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S. II - 1

A HYDRO-METEO SYSTEM FOR MONITORING SHIPPING TRAFFIC IN NARROW CHANNELS IN RELATION WITH THE PROBLEM OF THE NAUTICAL BOTTOM IN MUDDY AREAS

by

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1. INTRODUCTION

This paper presents two related study programs, organized by the Coastal Services of the Belgian Ministry of Public Works, to assure safe navigation and optimal use of the available depth in the approach channels before the Belgian coast to the ports of Antwerp and Zeebrugge :

a. The study of a hydro-meteo system for monitoring shipping traffic, carried out by the Coastal Service in collaboration with the T.V. Haecon-C.E.I.

b. The study of the nautical bottom in muddy areas, subdivided in two parts :

- in situ measurements of the physico-chemical characteristics of the mud layer and ship manoeuvrability above it, carried out by the Coastal Service in collaboration with the N.V. Haecon and the T.V. Optimalisatie-Studie;
- model tests to evaluate the total effect of a mud layer on a ship's performance, carried out by the Hydraulics Research Laboratory, with the scientific support of the Office of Naval Architecture.

2. A HYDRO-METEO SYSTEM FOR MONITORING SHIPPING TRAFFIC

AIM OF THE PROGRAM

Before the Belgian coast lie important shipping channels which lead to the port of Zeebrugge and to the Western Scheldt, which is the access-river to the port of Antwerp (figure 2.1).

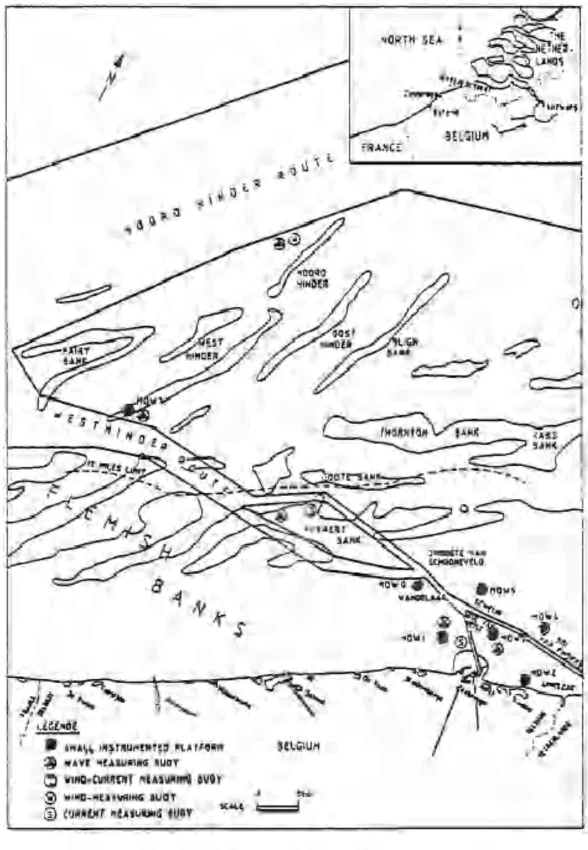

Figure 2.1. : Existing and planned instrumentation

The bottom of these channels is mainly constituted of sand and mud and, in part of the channels, important maintenance dredging is necessary to guarantee a sufficient depth. In the coming years, the channel leading to the Western Scheldt will be deepened so as to accommodate ships with a draught up to 48 feet. Dredging will be kept to a strict minimum and since the tidal range before the Belgian coast is of the order of four meters, with a period of about twelve hours, these ships will have to use « tidal gates » to get to the port of Antwerp in one or two tides.

However, under certain conditions of low tide and swell, it is possible that the available depth in certain parts (the parts called « Scheur - Wielingen ») of this channel will force deep draught vessels to enter the channel with a narrower « tidal gate », or to wait until tidal and wave conditions are more propitious.

In order to always guarantee a safe passage to the port of Antwerp and to reduce « waiting-times » of ships to a strict minimum, so as to make an optimal use of the available depths, the Belgian Government has decided to install a so-called « hydro-meteo system » for the shipping channel leading to the Western Scheldt and to the port of Antwerp. The aim of this « hydro-meteo system » is to provide the nautical authorities with accurate data about actual and expected water-level and wave climate in this channel, in order to assist in the admission policy of deep draught vessels to this channel.

THE EXISTING MEASURING NETWORK ON THE BELGIAN NORTH SEA

The decision to install a hydro-meteo system for the important shipping channel before the Belgian coast leading to the Western Scheldt was the logical conclusion of the efforts of the Belgian Ministry of Public Works over a number of years to install a network of sensors to measure oceanographic and meteorological parameters on the Belgian North Sea and along the Belgian coast.

This network was called « Meetnet Vlaamse Banken » (Measuring Network Flemish Banks), referring to a complex of sand-banks before the Belgian coast.

The installation of this network was necessary for a number of reasons :

a. The Ministry of Public Works is responsible for storm-flood warning.

b. To monitor the activities of the Ministry of Public Works on the Belgian North Sea : dredging works, hydrographic activities, coastal defence works, harbour building, etc.

c. To create a databank for the Belgian Continental Shelf.

The measuring network has been growing over a number of years and comprises now (beginning of 1989) the following instrumentation :

- six small platforms in the North Sea equipped with sensors for measuring meteorological and oceanographic parameters (see photo) ; these platforms have their own energy provision system and all data are sent on-line to the Coastal Service;
- a number of wave-measuring buoys which give on-line information about wave-height and one special buoy which also gives on-line information about wave-direction;
- telemetric water-level gauges in the harbours of Nieuwpoort, Ostend and Zeebrugge;
- a telemetric current meter at the entrance of the Port of Zeebrugge;
- a meteo park at Zeebrugge.

In the near future it is planned to extend the instrumentation on the North Sea; in table 2.1., the list is given of the existing and the planned instrumentation (see also fig.2.1.).

