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New electric powered drill rig to meet sustainable geotechnics

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Case Study

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Abstract

Drilling boreholes for geotechnical purposes such as sampling, in-situ tests and permeability testing are usually performed with the aid of drilling machines. These heavy duty machines generally use internal combustion motors to provide energy to hydraulic pumps feeding the different actuators needed to push, rotate and hammer the drill bit into the ground. This results in a relatively noisy and polluted environment for the workers and the surrounding area. With the popularization of electric vehicles, it's time drilling machines also make the switch to electric power. This paper presents one such prototype machine developed by Fondasol company, with the initially proposed technical specifications and the realized equipment. Autonomy for up to one week has been observed on real sites, depending on the project's drilling objective. The use of electric motors allows for a new type of measuring while drilling, as the measurement of electric current and voltage is much more reliable than hydraulic pressure and flow rates. With this electric-based design, additional external sensors are no longer necessary. A first insight into this new type of measurements and its physical meaning is also given and discussed within this paper.

1. Introduction

Historically used in the oil and gas industry but gaining popularity in the field of geotechnical engineering in the last decades, the method of measuring while drilling (MWD) involves monitoring and recording drilling parameters during the drilling process (Rodgers et al., 2020). In this method, a drill bit destroys the terrain as it advances downward, pushed and spun by hydraulic motors while a fluid cools down the equipment and removes loose debris from the hole, with the eventual use of a hydraulic hammer to break down tougher material (Reiffsteck, 2010). Typically, the parameters monitored are the penetration rate, downthrust, torque, rotation speed and fluid injection pressure; while other data can also be collected such as fluid injection rate, drill string vibration, both the frequency and energy of the percussion blows and the energy reflected back after each blow (Moussouteguy, 2002).

The drilling may have multiple objectives: creating holes for sampling, in-situ tests like pressuremeter tests, installing piezometers and inclinometers, verifying the efficacy of soil treatments or simply gaining knowledge about the subsoil. It has the advantage of being a rapid essay giving continuous information, much like the cone penetration test, while allowing an identification of the soil (Fortunati & Pellegrino, 1998; Cardu et al., 2013).

The drill rigs used in creating these holes may vary in size and overall power but share similar architecture: they all have a mast on which the drilling head moves vertically. The length of the mast and the characteristics of the drilling head may differ according to the project's objectives (Reiffsteck, 2010).

In addition to the translation motor, the drilling head is equipped with a rotation motor and eventually a hammer that transmits rotating forces to the drill bit underground through the drill string. Both elements are usually hydraulic. The mast has the functions of guiding and driving the drilling head vertically, pushing the drill bit into the soil. This movement is also achieved by a hydraulic system (Reiffsteck, 2010). Other special mechanisms may be attached to either the mast or the drilling head to increase the versatility of the machine by allowing it to perform SPT investigations or to collect undisturbed samples. Figure 1 shows a simplified scheme of a drill rig.

There are other hydraulic systems in the rig as well, such as the stabilizing cylinders, the mud pump, the winch,

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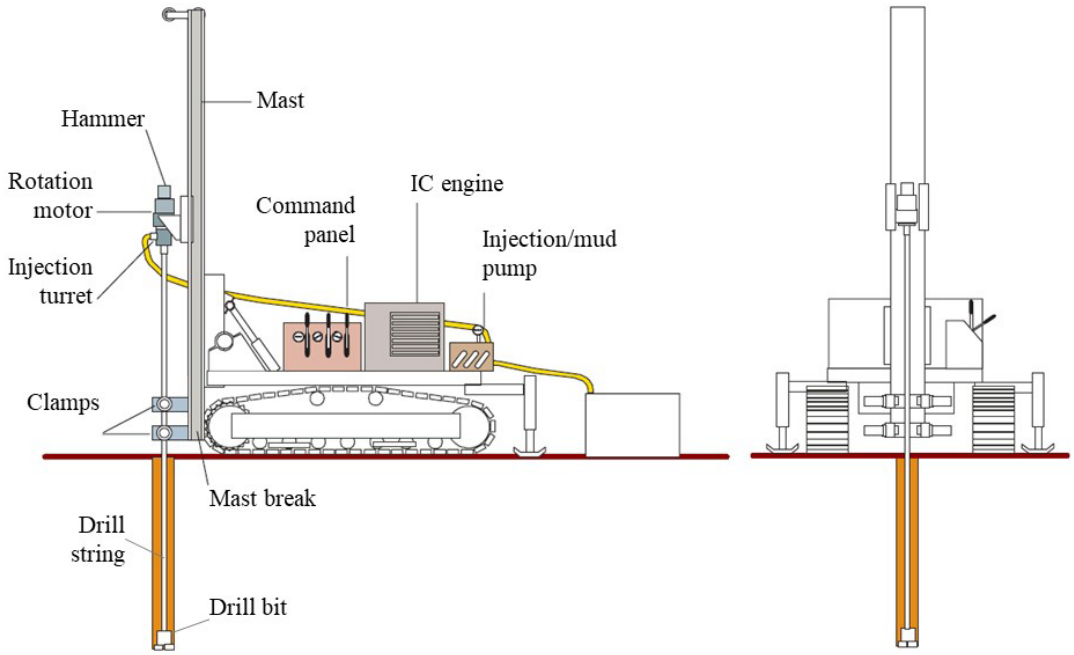

