Current surveying strategies in ports with fluid mud layers

Kirichek, Alex ; Rutgers, Ronald; Nipius, Karoune; Ohle, Nino; Meijer, Herman; Smits, Joop

Publication date
2018

Document Version
Final published version

Published in
Proceedings of the Hydro18 Conference and Trade Exhibition

Current surveying strategies in ports with fluid mud layers

Dr. Alex Kirichek[1], Ronald Rutgers[2], Karoune Nipius[3], Nino Ohle[4], Herman Meijer[5] and Joop Smith[6]

[1] Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, TU Delft, Stevinweg 1, 2628 CN Delft, the Netherlands, O.Kirichek@tudelft.nl

[2] Department of Asset Management, Port of Rotterdam, Wilhelminakade 909, 3072 AP Rotterdam, the Netherlands, R.Rutgers@portofrotterdam.com

[3] Rijkswaterstaat PPO, Boompjes 200, 3011 XD Rotterdam, The Netherlands, Karoune.Nipius@rws.nl

[4] Hamburg Port Authority, Neuer Wandrahm 4, 20457 Hamburg, Germany, Nino.Ohle@hpa.hamburg.de

[5] Department of Data Management, Port of Rotterdam, Wilhelminakade 909, 3072 AP Rotterdam, the Netherlands, H.Meijer@portofrotterdam.com

[6] Department of Environmental Management, Port of Rotterdam, Wilhelminakade 909, 3072 AP Rotterdam, the Netherlands, JJ.Smits@portofrotterdam.com

Abstract

This paper provides a new insight into the surveying strategies that are used (or can be potentially used) in ports and waterways with fluid mud layers. The combination of acoustic methods with other methods, which are based on the density or on the shear strength measurements, is discussed. In particular, the measurements by the DensX, the Rheotune, the Graviprobe and the Rheocable are presented.

Due to the complexity of mud, the strength of mud exhibits a non-linear relationship with the density due to the thixotropic behaviour (deformation, history and time dependence). Therefore, sampling and measuring procedures, followed by data processing and interpretation of the measurements, have to be standardized by means of recognized practical protocols.

In-situ measuring tools are available for characterizing the behaviour of fluid mud. Based on our observations, we can conclude that the new surveying strategies can be potentially developed in the ports and waterways with fluid mud layers.

Introduction

The surveying strategies in ports and waterways with fluid mud layers are of primary importance for safeguarding navigation of maritime transport. These muddy waterways are typically monitored more regularly by surveying vessels providing up-to-date hydrographic data, from which the bathymetry charts are derived. In case the Nautical Guaranteed Depth is higher than the depth that is provided by the hydrographic data, the maintenance dredging has to be carried out in the area.

Typically, fluid mud can be described as a mixture of water, organic matter and mainly cohesive mineral sediment that is usually found in estuaries and in rivers with low-intensity currents. It has a weak strength that develops over time forming a structured bed of considerably higher rigidity. Fluid mud is in a transient state and will eventually settle and consolidate with time, unless mixing energy is added by means of maintenance dredging or natural currents.

The traditional echo sounding techniques typically fail to detect a sharp interface between the fluid mud and consolidated bed. The fluid mud layers can be of substantial thickness with small density gradients within the muddy layer. These density gradients make it challenging for detecting sufficient acoustic impedances within naturally deposited mud layers by means of traditional sounding. Therefore, other strategies have been developed for surveying in ports and waterways with fluid mud layers.

