Safely uncovering deep foundations and services with magnetometer cone

S. N. Elgun, C.A.H.M. van Isselt & R. Jansch
Fugro Ingenieursbureau B.V., Leidschendam, the Netherlands

ABSTRACT: A recurring issue for drillers, building contractors, water board districts, service and energy companies is the lost or lacking knowledge on the dimensions or positions of existing underground structures and obstacles such as unexploded ordnance (UXO). There are problems with old barriers and reinforced dams, where the length of old sheet-pile walls are often unknown. To build safely close to a water-retaining structure, the position of ground anchors need to be known to avoid problems during pile driving. When adding more power lines to existing suspension towers, the position and length of the reinforced foundation piles needs to be known. A CPT penetrometer with built-in tri-axial magnetometer has been developed. With this combi-cone, ferromagnetic materials in the underground can be detected. Together with the earth's magnetic field strength in 3D, the normal CPT parameters such as point resistance, sleeve friction, slope and pore pressure can be measured.

1 INTRODUCTION

In 2004 Fugro developed a cone with a built-in magnetometer. With the magnetometer ferro-metallic objects in the underground can be detected. In addition to the magnetic field, the normal CPT parameters, like point resistance, sleeve friction, slope and pore pressure, can also be measured with this cone.

This paper briefly highlights the rationale to develop this combi-cone, its technical implementation and the application possibilities by means of examples. The advantages of this combi-cone over traditional detection techniques is also discussed.

2 MOTIVATION FOR DEVELOPMENT

The reason for developing the magnetometer cone was two-fold. The first reason was the desire to improve safety conditions during regular CPT work. Engineers and contractors can encounter many problems with underground high voltage cables, pipelines, etc., often forming a dense network of obstacles. In addition, unexploded ordnance (UXO) from World War II also causes unsafe situations and risks for the operators and equipment in the field.

The second reason for developing the combi-cone was the ongoing request from clients for more information on the underground and the location of constructions and obstacles. There were requests from water board districts regarding the determination of the length of steel sheet pile walls and the location, length and inclination of the ground anchors connecting the sheet pile wall. There were also requests from building contractors regarding the length and inclination of underground concrete foundation piles.

3 TECHNICAL PERFORMANCE

The Fugro magnetometer cone is a combination of a normal cone, with sensors that measure parameters such as point resistance, sleeve friction, slope and pore pressure, and a magnetometer sensor that measures the earth's magnetic field strength in 3D. For the magnetometer sensor, a magnetometer chip was selected that fits in the same housing as the normal sensors, while the housing itself is demagnetised steel that prevents measuring inaccuracies. The magnetometer sensor measures the earth's magnetic field strength in three orthogonal directions, with an accuracy of 20 nT. For a schematic presentation see Figure 1.

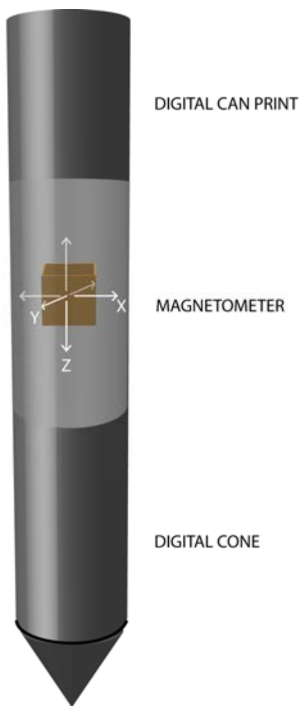

Figure 1: Schematic magnetometer cone

The cone is available as a stand-alone tool (i.e. magnetometer + inclinometer) or as a combination tool that includes regular Fugro cones (i.e. sleeve, friction, slope, pore pressure). Certain special cones (i.e. seismic, ROST and MIP) can also be equipped with a magnetometer sensor.

