey sand, silty sand or sandy silt, soft to loose (N_{60} = 1 to 7, typical) group symbols CH, SC, SM, MH, with the variation due to only slight changes in the constituents. Typically, the stratum becomes firmer and sandier with depth, and may contain shell fragments and occasional cemented layers although none were observed in the tested zones. Soils in-situ are moist to wet and often have low permeability. Notably, these soils are sensitive: they lose strength when remolded. The low N-values reflect in part remolding from dynamically driving the sample spoon.

3 FIELD TESTING

3.1 Equipment and Procedures

For the pre-bored pressuremeter tests, an experienced driller prepared the test zones with mud rotary techniques using a 2-15/16 inch (74 mm) diameter three-winged drag bit. He advanced the bit slowly cutting the fine-grained soil into small pieces, which minimized the disturbance to the borehole sidewalls. The pressuremeter tests had the classical “S” shape, indicating high quality tests. The tests used a Roctest monocell “N”-sized (74 mm) probe with the Texam control unit. A digital counter, accurate to the nearest 0.1 cm^3, measured the volume and a digital pressure gauge, accurate to the nearest 1 kPa, measured the pressure.

For the pushed-in pressuremeter tests, a direct push rig inserted the pressuremeter into the soil. A Hogentogler seismic piezocone, exactly 1.00 meter below the center of the pushed-in pressuremeter probe, was pushed into the soil and measured tip resistance, friction sleeve resistance, pore water pressure at the U2 position, and inclination at 1 cm depth intervals. At one meter depth intervals seismic shear wave tests were performed. During the pressuremeter testing, pore pressure dissipation tests were performed.

Figure 1 illustrates the pushed-in pressuremeter equipment. A Roctest Pencil pressuremeter was placed inside a steel pipe [1.5 inch (38 mm) ID and 2.0 inch (51 mm) OD] that had 16 longitudinal slots with 0.01 inch (0.254 mm) widths. The pushed-in pressuremeter probe served as the friction reducer for the push system. The steel casing flexed enough to expand laterally yet was strong enough for pushing into dense sands without damage. The narrow slots prevented sand from migrating into the steel casing. Both the cone penetrometer and pressuremeter cables were threaded through the push rods, whose inside diameter was 1.0 inch (25.4 mm).

Figure 1: Photo of a) expanded pushed-in PMT b) close-up of longitudinal 0.254 mm wide slots c) lowering slotted PMT into thick walled steel calibration pipe d) Texam pressuremeter control unit

Swagelok quick-connect fittings conveniently connected the pressuremeter tubing and probe. These fittings were taped together to prevent them from inadvertently disconnecting.

For both tests, the probes were carefully saturated and then calibrated for membrane resistance and system compressibility. The raw pressuremeter data were corrected for these calibrations to get the true pressuremeter curves. Both the pre-bored and pushed-in pressuremeter probes had similar system compressibility calibrations. The push-in pressuremeter probe inside its slotted steel casing had a membrane resistance of 300 kPa when fully expanded, while the pre-bored probe had a membrane resistance of 50 kPa when fully expanded. The smaller pushed-in probe could be inflated to a maximum of 300 cm^3, while the pre-bored probed could be inflated to 1600 cm^3. Volume-controlled tests for the pushed-in probe used increments of 10 cm^3 and for the pre-bored probe used increments of 40 cm^3. For unload-reload cycles their volumes were decreased and increased using half volume increments.

After reaching the top of the elastic portion of the pressuremeter curve, an unload-reload stress-strain cycle was performed. At the next volume increment, the pressure was held constant for ten minutes and the creep volumes were measured at elapsed times of 1, 2, 4, 7 and 10 minutes. The creep results were compared to the dissipation test results. The probes were expanded until the limit pressures could be determined and then deflated, with an unload-reload stress-strain loop at the beginning of the deflation. Example plots of the corrected pushed-in and pre-bored pressuremeter tests are presented as Figure 2.