Figure 1. Diagram of a hydraulic drill rig.

the clamps and the cylinder that folds down the mast to put the machine in displacement mode. All these systems, as well as the pump for drilling fluid, are typically powered by a hydraulic pump connected to an internal combustion (IC) engine (Nishi et al., 1998; Reiffsteck, 2010).

According to Reiffsteck (2010), one of the risks associated with this method is the accidental release of hydrocarbons (oils or fuel) into the soil from the various hydraulic systems or the engine, which could contaminate the water table. The combustion motor also produces polluting gases and a lot of noise which can be detrimental to the workers' health and the surrounding area, even more so when used in closed environments.

To remedy these issues and improve on the method's energy efficiency, this paper presents the design and construction of one such machine. The use of electric motors also allows a different way of measuring drilling parameters, which is also discussed in the article.

2. Objectives of the project

The new CLEA (connected, light, electric and autonomous) drill rig proposes to change soil investigations by using electric motors instead of mechanic/hydraulic actuators fed by an internal combustion engine. The new machine retains the same architecture and usability as the currently used rigs, with a foldable mast and mounted on a crawler while being mechanically simpler as there is no clutch or gearbox.

This allows more efficient drilling, as electric motors are more energy efficient than hydraulic systems, while producing less noise and air pollution. The deployment of one such machine is estimated to avoid the emission of 8.2 $t_{eq}CO_2 / \text{year}$, which would greatly reduce the carbon footprint of geotechnical investigation companies. The drilling parameters can also be measured more reliably, as it is easier to continuously monitor electrical currents and voltages than fluid pressure or flow rate. A digital model and the realized prototype are shown in Figure 2.

3. Drill rig specifications

The proof of concept can achieve vertical speed of 900 m/h or 1500 mm/min with a maximum force of 21 kN. This movement is powered by an electric motor. The electric rotation motor allows a rotation speed of 350 rpm and a torque of 1500 Nm. These specifications, shown in Table 1, were chosen to approximate those of a conventional 32 kW hydraulic drill rig: vertical speed of 900 m/h, down force of 20 kN, rotation speed of 300 rpm and 1500 Nm of torque.

The second prototype was built to have the same specifications as the proof of concept. The translation and rotation motors were kept the same while the battery was

Table 1. Drill rig specifications.

	Conventional machine	Electric prototype
Translation speed (m/h)	900	900
Rotation speed (rpm)	300	350
Torque (Nm)	1500	1500
Vertical force (kN)	200	210
Mast length (m)	2,5	2,2

