NAVIGATION IN MUDDY AREAS - THE ZEEBRUGGE EXPERIENCE

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by

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I. INTRODUCTION

Defining the nautical depth in mud areas is confronted with both problems how to define this depth and how to measure it. The nautical depth in mud is not necesseraly the interface water-mud since the upper part of the mud-deposit is characterised by low shear-strength. This low shear strength of the upper mud layers is as important for navigation with negative keel-clearance as with restricted keel-clearance (less than 10% above mud-water interface).

Previous work and investigation tend to define the nautical bottom as a density level within the mud deposit. Some relevant work herein can be summarized in this introduction. Extensive investigations have been made in Bangkok and along the coast of Surinam where ships sail in mud with negative keel-clearance; in Bangkok a volume-mass value of 1.230 t/m^3 of mud is still considered as a safe value in which vessels can sail. On the basis of these investigations and a literature search it was found that densities up to 1.2 had only a slight influence on manoeuvrability (Kirby R., Parker (1979), van Bochove, Nederlof (1979)). Actually in Rotterdam-Europoort the choice of the so-called "nautical depth" has been put at the 1.2 t/m^3 density limit to be on the safe side (Nederlof (1981).

The question remains if similar density values are applicable in all cases to define nautical depth.

To give a clear definition of navigable depth in soft bed areas one has to take into account the deformation characteristics of the channel-bottom sediments (ref. Report of Working Group No. 3-a - PIANC Bulletin No. 43 - 1982/1983). Relying shear stresses, exerted by ships' hull, to the deformation characteristics of mud can be performed by the analysis of the rheological properties of the sediment (Malherbe et al., 1982).

This concept is also important in recommendation the survey techniques and the preceding study of the sediment behaviour under applied shearing stresses (i.e. stress-strain relation).

Research has also been done to develop measuring devices of rheological properties in situ (Migniot 1984, Granboulan et al. 1984).

Taking this into account, this article tries to give a better understanding of the mud behaviour and to deduce from it a definition of the nautical bottom, using the experience acquired in Zeebrugge.

The seabottom in the vicinity of Zeebrugge (see fig. 1) and its entrance channels consists mainly of natural marine mud deposits. Some sand deposits do also occur and may mix with the mud sediments resulting in the presence of a broad range of sand-mud mixture-sediments.

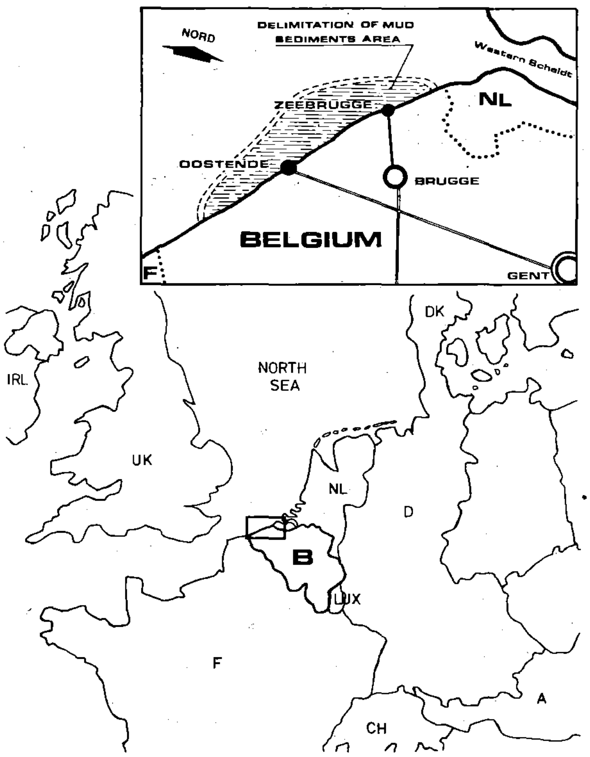

Figure 1
Zeebrugge in the North Sea.
Zeebrugge en Mer du Nord.

II. NAVIGATION RELATED TO THE PROPERTIES OF MUD

Navigation and manoeuvring with restricted keel-clearance will influence the manoeuvring characteristics mainly caused by underflow; navigating and manoeuvring with restricted keel-clearance above loose mud deposits will additionally be influenced by the deformation characteristics of the bed (Sellmeijer, van Oortmerssen, 1983). The mud bed will be deformed according to the applied shear stress and to the rheological characteristics of the mud. From model results with ships sailing with restricted keel-clearance it appeared that in some cases internal waves may form at the water-mud interface (van Bochove, Nederlof (1979); those internal waves enhance the total wave making resistance of the ship and affect in this way the manoeuvring behaviour of the ship. The formation of those waves is, of course, completely dependent of the deformation characteristics of the considered mud.

