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Philippe Reiffsteck

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STANDARDIZATION OF MWD THROUGH ISO 22476-15

A Step in the Right Direction

By Philippe Reiffsteck, Ph.D.

The purpose of the first generation of Eurocodes developed in the European Union was to facilitate free access to markets in other member states for construction companies and engineering consultants. Eurocode 7, dedicated to geotechnical design, was produced in 1990 by the Technical Committee for Structural Eurocodes, CEN/TC250 SC7, "Geotechnical Design." At the same time, it was complemented by a set of testing standards covering all areas of geotechnics, earthworks, and geosynthetics, the first one drafted under the auspices of the Technical Committee for Geotechnical Testing and Investigation, CEN/TC341, "Geotechnical Investigation and Testing."

The standardization of drilling parameter recording, referred to as "MWD" for "Measuring While Drilling," was originally included in the older standard for "Geotechnical Investigation and Testing," EN ISO 22475-1. However, it was necessary to include MWD within a separate standard because the latter, which also included water testing, was considered too long. In 2008, following acceptance by the Technical Committee, work started on a document based on French and Swedish pre-standard documents. Under CEN/TC 341, a working group was set up with representatives from Germany, Finland,

France, Luxembourg, Sweden, and Belgium. A draft of the MWD standard was completed in 2014 and submitted to member countries for comment and then balloting. It was published under the number EN 22476-15, "Geotechnical Investigation and Testing — Field Testing — Part 15: Measuring While Drilling." An ISO version of EN 22476-15 was also published in accordance with the Vienna Agreement between the European Committee for Standardization and the International Organization for Standardization, which calls for parallel adoption of standards at the international and European levels.

The MWD Method

MWD involves recording parameters from the drilling equipment during the drilling process. EN 22476-15 specifies the technical requirements for measuring equipment, the execution, and reporting on the parameters from drilling for geotechnical applications, such as advancing boreholes. According to the Standard, monitoring can be done manually or by using computerized systems to monitor a series of sensors installed on rotary and/or percussive drilling equipment. These sensors continuously and automatically collect data on all aspects of drilling, in real time, without interfering with the drilling progress.

All geotechnical drilling machines used in Europe, whether manufactured in Spain, Italy, Sweden, France, or Germany, are fully hydraulic. This means the functions of moving the carriage on the mast, rotating the tool, and percussion are powered by hydraulic pressure supplied by several pumps driven by the motor unit. It's also noteworthy, in general, that SPT testing is not performed as the borings are advanced.

Commercially available MWD systems can monitor and record several drilling parameters, including advance rate, down-thrust pressure, holdback pressure, torque, rotation rate, percussion energy, drilling fluid flow in and out, and fluid pressure. A typical installation consists of a set of sensors installed on the drilling rig, a digital recorder with user interface, and a data transfer device to display the drilling parameters in real time and store the signals for further analysis. Figure 1 shows a schematic of a crawler drill rig and the location of each sensor.

With the exception of advance and rotation rates, and percussion energy, these parameters are typically recorded as pressures. The advance rate is measured during drilling by an internal clock and a depth sensor. The depth sensor may be a coil placed directly on the sprocket chain drive or on an encoder attached to the drill rig mast that's often connected to the drill head with a small cable that runs along the

