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VERTICAL MOTIONS DAMPING MODEL TEST OF A LIFEBOAT LOWERED ONTO A FLAT SEA SURFACE

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ABSTRACT

The article presents the experiment's results of the lifeboat model lowered with an initial speed and then released to fall onto a flat water surface. The purpose of the research is to determine the trajectory of the vertical boat motion and describe it with a mathematical model. This is closely related to determining the damping factor since the vertical motion is damped and the lifeboat gets balanced and stops moving after some time. The procedure of selecting parameters in the mathematical model to adjust to the results of the experiment was described in details. The summary describes the imperfections of the presented damping model and their probable causes.

Keywords: damping, dynamics, differential equations, lowering a lifeboat, numerical simulations

INTRODUCTION

The subject of the study of the lifeboat motion during the lowering in the performance of evacuation action from the ship is important for the safety of the evacuees. A comprehensive description of this process is included in publications [4] and [5]. Safety problems are a constant challenge for companies operating in the field of maritime economy as well as the scientific community. Emerging new requirements and solutions are reflected in the SOLAS Convention (part III) and applied in the regulations of classification societies.

Due to the more and more perfect computational tools in the field of fluid dynamics (CFD), continuous progress is observed in the motion simulation of different types of vessels. Publication [7] presents a three-dimensional dynamic model of the vessel's behavior in the time domain.

The problem of damping the motions of a floating vessel is widely known and described. In [2] this issue is presented from the point of view of harmonic wave propagation. Publications [1] and [11] present the details of determining the damping coefficient for rolling motion. In [10], the relationships between different damping coefficients for symmetrical ship hulls are described.

The aim of this research is to describe the physical phenomena as accurately as possible so that they can be simulated with an appropriate mathematical model. However, for now, only classical Newton's mechanics is applied without the use of CFD methods. It is assumed that the mathematical model will then be used to analyze the proposed new technical solutions or changes in procedures using computer simulations, which is cheaper and easier to perform than experiments. Of course, this does not mean that experiments and trials will be abandoned completely, but their number might be limited and thus the design process can be improved.

THE RESULTS OF THE EXPERIMENT

The experiment included recording the vertical motions of a lifeboat being lowered with initial speed and then released on a flat water surface. According to the classification societies' guidelines [8] the safe speed at which the lifeboat can fall into water is considered to be about 0.6m/s.

The model of a lifeboat used for experiments at the test basin of the Faculty of Ocean Engineering and Ship Technology at Gdańsk University of Technology was borrowed from the Ship Hydromechanics Center of the Ship Design and Research Center in Gdańsk. The model was made in 1:20 scale. Its physical parameters are: length: 440mm, width: 200mm, draft: 80mm, weight: 5.2kg.

The model must be freely dropped from a height of 18mm to achieve a speed of 0.6m/s at the time of contact with water. For this purpose, a special handle was prepared, on which the boat model was suspended at a specific height. The handle has been equipped with a release mechanism that allows the boat to fall freely into water.

The model motion during the experiment was recorded using the QualiSys measurement system. It is an optical registration system, which uses cameras that track special markers attached to the model. The system consists of five cameras. Four of them are used only for spatial registration of marker motions, and the fifth allows for recording of the whole image for illustrative purposes. During registration with a sampling rate of 60 Hz, marker motions are recorded at all six degrees of freedom - three displacement components and three rotation angles. In the case of this test, a cross with four markers, shown in Figure 1, was attached to the deck of the lifeboat model. Its mass was included in the calculations.

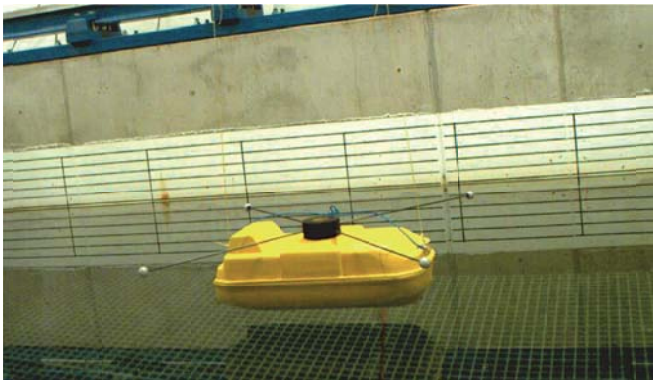

Fig. 1. The lifeboat model suspended on lines with visible QualiSys markers.

