American Academic Scientific Research Journal for Engineering, Technology, and Sciences

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

https://asrjetsjournal.org/index.php/American_Scientific_Journal/index

# Verification of Design Solutions for Port Hydraulic Structures with the Use of Physical and Mathematical (Numerical) Simulation to Ensure Safety of Marine Terminals and Seaports

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**Abstract**

The article considers the possibility of verification of design solutions for port hydraulic structures with the help of physical and mathematical (numerical) types of simulation to ensure the safety of marine terminals and seaports, including under the impact of various natural phenomena. The features of these types of simulation are discussed, a brief description of the range of problems to be solved is given.

***Keywords:*** port hydraulic structure; terminal; port; water area; design; natural factors; physical simulation; mathematical (numerical) simulation.

## 1. Introduction

The openness of the economy is the basis of sustainable economic development for any country. Modern well-developed transportation infrastructure is one of the key pillars of the economy's openness.

Seaports are the core elements of the transportation infrastructure providing foreign trade cargo turnover.

Long term planning for port development usually includes:

– Increasing port capacities and providing efficient development of port infrastructure;
– Ensuring safe operation of seaport infrastructure and maritime traffic.

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*Received: 1/20/2025*
*Accepted: 3/6/2025*
*Published: 3/15/2025*

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Hence, absolute provision of safe operation of the port infrastructure and in-service maritime transport is one of the main factors in the port complexes development.

Marine terminals, ports and port complexes include many facilities, but the key objects are: piers, moorage berths, moles, approach channels, bank protection structures, breakwaters, levees, as well as underwater structures created as a result of bottom dredging. These objects belong to the port hydraulic engineering structures, which distinctive features are to ensure the safety of navigation and moorage, as well as interaction with the aquatic environment.

In its turn, interaction with the aquatic environment causes permanent impacts on the port hydraulic structures from such natural phenomena as sea waves, currents, impact from the aquatoria ice coverage and individual ice floes (hereinafter - Natural phenomena). These impacts occur both directly from Natural phenomena and from moored vessels that are also affected by these phenomena.

The crucial element of these Natural Phenomena is water, the simplest but also one of the most difficult substances to understand.

The flow of water, the interaction of water with other objects, has been studied for many hundreds of years on scales from molecules to oceans. But, unfortunately, despite the rapid development of science, there is still no single theory that can fully describe these phenomena.

This leads to a paradoxical fact: although hydraulic engineering construction is one of the most science-intensive types of construction, there is no theoretical calculation methodology at present that is capable of exhaustively determining the impact of Natural phenomena on hydraulic structures, including port hydraulic structures.

Incomplete or not correct enough consideration of the factor of the Natural phenomena impact in the design of port hydraulic structures may further lead to damage or destruction of these structures at the stage of construction or operation. Given the fact that such dangerous cargoes as explosives, compressed and liquefied gases, self-igniting substances and substances releasing flammable gases when interacting with water, poisonous substances, infectious substances, radioactive materials, etc. [1] are transshipped through the seaport infrastructure, damage or destruction of some port facilities involved in transshipment can potentially lead to a catastrophe.

Works within the framework of engineering surveys (mainly hydrometeorological) are the main source of information on the influencing Natural phenomena. Various researchers have widely recognized the importance of consideration of hydrometeorological conditions when selecting the layout of cargo terminals and ports [2]. According to experts [3] the lack or insufficient amount of surveys in the marine part are the most frequent and serious errors identified at the stage of preliminary inspection and during the main period of expert examination of design documentation for port hydraulic structures. Insufficient survey work and incorrect assessment of engineering-geological, hydrological, climatic conditions of construction, as well as mistakes in design are some of the main reasons that can cause the collapsing of hydraulic structures [4].

This is the reason why the design solutions adopted during the design of port hydraulic structures should be verified and validated. This requirement is set forth in a number of normative technical documentation,

For example, in the normative document of the Russian Federation SP 58.13330.2019 "Hydraulic structures. Insufficient survey work and incorrect assessment of engineering-geological, hydrological, climatic conditions of construction, as well as errors in design are some of the main reasons that can cause the collapsing of hydraulic structures [4].

One of the types of research work on design verification is physical simulation.

The point of physical simulation is that an exact copy of port hydraulic structures is built in an experimental basin in a certain scale, models of ships (if necessary) are placed at mockups of berths, the relief of the water area bottom is reproduced from sand, angular rock and other materials. With the special equipment, waves with the required parameters are created in the of the experimental basin area. In required places according to the simulation program, video cameras and special sensors are installed.


