New measuring while drilling technology ASFOREC

Michaël PERONNE
Jean Lutz SA, Jurançon, France, mperonne@jeanlutzsa.com

Michel RISPAL, Catherine JACQUARD
Fondasol, Avignon, France, michel.rispal@fondasol.fr, catherine.jacquard@fondasol.fr

Philippe REIFFSTECK
Université Paris-Est, French institute of science and technology for transport, development and networks (IFSTTAR), Marne La Vallée , France, philippe.reiffsteck@ifsttar.fr

ABSTRACT: This paper will present a new measuring system for drilling parameter recording. During drilling, parameters are usually obtained from transducers inserted in the hydraulic circuit of the drilling machine. This new system with transducers located on the drilling rods records parameters close as ever to the tool allowing the knowledge of the direct response of the soil. Comparison of the parameters recorded with both techniques is presented and the influence on the quality of compound parameters with other *in situ* tests as CPTu and pressuremeter tests are discussed.

Keywords: drilling parameter recording; pressuremeter test; measuring system.

1. Context

As part of the industry for design and construction of buildings (towers, high-rise buildings, etc.) and infrastructure (ports, bridges, power plants, tunnels, etc.), the necessary knowledge of the subsoil that will carry these works implements a process of investigation. It's about "probing" the terrain punctually by machines This is an old activity already practiced by the Roman engineers that has evolved very quickly from the industrial revolution to now by improvement of motorization.

The drilling of geotechnical boreholes is currently based on drilling machines equipped with a physical parameters measurement system whose analysis is largely based on the experience of the site operator.

The measuring device nowadays available on the market and equipping the machine indirectly record the drilling parameters on the hydraulic elements of the machine. This equipment leads to numerous developments [1, 2, 3, 4, 5, 6, 7].

Therefore, to be interpreted, these measurements require a calibration of the machine that does not consider the conditions of use (heating, wear etc.). This is the major difficulty in being able to derive compound parameters that can be linked to mechanical parameters and geotechnical properties [8, 9, 10, 11, 12, 13, 14].

Incorrect adjustment of the control parameters of the machine leads to deteriorate the quality of the borehole walls in the case of *in situ* tests, spend excessive energy and increase the risk of wear or breakage, often with consequences on the productivity of the sites.

Besides, the signals measured by the sensors are always transmitted by wire technology, which is a major source of defaults (60% of defaults come from cable breaks).

Another source of difficulties results from the mechanical coupling of the sensors with certain moving parts, which causes early failures.

On the other hand, the proliferation of poor-quality measures (low-cost sensors), even massively carried out at the request of the market, discredits the very interest of the measures, failing to interpret them properly.

Finally, the improvement of drilling management will only be possible by further improving the quality of measurements (precision). This paper presents the design and the validation of a new type of sensor for MWD (Measurement While Drilling) aiming to handle all these drawbacks.

2. Objectives of the new ASFOREC technology

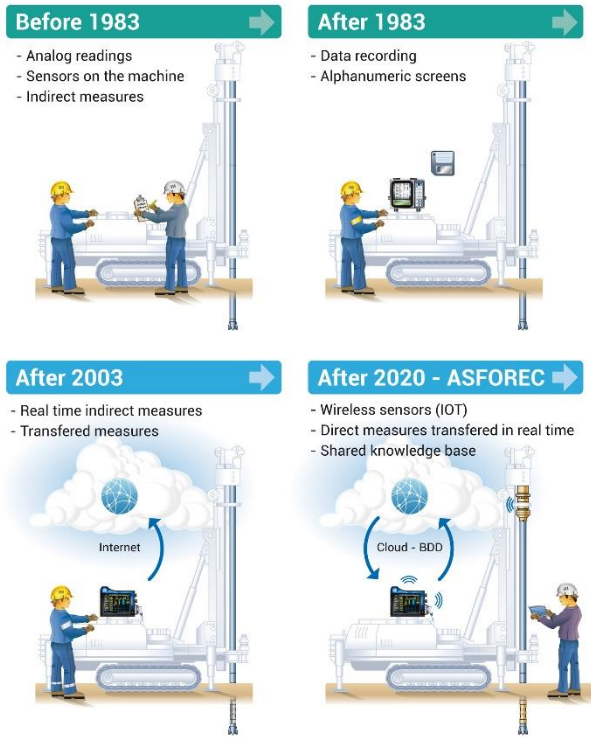

Figure 1. Instrumentation evolution in Measurement While Drilling.

