DEVELOPMENT OF AN ALGORITHM FOR CALCULATING THE STABILITY OF A SHIP, APPLIED IN OBSS

*Emiliya Koleva *, Mariya Nikolova*

Naval Academy "N. Vaptsarov", Varna,
Bulgaria

*Corresponding Author: e-mail: e.koleva@nvna.eu

Abstract: The paper presents an algorithm of the developed on board stability system (OBSS). The OBSS covers the new requirements for damage stability on tankers. The methods for calculations provide the opportunity to build the hydrostatic and the cross curves at a given condition. The program includes a module for direct construction of the limited curves for the maximum allowable applicable values of the center of gravity KG and the minimum allowable values of the initial metacentric height GM. In addition, a range of allowable values for GM is defined, which guarantee smooth fluctuating movements and minimize the kinetic symptoms.

Key words: algorithm, marine transport vessel, Matlab, software, stability criteria, sea sickness.

1. INTRODUCTION

With the development of contemporary information technologies, the volume of information that must be stored and protected from unauthorized access is growing [1-3]. For ships, this is particularly important given the large amount of data that is stored and processed. In addition to personal data, the ship`s information systems also store cargo data related to the stability of the ship. During operation, the need of the stability check of the ship occurs in any time, otherwise the lack of it may result major accidents and disasters. The stability check is fully achieved by directly plotting the static stability curve (SSC), which requires a significant amount of computing and graphics activity. In accordance with the requirements of the International Convention for the Prevention of Pollution from Ships (MARPOL convention), from 2021 tankers have to be fitted with a stability instrument capable of verifying the relevant intact and damage stability requirements [4].

The paper presents an algorithm for calculating the intact and damage stability, designed for marine transport vessels. The proposed algorithm has been applied and an on board stability system was made. The software is consisted with the requirements of the MARPOL convention. It is realized in Matlab R2016b environment and run on a 2.40 GHz PC with 4.0 GB RAM. It is type 2 stability software [5] – software calculating intact stability [6, 7] and checking damage stability on basis of a limit curve or previously approved loading conditions.

There are two types of calculations: experimental and corresponding to real sailing conditions. So, the system has two modes: simulation of loading conditions based on pre-calculated and stored in the programming environment information and interactive mode. Changes could be made in the loading conditions in the second case, or some damage scenario could be specified by the user from the main screen of the program.

2. EVALUATION OF SHIP DISPLACEMENT. PLOTTING THE HYDROSTATIC AND CROSS CURVES

The ship used for testing the program is chosen from the International Towing Tank Conference for the program SIMMAN [8]. The main dimensions of the test ship are shown in Table 1.

Table 1. Main dimensions of the test ship

Parameter	***Value***
Length between perpendicular	*Lpp =320 m*
Length at waterline	L_{WL}= *325.50 m*
Breadth	*B=58.00 m*
Depth	*D=30 m*
Draft	*d=20.80 m*
Displacement Volume	*V=312622.00 m3*
Block coefficient	C_B=*0.8098*
Midship coefficient	C_M=*0.9980*
Speed	v_s=*15.50 kn*

The system starts from the exact 3D geometry of the ship hull, described by the expanded table of offsets. Using it, a 3D visualization of the test ship is drawn in Matlab, and shown on fig. 1.

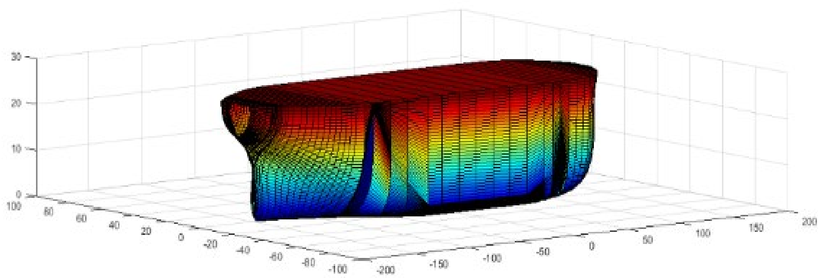

Fig. 1. Ship hull

The program contains initialized program module. It involves the calculation of the hydrostatic curves and the cross-curves, needed for the further operation of the program. The limited curves for $\overline{KG}$ and $\overline{GM}$ could be introduced in the ship's documents as reliable evaluation of stability. This module should be executed only once – on the first use of the software. The flow chart of the algorithm used for receiving the data is shown on Fig. 2.

