

K. van Craenenbroeck, J. Duthoo, M. Vandecasteele, J.A. Eygenraam and J. Van Oostveen

Application of Modern Survey Techniques in Today's Dredging Practice

Abstract

Because of the growing demands of public and private clients the dredging industry has developed means for measuring the performance of dredging equipment. These instruments measure aspects such as production, accuracy, efficiency and environmental safety. The performance then has to be maximised as a function of the dredging task, be it capital or maintenance dredging.

The monitoring of dredging works can be done by a whole range of survey techniques, on board both dredgers and survey vessels, including multibeam echosounding, in-situ density profilers, positioning systems, as well as specialised environmental monitoring devices. The most recent developments are reviewed here.

Introduction

Survey activities to monitor water works are probably as old as the practice of dredging itself. From milestones such as the first floating grab (driven by "human-feet-power") to the launching of hopper dredgers, super-cutters and jumbo trailers, operators as well as clients have wanted and needed to know the progress and the results of their activities.

Because demands of public and private clients continue to grow, the performance of dredging equipment – production, accuracy, efficiency – has to be maximised as a function of the dredging task, whether it is capital or maintenance dredging: harbour construction, shore protection, the navigability of fairways and harbours, offshore trenching, and pre-sweeping.

The monitoring of these works is done by a whole range of survey techniques, on board both dredgers and survey vessels. The present paper reviews some of the survey and monitoring techniques commonly used today, such as multibeam echosounding, in-situ density profilers, positioning systems, and environmental monitoring systems.

A multi-tasking and versatile survey tool might look like the vessel depicted in Figure 1. Although most survey-

ors of the world only dream of it, this "ideal" vessel can be used as a guide through this paper.

MULTIBEAM ECHOSOUNDING

Working principle

As is the case with the commonly used single-beam echosounders, multibeam echosounders also use short acoustic transmission pulses to scan the seabed.

Each seabed element produces its own echo which is received at the receiving part of the acoustic transducers. These echoes, together with sound travelling time and other system parameters, are processed into calculations of angle between the element on the seabed and the transducer normal. In this way the horizontal distance and depth to each seabed element can be calculated.

Experience

Several multibeam echosounding systems have found their way to the international dredging community, not only as a valid pre- and post-dredging survey tool, but also as an on-line monitoring device on board (trailing) dredgers.

From a survey vessel

Multibeam echosounding data allow the production of detailed progress reports and to make accurate volume calculations. For example, this new survey system has been successfully used during the Interconnector pipeline project (Bacton, UK to Zeebrugge, Belgium), where a trench had to be dredged through the access channels "Scheur" and "Wielingen" to Antwerp and nearshore close to the landfall.

With multibeam echosounding on board the survey vessel *Oostende XI*, where the transducers are mounted in the bow of the ship (Figure 2), lines were surveyed parallel to the axis of the pipe. The trench, 10 metres wide and with slopes 1 in 9, was 100% covered by the echosounders in a couple of runs, depending on the water depth. Dredging activities were monitored on a daily basis. Once the trench was



Karel van Craenenbroeck

Karel van Craenenbroeck graduated as a geologist in 1985 and joined Overseas Decloedt as part of the R&D team developing the Navitracker density probe. Since 1987, he has been involved with treatment and disposal of contaminated sediments and environmental monitoring, and in 1991 he became project manager with Silt NV in this area.



J. Duthoo

Since 1978 J. Duthoo has been involved as electronic engineer on hydrographic and shore-based systems during the expansion of the Zeebrugge Harbour. In 1985, he moved to Overseas Decloedt as senior service engineer. In 1991 he joined Silt NV as head of the electronic department, where he is responsible for the technical aspects of the hydrographic systems and environmental monitoring systems.



M. Vandecasteele

M. Vandecasteele started 25 years ago as member of one of the study teams for the extension of Zeebrugge Harbour. He then worked as surveyor in the hydrographic department of Silt NV. He became survey manager of the hydrographic department of Silt N.V. and is now based at Zeebrugge where he is responsible for the execution of all the environmental and hydrographic surveys.



Jan A. Eygenraam

Jan A. Eygenraam graduated from Delft University of Technology, The Netherlands in 1974 with a MSc in Mechanical Engineering (Dredging Technology). He started his career as a research engineer with Zanen Verstoep NV. Since 1988 he has been manager Dredging Development, Survey and Fleet Automation at Baggermaatschappij Boskalis BV.



