Evaluation and combination of techniques used to determine the Nautical bottom

A call for rheology based instruments.

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The rheology properties of the underwater sediment will influence the possibility of navigation through it (or just above it). The rheology of the fluid/partially consolidated mud is a very complex issue. Most of the techniques to determine the nautical bottom are based on density information because of the relatively easy way of measuring. The problem is that the relation density - rheology can not be used as such. More correct and direct ways to relate the rheological parameters to the sludge are: in-situ sampling (of disturbed and undisturbed samples) combined with performing laboratory rotoviscosimeter tests on these samples or direct in-situ rheological measurements with body-profiling rotoviscosimeter. Relating this information to the structural information from the acoustical profiling methods is a step forward, but because of its complexity, it is seldom used. An accurate and easy to use online rheology properties measuring instrument (measuring shear-strength (rigidity and viscosity)) is still to be designed.

The influence of deep and shallow water on ship behaviour.

A ship experiences a large difference in sailing behaviour when it navigates in either shallow or deep waters.
In shallow water, meaning a keel clearance of about 10-15% of ships draft, a ship experiences completely different behaviour compared to when sailing in deep water.

Deep water is defined as being: more than a few times the draft of the vessel.

In shallow water the maximum allowed sailing speed will be much lower with the same power, and the turning circle for a given speed will need to be considerably larger.

Ship trials on new vessels are carried out to determine their sailing characteristics, and typically amongst other factors attempt to establish the maximum speed and the turning circle (at maximum speed). Normally these trials are performed in "deep water". This can be a source concern in terms safe operation in shallow water, where expectation are based on trial data from deep water. Typically, a ship operating at high speed in shallow water will experience significant and irregular vibrations and other dynamically navigation hazards.

The problems of muddy bottoms in navigation

In addition to the phenomena resulting from shallow water sailing, is the further influence of bottom type.

In "hard" bottom conditions (e.g. sandy bottom) navigators find that they have better control over the 'shallow' situation insofar as the behaviour is more predictable and less safety problems arise.

Theoretically, one would anticipate, that fewer problems should arise when sailing over fluid mud compared with a hard bottom. In fact the opposite is true.

The speed of the vessel is the determining force in maintaining the control over the vessel (i.e. reduced speed will reduce shallow bottom affects). However, because of the presence of currents (e.g. tidal and littoral), reducing speed is not always a safe possibility. In the example of the high sideways-on tidal currents, at the entrance of the Belgian harbours, vessels do not have a choice other than to use potential unsafe speeds to enter these harbours (see currents Atlas of Zeebrugge harbour published by the Flemish Government, made by Gems International).

If we don't take into consideration the effect of the mud level, it is inevitable that ships will encounter critical speed situation problems whilst sailing above muddy bottom during in and out manoeuvring of the harbours.

The solution

Ongoing maintenance dredging is the principal tool to solve these problems.

But at what economic level do they need to dredge out?

The top layer of the fluid mud can be detected with a single frequency of around 100 kHz. This acoustical top-level, unfortunately, is very difficult to handle by dredging. Removing only the effective zone of the "muddy bottom", and where that level is influence lies is still only a manner of speculation.

Influences other than the means detecting and determining the economic level of treatment (dredging), are the spatial and time variance triggered by weather, tidal and anthropogenic forces.

Therefore a nautical depth has been determined, that lies somewhere between the top of the fluid mud and the hard bottom.

The debate as to what is the correct level to dredge is based on:
- marine/mariner experience (at best poorly recorded)
- dredger trials (largely uncorrelated); and
- Laboratory scale tests

Moreover, the correct rheological model (and instrumentation) to efficiently determined the depth have yet to be designed.

Nautical bottom

The nautical bottom is defined as the level of a muddy sediment at which the vessels experience no difficulties when sailing at or above it. Below that level navigation problems could occur. The sediments lying above this level, therefore, have no important effect on the navigation of the vessels.

Only the rheology properties of the sediments will influence the possibility of navigation through the muddy layer (or just above it).

The rheology of this fluid/partially-consolidated mud is very complex and there exists of at least seven parameters/sets of influences that define it. These include:
- hydrodynamic and electrostatic forces;
- strength of inter-particle action;
- visco-elasticity;
- viscosity (zero shear and maximum viscosity of the fluid phase preventing sedimentation);
- size and shape of the particles;
- creep recovery.

The determination of these parameters and influences, and their relative importance to the nautical bottom model is difficult and complex. Measurements, of such rheological properties, even on laboratory scale is equally so. Another problem is that the laboratory circumstances do not always reflect the in-situ reality.

For decades now research have been carried out into "nautical bottom" these have included:
- laboratory and in-situ tests;
- scaled and normal size simulations; and
- use of natural and artificial mud.

But still no effective models or rules of thumb exist for determining "nautical bottom" for particular circumstances.

