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Physical Modelling in Development of the Regulatory Framework for Transport Construction

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ABSTRACT

Application of the physical modelling method to justify regulatory requirements for design of structures for engineering protection of transport facilities from wave action is considered using the example of three completed research and development works. The described experimental studies of interaction of waves with structures were carried out in wave basins and tanks.

The objective of the research is to scientifically substantiate the requirements of regulatory documents for design of shore protection to ensure safe operation of the roadbed of railways and roads, bridge supports, and other transport structures operated under conditions of wave action on the shores of seas and lakes. In this case, the normalised parameters, depending on the hydrological (wind-wave and sea-level regimes of the water area and current), geological-morphological and lithodynamic (coastal zone dynamics) conditions are the types of protective structures used, planned and design solutions for protective hydraulic structures (location, elevations, dimensions), as well as the materials and products used for construction (including quality requirements).

The experimental design part of the described studies was carried out by the method of physical (hydraulic) modelling in wave basins and tanks. Physical modelling was carried out in accordance with the theory of similarity. At the same time, a «flat problem» is solved in wave tanks, and a «spatial problem» is solved in wave basins.

Keywords: *shore protection structures, wave basin, wave tank, roadbed, regulatory framework, physical modelling.*

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INTRODUCTION

The development of the regulatory framework in general and, in particular, in the field of transport construction, is based on scientific research [1]. Scientific research in development of the regulatory framework in the field of engineering protection of transport structures on the coasts of seas is carried out mainly by field observations and surveys [2–5] and by the method of physical modelling (laboratory studies in wave basins and tanks) [6–9].

Insufficient scientific substantiation of provisions of regulatory documents leads to a loss in reliability of engineering structures or to a decrease in efficiency of their operation, which in turn entails large financial losses. In this regard studies, including experimental ones, to substantiate the requirements of building codes and construction standards are very important.

The objective of the work is to summarise a series of studies that consisted in identifying new aspects of standardisation (methods for calculating wave-damping structures in tidal seas, methods for calculating the mass of elements for fastening wave-damping slopes with oblique approach of waves, as well as calculating wave loads and impacts on wave-damping structures with a wave chamber), carrying out experimental studies on physical models and preparing proposals for inclusion in the regulatory framework in the field of engineering protection of transport structures from the hydrodynamic influences of the aquatic environment.

RESEARCH METHODOLOGY

Research to develop the regulatory framework in the field of interaction of sea waves with structures of engineering protection of transport structures (roadbed of railways and roads, bridge supports, and others) is carried out by the method of physical modelling in wave basins and tanks. The following tasks are solved step by step:

• Analysis of the state of the problem under study.

• Development of a program of work, including research methodology.

• Conducting laboratory research in wave tanks and using spatial models in wave basins.

• Development of proposals for the use of the obtained results in regulatory and technical documents on the issue under consideration.

This work is based on a generalisation of individual results of scientific research conducted under the guidance of the author through recent years by the Research Centre «Sea Coast» to develop the regulatory framework in the field of engineering protection of the roadbed of railways and roads, as well as bridge supports from wave action. These studies were carried out on the commission of FAA FCS [Federal Centre of Standardisation and Regulation], approved by the Ministry of Construction of the Russian Federation [1]. The research included the following research and development works: «Development of methods for calculating wave-damping structures in tidal seas», «Study of stability of fastening elements for slope wave-damping structures» and «Study of wave loads and impacts on wave-damping structures with a wave chamber». Some of the results of those works were used to develop new sets of rules and national standards.

The experimental design part of the research was carried out by the method of physical (hydraulic) modelling in wave basins and tanks in accordance with the theory of similarity. Both geometric similarity (in accordance with the chosen scales) and dynamic similarity (similarity of surface and volume forces) were provided.

Physical modelling was carried out according to the method described in [8, 9]. In this case, the Froude number should be used as the main similarity criterion, that is, it is necessary to ensure the equality of the Froude numbers of the object and the model [9]:

$$Fr = \frac{V^2}{gL} = idem \qquad (1)$$

where Fr – Froude number;

V – characteristic speed (e. g., wave propagation speed);

g – acceleration of gravity;

L – characteristic linear dimension (e. g., wavelength).