In this way it is possible to deduce theoretically, for instance, the absorbed energy by shear stress when navigating at 0% keel-clearance above a loose mud bottom (Malherbe et al. 1982); some results of these calculations are illustrated on figure 2.

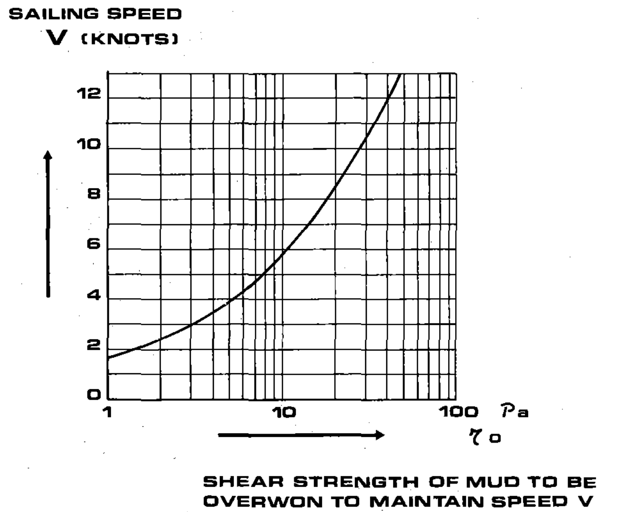

Figure 2
Navigation above mud at 0% keel-clearance.
Navigation sur fonds de vase à pied de pilote de 0%.

As mentioned clearly in the Report of the Working Group no. 3-a Navigation in Muddy Areas (PIANC Bulletin no. 43 - 1982/1983) the rheological characteristics of mud are mainly determined by :

a) the specific gravity or concentration of dry-sediment
b) the composition and the sand-content of the mud
c) the physico-chemical properties of the mud considered.

III. RHEOLOGICAL PROPERTIES OF MUD

The two most important rheological characteristics of mud sediments to define deformation characteristics (stress-strain relation) and shear strength are (see fig. 3) :

a) the initial rigidity τ_Y (low shear rate or deformation)
b) the dynamic viscosity η (high shear rate or deformation).

Both characteristics can be measured in a laboratorium with a coaxial viscosimeter. The

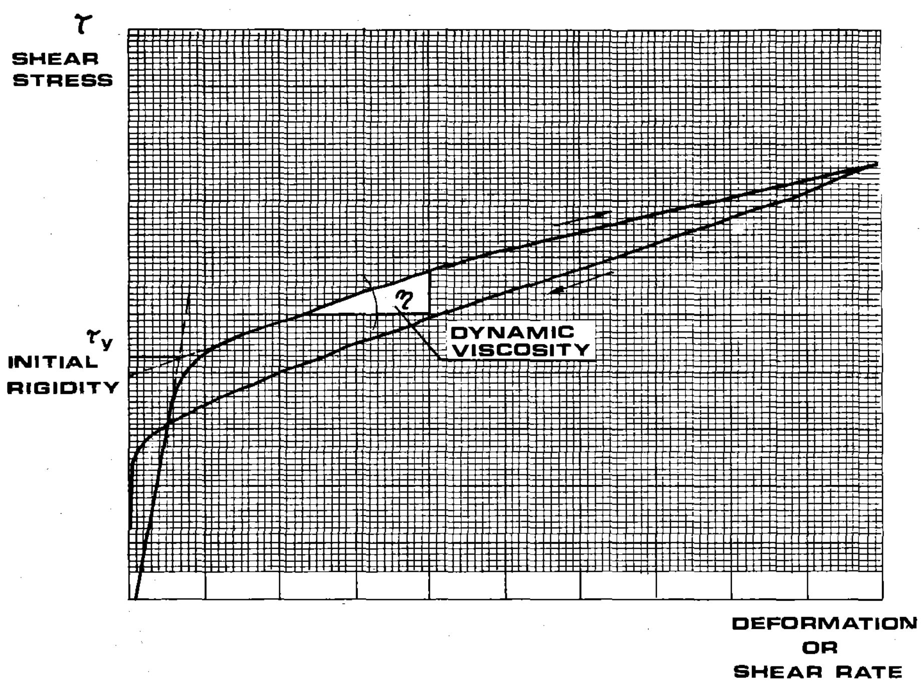

Figure 3
Rheogram of mud.
Analyse rhéologique de vase.

figures 4 and 5 express the relations between τ Y, η, concentration Ts and mud content S (% < 63 micron).

