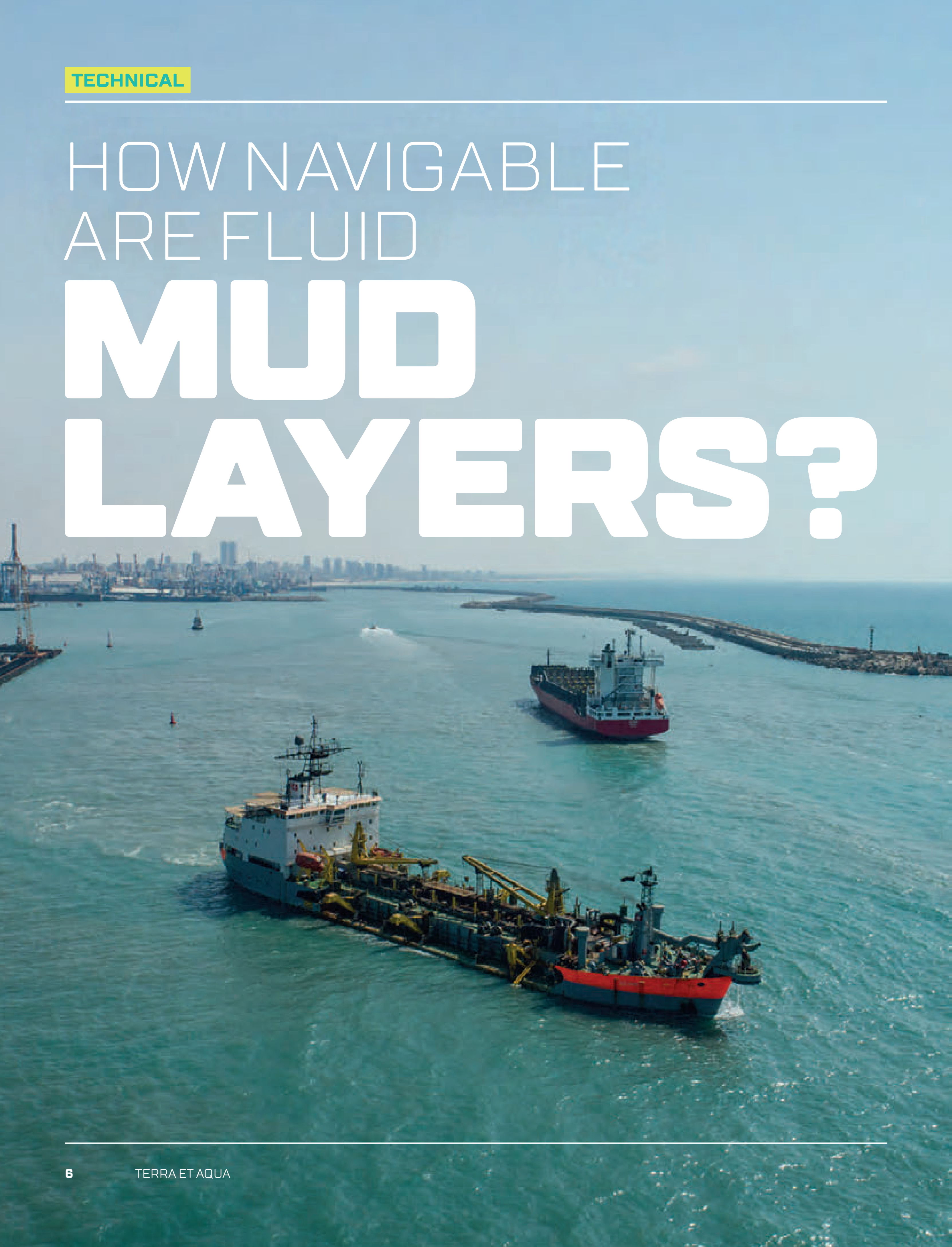
TECHNICAL

HOW NAVIGABLE ARE FLUID MUD LAYERS?



Navigation in ports and waterways with fluid mud seabed can be challenging due to several factors.

Safe navigation in ports and waterways should be insured by the port authorities and a good safety record is of utmost importance for the competitive position of the harbours. An important factor for safe navigation is the space that is available under a ship's keel, known as the under keel clearance (UKC).

Sufficient UKC can be achieved by either setting a restriction on the maximum draught of incoming vessels or by maintaining the desired navigable depth with intensive dredging operations in silted areas. The first option is usually undesirable from an economic point of view and would result in a severe restriction on future development of larger and thus more energy-efficient ocean traversing vessels. The second option is favourable in general, although the cost and environmental impact of the required dredging operations to dispose the fluid mud can become quite substantial.

Fluid mud is typically deposited on the bottom of the shipping route when the net sedimentation rate is larger than the consolidation rate (Winterwerp, J. C. & van Kesteren, W. G. M., 2004). Settling and consolidating in low-energy areas, fluid mud forms river and sea beds. Fluid mud consists of a highly concentrated suspension of sediment particles combined with microbial slimes. These slimes can be seen as a network of polyelectrolytes that keep the sediment particles in suspension, and fluid mud can be seen as a visco-elastic fluid.