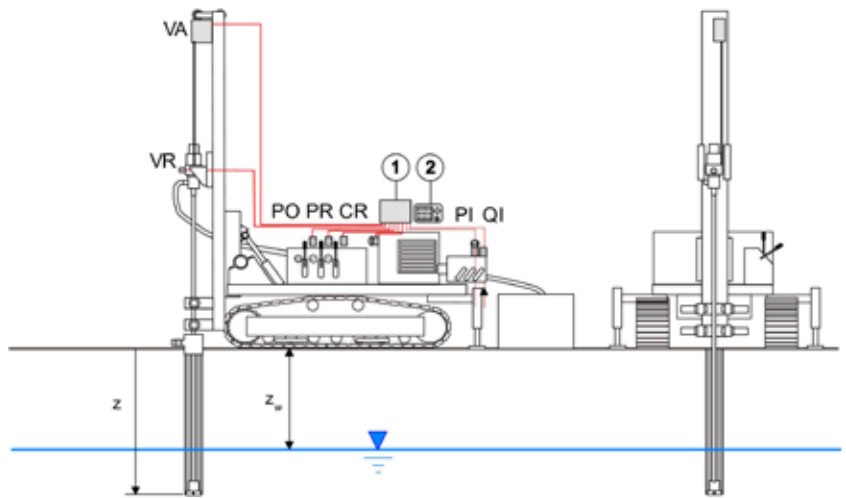


Figure 1. Measuring While Drilling sensors and drilling components (VA: penetration rate, VR: rotation speed, QI: drilling fluid flow rate, PO: down-thrust pressure, CR: torque, PR: hold back pressure, PI: drilling fluid injection pressure).

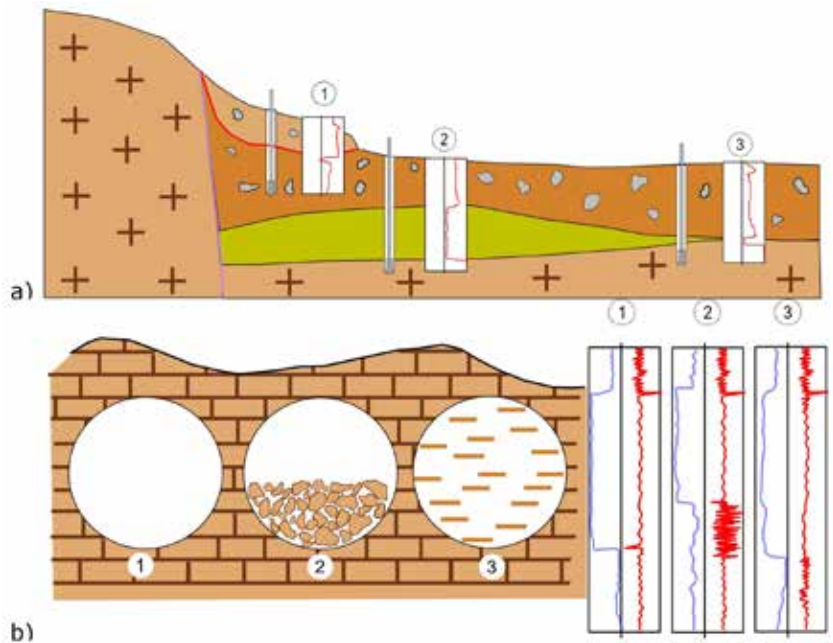


Figure 2. Application of MWD to (a) build a reliable geotechnical model, and (b) locate cavities.

axis of translation. The driller typically uses a switch, referred to as a driller's button, that controls the start and end of recording during the addition of rods or other necessary drilling maneuvers. Pressure measurements on a drill rig are easily accomplished by installing pressure sensors in line with the appropriate hydraulic circuit using a tee connection.

For example, the thrust pressure on the drilling tool is recorded by measuring the pressure in the hydraulic cylinders or the hydraulic motor responsible for applying the pressure on the drill bit. On most drill rigs there's a restraint system or holdback pressure for the drill head to prevent sudden acceleration of the drill rods when moving through voids or weak zones in