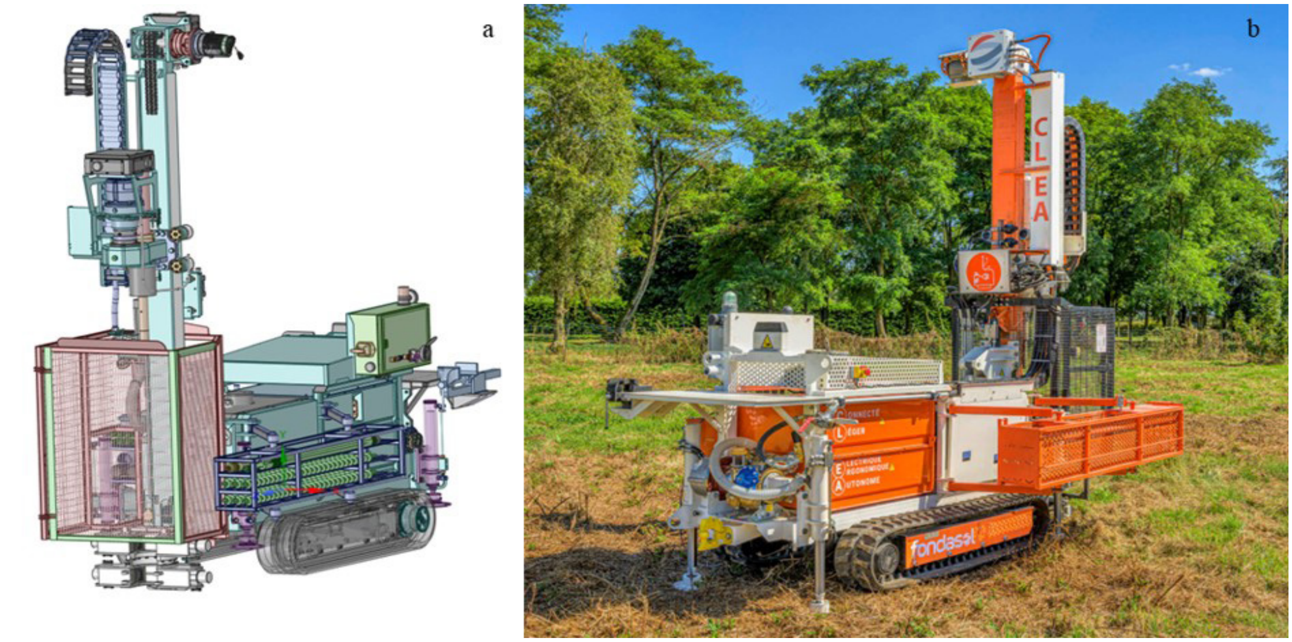

Figure 2. Electric drill rig: a) project prototype (a); finished machine (b).

now incorporated into the rig's chassis, occupying the space typically reserved for the IC engine. For this model the battery capacity was reduced, with the option of expanding it if necessary. With this new battery and the new electrical systems incorporated, autonomy fell to about 2 days (a bit over 40% of battery usage a day) during winter, when the lower temperature reduces battery life. Figure 3 illustrates all the motors and sensors installed on the proof of concept.

4. Project development

At first, a proof of concept was built over the chassis of a small 50 hp hydraulic drill rig, with the hydraulic mechanisms responsible for translating and rotating the drill string being replaced by electrical motors. The percussive hammer atop the mast and the vices used to separate the individual shafts from the drill string were still hydraulic pistons, but an electrical pump fed these systems alternatively, allowing the use of either one at a time. Meanwhile, the IC engine was still responsible for the rig's locomotion and set up.

For this first model, the battery bank used to power the various motors was kept separate in a detachable trailer as the IC engine remained in the chassis. This would also facilitate the adjustment of the battery capacity, in the case that the initial estimates on consumption were too far off. This initial estimate was made based on the fuel consumption of a traditional drill rig, aiming to give the prototype a similar performance.

As the controls on the machine were part of the replaced hydraulic systems, a new control pad was developed. Given that the new controls only send electronic signals to the motors instead of directly adjusting the flow and pressure of the hydraulic fluid, this new control pad could be detached from the machine and carried by the operator. Detaching the pad from the machine has the advantage of allowing the operators to position themselves during the operation to better observe the drilling. It also gives the team more flexibility to operate in cramped spaces. However, as the locomotion systems were still conventionally powered, the hydraulic levers remained on the machine and the remote-control pad was only used during the drilling phase.

