Metal objects detected and standard parameters measured in a single CPT using the Icone with Magneto click-on module

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ABSTRACT: The paper describes a digital CPT system called Icone®. This system is easily extendable by click-on modules to measure additional parameters and any module is automatically recognized by a digital data logger, thus creating a true plug & play system. By moving to smart digital communication, sufficient bandwidth over a thin flexible measuring cable was created to accommodate additional parameters, without the need for changing cones, cables or data loggers. The following click-on modules are described: seismic, conductivity, magneto and vane. Feedback from fieldwork with the Icone and the magnetometer module (Magneto) highlights the user experience with this approach.

Using the magnetometer module, metal objects in the underground can be detected by interpreting anomalies of the earth's magnetic field. The application of this module is illustrated by two unexploded ordnance (UXO) survey projects for clearance ahead of piling.

1 INTRODUCTION

Due to its benefits, digital technology is used in many applications and is now also available to support efficient soil investigation. The possibilities of this technology have led to the development of the digital cone, the digital data logger and digital click-on modules.

2 DIGITAL CONE

The paper describes a particular digital cone (Icone®) manufactured by A.P. van den Berg, which has been available since 2006. The integration of intelligent electronics provides a range of possibilities in order to make further improvements to the electrical cone and to simplify its use. In addition, the Icone was made stronger compared to its analog predecessor.

The Icone basically uses the same measuring sensors as applied in the analog cone. The difference however is that the analog signals are being digitized and multiplexed already inside the cone.

Digitizing means that the analog signals are being sampled with a certain frequency and converted into a digital data stream. This digital data stream is more robust, and therefore less sensitive to distortion and loss of accuracy in comparison with the analog signals.

By multiplexing, an almost unlimited amount of sensor signals can be combined into one digital data stream and transmitted through a simple 4-wired cable.

Figure 1. Icone 10 cm^2 and 15 cm^2 area with Icontrol data logger.

A built-in memory capacity increases the user friendliness of the Icone system. For example:

- the Icone number and calibration data are stored inside and are exchanged automatically with the Icontrol data logger.
- Extreme sensor values are stored in memory and can be read for evaluation purposes.
- The memory capacity allows the data storage of a full working day.

The Icontrol data logger provides power to the Icone and synchronizes the Icone signals with the depth signal, recorded from the pushing device. The Icontrol transmits the signals to a computer system, where the CPT-parameters are shown on real time graphs.

The use of smart electronics for the Icone system has provided the following benefits:

- The accuracy of the total data acquisition system is determined only by the accuracy of the Icone and the depth sensor.
- Interchangeable click-on modules with specific sensors can be easily added to the Icone without the need of changing cables and data loggers. These modules are automatically recognized by the Icontrol and the corresponding display is automatically shown on the screen.
- An Icone can be combined with one or more (different) modules.

3 ICONE AND CLICK-ON MODULES

In the past five years several click-on modules for the Icone were developed. In this chapter the following three are described: the seismic module, the conductivity module and the application for vane testing. A fourth application, a magnetometer module, is described in Chapter 4. All modules, except the Icone Vane, can be used in combination with a 10 cm^2 and a 15 cm^2 Icone®. When CPT-data is not required, the click-on modules can also be used with a dummy tip instead.

3.1 *Seismic module*

Seismic tests are performed to investigate the elastic properties of the soil. For this purpose a shear wave (S) or a compression wave (P) is guided into the soil. Elastic soil properties are essential input for prediction of ground-surface motions related to earthquake excitation and for assessment of: foundation design for vibrating equipment, offshore structure behavior during wave loading and deformations around excavations.

Figure 2. Seismic module with 10 cm^2 Icone.

3.2 *Conductivity module*

The measurement of electrical conductivity in the subsoil is a function of both the conductivity of the pore water and the soil particles, the first being the dominant factor. With the Conductivity module changes in the concentration of (dissolved) electrolytes are determined without specifying the exact nature of these electrolytes. Therefore the module facilitates separation of zones with differentiated water content, including determining the water table depth and the thickness of the capillary zone or separation of fresh and salt water carrying soil layers. Another very important application of the conductivity module is detection of (the degree of) contamination in a soil body. Further soil investigation should provide details on the actual contaminants.

Figure 3. Conductivity module with 10 cm^2 Icone.

3.3 *Vane module*

The vane test is primarily used to determine the undrained shear strength s_u of saturated clay layers. The test can also be used in fine-grained soils such as silts, organic peat, tailings and other geomaterials where a prediction of the undrained shear strength is required. The Icone Vane has many features that facilitate an accurate vane test. The actuator is integrated in the same compact housing, enabling easier, faster and more accurate operation. The vane is pushed out of its protection tube and retracted again after the test.