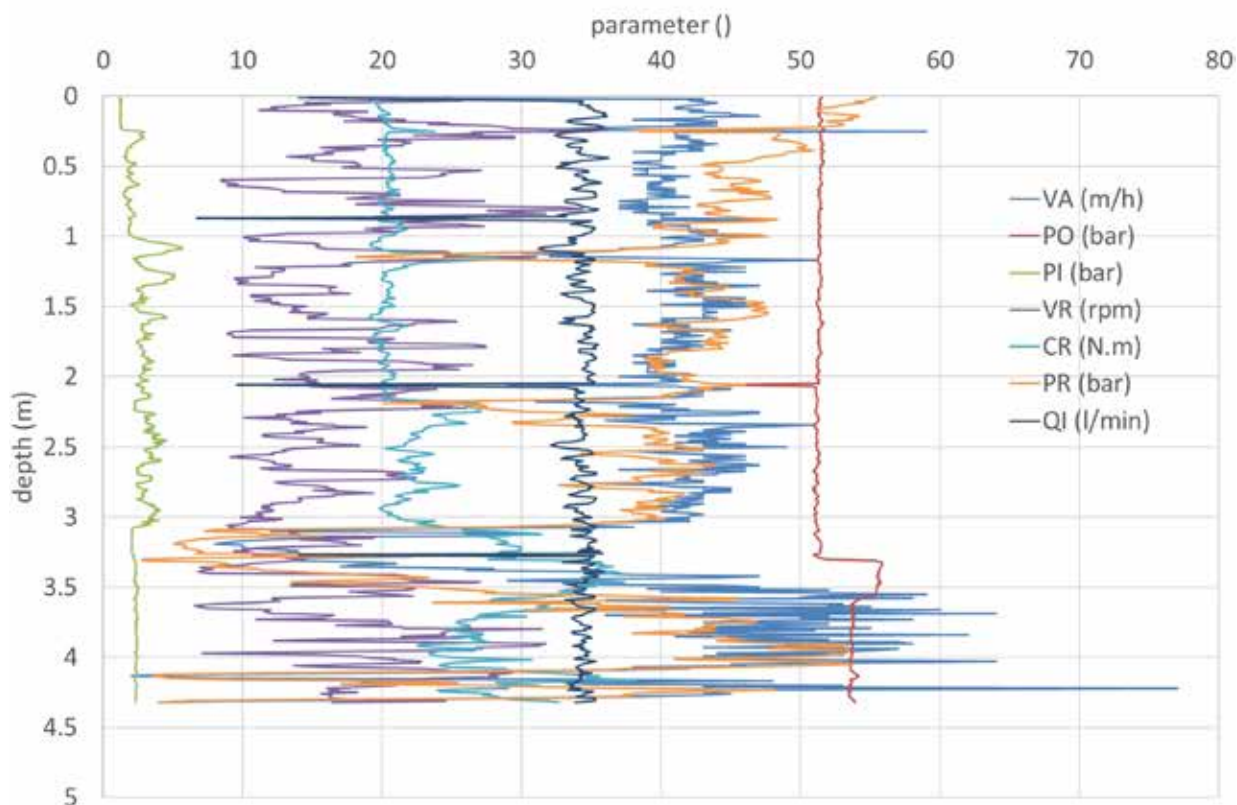


Figure 3. An example of drilling parameter measurement results (rotary drilling with a button bit in a silt layer).

the subsurface. This holdback pressure is typically the hydraulic pressure in the return line. Data are displayed in real time and recorded for further analysis.

In France, the primary objective of subsurface investigations carried out with machines equipped with MWD is to identify transitions between soil/rock layers as shown in Figure 2a. These data are useful in detecting variations in ground conditions, which in combination with other site investigation and sampling methods, leads to improved subsurface characterizations. The second main use, as depicted in Figure 2b, is for locating underground cavities caused by the dissolution of gypsum or mining of limestone for construction or agriculture. In Sweden, the main application is to determine the depth to bedrock (i.e., the Soil Rock Sounding Method). Many of these applications have a history that predates the use of geophysics.

The measured drilling parameters (the red curved line shown in Figure 2b) recorded as the holes are advanced into these cavities must be sufficiently contrasted to reliably locate the zones. Sometimes, the nature of the fills provides the

image of a progressive transition, so the use of combined parameters (i.e., the blue curved line shown in Figure 2b), derived by combining a number of drilling parameters described in Table 1, can be an alternative to increasing the size of the drill tool.