Navigation in ports and waterways with fluid mud seabed can be challenging due to several factors. The fluid mud layer cannot be reliably detected by traditional acoustic methods. The interpretation of the measured acoustic data in ambiguous since the position of the seabed on the acoustic charts is not clear. Another challenge for navigation in muddy areas is the generation of internal waves (undulations). The controllability and manoeuvrability of a vessel can be hindered by such waves in case of a ship navigating in a close vicinity of a water-mud interface. In particular, the amplitude of the undulations affects the rudder and

Together with outcomes of towing tank studies, the results of the full-scale experiments led to a change of the nautical bottom density criterion from 1150 to 1200 kg/m³

propeller efficiency as was observed during the both in-situ and laboratory experiments.

In 1970, it was recognised that sonar measurements are not reliable in areas with substantial mud layers and, therefore, are no longer normative. On the basis of full-scale experiments in the Port of Rotterdam, in Bangkok and along the coast of Suriname, it was found that densities up to 1200 kg/m³ had a tolerable influence on manoeuvrability. The 'Nautical Depth' was defined accordingly. The illustration of this concept is shown in Figure 1.

In 1980, a series of full-scale experiments was conducted at the Port of Zeebrugge. The water-mud interface, that could be detected by the high-frequency (180-210 kHz) echo-sounder, was chosen as the reference for the UKC. The experiments were conducted with positive and negative UKC that correspond to the level above or below the depth that was detected by high-frequency echo-sounder. It was concluded that fluid mud with a low density may lead to a modified sailing behaviour, but does not give rise to dangerous situations. Together with outcomes of towing tank studies, the results of the full-scale experiments led to a change of the nautical bottom density criterion from 1150 to 1200 kg/m³, see Table 1.

Currently, the following definition for nautical bottom is used for navigation in muddy areas: 'The nautical bottom is the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and manoeuvrability' (PIANC, 2014). Unlike other ports, the Port of Emden uses the yield stress as the criteria for the nautical bottom since 2005 (Wurpts, R., 2005). In Emden, the adopted criteria above which fluid mud is navigable is a yield point of 100 Pa. It is thought that this parameter is related to the specific dredging method or the slime properties in this port. It remains to be investigated how the dredging properties affect the composition of the mud, and hence its rheological properties.

The overviews of full-scale and scaled experiments, and modelling of a ship's navigation in the channels with fluid mud

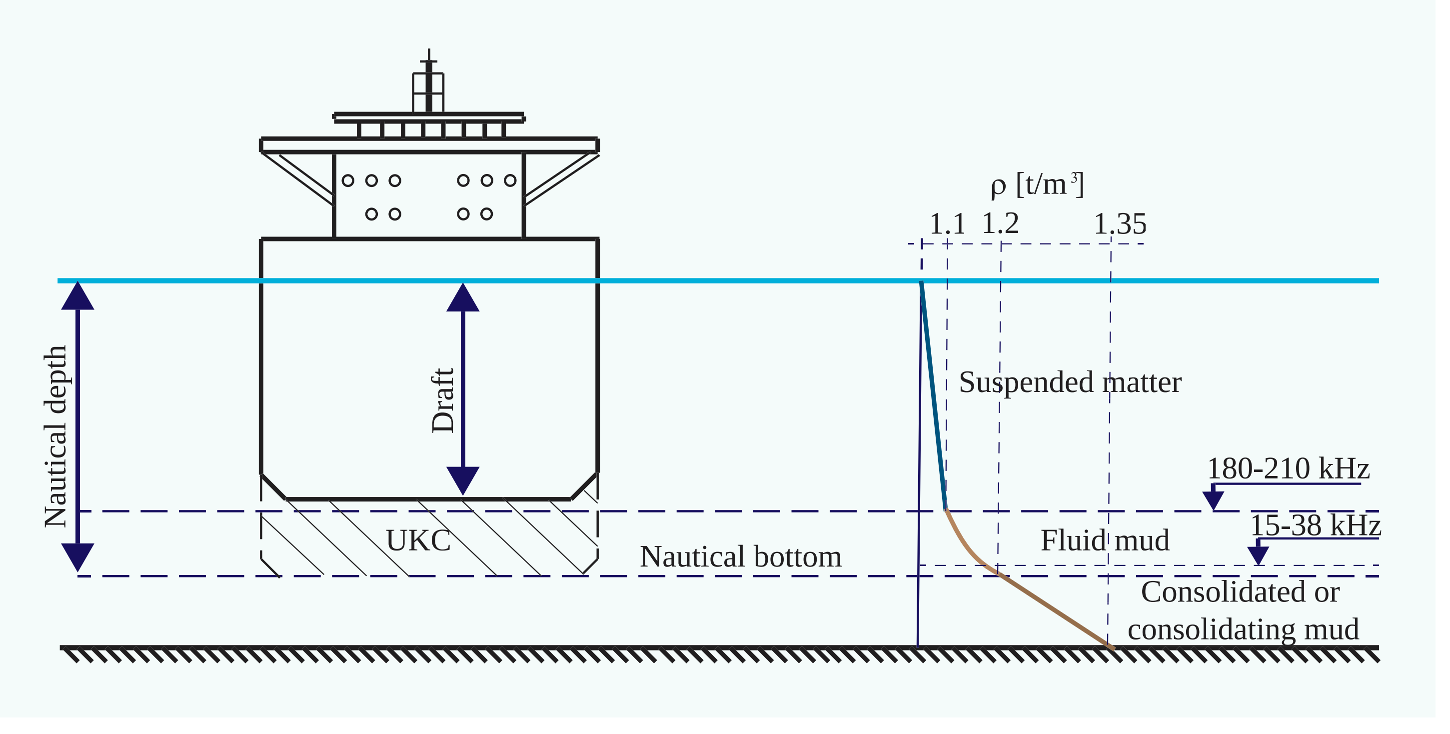


FIGURE 1

The nautical bottom concept, which was developed at the density limit of 1.2 t/m³. Diagram adapted from Nederlof, L. (1978).