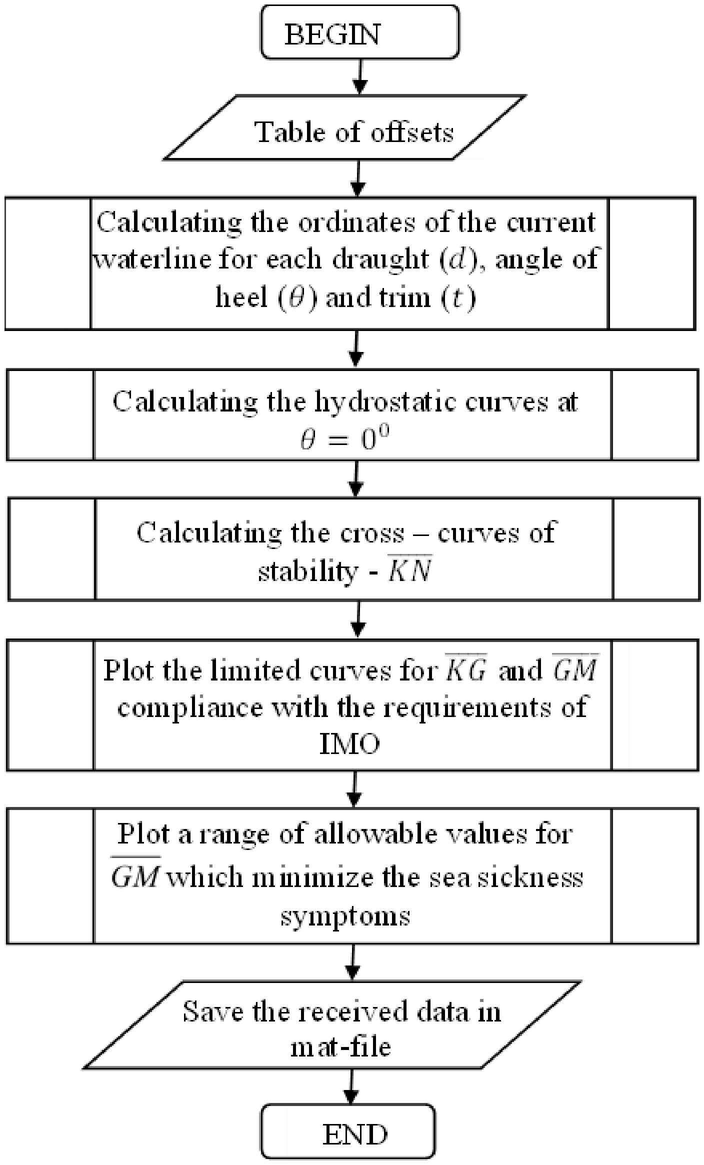

Fig. 2. Flow chart of the initialized program module

The software uses the description of the hull known as table of offsets for receiving the hydrostatic curves [9]. This 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 parameters, cross-curves and limit-curves for $\overline{KG}$ and $\overline{GM}$ are calculated for the trim range +/-1.0% Lpp.

