

Dynamics of the Moving Ship at Complex and Sudden Impact of External Forces

Bo Liu, Liangtian Gao, Idrees Qasim

Abstract—The impact of the storm leads to accidents even in the case of vessels that meet the computed safety criteria for stability. That is why, in order to clarify the causes of the accident and shipwreck, it is necessary to study the dynamics of the ship under the complex sudden impact of external forces. The task is to determine the movement and landing of the ship in the complex and sudden impact of external forces, i.e. when the ship's load changes over a relatively short period of time. For the solution, a technique was used to study the ship's dynamics, which is based on the compilation of a system of differential equations of motion. A coordinate system was adopted for the equation of motion of the hull and the determination of external forces. As a numerical method of integration, the 4th order Runge-Kutta method was chosen. The results of the calculation show that dynamic deviations were lower for high-altitude vessels. The study of the movement of the hull under a difficult situation is performed: receiving of cargo, impact of a flurry of wind and subsequent displacement of the cargo. The risk of overturning and flooding was assessed.

Keywords—Dynamics, statics, roll, trim, dynamic load, tilt, vertical displacement.

I. INTRODUCTION

CASES of accidents and deaths of river and sea vessels that have occurred during recent years make scientific analysis of some provisions on the stability of vessels relevant. Possible causes of accidents are:

- complex character and high level of external impacts on the ship, exceeding the normative value;
- complex dynamics of ship behavior as a reaction to external impacts;
- unskilled crew actions during the operation of the vessel.

All recommendations and regulations related to ship intact stability and safety against capsizing issued by the International Maritime Organization (IMO) are consolidated nowadays in the international code on intact stability (2008 is code) adopted by res. msc.267(85) on 4th of December 2008 [1]. The safety of the vessel's navigation is established by the satisfaction of the "weather criterion". The weather criterion determines the continuity of the dynamic angle of the ship's roll resulting from the action of the standard heeling moment of a certain value (tilting angle, filling angle, regulated value). The non-overturning of a vessel from a suddenly applied heeling moment is the first of the safety criteria for navigation. Non-slashing of the hull through the holes when the vessel is tilted is the second of the ship's safety criteria. The limiting value of the dynamic roll angle is, in this case, the angle of

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filling, which is determined in advance using an approximate geometric construction, which is not fully justified. In the case of a strong impact of external forces or a strong vessel reaction, such a construction will not be possible due to the additional incremental angle of the trim and the vertical movement of the hull.

II. PURPOSE AND METHODS OF RESEARCH

To solve this problem, it is necessary to investigate this issue based on approaches and mathematical models of ship dynamics (rolling and controllability of the ship). Methodically, the solution of the ship's dynamics problems is based on the classification of the system of differential equations of motion; the definition of the forces acting on the hull and integration of the equations of motion and analysis of the results obtained.

In numerous solutions of the ship's dynamics problems, the end result is the hull position, defined in the parameters of the fixed coordinate system $o\xi, \eta, \zeta$. At the same time, the simplest form exists, the equations of motion and many categories of external forces are determined in the coordinate system g, x, y, z , which is related to the body.

Because of the complexity and cumbersomeness of the resulting equations, it is often necessary to consider individual particular types of hull movements and apply particular or combined types of computational equations of motion (Fig. 1).

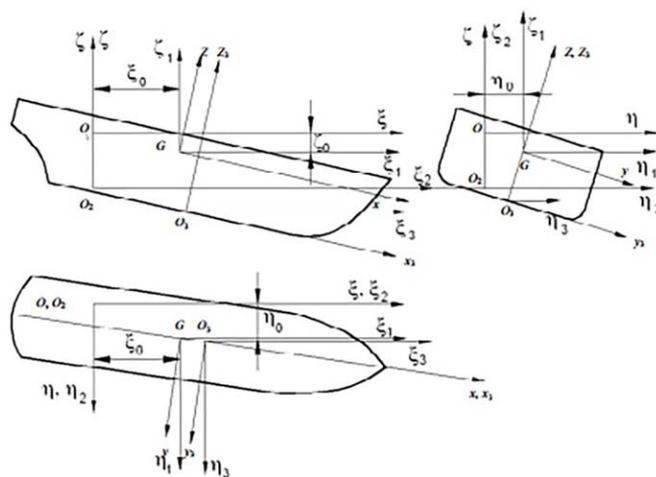


Fig. 1 Coordinate systems

To determine the landing and movement of the ship, the following coordinate systems are used [2]-[4]:

- (1) O, ξ, η, ζ is a fixed coordinate system designed to read the linear displacements of the hull. The Oz axis is vertical,

we integrate by the numerical method. Block diagram of the algorithm Landing, oriented to the use of sufficiently powerful computers, is shown in Fig. 3.