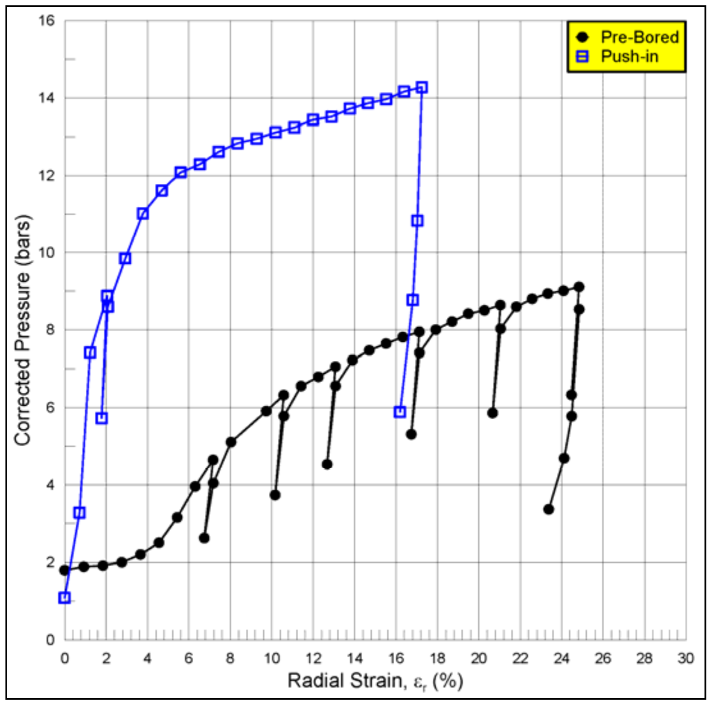


Figure 2: Example of pre-bored and pushed-in pressuremeter curves

4 TEST RESULTS

4.1 *Seismic CPT Results*

A Hogentogler seismic CPT was pushed ahead of the pushed-in pressuremeter tests. Figure 3 shows the results of this sounding. The Miocene Age formation started at a depth of about 6 meters and extended the full length of the sounding. The CPT tip resistance decreased from 6 MPa at 6 meters to 0.5 MPa at 10 meters and then gradually increased to 4 MPa at 26 meters. The shear wave velocity gradually increased from 200 m/s at 6 meters to 300 m/s at 26 meters. Excess pore pressure readings were measured at 8.5 meters and continued increase to the bottom of the sounding. In sandier zones, rapid pressure decreases were measured. When the penetration was paused to perform a pressuremeter test, the excess pressures dissipated fairly rapidly to 50% of their initial value, generally within 2 minutes.

