THE NAUTICAL DEPTH APPROACH, A REVIEW FOR IMPLEMENTATION

W.F. Fontein[1] and R.W. Byrd[2]

ABSTRACT

A vital element of harbor services is the guarantee of safe passage to and from the port facilities. When high siltation rates persist, adopting the concept of nautical depth may reduce the significant costs associated with maintenance dredging. To implement the nautical depth concept three important prerequisites should be met: 1) Criteria for mud characteristics that can be allowed within the nautical profile should be set. 2) A control system should be implemented to reliably monitor the status of the nautical profile in relation to the set criteria. 3) The participants will have to accept the new approach and be able to gain confidence in the system from both the safety of navigation aspect and as the contractual basis for dredging. All of these prerequisites are best served by a standardized survey method that can be tuned to cope with site-specific variation and variability. This working method requires survey systems with predefined, controllable settings and repeatable results. A survey method that combines acoustics with in-situ rheometric and/or density measurements is outlined below.

Keywords: Hydrographic survey, fluid mud, tuning fork, mud rheology, risk assessment.

INTRODUCTION

A vital element of harbor services is the guarantee of safe passage to and from the port facilities. Safe passage requires sufficient water depth for sailing and maneuvering. Variations in water depth are due to a variety of dynamic processes not a singe constant factor and consequently must be monitored on a regular basis. Hydrographic surveys with single beam and multibeam acoustic echo sounders are the industry standard for this monitoring. Based on the survey results appropriate dredging action is taken and pilots are updated on critical sections.

For harbors where high siltation rates persist the service required to assure safe passage implies significant maintenance costs. These costs will increase non-linearly for deeper access channels, required in potential future harbor developments, due to the further deviation of the channel depth in relation to the steady state natural water bottom elevation.

When based on high frequency single beam or multibeam survey data, only the low-density semi-fluid muds are detected. This situation can lead to misinterpretation of the condition of the bottom in shallow sections and dredging action is considered to be necessary. The top layer of the siltation material has, in general, such low strength characteristics that it does not cause problems for navigation. The charted depth may be guaranteed without removing the material. However, in order to detect the elevation of the relevant bottom level, and to assure the navigable characteristics of the channel, knowledge on the in-situ mechanical properties of the mud is required (Buchanan, 2005).

[1] Operation Manager, Stema Survey Services BV, Poppenbouwing 52, 4190CB Geldermalsen, The Netherlands, T: +31(0)345580395, F: +31(0)345570649, Email: willem.fontein@stema-survey.com.

[2] President, Odom Hydrographic Systems, Inc., 1450 Seaboard Ave., Baton Rouge, LA, 70810, USA, T: +1 225 769-3051, +1 225 766-5122, email@odomhydrographic.com.

NAUTICAL DEPTH

From the above mentioned perspective the nautical depth concept was developed and implemented in several major European ports. The PIANC defined best practice procedures for this concept (PIANC 1997). Since at the time the in-situ characterization of mechanical properties of harbor muds did not prove to be feasible, the density of the mud was chosen as a valid indicator of the sediment's mechanical properties. At that time nuclear density probes were available for in-situ measurements (De Vlieger, 1987). The nuclear devices are now largely replaced by the more environmental friendly tuning fork systems. These new systems offer stable results, with higher resolution and are combined with much better operational flexibility and less safety risks.

The choice of a density level to indicate the nautical bottom appears to be a practical solution, but is in fact an over simplification of the problem. Picking one density value also appears to have become a barrier to efficient communication regarding acceptable (density)-criteria for determining the nautical bottom. The 1.2 ton/m3 has over time become the de facto "standard" nautical density, but a global density criterion is not realistic. This fact is illustrated in Figure 2 where the relation of mud density with the shear strength required to initiate permanent deformation is plotted for several locations. From this Figure it becomes clear that a density criterion is site specific. Muds from Guyana, South-America show very low strength values at densities as high as 1.4 ton/m3. North European harbors show significant strength increase at density levels varying between 1.15 and 1.25 ton/m3. Significant differences are notable between neighboring harbors located only 50 km apart or even within a single harbor channel.

The asymptotic density level in Figure 1 marks the transition from semi-fluid mud to consolidated solid material. A transitional range exists from pure fluid to solid material. A safe upper density limit should however be chosen in the lower range before the bending point in the relational curve. At density levels above the bending point a small error in the density measurement would give a much larger error in the strength reading.