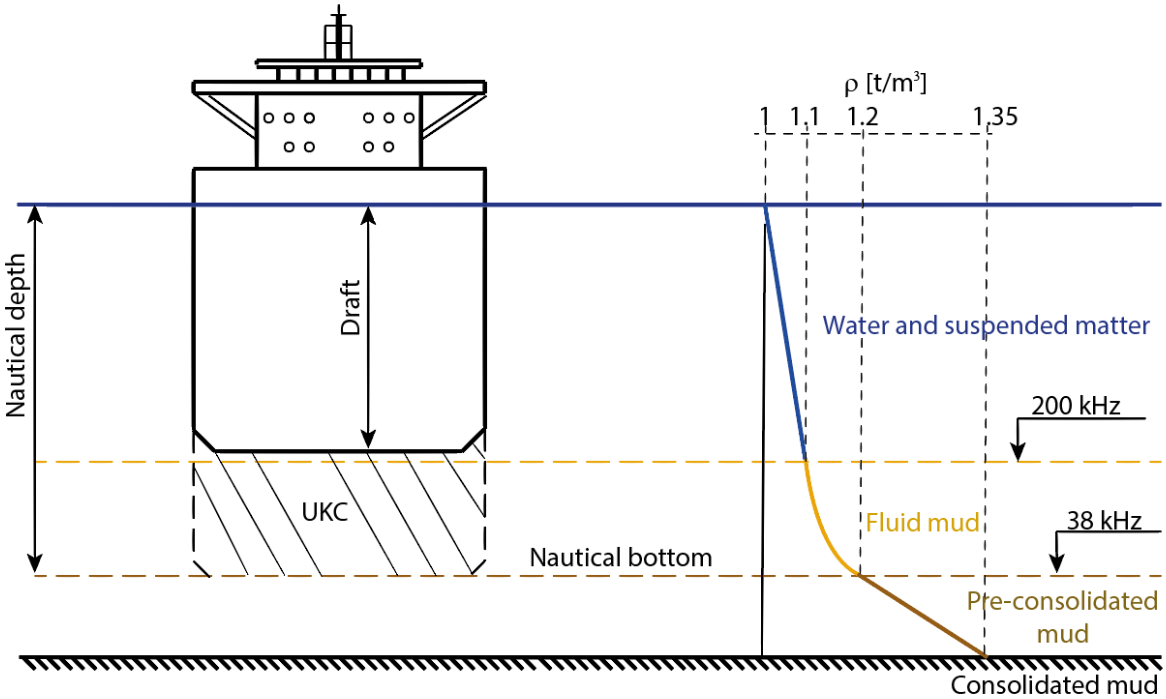

Figure 1. The nautical bottom concept at the Port of Rotterdam for the density limit of 1.2 t/m^3. From Kirichek et. al., 2018.

The PIANC maritime regulations have been developed to guarantee safe maritime navigation in ports and waterways with fluid mud layers. The PIANC Working Group 30 defined the nautical bottom as “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.” Accordingly, the nautical depth was defined as “the instantaneous and local vertical distance between the nautical bottom and the undisturbed free water surface.” The sketch of the concept is depicted in Figure 1. The application of these definitions requires insight in the physical characteristics of the mud that can characterize the effect of mud layers on the behaviour of a ship. Based on experimental research in the Port of Rotterdam in 1974, the density of 1.2 t/m^3 has been chosen in the harbour as the physical characteristic that defines the nautical bottom. In other harbours this density value is ranging approximately from 1.15 to 1.3 t/m^3 or the definition of nautical bottom is determined by high frequency echo sounding or rheological criteria (PIANC, 2014).

This paper provides an overview of existing surveying strategies and ongoing research activities in ports and waterways with fluid mud layers. In particular, we discuss our experience with the Graviprobe, the Rheotune and the DensX, which are owned by the Port of Rotterdam, the Hamburg Port Authority and Rijkswaterstaat, respectively. The Rheocable and duel-frequency echo sounding surveys are discussed in the paper for comparison.

Acoustic methods

Traditionally, the acoustic methods are used to determine the positioning of water-bed interface. The emitted acoustic pulse propagates through the water column and reflects back from the sharp water-bottom interface. The distance from the acoustic source to the reflecting surface is proportional to the 2-way travel time of acoustic waves in the water column. In muddy navigational areas, different frequencies of the emitted signal are employed. Figure 2 shows the measurements given by the duel-frequency echo-sounder in the area with fluid mud layers. 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 impedance contrast in recorded acoustic signal. 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.