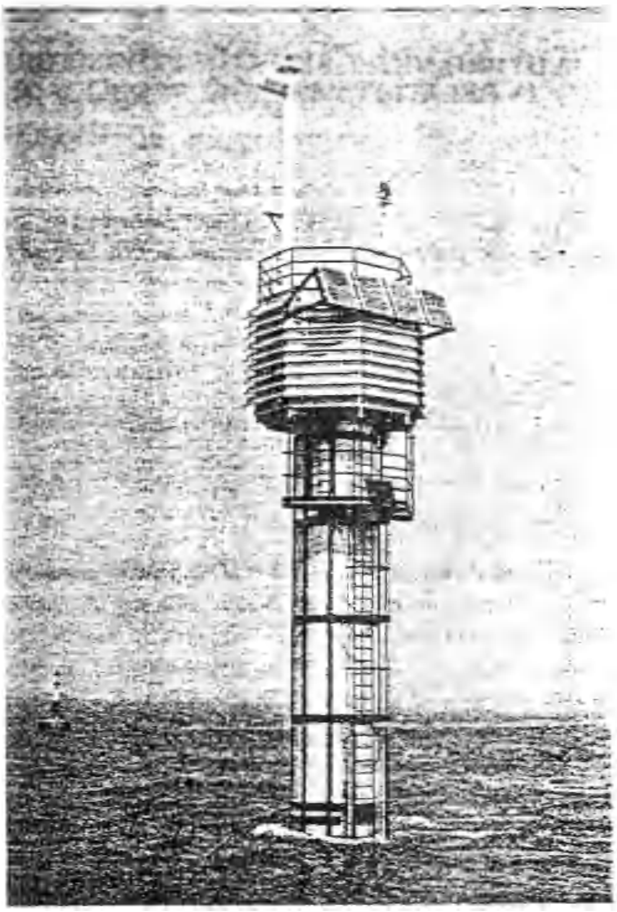

Fig. 2. : Small measuring platform

The platforms are necessary for an accurate measurement of the water-level ; they were however also instrumented with sensors to measure wave-height, wind, current, water-temperature, barometric pressure, etc. The six existing platforms were hydrostatically levelled so as to obtain a levelling that would be as accurate as possible. As can be seen on figure 2.1., the location of the instrumentation has been chosen so as to « cover » the shipping channels leading to Zeebrugge and to the Western Scheldt.

THE OCEANOGRAPHIC-METEOROLOGICAL STATION AT THE HARBOUR OF ZEEBRUGGE

After processing, all incoming data from the Belgian network on the North Sea are sent to the oceanographic-meteorological station of the Ministry of Public Works located in Zeebrugge.

TABLE 2.1. Existing and planned instrumentation on the Belgian North Sea

LOCATION	PLATFORM WITH HYDRO-METEO SENSORS	TELEMETRIC WAVE-BUOY	TELEMETRIC BUOY FOR CURRENT AND/OR WIND MEASUREMENT
Wandelaar	x (MOW0)		
A2-buoy	x (MOW1)	x (1)	
Appelzak	x (MOW2)		
Bol van Heist	x (MOW3)	x (2)	
Bol van Knokke	x (MOW4)		
Droogte van Schooneveld	x (MOW5)		
Akkaertbank		x (1)	P (current and wind)
Westhinder	P (MOW7)	x (1)	
Noordhinder		P (2)	P (only wind)
Entrance port of Zeebrugge			x (only current)

x : already present
P : planned
(1) : only wave-height
(2) : wave-height and wave-direction

This station is already in service since a number of years and is well equipped for meteorological purposes. It can capture satellite pictures, the weather charts from the most important European Weather Centers and there is a link with the international GTS-network for meteo-information so that it can use the results of the weather models of the European Weather Center at Reading (United Kingdom).

At the time of writing this paper, studies were under way to link this station up with the Dutch and British measuring networks on the North Sea, in order to make also the hydro-meteo parameters from the more northern regions of the North Sea available on-line to this station.

The oceanographic-meteorological station has sophisticated mathematical models at its disposal, as well as more simple « hand methods » for tidal and wave prediction. The task of the station, managed by specialised personnel, is to process all incoming data and to translate them into forecasts about meteorological conditions, wave climate and water-level on the Belgian Continental Shelf. These forecasts are not only used by the Belgian Ministry of Public Works but also by harbour authorities, shipping agencies, etc.

THE BELGIAN HYDRO-METEO SYSTEM FOR THE SHIPPING CHANNEL TO THE WESTERN SCHELDT

This hydro-meteo system is, at the time of writing of this paper being built up; it is expected to be fully operational early 1991. The task of running the system has been attributed to the Belgian Ministry of Public Works and the oceanographic-meteorological station of this Ministry will produce the necessary forecasts. These forecasts will be made every six hours and will cover the next 24 hours.

The general concept of the system is given in figure 2.2.

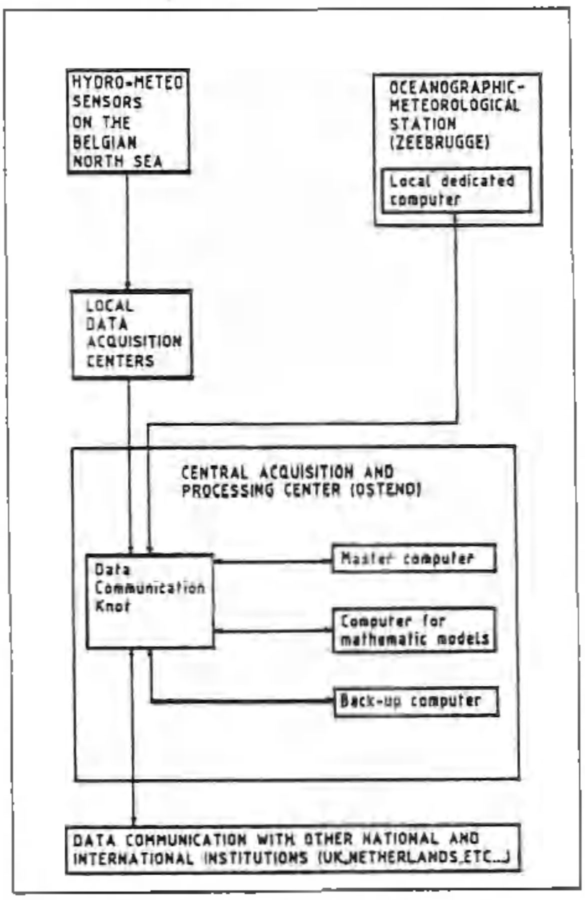

Figure 2.2. : General concept of the system

It consists of the following parts :

a. The Belgian measuring network on the North Sea described in table 2.1.

b. The local data-acquisition centers where the data from the Belgian network are gathered ; these centers are generally situated as near as possible to the location of the sensors of the network.
c. The central acquisition and data processing center at Ostend. were all incoming information is processed, stocked and distributed ; the data-communication knot and the main computer of the system is also situated there.
d. The data-communication with other Belgian and European institutions which gather hydro-meteo information on the North Sea.
e. The oceanographic-meteorological station on the Belgian coast at Zeebrugge. responsible for the production of the shipping forecasts.

These forecasts will contain information about meteo-conditions, water-level and low frequency wave energy (LFE) in the shipping channel. The deep draught vessels will indeed only be affected by waves with long periods (« swell »), which contribute to the low frequency part of the wave spectrum ; for this reason the LFE has been defined as the amount of energy contained in the wave spectrum between 0.035 and 0.100 Hz (corresponding to wave periods between 10 and 30 seconds). At the moment, a study is under way to determine the correlation between the amount of low frequency wave energy and the movement of a number of characteristic deep draught vessels.