The new ASFOREC technology proposes to revolutionize this soil investigation market by developing a new measurement system based on in situ instrumentation of the drill rods just below the rotation head using a purely wireless and contactless high-end sensor for both measurement and transmission.

The expected results of the project are a gain in precision, an increase in the quantity and quality of the information collected, and an improvement in efficiency.

The evolution of the measurement systems through the last decades and the resulting objectives of our project are summarized in the Fig. 1.

3. Instrumentation introduction

3.1. Parameters measured

All the current stakeholders in the field of drilling parameters use measurements made on flow rates or pressures of hydraulic oil feeding the active elements of the drill rig (geared motors, cylinders, etc.), rather than closer to the borehole (*i.e.* directly on the string of rods or at the drilling tool level), due to the mechanical stress and technological difficulties of measurements encountered *in situ*.

These are therefore indirect measurements of the underground phenomena which are rather imprecise (error of around 30% for a given machine) and may depend from machine to machine of the hydraulic circuit architecture.

Thus, the rate of penetration into the ground (used to qualify the resistance of the soil) depends on the nature of the ground but also (among others) on the thrust force and on the rotation speed exerted on the drilling tool by the machine.

This thrust force is itself approximated by the measurement of the hydraulic drive pressure, which is not strictly linearly related (hysteresis, temperature dependence, mechanical filtering of hydraulic components, etc.) while rotation speed is hardly measured because of the sensor exposure to a mechanical stress due to its proximity with the drillings rods.

3.2. Manufacturers solutions

Measurement technologies are made available by drilling machine manufacturers, who generally have an instrumentation service developed in-house and based on their know-how in monitoring machine operation.

The signal processing is not advanced enough and the interpretation of the data relatively rudimentary, which is detrimental for the quality of the measurements.

Other technology providers specialized in the instrumentation of geotechnical measurements and special foundation measures, offer more advanced products (elaborate signal processing, thorough data interpretation) but always resorting to indirect measurements, which are therefore inherently flawed.

3.3. Direct measurement system

Performing direct measurements, *i.e.* closer to the borehole, will significantly increase the accuracy of the measurements.

Jean Lutz already offers several embedded systems of *in situ* measurements among which can be cited:

- The TIGOR sensor, inserted into the drill string just above the drill tool for measuring deviations.
- The TAUPI sensor, installed at the bottom of the thin screen injection profile, for the measurement of deviations, the amplitude and the frequency of the vibrations applied to the profile.

It should be noted that other manufacturers (particularly in the United States) provide energy measurement devices transmitted to the drill bit during sheet pile driving without rotation: strain gauges and accelerometers positioned on the drill string transmit the measurements through cables to an electronic junction box for signal processing.

The use of such cables is not possible when carrying out ground investigation drilling, the tool then being rotated.

4. ASFOREC innovation

4.1. Current sensors

The table 1 below lists the measurements made with conventional sensors and the difficulties associated to them.

Table 1. List of classical current parameter sensors and their disadvantages.

Measured parameter	Disadvantage of the current sensors
Rotation torque	Indirect and imprecise measurement: sensor installed on a hydraulic circuit whose value depends on the speed of rotation, the oil temperature and the gear wear.
Thrust pressure	Indirect and imprecise measurement: sensor installed on a hydraulic circuit whose value depends on the speed of translation, the oil temperature and the gear wear.
Rotation speed	Accurate but fragile sensor due to its proximity with rotating rods.
Vibration amplitude and frequency.	Indirect measurement (performed on the drill string drive)
Drilling fluid pressure	Clogging or cavitation of arrangement
Drilling fluid flow	Flow meter not easy to embed on a machine
Advance rate	Fragile cable sensor.

4.2. Innovation brought

In 2018, Jean Lutz began developing a sensor for measuring torque and longitudinal force positioned at the top of the shaft.

The first field tests took place with Fondasol and IFSTTAR during 2019 establishing a first step towards the development of the expected solutions in ASFOREC.

Before the ASFOREC solution, there were no *in situ* technologies available for measuring drilling parameters adapted to geotechnical engineering.

The ASFOREC measuring system combines in one wireless sensor (radio communication, charging through induction) the measurement parameters required to develop a detailed geotechnical study of a site (as described in Fig. 2).

