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CPTU crossing existing boreholes in the soil

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ABSTRACT: One of the most difficult deviations to explain, has been an unexpected drop in measured values inside a homogenous clay layer. Using the correlations from Karlsrud et al (2005), the interpreted CPTU sounding show a drop in undrained strength far below a normally consolidated soil at some sites. The paper shows that the drop in cone resistance and interpreted shear strength is due to disturbance and remoulding of the clay caused by previous investigations at the same location, as it is common practise to at least perform either a Norwegian total sounding or a rotary pressure sounding at a location where a CPT is performed. Using the inclination of the probe registered during the CPTU soundings, and the thickness of the disturbed and remoulded layer in the profile, the horizontal extent of the disturbed zone around the previous sounding is estimated to be around 60 cm in diameter, or around 8 - 12 times the diameter of the drill bit that is 57 mm in diameter.

1 INTRODUCTION

During the last 15 years the use of CPTU has developed into becoming one of the most widely used ground investigation methods in Norway. CPTU is used to classify soil type behaviour and to provide interpretation basis for a range of strength and deformation parameters for the soil in geotechnical calculations. As the use of CPTU has spread, NGI have collected a number of CPTU soundings where the results deviate from what is expected. The results presented in this paper come from an internal research project at NGI, and are presented in Kåsin (2011), which looked into several different types of anomalies in CPTu soundings.

2 SIMULTANEOUSLY LOW TIP RESISTANCE, SIDE FRICTION, AND PORE PRESSURE

One of the deviations that has been most difficult to explain is an unexpected drop in the tip resistance, q_c, side friction, f_s, and pore pressure, u_2, within what appears to be a homogenous clay layer. Such a drop in the measured data from each of these sensors would normally indicate that there is a weaker layer at this interval. If the data from these CPTU are interpreted according to Karlsrud et al (2005), as is common practise at NGI, the clay in these layers appears to be far below the strength of a normally consolidated clay. However, to have a weaker layer of clay, with a strength that appears to be far below the strength of a normally consolidated clay is unrealistic, especially when other data like geological history or data from investigations nearby are taken into account. The anomaly can not be reproduced by performing a new CPT at the same location.

Figure 1 shows a typical example of this type of anomaly, with both a total sounding, and the CPT with the anomaly present in the depth interval between ca. 9.7 m and ca. 12.7 m. The total sounding does not show any indication that the clay is weaker in the same layer. The total sounding and CPT were performed in central parts of Oslo, just east of Gamlebyen gravlund, at a borehole location 411. The tests were performed by Rambøll in 2009 with a Geotech CPTu type Nova. Figure 2 shows the same CPTu sounding where the undrained shear strength is interpreted using the correlations presented in Karlsrud (2005). Between 9.7 m and 12.7 m the strength of the soil is below the trend at the site, and between 10.5 m and 12.4 m the interpreted strength is below 0.3 x P_0', that can be used as an estimate of the shear strength for a normally consolidated clay in the area. Both the total sounding and the CPT indicate homogeneous, sensitive clay, with an interpreted over-consolidations ratio, OCR, between OCR=3 just below the dry crust at 5 m, and reducing with depth down to around OCR=1.8 at 20 m. The anomaly can be seen between 10 m and 12.9 m where the measured values in both the tip resistance, qc, side friction, fs, and the excess pore pressure, u2, are lower than the rest of the profile.

3 POSSIBLE EXPLANATIONS FOR THE LOWER MEASUREMENTS

Several different explanations for the anomaly have been suggested:

1. Sensor malfunction in the CPTU probe.
2. CPTu test executed erroneously, leading to lower or wrong values.

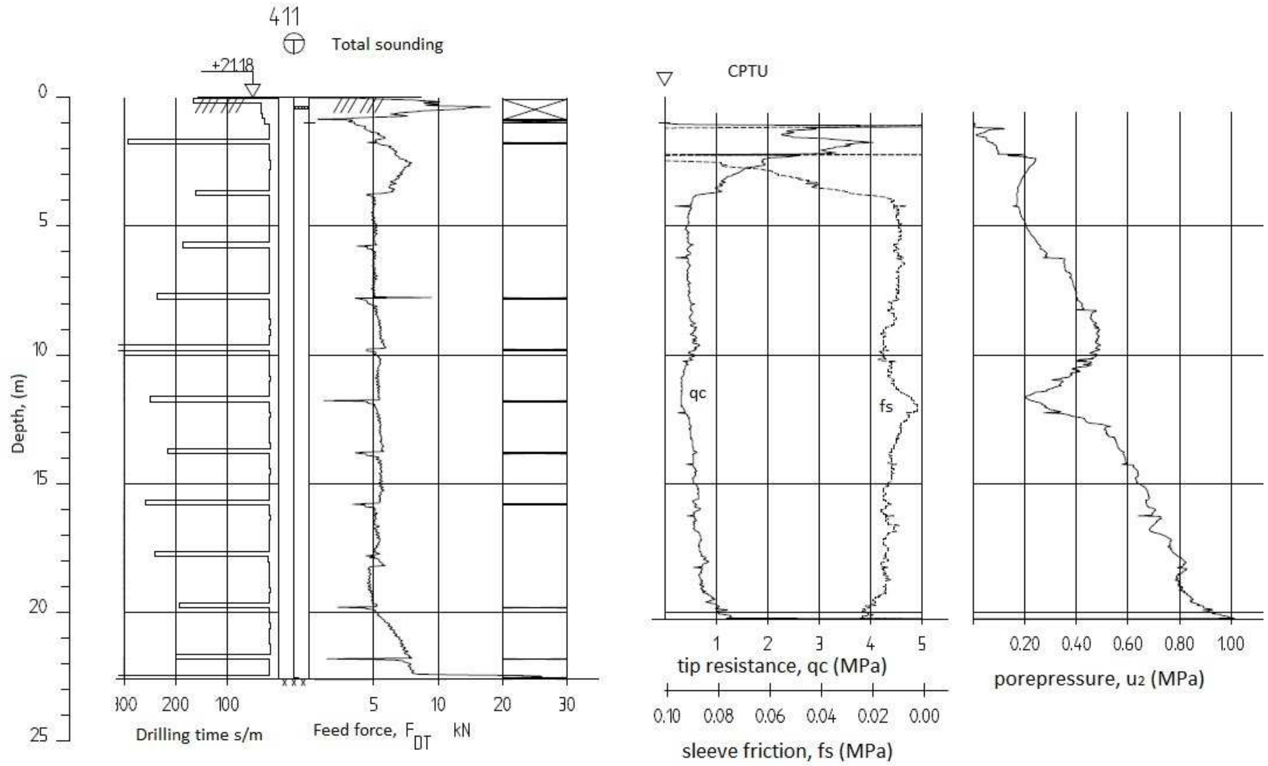

Figure 1: Plot of total sounding and CPT sounding in borehole 411, Oslo

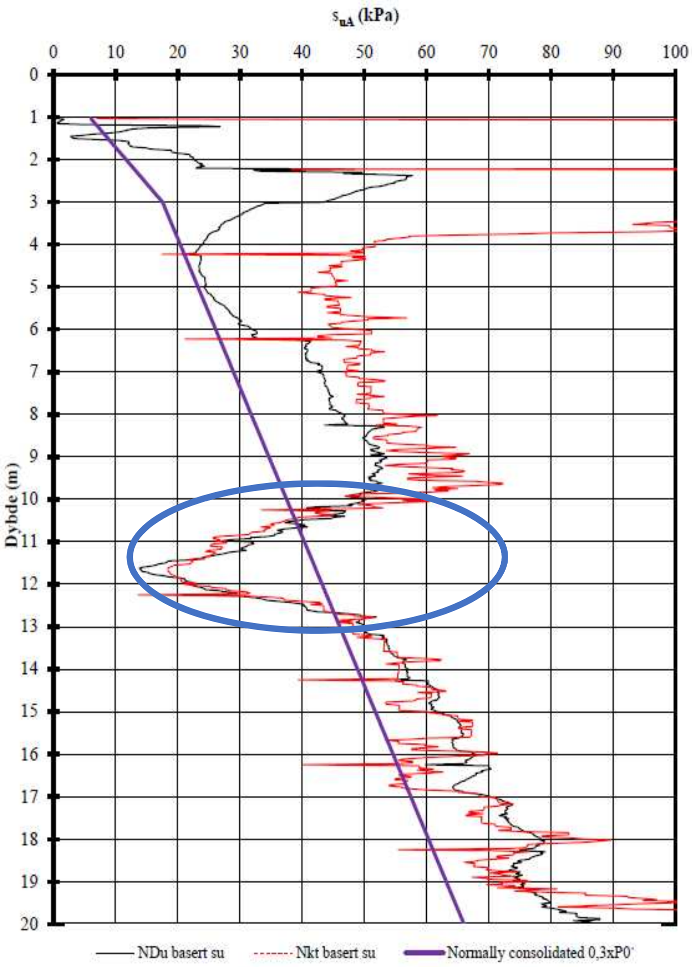

Figure 2. Interpreted shear strength

3. The strength of the clay layer is lower in just this interval – some kind of under-consolidated clay.
4. The strength is lower in the interval because of a shear band in the ground, reducing the strength of the soil.
5. The strength is lower in the interval because the CPTU passes through a previously drilled hole in the ground at an angle

Explanations 1 and 2 are often the "go to explanation" when geotechnical engineers receive data that does not conform to what is expected from the field, especially when the phenomenon cannot be replicated with another test at the same site, or if only one of several tests in the same deposit show an anomaly.

As this type of anomaly has been present in data collected from several locations with different types of clay, and from several renowned Norwegian geotechnical companies, and from both common CPT equipment manufacturers, it seems like it is not a problem with neither the personnel nor the equipment. Through the raw data files from the soundings, there are no indications that there is anything erroneous with the execution of the works in the field or with the sensors on the probe. To add to this it is in the authors opinion unlikely that a type of random error in the CPTUs sensors presents itself across several different probes of different makes, or that several drilling crews are performing the CPTu test wrongly in some way in just one interval.

Explanations 3 and 4 are also unlikely, as the anomaly normally is not reproducible if the CPTu test is redone at the same location. If the soil at the location actually has a lower shear strength, either because of a shear band or because of some other phenomenon, one should expect to be able to detect this if the CPT tests are redone.

4 CROSSING OF PREVIOUS BOREHOLES

It is in this authors opinion that the most likely cause of these anomalies is that the CPT probe crosses through the disturbed and possibly remoulded zone around a previously drilled borehole or sounding.