Rheology is the study of the deformation and flow of matter under the influence of an applied stress (Schramm, 2000). Rheological parameters, for instance shear strength and viscosity, are generally measured in laboratory conditions with roto-visco meters. These two parameters directly influencing ships navigation can now also be assessed in-situ. The yield strength criterion can be defined uniformly, based on measured parameters and independent of mud composition. However, in our opinion, no strict yield strength values can be assigned universally at present as the criterion should also account for environmental and local conditions (tugs assistance, channel width, etc.) and test methods and studies regarding ships behavior in muddy area's are ongoing (Delfortrie, 2004).

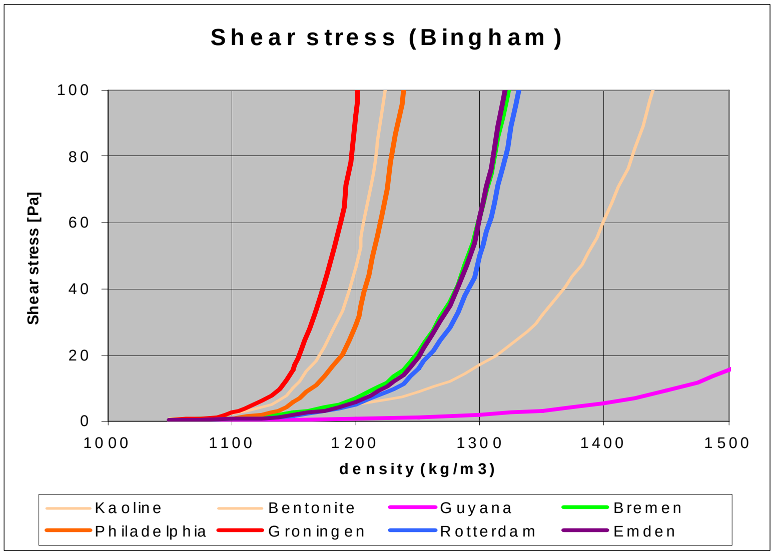

Figure 1. The relation of the shear stress (Bingham) with mud density for several harbours.

IMPLEMENTATION OF THE NAUTICAL DEPTH APPROACH

Implementation of the nautical depth concept appears to be a complex issue as an easily understandable water-bottom transition is replaced by a transition that is more diffuse. The transition cannot be related to a single echo sounder frequency and therefore not mapped with standard and commonly accepted single or multibeam systems. Implementation therefore requires more than just a technical measurement solution, and three important prerequisites for implementing the nautical depth concept are described below.

Evaluate Mud Characteristics and Define Criteria

These parameters should be studied and defined before the concept is adopted. During implementation these parameters should be evaluated and adapted when necessary in order to suit local conditions. This study implies both a study of the sedimentary processes and the operational conditions of the harbor.

As outlined above a mud density criterion is highly site specific and even in a single harbor realm, variation may occur. For instance a small increase in sand content will significantly influence the density of the mud and its rheological behavior. The study of sedimentary processes should focus on consolidation/settlement behavior in various realms of the harbor and laboratory tests of the local mud material. These tests should consist of rheometric measurements (roto-visco and vane tests) to evaluate both consolidation speed and strength development of the mud over time.

A definition of the mud characteristics that can be allowed within the nautical profile should be set. Though much less site specific than density, the criteria chosen will be influenced by local and environmental conditions. Factors like channel complexity and exposure, currents, cargo type, tug assistance, and the expected total thickness of the fluid mud layer will influence the acceptable density or yield-strength level. These criteria do not need to be permanently fixed before the start of such a program, but may be chosen with a generous safety margin in the beginning and adjusted during the implementation period.

Monitoring System

A control system should be implemented to monitor the status of the nautical profile in relation to the set criteria. This control system should monitor the nautical depth with reasonable accuracy. An important factor regarding the accuracy is the total amount of actual collected data points. A continuous profiling method should therefore be preferred over point measurements. Since transition areas are both diffuse and subtle, not only the accuracy, but also the reliability of the measurement system output should be monitored (calibrated). Furthermore, the system should be operationally efficient. It must be feasible to collect and process data at regular periods and to produce information on the status of the monitored area with only a short delay.