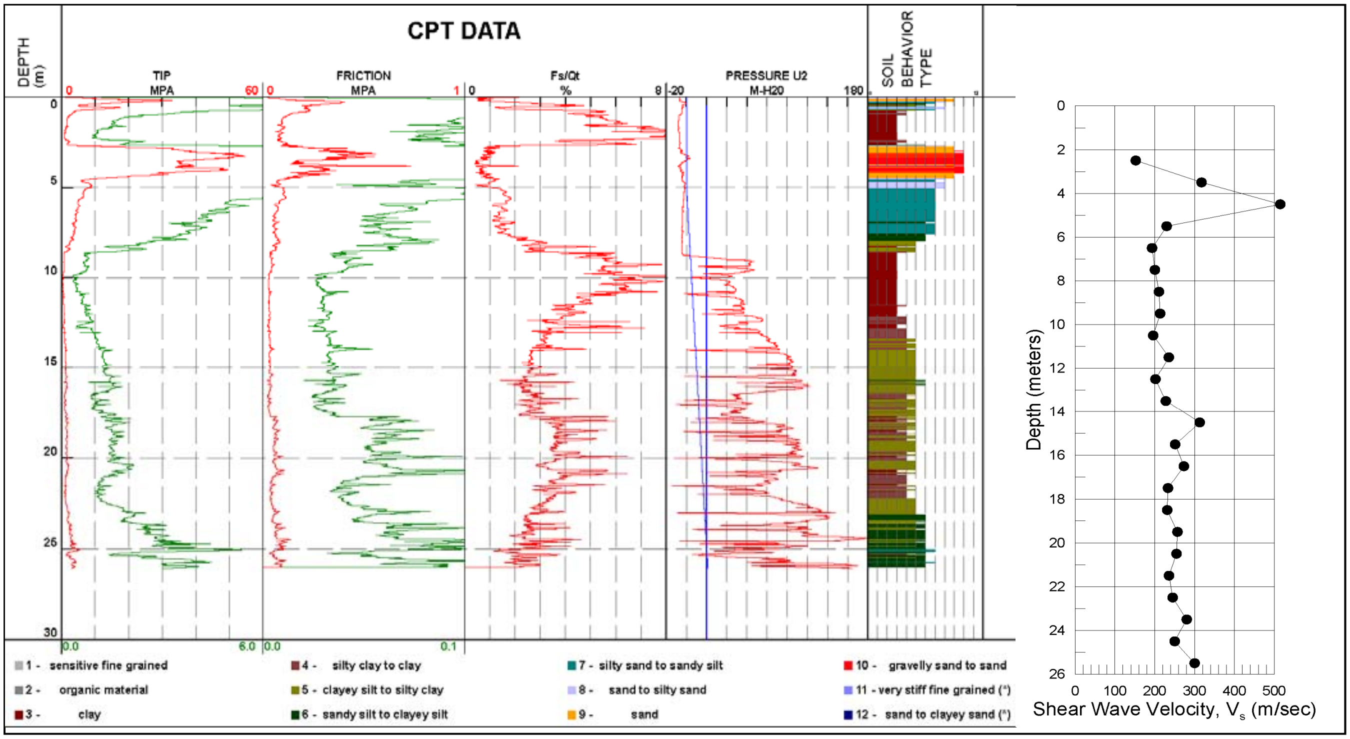


Figure 3: Results from Seismic CPT Sounding

4.2 *Laboratory Test Results*

Within the pre-bored pressuremeter test sounding, standard penetration tests (SPT) were performed between pressuremeter tests. General index tests (gradation, Atterberg limits, and moisture content) were performed on these samples and Figure 4 presents their results.

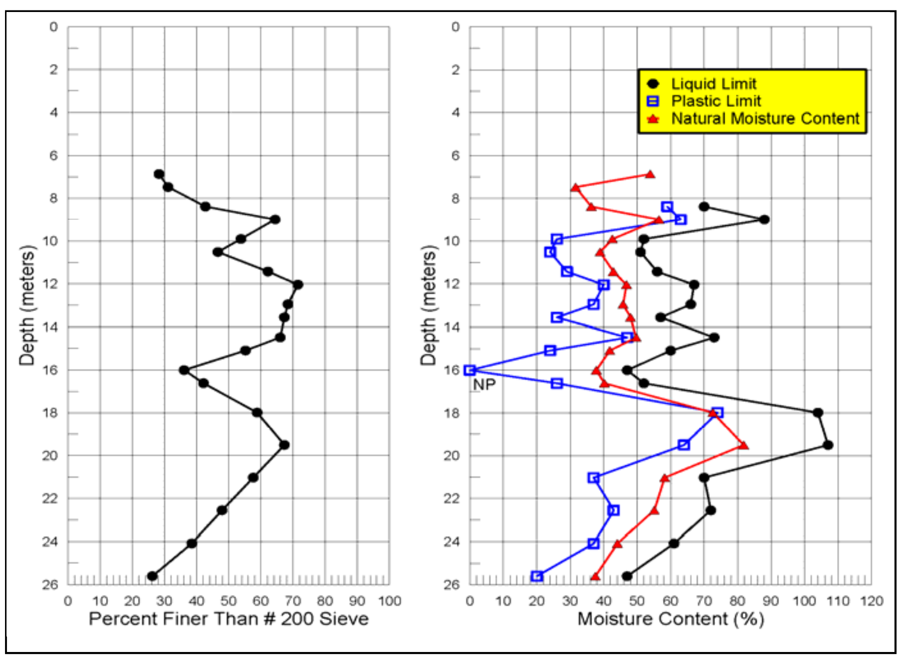


Figure 4: Laboratory Test Results

4.3 *Pressuremeter Test Results*

In two holes separated by 1.5 meters, twelve (12) pre-bored and pushed-in pressuremeter tests were performed from 6 to 24 meters. From these tests, the initial elastic modulus, reload modulus, unload modulus, creep factor, and limit pressure were interpreted. Figures 5a through 9a show those values plotted versus depth. Figures 5b to 9b present the ratio of the pushed-in/pre-bored pressuremeter values with increasing depth.