One can deduce from these relationships that two distinct mud behaviours do occur :

a) a first behaviour domain where initial rigidity τ Y and dynamic viscosity η are less dependent of the concentration (first part of curves - small slope)

b) a second behaviour domain where initial rigidity τ Y and dynamic viscosity η are strongly dependent of the concentration (second part of the curves; steep slope).

In every case the influence of sand content (100% - S) on the rheological properties is obvious : the higher the sand content in the mud, the lower the initial rigidity and the dynamic viscosity will be at a same concentration value.

IV. THE DEFINITION OF NAVIGABLE DEPTH BASED UPON RHEOLOGICAL PROPERTIES

Since harbour authorities want to indicate a navigable depth with a certain degree of safety, this depth has to indicate the minimum level where the medium in which navigation occurs changes drastically its behaviour. For sand bottoms it will be clear that the navigable depth will be defined by the interface water-sand. For mud-bottoms, however, such interface exists also but the significant change in stress-strain behaviour occurs within the mud deposit itself (see figures 4 and 5). From the point of view of navigation and manoeuvring those two rheologic behaviour domains indicate the validity of following interpretation :

a) first behaviour domain where navigation and manoeuvring is not or poorly affected by the concentration of the deposit.

b) second behaviour domain where navigation and manoeuvring is strongly affected by the concentration of the deposit.

The rheologic behaviour change-over is not sharply defined. Using an intermediate value between those 2 behaviour domains to define the nautical bottom will include a certain margin of safety, since the second behaviour domain of affected navigation has not yet been reached.

So the determination of the behaviour change-over is done with the help of the point on the curves where the minimum radius of curvature occurs.

In this way, it is possible to determine for Zeebrugge harbour mud, the nautical depth values in terms of volume-mass (abscis) from the experimental rheological relations shown in the figures 4 and 5.

The nautical bottom values expressed in volume-mass are summarized in table 1 hereafter for the considered mud contents :