Communication

As a law of nature, changes will always invoke resistance. When material that has always been qualified as solid suddenly is declared to be water, or at least very similar, suspicion and objection are to be expected. The participants (dredging departments, pilots) and clients (commercial shipping) will have to accept the new approach and be able to gain confidence in the system. Not only at the start, but also during on-going operations, adequate feedback on the navigability of the channel from all partners is essential.

SURVEY APPROACH

All these prerequisites are best served by standardized working methods that can be tuned to cope with site specific variation and variability. This working method requires survey systems with predefined, controllable settings.

In Figure 2 a typical survey scheme is outlined based on a combination of very high resolution acoustic profiling and in-situ rheometric and/or density measurements. Similar combined systems are currently in operation in the Port of Rotterdam, The Netherlands; and the State waterway authority of Germany, Emden Section. In Rotterdam an Odom Echotrac CV with Silas technology and the DensiTune or RheoTune in-situ probes are in operation.

The density calibrated acoustic system is based on seismic reflection theory. Reflected energy is governed by acoustic impedance contrasts, the product of density and sound propagation velocity. Very high water content in mud mainly governs the speed of sound and shows no significant change in the fluid material. After calibration to compensate for f.i. spherical spreading, the density can be calculated from the acoustic returns.

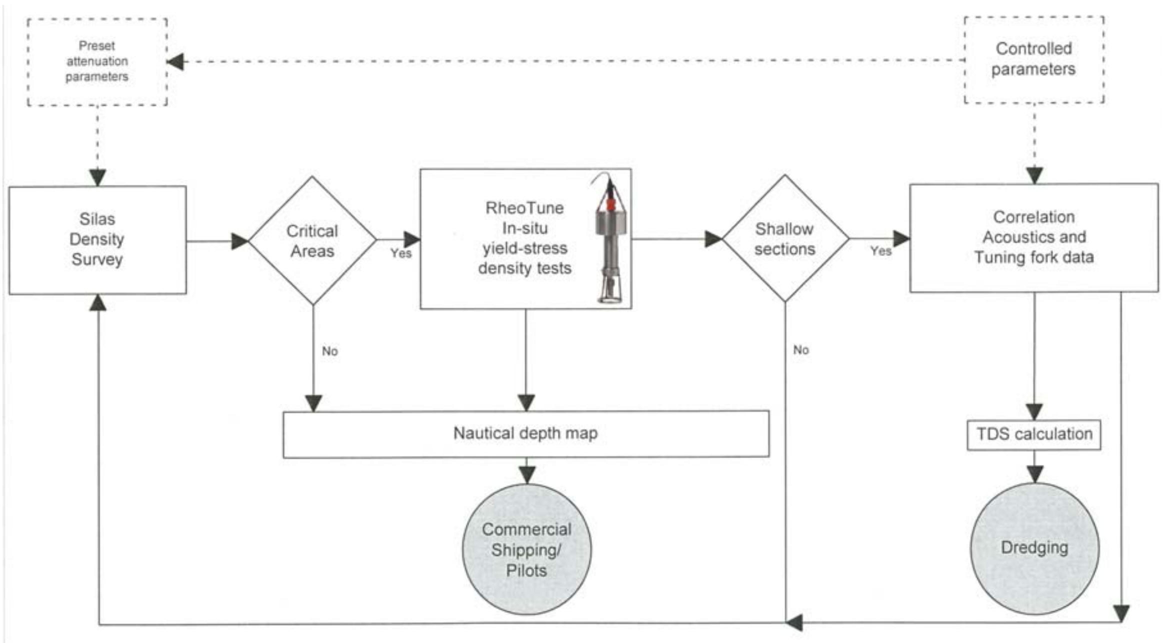

Figure 2. Combined nautical depth survey scheme based acoustic surveying techniques combined with direct in-situ density and rheometry measurements.

The density calibrated acoustic continuous survey approach is a time efficient method designed to map density levels over vast regions exhibiting lateral variability and to locate critical areas. The system output at this stage is generally the high frequency echo sounder depth reading and a real time calculated predefined iso-density level. This information is directly outputted to the survey computer to be integrated with position and tide information. The Port of Rotterdam uses the simultaneously operated multibeam system for mapping the line data to area covering nautical depth models. Full waveform data logging for post processing calibration purposes is user selectable. This option can be chosen in the real time mode only when shallow sections are encountered to reduce data volume. Figure 3 shows a typical fluid mud cross-profile including iso-density levels.

