Fluidization model for ship manoeuvring prediction in muddy navigation areas

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Abstract **The manoeuvring behaviour of vessels is significantly affected by restrictions of the navigation areas. Especially the clearance between the keel and the bottom of the seabed is important. Additional difficulties arise when this bottom is covered with a fluid mud layer. Most vessels are designed to navigate in deep water areas, although for simulation purposes pilots should be able to train with realistic mathematical models in confined areas. A mathematical ship manoeuvring model has been developed taking the under keel clearance and the bottom characteristics into account. Thanks to this mathematical model and simulation runs a redefinition of the nautical bottom in the harbour of Zeebrugge was possible, resulting in the acceptance of larger vessels or a reduction of maintenance dredging.**

Keywords **mud layer, ship control, manoeuvrability, container**

I. INTRODUCTION

Many harbours and access channels suffer from sedimentation and the formation of fluid mud layers; consequently maintenance dredging is needed in order to allow safe navigation in these areas. One of the major difficulties is the determination of the bottom of the seabed, which is usually carried out using echo sounding techniques. However, in case of a mud layer a high frequency echo will reveal the top position of the mud, while a lower frequency echo will reflect at a position deeper into the mud, but it is uncertain if this position is the actual bottom of the seabed. 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.*

The critical limit in this definition is mostly a critical density, as this is the only parameter that can presently be measured in a continuous way, a feature that is very important for the survey of mud layers. However, it should be borne in mind that the behaviour of mud cannot be characterised by one single parameter. From the ship manoeuvrability point of view the nautical bottom is located where the rheological transition, i.e. a sudden increase of shear strength, of the mud layer occurs. A comprehensive survey of the mud layer characteristics in the harbour of Zeebrugge in the 1980s showed that this rheological transition always occurred at a density above 1.15 ton/m^3, which was consequently denominated as the critical density of the mud layer.

Later surveys showed that the rheological transition had shifted to a deeper and denser mud. An increase of the critical density was thus possible, however it would result into contact between the ship's keel and the mud layer and possibly jeopardizing the safety.

II. EXPERIMENTAL PROGRAM

Additional knowledge on ship manoeuvring behaviour in muddy navigation areas was needed. In 2001-2004 a comprehensive experimental program has been carried out by the Maritime Technology Division of Ghent University in collaboration with Flanders Hydraulics Research (Antwerp), the hydraulics research station of the Flemish Authorities.

Figure 1. Flanders Hydraulics Research shallow water towing tank

The experimental program consisted of captive manoeuvring tests in a towing tank with three ship models (two container carriers and one tanker) in the presence of different artificial mud layers. With the results of the experimental data a mathematical model was developed that could be used for fast- and real-time simulation runs.

III. MATHEMATICAL MODEL

The mathematical modelling was achieved in two phases. In a first phase a mathematical manoeuvring model was developed for every tested bottom condition [2]. A modular mathematical model was developed 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 limitation of this model is that it could only predict the ship manoeuvring behaviour in the same conditions as the ones of the captive manoeuvring testing program.

Nonetheless the mathematical model was already adequate to carry out real-time simulation runs with the Zeebrugge pilots, resulting in a redefinition of the nautical bottom: ships could manoeuvre without damage or unacceptable effects above a nautical bottom of 1.20 ton/m^3. This new critical density has already been implemented in the harbour of Zeebrugge with positive effects on the admittance policy of larger drafted container vessels.

IV. EFFECT OF THE UNDER KEEL CLEARANCE

The second phase of the modelling consisted of making the mathematical model dependent of the under keel clearance and bottom. The effect of the under keel clearance can be modelled by:

$$F = F_{deep} + \xi . f(ukc) \quad (1)$$

In which F represents any of the forces acting on the ship, ξ represents a (set of) regression coefficient(s) and ukc stands for the under keel clearance parameter, which can either be a function of h/T, T/(h-T) or L/(h-T). An example of a linear correlation with the under keel clearance parameter is given in Figure 2, for the sway added mass; this is the additional mass of surrounding fluid that has to be accelerated when accelerating the vessel in a lateral direction.