This is supported by the fact that in Norway, it is common practise to perform either a total sounding or a rotary pressure sound at any given borehole location, before a CPTu is performed. The purpose of these soundings would be to collect data that CPT does not provide (eg. depth to bedrock, mapping of sensitive layers), and to map layers of elements in the ground that can damage the CPT-probe itself.

After performing the total sounding, the drill rig is moved 1 – 2 m, and the CPT-sounding is executed. The Norwegian practice follows Norges Geotekniske Forening melding 5 (2010), which specifies that a CPT has to be performed either 2 m or minimally 20 times the diameter, from a previous borehole to avoid performing the CPT in soil affected by the previous investigation. For the total sounding and rotary pressure soundings, these diameters are 57 mm and 56-51 mm, respectively. This corresponds to 1.14 m to 1.02 m if the latter requirement is to be used.

It is also common practice to predrill through hard layers of top soil or dry crust, as these hard layers are often dilatant, and can suck out the saturation fluid in the pore pressure sensor and can damage the probe. This practice of predrilling, often means that even in the start of the sounding, the CPT can be somewhat out of verticality, as the rods often will be unsupported horizontally within the predrilled hole at the start of the sounding. Any small rock or pebble at the bottom of the borehole will then push the CPT sideways, because of the long unsupported drill string in the hole.

As shown in Figure 3, which shows the horizontal deviation vs the true depth for CPT 411, the horizontal deviation of the CPT can be significant, and certainly more than the 1 – 2 m that is common practice to move the drill rig in between different tests at the same location. The horizontal and vertical deviations in each depth increment is calculated using the following equations:

$$\Delta h = \sin(\alpha), \Delta v = \cos(\alpha)$$

where α is the measured inclination angle in each increment in degrees. These incremental values can then be used to see how far the CPT has travelled horizontally during the penetration.

Going back to the sounding at location 411CPT and applying this, one can see that at 9.7 m depth, where the start of the layer with apparently lower shear strength, the CPT has moved a horizontal distance of 0.85 m, at 12.7 m the distance is 1.45 m, and at 20 m the horizontal distance travelled is over 3 m. The CPT travels around 60 cm horizontally within the 3 m thickness of the layer with lower shear strength, indicating that the width of a disturbed zone that is at least this wide.