The selected critical areas, once located, can then be checked with in-situ probing. In this way the efforts for in-situ probing can be focused on the interesting realms and the number of probes and time allocation reduced. This in-situ probing serves two purposes: Check rheometric characteristics and check accuracy of acoustic density mapping.

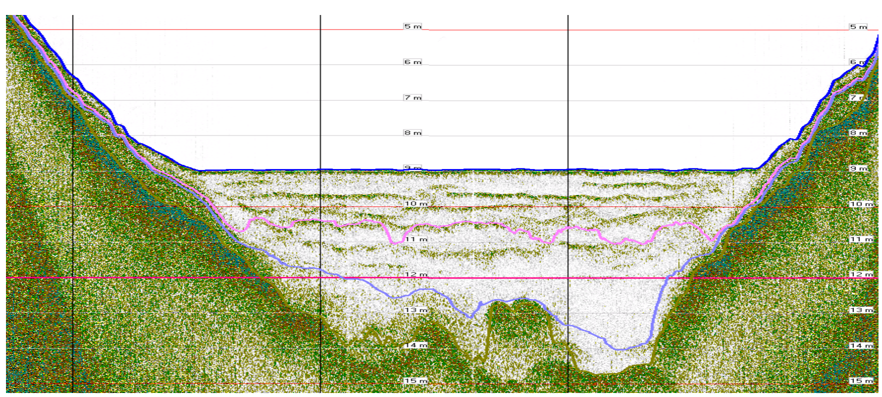

Figure 3. Vertical acoustic cross-section of a fluid mud profile. Blue line represents the 210 kHz high frequency echo sounder return. iso-density levels of 1150 and 1200 gr/l are calculated from the acoustic response.

The first check copes with the thixotropic behavior of fluid mud. Fluid muds are non-Newtonian fluids exhibiting a partial solid and fluid behavior. The solid behavior causes an initial resistance to deformation, the yield strength. The magnitude of the yield strength is only partly governed by the density. The ability of sediment particles to form bonds is a factor determining the yield strength. Mud rejected by the density criterion does not necessarily be rejected by the yield-strength criterion.

The selected critical areas, once located, can then be checked with in-situ probing. Tuning fork response induced harmonic motion of the in-situ material is related to the density/viscosity and yield-strength of the mud. Figure 4 shows vertical RheoTune profiles for density and rheometric parameter. These parameters are assessed with high vertical resolution. Note that in the upper range a large increase of density corresponds with only a small viscosity increase. In the lower range only a small density increase results in a large increase of viscosity. Small errors in density assessment will result in under or over estimation of the rheological properties.

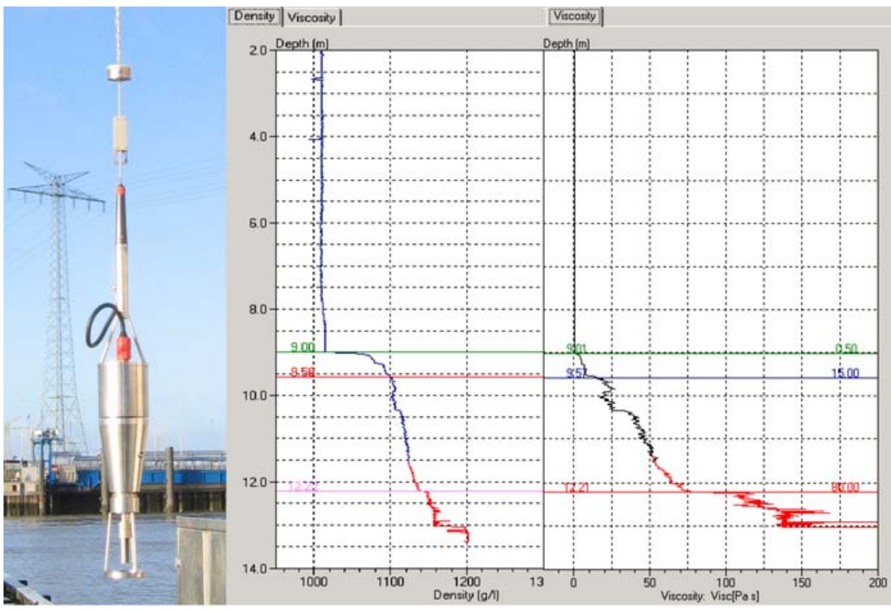

Figure 4. The RheoTune tuning fork in-situ probe simultaneously registers vertical density/viscosity and yield strength profiles with centimeter resolution.