Figure 4. Icone Vane (without protection tube)

4 MAGNETO MODULE

Unknown structures, obstacles like unexploded ordnance (UXO), and high voltage cables are a risk factor in the execution of earthworks. To avoid risks of damage and interruptions of work, these underground elements must be identified and mapped. Most underground structures are built out of metal such as sheet-piles, ground anchors and pipe lines or a combination of metal and concrete, such as reinforced foundation piles. Power supply cables and above structures have in common that they affect the earth's magnetic field.

Using a magnetometer (Magneto module, Figure 5), metal objects in the underground can be detected by interpreting anomalies of the earth's magnetic field. In addition, the standard CPT-parameters can also be measured if the Icone is mounted in front of the Magneto module.

Figure 5. Magneto module with 10 cm^2 Icone.

4.1 *Principles*

The earth's magnetic field consists of power lines that run from North to South. Ferro metallic objects have the property to be influenced by the earth's magnetic field, causing them to act as a magnet themselves. This local magnetic field disturbs the earth's magnetic field in such a way, that the object can be detected and localized with a magnetometer.

The magnetometer sensor used is able to measure magnetic field anomalies in three orthogonal directions with a sensitivity of 0.5 µT. Anomalies can be detected at a distance of 2 meter depending on the size of the object and the position relative to the natural North-South field lines. In practice it is not interesting to know the exact value of the magnetic field, but rather the difference in value at a particular location.

When the Magneto module is used without the CPT-functionality of the Icone, the pushing rate can be increased from 2 cm/s to 20 cm/s. To accurately respond to changes in the measured value, in particular when detecting UXO's, also the gradients of the orthogonal measured anomalies are determined. With the Ifield processing software, alarm values can be set to stop pushing when one of these gradients is exceeded.

4.2 *Technical specifications*

The technical specifications of the Magneto module are shown in Table 1. The module has a total weight of 4.8 kg.

Table 1. Magneto module technical specifications.

Item	**Specification**
Length	600 mm without Icone
Diameter	44 mm
Weight	4.8 kg without Icone
Sensors	Magneto: - measuring range 0 – 100 µT - sensitivity: 0.5 µT Inclination: - measuring range 0° - 20° - sensitivity: 0.5°

4.3 *Data processing and visualizing*

The parameters measured by the magneto module are the anomaly of the earth's magnetic field in three orthogonal directions and the inclination relative to the vertical Z-axis. The gradients of the anomalies are determined for analysis and assessment purposes during measurement. The position of the magneto module in the Z-plane at the actual depth is calculated in order to know more precisely the position of the measured object.

The above mentioned parameters and gradients are shown in real time graphs. An example of these graphs is shown in Figure 6.

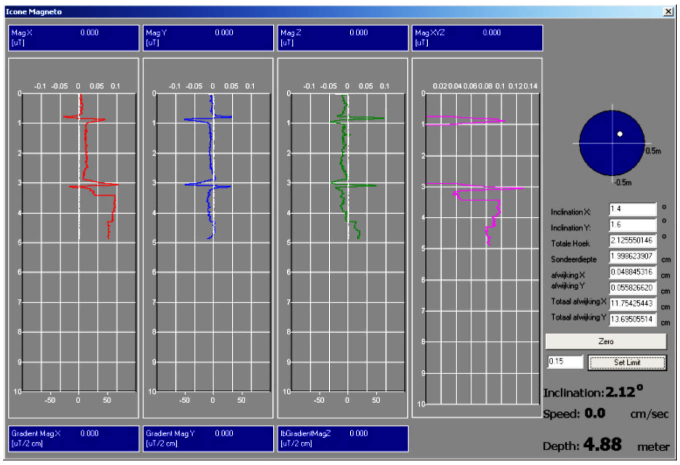

Figure 6. Results of a magneto test.

5 PRACTICAL EXPERIENCES MAGNETO MODULE

5.1 *Background and aim*

The discovery of suspected UXO during construction works and development projects can cause considerable disruption to operations as well as cause unwanted delays and expense. Unexploded ordnance in the UK can originate from three principal sources, including munitions deposited as a result of military training and exercises, munitions lost, burnt, buried or otherwise discarded either deliberately, accidentally or ineffectively, or munitions resulting from wartime activities including bombing in WWI and WWII, long range shelling and defence activities.