The numerical data obtained during the experiment was analyzed. It was confirmed that the speed at the time of contact with water was approx. 0.6 m/s. The changes of z coordinate of the lifeboat position during the experiment are shown on the graph in Figure 2.

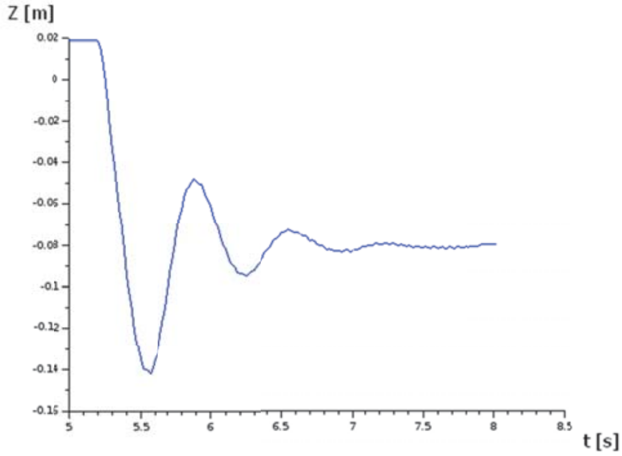

Fig. 2. The z coordinate value of the lifeboat position recorded during the experiment.

The experiment proves the damping of the lifeboat's vertical motions. Both from the observations during the experiment and from the graph it follows that after releasing the lifeboat from the holder it performs two full oscillations: two sequences of successive descents and ascents. Further boat motions are almost unmeasurable.

DAMPED MOTION MODEL

The basic mathematical model of the damped motion presented in [6] is described by formula (1)

$$m \cdot \ddot{x} = -k \cdot x - b \cdot \dot{x} \tag{1}$$

where

- m - object mass [kg]
- x - x coordinate of position in [m]
- k - coefficient of elasticity in [N/m]
- b - damping factor in [N·s/m]

In this formula, the damping is represented by the force linearly dependent on velocity and directed opposite to it - component $b \cdot \dot{x}$ on the right side of the equation (1). The b coefficient present in this component is called the damping factor.

Formula (1) is a second order differential equation and has an analytic solution in the form of a function (2).

$$x(t) = A \cdot e^{-\frac{b}{2m} \cdot t} \cdot \sin(t \cdot \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}} + \varphi) \tag{2}$$

The time of the oscillation decay depends on the value of the factor b. Fig. 3 shows how the value of the b factor influences the attenuation of the oscillations. The larger the b, the faster the oscillations decay. At a sufficiently large value of b, damping becomes critical and oscillations do not occur at all.

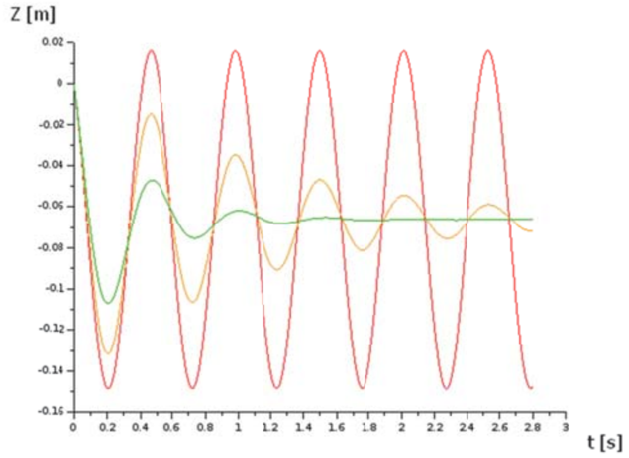

Fig. 3. The graphs of damped motion depending on the damping factor b value (red: b=0, orange: b=10 , green: b=30).

