

Wolfgang Dasch and Rewert Wurpts

Isoviscs as Useful Parameters for Describing Sedimentation

Abstract

To enable better judgement of the sludge situation in the outer harbour of Emden, a series of measurements were carried out in 1999. In this connection both a newly developed procedure to determine the nautical horizon in this typical Fluid-Mud Region and the more conventional "classical" procedures to determine and describe the density/consistency-relationship and the yield stress of these layers were applied. The first results of this investigation are described here and methods will be discussed of how these "new" procedures could be combined with the "classical" ones.

Introduction

In order to determine the position of the nautical horizon, rheological data are parameters of crucial importance as far as the hydrological characteristics of the water to be evaluated are concerned. Ideally it would be most desirable to obtain complete rheological cuts through the area to be explored and this ideally by applying "remote sensing" methods.

The interpretation of these parameters used for the determination of a nautical horizon has been carried out in the harbour of Emden for eight years with great success; since 1999 the navigability of the Europoort in Rotterdam has been determined by the application of a very similar method.

To enable better judgement of the sludge situation in the outer harbour of Emden a series of measurements was carried out in 1999. In this connection both a newly developed procedure to determine the nautical horizon in this typical Fluid-Mud Region and the more conventional "classical" procedures to determine and describe the density/consistency-relationship and the yield-stress of these layers were applied.

Wolfgang Dasch graduated in organic chemistry in 1977 from the Christian Albrechts University, Kiel, Germany. He received his PhD in physical chemistry in 1982. After a period at the Institute for Applied Physics, department of Maritime Measurement Technology, he entered the industry for R&D of sensors. In 1992 he joined the Technical University of Hamburg-Harburg, department of Maritime Technology, working on the measurement of sedimentation and erosion processes. In 1997 he founded a consulting bureau working primarily on sensor R&D and rheological sediment characterisation with the Nautisonde system.



Wolfgang Dasch

Rewert W. Wurpts graduated in 1967 as a hydraulic engineer from the Technical University of Hannover and joined the dredging division of Ph. Holzmann. He worked on the development of new dredgers, as a site agent on dyke building works in Germany and later as the manager of dredging projects in various countries worldwide. In 1986 he went to work as dredging expert for the state government of Niedersachsen. In his present position there he is responsible for R&D in general and specifically for dredging and surveying for the port of Emden. He has been a member of the CEDA Board of Directors since 1992. In October 2000 he was appointed CEDA President.



Rewert Wurpts



Figure 1. The NAUTISONDE probe. Mechanical data: Length, 68 cm; Diameter, 12 cm ; Mass, 23 kg (in air).

IN-SITU INVESTIGATIONS

In order to determine the position of the nautical horizon, rheological data are parameters of crucial importance as far as the hydrological characteristics of the water to be evaluated are concerned (refs.1,2,3). Ideally it would be most desirable to obtain complete rheological cuts through the area to be explored and this ideally by applying "remote sensing" methods.

Amongst the quantities to be measured primarily are rheological parameters and here above all flow limits and viscosities (ref. 4). The interpretation of these parameters used for the determination of a nautical horizon has already been carried out in the harbour of Emden for eight years with great success (ref. 5); since 1999 the navigability of the Europoort in Rotterdam has been determined by the application of a very similar method.

Surprisingly enough, many harbour authorities today still use turbine meters with wingprobes as a laboratory method in order to determine the parameters of the shearing forces of sludge layers in the harbour. The undrained yield stress C_u thus obtained refers to all grounds from soft to stiff, but it does not refer to fluid

mud and/or sludges. Using wingprobes for the determination of Bingham media yield stress, there is a risk of obtaining errors of dimensions amounting to up to one power of ten (!). Up to now, however, the construction of profiling measuring sensors measuring yield stress has not been possible.

However, recently developed methods allow the application of profiling measurements of the medium viscosity in situ covering the entire water column (refs. 6,7,8). Kerckaert and in 1985 Malherbe showed how to apply viscosity data in order to determine the nautical depth (ref. 9). This, however, owing to the technological standards at that time, was proved by results stemming from laboratory experiments.

In connection with the present investigations, the Nautisonde system was used (refs.1,8). The profiles thus obtained permitted a visualisation in the form of "rheological cuts" through the area to be explored. The relationship to data obtained from measurement procedures determining the yield-stress will be described below.