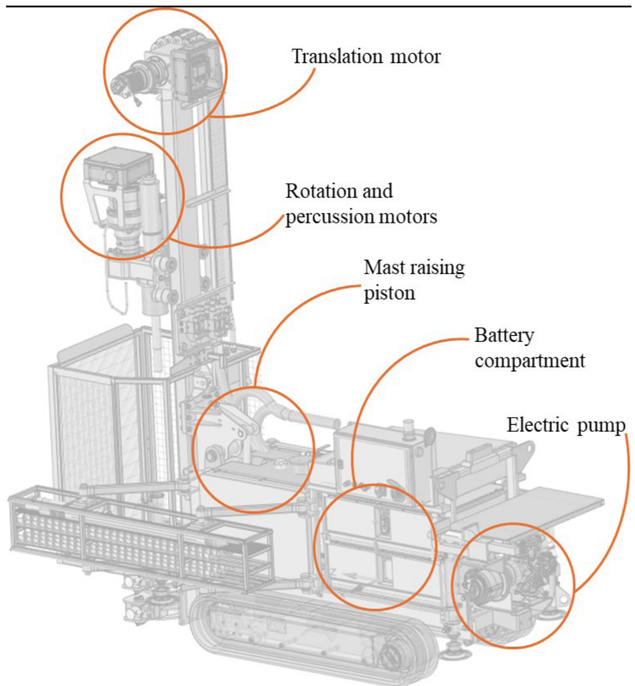

Figure 3. Scheme of all electric motors in the prototype.

After careful calibration, this proof of concept was allocated to one of Fondasol's investigation teams and used in various real work sites in northwestern France, mostly in the region of Pays de la Loire. During this period, it was observed that the machine met expectations and even exceeded some: the drillers approved the ergonomic changes to the controllers and the much more silent workplace, and the energy consumption was below expected with an average of 12% of battery usage per day. One investigation made with this machine is presented in item 6 of this paper.

After the successful deployment of the proof of concept, development began on the second prototype. This second model has a fully custom chassis to house the batteries and no IC engine. Just like in the first model, an electrical pump powers hydraulic circuits for either the hammer or the clamps, being activated only when necessary. Unlike in the proof of concept, the locomotion and stabilization systems are now also hydraulic systems connected to electrical pumps.

The ergonomics of the rig were also improved in the new version: as the control pad had been detached from the machine, this allowed the installation of telescoping racks on both sides of the rig. These racks can be extended around the security cage during the drilling operation and make the various tools and drill shafts more easily available to the assistant driller.

The control pad also got an update and now is also responsible for logging in all measurements made during the entire drilling operation without the need for an external data logger, as is usual in drilling machines. This data is visible through a touchscreen in the pad, where the operator can select the project, work site and investigation point being drilled, and any other additional information they might deem necessary. This data can then be transmitted to the company's internal database via cellular network as soon as the drilling is marked as finished or manually transferred with an USB flash drive. As the portable control pad is also a prototype, its screen can be mirrored to quickly troubleshoot with the engineer even if they are offsite.

Included in this new control pad were also a few automations for repetitive tasks, accessible by pressing specific button combinations. These automations include using the clamps to unscrew the drill string and automatically adjusting the advance rate according to the rotation speed when drilling with continuous flight augers.

In the same manner as the proof of concept, the prototype was allocated to an investigation team and successfully used in real work sites in Northwestern France. One of the investigations made with the prototype is presented in item 7.

5. Electrical MWD measurement

The use of electric motors allows the monitoring of drilling parameters through the current and voltage. These electrical parameters are directly proportional to torque and rotation speed, respectively. This advantageously replaces the pressure transducers and the optical/magnetic sensors used to measure rotation speed typically used in conventional hydraulic rigs that only indirectly measure each parameter. The pressure transducers also have the disadvantage of not measuring the forces truly delivered to the drill bit as they are placed beside the pumps and cannot account for pressure losses in the system (Peronne et al., 2021).

Unlike the typical measurements, the CLEA directly measures the current delivered to each motor, which is directly proportional to the torque applied on the drill bit. Instead of logging the values measured as a function of depth (typically each 2 cm), the proof of concept registered all the parameters as a function of time resulting in a much more detailed dataset. The newer prototype automatically displays this data as a function of depth, but the measurements are still logged every 0.4 seconds, and this more detailed dataset can still be accessed if necessary to evaluate the machine's performance.

The collected data can be displayed both as the conventional physical parameters in their respective units (MPa for downthrust and injection, Nm for torque, rpm for rotation speed) of measurement and in terms of energy spent or power in kW delivered to the motors. Calculating the power spent by each motor also has the advantage of providing the total energy spent during the survey, which can be used to confirm the battery indicator and visualize which motor spent the most energy at a given moment.