The innovation lies in the *in situ* approach to the realization of the measurements, meaning that the sensors are positioned closer to the drilling tool, which has the advantage of eliminating binding calibrations of the drilling machine and several approximations necessary when the measurements are made indirectly (*e.g.* the torque exerted on the tool is until now calculated from a hydraulic pressure.

To this end, miniature integrated circuits are introduced into a robust mechanical and electronic assembly. The latest wireless information transmission technologies have been implemented.

This set will eventually be able to meet its energy needs by taking advantage of the rotational movement of the rods to avoid regular recharging operations onboard batteries (in practice little done by site operators).

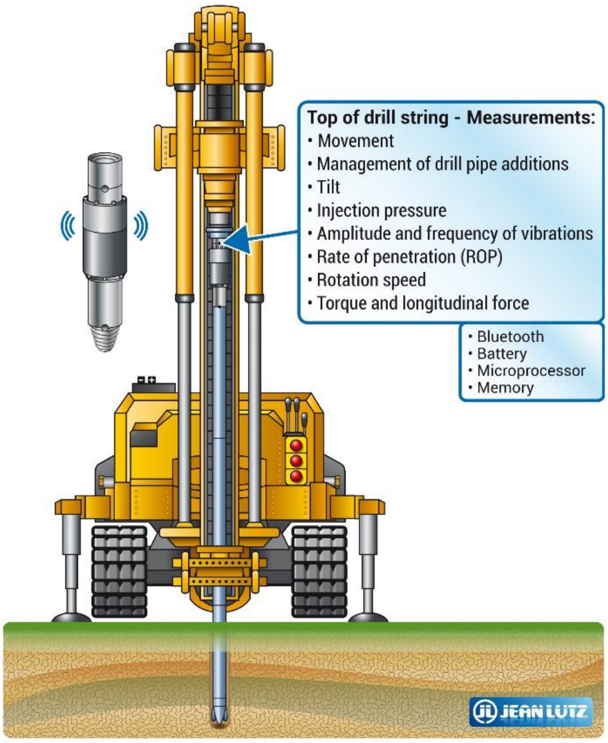

Figure 2. Description of the ASFOREC sensor system.

4.3. Installation on a drilling rig

The ASFOREC measuring system has already been installed on different geotechnical drilling machine representative of the one commonly used on the market.

Figure 3. Zoom on the ASFOREC sensor.

The ASFOREC sensor is installed in direct contact with the drill string, just below the rotation head and before the first drill rod (using drill pipe fitting), as shown in the Fig. 3, 4 and 5.

Figure 4. The ASFOREC sensor is installed before the first rod, just after the rotation system.

Figure 5. ASFOREC sensor installed on a standard drilling machine used for soil investigation.

5. Contribution in the measures

Below are presented the geotechnical reports for three boreholes performed on two different drilling machines with conventional sensors and the ASFOREC system.

These studies were conducted in order to carry out concurrent in situ tests (Menard Pressuremeter – PMT - or CPT test) to allow the establishment of correlations and determine a complete study of the soil encountered.

5.1. Test n°1 in Basque Country – France

The ground profile was composed of fill on the first meters, loose sands, over compact sands. The parameter presented in the Fig. 6, all regarding depth (drilling from 0 to 11.25 m length) are from the left to the right:

- (Blue) Rate of penetration using a conventional sensor (rotary encoder).
- (Pink) Rotation torque pressure (analogic pressure sensor mounted on the hydraulic pipe).
- (Orange) Rotation torque from ASFOREC sensor (direct measure).
- (Green) Thrust force pressure (analogic pressure sensor mounted on the hydraulic drive).
- (Yellow) Thrust force from ASFOREC sensor (direct measure).

The curves displayed show a good correlation on the rotation torque measurement, at least up to 6.5 m.

In the next zone, from 6.5 to 8 m the power of the machine tends to minimize the torque required for the rotation of the rod.

The analysis of the longitudinal force shows that the reaction on the rods are much “smoother” (through the ASFOREC sensor) than measured with the sensor installed on the hydraulic drive.

Then, starting at 8 m when the penetration rate drops, the parameters measured on the hydraulic circuits show a continuous variation meanwhile the ASFOREC sensor indicates a step increase and a plateau. Classical MWD show force and pressure losses due to dampers system on the drill rods and to actuator valves on hydraulic circuit.

