A 400-ft (122-m) deep dilatometer sounding in Atlantic coastal plain soils

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ABSTRACT: Foundation evaluation for a project located along the Coastal Plains of Maryland required detailed evaluation of the deformation properties of the subsurface soils. The area is underlain by highly over-consolidated clays that are interbedded with sands and are occasionally cemented. Due to large foundations and their depth of influence, in-situ tests had to extend to great depths. However, the testing depth presented a few challenges because of occasional penetration obstructions and the inability to advance the sounding to the required depth while maintaining the necessary testing requirements such as plumbness. To overcome these challenges, the "torpedo" method was used to advance the dilatometer blade. A CME-75 drill rig advanced the sounding to the start of each test zone and a 20+ ton direct push track rig pushed the dilatometer blade for the DMT tests. This paper describes the planning, logistics, and challenges of performing dilatometer testing to the 400-ft depth, which is believed by authors to be a record depth for DMT testing.

1 INTRODUCTION

The need for foundation design for a major facility in southern Maryland, USA, necessitated acquiring detailed soil engineering parameters representative of in-situ ground conditions. While obtaining suitable parameters for soils at shallow depths is typically accomplished by collecting relatively intact samples and laboratory testing, reliable intact samples of deeper soils can prove difficult to successfully retrieve and can become scarce, invariably subject to potential disturbance during handling. Those reasons thereby affect confidence in developing reliable soil parameters. And even when intact sampling is successful, prudent engineering includes supplementary methods for verification. For these reasons, Dilatometer testing (DMT) was chosen as the preferred method of choice for in-situ testing and derivation of in-situ soil parameters, and was performed in addition to typical drilling and sampling.

DMT testing is an established in-situ soil testing method, recognized as suitable means for investigation, assessment, and evaluation of soil properties for foundation performance (Marchetti, 1980; Schmertmann, 1982; Schmertmann, 1986; Leonards and Frost, 1988). However, DMT is commonly used for investigation of relatively shallow depths; whereas the planned DMT testing described herein would "push the envelope" to the fringes of available knowledge on performing such testing to great depths. Given the need to evaluate massive foundation sizes as large as 270 ft. x 300 ft. (82 m x 91 m), highly loaded foundations with contact pressures as high as 15 kips per square ft. (718 kPa), and the expectations that these foundation conditions would influence the native ground stresses to a large depth, deep DMTs would be required to a 400-ft. (122 m) depth range and terminated in relatively incompressible soils. In the authors' opinion, DMT testing to such great depths had never been attempted before, therefore, penetration to planned depths were expected to present a few challenges, and as such, detailed planning and discussions were made and eventually proved instrumental in the success of the program. This included review of representative available literature on DMT work for prior lessons learned on comparable situations, and as shown in Table 1, most DMT soundings were found to be in the 10-30m depth range, a few in the 30-50m range, with virtually none extending beyond 60m depths.

Table 1. Representative DMT Penetration Depths.

Reference	Year	Depth(m)
Burgess	1983	42
Lacasse & Lunne	1986	15
Schmertmann et. al.	1986	17
Powell & Uglow	1988	15
Marchetti & Totani	1989	36
Hayes	1990	18
Marchetti et. al.	1991	52
Campanella & Robertson	1991	25
Kamei & Iwasaki	1995	25
Marchetti	1997	40
Totani et. al.	1998	50
Tanaka & Tanaka	1998	20
Totani et. al.	2009	60

The absence of experience in very deep DMT work necessitated discussions and engagement of experts in in-situ testing and drilling, as well as informal discussions with DMT subject matter experts based on their personal experiences (Marchetti, 2008; Saccheto, 2008). As expected, the testing depths and the presence of known, naturally-occurring obstructions in the ground, particularly cemented zones, proved challenging to advancing the soundings and maintaining the necessary testing requirements such as rod plumbness. Also as expected, in order to overcome the deformation limit of the over-consolidated soils, a modified measurement system that allowed pressure readings of up to 100 bars was necessary and used. Other challenges and steps that were encountered and resolved are described below, in successfully penetrating the soils to depths of about 400 ft. (122m), which is believed by the authors to be a record depth for DMT testing to date.

