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Assessment of the Hydrodynamic Motions of a Floating Dock After Modernization

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Abstract: The article examines the hydrodynamic motions of a modernized floating dock. In the context of modernization, this consists of extending the dock structure without changes to its cross-section, structural configuration, structural elements, or their geometric characteristics. The modernization aims to increase the dock's load-carrying capacity, which affects its operational performance and is an important aspect of the ship-docking process. Two of the six degrees of freedom of the floating body—sway (lateral motion) and pitch (longitudinal rocking)—are evaluated and analyzed. These two motions, representing the corresponding degrees of freedom during dock operation, are assessed both before and after the modification. An analysis is carried out to determine the extent of the changes and whether they have a direct impact on the operational performance of the structure. The results indicate that after the modification, there is a change in the hydrodynamic characteristics of the dock, more specifically in the roll and pitch motions.

Keywords: Floating dock, Motions, Hydrodynamic, Modernization

Introduction

Floating docks are an important facility in ship docking within the shipbuilding and ship repair industry. They are characterized by their main dimensions and lifting capacity. These two characteristics are of crucial importance, as they determine the productivity and competitiveness of shipbuilding and ship repair enterprises. One way to increase the lifting capacity of a dock is by extending its length. For existing dock facilities, this is achieved through preliminary strength analyses related to the structural capability to withstand the additional loads. The extension, which represents a form of modernization, also affects the operational characteristics of the facility. For this reason, an evaluation and analysis of this effect is required.

To evaluate the behavior of the dock during operation, a quasi-static model has been developed. Using this model, the dynamic behavior of the dock during ship docking and launching operations has been simulated. Various loading cases were tested during the operation of the dock using the model. In the development of the model, the dock was considered as a rigid body with six degrees of freedom, including hydrostatic and hydrodynamic forces, as well as forces resulting from mooring ropes and the interaction between the ship and the dock. The model successfully controls the transverse and longitudinal motions of the dock during operation. This is achieved through the use of an automatic ballast control system (Wen, 2026).

The modernization of floating docks is carried out not only with the aim of increasing lifting capacity, but also to improve the operational performance of the facility. The conversion from a single-pontoon to a multi-pontoon dock structure is analyzed in Wahidi (2022). Using the Finite Element Method, the structure is analyzed and it is established that the stresses obtained after the conversion are lower than the allowable limits. The lifting capacity remains unchanged, while the draft increases and the freeboard height also increase. Ultimately, modernization leads to savings in operational costs, which can be used as an investment.

An analysis of the hydrodynamic characteristics of a floating dock, taking into account the connections between its individual sections and the location of its operation, was carried out in Fu (2023). The performed analysis

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clearly shows that under transverse and oblique wave conditions, the configuration with transverse pontoons behaves better compared to the configuration with longitudinal pontoons. This has a direct influence on the roll motion of the dock, with the roll amplitude being reduced by 14%.

Stability is of major importance from the operational point of view of a floating dock. It is evaluated under different operating conditions of the structure and is closely related to its hydrodynamic characteristics. In this context, a model based on differential equations has been developed in order to assess the motion of the dock under various scenarios, including emergency conditions. The angular velocity of listing can be used as a design parameter characterizing the operational stability of the dock. In addition, significant listing may occur under the action of ballast (Drobyshevskiy, 2001).

Two methods for determining the responses of a floating dock are proposed in (Zhang, 2025), namely static and dynamic. The static method is based on the equilibrium equations of a floating body, solved using the Newton–Raphson method. The dynamic method includes the six degrees of freedom and models of hydrodynamic and hydrostatic forces.

A model incorporating the six degrees of freedom of a floating dock was developed to evaluate its dynamic responses under accident conditions. Using this model, it was found that the maximum roll angles during an accident caused by intensive corrosion are 0.18° and 0.69° in the case of a single hole. When two holes are present, the roll and pitch angles increase to 0.42° and 2.04°, respectively (Zahi, 2023). These values are part of the dock's dynamic behavior and must be controlled, as there is a risk of the dock capsizing and causing an environmental disaster.

The statistical and dynamic responses, expressed in terms of significant motion and acceleration amplitudes, were evaluated against short-term seakeeping criteria to prevent flooding of the dock pontoon deck using a developed algorithm. In applying the algorithm, it was assumed that the dock is operating in irregular waves. The study results define the limit navigation conditions for safe operation during the relocation of a small-size floating dock (Burlacu, 2018).