Density

Most of current techniques used to estimate "nautical bottom" are based on density instead of a rheology, mainly because of the relatively ease of measurements. So the following techniques are in common use:
- Type 1: acoustical density profiling based on acoustical impedance transitions (e.g. Silas; Innomar Sonar); Because every beam travels through the mud column during transit (without physically profiling sensors), we can consider these as a means of "underwater remote sensing".
- Type 2: body-profiling absolute gamma-ray point measurements for direct sludge-density measurements (e.g. Navitracker; Dophin);
- Type 3: body-profiling tuning-fork-based point measurements (e.g. Admodus USP; Densitune; Mudbug and XL4 Density probe).

All these density based techniques can be used in towed or vertical profiling mode.

In the table 1 on the next page, the 'pro' and 'contras' of Type 2 and 3 are compared.

	Absolute density systems (gamma-ray) (type 2)	**Tuning fork density systems (type 3)**
Radioactive source	Disadvantage: - long procedure to get licence for transport, operation and storage - safety qualified personnel	Advantage: not radioactive
Weight/operation	High weight (200 kg): - advantage: good penetration into the high resistance mud - disadvantage: no handprofiling	Advantage: Depending on setup, but mostly too light and sensitive for penetration into high resistance mud
Repeatability	advantage: High repeatability	- disadvantage: Direct contact with mud is needed (action-reaction) =>; good refreshment of the contact surface is needed => medium repeatability - advantage: not radioactive
Sample volume	Big sample volume: - advantage: distance between the legs is large: a representative mean density value of the sludge can be obtained	Small sample volume: - disadvantage: Local errors occur because contact surface is small. Could give less representative values, no mean value compensate the local disturbance
Amount of profiles/time	Equal	Equal
Sticky mud	The error caused by the amount of mud that sticks to the legs of the sensor will be negligible because of the averaging of the big amount of measured volume of sludge	Can give wrong readings

Table 1: This table present the 'pro' and 'contras' of Type 2 and 3 density instruments.

Both type of systems are used together with acoustical information from echo sounders. Different information coming from the echo sounders can be used:

- Classical bathymetry: given by the time to reflect at a certain boundary =f(profiling depth of the sound of a chosen frequency)
- Backscatter information of the reflected waves on strong impedance transition in the sludge.

The backscatter information is used more and more to give an image of the structure of the sludge. These images are created by acoustical impedance transitions, and gives (again) an idea about the density structure of the sludge (type 1).

Because every beam travels through the mud column during transit (without profiling sensors), we can consider these as a means of "underwater remote sensing". The resulting picture gives a contour plot. The given image cannot, however be directly interpreted.

Other sensors are used to look for a relation between the visualised structures and the collected parameters. Examples of parameters that are tried to fit into the picture are:
- density profiles;
- drilling information (sediment types), and
- rheology information.

Returning to the importance of the rheology properties in defining the "nautical bottom": We believe that there is a trustworthy and repeatable relationship between a defined acoustical structure, and the collected rheological information. This relation can have a direct connection with visual structures or a repeatable offset of this structure.

Combining the acoustical contour plots with density is a commonly used method, but with the processing capacity of the new electronics, very detailed structures can be obtained (see fig. 1, which shows a possible combination of density measurements and Silas Software).

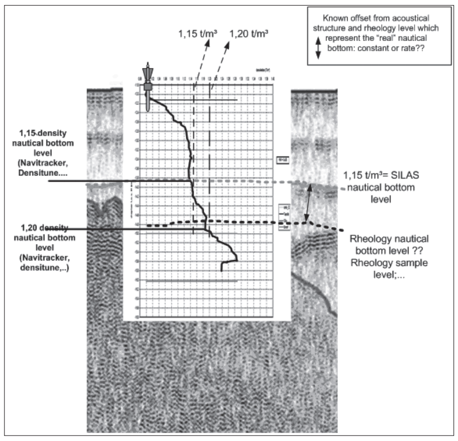

Figure 1: Combining acoustical contour plots with density to determine the nautical bottom.

More correct and direct ways to relate the rheological parameters of the mud need also to be further investigated:

- in-situ sampling (of disturbed and undisturbed samples);
- performing laboratory rotoviscosimeter tests on samples;
- direct in-situ rheological measurements with body-profiling rotoviscosimeter.

This information could be used directly for nautical bottom determination, but not as a stand-alone method, as they are time consuming and it is difficult to achieve repeatable results.

Relating this information, however, with its benefit of reduced amount of sampling, to the structural information from the acoustical profiling methods is a step forward. But because of its complexity, it is seldom used.

Research

Online and accurate rheology properties measurements for shear-resistance is still a thing for the future. Combining such information with the structural data derived from, the relatively easy to gather, acoustical profiling results, could significant improve determination of the "nautical bottom".

Before this kind of instrument (or combination with the acoustical contour plots) would be used, much research effort is needed (in-situ and laboratory simulation) to relate other available studies (mostly density-rheology based) in order to evaluate the new in-situ methods. These researches need to be done thoroughly to prove the efficacy of the results, and to convince the shipping and navigation industry.

The Flemish Government (Flanders Hydraulic Research, Division Maritime Access) had already invited GEMS International to test new in-situ methods. This project will be executed together with specialist from the university of Leuven and Gent.

This paper calls for other parties to join the test programme, and bring with them their innovated techniques to determine the in-situ rheology.

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