As examples for the calculations, the hull of a small passenger vessel was drawn, the outlines of which are shown in Fig. 4.

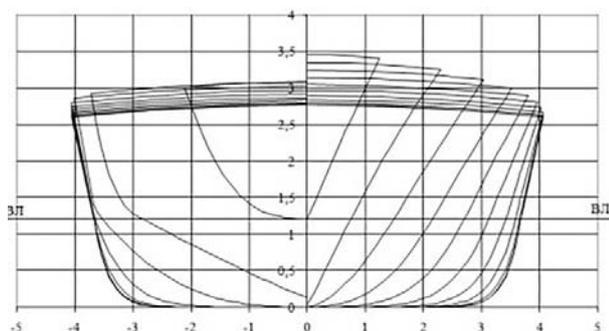


Fig. 4 Body plan

When choosing a numerical integration method, the Runge-Kutta method was used in the 4th order. In the flowchart, the algorithm TKOST is compiled according to the recommendations [7], using the method of the cross section of the hull and the rule of trapezoids with non-equidistant ordinates in the computation of certain integrals. The initial information is the arrays of coordinates of the transverse-vertical cross sections (frames) of the theoretical case.

III. RESULTS OF THE STUDY

In the Static method, the inclination of the ship's hull is kinematically regarded as a rolling along the horizontal plane of the "rolling curve" F0, F1, F2, etc. The horizontal component of this movement is not taken into account, the inclination of the hull is assumed to be equal to the volume, and the rotation of the hull is carried out around the axes F0x, F1x, F2x, and so on [8].

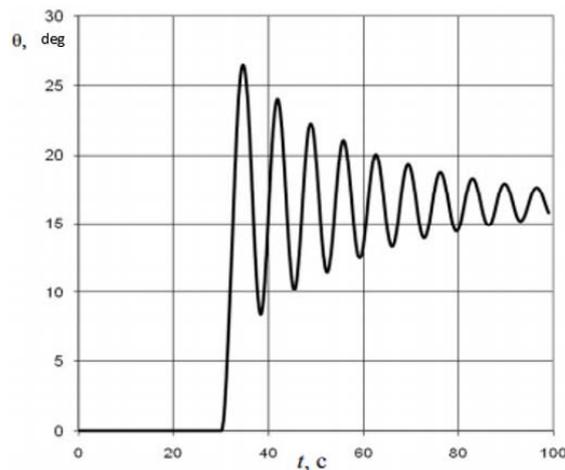
In the Dynamics method, the movement of the hull of a ship, described by the system of differential equations (1), is represented as a set of rotations of the axes Gξ, Gη (roll and trim) and displacement in the vertical direction, therefore the results for determining the hull movement and the landing parameters may be different. The difference depends on the ratios of the main dimensions (mainly on the ratio H / T). For high-altitude vessels, there are fewer dynamic deviations, while for low-altitude vessels there are more.

According to the developed algorithm and the program Landing, the dynamics of the ship is taken into account when receiving the cargo, in the subsequent application of the heeling moment and the displacement of the cargo [9], [10].

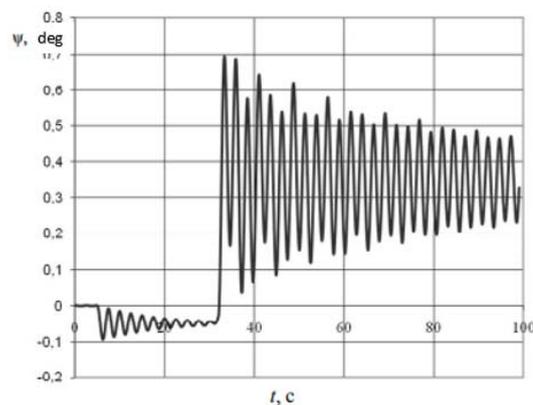
Calculation of the dynamic reception of cargo: the characteristics of the hull: L = 47.77 m; B = 7.33 m; T = 1.2 m; V0 = 294.6 m³; H = 2.6 m; ZG = 3.1 m; XG = - 1.2 m; weight of cargo - 150 kN; initial coordinates of the cargo: XF = - 2.2 m; YP = 0.0 m; ZP = 3.0 m; time of the beginning of reception of cargo trp = 5 with; the heeling moment MKR = 600 kN • m;

time of application of the moment: t = 30.0 c; time for the beginning of the shift of the load: t = 32.0 c; final coordinates of the cargo: XP = 15.0 m; YP = 3.0 m; ZP = 3.0 m.

Figs. 5 and 6 show graphical dependencies of ship landing parameters in time.