In the multiple investigations made with both rigs, it was seen that the rotation and percussion motors consistently spend the most energy while the energy used to translate the rotary table is almost negligible. The energy consumption on the injection pump varies greatly with the nature of the terrain, as to be expected, but also tends to be much lower than rotation and percussion.

6. Case study – worksite A

In the end of 2023, the proof of concept was deployed in the Loire Atlantique department of France, stationed in the city of Nantes. It took part in one project in the coastal city of La Baule and the drilling logs are shown in Figure 4 below. For this investigation, the drilling parameters are displayed in terms of electrical power consumed by each of the motors in the rig.

Figure 4 shows one of the drillings conducted for this project along with the lithology estimated by the driller, which consisted primarily of sandy layers, with a layer of soft clay and a bedrock of gneiss as well. The transition from the soft clay into the sandy clay layer can be easily identified at about 4 m by a drop in the advance rate and translation power as the rotation power rises. A slight increase in the injection power can also be seen. Finally, the bedrock can be quickly spotted by the need to activate the percussion at 14 m, but also by the decrease of the advance rate and the increase of rotation power.

From this investigation, we can see that the drilling logs from the electric machine can be interpreted much like those from a conventional hydraulic machine. Furthermore, monitoring electrical currents and voltages is easier and more precise than monitoring fluid pressure in a hydraulic system, making these logs potentially more precise than what could be acquired with a conventional machine. This happens because the points of measurement for the pressure in the hydraulic circuits are far from the motors and cylinders due to constraint in the machine's architecture which lead to energy losses not being accounted for.

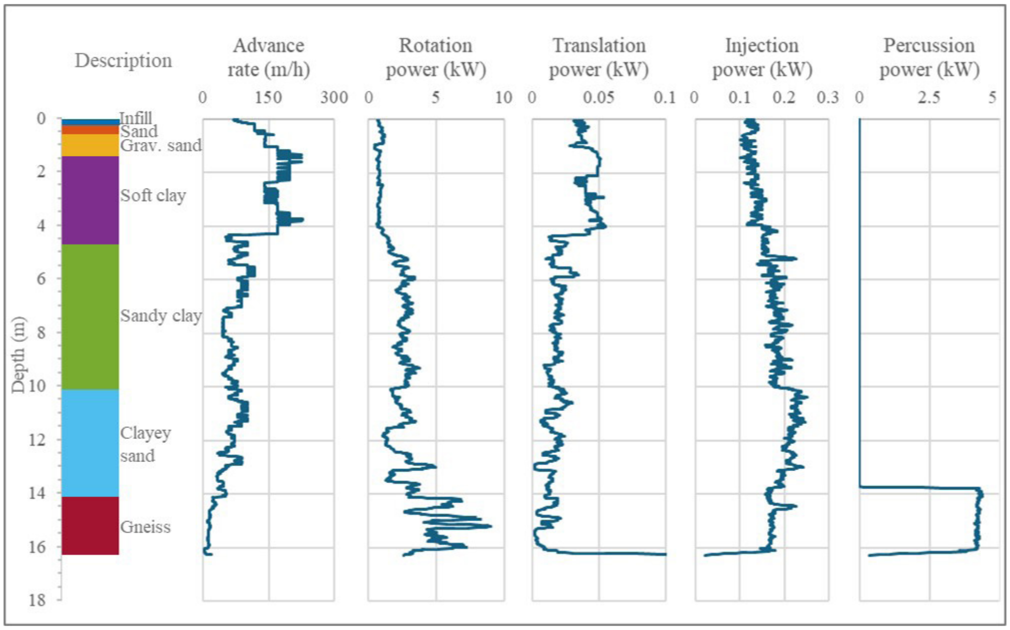

Figure 4. Drillings logs from an investigation campaign with the proof from concept.