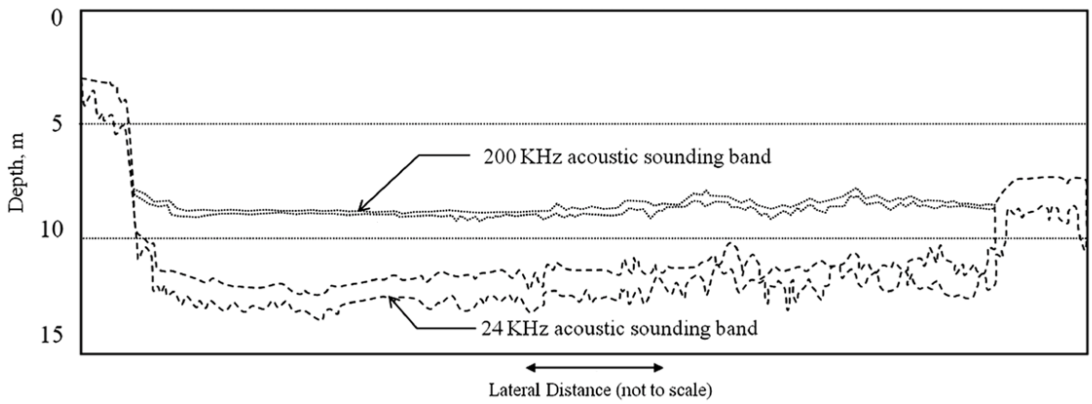

Figure 2: Dual-frequency echo sounding in a channel with fluid mud layers. From Alexander et al. (1997)

Eventually, it was recognized that low-frequency echo sounding surveys are not reliable in the areas with substantial fluid mud layers and, therefore, they are no longer normative (Kirby et al., 1980). This conclusion led to the development of alternative surveying strategies, which have been tested in different ports and waterways with fluid mud layers since then. The measuring tools are typically based on the physics of the scattered and transmitted gamma-radiation, acoustic and optical backscatter, or through mechanics. All the non-acoustical methods have common drawbacks. Firstly, the measuring principle of these methods is intrusive. The measuring tools have to be in a direct contact with fluid mud layers in order to characterize the fluid mud layer. Secondly, the spatial resolution of these tools is limited to a 1D vertical profile, thus, the interpolation between the measurements is necessary. In order to obtain a spatial variation, these methods are conventionally combined with the echo sounding.

DensX

Over the last decades, different density measuring tools have been developed and tested for mapping the depth level, where the density of mud can reach 1.2 t/m^3. At the Port of Rotterdam, the Navitracker and the D2Art were employed for measuring the density that can be used for the nautical bottom approach. Currently, the DensX is used by the Port of Rotterdam and Rijkswaterstaat. The density measurements of this tool are based on transmitted X-rays. This measuring principle provides a direct density measurements, thus this method can be considered as one of the most robust and reliable among other similar methods.