Since the wave action on the slopes of sill structures (made of stone or shape massifs) was studied, the following condition was also satisfied on the model:

$$Re \geq 1000, \qquad (2)$$

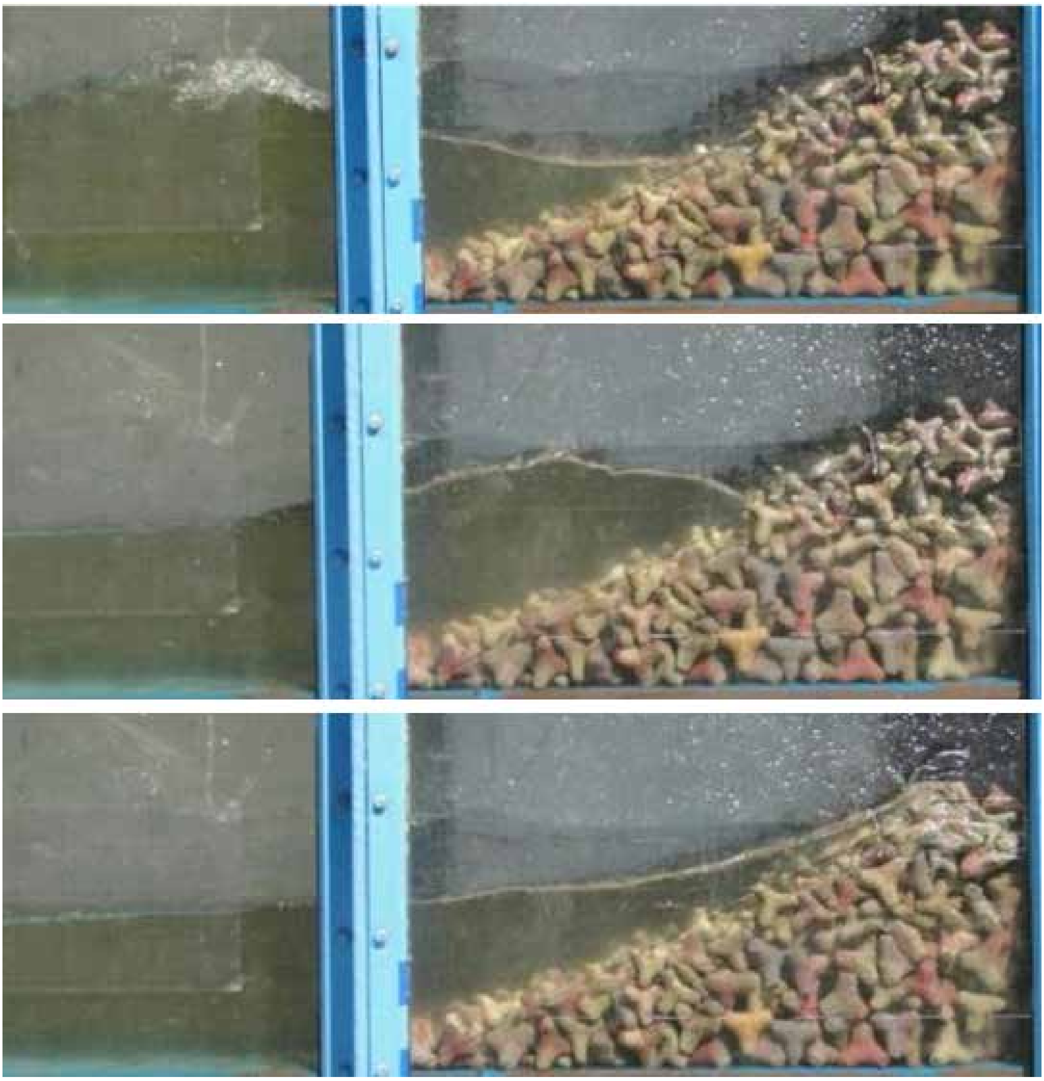
where Re is Reynolds number, determined by the formula

$$Re = \frac{VL}{\nu}, \qquad (3)$$

where V – characteristic speed (e. g. wave propagation speed);

L – characteristic linear dimension (for example, the diameter of the outline elements);

ν – kinematic viscosity of the fluid.



Pic. 1. Laboratory studies of wave-damping berms from shape arrays for protecting bridge piers, as well as linear structures (railway roadbed) in a wave tank under tidal conditions [performed by the author].