For logging of the magnetometer data the standard Fugro acquisition software has been adapted. Because the sensor measures the magnetic field in 3 orthogonal directions (X, Y, Z), metal objects located under the cone tip are also detected. The CPT data logging system continuously collects and displays tip resistance, cone friction, and magnetic field strength in real time, allowing immediate decision making on the presence of metal objects such as UXO. The probe is fitted with two perpendicular inclinometers to monitor the direction of the probe. See Figure 2 for an example of the online display screen.

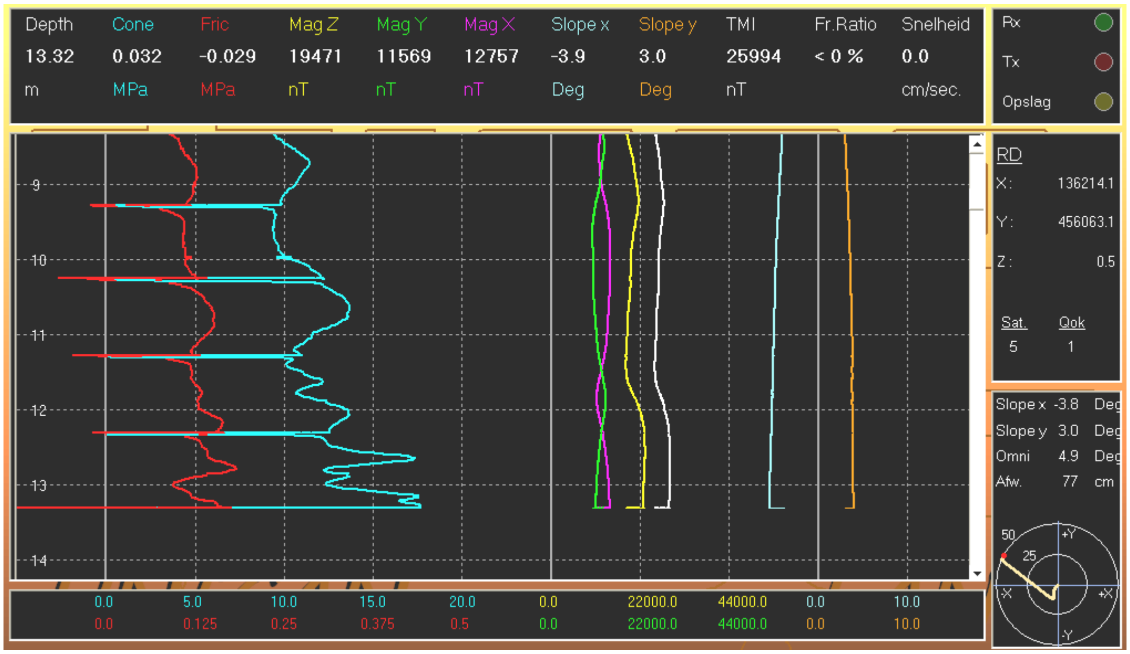

Figure 2: Screen shot of online logging software, showing the following data in the top window with the corresponding colours in the graph: Depth [m], Cone resistance [MPa], Sleeve friction [MPa], Magnetic Field in Z direction [nT], Magnetic Field in Y direction [nT], Magnetic Field in X direction [nT], Slope in X direction [Deg], Slope in Y direction [Deg], Total Magnetic Field [nT], Friction Ratio and CPT velocity [cm/s]. In the middle window on the right-hand side the coordinates are displayed. The lower window on the right-hand side shows a rose with cone direction of the cone and offset from the vertical.

4 APPLICATIONS

4.1 *Cables & Pipelines*

The location and depth of deep buried power cables and pipelines are often unknown. To determine the exact location and depth of a buried high Voltage power cable or pipeline, a series of magnetometer CPT's perpendicular to the direction of the cable or pipeline are executed. The first CPT is normally set at a 2.5m offset from the theoretical position of the cable/pipeline, the following CPT's are set 0.5 m from the previous CPT's in the direction of the cable/pipeline. An average of 3-4 CPT's is sufficient to determine the location and depth of the cable/pipeline.