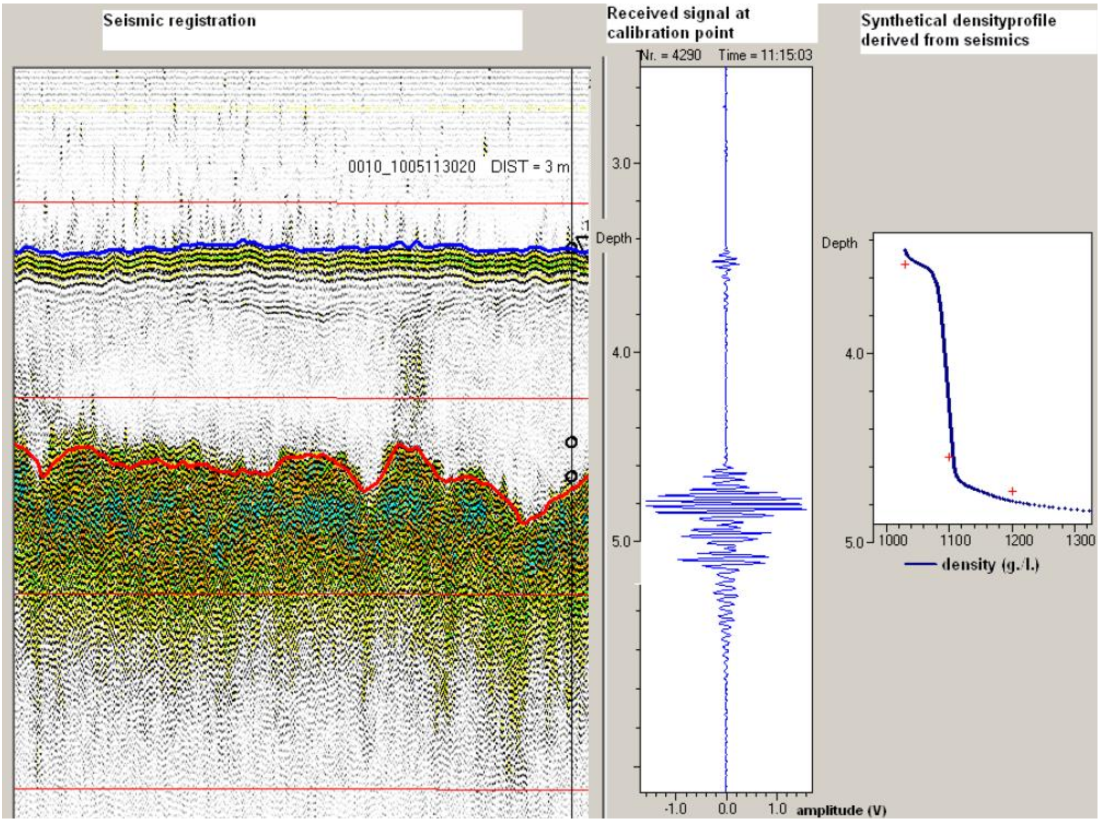

Figure 3: The density 'calibration' to the measured acoustic signal using SILAS From Diaferia et al. (2013)

Due to the nature of the DensX, its spatial resolution is limited to 1D vertical profiles. Therefore, the SILAS software is used to provide the Nautical Guaranteed Depth by matching the level of density 1.2 t/m^3. This level is derived from the DensX measurements and then linked to the acoustic data that is measured by the single beam echo sounder. In the SILAS software, the term 'calibration' refers to the mathematical relation that links the single-beam low frequency acoustic data to the density measurements for a certain location and for a chosen density level. The example is shown in Figure 3. A full explanation of the 'calibration' can be found in Diaferia et al. (2013).

Rheotune

The working principle of the Rheotune is 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 density, the yield stress and the viscosity of mud. For this purpose, an accurate calibration procedure, that requires laboratory density or rheological measurements, is necessary. This tuning fork can provide sufficiently accurate density and rheological recordings if it doesn't penetrate the consolidated (high concentration) layer of mud.