Drilling Parameters

Drilling parameter manual and real-time logging appeared originally in the oil industry, where they were largely used to manage drilling rates and aid decision-making during drilling operations. In the field of civil engineering, these parameters have played a growing role in geotechnical studies. Since the 1970s, researchers have strived to improve interpretations of MWD for use in engineering practice.

Drilling parameters are recorded directly during drilling, and then undergo digital processing. Corrections are necessary to consider specific characteristics of the hydraulic system, the weight of the drill rods, the influence of the mud column in the borehole, and other rig-specific factors. The number of parameters recorded depends on the type of logger and the type of work to be carried out. In most cases,

between four and a maximum of nine parameters are recorded. The parameters commonly recorded are (Figure 1): penetration rate (VA), down-thrust pressure (PO) and hold back pressure (PR), rotation speed (VR), torque (CR), drilling fluid injection pressure (PI), and drilling fluid flow rate (QI). Figure 3 shows how the recorded parameters are displayed graphically as continuous profiles with respect to depth.

Qualitative Results From MWD

Each parameter recorded can be assigned a qualitative meaning in terms of the characteristics of the soil being drilled, or in terms of the drilling operation. During drilling, each layer change generally results in the variation of one or more parameters.

The penetration rate, VA, is related to the mechanical strength of the drilled formation. Penetration rate will increase in softer ground. By comparing penetration rate with other drilling parameters like torque, CR, and net down-thrust, PO, changes in the characteristics of the ground can be characterized with more certainty. For example, the torque, CR, depends