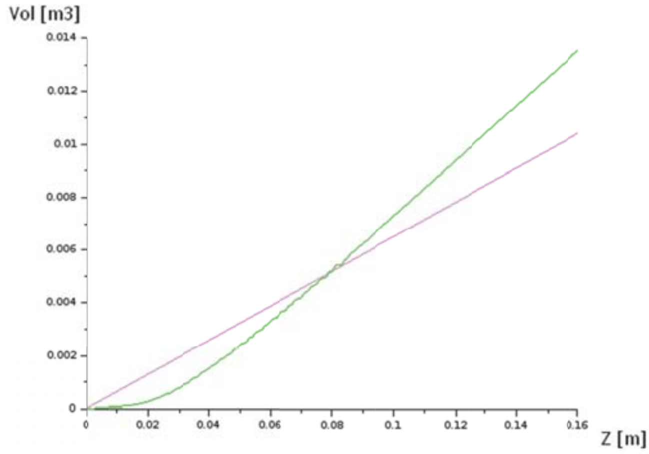

Fig. 4. The graph of the function Vol(z), which defines the water volume displaced by the lifeboat model depending on the draft (green) against the diagram of water displaced by a cylinder with a cross-section such as the average waterline of the model (violet).

In the case of a lifeboat, the equation of vertical motion is given by the formula (3)

$$m \cdot \ddot{z} = -m \cdot g - \rho_w \cdot Vol(z) \cdot g - b \cdot \dot{z} \quad (3)$$

where

m - lifeboat mass in [kg]

z - coordinate of the boat position or negative draft in [m]

g - gravity constant in [m/s^2]

ρ_w - water density in [kg/m^3]

Vol(z) - function, describing the volume of water displaced by the boat depending on the draft in [m^3]

b - damping factor [kg/s]

It is also a second order differential equation. The second component to the right of the equation (3) contains the function *Vol(z)*, which gives the volume of water displaced by the boat. This function is not an algebraic function but returns linearly interpolated tabular values. Fig. 4 shows the graphical form of this function for the model of the lifeboat being tested.

Since one of the components of the right side of equation (3) is not an algebraic function, the equation can be solved only with numerical methods.

SETTING PARAMETERS OF DAMPING MODEL

In equation (3), the *Vol(z)* function is known. It is determined for the model of the lifeboat being tested. All other parameters except the damping factor b are also known. Because equation (3) does not have an analytical solution, the coefficient b cannot be calculated from such a solution.

The solution and selection of the value of the b factor must therefore be pursued with the use of numerical methods. To resolve a differential equation, the initial conditions must be specified. In this case, the initial position of the boat (z coordinate) and the speed (derivative $\dot{z}$) at this position are known. It is assumed that the boat touching the water with the keel is in position $z = 0$, and falling descends towards the negative z values. According to assumptions in pt. 1, in the initial position $z = 0$ the speed of the boat should be $\dot{z}$ m/s.

To solve the numerical differential equation, the Adams method was used, using the SciLab [9] calculation software. The Adams method, as a method of solving ordinary differential equations, additionally requires the conversion of the 2nd order equation into the system of two first order equations.

In Fig. 5. the red color presents the solution of equation (3) for m = 5.2kg, g = 9.81m/s^2, ρ_w = 1000kg/m^3 and b=0.0kg/s in the time interval $t \epsilon \langle 0.0, 2.8 \rangle$. The results measured during the experiment are shown in blue.

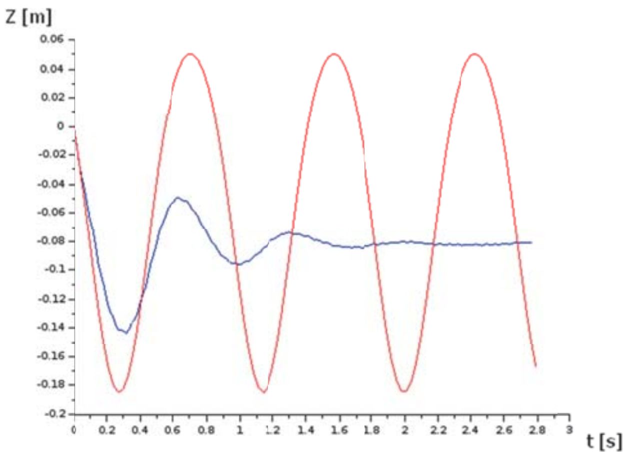

Fig. 5. The numerical solution of equation (3) for m = 5.2kg , g=9.81 m/s², ρ_w= 1000 kg/m3 and b = 0kg/s (red) against the results from the experiment (blue).