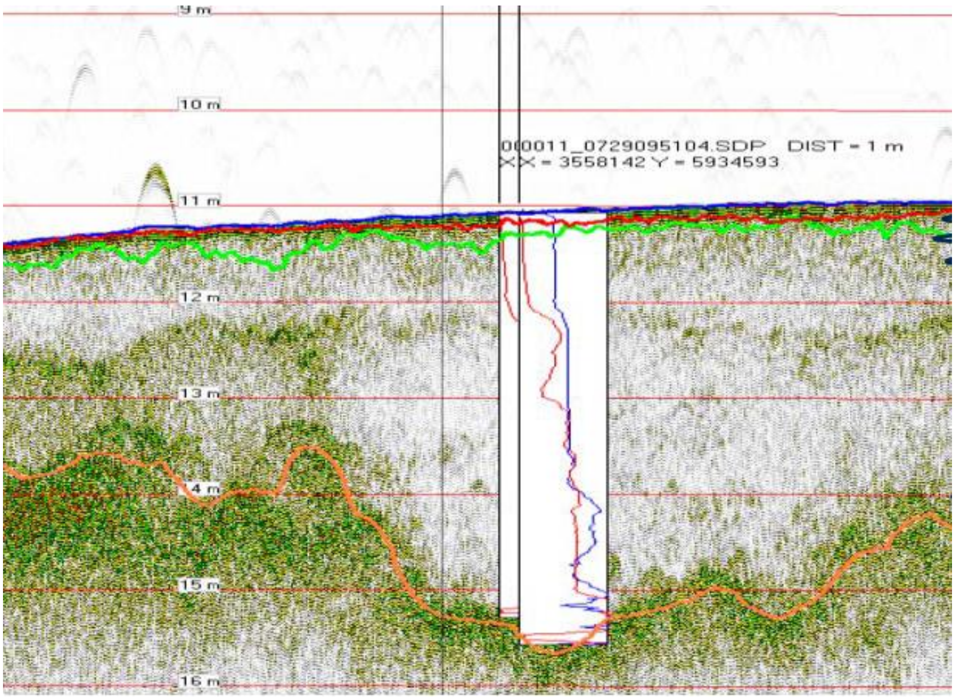

Figure 4: The Rheotune 'calibration' to the measured acoustics signal using SILAS in Hamburg.

The 1D profile measured by the Rheotune can be also extrapolated by using the SILAS software. An example of this extrapolation is shown in Figure 4.

Graviprobe

The physics of the Graviprobe is based on recording the penetrometer's acceleration/deceleration for getting the information about the cone penetration resistance. Using a calibration procedure, the shear strength 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 free falling cone penetrometer.

One of advantages of the Graviprobe 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. Another advantage is that the Graviprobe can also give an indication of the shear strength in consolidated layers of mud.

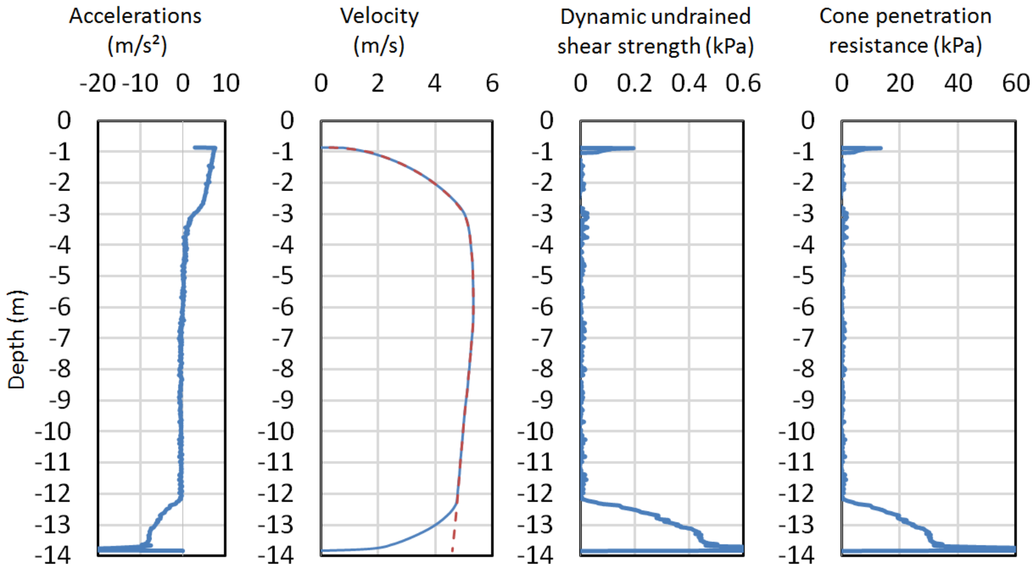

Figure 5: The date measured by the Graviprobe. The fluid mud layer is detected at the depth of -12 m