Looking back to Figure 2, the interpreted shear strength is falling between 9.7 m and 11.6 m where the interpreted strength is at the lowest. From 11.6 m the strength increases strongly with depth to 12.7 m. This points to the CPT seeking the path of least resistance as it is passing through the less disturbed soil furthest away from the previous sounding, and then passing through or close to the center of the borehole at 11.6 m. From the center of the previous borehole the probe goes through less and less disturbed soil until it reaches undisturbed soil at around 12.7 m. This fits well with an assumption that the disturbance or remoulding effect of the previously drilled sounding is greatest near the center of the drilled, and reducing with distance from the center.

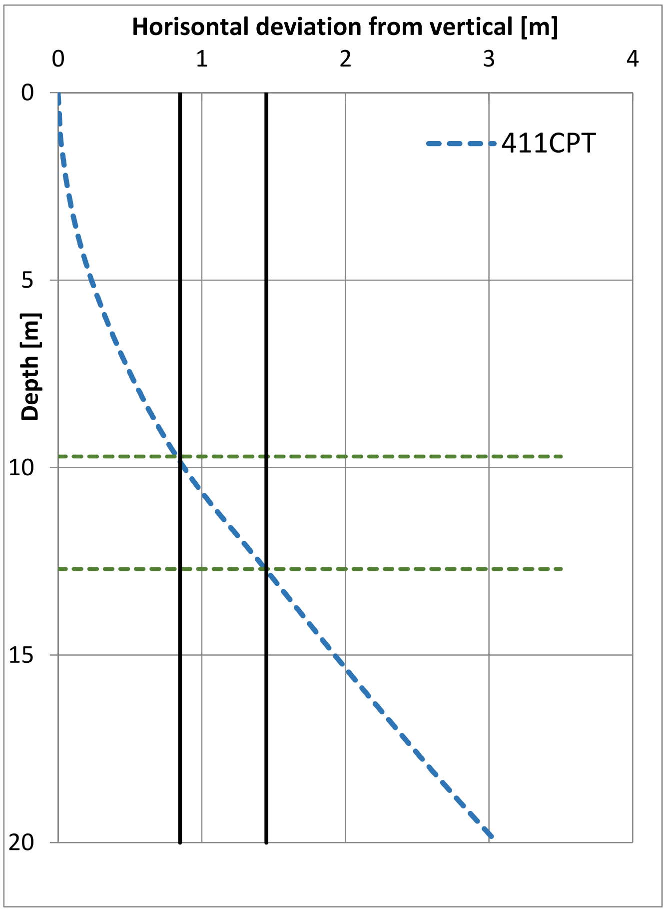

Figure 3. Calculated horizontal deviation of 411CPT using measured inclination data.

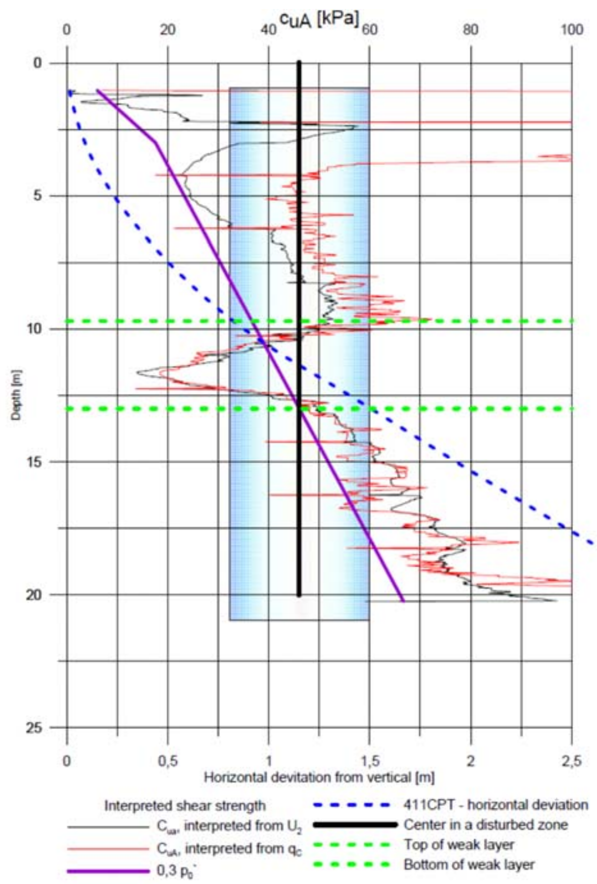

Figure 4. Interpreted shear strength, weak layer and the path of the CPT in the ground, from borehole 411CPT

