On the account of the free surface motion in the calculation of the hydrodynamic loadings on wedges

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***Abstract* – A nonlinear numerical simulation method for predicting wave loads on two-dimensional frame sections that entries the water with accounting of the free surface motion for determination of the hygdrodynamic loads has been developed. A complex boundary elements method and the mixed Euler-Lagrangian method are employed for the analysis of the problems. An attention is focused on the computational description of the jet stream without breaking the physics of free surface motion. Hydrodynamic force impacts the submerging wedges with different deadrise angles has been calculated using the developed software based on this method.**

Key words – two-dimensional water flow simulation, free surface motion, hydrodynamic loads, Euler-Lagragian scheme, complex boundary elements method, jet stream, frame section, strip theory.

I. Introduction

The determination of hydrodynamic forces interaction with waves are the most difficult challenge in the calculation of pitching and wave loads on ships. The "Strip theory" is the most effective steer of solving this problem for the practical usage now. According this theory hydrodynamic forces acting on a ship frame section could be obtained from the two-dimensional water flow problem. In the linear theory of pitching small harmonic oscillations of the frame contour and established water flow are considered. Hydrodynamic forces in this case also vary according to the harmonic law and have two components - the inertial and damping, which can be determined using hydrodynamic coefficients that depend only on the submerged part of frame sections.

Determinant wave loads for ship strength are occurring in storm conditions when the interaction of a ship hull and waves is essentially nonlinear, and therefore methods that take into account this nonlinearity must be used to calculate the loads.

II. Methods for determining the hydrodynamic forces in a frame section

Nonlinear methods for determining the hydrodynamic forces in a frame section are actually based on two approaches - those which using hydrodynamic coefficients of the linear theory, and those which are based on the two-dimensional water flow simulation in account of the water free surface (Fig. 1). The first group includes methods with calculation dependences based on the theorems of water flow momentum or kinetic energy, that are defined through linear theory added masses, but these added masses are variable over time due to the varying submerge part of frames.

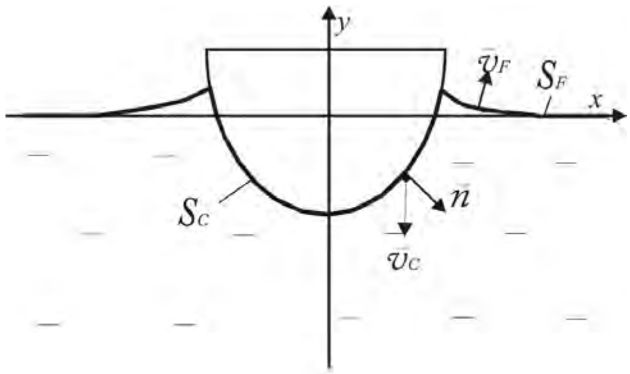

Fig. 1. Flow domain:
S_C – a frame section contour; S_F – a free surface contour;
$_C$ – frame section contour submergence velocity;
$_F$ – free surface contour elevation velocity;
n – normal velocity to the frame section

This approach does not account for the motion of the free surface, the result will be substantial errors in the determination of the the hydrodynamic forces (this indicates the twice difference between dependencies that received using the theorems of momentum and kinetic energy) [1].

This group includes methods that take into account the "memory effect" through the use of an impulse response function [2], that will be calculated on the basis of the linear theory hydrodynamic coefficients, which are also considered variable over time. Through the considerable complexity of calculations the improvement of the accuracy of this method is not proved .

Methods based on the numerical two-dimensional water flow simulation require substantially more computations, but allow to get results with proper accuracy and will be used for engineering calculations on the modern equipment. In [1] a method based on the using of nonlinear hydrodynamic coefficients that depend only on the shape of the ship hull is proposed. This method allows to reduce the required numerical simulation amount significantly.

An effective method of numerical simulation of the two-dimensional water flow with free surface is a complex boundary element method [3].

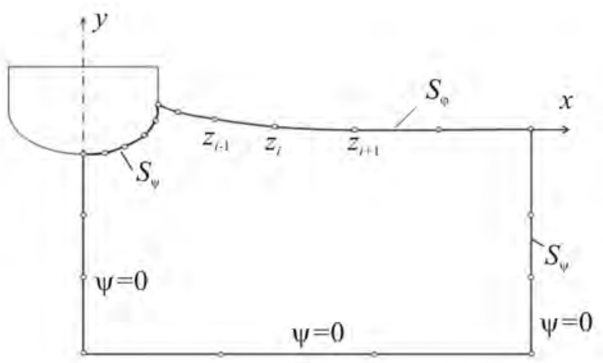

Fig. 2. Boundary elements of the two-dimension flow domain and boundary conditions.
ψ – stream function; φ – velocity potential;
S_ψ – a frame section contour; S_φ – a free surface contour;
z_i – a boundary's node

The resolve equations system is come out from Cauchy's integral formula that binds the analytical function value in any point z_0 of the closed area with an integral along the boundary *S*. The integral is written as sum of integrals along the boundary elements $[z_i;z_{i-1}]$ (Fig. 2).