Rheocable

The Rheocable measurements differ from above mentioned methods by means of a line measurement principle. The depth level of the towed Rheocable is continuously measured during this survey. 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 (Druyts & Brabers, 2012). In the case of the Rheocable, the continuous measurements of the electrical resistivity value are 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 seabed measuring the hydrostatic pressure. The Rheocable survey was conducted after the water injection dredging at the Port of Rotterdam. Figure 6 shows the correlation of the high frequency (200 kHz) echo sounding with the Rheocable measurements in a channel with fluid mud layers. In this channel the fluid mud layer was intentionally created by means of the water injection dredging.

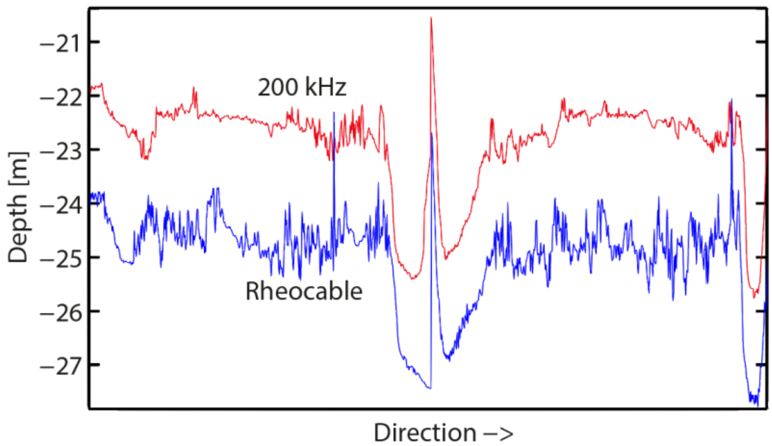

Figure 6: Correlation of the high frequency echo sounding (200 kHz) and Rheocable measurements after water injection dredging in the Port of Rotterdam.

Mud sampling and rheological analysis

The determining of the physical properties of mud can be done by sampling and subsequent analysis in the laboratory. Figure 7 shows different sampling methods. The sampling methods can be of importance since they can alter the desired properties of mud. In order to measure the strength-related (e.g. rheological) physical properties, the mud samples are suggested to be collected in a non-disturbed way as it is shown on the right panel of Figure 7. In this way, the mud properties measurements in the laboratory can be considered to be realistic and closer to the ones in-situ.