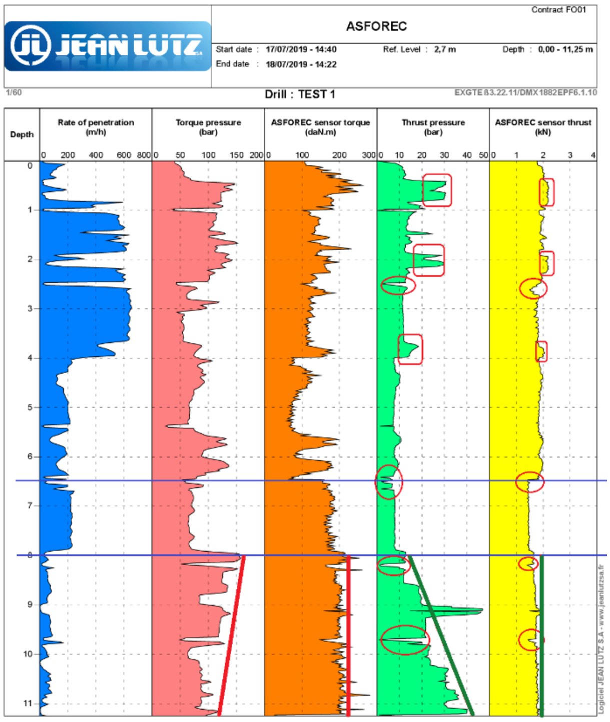

Figure 6. Geotechnical test report n°1.

5.2. Test n°2 in Saxony, Germany

The second test has been performed on a bigger and more powerful drilling machine in an alluvial area with presence of ancient conglomerates and coarse grained materials.

The parameter presented in the Fig. 7, all regarding depth (drilling from 10.4 to 80 m length) are from the left to the right:

- (Blue) Rate of penetration using a conventional sensor (Jean Lutz D907 rotary encoder).
- (Pink) Rotation torque pressure (Jean Lutz C16400 analogic pressure sensor mounted on the hydraulic pipe).
- (Orange) Rotation torque from ASFOREC sensor (direct measure).
- (Green) Thrust force pressure (Jean Lutz C16400 analogic pressure sensor mounted on the hydraulic drive).
- (Yellow) Thrust force from ASFOREC sensor (direct measure).

The geotechnical test report shows a quasi perfect correlation of ASFOREC sensor with classical MWD instrumentation. Compared to the two other tests, the signal is much more noised du to the different types of arrangement for the drill rig to apply thrust. However the signal both for the hydraulic and direct (ASFOREC) type of sensors show clearly the same trends.

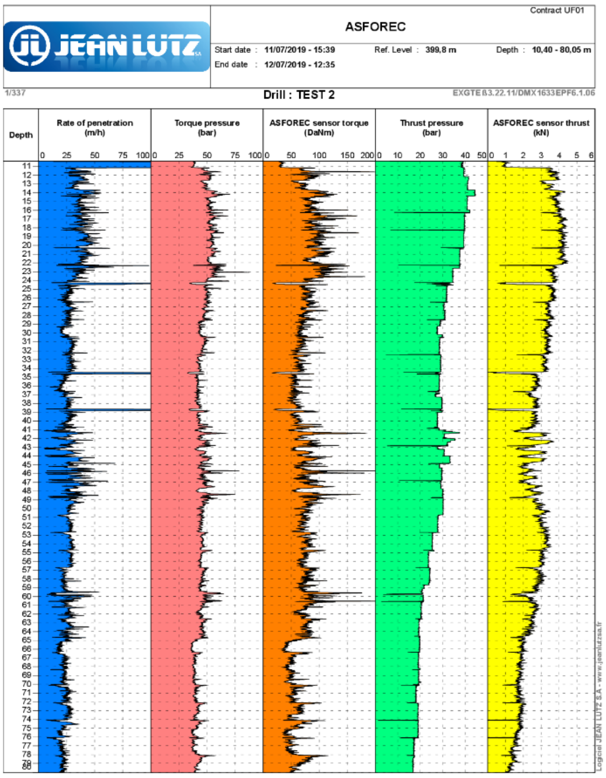

Figure 7. Geotechnical test report n°2.

