AUTOMATED INFORMATION SYSTEM FOR EVALUATION THE STABILITY OF THE SHIP

Emilia Koleva[1], Milena Lefterova[2], Mariya Nikolova[3]

N. Y. Vaptsarov NAVAL ACADEMY
73 V. Drumev St., Varna 9026, BULGARIA

E-mail: emilia_f@abv.bg[1]; mconsult.field@gmail.com[2]; mpn@abv.bg[3]

Abstract

The purpose of this paper is to present Automated Information System (AIS) used to evaluate the stability of a ship. The system is based on a new method for direct check of the ship's stability using the limited curves for the applicate of the center of gravity $\overline{KG}$ and the initial metacentric height $\overline{GM}$. The software provides an opportunity for buoyancy and stability evaluation of the ship in extreme situations. New recommend values for $\overline{GM}$ are set to minimize the human sickness, known as kinetosis. An advantage of the proposed and developed programming system is its work in interactive mode, in which there is a possibility to change the load on the ship from the command display.

1. INTRODUCTION

The safety of shipping is vital for the marine transport. When sailing each vessel is exposed to external forces like wind, heavy sea, surge and etc. Its safety depends on the seaworthiness qualities – buoyancy and stability. There is a growing need for opportunities for their current assessment in every moment, imposed by the circumstances.

In that matter there are new requirements for the software products on the board of the ship connected to the loading and the evaluation of the stability. After the enforcement of MARPOL Annex I, Regulation 28 and the resolution of Marine Environment Protection Committee [10] - MEPC.248(66) of the International Maritime Organization the ship owners are obliged to provide the necessary software on the board of the ship.

The resolution 66 of the Marine Environment Protection Committee (MEPC) is adopted on 04 April 2014 and entered into force on 01 January 2016. In accordance with the requirements of the resolution:

„All oil tankers shall be fitted with a stability instrument, capable of verifying compliance with intact and damage stability requirements approved by the Administration having regard to the performance standards recommended by the Organization." [4], [8], [9].

Oil tankers constructed before 1 January 2016 shall comply with this regulation at the first scheduled renewal survey of the ship after 1 January 2016 but not later than 1 January 2021.

Also statistics provided by IUMI, Global Marine Disaster Statistics and Lloyd Registry statistics show that the number of marine disasters and the magnitude of financial losses can be greatly reduced by ships modernization and the selection of trained and qualified crew. The use of information systems to assist the command staff in their day-to-day (routine) operations is also an opportunity in this direction.

2. AUTOMATED INFORMATION SYSTEM

The automated information system is based on a new method [2] [6], for the direct check of the ship's stability using the limited curves for the applicate of the center of gravity $\overline{KG}$ and the initial metacentric height $\overline{GM}$. The new method is based on the three-dimensional model of the hull form, mathematical model[7] for calculating the hydrostatic curves and $\overline{KN}$ – curves, the direct building of the static stability curves (SSC) and their normalization with the requirements of ISCode.

2.1. Software development environment

The software is realized in Matlab environment, version R2016b. One of the reasons for this choice is that Matlab is a software development environment that offers high-performance numerical computations (in this case the table of ordinates of the ship) and has a built-in function for 2D and 3D visualization.

2.2. Description of the software product

- The software uses the three-dimensional model of the hull, described by the expanded table of offsets, for receiving the hydrostatic curves. It gives the opportunity of plotting them not only when the ship is in normal condition, but when heeling and trim, leading to more accurate estimate of the stability of the ship. The hydrostatic curves are calculated for the trim range $\pm 1\% Lpp$. The received values could be displayed as graphics or in table form on the main screen of the software.

- The program calculates the $\overline{KN}$ – curves for the following operational trim range $\pm 1\% Lpp$. The received values could be displayed as graphics or in table form on the main screen of the software.

- Using the table of moments, a specific load on the ship could be set. The program calculates the current weight and the coordinates of the center of gravity of the ship for the current loading condition. The table with the new data is presented. There is a possibility of directly changing the load data in the table.

- The program system calculates the parameters of the equilibrium status of the ship and its initial stability. The received data is displayed.

- The righting arms are calculated and the static stability curves are built and displayed on the main screen of the program.

- The resulting data of all the calculations is stored in the programming environment.

- It is used to evaluate the intact stability of the ship in accordance with the requirements of IS-Code.

- The limited curves for maximal acceptable applicate's values of the center of gravity and minimum acceptable values of the initial metacentric height are built. The curves could be displayed at any time.

- The software could work also in an interactive mode. In this case changes could be made in the loading conditions from the command display.

- When the loading data is changed the system automatically updates the parameters of the equilibrium status of the ship and a new evaluation of the stability is made.

- In interactive mode some damage scenario (like flooding of separate cargo spaces) could be specified by the user from the main screen of the program. In this case the system evaluates the damage stability of the ship.