5 ESTIMATING THE WIDTH OF THE DISTURBED ZONE

To estimate the width of the disturbed zone around the previous sounding one look at the horizontal distance that the CPT travels within the disturbed layer. In sounding 411, the CPT travelled 60 cm horizontally within the disturbed layer. This suggest that the disturbed zone is close to this width, and this indicates a disturbed zone of 8 – 12 times the diameter of the sounding that was done before the CPT.

Through assuming that the disturbed zone around a total sounding in clay is mostly the same width as the size of the drill bit always is the same, and that the total/rotary pressure soundings are vertical, the only unknown in each location will be the distance between the CPT and the previous sounding, as this is normally not known. It is common practise when surveying borehole locations that the least advanced test represents the borehole location, and that the other tests at the same locations are given the same coordinates.

The horizontal distance between the previous sounding and the CPT can be estimated by varying the horizontal distance between the previous sounding and the CPT in each of the cases where this anomaly presents itself on a plot where the following is plotted:

- The horizontal distance travelled by the CPT.
- The top and bottom of the disturbed layer from the shear strength interpretation
- Lines representing the zone of disturbance in the soil around the previous sounding In all these cases a 60 cm wide zone of disturbance fits well with the available data.

6 RESULTS

Figures 4 – 6 show 3 examples of borehole locations where the CPT, in the author's opinion, has crossed the previous total sounding/rotary pressure sounding. The red and black curves are the interpreted shear strength using the correlations for N_{kt} and $N_{\Delta u}$ from Karlsrud et. Al. 2005, for q_c and u_2 respectively. The purple curve is an evaluation of the shear strength of a normally consolidated clay using S_u= 0,3p_0`. The blue dotted line is the horizontal deviation of the sounding that is calculated using the measured inclination angle during the sounding. Also marked on the plot is the thickness of the disturbed layer, and the assumed placement of a previous borehole/ sounding the disturbed zone around it.

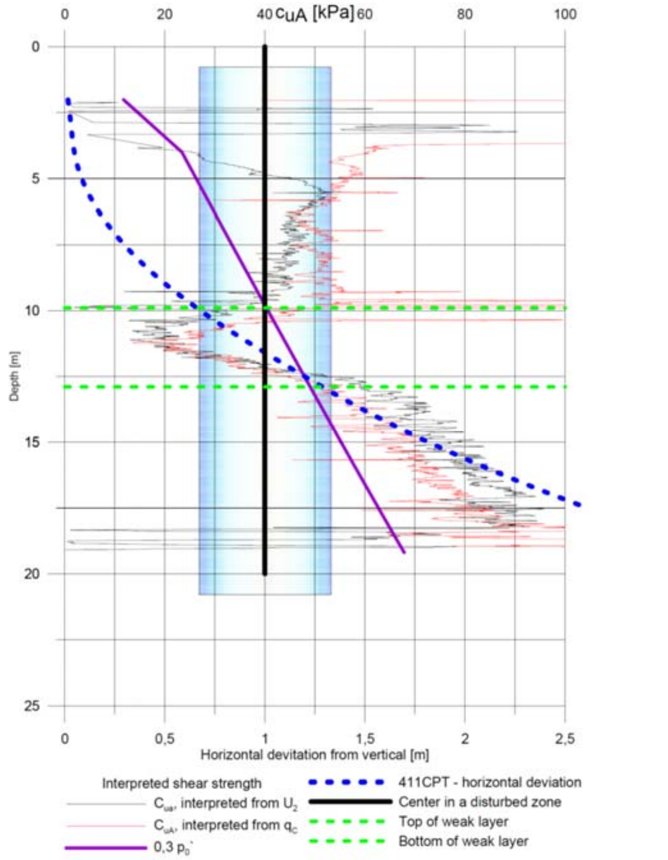

Figure 5. Interpreted shear strength, weak layer and the path of the CPT in the ground, from borehole 5 Stasjonsveien in Oslo