On the basis of the expected water level, the expected ship's movement and the necessary keel clearance, the nautical authorities will be able to determine the « tidal gate » for each of these ships.

The installation of the Belgian hydro-meteo system requires of course the installation of an important computer infrastructure, which is now being realised by Belgian specialised firms.

The Belgian authorities are convinced that the above described hydro-meteo system will allow an optimal use by deep draught vessels of the important shipping channel leading to the Western Scheldt and the port of Antwerp, further the safety of navigation and ultimately also lead to savings in dredging costs.

3. NAVIGATION AND NAUTICAL BOTTOM IN MUDDY AREAS

AIM OF THE PROGRAM

For the design and the dimensioning of access channels and harbour basins, harbour authorities want to indicate a navigable depth with safe and good manoeuvrability. The nautical depth and minimum keel clearance have to be defined, which is difficult in muddy areas where the upper part of the mud deposit is characterised by low density and weak shear strength. Moreover, a better definition of the nautical bottom can lead to an optimization of maintenance dredging.

Scientific research concerning the influence of a mud layer on the propulsion and manoeuvrability of ships is still in its initial stages. Only in Bangkok and Europoort-Rotterdam. has some relevant work been done. leading to a volume-mass value of 1.2 t/m^3 as a safe value above which vessels can sail (3.1) (3.2) (3.3).

The question remains if similar density values are applicable in all cases to define nautical depth. as manoeuvrability with restricted keel clearance is influenced by the underflow but also by the deformation of the mud deposit. which depends on the applied shear stress and the rheological properties of the sediment.

The subjects related to the in situ study of the nautical bottom within the global research project are as follows :
a. Investigations and research on the characteristics of the mud deposits (composition, rheological properties).
b. Development of field survey techniques, including both single-point and continuous detections of density and rheological properties.
c. Execution of full scale navigation and manoeuvring tests.
d. Development of an operational nautical bottom mapping procedure.

Description and results of these investigations are presented in Kerckaert et al.,1986 and 1988 (3.4) (3.5) with following summary.

RESEARCH ON THE CHARACTERISTICS OF MUD DEPOSITS

Echo-sounding surveys with high (210 kHz) and low (33 kHz) acoustic frequency, density measurements in the loose mud deposits and sample-analysis revealed that the definition of the nautical bottom has to take into account both volume-mass and deformation behaviour of the mud. The most important rheological properties of mud to define deformation characteristics and shear strength are the initial rigidity and the dynamic viscosity, mainly determined by the dry solid concentration and the mud particles content (3.4). Laboratory analysis of these parameters showed that two different domains of behaviour exist : a first domain where the rheological parameters are not or poorly affected by the concentration and very similar to those of water and a second domain where these parameters are strongly affected by the concentration. This observation seems to reflect a fundamental structural discontinuity of the mud properties within the mud layer which could indicate the nautical bottom.

Unfortunately, in every case the influence of sand-content is obvious, so that the rheological transition occurs at very different density values according to mud composition, origin and deposit-history. From the rheological investigations, a range of density values from 1.15 t/m^3 for almost sandless mud to 1.26 t/m^3 for a sand mixture of about 30 % seems to be valid for the definition of the nautical bottom in Zeebrugge.

Nevertheless, it is clear that the assumption that the change-over in rheological properties coincides with these of manoeuvring characteristics, has to be verified by means of full and small scale manoeuvring tests.

DEVELOPMENT OF FIELD SURVEY TECHNIQUES

For the purposes of these nautical bottom studies, three different detection techniques have been developed :

a. A single-point density profiler (JTD3 backscatter gauge).

b. A towed continuous density gauge (NAVITRACKER transmission gauge).

c. A single point rheometric profiler (RHEOMETER in situ consistency transmitter).

The last one seems to give a good idea of mud properties, mainly ensured by the rheological transition, which indicates a sudden and drastic increase in shear strength within decimeter ranges, confirming the above-mentioned laboratory results.

FULL SCALE NAVIGATION AND MANOEUVRING TESTS

Since it is unknown whether the rheological transition in the mud meets the requirements for the nautical bottom, full scale navigation and manoeuvring tests were a necessity.

These tests were executed in the harbour of Zeebrugge using the « VLAANDEREN XVIII » trailing suction hopper dredger (124 x 23 x 9.7 m C_B=0.82). Seventeen full scale tests with different keel clearances to the top of the mud layer (−0.50 to -0.35 m) were carried out, each test preceeded and followed by a survey of the mud layer. Due to low sand content the rheological behaviour transition occurred at a density level of about 1.16 t/m^3 (ca. 0.50 m below top mud layer). Four kinds of manoeuvres could be carried out, being short engine manoeuvres (50 to 150 seconds « full-ahead »), constant power manoeuvres, a pitch increase manoeuvre from stop-position, and finally a turning manoeuvre.

It was noted that, for all manoeuvres, the acceleration of the vessel was equal, mainly because the thrust of the propellers was much greater than the hydrodynamic forces acting on the ship's hull (limited speed so that all resistance forces were very limited in relation to the thrust).

In type 1 manoeuvres, the deceleration on the contrary was strongly affected by the keel clearance, meaning that the vessels resistance was considerably greater (200 to 300 %) with the vessels bottom touching and in the mud layer.

In type 2 manoeuvres acceleration was equal too, but the final velocities were decreasing with the keel clearance showing a drastical reduction when touching the top of the mud layer. In conclusion, one can state that the keel clearance was a critical parameter for ships resistance in the middle and high velocity spectrum (6 knots and more), resulting in a velocity drop of about 50 % at constant power, but not for short engine manoeuvres at the lower end of the velocity spectrum (0 to 6 knots).

Moreover it seems that the frictional resistance increase due to the shear strength of the mud is the most significant parameter affecting the manoeuvring behaviour. In the last type of manoeuvres (180° turning manoeuvre), the draft of the hopper dredger was adapted to 0 % keel clearance with respect to the 1.20 t/m^3 density layer and the rheologic transition level (during the test both levels coincided). A reduction of 50 % and more of the turning velocity was registered in these test conditions.

OPERATIONAL NAUTICAL BOTTOM MAPPING

From the above-mentioned results an overall procedure for nautical bottom mapping is now established in Zeebrugge. On a twice monthly basis, echo-sounding (210 kHz and 33 kHz) is performed simultaneously with continuous density and single-point rheometer surveys. At the moment an operational procedure run is as follows :

a. The echo-soundings are analysed and the areas where two echos have been detected are shaded.

b. In the shaded area the echo-sounded values are automatically replaced by the continuous profiled 1.15 t/m^3 levels ; this level is the « worst case » rheologic transition density value for the « Zeebrugge » mud.

c. When available, in the shaded area the echo-sounded values are automatically replaced by the rheological transition level.

