XVI Konferencja Naukowo-Techniczna
TKI2022
TECHNIKI KOMPUTEROWE W INŻYNIERII
18–21 października 2022

A scaled floating dock model to test & verify digital twin simulation software

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ABSTRACT: This paper presents a scaled, fully functional floating dock model designed and commissioned within the joined Polish-Norwegian research project called: *DigiFloDock* led by the Faculty of Mechanical Engineering and Ship Technology of Gdańsk Tech. This scaled model will test and verify the aim of the project, which is the digital twin software of the floating dock. The scaled model is expected to be especially valuable in verifying simulations of the most dangerous scenarios, that may lead to loss of stability of the dock-vessel system or damages to either of them. The scaled model was designed to resemble functionality and physical properties of the real floating dock as much as possible. However due to the large scaling factor we were not able to scale down correctly the stiffness of the model. The result of our research is the scaled model with proven properties and functionality, which mimics operation of the real dock. To keep the stability characteristics of the model similar to the real dock at a scale 1:70 with fully functional and controllable ballast system was a challenge, that required applying advanced modern technologies taken from RC models and IoT. Apart from digital twin verification, this scaled model will also be utilized to test and optimize different approaches to the floating dock automatic control.

KEY WORDS: simulation, digital twin, vessel stability, floating dock

1. Introduction

Building scaled models is a common practice in shipbuilding and industrial research. It might be done to avoid numerical simulations where appropriate mathematical model is missing or is not proven. On the other hand, the scaled model might prove theoretical studies [1], mathematical model [2] or numerical simulation [3], provided the transition from scaled model to the full scale object is known. Various scale effects may significantly alternate extrapolating the results of experiments with scaled model to full scale [4]. Due to the fact that floating dock operation is a very slow process [5], it can be considered as quasi-static so we may avoid considering the majority of the scale effects e.g. viscous effects, exact moments of inertia, structure resonance etc. However the reaction of the dock to an increase of its mass and changes to the position of its centre of gravity must be modelled precisely.

2. Scaled model description

Fundamental decision about the scaled model was the choice of scale factor and material to build the hull. The dimensions of the floating dock we consider in real scale tests are: 168.48 m length and 39.80 m width. A perfect scaling of the dock itself, without considering the flow similarity, would require scaling down the geometry, mass, mass distribution, moments of inertia, global stiffness and local stiffness. However, since different scaling laws apply to different physical quantities, one can readily see that even exact reproduction of all details in scale would not result in maintaining all required features at model scale e.g. the model would be stiffer than the actual object. On the contrary, scaling down the thickness of the shell plating with the scaling factor in the range 50-100 would make the model extremely prone to damage. For these reasons, the following decisions were made:

- the stiffness was not modelled and it is justified by the fact that the deflection of the steel structure of the dock is insignificant and do not influence the hydromechanics;
- a transparent material was used (PMMA), allowing for visual control of the ballasting;
- the shell plating thickness applied was 2 mm; this allows maintaining the required mass features while keeping the structure of the model robust enough without using stiffeners.

The overall view of the final model of the floating dock placed for tests in a model basin is shown in Fig. 1. The resulting mass of the model was marginally larger than the mass resulting from direct down-scaling of the dock.

Fig. 1. The floating dock model scale 1:70 floating in the model basin

For that reason, the height of the double-bottom was increased to get additional displacement and hence maintain the actual location of the deck above the water surface.

The stability of the floating object is a feature expressed by the value of the righting moment for the specified heel angle. In practice, a quantity used to characterize the stability is a righting arm (GZ) or an initial metacentric height, i.e. the distance between the metacentric point and the vertical centre of gravity. For the designed model, the metacentric height can be adjusted by minor changes of the vertical position of the centre of gravity. To make the model operational, a scale factor of 1:70 was used, resulting in the scaled model length of 2 407 mm. Comparison between the righting arm (GZ curve) of the original dock and the rescaled model is presented in Fig. 2.