Figure 3 shows an example of CPT data acquired with the magnetometer cone next to a buried pipeline.

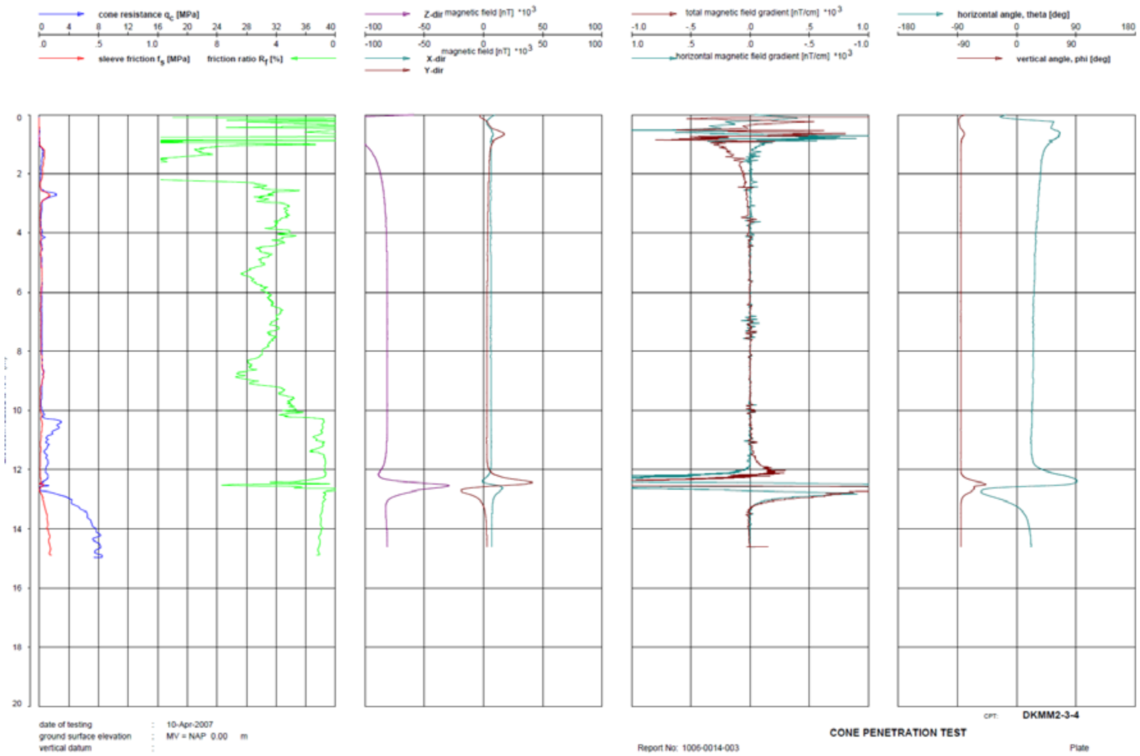

Figure 3: Example of a CPT plot with magnetometer data performed next to a buried pipeline at a depth of 12.5 m. The first window on the left side shows the regular CPT data, with the measured cone resistance and the sleeve friction and the calculated friction ratio. The second window shows the measured magnetic values in the X, Y and Z direction. The third window shows the calculated total magnetic field gradient and the calculated horizontal magnetic field gradient. The last window shows the calculated horizontal angle and the calculated vertical angle.

4.2 *UXO*

During World War II, Europe was severely bombed and it is estimated that 10% of the dropped bombs did not explode. A large portion of this unexploded ordnance (UXO) is still present in the underground and can be hazardous during groundwork, such as digging, drilling, foundation works, piling, dredging, etc. In the soft soil in the western part of Holland, UXO's are found up to a depth of 18 m below ground level, to deep for surface detection.