2 GEOLOGIC SETTING

The site of the DMT testing is located along the Atlantic Coastal Plain of Maryland. The deposits in this area are formed from ancient river sediments, placed in fresh water and marine environments. They include Holocene, Pleistocene, Miocene, and Eocene age soils. The upper, recent soils are primarily sands with varying degrees of silt, clay, and/or gravel. The middle soils, making up a substantial proportion of the DMT testing profile, are Miocene age clays and silts with varying degrees of sands, shell fragments, as well as interbedded cemented sub-layers. Below the middle soils lies an Eocene age deposit, consisting primarily of glauconitic sands with interlayers of silt, clay, shells, and with varying cementation. Geologic and stratigraphic information are summarized in Table 2 for general reference.

Table 2. Geology and Stratigraphy of Soils

Layer		Geology (Age, million yrs.)	Thickness (ft.)
I-Sand		Quaternary (<1.8)	28
IIa-Clay/Silt		Miocene (<16.4)	19
IIb-Cemented Sand	sub1		24
	sub2		23
	sub3		16
IIc-Clay/Silt			193
III-Sand		Eocene (<54.8)	>108

3 DMT TESTING DESCRIPTIONS

As noted earlier, the DMT could not simply be direct pushed to the full test depth of 400 feet (122 meters) because 1) cemented sand layers would cause penetration refusal, 2) the sounding would become too inclined from vertical, and 3) excessive rod friction would develop. For these reasons, we decided to drill using a small diameter hole; NWJ drill rod because of its strength, weight, fluid flow rates and displacement, a centralizer system for the drill string, and mud cleaning, as described in detail later in the paper.

The cemented sand layers and some of the highly over-consolidated clays had dilatometer “A” and “B” readings exceeding 60 bars, the maximum value of the standard control unit. Therefore, an auxiliary gauge with a maximum pressure rating of 100 bars connected to the standard gauge using the calibration quick connect fitting on the standard control unit. The control unit had a gauge minder to protect the 60-bar gauge from overloading. Figure 1 shows the control unit set-up with the auxiliary gauge.

Figure 1: Standard Control with Auxiliary 100-bar Gauge

In the beginning, a track rig with a 20,000+ kgf (20 ton) thrust capacity using screw anchors direct pushed the DMT. At a depth of 14 m, penetration refusal occurred in a cemented sand layer.

After removing the rods, the track rig moved off the sounding but left the screw anchors in place. Then the drill crew moved their CME-75 truck-mounted drill rig over the sounding hole and set 5-in (127-mm) inner diameter steel casings through the cemented layer to slightly below 14 m. The drill rig moved off the hole and the track rig set up over the sounding location. DMT testing then resumed using the "torpedo" method. The DMT continued to greater depths and only stopped after the thrust exceeded 20,000 kgf due to cemented sand layers, a hole developed in the DMT membrane or cable or when the cable exiting to the outside of the rods (at the top of the AW rods) would have contacted the surrounding soil. The two rigs changed places and the process continued. Below the 5-in (127-mm) casing, drilling proceeded using a 4.25 in (108 mm) bit barely larger than the DMT blade.

The DMT blade and seismic module screwed onto a 10-ft (3-m) long AW drill rod as shown in Figure 2. The DMT cable exited to the outside of the rods through a slotted steel adapter that attached to the top of the AW rod. The stiffer NWJ drill rods attached to this DMT torpedo section as the drill crew lowered them to the bottom of the drilled hole. Attached at the top of the NWJ rods, another slotted adapter allowed the DMT cable to enter back inside the rods. AW rods attached to the top of this slotted adapter.

The track rig used a camera with cross hairs to precisely re-position the rig back over the sounding location. The apparatus holding the camera in its center (shown in Figure 3) slid inside the guide push hole of the rig. The operator viewed the monitor for the camera, while he repositioned the rig over the hole.

Figure 2: Lowering Torpedo DMT Blade into Borehole

Because the outside diameter of the AW rods equaled the OD of the direct push rods, the direct push clamp without modification could push the AW rods. Shown in Figure 4, the clamp used four load cells, spaced 90^o apart, to measure the downward thrust (the sum of them), which the operator recorded for each test.

Figure 3: Camera with cross hairs for precise alignment

Figure 4: Push Clamp and the Four Load Cells to Measure Thrust

To prevent the drill rods from buckling, to keep the push force axial, and to protect the DMT cable from pinching between the hole and the rods, the NWJ rods had four steel strips (5/8 in or 16 mm square stock) welded to them at 90^o apart at every 25 ft. (7.6 m) interval. The DMT cable went between two of the strips and duct tape secured it at the top and bottom of the strips as shown on Figure 5. To prevent the AW rods from buckling, the drill crew slid large rubber washers over the AW rods spacing them at approximately 5-ft (1.5 m) intervals and using tape to temporarily secure them in place as shown on Figure 6. To provide further buckling protection for the upper AW rods, 3-in ID steel casing slid over the AW rods and rested on a rubber washer, also shown in Figure 4.