During the research program, the collected data have also revealed that the variations of the 210 kHz level can't be controlled by dredging operations and are entirely caused by weather conditions while the 1.20 t/m^3 level can easily be maintained at a constant depth by regular and effective dredging work. These findings have led to new concepts in maintenance dredging tactics, which are at the moment still the subject or further research.

4. SCALE MODEL EXPERIMENTS RELATED TO NAVIGATION IN MUDDY AREAS

AIM OF THE PROGRAM

It is clear that small scale model tests are very important in the study of the nautical bottom, since there is no theoretical approach available to deal in an accurate way with the problems of propulsion and manoeuvrability of ships sailing above, or in, a mud layer.

These experiments have to ascertain the similarity between the above-mentioned change-over in rheological and manoeuvring characteristics and must lead to a definition of the nautical depth in terms of both mud characteristics and manoeuvring behaviour.

A few years ago, a model test program was started at the Hydraulics Research Laboratory of Borgerhout-Antwerp, comprising the following items :

a. Investigations and realization of an adequate simulation of mud in the physical model.

b. Development of a pilot-model to get acquainted with the problem and to develop an accurate testing procedure.

c. Development of a detailed model equipped for planar motion mechanism tests.

d. Interpretation of the test results to extrapolate them to several design ships and to calibrate a mathematical simulator.

At the moment, major problems related to phase a and b have been solved. Pilot tests with a scale model of a design third generation containership, a LNG - carrier and the « Vlaanderen XVIII » suction hopper dredger have been executed. Phase c has also started.

DESCRIPTION OF THE PILOT-MODEL TESTS

The pilot-model tests were carried out in a small basin with dimensions 32.0 x 2.3 x 0.3 m. The incidence of the length restriction on the test program was not too important because only lower speed range was of interest, while the width restriction or blockage effect can also be expected in reality, as most problems with mud layers occur in canals and dredged channels. Moreover, the main purpose of the test program was not to obtain quantitative results but to select a suitable material to simulate the mud and to obtain a better understanding of the causes of the changements in ship's behaviour.

Three ship models were selected for the tests, being a third generation containership (258.5 x 32.2 x 12 m C_B= 0.68) and a LNG-tanker (280 x 41.6 x 11 m C_B=0.80), both on a scale of 1/70 and a trailing suction hopper dredger (124 x 23 x 9.7 m C_B=0.82) on a scale of 1/40. The ships, provided with self propulsion and rudder action activated by remote control, were beam-guided in the centre-line of the basin, so that only straight line tests were possible with the available experimental setup. The ships were able to move freely in vertical direction (figure 4.1).

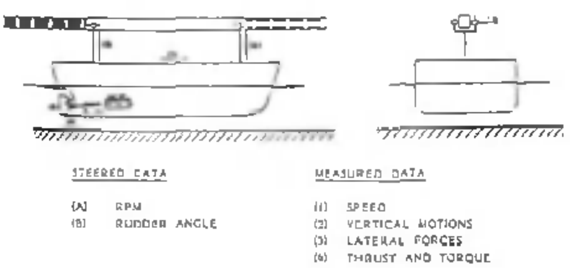

Figure 4.1. : Experimental setup

During the tests, velocity, vertical displacement and lateral forces were measured at two points on the ship, while for the two-propeller dredger model also propeller dynamometers were installed to measure propulsion and power values.

Beside the solid bottom tests, three mud simulating materials were tested :

a. Natural mud, with rheological properties scaled by means of sodiumhexametaphosphate.

b. Artificially composed mud (clay, active carbon and fine quartz) also with scaled rigidity and viscosity.

c. Organic liquid, mixture of 1-1-1 trichlorethane and petrol (TCE/P) (see table 4.1.).

With several layer thicknesses (0.70 to 2.10 m), densities of the mud layer (1.05 to 1.22 t/m^3) and keel clearances (+20 to -10 %), four types of tests were carried out :

acceleration and deceleration tests

tests with constant speed up to about 6 knots

tests with rudder action

and bollard pull tests.

RESULTS CONCERNING THE VERTICAL INTERFACE WATER-MUD MOTIONS

The difference between the behaviour of a vessel navigating above a mud layer and one navigating above a solid bottom appears to be caused by the occurrence of internal waves in the interface between water and mud. Observation of the mud layer during experiments with ship models above TCE/P, natural and artificially composed mud have shown that the shape of the internal wave pattern depends on the forward velocity :

- at very low speed ($V < V_1$), the interface remains undisturbed (« first speed range ») ;
- at intermediate speed ($V_1 < V < V_2$: « second speed range »), an interface sinkage is observed under the ship's entrance, but, at a certain section, this sinkage suddenly changes into an elevation. This phenomenon shows much similarity with a hydraulic jump in channels. The section at which the interface jump occurs, moves towards the stern with increasing speed. The angle between the wave front and the canal centre-line is approximately 90°.
- at higher speeds ($V > V_2$: « third speed range »), the interface jump occurs behind the stern. The angle between wave front and canal centre-line increases from 90° to approximatimately 135°.

TABLE 4.1.

BOTTOM	ρ_2 (t/m^3)	h_2/T	η (Pa.s)	τ_0 (Pa)
TCE/P 1	1.11	0.15	0.002	0.146
TCE/P 2	1.14	0.07	0.002	0.129
TCE/P 3	1.225	0.15	0.002	0.135

Theoretical and experimental investigations have led to following estimations for the critical speed values V_1 and V_2.

- The first critical speed value is related with the yield stress τ_0 of the mud. If a theoretical method developed by Mei and Liu (4.1) for estimating the behaviour of a mud-water interface due to surface waves is applied to the disturbance caused by a ship navigating in a narrow channel with a muddy bottom, following expression is found for V_1 :

$$V_1 = \left[\frac{\tau_0 \, L}{d\sigma/d\xi \; m_0 \; \rho_1 \; h_2}\right]^{\frac{1}{2}} \quad (1 - m_0 \, \sigma)$$

with L = ship length

x = coordinate along longitudinal axis of ship

ξ = x/L

S = sectional area of ship

S_0 = maximal sectional area of ship

σ = S/S_0

W = canal width

h_1 = water depth

h_2 = mud layer thickness

$\rho 1$ = water density

$\rho 2$ = mud density

τo = yield stress of the mud

m = blockage factor (= S/Wh_1)

m_0 – maximal value of blockage factor (= S_0/Wh_1)

This critical speed value is small for loose mud layers. For L = 200 m, τo = 2 Pa, $d\sigma/d\xi$ = 5, m_0 = 0.2, ρ_1 = 1025 kg/m^3 and h_2 = 0.5 m one obtains : V_1 = 0.71 m/s = 1.37 knots.