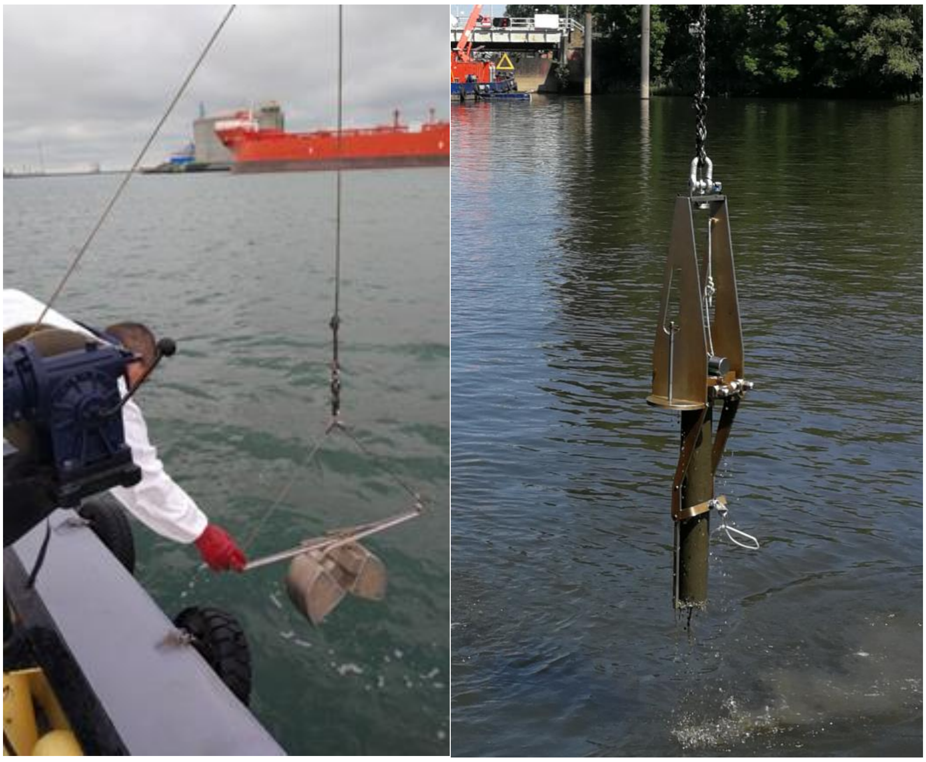

Figure 7: Disturbed (left) and undisturbed (right) sampling methods

Rheological properties can be 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, $\dot{\gamma}$, or shear stress, τ, that gives the flow curves (Figure 8a) for different mud samples. Typically, the yield stress, τ_y, is of interest for port authorities since it can be used as a criterion for the nautical bottom approach (e.g. in the Port of Emden). However, measuring the yield stress of mud is not trivial.

Currently, there are no protocols for measuring the yield stress of mud. The protocols have to be developed because of the following factors. Firstly, mud exhibits thixotropic behaviour (deformation, history and time dependence). Secondly, different geometries are currently utilized for rheology of mud. The most common geometries are the vane-type tests and rotational rheometers. So far, it is not clear what geometry is optimal for the rheological measurements on mud. Finally, there are several rheological methods that can be used to determine the yield stress of mud.

We compared four methods of these methods in order to determine the yield stress of samples from the Hamburg Port Authority and the Port of Rotterdam. These methods are:

a) Controlled shear rate;
b) Amplitude sweep;
c) Stress grow;
d) Controlled stress sweep.

The rotating cylindrical Rheometer was used to analyse the mud samples from two ports. The results are shown in Figure 8. It can be seen that the values of τ_y are consistent for all four methods. However, the sensitivity of these methods to various states of mud (e.g. fluid mud, consolidated mud) and organic content has to be analysed.