Figure 5: Taping DMT Cable to Outside of Rods Between Steel Centralizer Strips

Figure 6: Rubber Centralizer

3.1 *Seismic Equipment*

A 10-kgf weight, attached to a 1.5 m long rod pinned to the push rig like a pendulum, generated the energy for the seismic tests as the operator pulled back on a rope and then released it. The weight struck an aluminum block held in place by a leveling jack on the rig. A rubber pad placed between the jack and the block served to isolate the rig from absorbing the energy and focused the energy into the soil as shown in Figure 7.

Figure 7: Seismic Pendulum Hammer Striking Aluminum Block with Rubber Pad Focusing Energy into the Ground

The seismic dilatometer probe used a true interval geophone system, meaning that two geophones, spaced 0.5 m apart vertically, detect the shear wave created by the strike from the pendulum weight. Each geophone measures and records the wave as it arrives. While the second geophone records the same wave as the first geophone, it differs because it takes longer to arrive. The computer processes the shear wave velocity data and mathematically shifts the second wave by a delta time, Δt, to the left until it lies superimposed on the first wave. Each shear wave travels a distance equal to the hypotenuse of its depth and the horizontal distance between the aluminum strike block and the push rods. As the depth increases, the horizontal distance contributes less to the hypotenuse calculation. For each strike the computer calculates the shear wave velocity as the difference of the wave travel distances, Δs, divided by their difference in arrival times, Δt. At each test depth separate strikes generated similar waves demonstrating the repeatability of the seismic tests.

3.2 *Drilling Specialty Equipment*

When advancing the sounding to large depths selecting the appropriate equipment ensures success in overcoming issues. To efficiently drill the deep sounding and to lower and remove the dilatometer blade and drill bits, a CME-75 truck mounted drill rig was selected with 1) a high capacity Gardner-Denver piston pump, 2) three different speed/capacity winches, and 3) a hydraulically activated break-out wrench/rod clamp.

3.2.1 *Gardner-Denver Pump*

The piston pump had sufficient mud flow to force the soil cuttings out of the drill hole. The pump circulated the drilling mud out of a large pit, dug by a backhoe, with the sidewalls lined with plastic. The mud circulated through a de-sander, which removed the coarser grained soils.

3.2.2 *Hoisting Winches*

Faster winches have lower lifting capacity than slower ones. The quickest winch could lift the first 100 ft. (30 m) of rods; the middle speed winch could lift 200 ft. (61 m) of rods; the slowest winch could lift 400 ft. (122 m) of rods. The driller chose the appropriately sized winch to efficiently move the tools in or out of the hole. The rod sequence had 20 ft. (6 m) of NWJ rod and then a 5 ft. (1.5 m) long NWJ rod with four steel centralizing strips welded near the center of the rod. The drill crew temporarily stored the rods on steel sawhorses enabling them to conveniently pick them up with hoisting plugs. As shown on Figure 8, a reel kept the dilatometer cable from tangling while lowering or raising it from the hole. At the 400-ft (122-m) depth level, the 3-person experienced drill crew could trip the rods either in or out of the hole in about 45 minutes.

Figure 8: Reel to keep DMT cable from tangling

3.2.3 *Break-out wrench/rod clamp*

To hold the rods as the drillers added or removed sections and lowered or raised them in the hole, they used a hydraulically activated piston mounted on the drill rig that closed or opened vise jaws against the rods on shown in Figure 9. This device pivots either towards or away from the hole. Because the clamp is near the end of the apparatus, the weight of 400 ft. of rods would have bent the hinge. The drill crew poured a concrete footing near its end and pinned a steel rod resting on the footing to carry the rod weight. Notably, the drill crew carefully and systematically lowered and raised the rods and did not accidently drop them into the sounding hole.