- A simplified one dimensional theory (4.2) has led to an estimation for V_2. An interface elevation at a section with blockage m appears to be impossible if :

$$V > \left[\frac{8}{27} (1 - m)^3 \left(1 - \frac{\rho_1}{\rho_2}\right) g h_1\right]^{\frac{1}{2}}$$

so that the internal jump is situated behind the ships stern if V > V_2, with :

$$V_2 = \left[\frac{8}{27}\left(1 - \frac{\rho_1}{\rho_2}\right) g h_1\right]^{\frac{1}{2}}$$

As an example, for ρ_1 = 1025 kg/m^3, ρ_2 = 1100 kg/m^3 and h_1 = 15 m, one obtains V_2 = 1.72 m/s = 3.35 knots.

Following this approach, the maximal propagation velocity of internal waves does not seem to be of importance.

INFLUENCE ON THE SHIP'S SPEED

Figure 4.2. shows the effect of the presence of a mud simulating material layer on the rpm-speed curve of a self-propelled ship model. This influence is only important in the second speed range (V_1 < V < V_2) : a reduction of speed with about 40 % is observed at V = V_2.

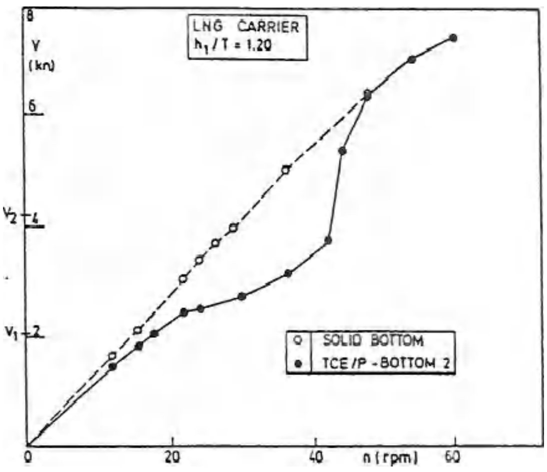

Figure 4.2. : Effect of mud on speed rpm relation

Figure 4.3. shows the influence of the keel clearance referred to the interface for several rpm values. It is surprising to see that a keel clearance reduction does not always lead to decrease in speed.

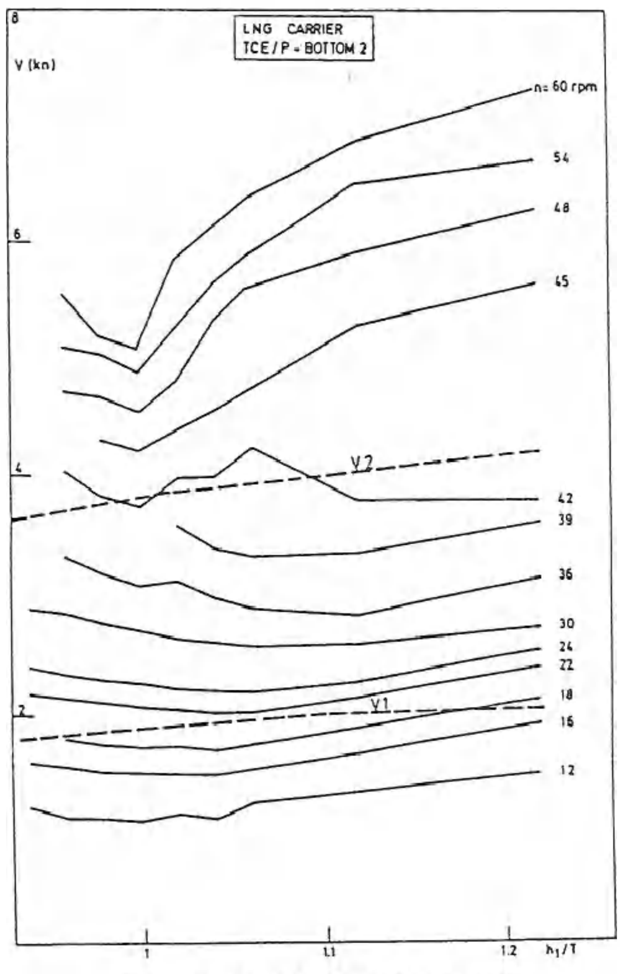

Figure 4.3. : Effect of keel clearance on speed

This phenomenon can be explained as follows : if an interface elevation occurs, the relative velocity of the ship to the mud is much smaller than the relative speed between ship and water, which results into a lower resistance, in spite of the higher viscosity of mud compared with water.

INFLUENCE ON PROPULSION CHARACTERISTICS

In figure 4.4., K_T and K_Q values are given for a constant rpm value, as a function of forward speed, with :

$$K_T = \frac{T}{\rho_1 \ n^2 \ D^4} \quad \text{and} \quad K_Q = \frac{Q}{\rho_1 \ n^2 \ D^5}$$

with T = propeller thrust
Q = propeller shaft moment
n = cycles per second
D = propeller diameter

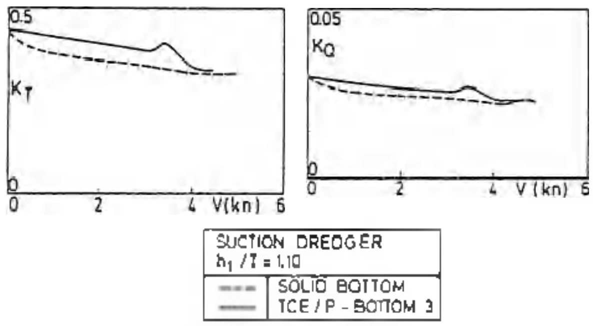

Figure 4.4. : Effect of mud on propeller characteristics

Above a solid bottom, the propulsion coefficients decrease with increasing speed. Above a mud layer, on the other hand, an increase of K_T and K_Q is observed if V ~ V_2. This phenomenon did not only occur during model tests above TCE/P, but also above artificially composed mud (suspension).

INFLUENCE ON RUDDER EFFECTIVITY AND MANOEUVRABILITY

Although it was only possible to execute straight-line tests with the available experimental setup, insight in the influence of the presence of a mud layer on manoeuvrability could be gained by measuring the lateral force Y and the moment N around a vertical axis which act on a ship model due to rudder action.

Some representative results are shown in figures 4.5. and 4.6., where

$$Y' = \frac{Y}{\frac{1}{2} \rho_1 \ V^2 \ L^2} \quad \text{and} \quad N' = \frac{N}{\frac{1}{2} \rho_1 \ V^2 \ L^3}$$

are given as functions of the rudder angle δ. The speed values at which the experiments are executed belong to the second speed range for figure 4.5. and to the third speed range for figure 4.6.