TABLE 1

Criteria for nautical bottom from McAnally, W. H. et al. (2007).

Port	Country	Criterion	Value	Dimension
Rotterdam	The Netherlands	density	1200	kg/m^3
Zeebrugge	Belgium	density	1200	kg/m^3
Bordeaux	France	density	1200	kg/m^3
Nantes	France	density	1200	kg/m^3
Saint Nazaire	France	density	1200	kg/m^3
Dunkirk	France	density	1200	kg/m^3
Avonmouth	the UK	density	1200	kg/m^3
Yangtze	China	density	1250	kg/m^3
Liang Yungang	China	density	1250-1300	kg/m^3
Yianjing Xingang	China	density	1200-1300	kg/m^3
Bangkok	Thailand	density	1200	kg/m^3
Paramaribo	Suriname	density	1230	kg/m^3
Emden	Germany	yield stress	100	Pa

layers can be found in Vantorre, M. (1994), Delefortrie, G (2008) and Delefortrie, G. & Vantorre, M. (2015). The present article provides an additional discussion on surveying methods that can be used for monitoring the fluid mud layers.

Full-scale experiments

The first reported full-scale experiments were conducted in the Port of Rotterdam in 1975

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It was concluded that during navigation with the UKC of +14%, less disturbance was caused with respect to the mud-water interface than to CSL Rhine at the same UKC.

FIGURE 2
The 318 tonne deadweight oil tanker SS Lepton was a subject of investigation for the full-scale experiment at the Port of Rotterdam in 1974. Here, the SS Lepton filled with water enters the Port of Rotterdam. Observers on board carefully follow the sailing behaviour of the ship. The Lepton was 350 metres long and 55 metres wide, the draught was 20.90 metres, the average throat clearance was 1.60 metres, and the average mud layer was about 1.15 metres (Nederlof, L., 1979).

(Nederlof, L., 1978 and Nederlof, L., 1979). The 318 tonne deadweight oil tanker SS Lepton (see Figure 2) was sailing within the Europort area at Hoek van Holland, in and out the port. During the tests, manoeuvrability data and the density depth profiles were recorded. The average mud layer thickness in the investigated area was about 1.15 metres. The manoeuvres were done at UKC of 6% of the draught with respect to the depth indicated by the 210 kHz echo-sounder. Although the pilots experienced the entry as 'difficult', a comparison of the manoeuvring behaviour of the Lepton with that of other incoming tankers shows that in fact it was not more difficult than other large ships and even easier than other vessels. This conclusion was also supported by the measurement of the speed of the tanker, maximal percentage of available rudder and propulsion which were analysed during the experiment.

Other well-reported full-scale experiments were conducted in Zeebrugge from 1986-1988. Seventeen full-scale tests of three types were carried out with the trailing suction hopper dredger Vlaanderen XVIII (van Craenenbroeck, K. & Vantorre, M., 1991). Short engine manoeuvres (acceleration/deceleration tests), constant power manoeuvres, yawing tests at zero speed by means of bow thrusters were conducted in the outer harbour of Zeebrugge. The manoeuvres were performed with keel clearances from -0.35 to +3.0 metres with respect to the depth indicated by the 210 kHz echo-sounder. The rotation tests were conducted at a keel clearance from -0.3 to -0.4 metres. During the trials, the presence of internal waves on water-mud interface was confirmed. The solitary stern internal waves were detected by the 210 kHz echo-sounder. An internal wave of about 2 metres height was detected by surveyor vessels during the passage of a deep-draughted OBO carrier.

Two full-scale trials were conducted in the Port of Delfzijl from 2013-2015. The first trial was conducted with the general cargo vessel CSL Rhine at positive UKC of 14% and larger with respect to mud-water interface that was detected by 210 kHz echo-sounder. The results showed that the manoeuvring and propulsion behaviour were influenced by the mud layer at UKC smaller than 18%. The second trial was carried out with the hopper dredger Geopotes 15. The tested UKC was between -5% and +17% draught to the depth detected by 210 kHz echo-sounder. During the test, it was concluded that during navigation with the UKC of +14%, less disturbance was caused with respect to the mud-water interface than to CSL Rhine at the same UKC. It was concluded that the manoeuvrability was much more favourable with fluid mud layers of 2.5 to 3.5 metres thickness in combination with a negative UKC than with a positive UKC from +1% to +13%. At the UKC from +10% to 20%, the ship-induced internal waves hindered the propeller and the rudder of the vessel at low viscosity mud layers. It was reported that the vessel's manoeuvres were in line with simulation studies (Verwilligen, J. et al, 2014 and Barth, R. et al., 2015).

Scaled experiments

Scaled modelled tests were performed to get a better understanding of ship's manoeuvring in muddy environment. These tests were coupled to mathematical manoeuvring models to quantify the effect of the mud layers on the controllability of the ship. The scaled experiments with real mud can be problematic because of the time effects (e.g. settling, consolidation) of mud. Therefore, a dense viscous fluid is typically used to mimic the fluid mud in a two layer system. The physical properties of an artificial mud (density, viscosity) are chosen to be close to the ones of the fluid mud.