Hydrodynamic Model of the Floating Dock

The hydrodynamic state of a floating dock depends on its shape, dimensions, and loading. The hydrodynamic forces acting on the floating dock include only the forces due to added mass, added moment of inertia, and damping forces. By its nature, this is a complex process that combines the six degrees of freedom of a rigid body. In a simplified form, it can be represented by the following equation.

$$D = [x\ y\ z\ \phi\ \theta\ \psi]^T \quad (1)$$

where:
- X y z- surge, sway, and heave movements;
- $\phi\ \theta\ \psi$- roll, pitch, and yaw movements;

The six degrees of freedom are shown in fig. 1

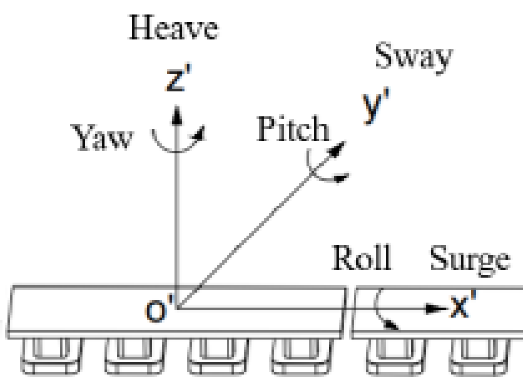

Figure 1. Floating dock six degrees of freedom

The complete equation describing the six degrees of freedom of the floating dock as a rigid body is as follows

$$(\boldsymbol{m}+\boldsymbol{m}_a)\frac{\mathrm{d}^2\boldsymbol{X}_G}{\mathrm{d}t^2}=\boldsymbol{F}_s+\boldsymbol{F}_d+\boldsymbol{F}_c \tag{2}$$

Where:
- m, ma- mass and added masses;
- X_G- center of gravity;
- t- time;
- Fs- hydrostatic force;
- Fd- hydrodynamic force;
- Fc- contact force.

The motion of the ship in the steadily translating coordinate system O(x,y,z)O(x, y, z)O(x,y,z) is described by three translational movements of the ship's center of gravity along the x-, y-, and z-axes. All of the motions are evaluated by following the equations.

$$\text{Surge} \quad : \quad x = x_a \cos(\omega_e t + \varepsilon_{x\zeta}) \tag{3}$$

$$\text{Sway} \quad : \quad y = y_a \cos(\omega_e t + \varepsilon_{y\zeta}) \tag{4}$$

$$\text{Heave} \quad : \quad z = z_a \cos(\omega_e t + \varepsilon_{z\zeta}) \tag{5}$$

$$\text{Roll} \quad : \quad \phi = \phi_a \cos(\omega_e t + \varepsilon_{\phi\zeta}) \tag{6}$$

$$\text{Pitch} \quad : \quad \theta = \theta_a \cos(\omega_e t + \varepsilon_{\theta\zeta}) \tag{7}$$

$$\text{Yaw} \quad : \quad \psi = \psi_a \cos(\omega_e t + \varepsilon_{\psi\zeta}) \tag{8}$$

If the motions of the ship's center of gravity (G), calculation the motions at any other point of the structure can be evaluated using the principle of superposition. The phase shifts of these motions are related to the height of the harmonic wave at the origin of the steadily moving system (O(x, y, z)) – which is the average position of the ship's center of gravity, even though no actual wave can be measured there.

$$\zeta = \zeta_a \cos(\omega_e t) \tag{9}$$

The harmonic velocities and accelerations in the steadily moving O(x, y, z) coordinate system can be determined by differentiating the displacements. This process will be demonstrated here using roll as an example for three conditions.

Displacement

$$\phi = \phi_a \cos(\omega_e t + \varepsilon_{\phi\zeta}) \tag{10}$$

Velocity

$$\dot{\phi} = -\omega_e \phi_a \sin(\omega_e t + \varepsilon_{\phi\zeta}) = \omega_e \phi_a \cos(\omega_e t + \varepsilon_{\phi\zeta} + \pi/2) \tag{11}$$

Acceleration

$$\ddot{\phi} = -\omega_e^2 \phi_a \cos(\omega_e t + \varepsilon_{\phi\zeta}) = \omega_e^2 \phi_a \cos(\omega_e t + \varepsilon_{\phi\zeta} + \pi) \tag{12}$$

In addition to the six motions of the floating dock, its stability is also important. It is regulated by the rules of classification societies, and unlike that of merchant fleet vessels, the stability of floating docks has a minimum value of 1.0 m (Korean register of shipping, 2015).

Floating Dock Geometry and Main Dimensions

The geometry of the dock is simple compared to that of ships. It consists of a pontoon and two side towers, intended for ballast during the submerging and surfacing of the dock in its various loading conditions. A schematic of the dock is shown in fig.