The predefined process „Calculating hydrostatic curves at $\theta = 0^0$ is shown in separate flow chart in Fig.5. The formulas [10, 11] used in it for:

- calculating the elements of the current waterline are:

$$A_W = \int_{x_A}^{x_F} (y_{\theta s} - y_{\theta p}) dx \tag{1}$$

$$M_{\theta x} = \frac{1}{2} \int_{x_A}^{x_F} (y_{\theta s}^2 - y_{\theta p}^2) dx \tag{2}$$

$$M_{\theta y} = \int_{x_A}^{x_F} (y_{\theta s} - y_{\theta p}) x dx \tag{3}$$

$$I_{\theta_x} = \frac{1}{3} \int_{x_A}^{x_F} (y_{\theta s}^3 - y_{\theta p}^3) dx \tag{4}$$

$$I_{\theta_{yF}} = \int_{x_A}^{x_F} (y_{\theta s} - y_{\theta p}) x^2 dx \tag{5}$$

- calculating the underwater volume features are:

$$V_\theta = \int_{x_A}^{x_F} \int_{d_1}^{d_2} (y_{\theta s} - y_{\theta p}) dz_\theta dx \tag{6}$$

$$M_{\theta yz} = \int_{x_A}^{x_F} \int_{d_1}^{d_2} x (y_{\theta s} - y_{\theta p}) dz_\theta dx \tag{7}$$

$$M_{\theta xz} = \frac{1}{2} \int_{x_A}^{x_F} \int_{d_1}^{d_2} (y_{\theta s}^2 - y_{\theta p}^2) dz_\theta dx \tag{8}$$

$$M_{\theta xy} = \int_{x_A}^{x_F} \int_{d_1}^{d_2} (y_{\theta s} - y_{\theta p}) z_\theta dz_\theta dx \tag{9}$$

where $y_{\theta s}(i)$, $y_{\theta p}(i)$ - are ordinates of control points on the surface of the hull for starboard and port of the ship for given angle of heel; $z_\theta(i)$ –applicate of control points on the surface of the hull of the ship.

They are calculated as a function of the angle of the heel using the coordinate transformation:

$$y_\theta = y.\cos(\theta) + z.\sin(\theta) \quad (10)$$

$$z_\theta = z.\cos(\theta) - y.\sin(\theta) \quad (11)$$

where y, z are ordinates and applicates of the control points on the surface of the hull of the ship when it is in the upright condition.

The hydrostatic curves for trim $t = 0\ m$ and $t = -1\ m$ are displayed on fig.3 and fig.4.