One of the first scaled tests that were carried out to investigate the effect of fluid mud on manoeuvres were conducted with a 1:82.5 scale model of a tanker that was equipped with rudder and propeller, sailing above or in contact with a dense fluid layer (Sellmeijer, R. & van Oortmerssen, G., 1983). A mixture of chlorinated paraffin and kerosene was used to simulate the fluid mud layer. Two density values, 1140 kg/m^3 and 1240 kg/m^3, were chosen to mimic the real mud conditions at the Port of Rotterdam during the winter and summer periods, respectively. The tested dense fluid layer thickness, from 1.35 to 3.85 metres, was varied. Both positive and negative UKC with respect to the water-dense fluid interface were tested by changing the water level in the basin. Two types of experiments were carried out: free running tests were conducted to evaluate the total effect of the mud on the manoeuvres of the vessel and the captive experiments were carried out to predict standard manoeuvres by means of mathematical models, which describe the ship motion in a horizontal plane. The effects of mud on squat and trim of the tanker were analysed. It was observed that the tanker becomes slower with the UKC of 3-5% of the draught above the dense fluid. However, further reduction to negative values of UKC makes the tanker less slow in its manoeuvres. Furthermore, the presence of dense fluid on the bottom tends to reduce the steady motion and to accelerate the dynamic motions.

FIGURE 3

Propagation pattern of internal waves of the water-dense fluid interface for viscosity 0.002 Pa s (left) and 0.03 Pa s (right) (Delefortrie, G. & Vantorre, M. , 2015).

Self-propelled tests were conducted with scale models of an LNG-tanker and a hopper dredger along a guiding rail above water-mud system with a dense fluid mud layer.

One important observation was the internal waves that occurred in the water-dense fluid interface when a ship is passing. The amplitude of these internal waves (see Figure 3) increases with the thickness of the dense fluid layer and with decreasing fluid density, and affect the propeller efficiency as was observed during the free running trials.

A series of model scale tests were carried out in a wave flume with a tanker model of scales 1:100, 1:70 and 1:55 (Brossard, C. et al., 1991). The model was equipped with sensors for measuring squat, trim and tractive force. The goal of the experiments was investigating the resistance and squat variations above an artificially composed mud layer. The tested mud layer had density gradients over the depth. Three types of mud were tested: with low, intermediate and high gradients. The layers with different yield stresses were used in the study. The undulations on the water-mud interface had been observed in this study.

The self-propelled tests were conducted with scale models of an LNG-tanker and a hopper dredger along a guiding rail above water-mud system with a dense fluid mud layer. Unstable rudder behaviour and poor propulsive efficiency was observed if due to a combination of initial UKC, squat effects and internal waves, the ship's keel is in contact with both fluids (Vantorre, M. & Coen, I., 1988). A series of captive tests were conducted for different simulated manoeuvres (Delefortrie, G. et al., 2005). During the tests, longitudinal and lateral force components, vertical motion, rudder parameters and propeller parameters were measured. A mixture of chlorinated paraffin and petrol was used to mimic the mud. Mathematical manoeuvring models were developed for fluid type of densities 1100-1250 kg/m^3 and of viscosities 0.03-0.46 Pa s, dense fluid layer thickness of 0.75, 1.5 and 3 metres, scaled models of 1:80 and 1:75 sailing with UKC of -12 to +21% relative to water-dense fluid interface, and with speeds between 2 knots astern and 10 knots ahead.

Monitoring methods

Traditionally, the reflections of acoustic signals are used to determine the positioning of water-bed interface. The emitted acoustic pulse propagates through the water column and reflects back from the bottom of the waterways. The distance from the acoustic source to the reflecting surface is proportional to the travel time of acoustic waves in the water column. In muddy navigational areas, different frequencies of the emitted signal are employed. Standard low frequencies (15-38 kHz) and high frequencies (180-210 kHz) signals are used to provide information about water-fluid mud interface (lutocline) and bed-fluid mud interfaces, respectively. The former typically exhibits a strong contrast. The latter is often inconsistent due to a weak density gradient within a fluid mud layer that plays an important role in the reflection of emitted acoustic signals (Kirby, R. et al., 1980). Therefore, other measuring techniques have been proposed for the monitoring of the water-bed interface in muddy navigational areas. These techniques are typically based on the physics of the scattered and transmitted gamma-radiation, acoustic and optical backscatter, or through mechanical devices. One of the most accurate methods so far is based on scattered and transmitted gamma-radiation. This nuclear method is typically used to determine the density of the water column, including fluid mud layers. The instruments that are based on acoustic and optical backscatter typically measure the concentration of suspended particles in the water column. All the non-acoustical methods have several common drawbacks. Due to the nature of the profilers, the spatial resolution of these tools is limited to 1D vertical profiles (see Figure 4). Thus, the interpolation between the measurements to obtain a spatial map is generally done by combining these methods with acoustic sounding. Another important