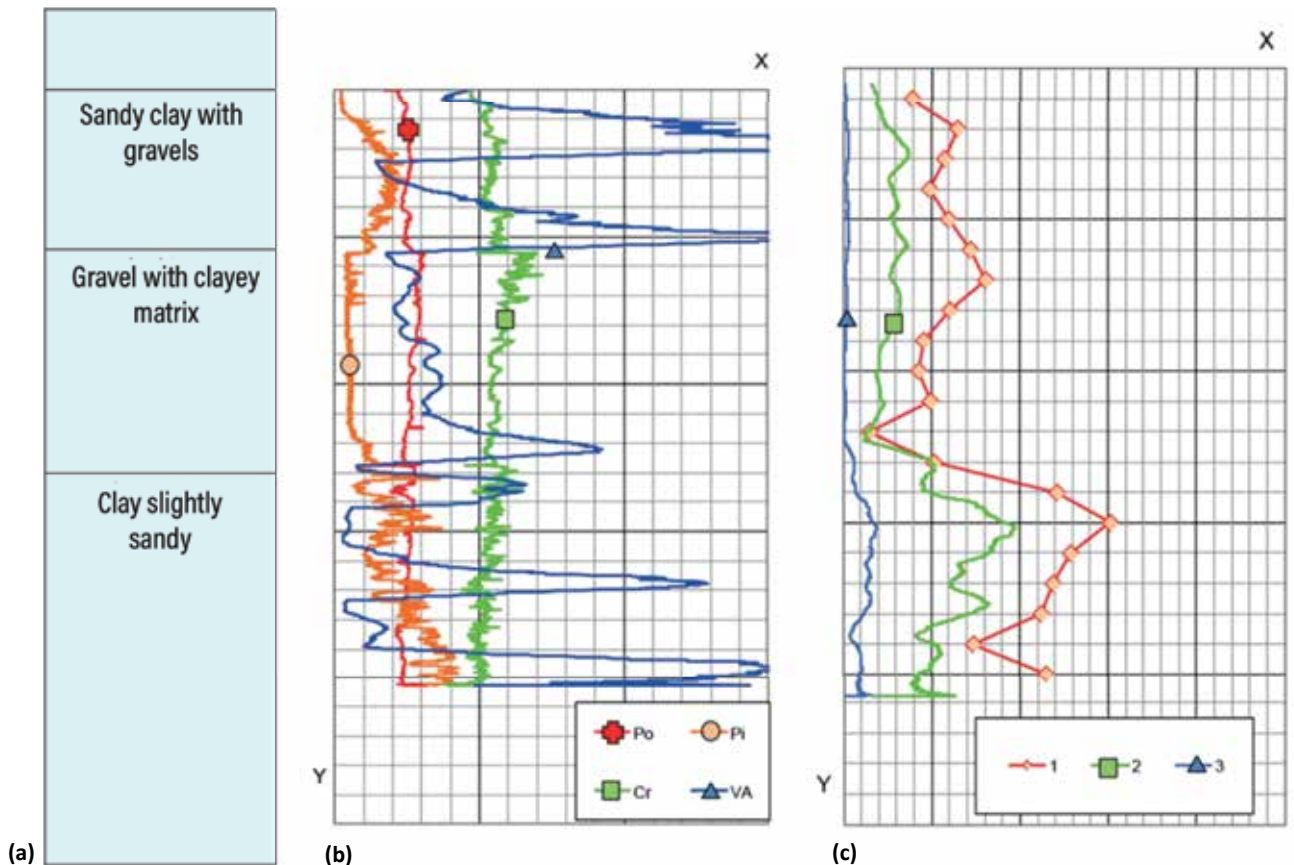


Figure 4. Comparison of Somerton Index, Soil-Rock Resistance profiles versus stratigraphy (1 – Menard Pressure Limit, p ; 2 – Somerton Index, S_d ; 3 – Soil-Rock Resistance, R_{sr} ; X – Calculated drilling parameter or compound parameter; Y – Depth). (a) Stratigraphy, (b) Profile of MWD Parameters, and (c) p , S_d , R_{sr} versus Depth.

on the selected drilling tool and provides information on the variations of the ground conditions. If the down-thrust, PO, is kept constant, the penetration rate, VA, is lower in dense materials and highest in loose materials. This rate is linked to the equipment used (e.g., drilling tool or hammer characteristic), the hardness of the formation, and its susceptibility to shocks and jetting. Also, the net down-thrust parameter PE (down-thrust pressure corrected for the holdback pressure, PR, and the weights of the drill rods and the rotation head), provides information on the locations of voids and cavities, as well as the transition between different layers in the ground.

The drilling fluid injection pressure, PI, is a measure of the conditions of the circulation of the fluid medium in the borehole. It's affected by fine particles that may clog the tool. Therefore, PI can indicate the fines content of a soil, and in weathered rock, it may be an indication of the presence of fractures.

The torque, CR, depends on the selected drilling tool and provides information on the variations of the ground conditions.

Compound Parameters

Measured drilling parameters can be classified into four categories:

- Parameters imposed by the drilling method and machine used, but not digitally recorded (type of tool and diameter, performance limits of the machine, injection system and fluid type)
- Machine parameters controlled by the operator (thrust on drilling tool, rotation rate and drilling fluid flow rate)
- Machine parameters resulting from the ground response (advance rate, torque, fluid injection pressure, drilling fluid return rate, and holdback pressure)
- Noncontrolled variable parameters (tool wear, changes in drilling fluid composition)

These categories clearly show that the parameters reflecting the ground response are highly dependent on other factors that are controlled by the drilling operation and process. Fortunately, these parameters can be normalized using compound parameters that can be derived from the combination of a number of drilling parameters, which are virtually independent of the drilling conditions.