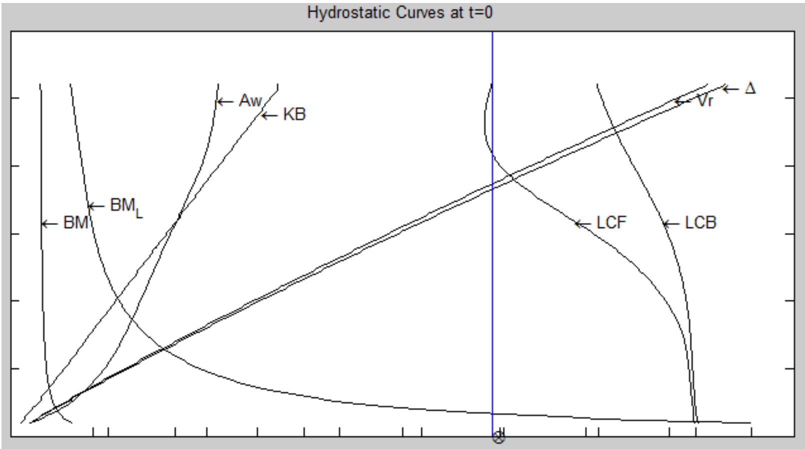

Fig. 3. Hydrostatic curves at t=0

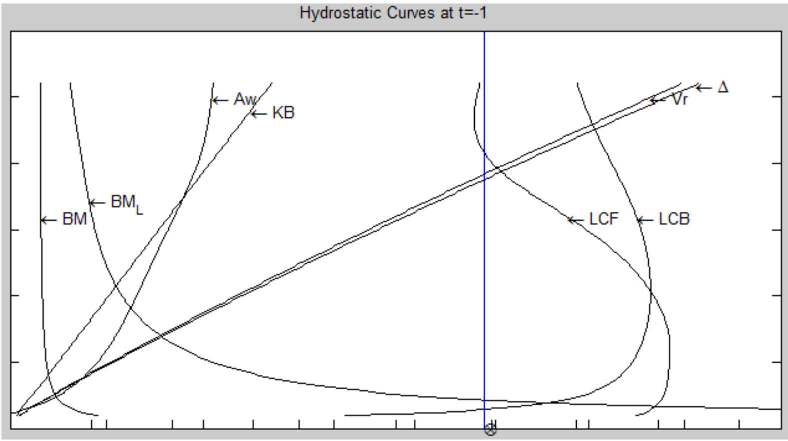

Fig.4. Hydrostatic curves at t=-1

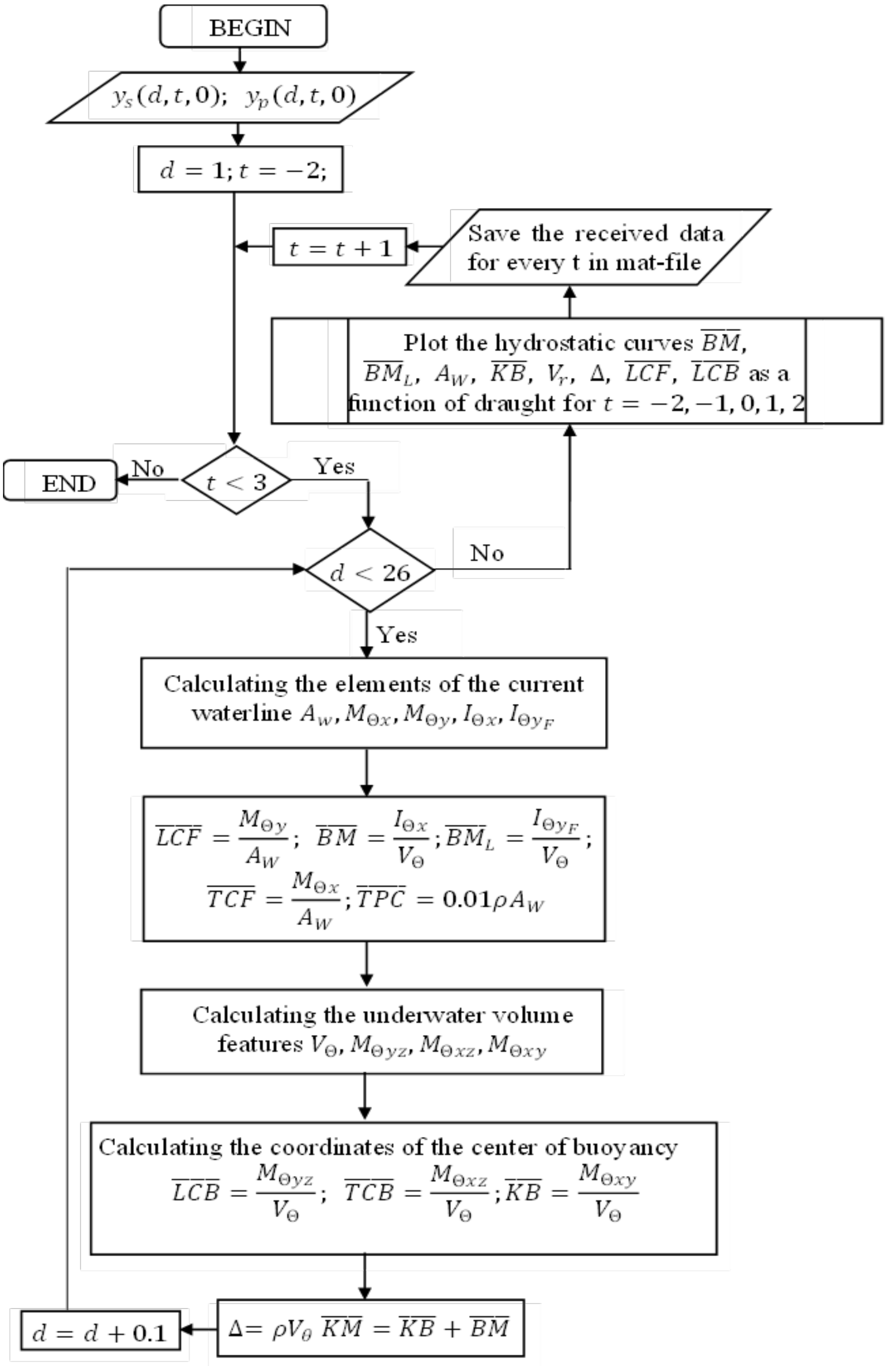

Fig. 5. Flow chart of the predefined process "Calculating hydrostatic curves at $\theta = 0^0$"