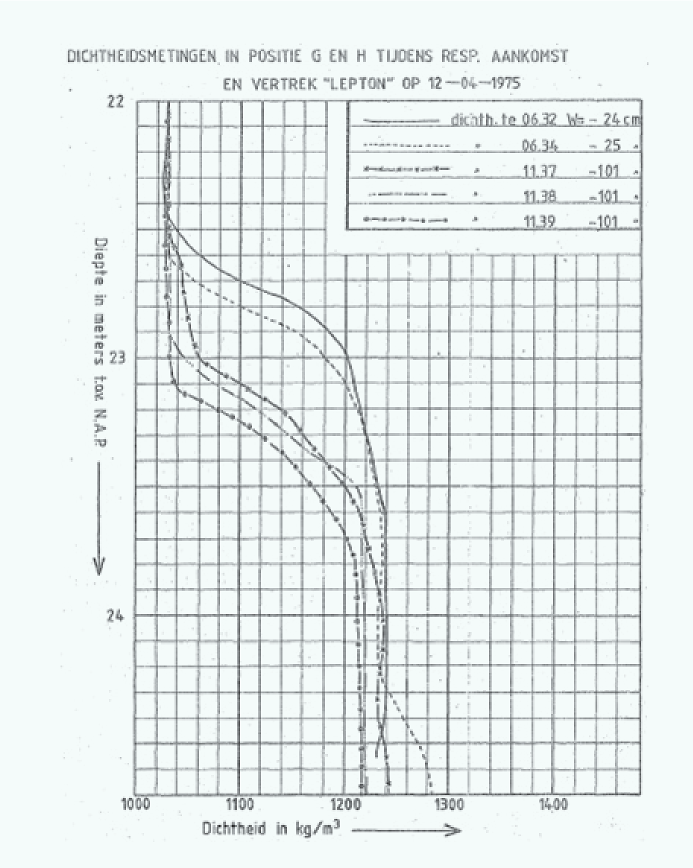

FIGURE 4

Diagram of the temporal changes in density profiles during the full-scale experiment of the SS Lepton in 1975 (Rijkswaterstaat, 1977).

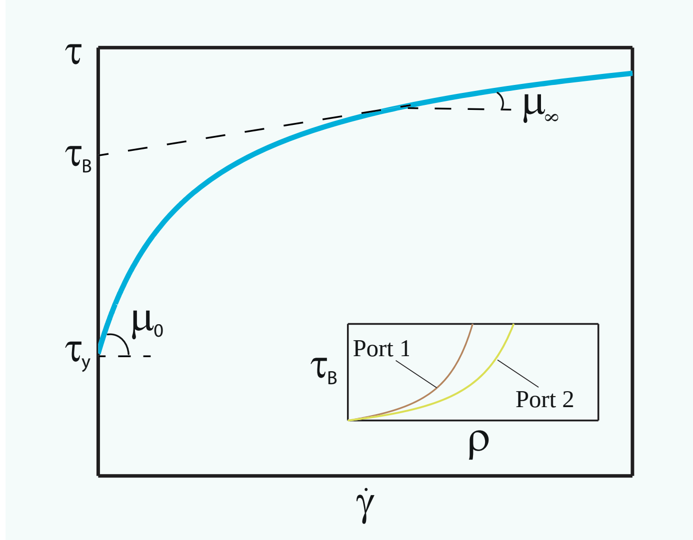

FIGURE 5

The sketch of the flow curve with rheological parameters.

Two mechanical behaviours of mud can be deduced from a traditional flow curve: elastic and viscous.

disadvantage of these methods is their intrusive nature of surveying. The measuring tools have to be in a direct contact with fluid mud layers in order to provide quantitative characterisation.

Even though it has been recognised that the surveying methods that are based on rheological parameters are the most suited for nautical purposes, the in-situ measurement of these parameters is a challenging task. Two strategies can be found to determine these parameters. The first one is that samples are taken in-situ and analysed in the laboratory. The second one is to use in-situ instrumentation. Both strategies are discussed in this article.

Laboratory

Rheological properties can be routinely determined in the laboratory, for instance by the vane-type tests or rotational rheometers. These laboratory methods measure the resistance of fluid mud samples to flow in response to applied shear forces. This can be done by controlling the shear rate, γ, or shear stress, τ, that gives the flow curves (see Figure 5) for different mud samples. Two mechanical behaviours of mud can be deduced from a traditional flow curve: elastic and viscous. The elastic behaviour is conventionally observed at very low shear strains rates. As soon as the strength of the soil matrix weakens, mud starts to flow exhibiting viscous behaviour. In this mechanical state, deformations correspond to the rate of deformation. The shear stress, at which this soil matrix starts to deform (or to flow) is conventionally called the yield stress. Typically, the yield stress, τ_y, and dynamic viscosity, μ_∞ , can be obtained for different mud samples from measured flow curves. Two additional parameters are required for reconstructing the complete flow curve: the Bingham stress, τ_B, and the initial differential viscosity, μ_0. As can be seen on