5.3. Test n°3 in the Landes, France

The site is located in the south-west of France in a sand quarry. A thick layer of dense sand with some intercalation of cemented and / or gravelly sand.

The machine used is the same than the one set up in the first test.

The parameters presented in the Fig. 8, all regarding depth (drilling from 0 to 13.7 m length) are from the left to the right:

- (Blue) Rate of penetration using a conventional sensor (rotary encoder).
- (Pink) Rotation torque pressure (analogic pressure sensor mounted on the hydraulic pipe).
- (Orange) Rotation torque from ASFOREC sensor (direct measure).
- (Green) Thrust force pressure (analogic pressure sensor mounted on the hydraulic drive).
- (Yellow) Thrust force from ASFOREC sensor (direct measure).

The geotechnical test report shows that ASFOREC sensor compares well with classical MWD instrumentation. Thurst was less sensible when reaching the more stiffer layer at around 8 m depth. Torque gives a correct and reliable characterisation of the gravel layer, being also less sensible to the layer located around 5 m.

As observed on site 1 results, ASFOREC sensor gives immediate and stepped variation while classical sensors produce damped variation

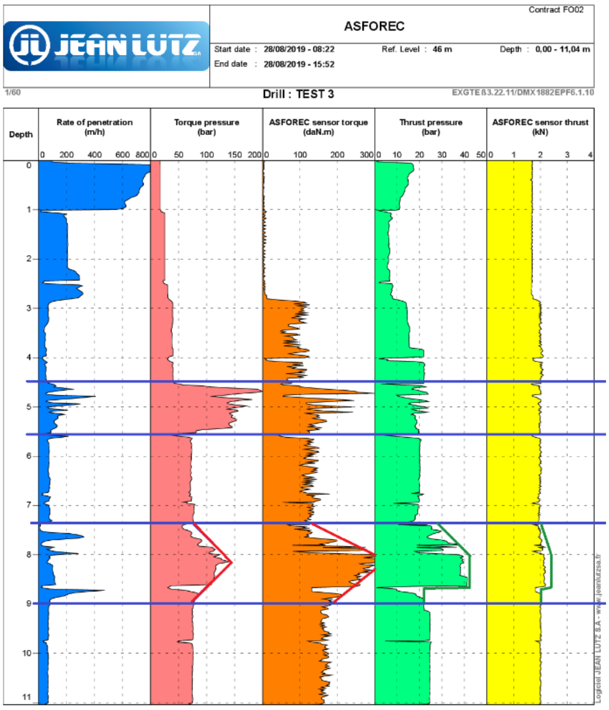

Figure 8. Geotechnical test report n°3.

6. Analysis – Influence on quality

These round robin tests on 3 real sites show that the ASFOREC sensor gives high quality measurement, very close to actual MWD based on pressure transducers located on hydraulic circuit of drill rigs. The main characteristics of the ground profile are well observed.

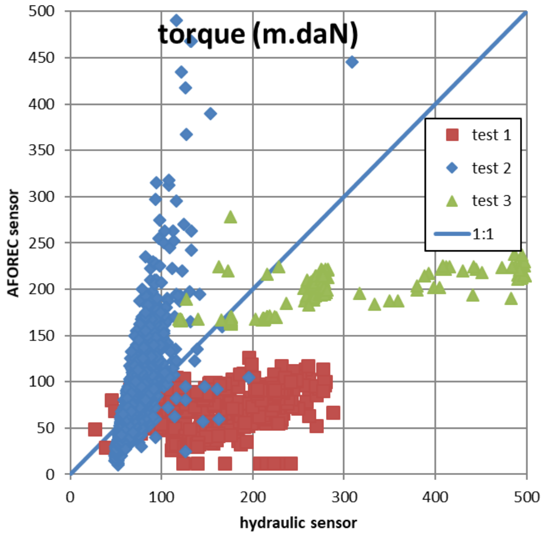

Figure 9. Comparison of the torque values for the three tests performed (ASFOREC vs hydraulic sensor).

