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Effective in-situ tests for measurement of soil properties for over water or deep investigations using wire-line methods

R. Failmezger
In-Situ Soil Testing, L.C., Lancaster, Virginia USA

M. Sacchetto
SPG srl, Adria (Ro) Italy

D. Marchetti
Studio Prof. Marchetti, Roma, Italy

ABSTRACT: While wire-line techniques have been successfully used for rock investigations for many years, new developments have now been made for using wire-line for soil investigations. Conventional soil sampling for over water and for deep investigations is very inefficient due to the high number of times that the driller has to screw and unscrew rods. With direct push techniques, cables are eliminated with wire-line methods and the test data are stored down the hole in the probe. With cone penetration tests, the probe is below the wire-line casing, and the operator simply turns and advances the casing to the desired depth as the data are collected. A bearing is used to prevent the cone from turning. For dilatometer tests, the blade is advanced up to 3 meter increments with tests performed at 0.2 meter intervals before it is retrieved and the data downloaded at the surface. If any obstructions are encountered, they are drilled through using a tri-cone roller bit. Undisturbed and disturbed soil samples can be obtained by latching those samplers to the wire-line casing.

1 INTRODUCTION

For deep subsurface investigations and often for investigations over water (near-shore and offshore geotechnical surveys), conventional drilling and sampling and direct push penetration test with rods are inefficient exploration methods. Much more efficient wire-line in-situ testing and sampling methods have been developed and provide the design engineer with higher quality data for better design. Wire-line methods should gradually replace the conventional methods for these otherwise difficult exploration conditions. The case studies presented in this paper demonstrate how effective and practical wire-line explorations are.

2 WIRE-LINE DRILLING AND SAMPLING

Conventional drilling with SPT sampling is quite costly and inefficient for deep boreholes because of screwing on and unscrewing of the rods. Occasionally rods will slip and accidentally fall in the borehole, and considerable effort can be expended trying to retrieve them. The SPT N-value is at best highly questionable due to energy transfer losses from numerous joints and rod length as well as additional vertical force from the weight of the rods. Often with deep boreholes larger and heavier rods are used.

With wire-line drilling and sampling, it is convenient to obtain undisturbed tube samples. A drill bit is locked into the wire-line casing and drilling is done to the desired sampling depth. The cable is lowered down to the bottom of the wire-line and the bit is retrieved. The wire-line casing is raised slightly more than the length that the sampler extends below the wire-line when it is locked in place. The sampler (usually a thin walled Shelby tube) is lowered into the wire-line casing and locked into place. Because the borehole has already been predrilled below the bottom of the wire-line casing, the sampler can be pushed without additional resistance from the wire-line casing. The undisturbed sample is retrieved from the wire-line and sealed with wax. It is then transported to the laboratory for testing.

3 WIRE-LINE DILATOMETER TESTING

A special wire-line dilatometer has been created that includes the nitrogen tank and automated dilatometer control unit with a data acquisition system. Up

Figure 1. Wire-line dilatometer with nitrogen tank and computer control unit inside large steel housing.

to 3 meters of rods, friction reducer and dilatometer blade are attached to the bottom of the DMT wire-line device. The engineer determines the length of the rods based on the pushing power of the rig and the anticipated soil resistance. The goal is to use the maximum number of rods that can be pushed into the soil. Presented as Figure 1 is a photo of the wire-line dilatometer.

The test procedure for performing wire-line dilatometer tests is as follows:

1. Lower a tri-cone bit to the bottom of the wire-line locking it in place. Drill to the starting test depth.
2. Remove the tri-cone bit and raise the wire-line casing slightly more than the length of the rods and dilatometer blade that protrudes below the wire-line casing.
3. Lower the wire-line dilatometer to the bottom of the wire-line casing, locking them in place.
4. Push the wire-line dilatometer to the first test depth.
5. The dilatometer test will automatically begin once pushing has been paused for five seconds.
6. Wait for 2 minutes for the test to be completed and then push to the next test depth. Continue pushing and testing until the entire protruded rod length has been pushed.
7. Remove the wire-line dilatometer from the casing. Perform ΔA and ΔB calibrations and download the recorded test data to the laptop computer. Insert the test depths into this data file.
8. Reinsert the tri-cone bit and drill to the next test depth and repeat the above steps.

If a dense, non-penetrable layer is encountered, the wire-line dilatometer is removed from the wire-line casing and a tri-cone bit is inserted to the bottom and locked in place. The operator drills through the non-penetrable layer, removes the tri-cone bit, reinstalls the wire-line dilatometer and resumes dilatometer testing.

A major advantage with the wire-line dilatometer is that the rod friction which increases with depth in conventional dilatometer testing is virtually eliminated with the wire-line dilatometer.