**Figure 1:** Example of physical simulation of a stationary marine export terminal [6]

As a result, with no possibility to perform an accurate theoretical calculation of the Natural phenomena impact on the hydraulic structure, the value of this impact is determined in the course of simulation on the basis of information from sensors and video cameras.

There is a number of normative technical documents regulating physical simulation of port hydraulic structures. For example, in the Russian Federation, such a document is GOST R 70023-2022 "Physical simulation of Wave Effects on Port Hydraulic Structures. Requirements for model creating, experimentation and results processing".

The main condition for physical simulation is to ensure mechanical similarity between the object and the model.

The Froude number Fr should be the main criterion of similarity, i.e. it is necessary to ensure the equality of Froude numbers of the object and the model [7:4]

$$F_r = \frac{V^2}{gL} = idem, (1)$$

where V means reference velocity (e.g., wave propagation velocity), m/s;

g means gravitational acceleration, m/s;

L means reference length (for example, wave length), m.

Other parameters should be scaled similarly. For example, the scale of time and wave period $m_t$ is calculated by the formula [7:4]

$$m_t = \sqrt{m_h}, (2)$$

where $m_h$ means linear ratio

The scale of mass of elements (slabs, stone or molded massifs) $m_G$ in the study of their stability is calculated by the formula [7:4]

$$m_G = m_h^3 , (3)$$

where $m_h$ means linear ratio - linear ratio

The greatest difficulty in performing physical simulation of the Natural phenomena impact on port hydraulic structures is modeling the impact of the aquatoria ice coverage and individual ice floes.


**Figure 2:** Example of physical simulation of the interaction between piles of the hydraulic structure base and drifting ice field

The peculiarity is that the strength properties of the ice have to be reduced in the simulation according to the scale of the model and this is usually the most challenging.

Another specific point of the physical modeling of the impacting ice cover of the water area to hydraulic structures is the need to monitor the interaction of ice and models from the bottom up from the water column.

For this, underwater video cameras are installed in the water column of the ice pool, or the bottom of the pool is made in the form of walk-through galleries with a glass roof, through which the experimenters carry out the necessary visual observations.

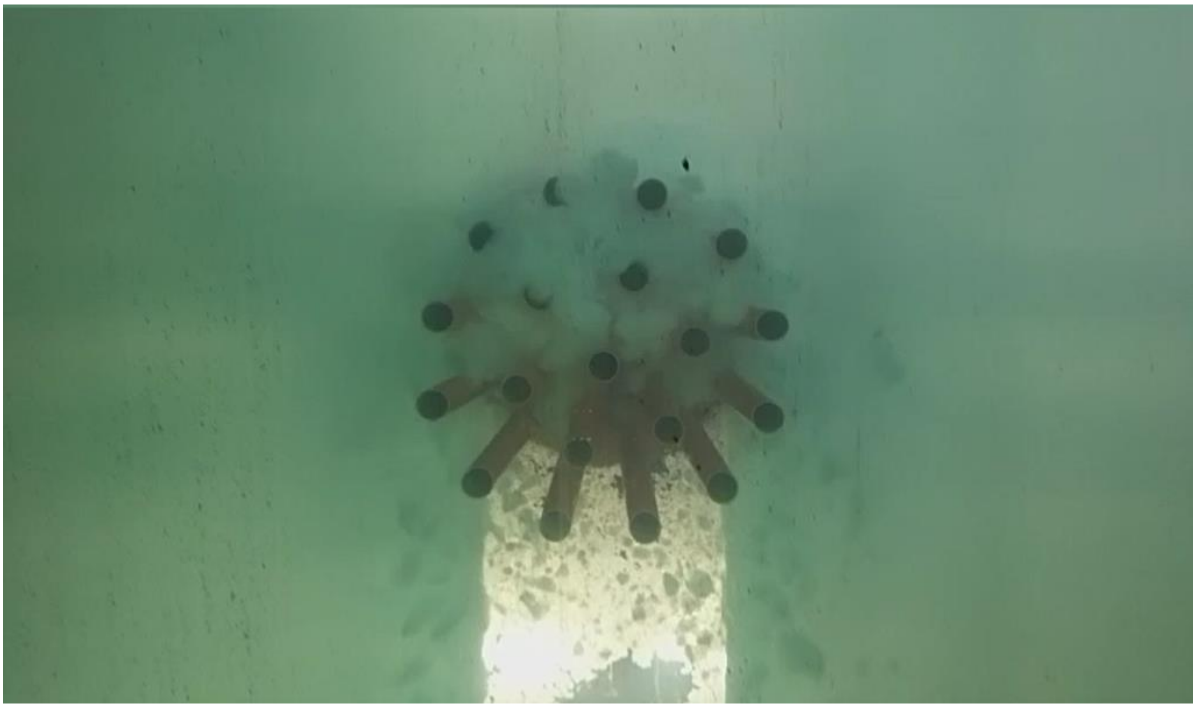

**Figure 3:** Visual observation of the process of ice accumulation in the space between the piles during the physical modeling of the interaction of a hydraulic structure base and drifting ice field