## 2.3. Description of the test ship used for the numerical research

The ship used for testing the automated system is chosen from the International Towing Tank Conference(ITTC) for the program SIMMAN[11]. The ship has a hull shape of a typical large tanker. (see Table 1).

Table 1. Main dimensions of the test ship

$Lpp = 320.00\,m$	Length between perpendiculars
$L_{WL} = 325.50\,m$	Length of waterline
$B = 58.00\,m$	Breadth of the ship
$D = 30.00\,m$	Depth of the ship
$d = 20.80\,m$	Draught of the ship
$V = 312622.00\,m^3$	Displacement of the ship
$C_B = 0.8098$	The block coefficient
$C_M = 0.9980$	Midship coefficient
$v_s = 15.50\,kn$	Speed of the ship

The exact 3D geometry of the ship hull is described by an expanded table of offsets. The table contains half-breadths measured at 65 stations and 200 control points (100 for each board) for each station.

On figure 1 is shown a 3D visualization of the test ship.
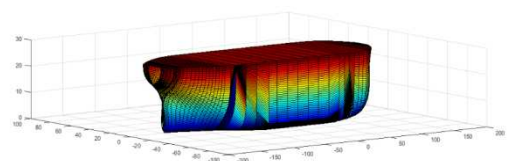
Figure 1. 3D visualization of the test ship

2.4. Validation and verification of the program product

The software calculates all necessary characteristics related to the buoyancy and stability of the ship. The validation of the obtained results is based on a comparison of the ship's seaworthiness quality –

buoyancy with the test ship data. For example, the estimated volume displacement of the ship for its projected draught differs from the one of the test ship by 0.1%, which is within the range recommended for analogue programming systems [3] - 2%.

2.5. Command display of the automated system

The main element of the automated information system is the command display. It consists of three panels. The first one contains tables, the second is graphical and visualizes the current static stability curve, and the third panel can visualize the hydrostatic curves, the $\overline{KN}$ – curves and the diagrams for maximal acceptable applicate's values of the center of gravity $\overline{KG}$ and minimum acceptable values of the initial metacentric height $\overline{GM}$ (see figure 2).

Changes to the table of moments can be entered from the command display (see figure 2). The system automatically checks for data entry irregularities, alerts for errors, and disables correction for light ship's data.
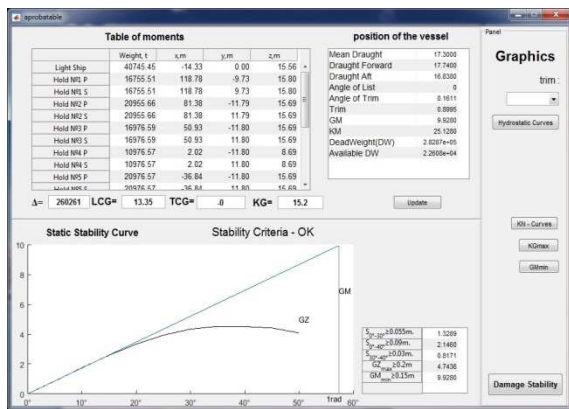

Figure 2. Command display of AIS

The changed loading data for a given compartment could be saved in the program environment after clicking the Update button. The system automatically updates the parameters of the equilibrium status of the ship and a new evaluation of the stability is made. A new SSC is generated according to the new condition. The current SSC of the ship is displayed for the assigned loading and its characteristics in accordance with the requirements of the IS Code.

The trim values ($t = -1, 0, 1, 2\ m$) could be selected from the third panel via drop-down menu and the corresponding hydrostatic curves and the $\overline{KN}$ –

curves are displayed. The $\overline{KN}$ – curves for trim $t = 0\ m$ are shown on figure 3.
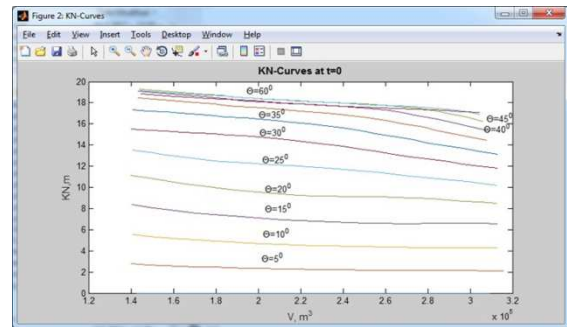

Figure 3. $\overline{KN}$ – curves for $t = 0\ m$

Notwithstanding the possibility of direct evaluation of the ship stability using the direct building of the SSC and its compliance with the requirements of ISCode, in the program system is integrated a program module for direct building of the limited curves for maximal acceptable applicate's values of the center of gravity $\overline{KG}$ (see figure 4) and minimum acceptable values of the initial metacentric height $\overline{GM}$ (see figure 5).
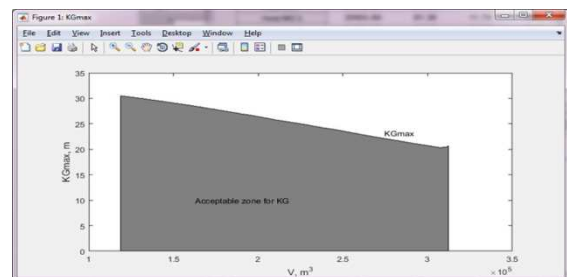

