Magnetometry in Wreck Removal Western Scheldt

The Western Scheldt is being deepened to give larger ships better access to the port of Antwerp. Over fifty wrecks and other obstacles have been removed from the main channel. Magnetometry was one of several surveying techniques deployed to determine the exact position and depth of the wrecks to be removed and as a final check after the wreck removal operation. In order to get the best positioning results an algorithm was developed to invert the magnetometry measurements.

The Western Scheldt is the gateway to Antwerp and one of the busiest shipping estuaries in the world. It is essential that Antwerp remain accessible to ships that will increase in size as time goes on. Moreover, container ships in particular will have to be able to sail into the port regardless of the tide. Deepening the Western Scheldt will reduce the number of tide-bound vessels on the river and shipping movements will be distributed more evenly.
The Western Scheldt has to be cleaned up before it can be deepened. There are an estimated two hundred known and unknown wrecks and remains of wrecks in the river. Other objects on the riverbed include large heaps of stones, containers, pontoons and buoys. Not everything will be cleared away: the first priority is to remove wrecks and other objects from the bars in the main channel. Many of these are partially or entirely embedded in the riverbed beneath sludge and sand, and these will be removed too. This should result in the shipping channel being freed from obstacles well below the riverbed.
In the period from 1998 to 2004, more than fifty wrecks were removed from the Western Scheldt (see Figure 1 for a map).

The Operation

Wreck-removal operations include the following work:

- detection and localisation: all of the wrecks were charted before they were cleared. The position of the wrecks should be determined as accurately as possible. For this purpose a number of surveying techniques were used, like side-scan sonar, multi-beam, magnetometry, seismic tomography and sub-bottom profiling. In particular, wrecks completely buried under the sand cause difficult surveying problems
- bringing wrecks to the surface: depending on the state and size of a wreck, the most applicable way was adopted to remove it (e.g. see Figure 2). Information on the position and depth of the wreck was used so as to perform the most economical removal
- inspection of the area: after a wreck had been removed, an inspection was performed to check whether all of it was gone. This inspection was usually performed by means of magnetometry.

The whole operation required much use of hydrographic surveying. In this paper we discuss the use of magnetometry in more detail.

Magnetic Surveying Objectives

In the preparation of wreck removal operations it is necessary to determine the position of a wreck as accurately as possible. This means determining the contours of the wreck with an accuracy of 1 metre or less. The depth of the wreck should also be determined as accurately as possible. All this information can contribute to optimising economical removal of the wreck.
The state of wrecks varies greatly. Some wrecks are almost totally intact, while others are broken into a number of pieces. Another distinction between wrecks is whether or not they are â€˜visibleâ€™ on the riverbed. When a wreck is not visible or partly covered by sand it can be easily detected by side-scan sonar and multi-beam echo-sounding, by which means the contours of the wreck may be determined very accurately (within 20cm). When a wreck is completely covered by sand these two surveying techniques are insufficient. In such instances magnetometry, seismic tomography and sub-bottom profiling may detect the wreck. The accuracy of these techniques is, however, less than can be achieved for wrecks lying on top of the seabed.
The Zeeland Directorate equipped a special surveying vessel, the *Lodijcke*, to perform the magnetic measurements. A tow-fish was employed that could be kept at a constant depth and the position of the tow-fish was monitored by a USBL positioning system.
During the removal operations multi-beam echo-sounding was used to monitor the progress of the operation. The contractor could thus easily check that major parts of the wreck had been removed.
Finally, after the removal operation an inspection of the area was made to check whether it had been successful. Magnetometry was used to verify whether large pieces of iron remained in the area. Based on an estimate of the amount of iron left (obtained from magnetometry) it was decided whether or not these had to be removed.

Magnetometry

Extensive use was made of magnetometry in the wreck-removal project. This detection method measures anomalies in the earthâ€™s magnetic field caused by iron masses in the riverbed. The size and intensity of the anomalies depends on the mass of the iron and the depth relative to the measurement level. Because it is not disturbed by the water bottom the method works equally well for both covered and non-covered wrecks. One complicating factor is that the magnetic anomaly is strongly influenced by the orientation of the wreck. Expert knowledge is necessary to interpret the measurements. In Figure 3 an example is shown of the magnetic anomalies measured above a wreck. Also drawn is the contour of the wreck as it was determined after free dredging.
Magnetometry is used to determine the contours of a wreck with an accuracy of about 1-2 metres. Unfortunately, the depth of a wreck cannot be determined by the standard application of this method. Therefore, in the wreck-removal project a modelling and inversion

method was developed to obtain a better positioning of the wreck, both in a horizontal direction and in depth, and to get an estimate of the mass of the wreck. This method will be explained in more detail in the next section.
At final site inspection magnetometry is applied to check whether all of the wreck has been removed. If anything is left, the mass of the remaining parts is estimated from the measurements. Tests with gradiometry showed for this application no significant improvement over standard magnetometry.

Modelling and Inversion in Magnetometry

The iron mass of the wrecks causes a disturbance in the earthâ€™s magnetic field. An anomaly of the magnetic field can be measured by magnetometry. For small masses, e.g. from uxo (unexploded ordnance) the anomaly can be easily calculated but for large objects such as shipwrecks the modelling is much more complex because the form and orientation of the wreck must be accounted for. In the wreck-removal project a method was developed to compute the magnetic anomalies caused by shipwrecks. In this model the wreck was considered to have the shape of a shoebox (see Figure 4) and to contain nine variables: length, width and height of the wreck, coordinates of the centre of the wreck, roll-and-pitch angles and the mass of the wreck. In contrast to some other examples, true 3D magnetic modelling can be performed here.
This modelling algorithm can be used in an inversion scheme together with the true measurements. Beginning with a starting model, the modelled magnetometry data is compared to the measurements. The nine variables are iteratively updated to obtain a better fit of the modelled and the measured data. After several iterations leading to a good match of modelled and measured data estimates are obtained of all nine parameters. In Figure 5 the process is illustrated for the wreck of the *m.v. Meppen*. The mismatch in the final data is caused by the inevitable simplification of the used shoebox model. The change in the centre of the wreck by different iterations is illustrated in Figure 6.

Conclusions

In this paper have we discussed the challenging task of surveying for wrecks in the Western Scheldt. In order to perform the most economical and efficient wreck-removal operation, very high accuracy is required from the surveying techniques. Leading-edge technology was applied in this project. It proves to be successful to translate experiences in other fields, like geophysics, to the field of hydrographic surveying. Magnetometry provided much information on the wrecks, which enabled a more efficient and economical removal operation. The Western Scheldt project enabled us to explore new techniques in more detail than smaller projects could afford.

Acknowledgement

The authors wish to thank the Project Bureau for Wreck Removal in the Western Scheldt of Rijkswaterstaat for their permission to publish this article.