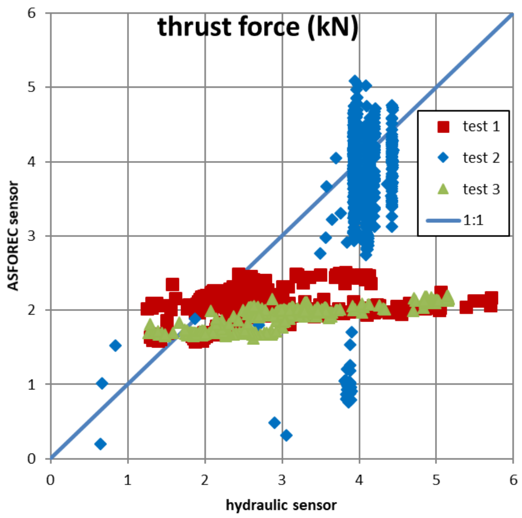

Figure 10. Comparison of the thrust force values for the three tests performed (ASFOREC vs hydraulic sensor).

The comparison shown on Fig. 9 and 10 of measured values obtained with both systems lead to the following conclusions:

- According to the drilling machine the range of variation can differ (test 1 and 3 have the same machine – type 1, differing from test 2 – machine type 2).
- On machine type 1, pressure loss and compressibility of the hydraulic circuit induce divergence of measured value from ASFOREC sensor values, giving in high pressure a more horizontal cloud of points.
- On machine type 2, the hydraulic circuit seems more “rigid” and an increase of pressure lead to an immediate variation of torque or pressure, inducing a more vertical scattered plot.

7. Conclusions

At this stage of developpement the concept has shown its pertinence. A further stage will be a more compact design to limit the length of this special "rod" and an optimisation of the measuring range of the various transducers.

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References

[1] Somerton W.H., A laboratory study of rock breakage by rotary drilling, Petroleum transaction, AIME, 1959, Vol. 216, pp. 92-97.
[2] Teale R., The concept of specific energy in rock drilling, International Journal Rock Mechanics and Mining Science, 1965, Vol. 2, pp. 57-73.
[3] Diehl G.W., Automation and optimization of rock drill parameters in hydraulic drilling, Mining magazine, 1978, pp. 38-43.
[4] Pfister P., Drilling Parameter Recording in Soil Engineering. Ground Engineering, 1985, Vol. 18 n°3, pp. 16-21.
[5] Cailleux J.-B., Étude des diagraphies instantanées en forage, (study of instantaneous logging of borehole), Rapport des laboratoires, GT12, 1986, 97 p. (in French).
[6] Falconer I.G., Normore D., MWD bit efficiency model provides real-time answers, Technology Oil & Gas Journal, 1987, pp. 40-48.
[7] CEN, Geotechnical investigation and testing — Field testing — Part 15: Measuring while drilling, EN ISO 22476-15, CEN, 2013, 45 p.
[8] De Paoli B., Viola G., Tomiolo A., The use of drilling energy for soil classification, 2nd International Symposium on Field Measurements in Geomechanics, Kobe, Sakurai Ed, 1988, pp. 313-321.
[9] Nishi, K., Suzuki, Y., Sasao, H. (1998), Estimation of soil resistance using rotary percussion drill, Proceedings First International Conference on Site Characterization, Atlanta, Robertson and Mayne Editors, vol.1, pp. 393-398.
[10] Reiffsteck P., Influence factors of measuring while drilling method, European conference on soil mechanics and geotechnical engineering, 15: Geotechnics of Hard Soils - Weak Rocks, Athens, 12-15 September 2011. Proceedings, vol. 1, pp. 67-72.
[11] Laudanski G., Reiffsteck Ph., Tacita J.-L., Desanneaux G., Benoît J., Experimental study of drilling parameters using a test embankment, Intern. Conference on Site Characterization ISC4, Porto de Galinhas, Brasil, 2012, 4 pages
[12] Gui M.W., Soga K., Bolton M.D. Hamelin J.-P., Instrumented borehole drilling for subsurface investigation, Journal of Geotechnical and Environmental Engineering. ASCE, 2002Vol. 128 n°4, pp. 283-291.
[13] Reiffsteck P., Benoit, J., Bourdeau, C., Tacita J.-L., Desanneaux G., Enhancing the geotechnical model using drilling parameters, J. Geotech. Geoenviron. Eng., 2018, Vol. 144, Issue 3, https://doi.org/10.1061/(ASCE)GT.1943-5606.0001836
[14] Reiffsteck P., Benoît J., Hamel M., Vaillant J.-M., Application and tentative validation of soil behavior classification chart based on drilling parameter measurements, Intern. Conference on Site Characterization ISC5, Brisbane, Australia, 2016, 4 pages