The magneto module can be used for UXO Intrusive Survey for clearance ahead of piling. This method permits survey at depths not achievable by non-intrusive survey methods. Anomalies identified during the survey having similar characteristics of an unexploded bomb are then avoided or investigated.

The two notable cases below are an investigation in Sheerness Bridge and Royal Wharf, both located in London and deemed to be medium UXO risk.

5.2 *Methodology & equipment used*

The program of the UXO Intrusive Survey is created based on an assessment of the scope of works for each project. Based on a drawing of the proposed pile layout, the minimum number of probe pushes with the Magneto module is then calculated to determine the length of time required. Each survey can provide a column of clearance with often more than one pile being covered by each survey reducing the overall number of surveys required.

The UXO Intrusive Survey is conducted with a CPT unit which can vary in size from 3.5 – 20 ton machines. For both case studies, a 20 ton Steyr CPT truck with the Magneto module was used. The CPT truck is positioned at a selected location and the Magneto module is inserted into the ground using hydraulic pressure applied to push rods (Fig. 7).

Figure 7. Magneto pushed into the soil.

The sensor is checked and tested at the beginning of each day and the results recorded. During each survey, magnetic field data is recorded real-time on a computer mounted inside the truck. During the survey the computer plots continuous graphical records of magnetic field data. The survey is terminated when the bomb penetration depth for the site is achieved.

On completion of the penetration phase of the test the probe and rods are retracted. As the rods re-enter the test vehicle they are cleaned of soil and fluid by using rubber scrapers fitted in the vehicle's casing hanging beneath the vehicle. Similarly during penetration the rods pass through the cleaning system preventing contaminants present on the rods entering the ground.

The data is interpreted within the entire nT amplitude capability from Magneto (1 to 100,000 nT). The program defaults the nT amplitude to the largest positive/negative nT value recorded on the survey currently on screen, with the view adjusted. In very clean ground with little ferrous influence, the nT amplitude usually defaults to about 10,000 to 20,000 nT. In ground with a lot of ferrous influence the nT amplitude usually defaults to anywhere between 60,000 and 100,000 nT.

Considerations must be in place when carrying out each survey test, including ground conditions, tonnage, inclination, speed of test, and any magnetic influence. Each test is carried out at a speed of 10 cm/s depending on the considerations above. The test is stopped once 5-6 tons of consistent pressure is applied, but this can also vary based on the density and conditions of the surround strata.

If an anomaly is identified during the survey works, additional data may be required as a confirmatory measure. This will require additional survey positions to the agreed works. This process is referred to as ‘triangulation’, a procedure to collect additional data in order to pinpoint the anomaly. Once the location has been identified, further investigation can be carried out in order to determine the identity of the object.

5.3 *Case Study 1: Sheerness Bridge*

5.3.1 *Purpose of Investigation*

In February of 2017, a UXO magnetometer survey was carried out ahead of construction piling locations. A detailed UXO risk assessment was carried out earlier, which showed a risk that the site may have been contaminated with items of both German and British unexploded ordnance. The aim of the intrusive survey was to minimize the risk that magnetic anomalies, which may have indicated the presence of unexploded ordnance, were located at proposed pile positions.

5.3.2 *Test Method*

The positions were set out by a site engineer using the GPS coordinates obtained from the drawing as indicated in Figure 8.

Each test was carried out by pushing to the maximum bomb penetration depth (specific to each location depending on the strata). The live data was first quality assurance checked by the on-site Explosive Ordnance Disposal Engineer in attendance, with the interpretation carried out by geophysicists.

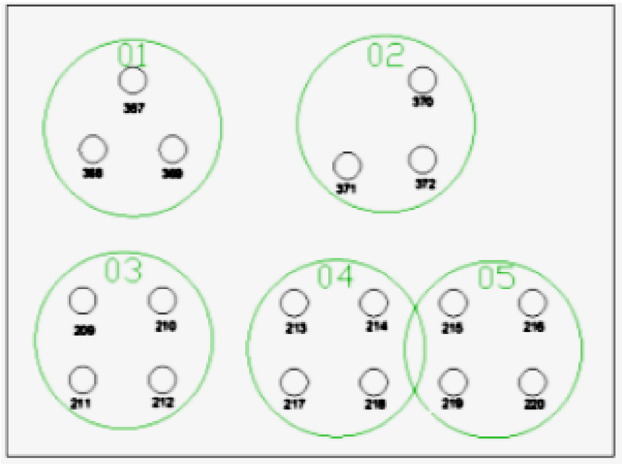

Figure 8. Drawing to set test positions

5.3.3 *Test Results*

One investigation at position 372 presented a ferrous anomaly that covered two individual pile locations, see Figure 8 (pile locations not indicated). The Magneto test as given in Figure 9 shows an anomaly between 5.2 and 6.2m depth. Additional testing was requested in order to collect more data; position 172A and 172B were investigated directly where the piles should be positioned. These tests resulted in the anomaly being present on position 172A as indicated in Figure 10.