3. CALCULATING THE STABILITY OF THE SHIP

3.1. Loading of the ship and equilibrium status

The program system calculates the parameters of the equilibrium status of the ship on the basis of iterative process. The loading of the ship is in accordance with its periodically updated table of moments. The program takes into account the free surface effect of the loaded liquids using the actual coordinates of the center of gravity. If there is a tank gauging system onboard it could be also integrated in the automated program for impact and damage stability. The results of the equilibrium condition calculations are the values of the following parameters: angle of heel, angle of trim, trim, draught – forward, aft and mean. The received values are displayed on the main screen of the software.

3.2. Intact Stability

The stability of the ship is evaluated by the change of the initial metacentric height $\overline{GM}$ – for initial stability. The current values are displayed on the main screen of the program, below the table of moments. The stability at moderate and big heeling angles is clearly made by graphical interpretation of the SSC for given loading condition. The check is assumed to satisfy all the requirements of ISCode [12, 13]. In assessing of the weather criterion, the actual windward area is reported for the corresponding draught value [14, 15.

The righting arms are calculated, based on the calculated and stored in the program environment values for the form stability arms ($\overline{KN}$), which are received for each displacement from "empty" to "full" ship and for an angle of heel from 50 to 600 at intervals of 50. The calculations for the form stability arms are made for the following operational trim range: -2.0, -1.0, 0.0, 1.0 and 2.0 meters. To ensure equal volume of the inclination of the ship, the calculations for $\overline{KN}$ are made again also in interactive mode. The current SSC is displayed on the main screen of the program.

Notwithstanding the possibility of direct evaluation of the ship stability and its compliance with the requirements of ISCode, in the program system is built a program module for direct building of the limited curves for maximal acceptable applicate's values of the center of gravity $\overline{KG}$ (fig.6) and minimum acceptable values of the initial metacentric height $\overline{GM}$ (fig.7) [16-18]. 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. If necessary, they can be displayed on the main screen.

