Comparison of direct and indirect MWD measurements

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ABSTRACT

Drilling boreholes for geotechnical purposes such as sampling and in situ tests is usually performed with the aid of drilling machines. In France, typically, the machine's drilling parameters such as applied torque and thrust are monitored in real-time and registered so that information about the subsoil's structure can be acquired. As these machines tend to use hydraulic systems, the oil pressures fed into each motor and actuator are the parameters commonly monitored. Recently, a new type of sensor and its application in geotechnical investigations through the measuring of drilling parameters was presented. This sensor is directly mounted on top of the drill string of a drilling machine and records the actual thrust, torque, and rotation speed transmitted to the drill string and bit. This bypasses the energy losses present in the hydraulic circuit between the machine's pressure sensors and the hydraulic actuators. This mounting position allows a more accurate measurement of the forces and, furthermore, the effective rotation speed applied to the drill bit. The data is transmitted through a wireless Bluetooth connection enabling real time monitoring. Nevertheless, finding the right balance between a soil's resistance, the drill rig's power and the sensor's optimal measuring range remains a topic for further development. This analysis of several worksites with different soils throughout France contributes to a better understanding of the last generation's sensor's precision and application range.

Keywords: geotechnical instrumentation; accuracy; in-situ testing; monitoring while drilling.

1. Context

To design safe and economical structures, civil engineers need good information about the soil upon which their structures will be built. To acquire this knowledge, geotechnical surveys are undertaken before or during the early design phases of a project. These surveys probe the terrain in a few locations to collect data about the underlying material.

In France, the surveys typically use hydraulic rigs to drill boreholes in the aim of undertaking pressuremeter tests. Different other tests such as SPT, soil sampling and installing monitoring equipment can also be done with these machines. To collect more data about the soil, the drilling parameters are recorded for each borehole in a process called Monitoring While Drilling (MWD). These parameters are measured indirectly through pressure transducers connected to the rig's various hydraulics oil lines and can be used to infer valuable information about the drilled soil or rock (Somerton, 1959; Teale, 1965; Pfister, 1985; Falconer and Normore, 1987; Moussouteguy, 2002).

To ensure accurate and precise values are recorded and that the pressure readings can be converted into forces, the pressure gauges need to be calibrated to the drill rig's unique architecture. However, these calibrations don't take into account external factors such as temperature variations and material wear, which can create random fluctuations of the oil's pressure. These variations are the main obstacle to obtaining reliable data from MWD logs which could be correlated to compound parameters to better represent mechanical or geotechnical properties (De Paoli et al., 1988; Nishi et al., 1988; Reiffsteck et al., 2016).

A way of circumventing this difficulty and increasing the quality of the data collected would be to directly measure the drilling parameters. And even more, if the parameters are measured as close as possible to the drill bit, then the lower the losses due to transfer are. This paper introduces a new mechanical sensor developed by Jean Lutz and studied in a partnership with Fondasol and University Gustave Eiffel, capable of surpassing these inconveniences and monitoring drilling parameters directly on the drill string.

2. Indirect and direct measures

2.1. Indirect measurements

All current drill rigs equipped for MWD use pressure measurements of the hydraulic systems (cylinders and motors) to indirectly determine drilling parameters such as downward pressure and rotation torque instead of directly measuring them close to the drill bit. This method was developed due to various mechanical and technological constraints encountered during in situ surveys. Peronne et al. (2021) estimate that these indirect measurements could have an inherent error of up to 30%, depending mainly on the drill rig's architecture and the disposition of the hydraulic circuit.

For instance, the penetration rate is one of the main drilling parameters used to calculate compound parameters and to differentiate soil layers. Its value depends on soil characteristics but also on the downthrust and rotation speed set by the driller, and also on the efficiency of the drilling fluid. Thrust is only approximately estimated through the measurement of the pressure fed into the hydraulic cylinder or motor. But, due to hydraulic pressure behavior, Peronne et al. (2021) don't consider that a linear relation exists between the oil's pressure and the value of thrust. This is due to hysteresis, temperature variation, energy losses in the mechanical components, and other factors.

2.2. Direct measurements

The TICOR device, proposed by Jean Lutz, is capable of directly measuring the forces applied to the drill bit. This tool is a small cylinder meant to be attached between the rotation table and the drill string, as shown in Fig. 1. This position allows a direct measurement of the drilling parameters, as the cylinder receives the same forces as those applied to the drill string.

Equipped with strain gauges, this cylinder can determine the downthrust and torque transmitted to the drill bit. It can also measure rotation speed. As the device rotates with the drill string, connection cables can't be used. The data is sent in real time to the control system via a wireless Bluetooth transmitter.