Locations marked as suspicious regarding the presence of UXO's require that CPT's and drillings are carried out during geotechnical or environmental investigations. The geotechnical investigation can only take place safely, if a pré-research to the possible presence of UXO's has been done.

The top 3 metres of a site is investigated using various surface detection methods, while the magnetometer cone is used for the deeper investigations. By using the combined magnetometer and regular cone, or combi-cone, the geotechnical investigation can be extended to investigate possible presence of UXO's, saving money and time. Regular types of ordnance can be detected at distances of 2 metres from the probe, extending the separation between test points to 2.8 metres and reducing ground disturbance.

Conducting CPT work in areas with possible UXO's using the combi-cone is therefore safer, quicker and cheaper than the more old-fashioned alternative of drilling holes, installing casings, deploying a magnetometer probe in the casings and finally performing regular CPT's.

4.3 *Foundation piles*

Placing extra power cables or antenna's on the power pylons owned by energy companies is always associated with an investigation of the strength requirements of the construction and foundation of the pylons. As most of the pylons are already decades old, the foundation data is often lost. Fugro is engaged to provide the missing foundation data of the pylons and the foundation blocks by means of geophysical surveys. Since the foundation piles for power pylons consist mainly of metal or reinforced concrete, the magnetometer cone has been successfully used to determine pile length, brace position, and the number of piles per pylon.