In the process of research, measurements of physical characteristics were carried out regarding average water level in a tank or basin; wave parameters (height, length, and period); wave pressure; current speeds; coastal slope profiles; sediment flow; sediment size. Also in the experiments, an analysis of stability of cast elements or individual structures was carried out.

RESULTS

Development of Metho\ds for Calculating Wave-Damping Structures in Tidal Seas [10]

The object of research referred to wave-damping structures – sill berms and dams of various design (made of stone, rock mass, shape arrays) and pebble beaches under tidal conditions [11].

The objectives of the study included:

• Obtaining experimental data on stability and efficiency of wave suppression structures under tidal conditions.

• Development of theoretical foundations of the methodology for calculating the parameters of wave damping structures designed on the shores of tidal seas.

• Formulating provisions for amending the existing regulatory framework.

Several series of experiments were performed to solve the set problems in the laboratory conditions in the wave basin and tank (Pics. 1 and 2) [11]. At the same time, the influence of both tides and ebbs on stability and wave damping efficiency of structures was studied.

Pic. 2. Laboratory studies of structures for protection of linear structures (railway roadbed) in a wave basin [performed by the author].

Pic. 3. Laboratory studies of a sloping wave-damping structure made of shape arrays (tetrapods) with a frontal approach of waves in a wave tank [performed by the author].

The choice of wave parameters for studying stability of studied structures was carried out considering the tides [10].

The performed experiments formed the basis of the methodology that is used when assigning planned and design parameters of wave suppression structures used to protect the roadbed of roads and railways, bridge piers, etc. from wave action (such as berms made of stone, shape array massifs, or rock mass, as well as beaches).

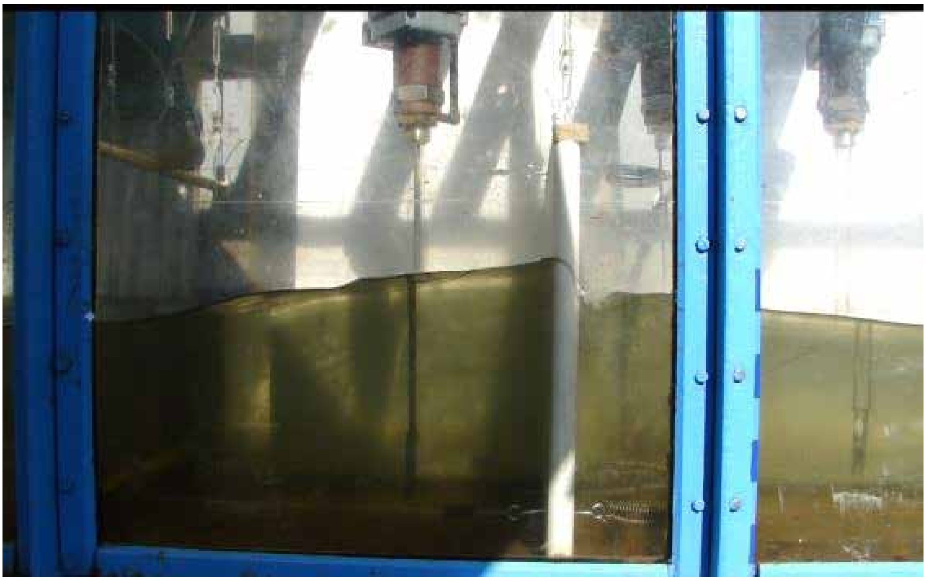
The analysis of the conducted studies showed that «calculation of the parameters and stability

Pic. 4. A wave basin with a turntable for laboratory studies with various angles of wave approach to structures [performed by the author].

Pic. 5. Laboratory studies of a sloping wave-damping structure made of stone in a wave basin [performed by the author].

of pebble beaches, rock mass berms, shape array massifs and stone erected on tidal seas is not allowed to be carried out according to the standards developed for non-tidal seas, namely, according to SP [construction rules] 277.1325800.2016» [10]. The provisions of this standard can be taken as a basis for calculation of wave suppression structures, but with significant adjustments regarding the calculation of wave-damping structures.

Based on the works [12–14] studying the interaction of sea waves with wave damping



Pics. 6–7. Experimental studies of interaction of waves with through walls in a wave tank [performed by the author].

structures, and considering tidal phenomena, under the guidance of the author, a new set of rules SP 416.1324800.2018 was developed.