The acoustic data corrected for the in-situ probing information can be used to model the nautical depth map and make this information available for navigational purposes. The data density of the dataset allows appropriate planning of the dredging efforts.

The combined dataset can be used to periodically check the accuracy of established and a-priori used relationships. When required, appropriate adaptations (for instance for seasonal variability) can be made. In this way a basically simple survey scheme for day-to-day use, with preset correlations, simultaneously collects data for later validation and system stability checks.

DISCUSSION

The nautical depth concept is not an easily adopted concept in modern harbor management. Though it is in use in several access channels, monitoring continues to be performed by the use of lead line probes. This process does not however provide the information required to assure access channel integrity. To implement the concept successfully more than just a measurement device is required. Survey procedures and schemes have to be drawn up and evaluated regularly.

New survey techniques will have to be introduced for monitoring the sedimentary system as a whole. The basic monitoring systems are at present in operation in harbors worldwide and have proven their reliability. The use of proven techniques will aid the acceptance of the procedures. In principle the procedures will be uniform for every setting. Admittedly, the intensity of surveys and the balance of acoustic surveys versus in-situ probing will have to be tuned according to each individual area.

The plan-do-check-act cycle for risk assessment (Figure 5) is fully supported by a combined system. Regular or incidence surveys are performed at regular intervals or based on preset criteria, for instance, feedback from pilots (plan). Surveys are performed with real-time acoustic density mapping potentially combined with in-situ probing (do). The check-act part can be read as checking the elevation of the nautical depth in relation to the guaranteed nautical profile and trigger dredging activity. But the full digital data-acquisition allows evaluation of the working process with internal checks on the validity of the calibration relations during the study of the relevant criteria and when monitoring (check). When acoustic relations fail to match the correlation parameters for the acoustic survey, they can be adjusted for the change in mud composition (act).

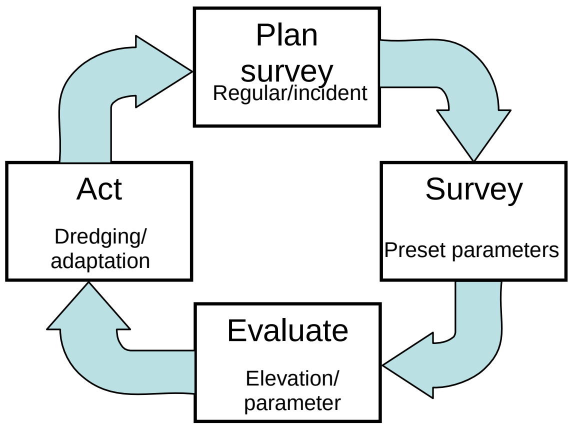

Figure 5. Plan-do-check-act cycle for acoustic monitoring of the nautical depth.

The established predefined settings can be well communicated and integrated in contractual agreements. This allows faster decisions on required dredging actions (contractor knows criteria for actions and can react without delay).

Additional benefits provided by the very high resolution acoustic data are the facilities for object detection and seabed classification. The Nautical Depth survey can reveal objects and other anomalies that may endanger shipping. Acoustic analysis can be used for acoustic sediment properties assessment, to be used for risk assessment on ships bottom collision.

Most important though is the total of checks and balances in the management system. All information regarding the safety of navigation should be discussed and evaluated regularly. This discussion will keep all related parties focused on the common goal of efficient and cost effective harbor management without compromising safety.

REFERENCES

PIANC (1997). “Approach channels - A Guide for Design”, *Final Report of the Joint PIANC-IAPH Working Group II-30 in cooperation with IMPA and IAL*.

Buchanan, L. (2005). “Difficulties of Surveying in Fluid Mud, The effects on bathymetry of suspended sediments in the water column.” *Hydro-International*, Volume 9, Number 6, 2005.

De Vlieger, H., De Cloedt, J. (1987). “Navitracker: A Giant step forward in tactics and economics of maintenance dredging ” *Terra et Aqua*, Number 35, 1987.

Schramm, G. (2000) “A practical approach ro rheology and rheometry” *Thermo Haake*, 2nd edition.

Delfortrie, G, Vantorre, M, Eloot, K (2004) “Linear manoeuvring derivatives in muddy navigation areas” *International Journal of Maritime engineering*, 2004