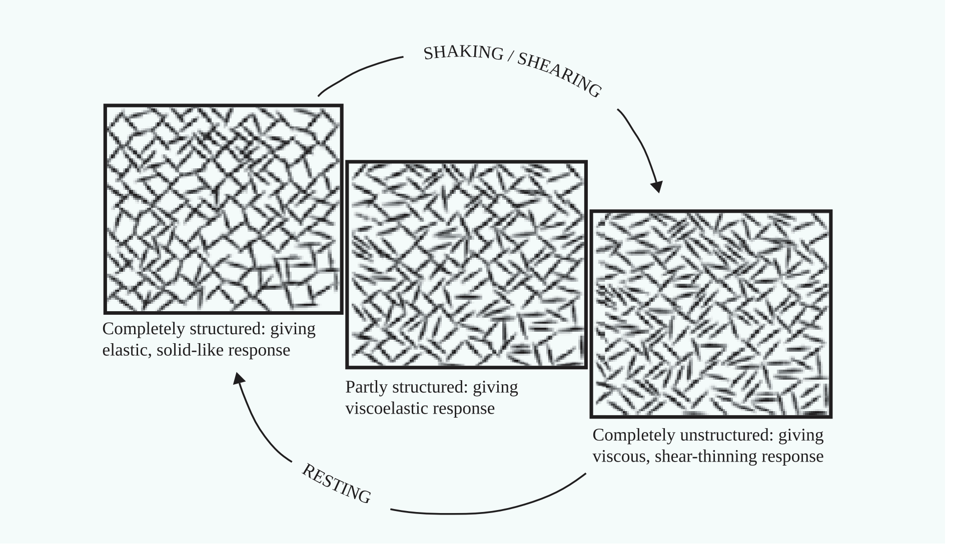

FIGURE 6

Breakdown of the thixotropic structure (Barnes, H. A., 1997).

Figure 5, a given density does not necessarily correspond to a unique yield stress. This implies that the relation between density and rheological parameters should be carefully studied in order to assess the best set of parameters required to characterise the nautical bottom.

Due to the complexity of fluid mud, the shear stresses exhibit a non-linear relationship with the density, ρ. This can be explained by the thixotropic behaviour (deformation, history and time dependence) that is illustrated in Figure 6. Therefore, sampling and measuring procedures, followed by data processing and interpretation of the measurements, have to be standardised by means of recognised practical protocols (Claeys, S. et al., 2005).

In-situ instrumentation

Free-falling cone penetrometers

The physics of a free-falling cone penetrometer is based on recording the penetrometer's acceleration/deceleration for getting the information about the cone penetration resistance. Using a calibration procedure, the rheological properties of the site-specific mud can be related to this cone-end resistance. In this way, the water-mud column profiles can be mapped by using this type of instrument.

One of the advantages of this type of equipment is that the vertical positioning of the penetrometer can be derived from the recordings of accelerometer. In general, an accelerometer is more accurate in indicating the depth than standard pressure sensors.

Tuning fork profilers

The tuning fork profilers are based on the recording of the amplitudes that are triggered by mechanical vibrations at different frequencies. These recordings can be used to get the information about the yield stress and viscosity of mud. For this purpose, an accurate calibration procedure that requires laboratory rheological measurements is necessary. The tuning fork profilers can provide sufficiently accurate rheological properties in the areas of low sediment concentrations.

Towing objects

The depth level of the towed object is defined by the viscosity discontinuity between consolidated and fluid mud. The high viscous forces in the consolidated mud and heavy cable weights attached to the towed object assure the cable to position itself on the interface between fluid and consolidated mud unless a critical towing velocity is exceeded and the towed object starts floating in the water above the fluid mud layer. In the case of the Rheocable, the continuous measurements of the electrical resistivity value is used to verify whether the cable is on the seabed or floating above it. The depth level of the towed object is defined by a pressure sensor on the

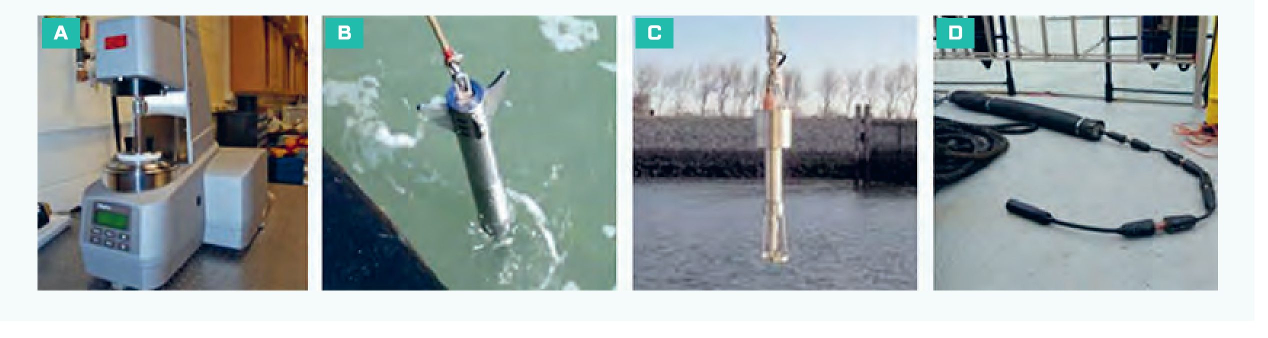

FIGURE 7

Photos show rheology-based methods including a lab rheometer (Anton Paar) [A] , free-falling cone (Graviprobe) [B], tuning fork (Rheotune) [C] and towing object (Rheocable) [D].

seabed measuring the hydrostatic pressure (Druyts, M. & Brabers, P., 2012).