Due to the depth of the object at approximately 6.5 m, a series of temporary works were carried out. Shoring was used, which allows excavations to be completed in a controlled safe manner. This allowed Explosive Ordnance Disposal engineers to locate the anomaly at staged intervals with handheld magnetometers.

The item in turn was identified to be part of a pre-existing old pile location as shown in Figure 11. The item was deemed safe and allowed the customer to carry on with works and proceed with building the bridge.

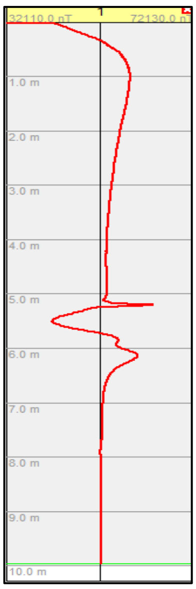

Figure 9. Magneto test position 172

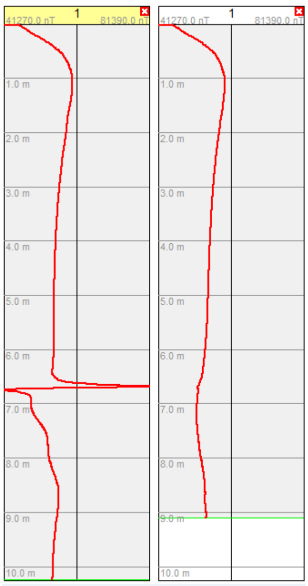

Figure 10. Additional test positions 172A & 172B

Figure 11. Item located at 5.2-6.2m depth position 172A

5.4 *Case Study 2 – Royal Wharf*

5.4.1 *Purpose of Investigation*

Royal Wharf, an area in London was assessed as medium UXO risk. Again, the aim of the survey was to minimize the risk that magnetic anomalies were located at proposed pile positions.

5.4.2 *Test Method*

The same test method as in Case Study 1 was applied.

5.4.3 *Test Results*

An anomaly was detected during the push of the (Icone®) Magneto module starting at a depth of 2.5m which spanned the entire depth of survey, see Figure 12.

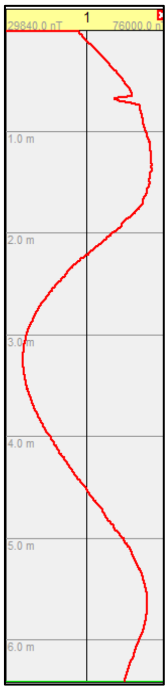

Figure 12. Data trace of 2.5m ferrous anomaly.

This particular object presented bomb like characteristics and was required to be investigated to make a visual identification of the object.

The position was investigated using a series of

200 mm staged excavations in order to determine the cause of the influence. This was overseen by an Explosive Ordnance Disposal Engineer, who exposed the item at 2.5m which was identified as an existing steel-reinforced concrete pile as shown in Figure 13. This allowed 1st Line Defence and the customer to confirm the ferrous anomaly was not unexploded ordnance and to carry on with the deep intrusive works.

Figure 13. Item causing ferrous influence at Royal Wharf

6 CONCLUSIONS

CPT systems are in the course of time continuously improved by the effective use of the latest state of the art. Developments include the application of digital electronics inside the cone, offer a range of new features and benefits. One of these is the ability to easily extend CPTs by click-on modules to measure additional parameters. This paper describes a particular system that allows any click-on module is to be automatically recognized by a data logger, creating a true plug & play system. Case studies for a magnetometer click-on module called " Icone® Magneto", which can directly detect metal objects in the underground by interpreting anomalies of the earth's magnetic field. In addition, the standard CPT-parameters can also be measured if a CPT penetrometer is mounted in front of the Magneto module. The risk of UXO asks for extra precautions and a controlled and precise way of working, whereby alarm values incorporated in the data acquisition software allow to stop pushing when one of specific variables is exceeded. When an anomaly is detected additional investigation is necessary to determine the exact location.

UXO survey with the (Icone) Magneto module has proven to give reliable results. In both case studies an anomaly was detected at a particular position. By additional investigation, the exact location could be stated and the item could be unearthed and identified, after which the customer could carry on with the deep intrusive works.

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