Figure 9: Break-out Wrench/Rod Clamp

4 RESULTS

The authors performed dilatometer tests taking “A”, “B” and “C” readings generally at 0.20 m depth intervals for the entire 122 m depth of the sounding. Four load cells built into the clamp measured the summed result as the downward thrust in kgf, which the operator recorded. At a few depths the cemented sands prevented penetration, which were drilled through instead of tested. The close interval test spacing detailed and profiled the geotechnical properties of the formations. These details produced enhanced understanding of the geotechnical properties of the foundation soils. The DMT data interpretation used Marchetti (1980) method for most of the interpretations of the geotechnical parameters and Schmertmann (1986) method with the thrust measurements for the strength and stress history parameters for cohesionless soils. Figure 10 shows the DMT test results; Figure 11 shows the strength properties; and Figure 12 shows the deformation properties.

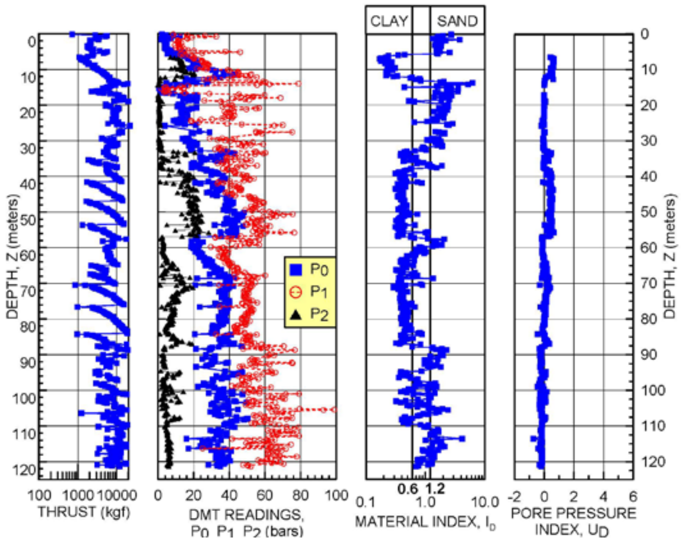

Figure 10: Dilatometer test results

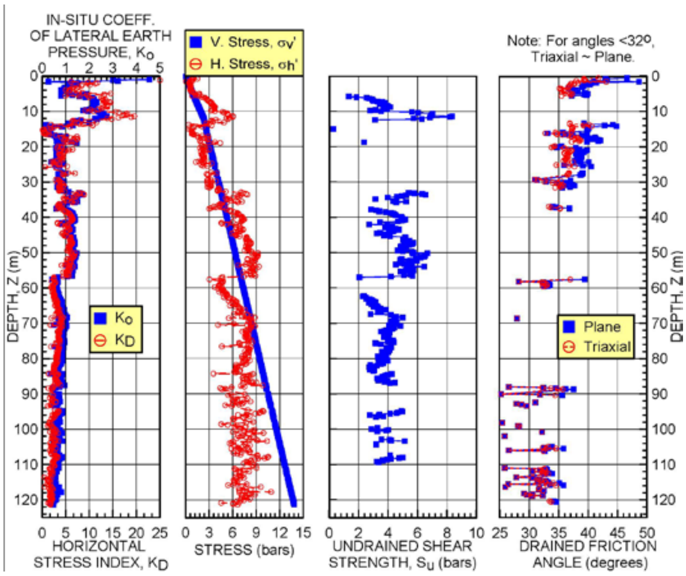

Figure 11: Dilatometer Strength Parameters

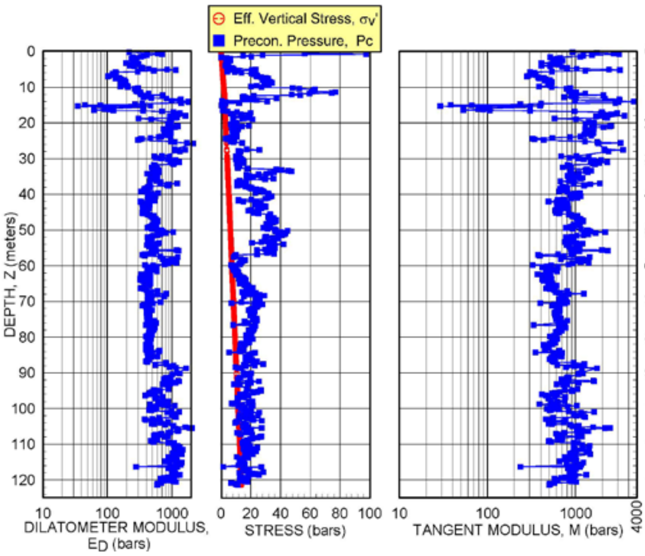

Figure 12: Dilatometer Deformation Parameters

In the cohesive soils, pore pressure dissipation tests evaluated their time rate of consolidation and permeability properties. After measuring the "A", "B", and "C" readings, the operator measured the "A" readings over time, following the "A2" dissipation test procedure. Figure 13 shows the dissipation test results obtained at 48.8 m.