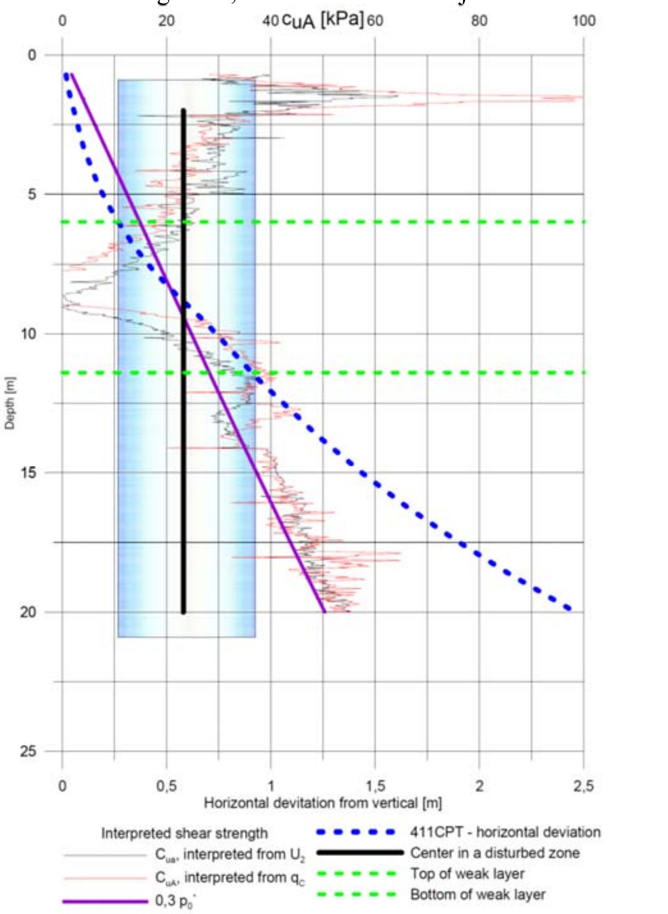

Figure 6. Interpreted shear strength, weak layer and the path of the CPT in the ground, from borehole V-NB-018 in Nykirke in Norway

7 DISCUSSION

In the estimation of the width of the disturbed or remoulded zone there is a couple of assumptions. Firstly, there is the assumption that the total soundings are vertical in the case where we see that the CPTs deviate strongly from verticality. However as the total soundings are rotating while penetrating the ground, they are less likely to deviate from the strait line, and as they are started from the terrain level, where the verticality of the drill string can be checked, the assumption of verticality of the total/rotary pressure sounding is not unreasonable for relatively short boreholes. The three examples in figure 4 – 6 shows that the CPT crosses the previous soundings at 9.8-13 m in figure 4, at 10-13 m in figure 5, and 6 -11 m in figure 6, and the width of the disturbed zone is the same, around 0,6 m, in all of them.

The second assumption is that the width of the disturbed zone is the same in all of the boreholes. The width of these may very well vary by several factors, some of which are listed below:

- Strength of the soil
- OCR of the soil
- Sensitivity of the soil
- Time in between the CPT and the previous sounding.
- Plasticity of the soil.
- Design of the drill bit/tool that generates the soil disturbance

However, there has not been enough data available to make any investigations into these factors and their impact, if any. It is the authors suggestion that further work are focused into collecting more data to look into which of these or other factors contribute to the generation of this type of anomaly and to look into what influences the width of the disturbed zone.

8 CONCLUSIONS

It is the author's opinion that the low values encountered in the presented soundings, cannot represent faulty equipment or low strength in the ground.
The geology in the area well known and the strength of the soil should not be as low as the measured values indicate. Moreover, since the low values cannot be reproduced by other CPTs or by sampling the most logical explanation for the low values is that the CPT has crossed a disturbed zone around a previous sounding.

The examples presented in the paper show that the path of the CPT can go through previous soundings in the ground near the CPT, even if the drilling rig is moved 1 m or more to the side, as the CPT can deviate several meters to the side during the sounding, as the horizontal deviations calculated from the measured inclinations. The zone of disturbance created by total soundings, which are performed with as seem to be the around 60 cm, and this is around 10 times the diameter of the drill bit used for total soundings.

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