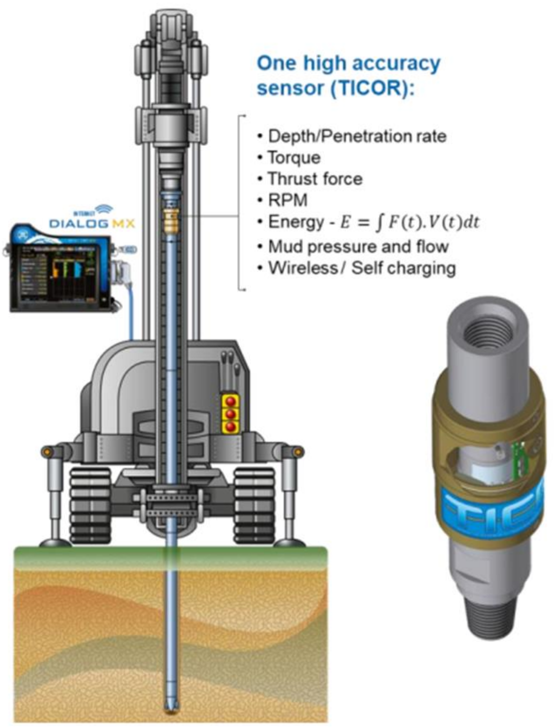

Figure 1. Positioning of the TICOR sensor on a drill rig

All of these sensors, the transmitter, and a compact battery are housed in a robust, waterproof metal casing that can be attached to the rotation table and the drill string. Jean Lutz aims to develop future models capable of wireless and even self-powering through the machine's own rotation, eliminating the need for external charging of the sensor.

3. Discussion and analysis

Multiple boreholes were undertaken with both the traditional hydraulic system and the new TICOR sensor in south-western France in the summer of 2023.

The two different types of MWD measurements, can be compared by plotting the hydraulic measurements in the horizontal axis and those from the new sensor in the vertical axis. Fig. 2 shows one such comparison between torque readings acquired through the TICOR sensor and readings from the pressure gauges installed on the rig.

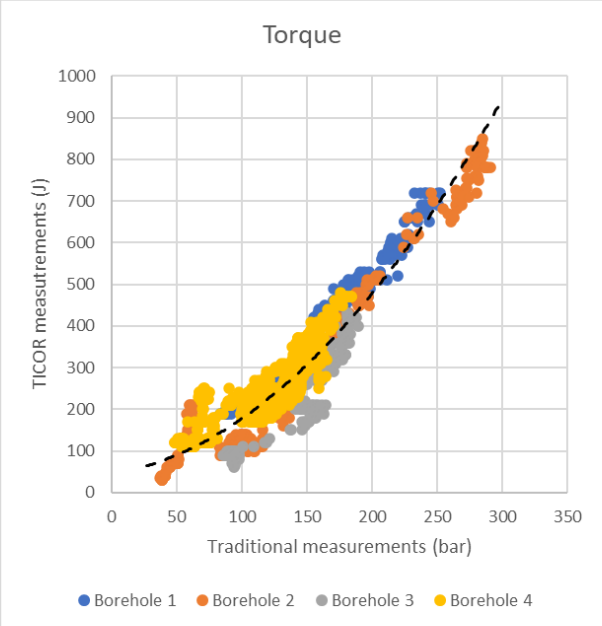

Figure 2. Comparison of torque measurements

The graph confirms the affirmation by Peronne et al. (2021) that the pressure of the hydraulic fluid does not linearly correlate with the work performed by a hydraulic engine. The values in Fig. 2 are better represented by a polynomial equation of the second order ($R^2 = 0.9024$), while a linear approximation also has a high determination coefficient of 0.8623.

As the authors affirm, this slight deviation from a linear correlation is likely due to a combination of factors such as hysteresis of the motor's components, thermal expansion or contraction of the hydraulic fluid and small energy losses throughout the system due to friction and hydraulic pressure behavior. These factors cannot be controlled by the driller and are difficult to monitor during daily operations, which may lead to inaccurate data when using hydraulic gauges to monitor drilling parameters.

The same comparison with the downthrust data in Fig. 3 shows a more linear correlation, meaning that the relation between hydraulic pressure and force transmitted to the drill bit varies from one drilling parameter to another.