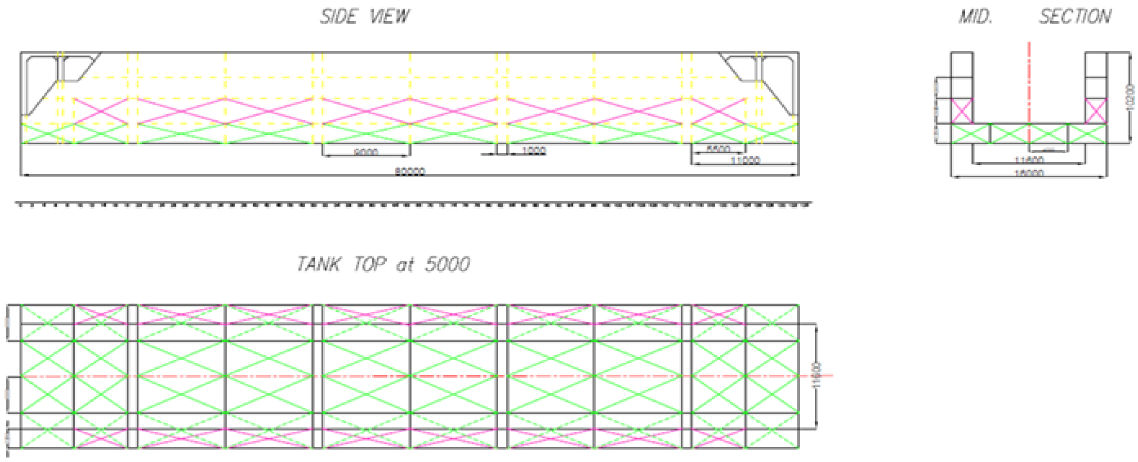

Figure 2. Floating dock arrangement

The dimensions of the dock before and after the modernization (extension) are presented in Table 1 and Table 2.

Table 1. Dock dimension before modernization

Item	Dimension
Length, m	80.00
Breadth, m	16.00
Depth, m	10.20
Draught, m	7.40
Lifting capacity, t	2000

Table 2. Dock dimension after modernization

Item	Dimension
Length, m	90.00
Breadth, m	16.00
Depth, m	10.20
Draught, m	7.40
Lifting capacity, t	2250

Using the hydrodynamic model and the dimensions of the floating dock before and after modernization, an assessment was made of all six degrees of freedom.

Hydrodynamic Motions Assessment

The assessment of the hydrodynamic motions of the dock was carried out using specialized software of the classification society Bureau Veritas. Through the software, the transverse cross-section of the dock is modeled by defining its main characteristic dimensions, topology, type of construction material, and loading. The assessment of four motions—two translational and two rotational—of the floating dock before modernization is presented in Table 3. The values shown were calculated at full draft of the dock, i.e., submerged with cargo on board. This is the main operating condition of the dock, in which it must withstand all applied static and dynamic forces.

Table 3. Motions of dock with L= 80,0m

Item	Value
Surge, m/s^2	0.50
Sway, m/s^2	1.586
Heave, m/s^2	2.047
Yaw, rad/s^2	0.040

Particular attention was paid to two of the six degrees of freedom—roll motion and pitch. These two degrees of freedom have a direct influence on the dock's behavior during docking and launching of ships. The results regarding amplitude, period, and accelerations in both cases are presented in Tables 3.1 and 3.2.

Table 3.1. Rolling motions

Roll	
Item	Value
Amplitude, rad	0.209
Period, s	11.641
Acceleration, rad/s^2	0.061

Table 3.2. Pitch motions

Pitch	
Item	Value
Amplitude, rad	0.057
Period, s	5.143
Acceleration, rad/s^2	0.085

The results of the hydrodynamic motions of the dock after modernization are presented in Table 4, and for the two motions—roll and longitudinal translation, along with their amplitude, period, and acceleration—in Tables 4.1 and 4.2

Table 4. Motions of dock with L= 90,0m

Item	Value
Surge, m/s^2	0.50
Sway, m/s^2	1.510
Heave, m/s^2	1.949
Yaw, rad/s^2	0.034

Table 4.1. Roll motions

Roll	
Item	Value
Amplitude, rad	0.199
Period, s	11.641
Acceleration, rad/s^2	0.058

Table 4.2. Pitch motions

Pitch	
Item	Value
Amplitude, rad	0.055
Period, s	5.455
Acceleration, rad/s^2	0.072

The modernization of the dock, aimed at increasing its load-carrying capacity without changes to the structure and structural elements, has a favorable effect on its hydrodynamic motions. A noticeable change is observed in the vertical and lateral motions, while the change in rotation about the Z-axis is insignificant. The surge remains unchanged, as it is not directly related to the modernization.

Conclusion

In the article, the hydrodynamic motions of a floating dock after modernization are investigated. The modernization consists of extending the dock without altering its structural design. From an operational point of view, the six degrees of freedom are analyzed. Particular attention is paid to roll and pitch motions. After the extension by approximately 10 m, changes are observed in all motions of the dock.

For a large part of them, a reduction in the values is noted, while for others an increase is observed.The reduction in the values after the extension is approximately 5% for sway and heave. A significant decrease in the values is observed for yaw, of about 17%. After a detailed analysis of the two motions, roll and pitch, and the evaluation of amplitude, period, and acceleration, it was observed that for both motions the amplitude and acceleration decrease by approximately 3–10%. There is no change in the roll period, while for pitch an increase of about 6% is observed. A significant reduction in pitch accelerations of approximately 18% is also noted.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that there is no conflict of interest.

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