Nautisonde system of measurement

By slowly lowering the Nautisonde probe (Figure 1) into the system water column – suspension – sediment a rheological profile is obtained. Figure 2 plots two of these rheological profiles at a position 1090 m from the Nesserland lock in the outer harbour of Emden at various times (i.e. various silting-up situations) within the campaign in 1999. The Nautisonde probe penetrates the sediment by itself due to a mass of approximately 23 kg.

Four important rheologic regions are subsequently measured:

- first, the water column;
- second, a layer of sediment suspension showing Newtonian behaviour whilst $\eta < 3 \text{ Pa} \cdot \text{s}$ (the so-called black water);
- third, the more-or-less slowly consolidating sediment layer which is mostly the object of dredging procedures (the typical fluid mud at about $3 \text{ Pa} \cdot \text{s} < \eta < 20 \text{ Pa} \cdot \text{s}$); and
- fourth, the strong consolidated (non-navigable) lower sediment layer usually not reached by dredging activities.

Taking the depth correlated to preset viscosity-limits of $\eta = 1, 2, 5$ and $10 \text{ Pa} \cdot \text{s}$ obtained by measuring the viscosity profiles, so-called viscosity-limits are gained. Connecting the said viscosity-limits of several rheological profiles leads to a two-dimensional > rheological cut < of the region of interest. Thus, the newly introduced "isoviscs" (lines of equal viscosity) are obtained, characterising the centerline of a harbour basin, for example.

Figures 3 and 4 respectively plot such a rheological

longitudinal cut in the shape of isoviscs running through the outer port of Emden at intervals of 3 months each, without dredging works having been carried out in this period. The cut is done seawards, following the direction of the main fairway starting at a distance of 100 m in front of the Nesserland lock. What can easily be observed is an increase in the thickness of layers consisting mainly of fluid mud of less than $5 \text{ Pa} \cdot \text{s}$ by more than 1 m at a distance of 500 m to 1200 m from the Nesserland lock. This area of the outer harbour, however, is decisive for the navigation of ocean-going vessels (e.g. car transporters).

What is also striking, is the fact that the layers detected by echo depth-sounding at frequencies of 15 kHz and 210 kHz do not change significantly. Thus there is a continuous increase of fluid-mud-like sediment within the so-called "critical echo depth sounding area". This non-trivial acoustic (and navigational, which is more important) situation is present when the plotted response of the high-frequency (mostly 100kHz...210kHz) echosounder shows different depth than the low-frequency sounder system (mostly 15kHz...30kHz) does.

Figure 5 plots the changes which the layers of sludge undergo in the area of the outer harbour of Emden within a longer period of time. At a distance of 700 m to 1400 m from the Nesserland lock, the mean values of a number of isoviscs, and of echo depth soundings respectively, were plotted. It is obvious that the thickness of the sludge body increased; in particular with reference to the softer sludges fraction, although echo depth-sounding only showed minimal changes and sometimes even a decrease was registered.

LABORATORY TESTS

For the first time, rheological measurement of samples extracted from the transition state near the nautical horizon was performed simultaneously with the Nautisonde-measuring system.

Thus it was possible to examine sediment samples from homogeneous layers of 1 m and more in thickness. As for the certainty of the samples taken, this is advantageous, especially with respect to the comparability of the results of the measurements in situ with those obtained in the laboratory. Comparing the viscosity data obtained by the Nautisonde system in-situ with the yield-stress data of laboratory tests (Haake Viscotester VT 550 with measuring body MV 1 P), a link with conventional methods for determining the nautical horizon is found.

