INCLINOMETER DEVICE FOR SHIP STABILITY EVALUATION

Helena Carvalho Mendes, len_inh_a@hotmail.com
José Márcio do Amaral Vasconcellos, jmarcio@peno.coppe.ufrj.br
Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

Abstract. *The excess of weight in irregular positions is a major reason for toppling the vessel. Knowing the maximum slope that a ship can carry, without heel, and then restore its initial position is one of the most important knowledge to be able to load the ship without creating moments that prevent the restoration. A boat loaded in the wrong way may have a resulting moment that causes a tilt at sea, preventing the initial position to be restored. To avoid such a problem, we designed an inclinometer for evaluation of stability, which allows us to know the maximum time that the prototype, used as a model, can support and restore its position. Thus we have, with a margin of safety, the correct load to be used in certain type of vessel. The experimental evaluation along with numerical models widely used in commercial software allows a better assessment of the static stability intact and in a breakdown of the floating unit. This article presents the development of a project to build a mechanical device that could cause a moment and, consequently, an inclination in the studied model. Using also a numerical model, the experiment to assess the static stability of floating units and run simulations at damage also.*

Keywords: *model; stability; moment; tilt*

1. INTRODUCTION

A vessel at sea is subject to many forces, such as external, like the action of winds and waves, and internal forces, like the positioning of the load and the level of liquids in its tanks, able to tilt it, and even heel it. The toppling of a vessel, besides putting at risk the lives of all crew, leads to the loss of load, may cause damage to the environment, and consequently lead to a loss of millions of dollars.

As the forces of nature are not an exact science, the best way to prevent such accidents happening is the correct loading of the vessel. The positioning of loads has a direct influence on the position of the center of gravity which is, in turn, one of the factors responsible for the righting moment.

So, in order to obtain a better stability, there must be made an assessment of all forces involved in each type of vessel followed by a calculation of the righting moment necessary to restore the stability and, finally, an optimization of the position of center of gravity.

Considering the fact that the exact value of the righting moment can be difficult to calculate, this paper highlights an inclinometer design to obtain the exact value of the angle of maximum inclination supported by a vessel and the moment that causes it.

2. STABILITY OF FLOATING VESSEL

A vessel at sea is subject to a number of external and internal factors capable of destabilizing it, like we can see in Fig. 1. A boat is called stable when it is able to return to its initial position after the forces acting on are ended. We divided the stability evaluation in three groups: initial stability, stability for large angles and damage stability. Software is nowadays available for all stability evaluation but the experimental results are very useful to compare.

Stability behavior is a necessary requirement to be fulfilled by any vessel. Rules have to be follow and international e national codes should be achieved.

Figure 1. A ship subject to forces that causes an inclination

A recent work (Vasconcellos, 2006) shows that, when in the upright position in calm waters, the line of action of the weight force (*Wf*) and the buoyancy force (*Bf*) are acting in the same vertical as shown in Fig. 2. If the vessel is now tilted by an external force, the relative position of the center of gravity and the center of carina changes, causing a separation of the line of action of weight and buoyancy forces, which will be separated horizontally.

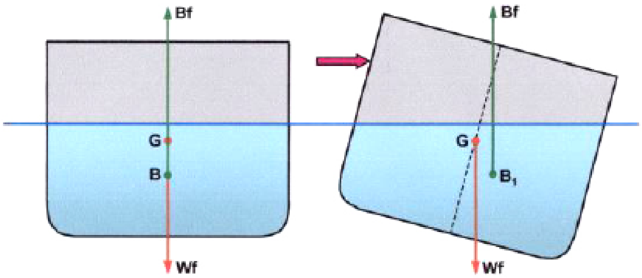

Figure 2. Position of center of gravity and the center of buoyancy

If the external force is removed it is clear that the vessel will return to its original position (vertical) as a result of the forces acting.

The horizontal distance between the center of gravity and the line of action of the buoyancy force, acting in the center of buoyancy, when the boat is inclined is defined as righting arm (GZ), shown in Fig. 3. When we multiply the results of the buoyancy force by the arm straightening we obtain the righting moment.