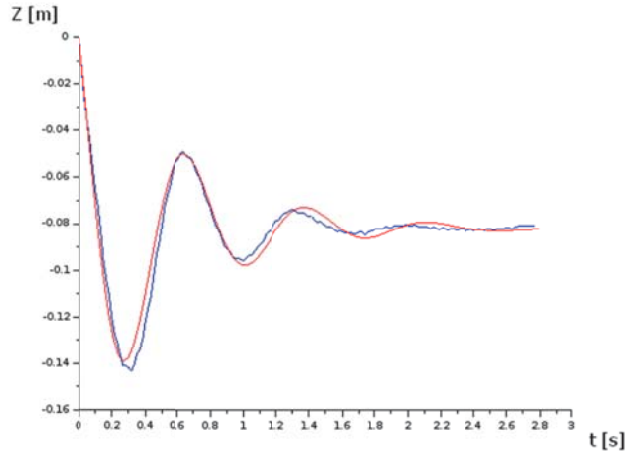

Fig. 6. The numerical solution of equation (4) for m = 5.2kg , m_a = 7.5kg , g = 9.81m/s², ρ_w=1000 kg/m³ and b = 44.0kg/s (red) against the results from the experiment (blue).

Because factor b = 0.0kg/s was assumed, the lifeboat's motions in the numerical simulation were not damped. The graph also shows that the period of oscillations recorded during the experiment does not match with those resulting from the calculation. To obtain the correct period in the calculations, the concept of added mass should be introduced and formula (3) should be modified accordingly. The new form of this formula is shown as (4).

$$(m + m_a) \cdot \ddot{z} = -m \cdot g - \rho_w \cdot Vol(z) \cdot g - b \cdot \dot{z} \tag{4}$$

where

m_a - added mass in [kg]

The added mass is the mass that is conventionally considered as a mass of water that moves along with the hull of the boat. It represents additional inertia during the motions of the boat so it is taken into account only in the inertial part on the left side of the equation (4).

Equation (4) has two unknown parameters: the damping factor b and the added mass m_a. Increasing the added mass m_a increases the period, and increasing the damping factor b decreases the amplitude of subsequent oscillations.

Next, the values of m_a and b were increased until the graph of the calculation results matched with the graph recorded during the experiment. This happened for m_a = 7.5 and b = 44.0. The result is shown in Figure 6.

The standard deviation between the simulation results and the measured data from the experiment for parameters m_a = 7.5 and b = 44.0 assumed in the model is 0.004m. This means that 68% of recorded samples do not differ from simulations by more than 0.004m, and 95% of samples do not differ by more than 0.008m.

SUMMARY

The presented method of numerical calculations and determining the damping factor confirmed the correctness of the assumed damping model for describing the examined physical phenomenon.

It should be noted that the mathematical model described above has been proved for specific initial conditions during the experiment and corresponding to the typical situations occurring when lowering a lifeboat. Detailed analysis of the graph in Figure 6, however, shows that the differences between the simulation and the experiment increase with time. Since the speed drops significantly over time, the damping factor may not be constant, but it may be slightly dependent on speed. However, confirmation of such a dependence requires further research.

The damping factor determined for a given shape of the lifeboat hull with a value of b = 44.0 allows to consider the presented damping model as a good approximation of the examined physical phenomenon, because the standard deviation is small and amounts to only 0.004m, which is 2.8% of the depth of the first largest dive.

The appropriate damping model allows to perform precise simulations of the motions of this particular lifeboat in the future and the calculated values of acceleration, velocity and position can be used for further analysis without bearing the costs of tests in reality.

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