Figure 6 plots the relationship between density and yield-stress. According to procedures used up to now,

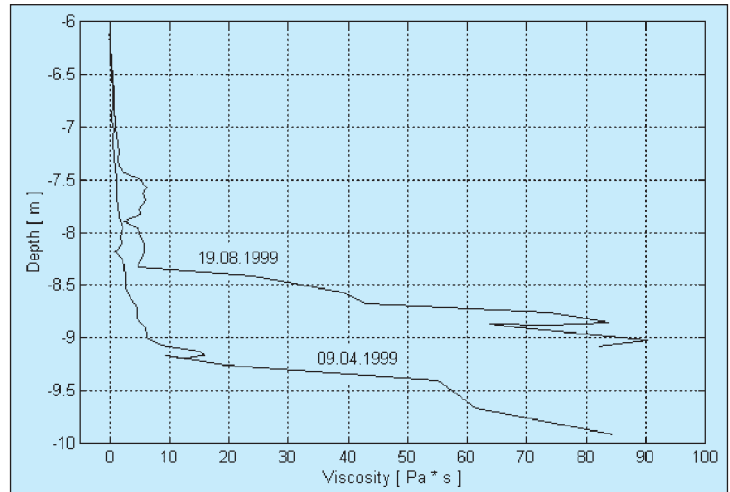


Figure 2. Rheological profiles taken at 1090 m from the Nesserland lock in the outer harbour of Emden during the 1999 campaign. No dredging activities in between.

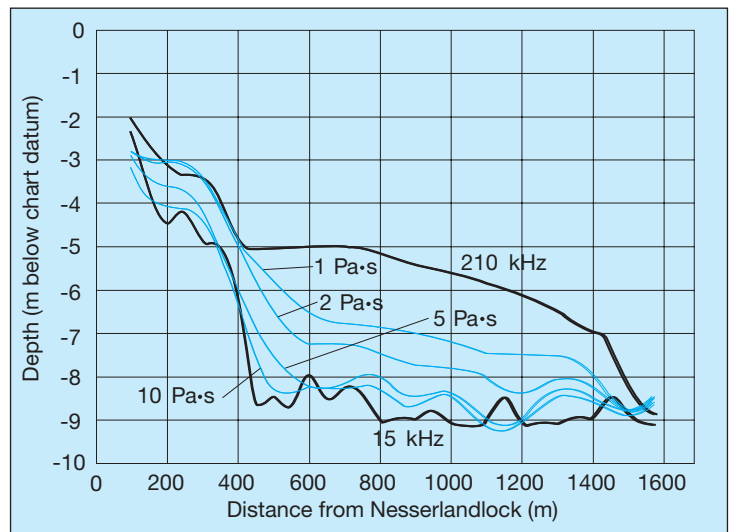


Figure 3. Isoviscs and echo soundings in the Outer Harbour of Emden on 9-4-1999.

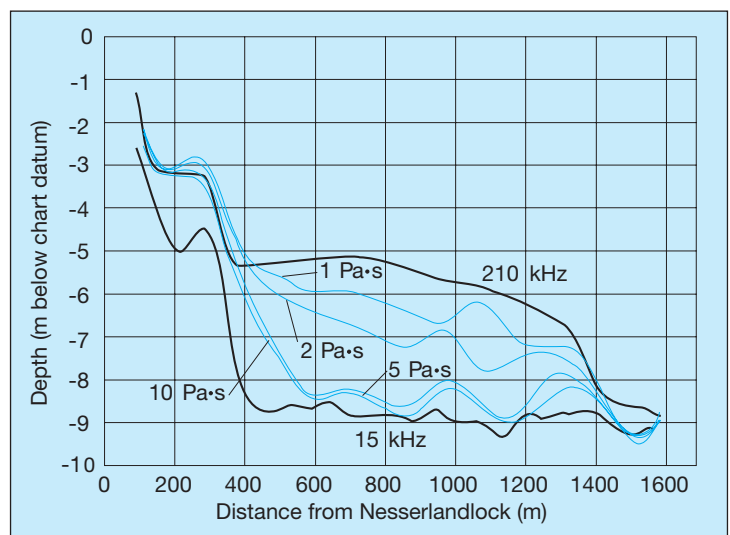


Figure 4. Isoviscs and echo sounding in the Outer Harbour of Emden on the 6-7-1999.