The ISO EN 22476-15 Standard and Table 1 list the most commonly used compound parameters. They originate from various European, Japanese, U.S., and Scandinavian practices, and are the result of years of practice and research in their own countries. They are based on combinations of raw parameters to represent effects that have been observed in the field. These combinations are based on two different approaches:

- Empirically developed to relate data from MWD to measurements from

Compound Parameter	Formula	Unit
Penetration Resistance	$R_P = (t)_{dz=0.2m}$	s/0.2m
Somerton Index	$S_d \approx P_E \cdot \left(\frac{V_R}{V_A}\right)^{1/2} \approx \frac{P_E}{\sqrt{V_A}}$	kPa
Drilling-specific Energy	$S_{DE} = \frac{P_E}{S_0} + \frac{2 \cdot \pi}{S_0} \cdot \frac{(V_R \times C_R)}{V_A} \dagger$	kJ/m ³
Specific Energy	$E_S = \frac{C_R \cdot V_R}{V_A}$	N.m/m
Normalized Energy	$E_{N\vec{z}} = \frac{\alpha \cdot P_E \cdot V_A + \beta \cdot C_R \cdot 2 \cdot \pi \cdot V_R + \gamma \cdot P_M \cdot f}{V_A} \#$	N.m/m
Alteration Index	$I_A = 1 + k_0 \cdot \left(\frac{PE}{PE_{max1} \frac{VA}{VA_{max}}}\right)^*$	-
Mathematic Entropy of Signal S (S may be PO, VA, PI, etc.)	$L(z) = \sum_{z_0}^z S(z + dz) - S(z) $	-

† S₀ the excavated area
 # P_M and f are the power and frequency of hammer, α, β, γ are coefficients
 * k₀ is a coefficient

Table 1. Compound parameter formulas.

other in-situ tests such as the CPT and the PMT. This is the case for the first two combinations shown in Table 1.

- Theoretically developed based upon first principles considering the energy expended to break up the soil/rock with the drilling tool (normalized energy) or on signal agitation (entropy).

Alteration and Specific Energy were mostly used to assess weathering of rock mass or the presence of discontinuities. Entropy is a mathematical function used to locate changes in layers by treating a drilling parameter as a signal whose information changes with the nature of the materials.

Details of EN 22476-15

The Standard provides guidance for selecting drilling equipment: the drill rig, drilling flow pump, drill rods, and drilling tools needed to achieve good MWD measurements. The measuring system is described, such as transducers for pressures, penetration length, rotational speed, etc., and their regular control and calibration.


The Standard specifies that test results be presented in graphical form

as continuous profiles as a function of the penetration depth or penetration length (Figure 4). The Standard also describes how MWD supplements other in-situ measurements. The borehole from which MWD data are collected is often used for other applications, such as installation of monitoring equipment, geophysical logging, or pressuremeter or flexible dilatometer tests. In cases where drilling is done to retrieve samples, the interpretation of the MWD results can be done in consideration of the information provided by sampling.

Figure 4 shows the profiles of the four main parameters measured. Down-thrust has been kept more or less constant in this example. The change in penetration rate gives an initial idea of the geotechnical model. Three layers can be defined, but their transition is more precise, and the evolution of resistance is better approximated by the compound parameters. The correlation that can be observed with the PMT and the soil profile provided by the operator validates this lithology. The same quality of observation was of course observed with the SPT or simply by core sampling.

Final Thoughts

Almost 10 years after its publication, the results of using EN 22476-15 show a harmonization of measurement systems and software dedicated to interpreting the MWD data, based upon standard national practices.

At a time when cloud-based data storage applications are being rapidly developed by national geological surveys and companies, EN 22476-15 has created the conditions for the industry to make the most of all the data generated by drilling machines. Until now, this information had not been utilized to improve the value of local or national databases. 

► **PHILIPPE REIFFSTECK, PH.D.**, is a professor of geotechnical engineering at Gustave Eiffel University, and research director at IFSTTAR, the French Institute of Science and Technology for Transport, both located in Marne la Vallée, France. His research work on experimental rheology of soil focuses on laboratory and in-situ testing with the goal of developing improved knowledge of soil behaviour for practical geotechnical applications. He's also contributed to the standardization of tests for Eurocode 7, Part 2. He can be contacted at philippe.reiffsteck@univ-eiffel.fr.