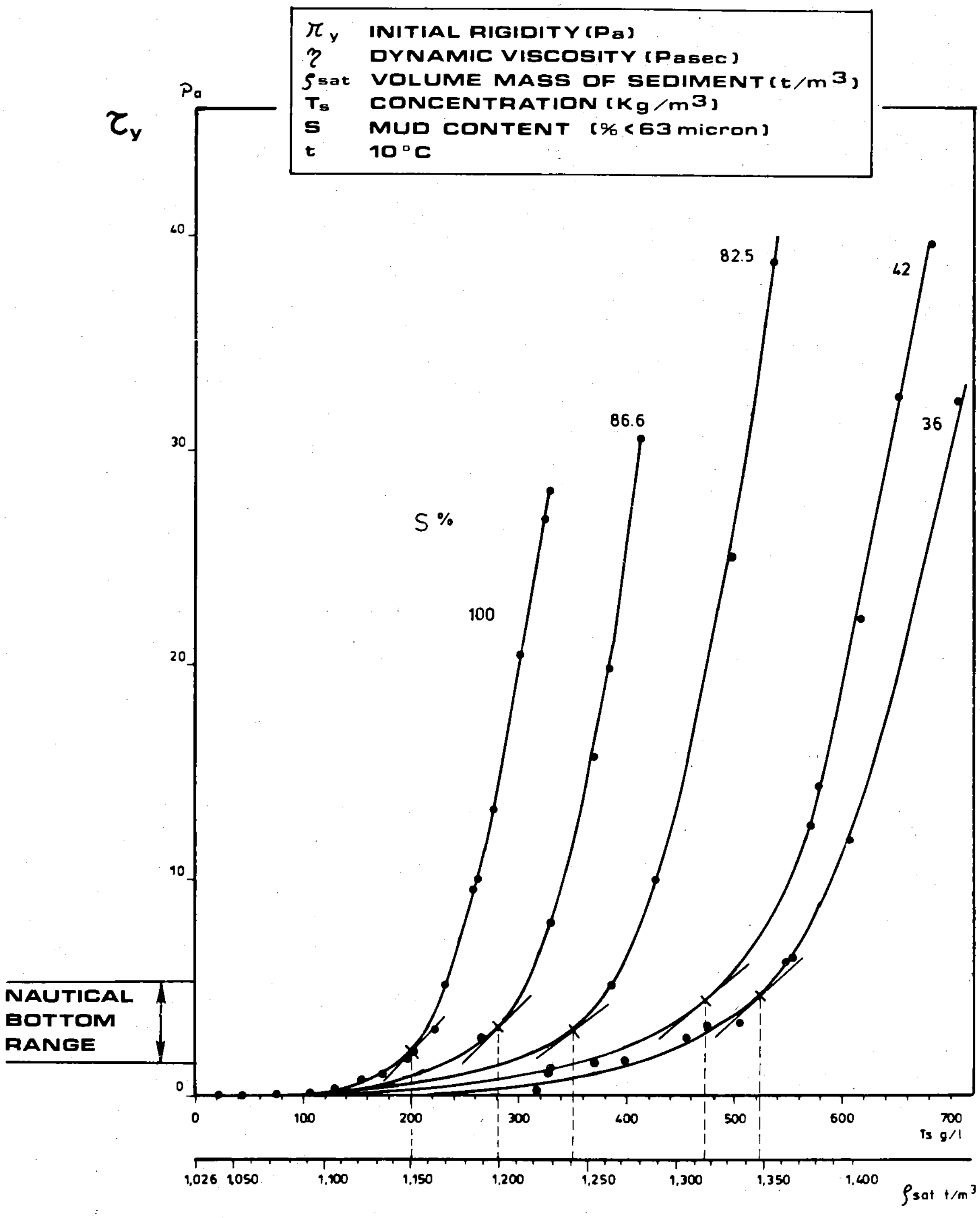

Figure 4 :

Initial rigidity τ Y in function of concentration and mud composition (Zeebrugge).

Rigidité initiale τ Y en fonction de la concentration et de la composition.