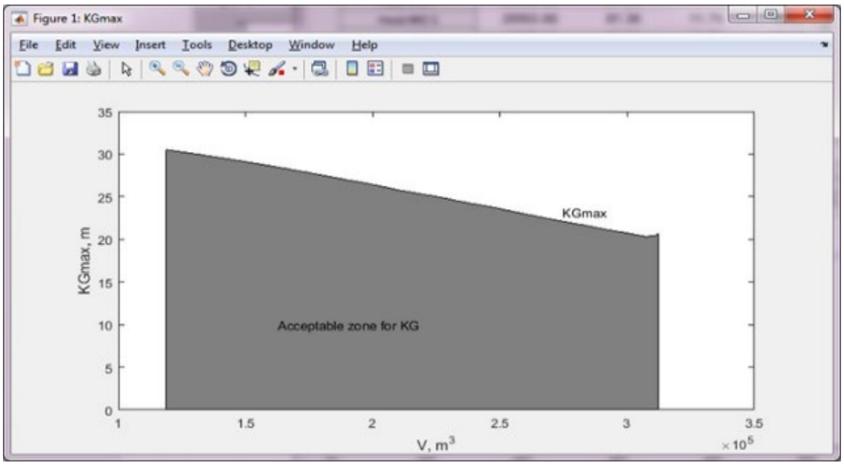

Fig. 6. Limited curve for maximal acceptable $\overline{KG}$

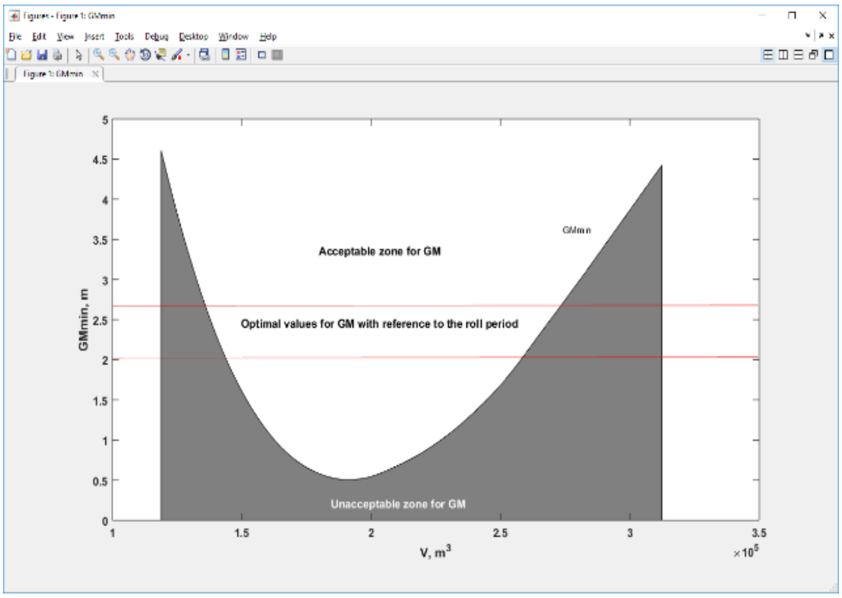

Fig. 7. Limited curve for minimum acceptable $\overline{GM}$

Stability is one of the most important seaworthiness of a ship related to crew safety. Excessive stability causes the ship to intense and sharp fluctuations and increases the risk of "kinetosis", also known as "sea sickness". The choice of optimal values of the characteristics of the ship can reduce the manifestation of clinical symptoms of kinetosis. For this purpose, additional curves to $\overline{GM}$ are constructed in the software system, shown in fig. 7. They are used to determine the optimal zone of 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 roll period is typically calculated based on the initial metacentric height of a ship (1) [19, 20]. The average values of natural roll frequency for different kinds of marine ships, obtained by (1), 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.

$$T_\theta = \sqrt{\frac{I_x + \lambda_{44}}{\Delta g \overline{GM}}} \tag{12}$$

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 Automated information system.

After applying formula (1), two values for $\overline{GM}$ are received. The first value $\overline{GM} = 2{,}02m$ is for a roll period $T_\Theta = 12s$, and the second one $\overline{GM} = 2{,}63m$ for $T_\Theta = 7s$. The results obtained for the $\overline{GM}$ are plotted in the form of two horizontal lines. They are shown on fig. 7. Choosing a value for $\overline{GM}$ between the two vertical red lines ensures smooth fluctuating movements with a period in the required range. To select a specific value for $\overline{GM}$ in the given interval, the current displacement of the ship must be taken into account. Fig. 5 shows that there are displacements of the ship for which no value for $\overline{GM}$ can be selected in the given range.

3.3. Damage Stability

In this approach damage is applied directly to the approved loading conditions on a case by case basis. The calculation is performed for a series of alternative damage cases. The program calculates all the data for the damaged ship. The equilibrium status of the ship is calculated based on the method of the constant displacement. Stability of the ship is checked on the basis of the above approaches. The resulting SSC are analyzed, so that they need the requirements for damage stability IMO/MARPOL.

The limited curves for maximal acceptable $\overline{KG}$ and minimum acceptable $\overline{GM}$ are built for the given damage condition.

The algorithm used in the program for calculating the intact and damage stabiity is shown on fig. 8.