Step by time mixed Euler - Lagrangian scheme is used to calculate the motion of the free surface. The complex potentials and velocities in the free surface nodes are calculated by the Euler scheme, and the positions of the free surface at the next time moment, potential values in the nodes of the free surface are determined by integrating the current conditions by the Lagrangian scheme. One of the major problems when using this method is to ensure stability of the calculation if a jet-stream appears at the intersection point of the free surface and the frame. Jet-cut methods were offered in a number of publications ([4]), but these methods don't ensure reliable stability at any case.

III. Hydrodynamic forces determine method with the account of the free surface motion

In the present paper methods for the motion of the free surface simulation in the area of the jet stream formation are proposed. The method's impact on the stability and convergence of calculations by the Euler - Lagrangian scheme is investigated. Such methods should properly consider two related effects of free surface motion - the elevation of a free surface level through the water displacement by the ship hull and the jet stream formation without breaking the physics of the free surface motion.

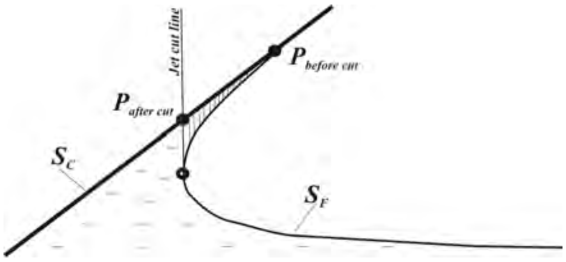

Fig. 3. Jet-cut way:
S_C – a wedge contour; S_F – a free surface contour

Upon a shape of the intersected part of the submerging frame section is close to vertical, jet stream isn't form. For small and medium angles between a frame section and a water free surface both effects present and jet-cut would be made along a vertical tangent to the free surface contour (Fig. 3). If a frame shape is convex it should be necessary to determine a possibility of jet stream separation to avoid the destruction of the calculation.

A software for simulation hydrodynamic loads using this method on any frame section that moves vertically by a given motion law was developed.

Submerging of wedges with different deadrise angles were simulated. Dependance of the hydrodynamic force on time that impacts on the wedges with different deadrise angles (a deadrise angle – an angle between a wedge and a horizontal line) constant submerge velocity 1 m/s is shown on Fig. 4. The motion starts from the calm state that result in the great jump of the hydrodynamic force value on the first steps of calculation. Then the wedge submerging continue, its impact on the free surface wanes and the hydrodynamic force values go down. On time the hydrodynamic force stability grows and it increases depands on the volume of the submerge wedge part without great jumps.

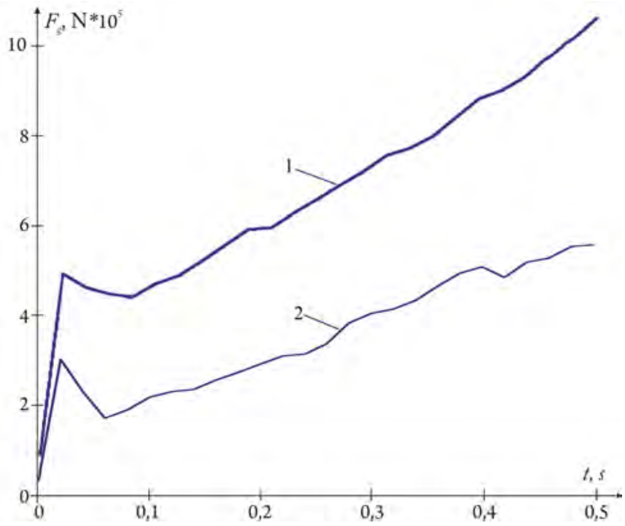

Fig. 4. Change in time of the hydrodynamic force impacts on the immerging wedge with different deadrise angles:
1 – deadrise angle $\pi/20$; 2 – deadrise angle $\pi/4$

Conclusion

In this paper hydrodynamic forces determine method with account of the free surface is given. The research are not finished yet, but intermediate results show that method helps to increase stability of the calculations.

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