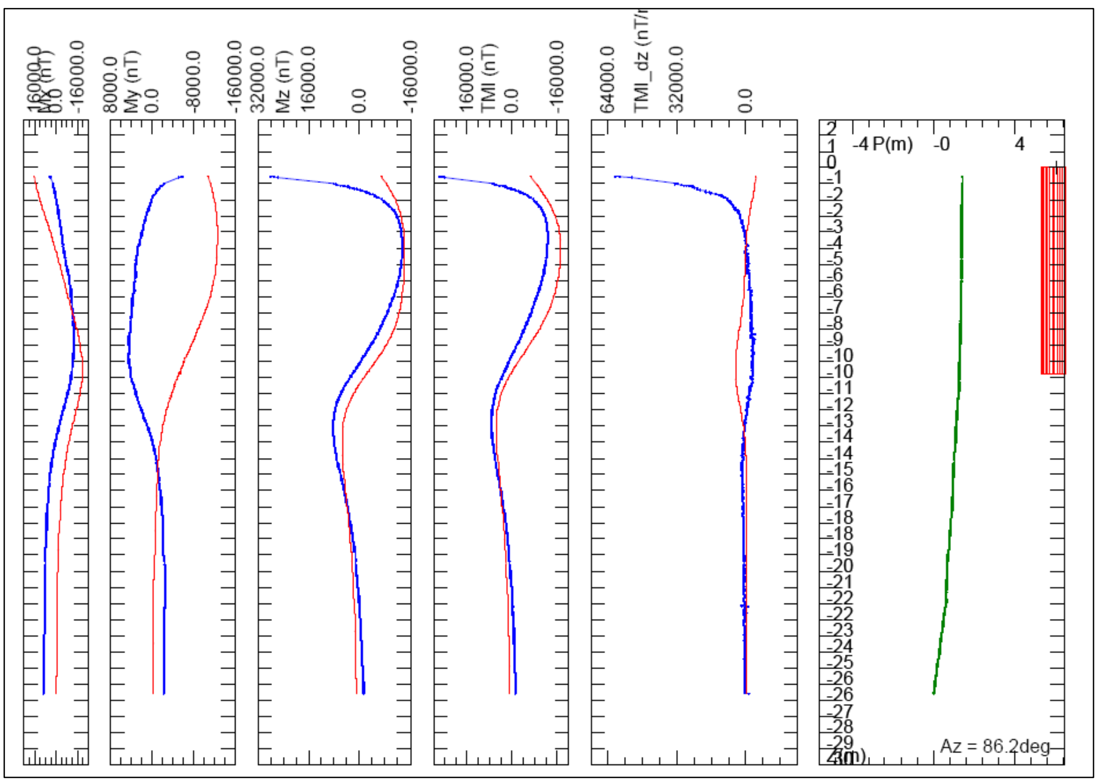

Figure 4: Example of an interpretation of magnetic CPT data of a foundation pile. The blue line is the measured data, the red line is the interpretation of the model, both plotted against depth. The first five windows from left to right showing respectively: the measured magnetic field in X, Y and Z, the calculated total magnetic field and the calculated vertical gradient of the total magnetic field. The last window shows a model of the foundation pile in red and the CPT in green, both plotted against depth.

4.4 *Steel and reinforced sheet pile walls*

With the rising of the water level in channels, rivers and at the coast, several water board districts encounter problems with barriers and dams. A part of the problem is the unknown length and strength of old sheet-pile walls. The combi-cone determines both the length of the sheet pile wall as well as the soil structure of the underground.

Contractors building close to a water-retaining structure such as a sheet pile wall will encounter ground anchors with their foundation piles. To build safely, the position, length and inclination of the ground anchors needs to be known. With two or three magnetometer CPT's per anchor, and the GPS position of the visible anchor head in the sheet pile wall, the position, length and inclination of the ground anchors can be determined.

5 CONCLUSIONS

The development of the combi-cone cone opens up many new possibilities for detecting metal obstacles in the ground. The combination of magnetometer and regular CPT has shown many applications and advantages. Performing CPT's with the combi-cone is safer than without. The magnetometer cone (combi-cone) has solved many problems caused by lack of good documentation or missing data on foundation structures and has been successfully deployed in UXO projects for over 5 years.

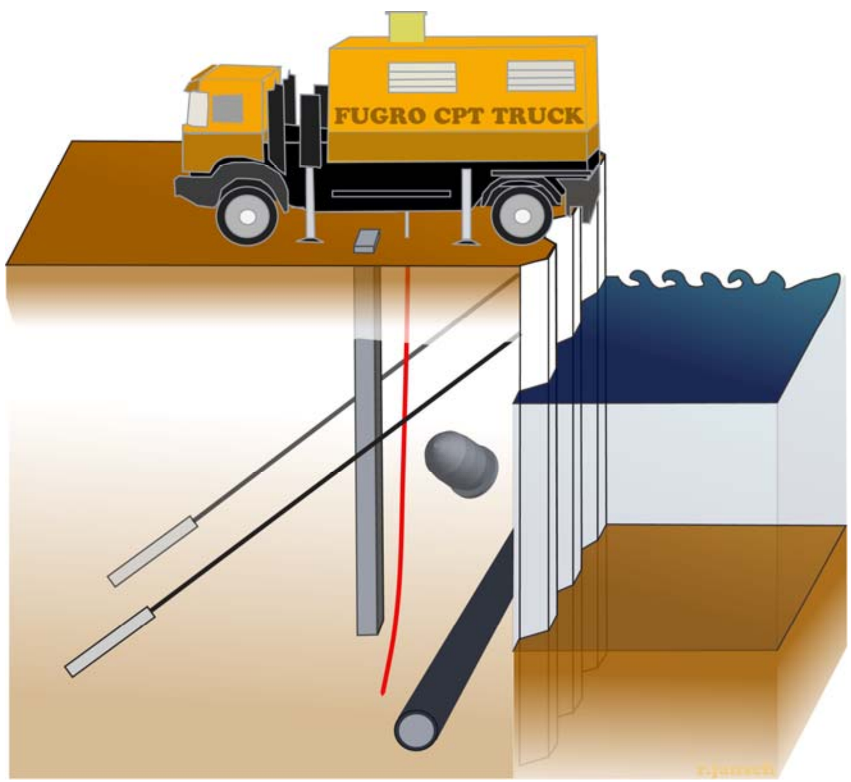

Figure 5: Schematic of different applications for the magnetometer cone.