In the second speed range, the $Y'(\delta)$ and $N'(\delta)$ curves behave as should be expected above a solid bottom for h_1/T = 1.20, but show great instabilities for small rudder angles if $h_1/T \leqslant 1.10$; forces and moments by rudder action only take the « normal » sign for $\delta \geqslant 20°$ (approximately). In the third speed range, on the other hand, rather small instabilities can be observed for negative keel clearance ($h_1/T \leqslant 0.96$).

Figures 4.5. and 4.6. show that the instability effects mentioned decrease for large negative values of the keel clearance (h_1/T = 0.90), but in this case forces and moments

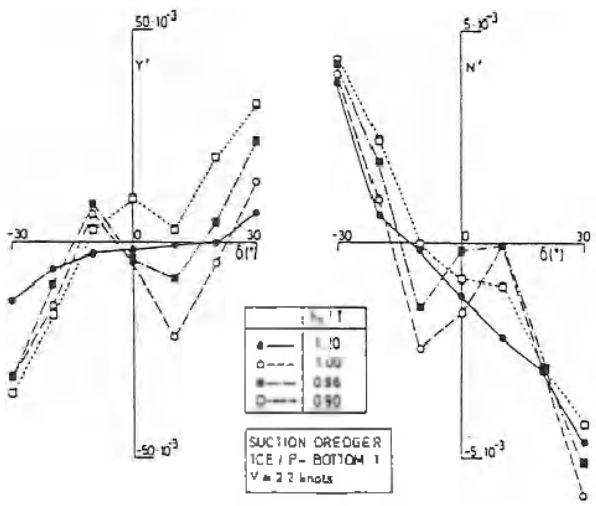

Figure 4.5 : Second speed range : effect of keel clearance on rudder action

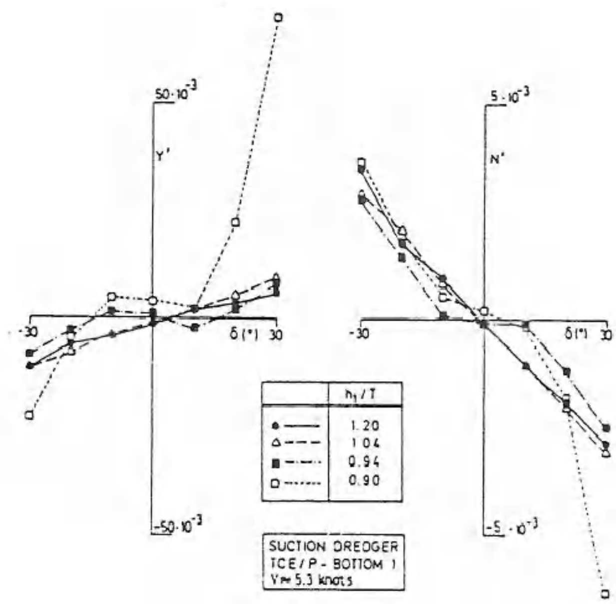

Figure 4.6. : Third speed range : effect of keel clearance on rudder action

induced by rudder action take very large values. In both ranges, instabilities appear to take place when contact between the ship's hull and the mud layer occurs.

INFLUENCE ON VERTICAL SHIP MOTIONS (SQUAT AND TRIM)

For large values of the keel clearance, theoretical and experimental aspects of this topic have been treated in (4.2).

Especially the ship's trim is influenced : in the vicinity of the second critical speed value, the effects of the presence of a mud layer result into an increase of the trim angle, which means that the ship tends to trim by the stern. This effect is illustrated in figure 4.7. where results obtained above a solid bottom and above a layer of mud simulating material are compared, for h_1/T = 1.20. Effects on the ship's mean sinkage are less important for large keel clearance values, as is shown in this figure.

In the third speed range, squat decreases slightly above a muddy bottom. For smaller and negative values of the keel clearance, referred to the interface, figure 4.8. shows that the effect of the mud layer on the ship's trim is somewhat smoothened.

In the second speed range, the trim curve shows some undulations. The influence of keel clearance on the ship's mean sinkage is also illustrated in this figure : in the second speed range, squat appears to be practically completely eliminated.

EVALUATION OF MUD SIMULATING MATERIALS

One of the main results concerns the selection of a mud simulating material for further investigation. Mixtures of 1-1-1 trichlorethane and petrol (TCE/P) have proved to be the most suitable materials.

- Compared with other mud simulating materials, physical properties of TCE/P mixtures are stable as a function of time, which allows the running of systematic experimental series.
- The mixtures appear to behave as Bingham fluids, with rather small yield stress values τ_0. As the first critical velocity value depends on τ_0, yield stress should be scaled according to a Froude law. For the scale of the ship models used at the Hydraulics Research Laboratory (1/70 and 1/40), a sufficiently correct scaling is obtained for simulating loose mud layers.