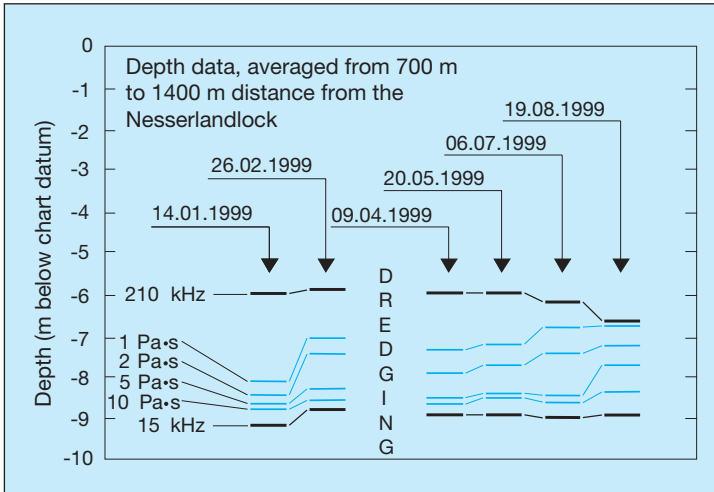
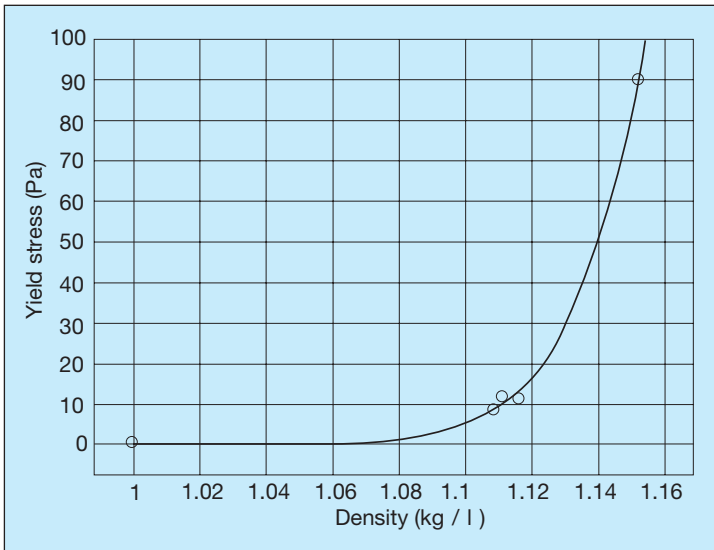


Figure 5. Change with time in the position of the isoviscs and the echo sounding levels in the outer harbour of Emden.

Figure 6. Density-yield-stress diagram for mud from the outer harbour of Emden.



assuming a yield-stress limit of 100 Pa, a corresponding density limit of 1.15 kg/l is obtained for the nautical horizon. The correlation obtained theoretically has been shown to be exponential (ref.10).

In analogy to this the functional correlation between the density and viscosity (data measured in situ by means of the Nautisonde system), the relation obtained was as plotted in Figure 7. This correlation, which is similar to that of Figure 4, already demonstrates that the viscosity measured in situ is an appropriate parameter for use as a basis for determining the nautical depth.

Figure 8 shows the relationship between viscosity and yield-stress. According to well-established procedures, the nautical horizon can be fixed here at a viscosity-

value of about 12 Pa · s. This value is in good agreement with the viscosity criterion for navigability of 8 Pa · s used by Allen M. Teeter during fluid-mud field investigations of the Gulfport and Calcasieu channels in 1992 (ref. 3). Here it is advantageous that the correlation between viscosity and yield-stress is almost proportional (rule-of-thumb: yield Stress [Pa] = ten times the viscosity [Pa · s]), whereas that between density and yield-stress – within the interval of interest – shows a rather steep curve, i.e. a very high sensitivity to the density data was found. This can lead to difficulties in connection with the determination of the yield-stress from density measurements. The radio-metric determination of density – being stochastic by nature – is not very precise, unless more powerful radiation sources are used.

The relationships depicted in Figures 6, 7 and 8 should give the connection to the old-fashioned methods investigating the navigable depth. All of these relationships may be strongly dependent on site, sand-content, season and so on. It is the aim of the application of the Nautisonde system to gather a parameter not dependent upon the cited parameters whilst determining the navigable depth. This is obtained because the rheological properties, mainly one of them – the viscosity – is the leading parameter to determine the nautical horizon (ref. 2).