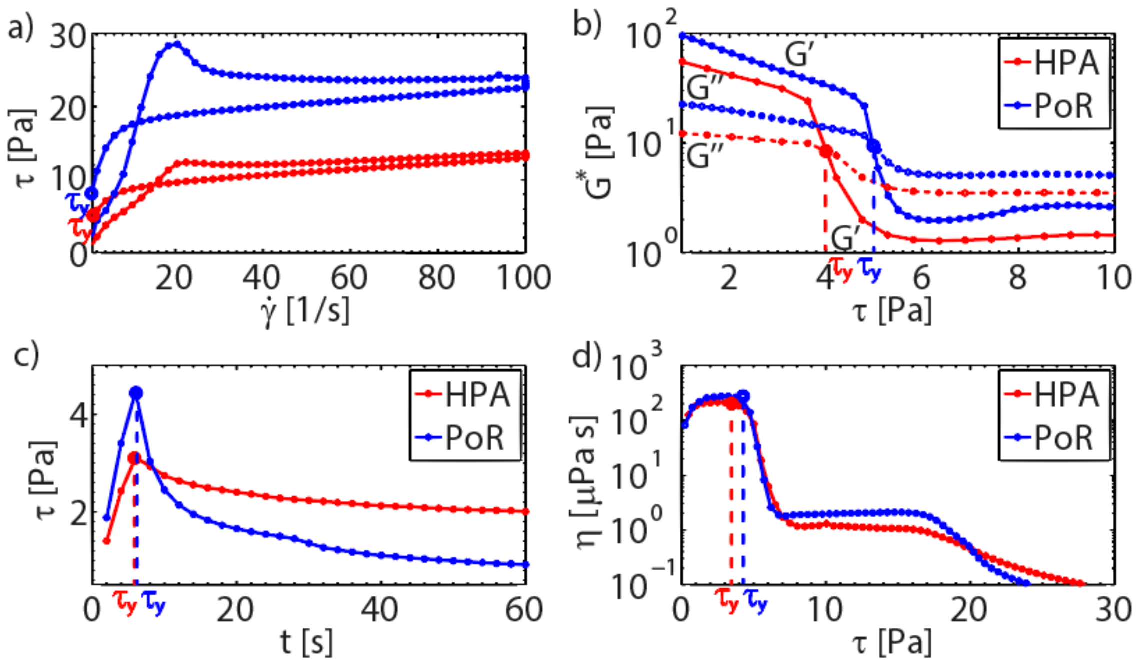

Figure 8: Rheological methods for determining the yield stress τ_y of fluid mud at the Port of Rotterdam and the Hamburg Port Authority. a) Thixotropy of mud measured by controlled shear rate experiment. b) Amplitude sweep experiment. c) Stress grow experiment. d) Controlled stress sweep experiment.

Due to the complexity of mud, a given density does not necessarily correspond to a unique yield stress of mud (see Figure 9). This implies that the relation between density and rheological parameters should be investigated in order to assess the best set of parameters required for defining a practical criteria for port authorities. This can be done by systematic practical experimental study in the laboratory.

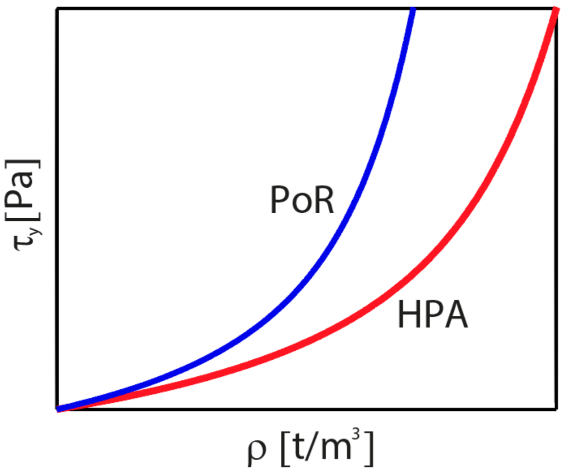

Figure 9: Non-linear relationship between the yield stress τ_y and the density ρ of mud

Conclusion

In-situ measuring tools are available for characterizing the behaviour of fluid mud. Based on our observations, it is concluded that new surveying methods can be developed resulting in novel cost effective maintenance strategies in the ports and waterways with fluid mud layers.

The existing in-situ methods have to be properly calibrated in the laboratory before their deployment. However, reliable laboratory protocols have to be developed for measuring rheological for standardization of the calibration procedure.

Hydro acoustic technologies allow time efficient scanning of large volumes of the water column. This advantage makes acoustic methods have a good potential for the non-invasive spatial characterization of channels with fluid mud layers.

References

Alexander, M. P., Teeter, A. M. & Banks, G. E. (1997). Development and verification of an intrusive hydrographic survey system for fluid mud channels. Tech. Rep. No. DRP-97-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Diaferia, G., Kruiver, P. P. & Vermaas, T. (2013). Validation study of SILAS. Final report. Deltares, 1207624-000-BGS-0006.

Druyts, M. & Brabers, P. (2012). Nautical depth sounding – the Rheocable survey method. International Hydrographic Review.

Kirichek, A., Chassagne, C., Winterwerp, H., Noordijk, A., Rutgers, R., Schot, C., Nipius, K. & Vellinga, T. (2018). How navigable are fluid mud layers? PIANC-World Congress Panama City, Panama.

Kirby, R., Parker, W.R. & van Oostrum, W.H.A. (1980). Definition of the seabed in navigational routes through mud areas. International Hydrographic Review, Monaco, LVII (1).

PIANC. (2014). Harbour Approach Channels - Design Guidelines, Report 121, PIANC, Brussels.