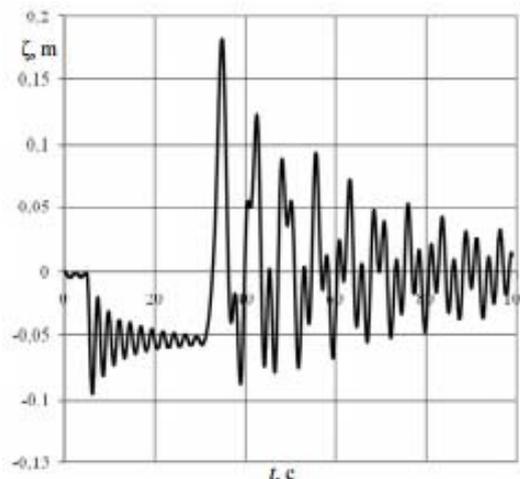


(a)

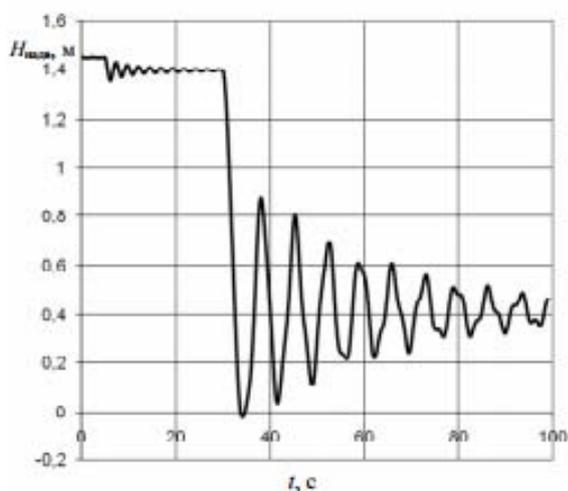


(b)

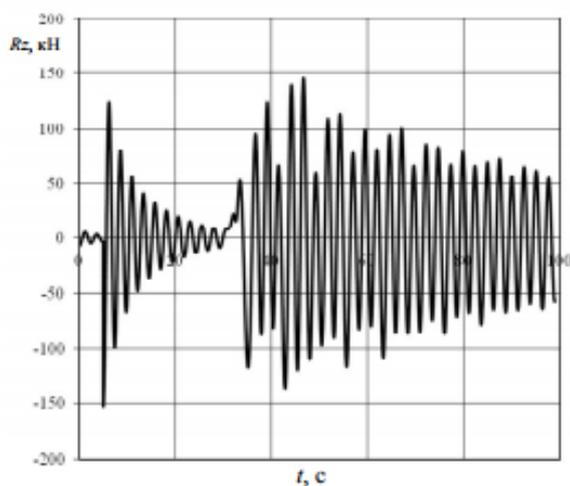
Fig. 5 (a) the angle of heel, (b) trim angle



(a)



(b)



(c)

Fig. 6 (a) the vertical displacement of the center of gravity of the vessel, (b) heights of the ship's overboard ship in the area of the mid-frame, (c) excessive buoyancy force

It should be noted that the movement of the hull has a pronounced dynamic character: the dynamic roll angle (the first initial inclination) $\theta_d = 26.5$ degrees; $\theta_{stat} = 12.0$ degrees; dynamic vertical movement $\zeta_d = 0.18$ m; a dynamic change in the excess buoyancy force $\Delta R\zeta = 145-152$ kN; the dynamic value (the minimum value) of the height of the freeboard $\zeta_{adw} = -0.021$ m, stat above $\zeta = 0.40$ m; the dynamic trim angle (the first initial inclination) $\psi_d = 0.705$ deg, $\psi_{stat} = 0.35$ deg.

IV. CONCLUSIONS

According to the results of the study, the following conclusions can be drawn:

- (1) The proposed method makes it possible to determine the dynamics of the hull under the action of time-varying external forces and to estimate the hull movements dangerous from the point of view of stability and

floodability. It becomes possible to simulate such calculated situations that are not available for research using the Static method.

- (2) When a heeling moment is dynamically applied, along with the roll, a vertical movement of the hull arises, which is significant in comparison with the draft and which has a dynamic character. In this case, one maximum amplitude is observed, which can be estimated as the most dangerous.
- (3) The change in the excess buoyancy force with dynamic roll and vertical movements of the hull indicates the non-uniformity of its inclinations. The nature of vertical movements depends on the shape and main dimensions of the hull. Ships with a high freeboard surface float at a roll, and the low-breasted ones sink.
- (4) Instead of the concept of "angle of flooding", it is advisable to consider the instantaneous height of the freeboard (instantaneous elevation of the lower edge of the open hole in the hull above the operating waterline). This parameter is complex, taking into account all changes in landing parameters.
- (5) Determination of the inertial and hydrodynamic characteristics of the hull is a necessary task in the theory of rolling of ships.

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