Research of Stability of Fastening Elements of Sloping Wave-Damping Structures

In this study, stability of the protective fastening of wave-damping slopes was studied for different angles of wave approach. Such studies are especially relevant for the design of engineering protection structures for bridge supports [15].

The stability of slopes under wave action is studied by researchers on physical models, mainly under frontal wave action [16; 17].

That research, reproduced cases of frontal approach of waves to a hydraulic structure using models in a wave tank (Pic. 3), and cases of oblique approach of waves to a hydraulic structure in a wave basin equipped with a turntable to change the angle of wave approach (Pic. 4). The wave pattern near the wave damping slopes was studied under the influence of obliquely approaching waves (Pic. 5). The main task of the research was to evaluate the influence of the interference of waves approaching at an angle and reflected waves on the increase in the height of waves and, as a result, the increase in the wave action on the elements of the slope fastening (relative to the frontal approach).

The results of the experiments showed a significant difference with the calculations performed in accordance with SP 38.13330.2018 in terms of the mass of the limit equilibrium of fastening elements (stone or shape arrays). It was found that in case of a non-frontal approach of waves to a wave-damping slope, there is an interference of reflected and approaching waves.

The method that has been developed following the study using a hydraulic model for calculating the mass of fastening elements of wave-damping slopes can be recommended for adjusting the current regulatory documents on the issue under consideration, namely SP 38.13330.2018 and SP 277.12325800.2016.

Proposals have been prepared on the use of R&D results in regulatory documents.

Investigation of Wave Loads and Impacts on Wave-Damping Structures with a Wave Chamber [18]

That work studied the process of wave action on wave-damping structures with a wave chamber.

The objective of the research was to obtain experimental data on wave loads on the structures under study for subsequent comparison with the results of calculations according to the standard method SP 38.13330.2018, as well as to correct and clarify the normative methods for calculating the structures under study.

According to the results of laboratory studies (Pics. 6–7), the formulas used in the current standards for calculating the interaction of waves with through walls were corrected and refined [19, 20].

In addition, the experimental data obtained can be used to develop and improve the regulatory framework in transport construction.

APPROBATION AND IMPLEMENTATION OF RESEARCH RESULTS

The results of the conducted studies served as the basis for compiling the relevant sections (calculation of wave-damping structures on tidal seas, calculation of the mass of fastening elements of wave-damping slopes with an impact of oblique wave, as well as calculation of wave loads and impacts on wave-damping structures with a wave chamber) of the following regulatory documents:

• SP 277.1325800.2016 on Marine coastal protection structures. Design rules (introduced by the Technical Committee for Standardisation; approved by order of the Ministry of Construction and Housing and Communal Services of the Russian Federation of December 16, 2016, N 963/pr and entered into force on June 17, 2017);

• SP 416.1324800.2018 on Engineering protection of tidal seacoasts. Design Rules (introduced by the Technical Committee for Standardisation; approved by Order of the Ministry of Construction and Housing and Communal Services of the Russian Federation of November 30, 2018, N 781/pr and entered into force on May 31, 2019).

CONCLUSION

The scientific novelty of the research lies in the fact that new aspects of regulation have been identified (methods for calculating wave-damping structures on tidal seas, a method for calculating the mass of fastening elements of wave-damping slopes with an oblique wave approach, as well as calculating wave loads and impacts on wave-damping structures with a wave chamber); experimental studies on physical models have been prepared and carried out; based on the studies performed, proposals have been prepared for inclusion in the regulatory framework in the field of engineering protection of transport facilities from the hydrodynamic effects of the aquatic environment.

The described research and development works are an example of scientific substantiation of provisions of regulatory documents and national standards in the field of engineering protection of transport structures from wave action. The regulatory requirements developed based on such R&D will ensure reliability and efficiency of engineering protection structures, which in turn will have a positive impact on overall safety of transport facilities.

Developed based on the results of the studies presented in this paper, methods for calculating wave-damping structures on tidal seas, a method for calculating the mass of fastening elements of wave-damping slopes with an oblique approach of waves, as well as calculating wave loads and effects on wave-damping structures with a wave chamber, will fill a significant part of the gaps in the regulatory documentation in the field of engineering protection of bridge crossings, railway roadbed and roads, as well as other transport facilities.

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