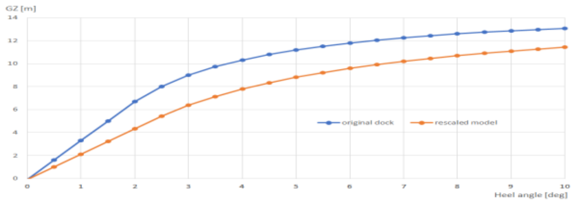

Fig. 2. Righting arm (GZ curve) comparison of the original dock and rescaled model

Another fundamental decision was on the ballast system. In the full scale dock, 18 ballast tanks are controlled with 3 pumps and a system of valves that allows filling/emptying of chosen tanks as well as assures redundancy. For the scaling factor 1:70, it was impossible to mimic the actual ballast system due to very large relative dimensions of available pumps. Moreover, there are no remotely operated valves available for such size. Thus finally the ballast system on the model consist of:

- 18 gear pumps each for one individual tank,
- 18 programmatically driven PWM generators controlling individual pumps,
- IoT microchip ESP32 controller unit to allow WiFi communication with the model and drive PWM generators (the model is bound to the bank only with a flexible power cord – control signals are sent over WiFi),
- 4 draft sensors in the corners of the base of the model.

To monitor ballast water levels in tanks of the model it was necessary to identify the characteristics of the ballast pumps. Fig. 3 shows sample response of the flow rate of the pump to the PWM pump control signal. Since there are roughly 10% to 15% differences in flow rate of used pumps, the non-linear characteristics of all pumps were later approximated with a 3rd degree splines and stored in the control program. Before setting the ballast system each chosen pump was to pass series of tests at the special rig to establish its characteristics.

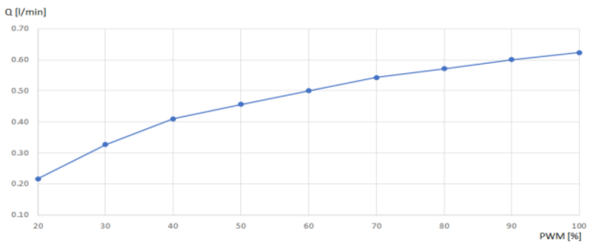

Fig. 3. A sample ballast pump characteristics: flow rate vs. PWM control signal

3. The digital twin solution

The digital twin, which is the subject of *DigiFloDock* project, is a software solution that will offer the following functionality:

- time domain simulation of the positions of dock-vessel system during a docking/undocking process,
- time domain simulation of the strain/stress in the structure of the hull of the floating dock,
- signalling of approaching and exceeding allowable stress in the structure of the floating dock,
- signalling of loss of stability of the dock-vessel system and danger of excessive heel angle or capsizing,
- monitoring/logging of data from on-board sensors of the floating dock,
- automatic control of the position of the floating dock,
- automatic control of the docking/undocking process.

To assure the above features, the dynamic model presented in [6] governed by eq. (1) is being employed in the digital twin solution.

$$(\boldsymbol{M} + \boldsymbol{A}(t))\ddot{x} = \boldsymbol{P}(t) - \boldsymbol{M}g - \boldsymbol{B}\dot{x} - \boldsymbol{K}x \qquad (1)$$

where: $\boldsymbol{M}$ is the lumped mass matrix, $\boldsymbol{A}(t)$ is the added water matrix, $\boldsymbol{P}(t)$ is the hydrostatic forces vector, g is the gravity constant, $\boldsymbol{B}$ is the damping coefficient matrix, $\boldsymbol{K}$ is the stiffness matrix and x is the displacements vector.

4. Summary

The fully functional scaled model of the floating dock will be used to do the following test and verifications:

1) Consistency check of motion simulations and real dock motions.
2) Investigating scenarios that may lead to excessive heel angle or even capsizing of the floating dock-vessel system.
3) Investigating scenarios when the floating dock operation is endangered by a malfunction of a ballast pump or a leakage.
4) Investigating different strategies of optimized floating dock's control.

By completing the scaled model of the floating dock, the milestone in *DigiFloDock* research project has been reached. Further experiments to develop digital twin can be performed to prove its correctness and prepare the solution that may advance techniques used in the shipbuilding industry.

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