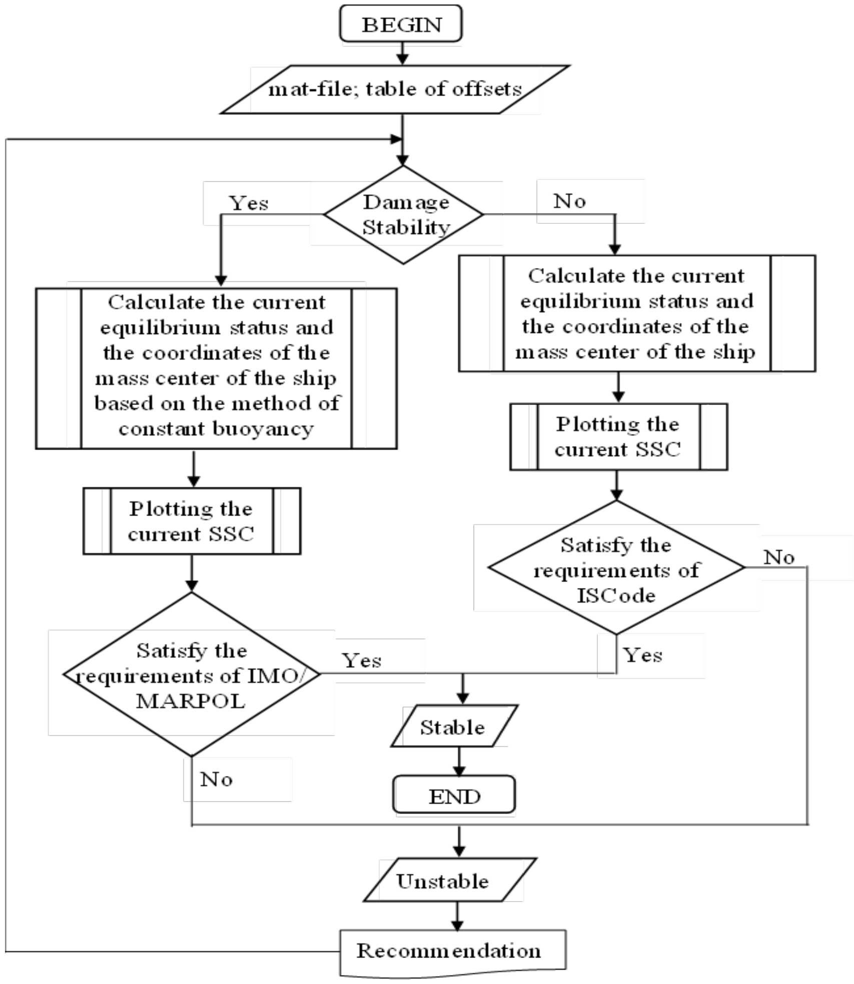

Fig. 8. Flow chart of the main program

4. CONCLUSION

The automated system, based on the proposed algorithm, is convenient tool for daily use on the board of the ship. The system provides an opportunity for buoyancy and stability evaluation of the ship in the absence of loading software or in extreme situations.

The algorithm is developed in accordance with the requirements of the international conventions for fitting all the tankers with such kind of software.

The automated system could be use in the educational program for marine cadets. 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.

REFERENCES

[1] Romansky, R., Privacy and Data Protection in the Contemporary Digital Age, *International Journal on Information Technologies and Security*, vol. 13, No.4. 2021, pp. 99-110.

[2] Noninska, I., Romansky R., Organization of Technological Structures for Personal Data Protection. *International Journal on Information Technologies and Security*, vol. 14, No. 1, 2022, pp. 97-106.

[3] Yordanova, Y., Andreev, E., The impact of technology on the maritime industry. *Proc. of the Annual University Scientific Conference*, Bulgaria, June 28-28, 2019, pp. 130-136, ISSN 1314-1937 (in Bulgarian).

[4] http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_I/r28.htm

[5] https://rules.dnv.com/docs/pdf/gl/maritimerules/gl_vi-11-7_e.pdf (visited on 10.01.2022).

[6] Francescutto A., Intact stability criteria of ships—Past, present and future, *Ocean Engineering,* ISSN 0029-8018, vol. 120, 2016, pp. 312–317, https://doi.org/10.1016/j.oceaneng.2016.02.030.