J. Van Oostveen

J. Van Oostveen holds a BSc in Electronic Engineering and has been involved in hydrographic surveying from 1969 as an officer (RNR) of the Hydrographic Service of the Royal Dutch Navy. Until 1988 he was employed in the hydrographic department of Delft Hydraulics in various functions. Since 1988 he is manager of the Survey Department of HAM.

dredged to the theoretical profile, the pipelaying started. Afterwards, the backfilling with gravel took place. With the multibeam echosounder, the progress of the backfilling could be observed clearly, which enabled the daily re-definition of the backfilling areas.

Another application of accurate observations of dredging operations is found in the “unveiling” of wrecks.

On board dredgers

Multibeam echosounders can also be used on the dredgers themselves, especially on trailer dredgers. When a multibeam system is built into the bow of the vessel, or mounted in the bottom, the wide coverage of the multibeam makes it possible to “view” the seabed accurately on both sides of the dredger. Making use of dedicated software, the cross-profiles of the seabed, can be shown on the computer three-dimensionally as the dredger moves forward. This enables the crew to anticipate and optimise the dredging, while bathymetric surveys can be carried out at the same time.

One of the newest super trailing suction hopper dredgers *WD Fairway* is equipped with a dual head Simrad EM3000 multibeam echosounder. Two multibeam transducers are mounted in the bottom of the vessel. The vessel has been operating on a few off-shore projects on the North Sea during the past year. During the Gannet Project for Shell UK Exploration and Production several pipeline bundles had to be covered by sand for insulation purposes over a length of approximately 12 km. Prior to the dumping operations a pre-survey was carried out by the *WD Fairway* using one of the multibeam transducers. Owing to the depth of the location – 95 metres – a single run over the centerline of the bundles was sufficient to cover more than the width of the sandberm to be dumped.

After each trip of approximately 17,500 m³ of sand an intermediate survey was carried out, again by sailing one single run over the centerline of the bundle under construction. The results of these intermediate surveys were processed during sailing to and from the win area. Before arrival in the field the latest situation was known and the next dump location prepared.

The advantages of surveying with the trailing suction hopper dredger instead of surveying with a separate offshore survey vessel are:

- no additional costs for an offshore survey vessel;
- fewer survey crew members are needed; and
- there is no date transfer between survey vessel and dredger.

On the next project of the TSHD *WD Fairway*, a pre-sweep job for ELF Exploration UK Plc. in the Elgin/Franklin Field, the multibeam echosounder on board the vessel proved again to be very efficient.

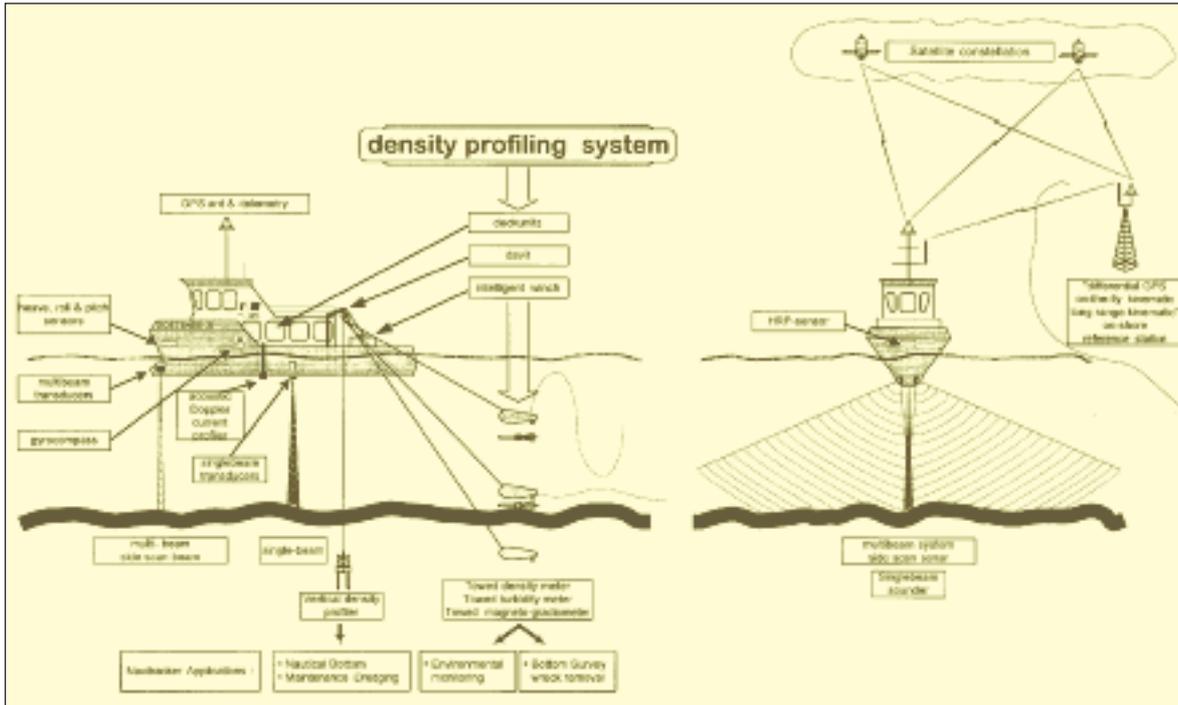


Figure 1. Survey vessels and systems: general application programme.