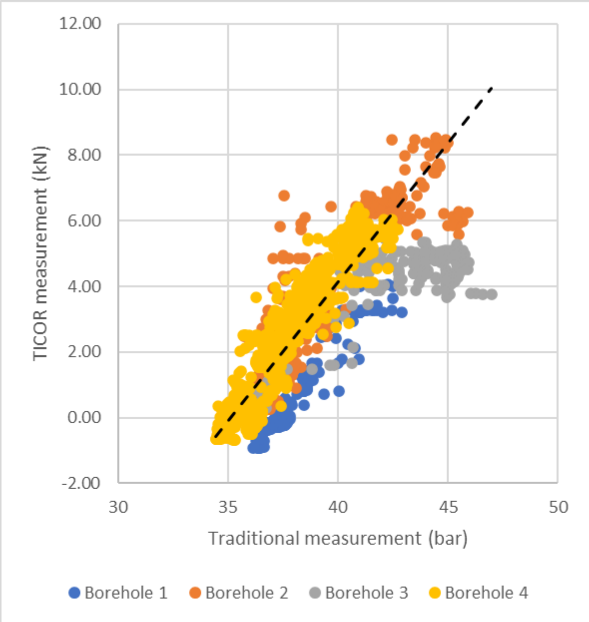

Figure 3. Comparison of downthrust measurements

Both direct and indirect drilling logs for the same parameter, as shown in Fig. 4, show the same overall behavior of both curves, such as the rises in downthrust between 8 and 17 meters and below 25 meters. However, the direct measurement method is able to detect small variations when the indirect measurements present a seemingly constant behavior due to specific features of the hydraulic circuit (3–8-meter range). This information may be valuable to specify the local lithology.

Observing the raw data, it can be seen that the greater sensibility exhibited by the TICOR sensor leads to a relatively higher level of signal noise due to the vibrating behavior of the drill bit. Still, this noise can be reduced by a simple median filter and does not interfere with the log's interpretation.

Figure 5 presents a section of the logs shown in Fig. 4, in which the downthrust tends to slightly decrease with depth along the length of one rod, as marked by the trendlines. A higher level of noise is discernible in the TICOR measurements but the trend is still discernible, showing that it does not interfere with interpretation. As downthrust is a parameter controlled by the driller, it might be possible to reduce the level of noise with careful monitoring of the TICOR readings during the drilling operation.

While it does not affect a qualitative interpretation of the curve, which mainly focuses on its form, the values recorded by the new sensor have a different order of magnitude than the ones registered by the pressure gauges. This means that equations used to calculate compound parameters might need to be tweaked to present comprehensible values. It is important to highlight that any negative readings on the TICOR's logs for downthrust can be attributed to a calibration error.

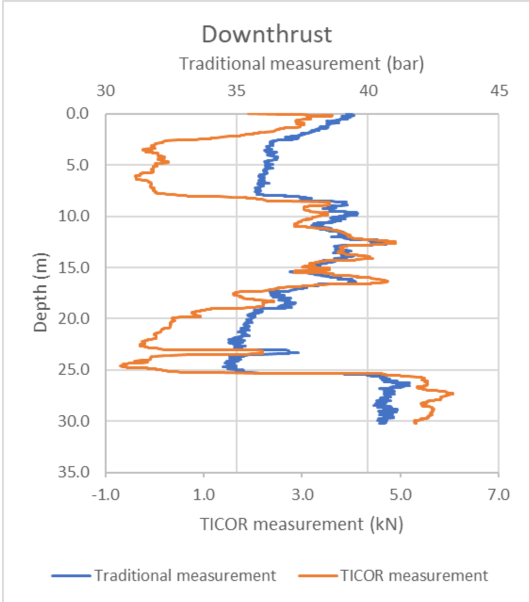

Figure 4. Downward thrust drilling logs for a given borehole (filtered)

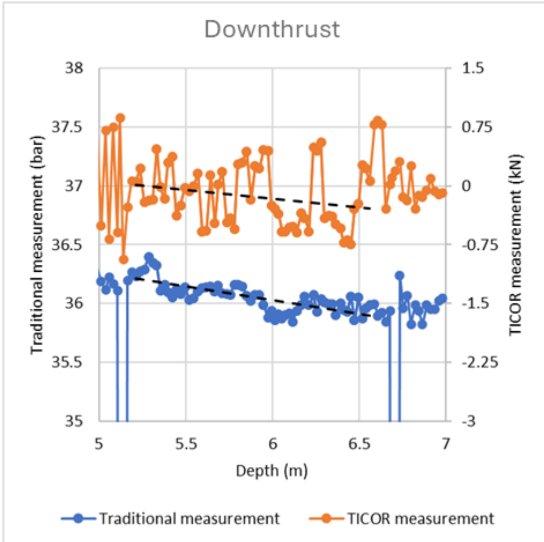

Figure 5. Closer look at a section of the drilling logs (unfiltered)

Comparing the torque readings from both systems in Fig. 6, it is noticeable that both sensors output values are in the same order of magnitude. As with the downthrust parameter, a good correlation exists between the two sets of measurements. For this parameter, the TICOR sensor also appears to have a greater sensitivity, showing larger variations where the pressure sensor presents very slight oscillations.