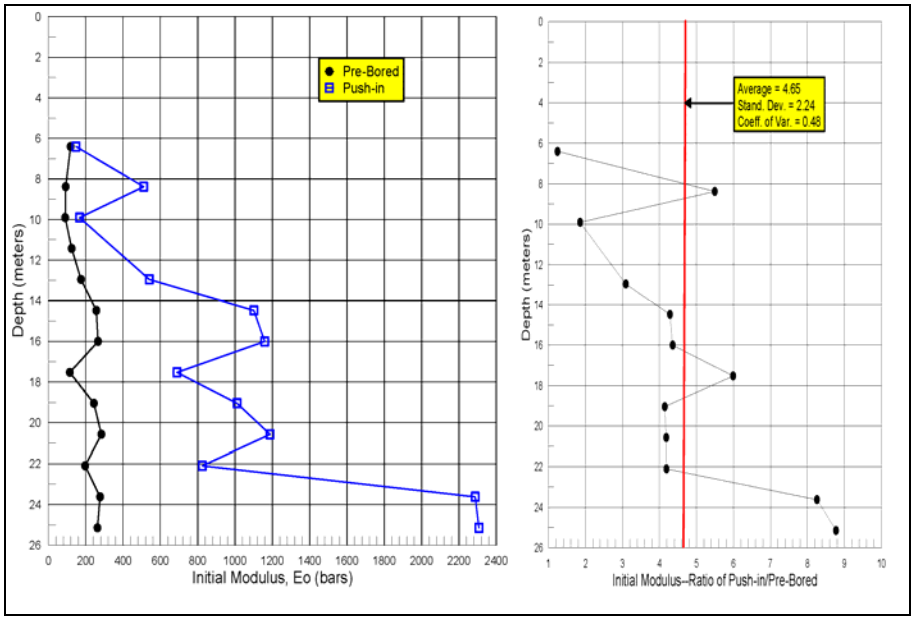


Figure 5a, 5b: Initial Modulus from Pushed-in and Pre-bored Pressuremeter Tests

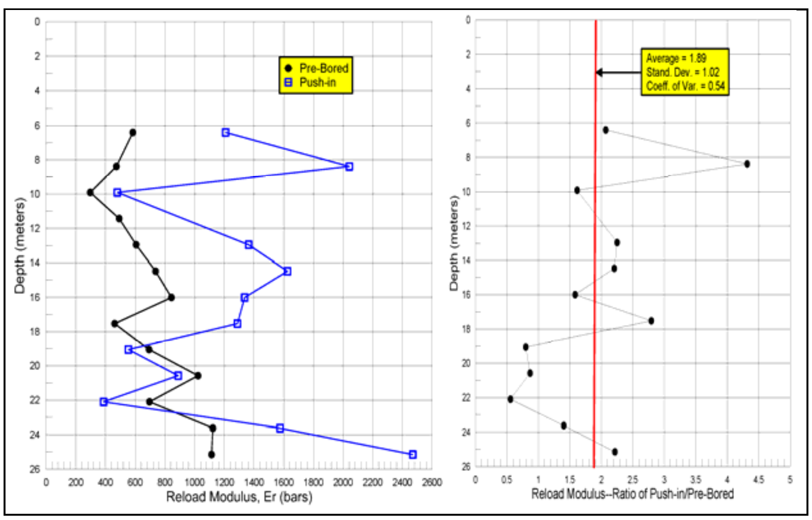


Figure 6a, 6b: Reload Modulus from Pushed-in and Pre-bored Pressuremeter Tests