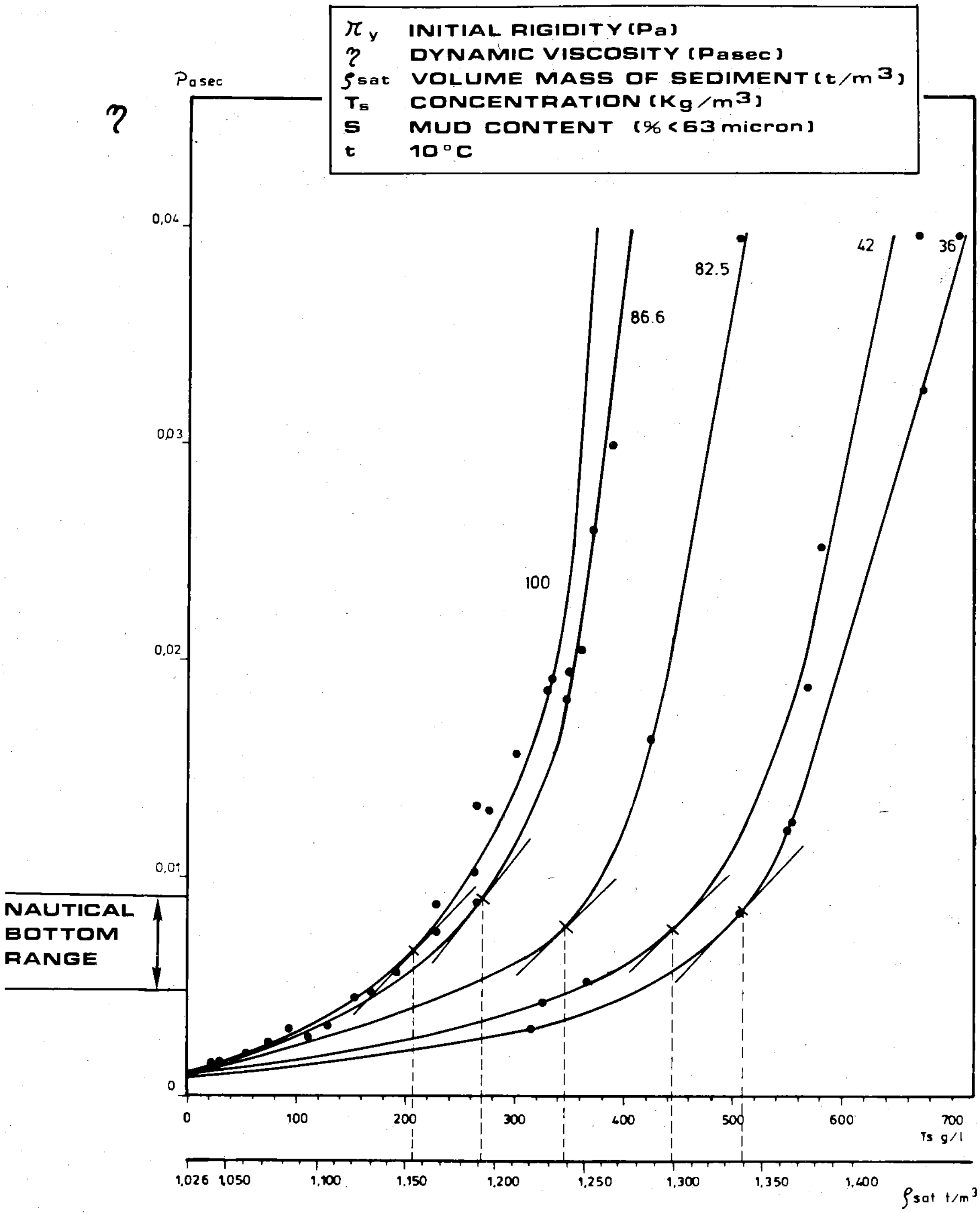

Figure 5 :

Dynamic viscosity η in function of concentration and mud composition (Zeebrugge).

Viscosité dynamique η en fonction de la concentration et de la composition (Zeebrugge).

Mud content (< 63 micron) S (%)	Nautical bottom volume mass T/m^3		
	determined with initial rigidity	determined with dynamic viscosity	mean values
100	1.151	1.153	1.152
86.6	1.199	1.194	1.197
82.5	1.242	1.238	1.240
42	1.316	1.301	1.309
36	1.347	1.340	1.344

TABLE 1 : Deduced nautical bottom volume-mass for different mud compositions (Zeebrugge mud).
Masses spécifiques de fond nautique pour différentes compositions de vase (vase de Zeebrugge).

From the results in table 1 it appears that the behaviour change-over in mud occurs at approximately the same volume-mass value (for a given sand/mud proportion) independently for low shear rates (initial rigidity) or for high shear rates (dynamic viscosity).

Rheological analyses provide only relative values of shear stresses since the values are dependent upon the system being used. Volume-mass measurements are absolute and provide in this way an exact link between relative and absolute measurements. On the other hand the chage-over rheological value (initial rigidity or dynamic viscosity) seems to lie within a small range and being poorly affected by the mud composition S (% < 63 micron) and the mud concentration (see figures 4 and 5).

Table 1 shows that the nautical bottom criterion, expressed as a volume-mass of the sediment, varies in a broad range from 1.151 t/m^3 to 1.347 t/m^3 for the tested mud compositions; using a single volume-mass value in all cases is thus a risky operation in Zeebrugge.

A test-program using small scale model experiments and full scale tests in the field, has been set up to evaluate in which way the inclusion of a mud layer in the keel-clearance of a sailing ship affects the manoeuvring characteristics. These experiments will ascertain the similarity between the change-over in rheologic and manoeuvring characteristics. As a part of the whole program, these investigations must lead to the definition of the nautical depth in terms of both mud characteristics and manoeuvring behaviour.

V. MEASURING THE NAUTICAL DEPTH IN THE FIELD

From the definition of a nautical bottom as a rheological change-over level and from the considerations mentioned above it will be clear that a "nautical depth measuring device" should measure simultaneously volume mass and a rheological property (or a characteristic proportional to one or two rheological properties) to give maximum information about the mud considered.

Volume-mass measuring systems (like radio-active gauges) can provide all absolute values to draw the density profile within the mud (fig. 6).

On figure 6 these density profiles have been related to the recorded echoes from a double frequency echosounder; the first echo defines well the sharp interface water-mud while the second echo does not seem to correspond to a specific density value (see figure 6). Experience with acoustic measuring systems shows that reflections in mud depend upon a lot of parameters affecting the acoustic impedance (gas bubbles, sandy-horizons,...).

On the other hand rheological measuring devices allow the localization of the nautical depth and the combination of both volume-mass and rheological properties give all further information about the absolute values to be detected.