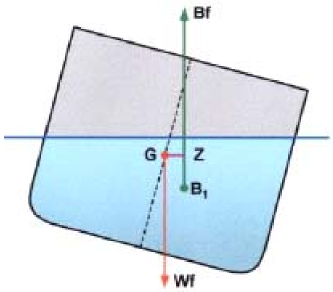

Figure 3. Righting arm (*GZ*)

The righting moment for any angle of inclination represents the instantaneous value of the capacity of the vessel to return to its original position. This is calculated when the boat is in calm waters and is momentarily at rest, in which case the acceleration forces due to the inclination movement are overlooked.

In naval engineering, the determination of weight and center of gravity of the vessel has a strong influence on the technical characteristics such as buoyancy, stability, performance and resistance to the sea propulsion, and is also the main parameter to estimate the cost and extent of progress in construction. The calculation for determining the weight and center of gravity starts at the beginning of the project and will evolve in the following phases until the end of construction.

With the calculations is possible to know the exact amount of ballast to be placed to ensure a better stability of the vessel. The correct stability can change with the use of the ship, load, and design. Because of that many sectors of maritime engineering have different criteria for stability to be ensured.

However, the imprecision in calculating the center of gravity and the weight is still very high even with all the technological advances. Several discrepancies can be observed between the initial values, as used in the construction documents, and the values obtained on the ship after its construction. As a result, it was necessary to enlarge the scope of service, having been checked and /or corrected over 2300 items of weight and 310 items of volume, a task that required great effort, lasting nearly 2 years.

The completion of this study identified the necessity for improvements in the process of control stability. Because of that, we work to design an inclinometer, a device that is able to make the inclining test, measuring the stability curve evaluation and many damage stability simulations also. The fundamental idea is simulate the behavior of the structure subject to many loading conditions and study the possibilities of damage and then determine the final state of fluctuation and stability of floating.

As part of a scientific student study we decide to design our own inclinometer device. One of the reasons is the high price offered by the specific market and the also the possibility to put the students in real challenge.

3. THE INCLINOMETER

The model tests are a powerful tool for the study /analysis of the complex hydrodynamic phenomena of floating vessels. These tests are done in models in small scale and they are designed to provide information about the behavior of vessels in real scale, particularly in cases where, due to complexity of physical phenomena involved, the numerical methods are not very precise.

The methodology of these tests for assessing the resistance to progress and propulsion, and to study the handling of vessels and determining the characteristics of buoyancy and stability, are already standard and they are an extremely useful tool available in the case of a vessel project.

There is a theoretical development to base the pattern of stability in tests of models for tests of inclination. This method was discussed and approved at the IMO (1975-1990). However, due to implementation of these tests is extremely expensive, they are not being made on a large scale, with few exceptions described below.

In general, the existing method was not used to develop stability criteria, but to investigate the modes of inclination, validate the theoretical predictions and evaluate the relation between the shape of the hull and the characteristics of stability and performance at sea.

Observing the behavior of the model in different situations, we obtain very useful information related to the inclination. This information has not been used to measure and improve the mathematical models for computer simulation of inclination of floating structures.

A proposal for classification of experimental models related to slope of vessels includes models for:

1) Tests that seek information of hydrodynamic forces which are used as input into equations of motion in mathematical models;
2) Tests that seek information about physical phenomena involved, when the boat tilt. Are also included in this group, test with models to explain the causes of heel;
3) Systematic tests with models of heel /tilt aiming the development of safety standards;

4. SIMILARITY OF CONDITIONS AND PREPARATION OF MODELS

To determine the possibility of estimating the behavior of a ship based in models tests, it is necessary to know the geometric similarity, kinematic and dynamic model.

Geometric similarity is satisfied when all the dimensions of the model are in scale. The scale of the model is given by Eq (1):

$$E = \frac{1\ \text{ship}}{1\ \text{model}} \tag{1}$$

For the tests of inclination, the geometric similarity and mass (weight and center of mass) ensures the quality of the prototype response given by the model response.

Once submitted to the righting moment, the vessel can either return to its position of balance or, in certain cases, capsize. To know if it is possible to maintain the balance of a ship it is necessary to know the moment that is causing the inclination and to obtain the maximum angle of tilt that can be restored.

The knowledge of the maximum angle of inclination is extremely important since this allows us to do a better risk analysis and, if necessary, make changes in the design or even the load distribution inside the ship in order to modify its righting moment and to ensure its stability in adverse sea conditions.

In order to discover the relation between moment and inclination in each vessel, we designed an inclinometer, as the one showed in Fig. 4, which, when subjected to a force, create a moment and, consequently, inclines the boat model.