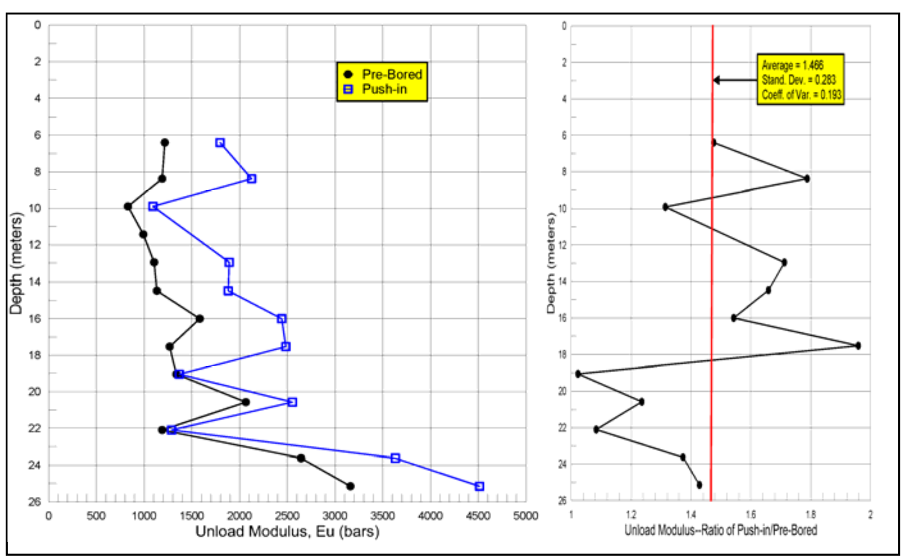


Figure 7a, 7b: Unload Modulus from Pushed-in and Pre-bored Pressuremeter Tests

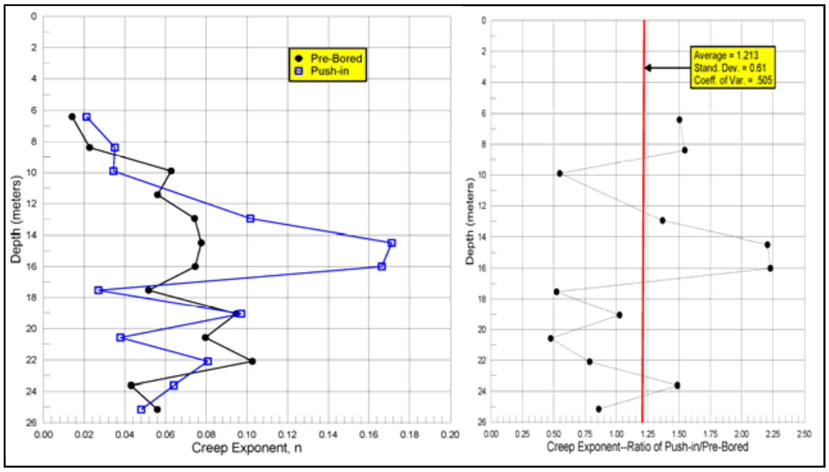
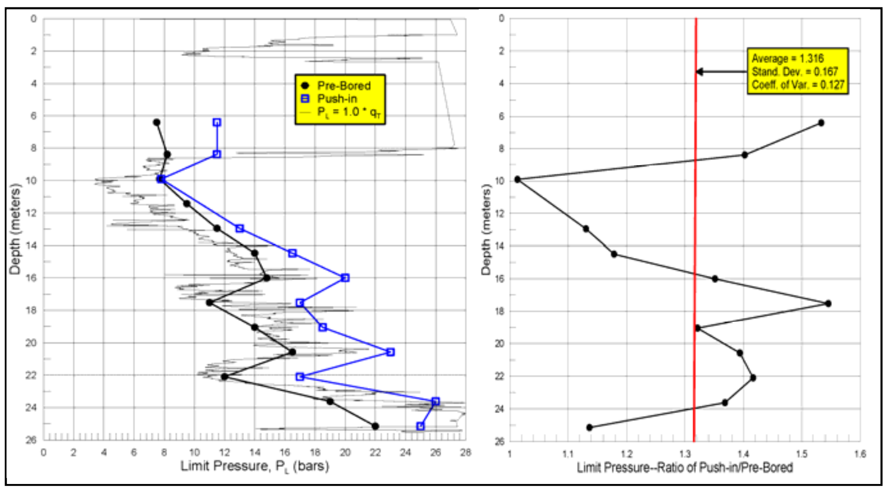