It seems indeed that measuring rheological properties is always relative; defining the navigable depth in the way of a mud behaviour change-over does not care about the rheological measuring system as long as these measurements can be calibrated to volume mass and sand/mud proportion. Of course, both measurements of volume mass and rheological properties have to be reproducible.

VI. CONCLUSIONS

1. Navigation with restricted keel-clearance in mud areas requires a better definition of the nautical depth than just by echo-sounding.

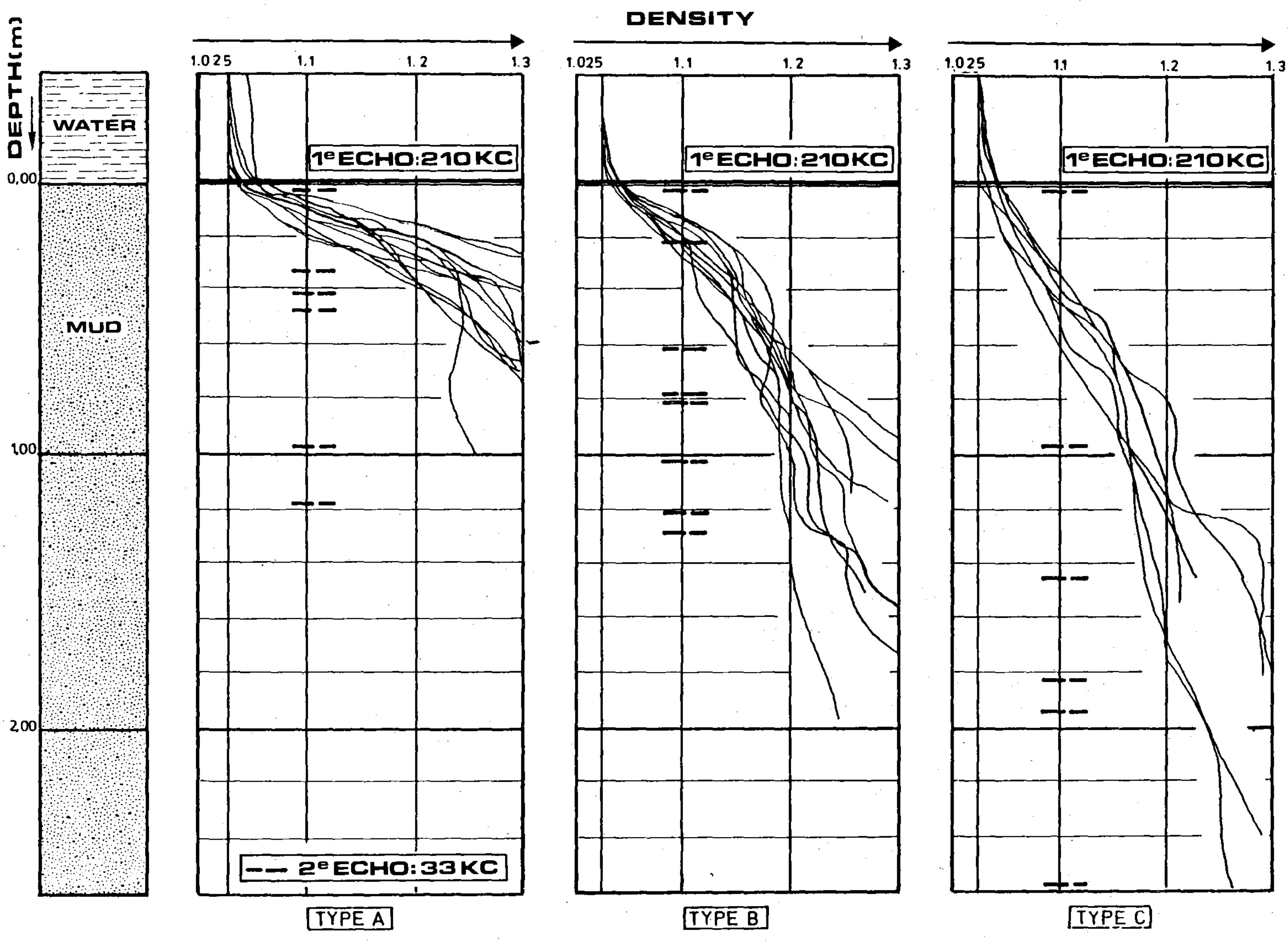

Figure 6 :
Density profiles racorded in mud of Zeebrugge.
Profils de densité enregistrés dans la vase de Zeebrugge.