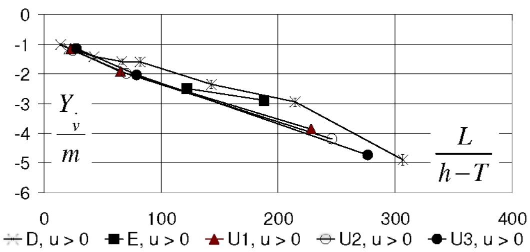

Figure 2. Sway added mass, ship models D, U (container carriers) and U (tanker), forward speed, no propeller action. The difference between U1, U2 and U3 is the draught. Solid bottom.

V. EFFECT OF A MUDDY BOTTOM

Be h_2 the thickness of the mud layer and h_1 the height of the upper lying water layer, the total depth can be written as:

$$h = h_1 + h_2 \quad (2)$$

The bottom material can vary from water over soft mud to consolidated mud. If the mud has large viscosity and density values, like sand or clay, the material will hardly move when a ship passes by and its top can be considered as the actual seabed. In this case the under keel clearance parameters can be written with $h = h_1$.

On the other hand if the material is very fluid the mud layer cannot be considered as a solid bottom. In the limit condition of two equivalent water layers, the under keel clearance parameters can be used with $h = h_1 + h_2$. For intermediate situations a parameter Φ can be defined, so that:

$$h = h_1 + \Phi h_2 \quad (3)$$

Particular values for this fluidization parameter Φ are 0 (hard layer of thickness h_2) and 1 (watery layer of thickness h_2). The fluidization parameter of the mud covering the seabed depends on the following parameters:

- the rheological properties (e.g. viscosity) of the mud: a decrease of the latter logically result into an increased fluidization parameter;
- the under keel clearance referred to the mud-water interface: the fluidization parameter increases when the ship's keel is located closer to the mud or penetrates the mud;
- undulations of the mud layer (see Figure 3).

The latter affect the manoeuvring behaviour of the vessel, and may even lead to a negative fluidization parameter, especially when the ship navigates with a small positive under keel clearance above the mud layer.

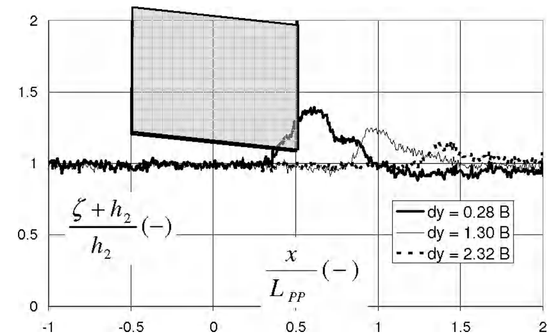

Figure 3. Undulations of the interface at various lateral distances of model D. Mud of density 1.20 ton/m^3, +3.9% of under keel clearance above the mud layer, u = 0.6 m/s, no propeller action. The ship is represented taking squat into account.

The principle of fluidization has been used to build a new mathematical model, which has some major advantages:

- the same degree of accurate prediction can be achieved with a significant decrease of the number of coefficients;
- the bottom conditions in a ship manoeuvring simulator are no longer restricted to the ones that were used in the captive testing program

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SYMBOLS

B	ship's beam	(m)
C_B	block coefficient	(-)
dy	lateral distance	(m)
F	force	(N)
h	depth	(m)
h_1	water depth (free surface to interface)	(m)
h_2	thickness of the mud layer	(m)
$L_{(PP)}$	ship's length (between perpendiculars)	(m)
m	ship's mass	(kg)
T	ship's draft	(m)
V	ship's speed	(kn)
x	longitudinal position	(m)
$Y_{\dot v}$	sway added mass	(kg)
Φ	fluidization parameter	(m)

REFERENCES

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