[7] Woo D., Nam-Kyun, Im, A Methodology for Simply Evaluating the Safety of a Passenger Ship Stability Using the Index for the Intact Stability Appraisal Module, *Sensors (Basel)*, 22(5):1938, 2022, doi: 10.3390/s22051938.

[8] http://www.simman2008.dk/ (visited on 10.01.2022).

[9] Biran, A., Pulido, R., *Ship Hydrostatics and Stability*, 2nd Edition, ISBN13: 9780080982878, Elsevier Science & Technology, United Kingdom, 2014.

[10] Lefterova, M., *Mathematical models of ship maneuverability*, ISBN 978-954-20-0810-1, University publishing house, Technical University of Varna, Bulgaria, 2020 (in Bulgarian).

[11] Lefterova, M., Verification and Validation Strategy for Precisely Drag Estimation of ERCOFTAC Test Body, *Proc. "Black Sea'2010"*, Bulgaria, 2010, pp.150-156, ISSN 1314-0957.

[12] IMO, *Code on Intact Stability 2008*, ISBN: 9789280117202, International Maritime Organization, United Kingdom, 2020.

[13] https://imorules.com/IMORES_A749.18.html (visited on 10.01.2022).

[14] Degan, G., Braidotti, L., Marinò, A., Bucci, V., Lctc ships concept design in the north europe-mediterranean transport scenario focusing on intact stability issues, *Journal of Marine Science and Engineering,* vol. 9, No. 3: 278, 2021, https://doi.org/10.3390/jmse90302782021.

[15] Liwång, H., Exposure, vulnerability and recoverability in relation to a ship's intact stability. *Ocean Engineering*, ISSN 0029-8018, vol. 187, 2019, https://doi.org/10.1016/j.oceaneng.2019.106218.

[16] Koleva, E., Lefterova, M., Nikolova, M., Evaluation of Ships Stability using Matlab, *Mechanics of Machines*, ISSN 0861-9727, vol. 1, 2017, pp.94-98.

[17] Koleva, E., Nikolova, M., Eremieva, M., Sabeva, V., An algorithm and a program module for calculating the border height of the mass centre of a vessel, *ICEST 2012 Proceedings of the XLVII International Scientific Conference on. Information, Communication and Energy Systems and Technologies*, 2012, Bulgaria, ISBN: 978-619-167-002-4, pp.159-162.

[18] Eremieva M., Sabeva V., Nikolova M., Koleva E., Method for calculating the stability at moderate and big heeling angles of a vessel, *ICEST 2012 Proceedings of the XLVII International Scientific Conference on. Information, Communication and Energy Systems and Technologies*, Bulgaria, 2012, pp.263-264, ISBN: 978-619-167-003-1.

[19] Chung, J., Shin, D., M., Kim, W., D., Moon, B.Y., Current Status of the 2nd Generation of Intact Stability: Investigation of the Pure Loss of Stability and Parametric Roll Mode, *Journal of Ocean Engineering and Technology*, Vol. 34. 2020, https://doi.org/10.26748/KSOE.2019.047.

[20] Wawrzyński, W., Krata, P., Method for ship's rolling period prediction with regard to non-linearity of GZ curve, *Journal of Theoretical and Applied Mechanics*, ISSN 1429-2955, vol. 54, No. 4, 2016, pp.1329-1343, https://doi.org/10.15632/jtam-pl.54.4.1329.

Information about the authors:

Emiliya Koleva – Assist. Prof.. at the Department "Mathematics and Physics " in the Nikola Vaptsarov Naval Academy, Varna, Bulgaria. Areas of scientific research: Automation, Programming, Mathematical models, Algorithms.

Mariya Nikolova – Assoc. Prof., PhD at the Department "Information Technologies" in the Nikola Vaptsarov Naval Academy, Varna, Bulgaria. Areas of scientific research: Mathematical and simulation modeling, Programming, Web design.

Manuscript received on 17 March 2022