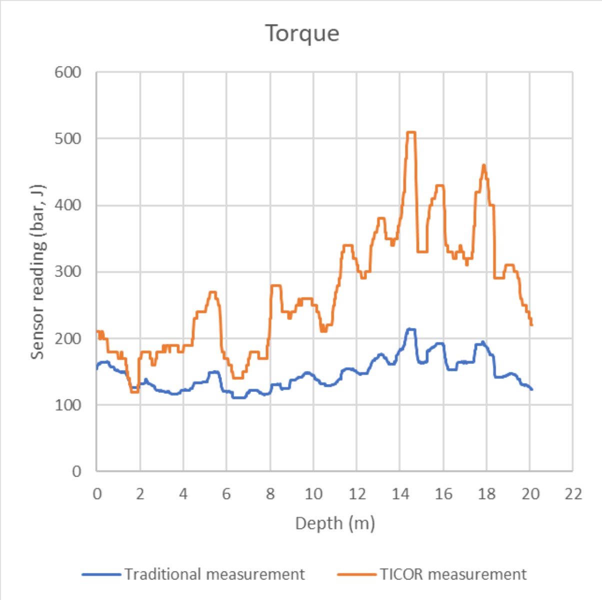

Figure 6. Drilling torque logs for a given borehole (filtered)

However, as the TICOR sensor is much closer to the drill bit and torque is a parameter governed by the soil's response, it presents a much higher level of noise than the hydraulic parameter. This difference is visible in the unfiltered logs of Fig. 7.

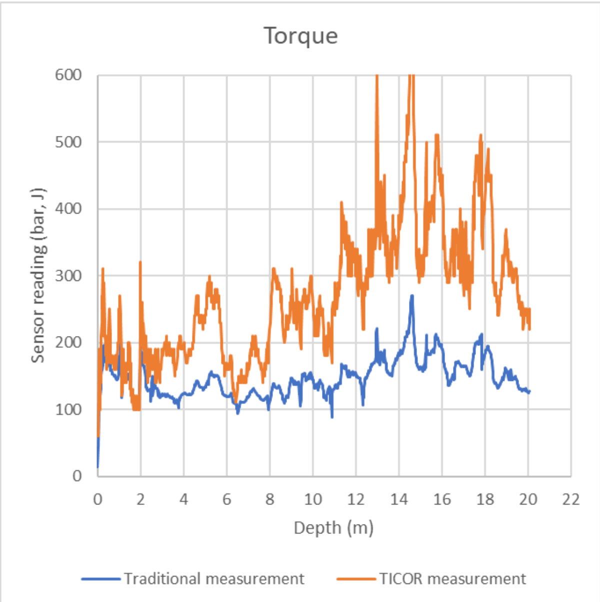

Figure 7. Drilling torque logs for a given borehole (unfiltered)

The mechanism of the rotary table between the pressure sensor and the drill bit likely acts as a cushion for smaller random variations in torque, which results in the cleaner log. However, this cushioning effect also masks changes in soil response, reducing the accuracy of the data collected and creating the difference seen in Fig. 6.

Another advantage of the TICOR is to provide measurements of the rotation speed, which are used to calculate multiple compound parameters. In modern practice, rotation speed is never measured as the optical or magnetic sensor needed must be placed at the bottom of the rotary table and very close to the drill string to observe the movement of sprockets installed there specifically for the measurement. The location of the sensor makes it very prone to being damaged during drilling operations, which lead to most teams choosing to not measure this parameter.

As the TICOR sensor uses internal accelerometers to determine its movement and calculate rotation speed, it is less susceptible to breaking than traditional sensors. Measuring this parameter is useful to monitor the drilling process, as it is one of the parameters directly controlled by the operator.

4. Conclusion

In this paper, the thrust and torque measured by the new TICOR sensor rod were compared to measurements from the hydraulic gauges typically used to monitor drilling parameters. The TICOR direct measurements show a good correlation with their counterparts with slightly curved trendlines. The new sensor is also more sensitive to small variations in soil response, which makes the interpretation easier but also introduces more noise to the drilling logs.

The sensor has proved to be useful and to accurately measure drilling parameters. The next steps would be to work on methods to filter the noise at the source and the further integration of other sensors into the device, in the aim of measuring injection pressure or flow as the drilling fluid passes through the drill rod.

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