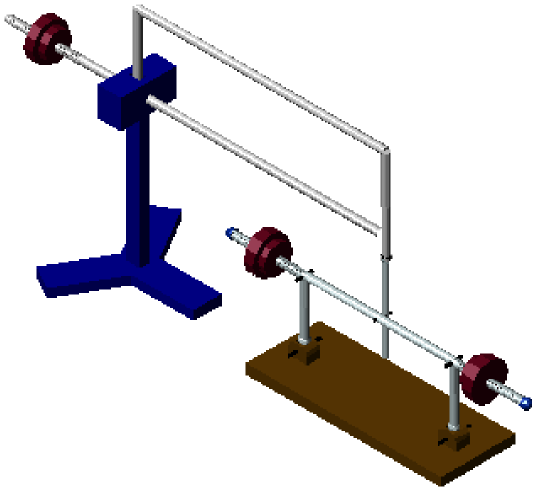

Figure 4. Design of the inclinometer

The equipment consists of a structure that is able to rotate. It is supported by the ship and sustained by a base, located outside the tank in which the experiment will occur. Weights of equal mass are placed on the top bar of the apparatus, equidistant from the center. After loading, is necessary to find the position of initial stability to be used for comparison.

When a weight is away from its initial position, the difference between the distances creates a lever arm and consequently a moment in the structure. This moment is given by Eq. (2), where *m* is the mass of the displaced weight, *g* is the gravity, θ is the angle of inclination of the structure end *d* is the distance between the initial and the final position of the weight.

$$M = [(m * g)\cos\theta] * \mathrm{d} \quad (2)$$

Then, this moment is equivalent transmitted to the model that will suffer an unknown inclination, as seen in Fig. 5. The tilt will be calculated by the apparatus by means of sensors.

Knowing the angle of inclination and the moment create, we can plot a graph of stability of the vessel, and, by the graph, we know its maximum strength until the moment of its heel.

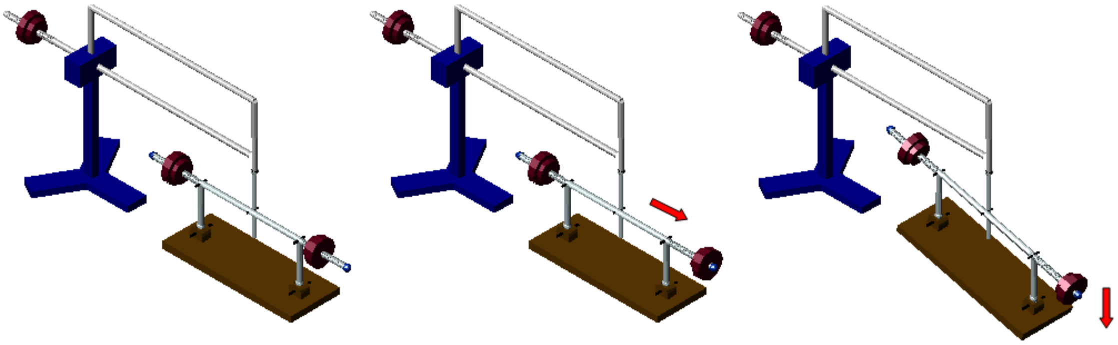

Figure 5. Handling of inclinometer

With the help of sensors and other electronic equipment we can move the weights by the computer and get the exactly distance of their displacement, beyond the exact angle of tilt. The data generated are sent directly to the computer that will evaluate and plot the graphs. Besides the faster analysis of data also have more real results with fewer errors.

5. CONCLUSION

Although the project is in its start phase, the primary prototype seems simple and very cost effective. The next phase results will be compared with software for stability curve evaluation and damage simulation performed.

As part of scientific student research this project is following the chronogram.

6. REFERENCES

Ferraz C., Souza V., Vasconcellos J.M., Experimento como Auxilio na Avaliação da Estabilidade Estática de Embarcações, SOBENA 2006.

Laboceano, Inertia Calculation Procedure for Model Test

Lech K. Kobylinski and S. Kastner, Stability and Safety of Ships, Ocean Engineering Series Editors, Elsevier, 2005.

Vasconcellos, J. M. A., 2006, “Studies of Stability”, studies in floating off-shore engineering systems, Class Notes.

Vasconcellos, J. M. A.,Cid M. 2006, “SOBENA”, calculation of weights and centers.