Figure 8a, 8b: Creep Exponent from Pushed-in and Pre-bored Pressuremeter Tests

Figure 9a, 9b: Limit Pressure from Pushed-in and Pre-bored Pressuremeter Tests



The pressuremeter moduli for the pushed-in tests exceeded the pre-bored values, particularly for the moduli computed at the lower radial strains. In a few cases the initial modulus of the pushed-in PMT was more than the reload modulus, which was incorrect. Here, at the end of the elastic portion and beginning of the plastic portion of the pressuremeter curve, the incremental modulus abruptly decreased. But, for all the pre-bored PMT, the incremental modulus gradually decreased when transitioning from the elastic to plastic phase.

The limit pressure for the pushed-in PMT exceeded the pre-bored tests by an average of 32%. The CPT tip resistance approximately equaled the limit pressure from the pre-bored pressure tests below 8 meters.

4.4 *Borehole wall disturbance*

When making the pressuremeter test zone for pre-bored tests, an experienced driller makes all the difference. As he slowly and carefully carved the soil away, Ronald Stidham, our driller, created excellent holes for these tests, which can be easily observed by the consistency and trending of the data.

For the pushed-in pressuremeter tests, the radial distance disturbing the borehole sidewalls was likely the same for each test. In these sensitive Miocene-aged soils, the disturbance significantly affected the initial modulus and reload modulus and to a lesser degree the unload modulus and limit pressure, which is evident by the scatter in their values. The radial thickness of the disturbance generally remains constant regardless of the probe diameter. Briaud (2013) For these soils, perhaps a larger diameter probe, although more difficult to push, would have given better results.

4.5 *Comparison of computed Young's moduli values*

From the seismic shear wave tests, the low strain shear modulus can be computed using:

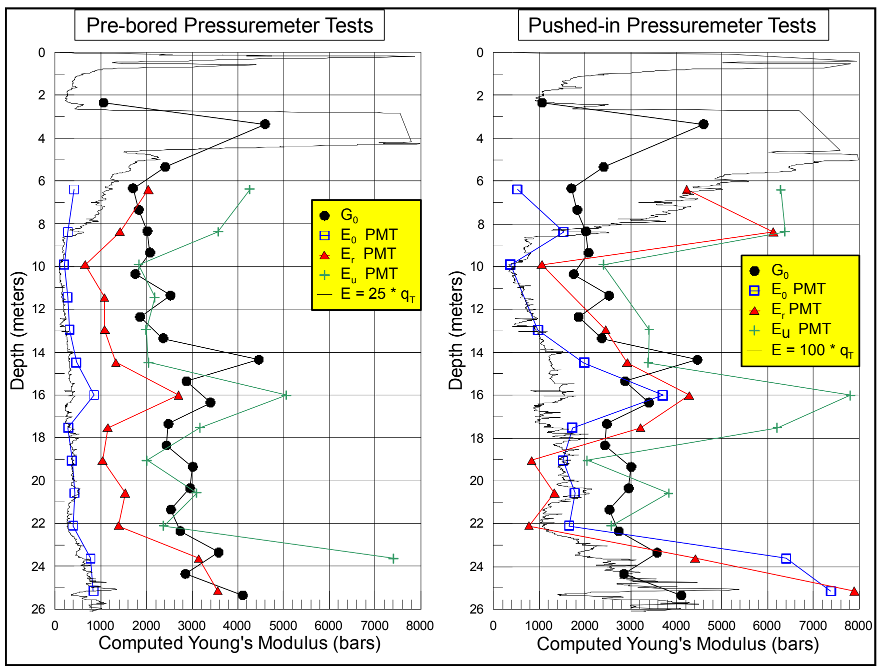
$G_0 = \rho\ (V_s)^2$, (1)

where ρ equals the total mass density, and
V_s equals the shear wave velocity. For these comparisons, ρ = 1.9.
From the shear modulus, the Young's modulus can be computed using:

$E_0 = 2G_0\ (1 + \nu)$, (2)

where ν equals the Poisson's ratio. These comparisons use a value of 0.2.