The definition of the nautical depth has to take into account both volume-mass and deformation behaviour of the mud.

2. Rheological or deformation behaviour of mud is determined by :

   a) the volume-mass of the sediment
   b) the composition (sand/mud propertion)
   c) the physico-chemical properties of the mud.

Nautical depth within the mud deposit can be defined as the level where the mud changes drastically its rheological behaviour. This behaviour change-over occurs at approximately the same volume-mass value for both low and high shear rates (figs. 4 and 5).

3. Nautical depth values defined by rheological properties occur within a small range of initial rigidity or dynamic viscosity, independently of sand/mud proportions, and density or concentration.

4. As the behaviour change-over level is not sharply defined such definition of nautical bottom does include a margin of safety : the mud is not yet strongly dependent of the concentration value (second behaviour domain).

5. Recent work has led to a lot of instruments capable of measuring either volume-mass or a

rheological value.

As rheological measurements are dependent upon the system being used, nautical depth sensors should rather measure both volume-mass (absolute values) and rheological properties (relative values) to get maximum information about the considered mud.

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RESUME

LA NAVIGATION DANS LES CHENAUX ENVASES
LES EXPERIENCES ACQUISES A ZEEBRUGGE

1. Introduction

La définition de la profondeur nautique dans des chenaux et des zones de navigation concernées par des envasements, n'est pas aisée vu la très faible résistance au cisaillement des couches supérieures de vase fluide.

La plupart des études effectuées dans différents ports du monde tendent à définir le fond nautique par un niveau de densité au sein même du dépôt de vase. Suivant ces résultats, ce niveau du fond nautique oscillerait autour d'une densité de 1,2 à 1,25.

Il est clair à présent qu'une définition du fond nautique devra tenir compte des relations contrainte-déformation des dépôts du fond.

Peu d'études ont été effectuées pour tâcher de définir ce fond nautique à partir de la densité et des propriétés rhéologiques de la vase. Cet article présente, pour le cas de Zeebrugge, une partie des résultats d'étude menée dans cette optique.

2. La navigation en relation avec les propriétés de la vase

Les tensions de cisaillement excercées par une coque de bateau sur un fond de vase, même à pied de pilote positif, vont y provoquer des déformations qui dépendront des propriétés rhéologiques (fig. 2). Cette notion est importante entre autre lors de la modélisation de ces processus.

3. Propriétés rhéologiques de la vase

Rigididé et viscosité dynamique de la vase sont les deux paramètres les plus importants qui décrivent le comportement rhéologique d'une vase.

Pour la vase de Zeebrugge les relations entre ces deux paramètres et la densité et la teneur en sable (100% - S) sont illustrées sur les figures 4 et 5. L'aspect de ces courbes indique clairement deux domaines rhéologiques distincts :

1) le premier domaine où la viscosité et la rigidité sont peu dépendantes de la densité.

2) le second domaine où la viscosité et la rigidité dépendent fortement de la densité.

Ce changement de comportement rhéologique se situe à différentes densités de la vase suivant la composition de celle-ci.

4. La définition du fond nautique à l'aide des propriété rhéologiques

Ce changement brusque de comportement rhéologique signifie un niveau au-dessus duquel la vase se comporte plutôt comme un fond rigide.

En ce qui concerne les deux domaines rhéologiques de la vase par rapport à la navigation on peut dire que :

1) dans le premier domaine la navigation ne sera pas ou peu influencée par la concentration du dépôt

2) dans le second domaine la navigation sera fortement influencée par la concentration du dépôt.

Ainsi il serait possible de définir ce fond nautique par le niveau où se situe ce changement de comportement. Puisque ce changement rhéologique n'est pas brusque, cette définition du fond nautique implique une marge de sécurité, la vase se trouvant dans un état intermédiaire entre les deux domaines rhéologiques. Les expériences en modèle et en nature serviront à justifier ces considérations.

5. La mesure du fond nautique

De ce qui précède, il est à conseiller que, pour définir le fond nautique dans les vases fluides, il s'agira de mesurer simultanément la densité et une propriété rhéologique.

Ceci est important dans la mesure où les mesures rhéologiques sont relatives tandis que les mesures de masse spécifique ou de densité sont absolues.
