Ship manoeuvring behaviour in muddy navigation areas

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Abstract: **In the frame of an optimisation strategy for the maintenance dredging works for the port of Zeebrugge, systematic series of captive manoeuvring tests with ship models are being carried out. The main purpose is to investigate the effect on a ship's controllability of a mud layer covering the bottom of a navigation area. An overview of the so-called *nautical bottom* problem is given. A detailed mathematical manoeuvring model has been developed in order to perform fast-time and real-time simulation runs. Results of simulated standard manoeuvres are discussed in relationship with the internal wave pattern observed in the mud-water interface.**

Keywords: **mud layer, ship control, manoeuvrability, fast-time simulations**

I. Introduction

In many locations, such as in ports and access channels, ships have to carry out manoeuvres at very small under keel clearances. Navigation at a negative under keel clearance, however, is only possible when the bottom is a soft one, e.g. a fluid mud layer.

A bottom covered with a fluid mud layer is a typical situation for harbours and access channels. If the bottom is covered with a mud layer it is difficult to define the exact bottom. Depth measurements are made using echo sounding methods. The higher frequency measures the interface between the water and the mud layer while the lower frequency measures a more rigid type of mud, but it is not clear whether this is the real bottom or not.

Therefore another definition of the "bottom" is required. In muddy areas the *nautical bottom* concept is used, as stated by PIANC [1] being *the nautical bottom 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.*

For the harbour of Zeebrugge, on the Belgian North Sea coast, the nautical bottom is defined as the level where the density of the mud layer reaches 1150 kg/m³. This critical value has been adopted because of the significant change of the rheology profiles of the mud layer at that point.

The waterway authorities would like to increase the critical limit, as nowadays the dredging is still expensive and time consuming. However, it is not clear which effect this will have on the controllability of the ship. Therefore, additional research is required on the behaviour of a ship navigating at very small and even negative values for the under keel clearance, referred to the water-mud interface.

II. Experimental Research

An experimental program consisting of captive manoeuvring tests is being carried out at the *Towing tank for manoeuvres in shallow water (co-operation Flanders Hydraulics – Ghent University)*, Antwerp, Belgium (88*7*0.6 m³) (Figure 1).

Two 1/75-scale models, a container carrier and a bulk carrier, were selected. In the first place only the results of the container carrier (L_{pp}=289.8 m; B=40.25 m; T=13.50 m; C_B=0.59) are being analyzed as the container traffic is the most important one for the harbour of Zeebrugge (Figure 2).

Both ship models have been tested at several bottom conditions. The mud layer has been simulated using a mixture of two chlorinated paraffins and petrol, so that both density and viscosity can be controlled within certain ranges. The different simulated mud layers are represented on Figure 3. Until now (September 2003) mud layers E-F-G-H-B have been tested.

The experimental program consists of: bollard pull tests with varying rudder angle and propeller rate; stationary tests with varying speed, rudder angle, drift angle and propeller rpm; harmonic sway and yaw tests; multimodal tests with variable speed, rudder angle and/or propeller rpm.

III. Mathematical Modeling

For every tested bottom condition a mathematical manoeuvring model has been developed. The mathematical model is a modular one based on the hydrodynamic characteristics of the ship's hull, propeller and rudder. Each force or moment acting on the ship in the horizontal plane can be expressed as the sum of a hull, a propeller and a rudder component.

The mathematical models can be used as input for fast-time and real-time simulations. Until now some fast-time simulation runs have been carried out for the bottom conditions investigated so far.

IV. Fast-time simulation results

In fast-time simulation runs the behaviour of the ship is analyzed in various, simplified conditions, such as a turning circle due to rudder action or an acceleration test.

Figure 4 shows the final diameter of a turning circle due to rudder action. The diameter increases with decreasing water depth, although it seems to reach a maximum at small positive under keel clearances.

The average speed a ship reaches when navigating full ahead is shown on Figure 5. In the conditions investigated so far, navigating in contact with the mud layer will significantly increase the ship's resistance.

V. Interface motions

When a ship navigates above or within a mud layer, undulations of the interface are caused. The shape of the internal wave pattern depends on several parameters, such as speed, propeller rpm, layer thickness, composition of the mud,…

In general, the rising will be higher and will be located more aft when the ship's forward speed and propeller rpm increase while the density and thickness of the mud layer decrease. When the rising occurs aft and the ship is navigating at a small positive under keel clearance, the propulsion will be disturbed by the mud particles interfering with the water flow. Propulsion and rudder action will be less effective, so that the turning radius of the ship will be greater.

When the ship navigates at a negative under keel clearance through high-density mud, the rise of the interface will be located near midships. The ship's resistance is significantly affected in this condition and is not longer proportional with the square of the speed.

VI. TABLES AND FIGURES

Figure 1. Towing tank for manoeuvres in shallow water.

Figure 2. Ship model during captive manoeuvring test.

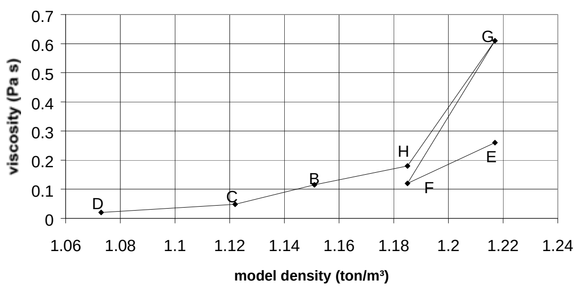

Figure 3. Characteristics of mud simulating materials.

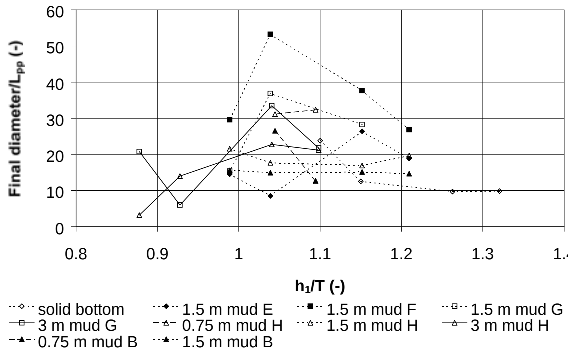

Figure 4. Container carrier: final diameter of a turning circle due to rudder action 35° to port, full ahead.

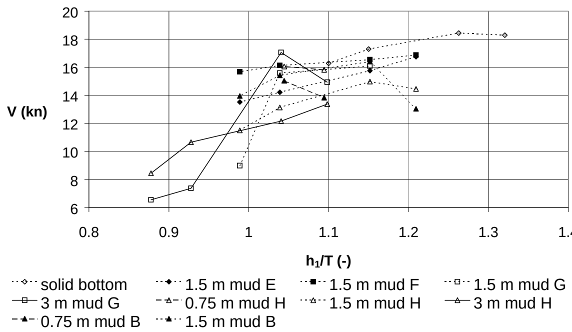

Figure 5. Average forward ship's speed when navigating full ahead.

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SYMBOLS

B	ship's beam	(m)
C_B	block coefficient	(-)
h_1	water depth (free surface to interface)	(m)
L_{pp}	ship's length between perpendiculars	(m)
T	ship's draft	(m)
V	ship's speed	(kn)

REFERENCES

[1] PIANC/IAPH (1997). Approach channels – A guide for design, Final repot of the joint Working Group PIANC and IAPH, in cooperation with IMPA and IALA. Supplement to *PIANC Bulletin*, **No.95,** 108 pp.