With pressuremeter tests, the Young's modulus can be computed from the pressuremeter modulus depending on its compression/tension modulus ratio. Briaud (2013) shows this ratio ranges from 5 for clay to about 20 for sand, making the Young's modulus to pressuremeter modulus ratio of 1.5 for clay and 3.5 for sand. Multiplying the CPT tip resistance by 25 compared well with the initial modulus for the pre-bored pressuremeter tests and by 100 compared well for the initial modulus of the pushed-in pressuremeter tests. Figures 10a and 10b present computed Young's moduli from seismic CPT data and pre-bored pressuremeter/pushed-in pressuremeter data, respectively. A couple values exceeded 8000 bars and were cropped from the graphs.



Figures 10a, 10b: Computed Young's moduli from pre-bored and pushed-in pressuremeter tests

4.6 *Time Rate Effects*

At the next volume increment following the unload-reload stress loop at the end of the elastic portion of the pressuremeter curve, the pressure was held constant and volumes were measured at 1, 2, 4, 7, and 10 minutes. The creep exponent was calculated as the slope of the log of volume increase versus log of elapsed time. Simultaneously, while performing the pushed-in pressuremeter tests, the CPT data acquisition computer measured the dissipation of the excess pore water pressures. The pore water pressures dissipated normally during the pressuremeter test until the pressuremeter was expanded into the plastic zone following the creep test. The pressure measured at the piezocone transducer (1.0 meter below the center of the pressuremeter) abruptly increased as the pressuremeter volume/pressure increased. But when the pressuremeter was unloaded the pore pressures returned to the normal dissipation curve. Figure 11 shows the pressuremeter creep exponent for pre-bored and pushed-in tests, coefficient of consolidation in the horizontal direction from the dissipation tests and the percent finer than the #200 sieve from the gradation lab tests. As expected, as the percent passing the #200 sieve decreased, the pressuremeter creep exponent decreased and the horizontal coefficient of consolidation increased.

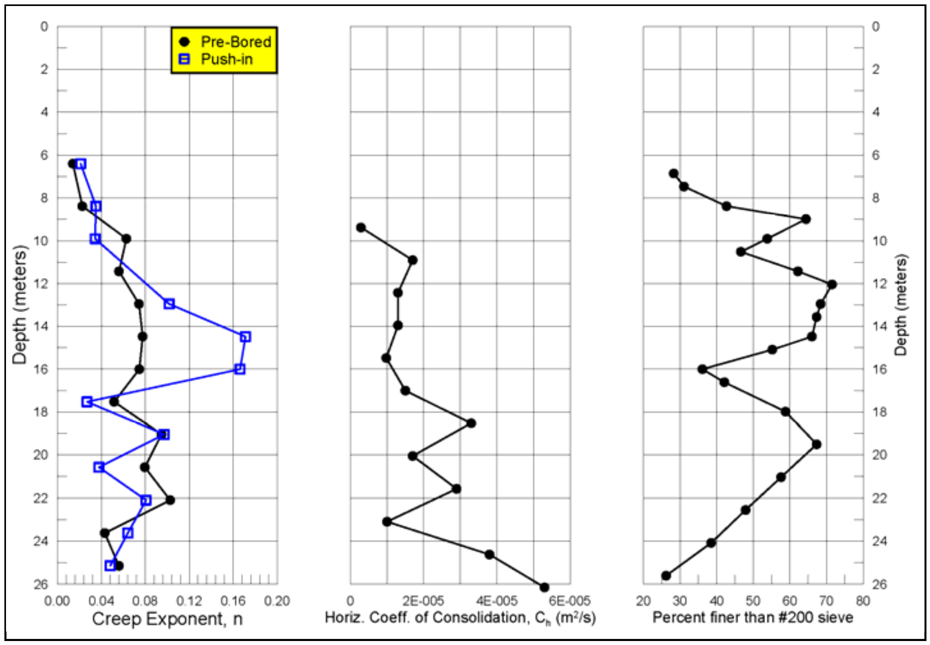


Figure 11: Comparison of PMT creep exponent, C_h from CPTu dissipation tests, and percent finer from lab gradation tests

4.7 *Comparisons with Jefferies and Davies' correlations for N_{60} and percent finer*

Standard penetration tests that used a CME automatic hammer were performed adjacent to the SCPT-PMT sounding. Gradation tests performed with these samples measured the percent passing the #200 sieve. Figure 12 compares the SPT N_{60} values and the percent passing the #200 sieve with the Jefferies and Davies' correlations for those values. For this site, the CPT correlations for N_{60} values were quite good, while they overpredicted the percent passing the #200 sieve.