4 WIRE-LINE CONE PENETROMETER TESTS

Earlier wire-line cone penetrometer test (CPT) methods were similar to those described for the wire-line dilatometer. Recently, a bearing was inserted at the coupling between the wire-line CPT and the wire-line casing. And thus as a result, tests can be done continuously to the desired bottom of the sounding without removing the wire-line CPT.

The memocone is a digital piezocone that contains a microcomputer with RAM that stores the tip resistance, sleeve friction and pore pressure data and time in the cone. The data are transmitted acoustically to a computer at the surface for monitoring as well as being stored inside the cone. The depths are recorded at the surface using a rotating wheel (encoder) that is pressed against the wire-line casing. As the wire-line casing is advanced, the wheel rotates and the displacements and the time are recorded on a computer at the surface. When the cone is removed from the casing, the stored data are downloaded to the surface computer. The time that was recorded on the computer and in the memocone is used to synchronize the depth measurements with the stored CPT data.

The wire-line CPT procedure is somewhat simpler than the wire-line dilatometer DMT procedure. There is no need to withdraw the CPT probe unless penetration refusal occurs or unless the operator wants to check the data. The procedure is as follows:

1. The cone is saturated
2. The initial zero baseline measurements are obtained and the time is synchronized between the cone and the surface computer.
3. The cone is lowered into the wire-line casing and locked in place. There is a bearing inside the attached device that allows the wire-line casing to be turned and prevents the cone from turning. The cone protrudes far enough below the wire-line casing so that there is no influence from the drilling of the wire-line casing on the CPT results (usually about 50 cm). Figure 2 shows a photograph of the wire-line CPT.
4. The driller simply drills with the wire-line casing to the desired depth while the CPT probe collects and stores the data. The data are transmitted acoustically to a computer at the surface, which plots the data, allowing the engineer to monitor them. Field decisions can be made to perform a pore pressure dissipation test or retrieve an undisturbed sample.

Figure 2. Wire-line CPT probe.

5. If penetration refusal occurs or the tip resistance becomes too high, the CPT probe is withdrawn from the casing and the data are downloaded to the surface computer. A tri-cone bit is inserted into the wire-line casing, and driller advances the wire-line through the non-penetrable zone. The tri-cone bit is removed from the wire-line casing and the CPT is inserted and locked back into the wire-line casing. The cone penetration testing is resumed until the final depth is reached.
6. The CPT probe is retrieved from the wire-line casing and the data are synchronized with the surface computer. Completion zero baseline readings are made. The initial and completion zero readings are averaged and used for data reduction.

5 CASE STUDIES

5.1 *Defense Dam – Venice, Italy*

Relatively deep (60 m) wire-line dilatometer test soundings were performed in the Venice area for the Defense Dam Project. Presented as Figure 3 are data from a wire-line dilatometer sounding at this site. They suggest no depth induced deviations from normal results, hence the usability of the current correlations. In particular the horizontal stress index, K_d, remains similar throughout the full profile, always in the range 1.5-2 typical of normally consolidated sands and silts (apart from the see-saw data due to intense layering).

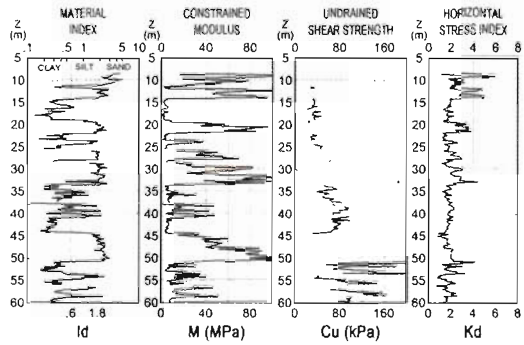

Figure 3. Wire-line dilatometer test data.

Because K_d equals a constant with depth there was a linear increase of lift-off reading, po, which in turn means no arching effects. In the other profiles there were no deviating tendencies showing up in the deeper portions of the soundings.

5.2 *Porto Tolle, Italy*

Seven deep CPTu soundings (up to 120 m) using the standard direct push method were planned for a site in Porto Tolle (Italy), where the lithology is well known. However, due to the high density of the sand after −40 meters and due to high total friction on the rods of the penetrometer, the holes had to be predrilled to reach the planned depths. Even after predilling, the CPTu sometimes could only be advanced another 4 to 5 meters. The total time to perform one test sounding was more than 2 weeks. Therefore, it was decided to perform wire-line CPTu testing and compare the test results with the results from the standard direct push method. It only took 4 days to complete the wire-line CPTu sounding. The results of the comparison are shown on Figure 4.