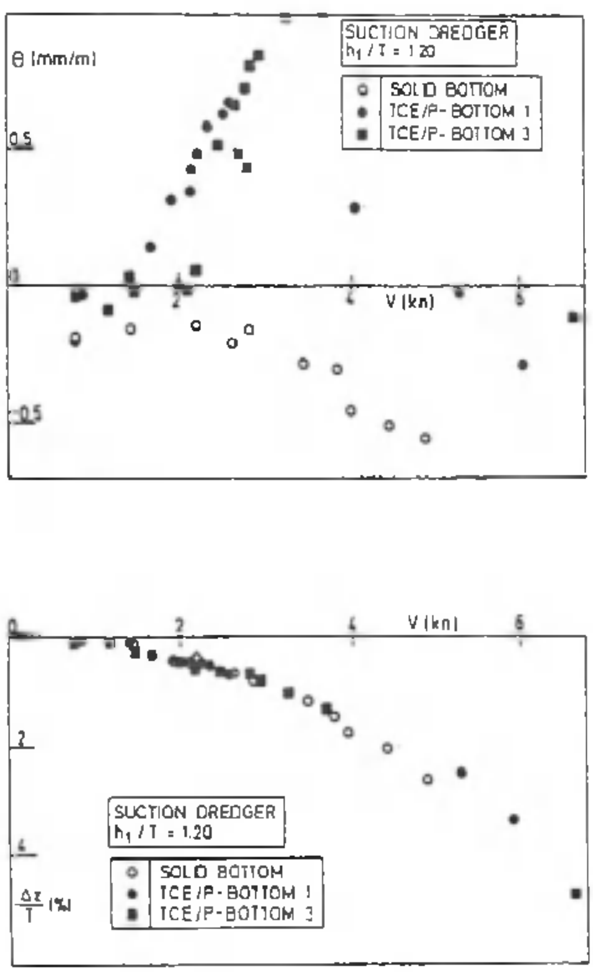

Figure 4.7. : Effect of mud on vertical ship motions

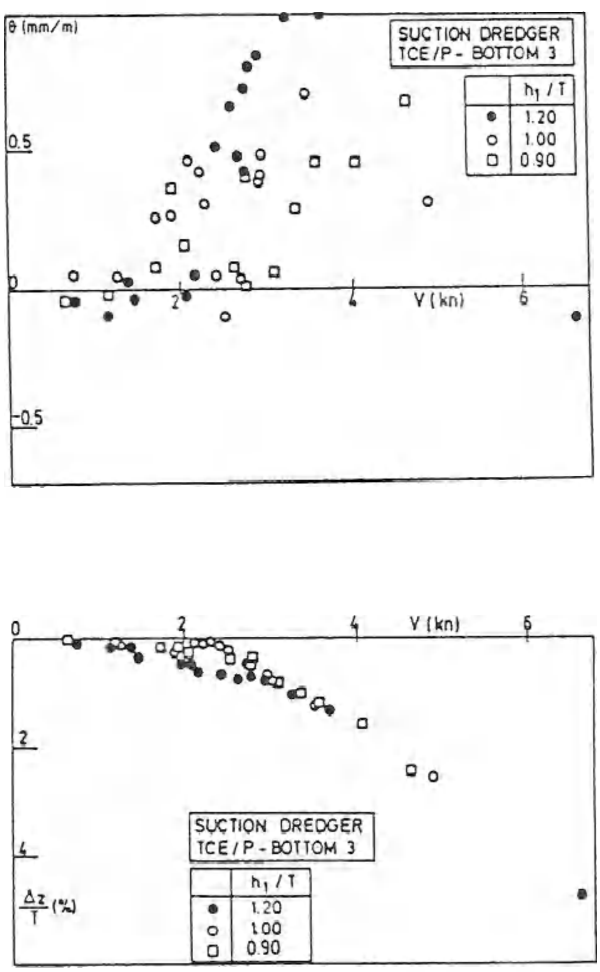

Figure 4.8. : Effect of keel clearance on vertical ship motions.

It has to be stated that perfect scaling of the behaviour of a two layer system mud-water due to the influence of a vessel navigating above it, is in principle impossible, as viscous effects cannot be scaled by means of a Froude law. This is a major problem in ship model testing in general, which becomes even more complicated because of the rheological characteristics of the mud.

The use of a TCE/P mixture as a mud simulating material might be criticized : such fluids are immiscible with water, in contrast with natural mud, which is a suspension of solid materials in water. On the other hand, experimental results have shown that this difference does not essentially affect the behaviour of the interface or of the ship model :

- observations of layers of TCE/P mixtures, artificially composed mud and natural mud have shown an great similarity between the behaviour of the respective interfaces, although internal waves in a natural mud-water interface are damped more easily than in the case of a TCE/P-water two layer system ;
- the effect of the presence of a mud simulating material on the ship model's performance (e.g. concerning propulsion characteristics, speed-rpm curve, ...) does not essentially depend on the mud simulating material used ;
- tests with models above natural mud layers (without scaled properties) have shown the high stability of the interface, so that there is no objection to simulating it by a completely immiscible fluid.

PRELIMINARY CONCLUSIONS FOR NAVIGABILITY OF SHIPS IN MUDDY AREAS

Although the limitations of the experimental setup used for this investigation mainly allows for qualitative results, some preliminary practical conclusions for the navigation in muddy areas can already be produced :

- significant modifications in a ships behaviour (speed-rpm relation, rudder effectivity, vertical motions, propulsion) take place if contact between the mud layer and the ships keel occurs ;
- due to the presence of internal waves, such a contact already occurs at positive keel clearance values in the second speed range and only occurs at negative keel clearances in the third speed range ;
- in muddy areas, a decrease of water depth does not necessarily lead to an increase of resistance and consequently to a faster stopping manoeuvre ;
- ships navigating with small or negative keel clearance in laterally restricted muddy areas should avoid the vicinity of the second critical speed value, as considerable changes in rudder effectivity take place at this velocity. Some sizeable incidence on ship manoeuvrability may be expected as well, although captive manoeuvring tests with ship models have to be carried out to investigate this important aspect of ship's behaviour.

FURTHER INVESTIGATION PROGRAM

In order to study the effects of the presence of a mud layer on ship manoeuvrability, captive model tests have to be performed. For this purpose, experimental facilities for ship models of three to five meters of length are under construction at the Hydraulics Research Laboratory, consisting of a 70 x 7 x 0.60 m towing tank, equipped with a computer controlled planar motion mechanism. As it will be possible to vary the forward speed of the main carriage as a function of time, this mechanism will be able to force a ship model to perform almost every horizontal motion. The concept of these installations is the result of a cooperation between several services of the Belgian Ministry of Public Works and the Office of Naval Architecture of the Ghent University. With this equipment, the Hydraulics Research Laboratory will be able to obtain numerical values for manoeuvring coefficients of ships navigating above solid and muddy bottoms ; in this way, it will be possible to study the effects of the presence of loose sedimentations on the behaviour of ships by means of the ship manoeuvring simulator, which was installed at the Laboratory in 1988.

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RESUME

Système hydro-météo pour l'accompagnement de la navigation en relation avec le problème de la profondeur nautique dans des chenaux envasés

1. *Introduction*

Pour assurer une navigabilité sûre dans les chenaux d'accès vers les ports de Zeebrugge à la côte Belge et d'Anvers par l'Escaut Occidental, le Service de la Côte du Ministère des Travaux Publics de Belgique a organisé deux études :

a. l'étude d'un système hydro-météo pour l'accompagnement du trafic des navires

b. l'étude de la profondeur nautique dans les zones envasées. étude composée de deux parties :

— mesure sur place des propriétés physico-chimiques des dépôts de vase et de la manœuvrabilité des navires au-dessus de ces dépôts,

— essais sur modèle réduit pour évaluer l'effet total d'une couche de vase sur les performances d'un navire naviguant avec pied de pilote réduit.

2. *Système hydro-météo pour l'accompagnement de la navigation*

Le long de la côte Belge se trouvent d'importants chenaux d'accès vers le port de Zeebrugge, situé à la côte, et vers le port d'Anvers, par l'Escaut Occidental. Dans les années à venir, le chenal vers l'Escaut Occidental sera approfondi pour permettre le passage de navires à tirant d'eau de 48 pieds, mais pour limiter les travaux de dragage, ces navires devront utiliser le marnage de la marée, de l'ordre de quatre mètres, pour atteindre le port d'Anvers après une ou deux marées.

Parce que le temps de passage possible dépendra de la marée, de l'influence du vent sur les niveaux d'eau et des houles, le Gouvernement Belge a décidé d'installer un système hydro-météo fournissant aux autorités portuaires des prédictions précises sur les niveaux d'eau et les houles, afin d'assister la politique d'admission de ces navires.