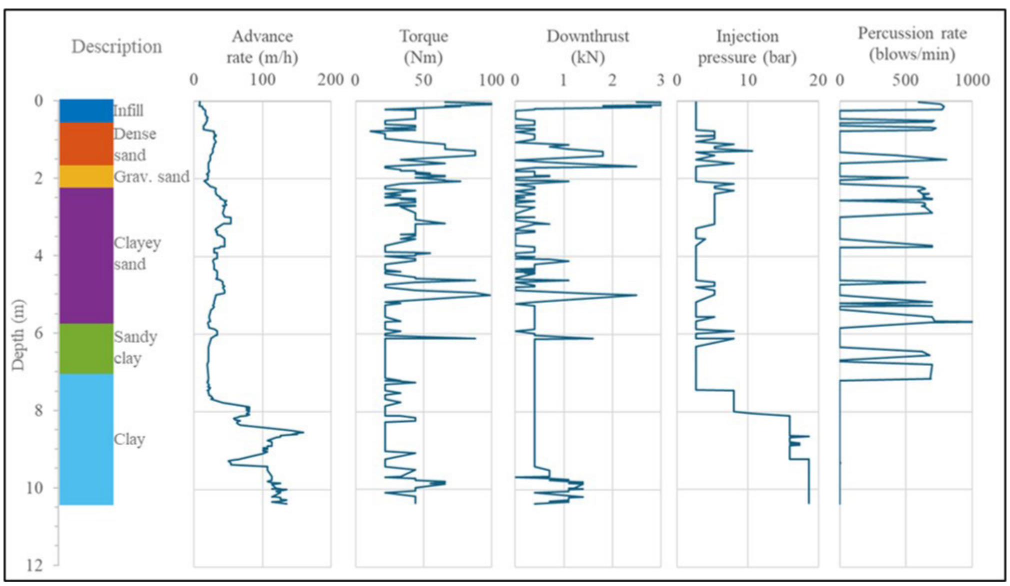

Figure 5. Drillings logs from an investigation campaign with the prototype.

7. Case study – worksite B

In 2024, the prototype was transferred to the department of Sarthe, stationed in the city of Le Mans, so that the machine could be tested in different types of terrain. It took part in one campaign in an industrial zone at the southern end of Le Mans, near the banks of the river Sarthe. The logs for one of the drillings from this campaign can be seen in Figure 5. For this project, the drilling parameters are displayed as the forces delivered to the drill bit, not as the power consumed by the electrical motors as in the previous example.

The lithology encountered consisted of sandy layers on top of a clayey layer. The transition between these layers still has a large quantity of sand mixed in and thus the drilling parameters show little change, but the rise in injection pressure after 7.5 m clearly indicates a rise in clay content. In this drilling the hammer had to be used intermittently because of the high lateral earth pressure that would frequently block the drill string, even though it wasn't a particularly hard soil. Due to this, the downthrust necessary to advance was greatly reduced and at some points only the weight of the assembly and the percussion was enough to make the drill bit advance at the desired speed.

8. Conclusion

This paper has presented the architecture of a new generation of drill rig that uses electrical motors instead of hydraulic ones powered by an internal combustion engine. The proof of concept and the prototype tested in situ have performed better than expected, with autonomy for over a week of surveying without recharging, all the while being more silent and not generating greenhouse gas emissions. Both machines can be quickly mastered by experienced drillers as they use the same control scheme as the traditional hydraulic ones, leading to similar productivity. The data collected by logging the current and voltage used by the various motors has been shown to be as detailed or more so than the data registered while using pressure transducers in a conventional drill rig. The data can be displayed as the conventional physical parameters delivered to the drill bit or in terms of power spent by each motor and can be interpreted in the same manner as regular MWD logging.

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Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Michel Rispal: conceptualization, funding acquisition, data curation, project administration, writing – review & editing. Catherine Jacquard: funding acquisition, supervision, writing – review & editing. Guilherme de Oliveira Souza: data curation, formal analysis, methodology, visualization, writing – original draft. Philippe Reiffsteck: methodology, supervision, writing – review & editing.

Data availability

Data generated and analyzed in the course of the current study are not publicly available due to them being proprietary data, but a complete or limited dataset can be made available by Fondasol upon reasonable request.

Declaration of use of generative artificial intelligence

This work was prepared without the assistance of any generative artificial intelligence (GenAI) tools or services. All aspects of the manuscript were developed solely by the author, who takes full responsibility for the content of this publication.

List of symbols and abbreviations

CLEA Connected, light, electric and autonomous (in French)
IC Internal combustion
MWD Monitoring while drilling

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