First of all, a pre-dredge survey was carried out over the sandwaves to be dredged. In between dredging and dumping intermediate surveys were carried out over the centerline of the pipeline route, causing hardly any delay in the dredging cycles of the dredger. The results of the multibeam echosounder surveys were handed over to the client for stress analysis.

Another possibility is to mount a multibeam on the suction pipe(s) of a trailer dredger. *Geopotex 14* and *HAM 310* have both in the past years on a number of occasions been provided with such an installation of multibeam and motion sensor mounted together on one of the pipes. When dredging trenches, doing pre-sweeping but also when covering and uncovering e.g. pipelines, the multibeam will give full survey capabilities to the dredger. It will yield accurate steering information for the vessel and at the same time show results achieved the last run. In order to obtain in- and out-survey data only, an additional run will have to be made by the dredger over the theoretical line at the start and at the end of the work. In this way all control stays on board the dredger and no (costly) additional survey vessel, with transfer of data to the dredger and back, is necessary.

IN-SITU DENSITY PROFILERS

During the last decades, the presence of loosely packed silt layers in maritime access channels and harbours has caused the responsible authorities severe problems in trying to determine and maintain their Port

Figure 2. Multibeam transducers mounted in the bow of the survey vessel Oostende XI. This system is fixed. Mobile systems are also commonly available.



Operations Policy and Maintenance Dredging Strategy. Owing to the presence of this "fluid mud", traditional acoustic hydrographic survey methods are insufficient. This fluid mud results in unpredictable changes in the registered depth which is mainly caused by hydro-meteorological conditions and seasonal variations. This also hampers a correct monitoring of maintenance and capital dredging work in these areas.

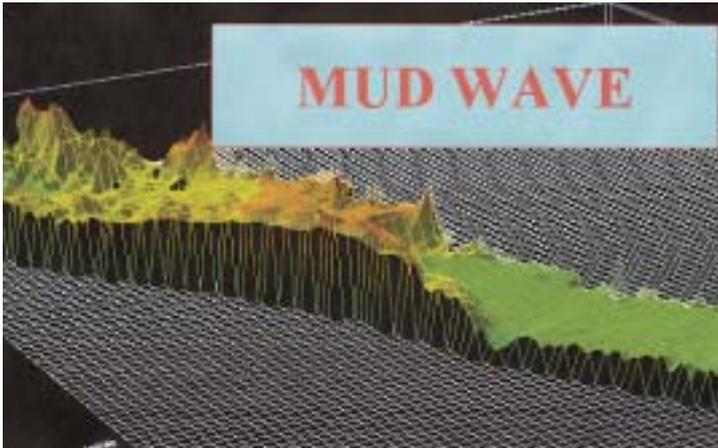


Figure 3. In fluid mud areas, deep-draughted vessels sail above a clearly defined physical (density) level within the fluid mud body. Although an internal wave is observed at the sediment-water interface, safe navigation is not hampered and is guaranteed by the navigable depth concept.

To allow deep-draughted vessels to enter these ports under adverse “mud” conditions and to optimise the use of the maintenance dredging budget, the concept of the navigable depth in muddy areas has been developed. The navigable depth corresponds with a physical level within the fluid mud layer indicating a safe navigation limit for deep-draughted vessels. Extensive laboratory research, real scale sailing tests and modelling work was done in order to observe the behaviour of ships sailing above and within the mud. Based on this, many ports established a safe navigation limit as a density level within the fluid mud (Figure 3). Because of the different physical properties of the mud, this level has to be established for each port individually. In Rotterdam (The Netherlands), for example, the depth of the 1.2 t/m³ density level has been established as the navigable depth, whereas in Zeebrugge (Belgium), the 1.15 t/m³ density level is considered a safe limit for navigation.

For the in-situ measurement of these density levels, several types of density gauges have been developed. The first of these to measure continuously was the towed density probe “Navitracker”.