Cette décision était la suite logique des efforts menés depuis plusieurs années par le Ministère des Travaux Publics de Belgique pour installer un réseau de points de mesure océanographiques et météorologiques dans la Mer du Nord et le long de la côte Belge, comprenant :

- six plate-formes avec équipement de mesure hydro-météorologique (niveau d'eau, hauteur des houles, vent, courant, température, pression de l'air, etc.)
- des bouées de mesure, livrant des données continues sur la hauteur et la direction des houles
- des marégraphes télémétriques dans les trois ports côtiers
- un courantographe télémétrique à l'entrée du port de Zeebrugge
- une station météorologique à Zeebrugge.

Apres traitement, toutes les données du réseau Belge de la Mer du Nord sont rassemblées à la station océano-météorologique de Zeebrugge, aussi équipée pour capter les photos de satellite et les cartes du temps des Instituts Météorologiques les plus importants de l'Europe et pour utiliser les résultats du modèle météorologique de Reading (Royaume-Uni). Des modèles mathématiques sophistiqués, ainsi que des méthodes simples pour prédire la marée et la houle sont disponibles. La fonction de la station est de traduire les données traitées en prédictions précises.

Le système hydro-météo, en cours de construction, sera opérationnel début 1991 et comprendra les éléments suivants :

- le réseau de points de mesure, décrit plus haut ;
- des centres locaux d'acquisition de données, situés près des points de mesures ;
- le centre de traitement à Ostende, où les données seront traitées, stockées et distribuées ;
- le centre de communication en rapport avec les autres institutions Belges et Européennes qui collectent des données hydro-météorologiques concernant la Mer du Nord.
- la station océano-météorologique de Zeebrugge, traduisant les données traitées en prédictions.

A ce moment, une étude est en cours pour déterminer la corrélation entre l'énergie des houles et les mouvements d'un navire. Sur base de toutes ces données, les autorités portuaires seront en mesure de déterminer le temps de navigation disponible sur la marée. En d'autres termes, le système permettra d'utiliser de façon optimale la profondeur des chenaux d'accès, assurera une navigation sûre et aboutira à une réduction des dragages d'entretien.

3. *Etude de la profondeur nautique dans des zones envasées*

La définition de la profondeur nautique dans des zones de navigation envasées n'est pas aisée, vu la très faible densité et résistance au cisaillement des couches supérieures de la vase. Les études sur place comprenaient les sujets suivants :

- mesure et étude des propriétés physiques de la vase
- développement de techniques de mesure de la densité et des propriétés rhéologiques
- essais de manœuvrabilité à grande échelle
- développement d'une procédure operationnelle de mise en carte des profondeurs nautiques.

On a cherché à définir le fond nautique à partir de la densité et des propriétés rhéologiques de la vase. L'étude a révélé qu'il existe une discontinuité fondamentale des propriétés rhéologiques (rigidité et viscosité dynamique) dans la couche. Au-dessus de cette transition, ces propriétés ne dépendent pas de la concentration et sont très proches de

celles de l'eau pure, au-dessous elles dépendent fortement de la concentration. Malheureusement, la teneur en sable influence ces propriétés. A Zeebrugge, cette discontinuité se présente à des densités très différentes suivant la composition, variant de 1.15 t/m^3 dans le cas de vase sans sable à 1.26 t/m^3 pour un mélange contenant 30 % de sable. Le changement brusque de comportement rhéologique pourrait définir le fond nautique, mais des essais de navigation sur modèle et à grandeur nature doivent corroborer cette hypothèse.

Dans ce contexte, les essais de manœuvrabilité au-dessus et dans une couche de vase avec la drague suceuse porteuse « Vlaanderen XVIII » ont montré que le ralentissement après une manœuvre courte à grande puissance, ainsi que la vitesse finale après une manœuvre à puissance constante, sont fortement influencés à partir du moment où la coque du navire touche l'interface eau-vase.

A partir de ces résultats, à Zeebrugge, la procédure suivante de mise en carte du fond nautique est appliquée : dans les zones où les échosondages bi-hebdommadaires (210 kHz et 33 kHz) révèlent deux échos, les valeurs des échosondages sont remplacées soit par les niveaux de densité 1.15 t/m^3, mesurés par la sonde continue Navitracker, soit par le niveau de transition des propriétés rhéologiques, mesuré par la sonde rhéologique.

4. *Essais sur modèle réduit concernant le fond nautique dans des zones envasées*

Puisqu'il n'y a pas d'approche théorique existante pour traiter les problèmes de propulsion et de manœuvrabilité des navires naviguant au-dessus d'une couche de vase, l'étude sur modèle réduit est d'une grande importance. Les points suivants en faisaient l'objet :

- étude et réalisation d'une simulation adéquate de la vase en modèle réduit;
- développement d'un modèle-pilote pour se familiariser avec le problème et pour développer une procédure d'essais précise;
- développement d'un bassin de carènes équipé d'un mécanisme de mouvement plan d'un navire retenu;
- interprétation des résultats afin de les extrapoler à d'autres navires et d'étalonner un simulateur mathématique.

Les essais sur modèle-pilote, avec un modèle de porte-conteneurs et de méthanier sur échelle 1/70 et de la drague « Vlaanderen XVIII » sur échelle 1/40 en navigation guidée rectiligne, ont montré qu'au-dessus d'une couche de vase, le comportement est fortement influencé par la formation de houles internes à l'interface eau-vase et qu'il y a trois champs de vitesses :

- un premier champ où l'interface n'est pas perturbée ;
- un deuxième, où l'interface baisse initialement sous le navire pour ensuite s'élever brusquement vers l'arrière du navire ;
- un troisième, où l'élévation de l'interface se produit derrière la poupe.

Des modifications importantes dans le comportement des navires (vitesse et propulsion, effectivité du gouvernail, mouvements verticaux) surviennent au moment où la coque du navire touche l'interface. Par suite de la présence des houles internes, ce contact se produit déjà avec un pied de pilote positif dans le deuxième champ de vitesses et uniquement avec un pied de pilote négatif dans le troisième champ. Des changements importants dans la manœuvrabilité semblent survenir en particulier autour de la deuxième vitesse critique, mais des essais sur modèle-détail doivent confirmer cette thèse.

Trois matériaux pour simuler la vase ont été testés, à savoir :

- une vase naturelle dont les propriétés rhéologiques ont été mises sur échelle à l'aide de hexametaphosphate de soude ;
- une vase artificielle (argile, carbone actif et du quartz fin), dont les propriétés rhéologiques ont également été mises sur échelle ;
- un liquide organique, mélange de 1-1-1 trichloréthane et de pétrole (TCE/P).

Ce dernier s'est avéré être le plus approprié pour l'utilisation en modèle et sera utilisé dans le modèle-détail, actuellement en construction.