SUMMARY

Similar to the application of the “classical” procedures, the situation as described in the Figures 2 through 4 does not require immediate dredging activities to achieve the required depths as published by the authorities. Monitoring the increasing sediment deposition inside the sludge-body layers helps to optimise the dredging activities, which is of benefit to quality assurance. Without difficulty, it is now possible to use the rheological shape in total for the cost-effective determination of nautical depths thus avoiding measurement procedures which harm the environment’ so, for instance, in a sludge body consisting of layers of up to 6 m in thickness and a yield-stress of 80 Pa using conventional procedures to measure the yield-stress limit of navigability, there would be no nautical horizon although the area certainly would not be navigable.

Conclusions

New measurement procedures should be developed which would enable us to obtain descriptions of the total sludge body in the form of evaluated yield-stress data of the respective depths explored, as well as the viscosity data, in order to obtain the necessary information concerning the navigability, in particular for fluid-mud areas. Using this new measurement method, this becomes possible.

In this context it is noteworthy that now one of the rheological key parameters in question is determined directly in situ instead of substitute parameters as, for example, is the case with density radioactive probe (g-Sonde) or the gradient of the acoustic impedance (echo-sounder).

Using the Nautisonde system it is possible to determine the in-situ navigable depth directly, without expensive laboratory-based investigations which first require the area sensitive correlation between density and yield stress. Using such highly efficient measurement procedures/systems, the required depth has been maintained in the outer harbour of Emden for more than 6 years without any sludge extraction whilst dredging. By now, first steps have been undertaken to verify the important connection between the rheological status of the site of interest and the navigability, depicted by the results of 1:1 in-situ ship passage trials, model and theoretical investigations. The results of this work will be presented in the future.

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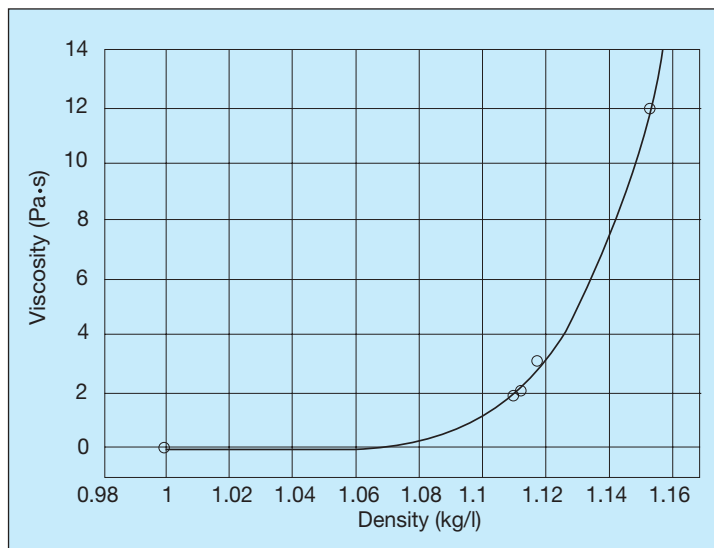
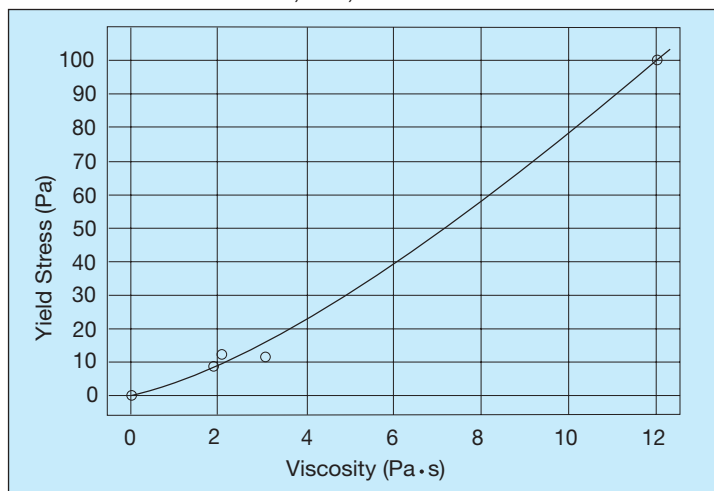


Figure 7. Sludge-layers in the outer harbour of Emden: the correlation between density and viscosity.

Figure 8. Sludge-layers in the outer harbour of Emden: the correlation between viscosity and yield stress.



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