“Navitracker”: Basic system

The basic Navitracker system was originally designed to track automatically a pre-determined density level within the fluid mud in order to allow the production of navigable depth charts on the basis of sufficient data, comparable with the quantity of data collected during a traditional acoustic survey.

The basic Navitracker system consists of:

- a hydrodynamically balanced streamlined towfish with built-in scintillation-type transmission gauge, pressure sensor and relocation transponder;



Figure 4. The Navitracker survey system as installed on board the RWS survey vessel Octans.

- a computer-controlled “intelligent” survey winch; and
- the deck equipment, including density calculation unit, filtering and conditioning unit, 4 channel pen recorder and the control computer with Trackersoft software

The measured density data are gathered by the control computer and sent to the survey computer.

These measurements are integrated with other survey data such as X,Y,Z -position, echosounder information, heave systems, and so on.

Basic system operation

The Navitracker system is used daily in Rotterdam, Zeebrugge and Emden (Figure 4). The winch control computer of the system controls the towfish depth by paying out or hauling the tow cable. The cable speed can be set from 0 to a maximum of 50 cm/s (typical 20 cm/sec) with a maximum acceleration of 50 cm/s².

The Trackersoft software of the control computer monitors the sensor acquisition from the towfish, controls the winch, and the survey computer communication. This allows six operating modes:

1. vertical profile mode, in which case the towfish is used to measure stationary density profiles
2. horizontal undulation of towfish at constant speed between two depths or density levels (e.g. 15 to 17 m or 1.15 to 1.20 t/m³)

Maximum depth can be set 210 kc - echosounder depth minus a presettable offset

(e.g. 12 m top layer - 1 m above top layer)

3. horizontal tracking of the towfish at fixed or variable speeds:

- a. on a fixed depth, e.g. 17 m
- b. on a fixed density layer, e.g. 1.15 t/m³
- c. on the base of paid-out cable length, e.g. 20 m
- d. on the base of 210 kc echosounder minus an offset, e.g. 15 m - 1 m = 14 m.

Basic system output

Charts produced are nautical charts, indicating the position of the navigable depth compared to the official reference level (Figure 5).

Upgrades

The original Navitracker towfish was designed to be towed within a fluid mud layer to obtain as much data as possible of a pre-determined density level to allow the production of reliable nautical charts on the basis of a huge amount of data. However, to be able to study the composition, the structure and the behaviour of a fluid mudbody, it is necessary to collect data throughout the mud column. Because of its shape, the towed body only penetrates in mud with a density up to 1.3 t/m³. To allow the collection of data in more consolidated material, an H-shaped inclinometer-equipped Vertical Density Profiler was added to the basic system. This VDP is fully compatible with the existing towfish, towcable and electronics.

Another high accuracy VDP silt density profiling probe (Figure 6) was developed by the Dutch companies TNO Applied Physics and Seabed Systems in cooperation with dredging companies Boskalis and Van Oord ACZ, Rijkswaterstaat Directorate South Holland and the Port of Rotterdam.

Unlike the Navitracker gauge, where a Cs 137 radioactive source is in use, density measurements are based on the absorption by the fluid mud of gamma rays as radiated by a small Barium 133 source. This Barium source is placed in an H-shaped frame opposite to a so-called "Scintillation detector", a highly sensitive gamma ray detector. This type of detector gives a quantitative analyses of the amount of gammas passing through the medium, but it also allows the possibility of producing a spectral image which gives an indication of the physical properties. For optimum safety the Barium source is of a relatively low activity and when the system is not measuring the source is fully encapsulated in a special gamma absorbing material. The resulting level of radio activity on the surface of the probe housing is very low and when handled with normal care it will impose no risk to the health of the operator.

Besides these density measurements the probe also has sensors for the measurement of tilt in both



Figure 5. Chart indicating the navigable depth in the Port of Zeebrugge.

Figure 6. The vertical density profiler D2ART.





Figure 7. Positioning system of the disc bottom cutter dredger *De Vecht* during dredging trials at Lake Ketelmeer.

directions, pressure, temperature and conductivity. Although these parameters are primarily used for the accurate calculation of the depth of the sensor, they are also available for further analyses. The data acquisition and control programme takes care of the fully automated measuring procedure.

A complete D2ART silt density measuring system consists of three main components:

- the nuclear probe;
- a data acquisition and interfacing computer that controls the fully automated measuring process, acquires the probe data and interfaces to the ships echosounder and navigation system; and
- a computer-controlled winch that holds up to 80 metres of tow/signal cable.