Performing wire-line CPTu soundings requires a skilled operator. To keep the rate of penetration as close as possible to the standard of 2 cm/second, the operator has to use the proper mud flow pressure, torque, and down pressure. He must use the correct viscosity for the mud to prevent clogging. However, a skilled operator can perform a wire-line CPTu sounding 3 to 4 times faster than a direct push sounding. This increased speed can save large amounts of money where the rental of the barge is very expensive.

6 CONCLUSIONS

1. For deep soundings and over water soundings, wire-line methods are 3 to 4 times more efficient than conventional direct push methods. They are modern methods to solve a difficult exploration

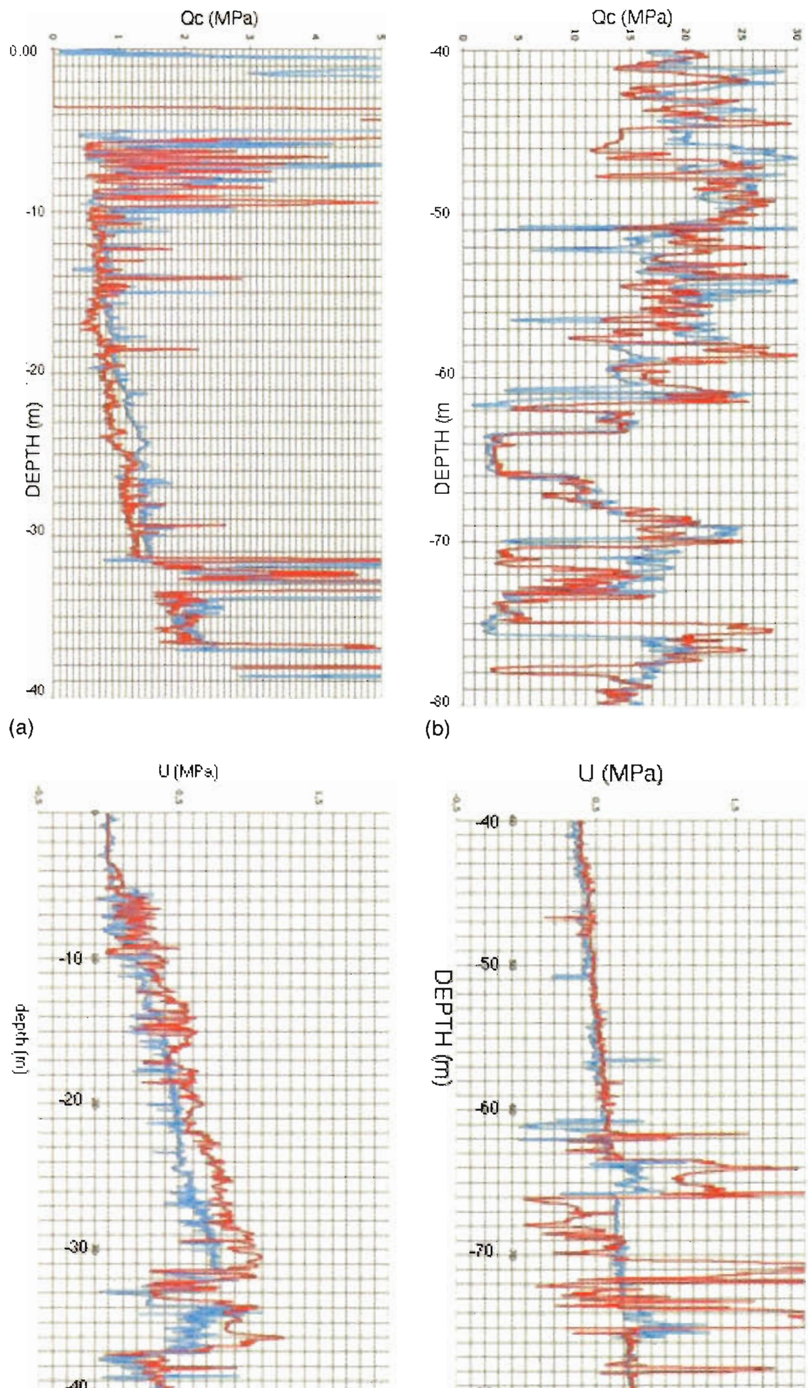

Figure 4(a–d). Tip resistance from 0 to 40 m – wire-line (red)/direct push (blue).

problem and should gradually replace conventional exploration methods for deep holes.

2. For deep explorations, the SPT N-value is unreliable due to questionable energy transfer from numerous joints and the additional penetration force from the heavy rod weight.
3. There was no difference in the quality of data between wire-line dilatometer and CPTu and conventional direct push dilatometer and CPTu.
4. Non-penetrable zones can now be conveniently drilled through by simply replacing the testing probe with either a tri-cone bit or a core barrel.
5. Rod friction is removed with wire-line methods.
6. Soundings have less inclination with wire-line methods.

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