Comparison of density- and rheology-based monitoring

In order to compare the density- and rheology-based monitoring, the water injection dredging method was employed in the 8th Petroleumhaven at the Port of Rotterdam (see Figure 8). The water injection dredging (WID) was used for liquefying the top layers of the sediment around a man-made pit in the river bed so that the mud would flow into the pit (500 x 200 metres). The pit collected the fluid mud layer up to 1.5 metres thick from the surrounded area. The Graviprobe and DensX were used to capture the development of the fluid mud layer in the pit over a period of two months. The results of the monitoring are presented in Figure 9.

The recordings of the Graviprobe are shown as the cone resistance measurements as function of depth. The dark blue profile represents the measurements in the pit conducted before mobilising of fluid mud into the pit by water injection. The cyan, green, magenta and red profiles show the fluid mud strength development in the deepening after two weeks, three weeks, one month and two months after the water injection, respectively. The same colours are used to show the density profiles that were measured with DensX. From the measurements, it can be concluded that the density of fluid mud develops faster than its strength.

Figure 10 shows the comparison of the Rheocable and Graviprobe surveys which

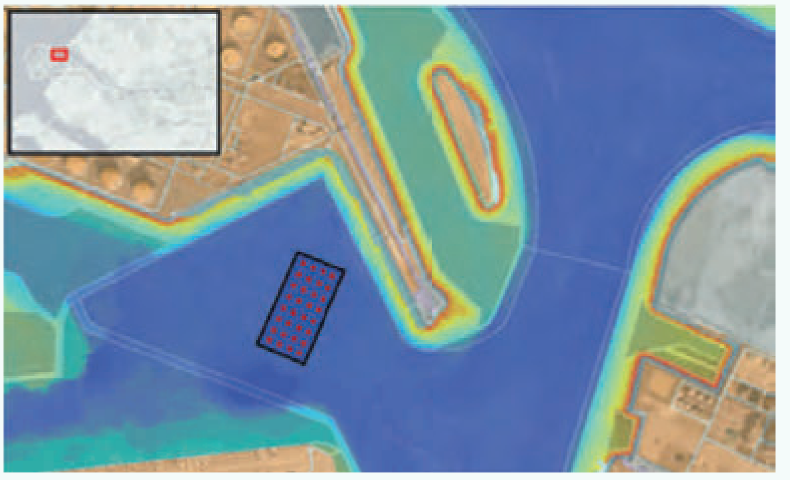

FIGURE 8

Location of the experiment in the 8th Petroleumhaven. The man-made pit has dimensions of 500 x 200 metres.

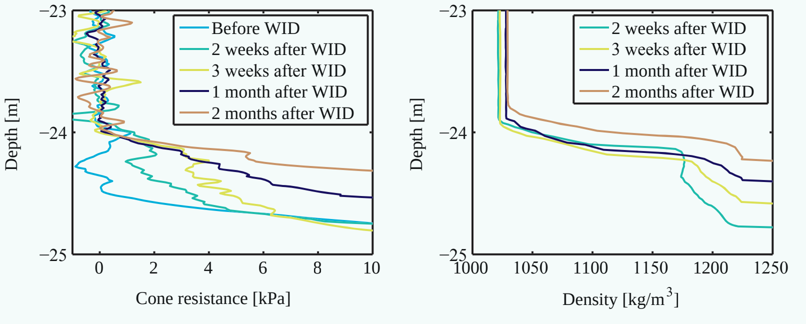

FIGURE 9

Fluid mud development in time, that is measured by Graviprobe (left) and DensX (right).

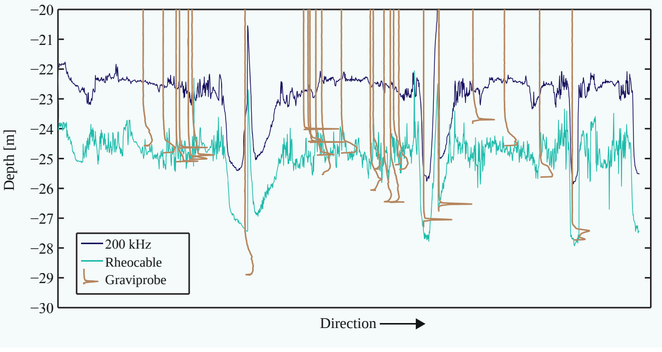

FIGURE 10

Correlation of the high frequency echo-sounding (200 kHz), Rheocable and Graviprobe measurements in the 8th Petroleumhaven.

were conducted after the WID in the 8th Petroleumhaven. The results provide a good agreement regarding navigable depth that is given by the methods. The high frequency echo-sounding measurements (200 kHz) are included for comparison.

The way forward

The safe navigation requires a new reliable and universally accepted criteria for the definition of the nautical bottom. Until now, this criteria was related to the density of fluid mud layers. Some steps have already been taken toward the new definition, for example in the Port of Emden that considers the yield stress as the parameter for the nautical bottom.

Already several decades ago, the importance of improving the parameters used in the definition of the nautical bottom was recognised. At that time, in-situ rheological experiments were practically impossible. This forced the community to adopt an alternative parametrisation, based on density. Over the years, there has been a whole new set of equipment put on the market meant to study the rheological properties of the fluid mud layer (e.g. Graviprobe, Rheotune, Rheocable). These instruments are currently tested in different ports, and it remains to be investigated if the parameters derived from the experimental results are compatible with one another. More advanced 3D acoustic methods are needed for mapping the fluid mud layers. Open questions are:

1. How to relate acoustic measurements to the rheological properties of fluid mud?
2. Can rheological point-measurements be used to calibrate acoustic mapping?