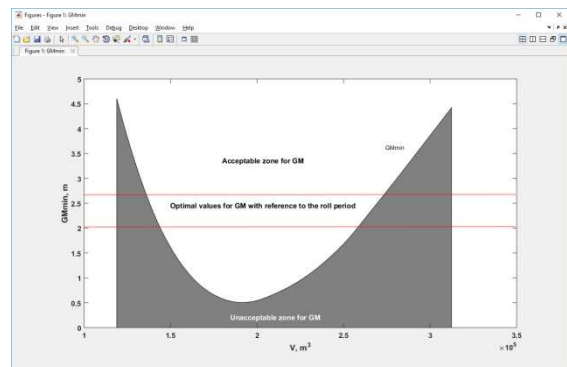**Figure 4.** Limited curve for maximal acceptable $\overline{KG}$

Figure 5. Limited curve for minimum acceptable $\overline{GM}$

If the calculated values for $\overline{KG}$ and $\overline{GM}$ for a given displacement are in the acceptable zones of the corresponding diagrams, the ship is considered to be stable. The limited curves meet all the requirements of ISCode. They give the opportunity for

direct evaluation of the ship stability (without building the SSC) for the chosen loading condition.

The stability of the ship, as one of its important seaworthiness qualities, is closely related to the life aboard the ship. Excessive stability leads to intense and sharp fluctuations during navigation. As a result, there are a number of negative consequences for the human body ("kinetosis"). In maritime practice this state is known as sea sickness. By choosing optimal values of ship characteristics, the kinetic symptoms can be significantly reduced. For the purpose additional curves are built in the programming system, to the abovementioned limiting curve $\overline{GM}$. They are used to define an optimal zone for stability characteristics guaranteeing minimal manifestations of sea sickness.

It's well known that the main problem with the oscillating movements that the ship performs during sailing is the intensity of rolling. The average values of natural roll frequency for different kinds of marine ships are:

Marine transport vessels: 7–12s.
Large passenger ships: 16–20s.
Passenger ship (up to 10000 t.): 10–15s.
Tugboats and fishing vessels: 6–10s.

These values are obtained by (1). The formula presented the direct relationship between the metacentric height and the roll period.

$$T_\theta = \sqrt{\frac{I_x + \lambda_{44}}{\Delta g \overline{GM}}} \ , \qquad (1)$$

where:

T_θ - rolling period,

I_x - the transverse moment of ship inertia,

λ_{44} - the moment of added mass due to water dragging by the rolling hull,

Δ - weight of the vessel.

The values of I_x and λ_{44} are calculated in the table of moments of the AIS.

After applying formula (1), two red straight lines corresponding to $\overline{GM} = 2{,}02 \, m$ and $\overline{GM} = 2{,}63 \, m$ are build. They are shown on figure 5. The first value is for a roll period $T_\theta = 12 \, s$, and the second one for $T_\theta = 7 \, s$. Choosing a value for $\overline{GM}$ between the two bars guarantees smooth fluctuating

movements with a period in the required range. From the figure it is apparent that it is not possible to select such values for some displacements of the ship.

2.6. Application of the AIS

The program system is applicable to different types of marine transport vessels.

The software is built in a way that takes into account the specifics of a particular ship. It is possible to use it as an OBSS as well as in a separate operating center.

The program system could work in two modes:
   - Assessment of stability parameters and ship's equilibrium status for different load cases based on the hydrostatic data, stored in the program environment, including different load cases preview prior to the actual loading of the ship.
   - Working in interactive mode. In this case, the changes in the table of moments might be inputted from the command display, including imitation of extreme situations associated with flooding of individual compartments and tanks in the ship.

Expansion of the capabilities of the programming system is foreseen by an additional module allowing the capture of signals from sensors located in the ship's hull and receiving the data for the current ship's loading.

3. CONCLUSION

The system is applicable to different types of marine transport vessels and the software is built in a way that takes into account the specifics of a particular ship.

The programming system enables the assessment of buoyancy and stability during the exploitation and simulates extreme situations.

The program system allows users to choose an optimal value for $\overline{GM}$ with reference to the roll period, guaranteeing minimal manifestations of sea sickness.

An advantage of the proposed and developed programming system is its work in interactive mode, in which there is a possibility to change the load on the ship from the command display.

The software could be used as an OBSS, in a separate operating center and in the educational program for marine cadets.

References

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