The following issues can be addressed with this simulation method [7:3]:

– Assessment of port water area protection from seas;
– justification of planning and layout solutions of mooring and protecting structures;
– assessment of the stability of structural elements;
– assessment of wave runup onto structures and (or) territory;
– assessment of wave-reflecting and wave- annihilation capacity of structural elements;
– determination of wave impact on structural elements.

Physical simulation is not the only type of simulation used to verify design solutions.

Nowadays, the capacity of computing systems and the level of development of computational algorithms have reached the level when it became possible to perform virtual simulation of the Natural phenomena impact on a hydraulic structure - the so-called mathematical (numerical) simulation.

For the purpose of mathematical (numerical) simulation a number of software products have been developed, for example, the software package "Anchored Structures" ™.

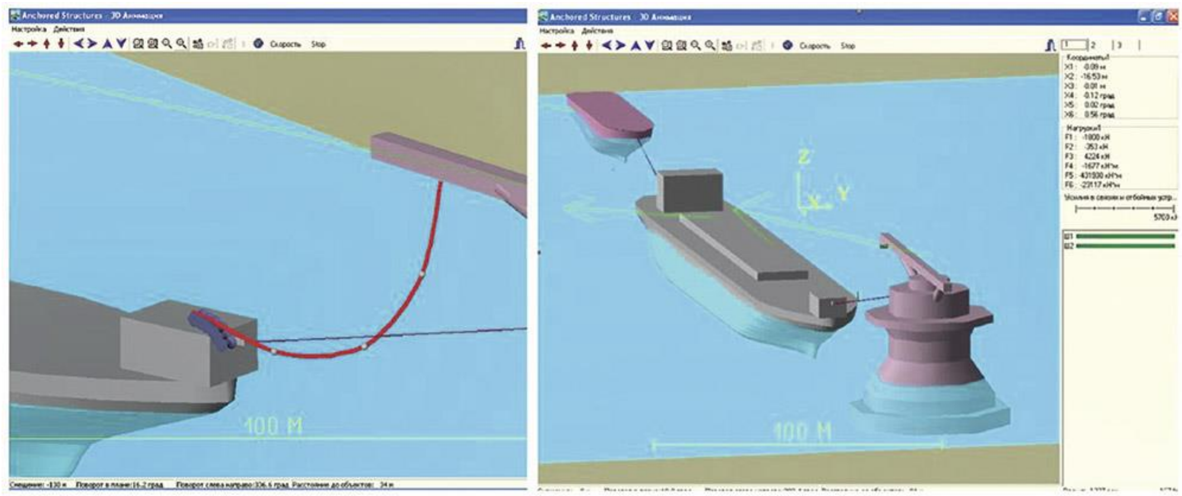

**Figure 4:** Mathematical (numerical) simulation using software package "Anchored Structures" ™

A number of scientific studies are devoted to the study and mutual comparison of the results of physical modeling and mathematical (numerical) simulation of port hydraulic structures, for example, "Numerical and physical simulation of seaport hydraulic structures" [8]. On the basis of the comparison results we can say that, while solving similar problems, physical simulation and mathematical (numerical) simulation effectively complement each other due to their essentially different methods.

Correctness and efficiency of physical, mathematical (numerical) simulation types for verification of design solutions is confirmed by the representation of these types of simulation in normative technical documents in the field of design of hydraulic structures. For example, in the document "API RP 2N Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions" the clause. 8.2.1. states "Small scale ice strength data obtained locally, preferably in situ, can be of assistance in the extrapolation. Physically based models and scale model tests may also be used to complement the full-scale data, with due account for uncertainties in their application" [9].

The design of port hydraulic structures, terminals and, in general, seaports is one of the most complex types of design. Design specialists need to take into account a lot of variable interdependent factors and features when developing design solutions. At the same time, the design solutions adopted should ensure the maximum level of safety of hydraulic structures, including under the impact of sea waves, currents, aquatoria ice coverage and individual ice floes.

In the meantime, the present level of science and computer technology provides designers with a number of powerful tools for verification of adopted design solutions, including for confirmation of the required level of safety. Physical and mathematical (numerical) simulation techniques are some of the most prominent examples of these tools.

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