It is anticipated that the type of supporting (towed) bodies used to execute density measurements, will become Christmas trees, carrying various sensors, samplers and measurement devices for all types of monitoring operations (see below).

POSITIONING

Simultaneously with the accuracy of sounding devices, the performances of positioning systems have strongly increased. To achieve this, not even the sky was the limit.

Whereas two decades ago dredge operators and clients were satisfied with range-range and (pseudo-) hyperbolic positioning systems such as Mini-Ranger, Trisponder and Syledis and went wild with the introduc-

tion of more accurate systems such as MicroFix, Axyle and laser-beam- based systems (Navitrack 1000 and Polarfix), these days, many of them can already be found in the antique shop.

When the cold war ended, satellites were soon used to support global positioning systems for the industry, who quickly improved it to differential global positioning systems, which was then followed by enhanced differential GPS. Nowadays, on-the-fly kinematic and the introduction of long-range kinematic techniques complete the inauguration of a new era in positioning.

Together with the important increase of the accuracy of positioning systems for vessels, the accuracy of the positioning of the sediment-removal tools – dragheads, cutters, backhoes – increased drastically and was even more improved by the development of systems to monitor on-line the position of the removal tools with regard to the sediment. This is of particular importance when performing trench dredging or when removing contaminated sediments.

During the test dredging operations at Lake Ketelmeer, the positioning of the dredgers were based on dGPS-KART and dGPS-Trimble systems, combined with ladder angle, pressure sensors and tide gauges.

A particular positioning system was developed for the disc bottom cutter *de Vecht*, where a high frequency echo-sounding system was mounted in an acoustic mirror mode at both sides of the disc cutter (Figure 7). This acoustic mirror enables the dredger to avoid problems related to gas bubbles and turbidity caused by the removal of the sediments.

ENVIRONMENTAL MONITORING

During the last few years, a new task has been addressed to the survey departments of dredging companies: environmental monitoring. Current and wave monitoring already were part of the tasks, although in very specific cases. Now, these measurements have become common practice, together with turbidity- and water-quality measurements and sediment transport analysis. The works that boosted these types of survey and monitoring are undoubtedly the works performed in Hong Kong and for Øresund/Storebaelt. There is inevitably a growing demand from clients to offer these monitoring services.

Especially for environmentally sensitive works (and which aren't nowadays?) these types of measurements appear in tender documents. In most cases, two types of measurements are required:

- stationary measurements, done from a measurement platform; and
- continuous underway measurements, operated from a survey vessel.

Stationary measurements platforms mainly contain:

- a datalogging system (self contained or direct reading);
- turbidity measurements at selected depths (optical transmission or backscatter);
- current measurements (mechanical or electromagnetic);
- conductivity and salinity; and
- temperature.

Vessel-mounted systems generally include:

- turbidity measurements;
- CTD measurements; and
- water sampling devices.

These measurements are generally integrated with acoustic Doppler current profilers, in order to achieve an idea of the mass transport of particles in suspension generated by the dredging operations. Following the development of the VDPs (see above), the devices were adapted to be used for horizontal towing purposes in the water column..

Both the profiler/towfish and the acquisition software can be adapted to support additional sensors on board. This enables the continuous profiling of the water column, in order to monitor turbidity, salinity and temperature. Currently, environmental monitoring operations of that type are done on a regular basis in Zeebrugge Harbour (Figure 8).

Final upgrades of the monitoring bodies so far are the integration of in-situ particle size profilers and tri-axial magnetometers with the towed bodies. Tests on the River Schelde proved that the processing performance



Figure 8. Optical sensors mounted on the Navitracker VDP, for the environmental monitoring (turbidity, salinity, temperature) of the water column during dredging and relocation operations.

of the magnetometer measurements shows significant increases by towing the instruments close to the seabed (higher signal returns, less influence of vessel traffic).

Thanks to the development of towed bodies and measuring vehicles as described above, this is no longer wishful thinking but the next logic step in the environmental monitoring of dredging operations.

Conclusion

During the past five years, both dredging and survey technology have developed rapidly. Positioning as well as specific monitoring techniques have made major strides. Many techniques – especially positioning and acoustic survey systems – are improving very quickly. These techniques include:

- the multibeam echosounders on board survey vessels or mounted on board dredgers;
- density profilers such as the Navitracker;
- Vertical Density Profilers (VDP) such as D²ART; and
- differential global positioning systems (dGPS).

Along with the other improvements in the dredging industry, survey departments have been contributing their share in the implementation of modern technology and concepts in the monitoring of dredging operations. Especially environmental monitoring has received and continues to receive increased attention.