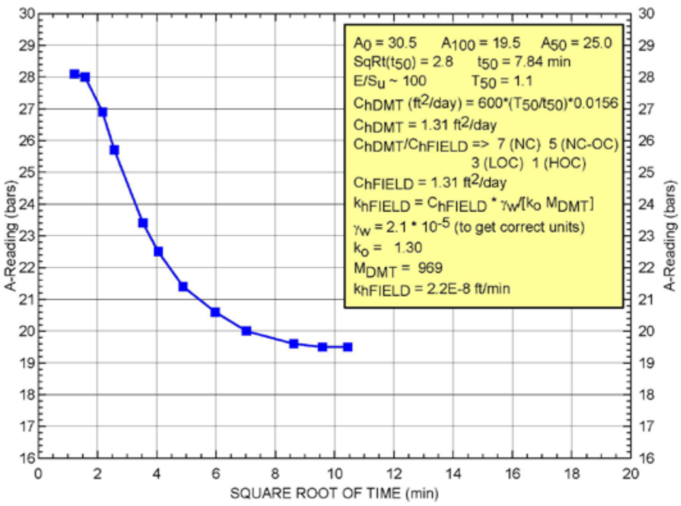

Figure 13: Typical Dissipation Test Results

Seismic shear wave tests were performed at approximately 1 m depth intervals using the true interval seismic module and the pendulum hammer. Figure 14 shows typical results at some of the larger depths. At much greater depths, the energy from the pendulum hammer strike that reached the geophones decreased, which created more ambient noise making the graphs fuzzier. The seismic tests were discontinued below 70 m depth due to the noise.

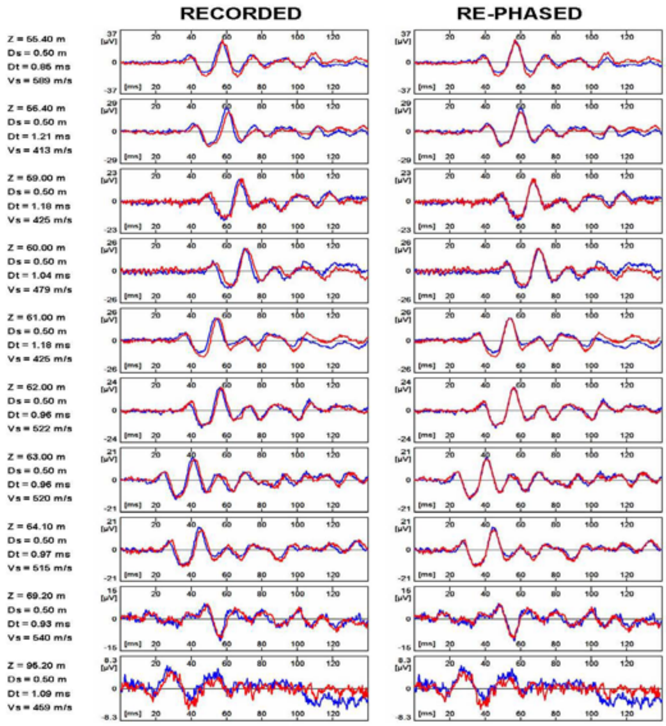

Figure 14: Seismic Shear Wave Velocity Measurements

5 CONCLUSIONS

Careful planning and selecting the most suitable equipment enabled successful and efficient performance of an approximately 400-ft (122-m) dilatometer test sounding. On-going coordination among the experienced driller, support crew, and the dilatometer operator eliminated much of the field challenges that would have otherwise been faced in such endeavor.

Supporting the rods laterally using either steel or rubber centralizers prevented their buckling and kept the push force axial. By efficiently using the different winches, several hoisting plugs, steel saw horses, rod clamp, and the reel for the dilatometer cable, the driller lowered or removed the dilatometer or the drill bit, in or out of the hole from the 400 ft. (122 m) depth level in about 45 minutes.

High quality data from calibrated DMT tests provided enhanced understanding of the engineering properties of soils, especially at large depths.

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