Method for calculating the stability at moderate and big heeling angles of a vessel

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Abstract – **Calculating the stability of a vessel at moderate and big heeling angles by building Static Stability Curves. The method introduces the notation Dynamic Height of the Mass Centre (DHMC).**

Keywords – **Static Stability Curves, Dynamic Height of the Mass Centre, Metacentric Height**

I. Introduction

“Stability” is the ability of the vessel to return to its initial position before capsizing after the inclining forces have ceased to operate. Hence the stability issue is an issue of the ship behavior in transverse and longitudinal angle inclination caused by external effects. The change of the stability is searched by the change of the metacentric height and the corresponding coefficients. The existing dependences for evaluating the stability are based on the criterion of minimal starting metacentric altitude and guarantee basically the starting stability. This report presents a new method for evaluating the stability using “dynamic metacentric height” (DMCH).

II. Method for evaluating the DMCH

When sailing each vessel is exposed to external forces like wind, heavy sea, surge and etc. Its safety depends on the seaworthiness quality - stability. In basic aspects this means that the ship must counteract the negative force effects. That is to say not to heel to dangerous angles and to redress its initial balance after the external influences are over. According to the magnitude of the heeling angle θ (transverse inclination of the vessel) the stability is classified in two types: initial stability and stability at moderate and big angles of list (heel). In both cases the counteraction is due to the couple forces: buoyancy (Archimedes) force and the weight P. They form a moment M_r that is the bases of stability and is opposite to the heeling moment M_l. At small angles θ is defined the notation “initial metacentric height” $\overline{GM}$. This altitude is enough to evaluate the initial stability in details. (Figure 1)

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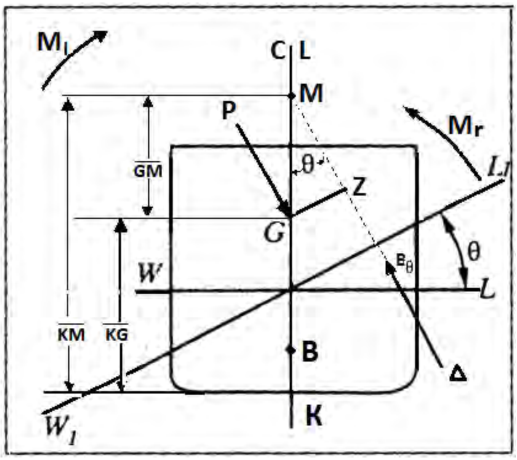

Fig.1. Stability at external effects

Furthermore, some basic assumptions are usually taken into consideration, one of which is the principle of the geometric inverse which states that the vessel is always considered upright and the waterline WL is inclining at a certain angle (θ). Assume that the point M is the cross point of the directrix of two infinitely closed buoyancy forces. At moderate and big angles of the heel, after applying the principle of geometric inverse, the point M doesn’t lie down in the diametrical plane CL of the ship. This assumption makes pointless the using of $\overline{GM}$ and it’s necessary to investigate the change of the arm $\overline{GZ}$ (the arm of the righting moment) or the righting moment itself (M_r). Hence

$$M_r = \Delta\overline{GZ} \tag{1}$$

could be represented as a function of the heeling angle θ

$$\overline{GZ} = f_1(\theta) \text{ or } M_r = f_2(\theta) \tag{2}$$

denoted as Static Stability Curve (SSC). (Figure 2)

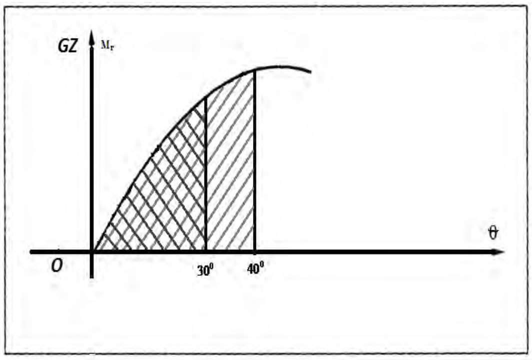

Fig.2 – Dynamic areas in Static Stability Curve

The SSC examination, used to evaluate the stability, is related to the way the external effects are enforces – static or dynamic [1]. In practice dominates the dynamic enforce. That's why the given evaluation is expressed in determining the work of the righting moment i.e. the magnitude of the area under SSC to certain heeling angles. The requirement of the International Maritime Organization (IMO) concerning the minimal values of the areas and angle ranges are lied down in resolution A749(18) as a guarantee for certain aspect of stability. They are the following [3]:

1) Area of diagram S_1 for $\theta = 0^0$ up to $\theta = 30^0$, $S_1 \geq 0.055$ (but not smaller than 0.055)m.rad
2) Area $S_2 \geq 0.09 m.rad$ up to the utmost angle χ, which is interpreted as the smallest of the three variants:
   a) flooding angle θ_f;
   b) heeling angle corresponding to $\overline{GZ}$ θ_m;
   c) angle equal to 40^0.
3) Area S_3 between $\theta = 30^0$ and $\theta = \chi$, $S_3 \geq 0.03 m.rad$

The direct building of the diagrams under the terms of IMO is too hard for the command staff because of the many calculations. Therefore the suggestion is to introduce in ship's papers a diagram of the dynamic height of the mass centre (DHMC) of the vessel that meets the required norms of IMO and represents the upper limit for placing the mass centre in height. That way in designing the cargo plan is estimated whether the obtained mass centre satisfies the requirements for dynamic stability.

In creating the shown diagram (fig.2) are examined all the SSC in the range from "empty" to "full" ship with given realistic height tolerance of the mass centre. It means that the arm of the righting moment $\overline{GZ}$ is considered as a function of the displacement ∇_i, the altitude of the mass centre $\overline{KG_j}$ and the accepted angle interval θ_n. (Fig. 3) Since the indicated argument define the arm of the form

$$\overline{KN}_{i,n} = f(\nabla_i, \theta_n) \tag{3}$$

and the arm of the height

$$(l_G)_{j,n} = \overline{KG}_j * \sin\theta_n , \tag{4}$$

hence

$$(\overline{GZ})_{i,j,n} = \overline{KN}_{i,n} - (\overline{KG})_j * \sin\theta_n . \tag{5}$$

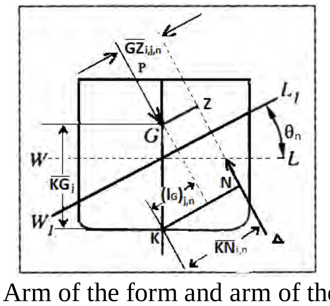

Fig.3 – Arm of the form and arm of the height

For the arm of the form $(\overline{KN})_{i,n}$ are used the KN - curves for the specific ship for $\theta = 10^0$, $\theta = 20^0$, $\theta = 30^0$ and often $\theta = 40^0$. (Fig. 3) Next step is to calculate the areas $S_{0^0-30^0}$, $S_{0^0-40^0}$ and $S_{30^0-40^0}$ (Fig. 2) for each SSC and compare them with the ones required in IMO. If the three areas are the same as the required or one of them is the same and the others are bigger, than the value $(\overline{KG})_{\max}$ is maximum acceptable altitude for positioning the mass centre according to this displacement. The graph of all $\overline{KG}_{\max} = f(\nabla_i)$ shows that the mass centre of the ship should not be above it when constructing a cargo plan [2].

The method is applied in the paper "An algorithm and a program module for calculating the border height of the mass centre of a vessel" using documentation from the Naval Academy's training ship "Nikola Yonkov Vaptsarov".

III. Conclusions

1) The evaluation of the stability using the dynamic height of the mass centre (DHMC)

$$\left(\overline{KG}\right)_{j\max} = f(\nabla_i) \tag{6}$$

is better than the existing similarly dependences

$$\overline{KG} = f(d) = f_1(\nabla), \ (d \text{ - draught}) \tag{7}$$

or

$$\overline{GM} = f(d) = f_2(\nabla) . \tag{8}$$

They are based on the criterion of minimal starting metacentric altitude and guarantee basically the starting stability i.e. they should not be considered as reliable evaluation of stability.

2) The suggested DHMC removes the necessity of building SSC when realizing a cargo plan. The results are as authentic as the more complex classical SSC.

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