Measuring rheological parameters, and in particular yield stresses, require a well-thought and universally accepted protocol, as these parameters are strongly history-dependent and lead to thixotropic effects.

3. What would be an accepted protocol for measuring rheological parameters?

The measured in-situ rheological parameters have, for calibration purposes, to be compared to samples analysed in the laboratory. Care should be taken during the sampling, storage and analysis of these samples. The composition of the mud samples (in terms of mineralogy, biological and organic matter content) should be related to the rheological properties and the thixotropic behaviour of mud.

4. How can mud composition be incorporated in the rheological parameters?

The mud properties (density, viscosity, yield stress, mud layer thickness) are time-dependent because of consolidation processes in the fluid mud layer. Moreover, mud layers can be mobile. More knowledge is needed to understand the time dependence of the fluid mud layers.

5. What is the development of the mud layers over time and what is the link between density and rheological parameters?

The rheological parameters are to be incorporated in computational fluid dynamics (CFD) models to predict the forces acting on the ships, in accordance with the suggestions made by Delefortrie, G. & Vantorre, M. (2015).

6. How to successfully implement the complex rheological behaviour of fluid mud in CFD models?

After answering the questions given above, it is necessary to engage all the key stakeholders into the discussions on a global acceptance of new criteria for the nautical bottom.

7. How to obtain and promote an international implementation of the new criteria related to the nautical bottom definition?

All these points are currently under investigation in different research groups world-wide.

Summary

This article gives an overview of the research that has been conducted to get a better understanding of the navigation in ports and waterways with fluid mud layers. In particular, the up-to-date review of reported full scale experiments that involve real vessels is provided. To study physical processes, the full-scale experiments are accompanied by scaled experiments and numerical modelling. This combination provides valuable insight into ship behaviour with respect to different navigation conditions and physical properties of fluid mud. Another aspect of this article involves the surveying methods that can localise the fluid mud layers and potentially provide information about the strength of these layers. Some of these methods were tested on fluid mud produced by water injection dredging in the Port of Rotterdam. It was concluded that the new rheology-based method show a potential for understanding of strength development in fluid mud layers. Finally, some open research questions with respect to the applicability of the navigation through fluid mud are discussed.

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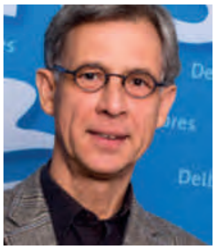
Dr Alex Kirichek

Alex developed a strong background in soil mechanics and rheology during his MSc study in Civil Engineering (Cum Laude). Later on, he obtained his PhD degree in Applied Geophysics at Delft University of Technology, where he developed a novel geophysical monitoring method for quantitative characterisation of undrained porous rocks and granular soils. Currently, Alex works as a postdoctoral researcher at the Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology. His postdoctoral project is supported by the Port of Rotterdam and Rijkswaterstaat, who are aiming to develop an innovative cost-effective maintenance concept for ports and waterways with substantial fluid mud layers. This goal can be achieved by revising current criteria for the nautical bottom concept and applying new dredging and surveying methods.

Dr Claire Chassagne

With a background in physics and mathematics, Claire specialised in colloid science. Her work focuses in particular on the use of electrokinetic techniques (electrophoresis, impedance spectroscopy, electroacoutics) to characterise colloidal suspensions and sand/mud layers. In her current position as assistant professor at the Delft University of Technology, she specialised in the physico-chemistry of clays. Over the years, she has demonstrated that colloid science and electrokinetics can provide useful information about the behaviour of clays and in particular explain their cohesive properties in given environmental conditions. At present this knowledge is parametrised in view of being integrated in large-scale sediment transport, deposition, consolidation and erosion models.



Han Winterwerp

Han is Professor Emeritus at Delft University of Technology, as the chair of Sediment Dynamics. He is an expert on morphodynamics and sediment transport, and Senior Specialist on cohesive sediment transport at Deltares. He is participating in and responsible for basic research and consultancy on sediment transport and morphological development in estuarine and coastal environments. He has executed many hydrodynamic, hydro-thermal and hydro-morphological studies all over the world as project leader and as expert in multi-disciplinary project teams, using the various mathematical models developed by Deltares. For many years, a major part of his work is dedicated to basic research into the behaviour and properties of cohesive sediments and the application of the results to estuarine studies. A part of this research is carried out during his part-time affiliation as associate professor with Delft University of Technology.

Tiedo Vellinga

Tiedo obtained his degree in Civil Engineering (coastal engineering) at the Delft University of Technology in 1979. For 38 years until 2017, he worked for the Port of Rotterdam Authority in the field of infrastructure- and water management. He was in the management team for the realisation of the port expansion Maasvlakte 2 as As Strategic Advisor Environmental Management. Since being appointed in 2010, he was Professor Ports and Waterways, Hydraulic Engineering Section, Civil Engineering and Geo-Sciences at Delft University of Technology, and continues as Professor Emeritus mainly doing research projects. He was a project manager for the development and the implementation of the Environmental Ship Index (ESI), an IAPH World Ports Climate Initiative. For PIANC's Environmental Commission, he has served as chairman of the PIANC/IAPH joint WG 150 on Sustainable Ports and is now co-chairman of WG 174 on Sustainability Reporting for Ports.

Safe navigation requires a new reliable and universally accepted criteria for the definition of the nautical bottom.

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