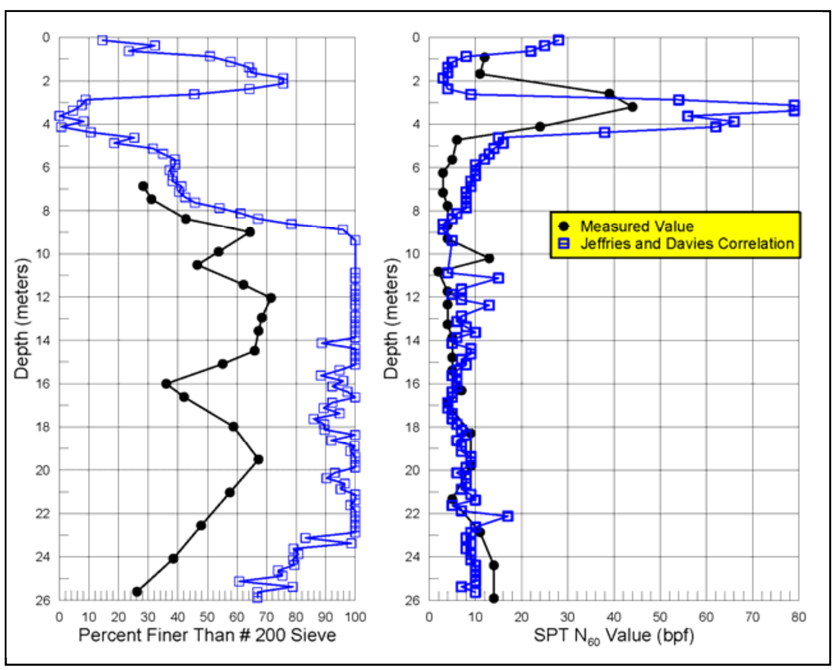


Figure 12: Comparisons with Jefferies and Davies correlations

5 CONCLUSIONS

- The pushed-in pressuremeter inside 16 narrow longitudinal slotted steel casing was an effective method to perform pressuremeter tests with direct push equipment. The disturbance to the soil, although likely consistent, was significant in the sensitive Miocene Aged deposits. The pressuremeter parameters that are interpreted at the lower radial strains (i.e., initial modulus and first reload modulus) had the most variability. Perhaps a larger diameter pressuremeter probe would have given better results. While we hoped that the pushed-in pressuremeter test data would have had less variability, we can only tentatively suggest dividing by the average ratios, which follow, to correct pushed-in PMT to pre-bored PMT values.

  Initial Modulus = 4.65

  Reload Modulus = 1.89

  Unload Modulus = 1.47

  Creep Exponent = 1.21

  Limit Pressure = 1.32

- In these sensitive soils, the CPT tip resistance was approximately equal to the limit pressure from the pre-bored pressuremeter tests.
- The Jefferies and Davies correlation for N_{60} was quite good while correlation for fines content overestimated the measured values.

REFERENCES

Briaud, Jean-Louis, 2013, "The pressuremeter test: Expanding its use", Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical engineering, Paris

Failmezger, Roger, 2005, "Development of a robust push-in pressuremeter", International Symposium 50 Years of pressuremeters, Paris, pp. 75 – 80.

Jefferies, Michael G., Davies, Michael P., "Use of CPTu to estimate SPT N60", ASTM Geotechnical Testing Journal, December 1993, pp. 458 - 468

Mayne, Paul W., 2001, "Stress-strain-strength-flow parameters from enhanced in-situ tests", Proceedings International Conference on In-Situ Measurement of Soil Properties & Case Histories, Bali, Indonesia, pp. 27 – 48.