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Method of integrated consideration of factors for calculation of anchor system of pontoons

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Abstract. The work is devoted to the study and analysis of hydrodynamic and climatic loads on hydraulic structures of the Neva Bay – the eastern part of the Gulf of Finland, which is exposed to significant anthropogenic and natural impacts. The geographical position of the Neva Bay, as well as the complex of flood protection structures of St. Petersburg, affect the predicted load levels. In these conditions, special attention is paid to the design and operation of pontoons and other hydraulic structures resistant to waves, ice cover and wind loads. The study calculated the wave-protective characteristics and stability of pontoons used in the Neva Bay as moorings for small vessels. The main parameters of wave loads were estimated using wave models, which made it possible to take into account irregular water oscillations and their effect on the dynamic behavior of structures. A test was carried out for the stability of pontoons with various configurations of anchor systems that ensure their fixation at a given point in the water area. The simulation showed that under conditions of irregular waves and changing water levels, floating structures experience significant loads that are distributed to the anchor system and require accurate calculations to ensure reliability. Additionally, ice and wind load on hydraulic structures, loads associated with thermal expansion of ice, changes in water levels, and wind effects were studied, taking into account the characteristics of ships of different lengths and above-water heights. The simulation results make it possible to identify key operating conditions for protective and berthing structures in the Neva Bay and provide information for inclusion in the information model of the water area, which will allow predicting the behavior of structures under changing natural and climatic conditions.

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1. Introduction

The object of this work is the development and analysis of an anchoring system for pontoons designed to serve as mooring facilities for small vessels in the Neva Bay, located in the eastern part of the Gulf of Finland. This work addresses the engineering challenges associated with ensuring the stability and durability of pontoon structures under variable environmental loads, including wave, wind, and ice pressures, as well as the effects of erosion and sedimentation.

The study focuses on creating an information model that considers the hydrodynamic and climatic conditions specific to Neva Bay, with an emphasis on developing mathematical models for predicting the behavior of waves and currents under changing external conditions. The research highlights the advantages of pontoons over fixed structures, including their adaptability to water level changes and ease of relocation, and investigates the mechanics and durability of anchoring systems under diverse loading conditions. This involves calculations of anchor fastenings, analysis of mooring systems, and assessment of potential structural defects in the anchoring devices.

The aim of this work is to provide a scientifically grounded approach to optimizing the stability and operational characteristics of pontoons, specifically for applications in a harbor near Kotlin Island. The findings contribute to enhancing the reliability and safety of floating hydraulic structures in coastal areas subject to intensive shipping and high anthropogenic impact.

Hydraulic structures play a key role in the development of coastal infrastructure, providing protection of coastal areas and objects from the impact of natural factors, such as waves, currents, ice and wind. This issue is especially relevant for water areas with intensive shipping and a high degree of anthropogenic impact, which includes the Neva Bay. This is a water area in the eastern part of the Gulf of Finland of the Baltic Sea, located between the Neva River delta and Kotlin Island. Its unique location and specific hydrological regime necessitate the use of complex engineering solutions, such as the St. Petersburg Flood Protection Complex, which provides reliable protection of the city from rising water levels [1, 2]. However, the creation and operation of such structures require a comprehensive analysis and consideration of many natural and man-made factors, which makes the development of an information model of the Neva Bay an urgent scientific and practical task. A special feature of the Neva Bay is its relatively limited water space, which changes as a result of anthropogenic factors and natural processes, such as erosion and sedimentation. The construction of protective and mooring structures affected the bottom relief, the speed and direction of currents, as well as the wave regime of the water area, which in turn affected the overall stability of hydraulic structures. In this regard, it becomes necessary to conduct a detailed study of the hydrodynamic and climatic loads affecting various types of structures, as well as an assessment of their durability and operational characteristics. A key element of such studies is the development of information and mathematical models that allow forecasting the behavior of waves and currents in the water area when external conditions and parameters of structures change [3, 4].

The development of information technologies and numerical modeling methods has made it possible to analyze and predict in more detail the dynamic interaction of water with various hydraulic structures. Modern mathematical models are capable of taking into account complex factors, such as irregular wave processes, wind loads, thermal expansion of ice and other mechanisms that create loads on structural elements [5, 6]. One of the main approaches to wave modeling is the use of models, which allows describing wave loads based on the amplitudes and phase characteristics. It allows taking into account the influence of all the main components of waves on floating structures and anchor systems used to secure them at a given point in the water area. Of particular interest for the Neva Bay are studies of wave and ice loads on pontoons intended for use as berths for small vessels. The advantages of floating structures over stationary ones are due to their ability to adapt to changes in water levels and mobility, which is especially important in coastal waters with high wave amplitudes. However, floating structures require additional calculations to ensure their stability under conditions of time- and space-varying loads. Particular attention should be paid to the mooring systems that hold the pontoons in a given position and limit their horizontal movements. These systems, represented by anchor chains and cables, experience significant loads when the water level changes, when the waves and wind oscillate, and when there is ice cover. The reliability of such systems is determined by the strength of the anchor ties, their resistance to corrosion and wear, and the ability to withstand short-term overloads without damage.

This work provides for the calculation of the anchor fastening system for pontoons. Pontoons can be used for various purposes. They are usually considered as floating berths [7], breakwaters [8, 9], foundations for offshore wind turbines [10], photovoltaic systems [11] and other structures. In this case, the pontoon is considered as a place for small vessels to moor in the harbor near Kotlin Island. At the same time, floating berths for ships have a number of advantages compared to stationary structures. They are less susceptible to fluctuations in water levels, do not depend on the state of the seabed, and are also mobile and easily relocatable structures. Pontoons used as berthing hydraulic structures can have different configurations depending on the size of the water area and mooring vessels. Pontoons can be considered as separate berths, as well as combinations of modules (pontoons) of different shapes and sizes. In addition, pontoons can be secured at a point in the water area using an anchoring system in the form of steel chains or synthetic cables, as well as using piles that limit horizontal movements [12]. The interaction of waves and currents with moored pontoons of various shapes and configurations, an assessment of the influence of their shape, direction of waves and the reaction of anchor ties are presented in works [13–16]. The authors of [17] study the behavior of floating moored structures under the influence of regular waves. The influence of irregular waves on the hydrodynamic reactions of floating objects is shown in studies [11, 18]. Methods of numerical hydrodynamic modeling are considered by the authors in work [19], where the influence of currents caused by tsunamis on pontoons with anchor ties is studied. A moored pontoon is installed in a coastal harbor, with the maximum wave height set by design standards at 0.3 m. Such a wave is ensured under conditions of constructing protective moles, which is what is proposed in the study. Paper [19] provides an example of performing a destruction analysis in the event that protective moles are not constructed. At the same time, some authors study the dynamic characteristics of pontoons under the influence of irregular and regular waves using model tests [20, 21], comparing the results with numerical calculations.

In addition to the problems associated with the impact of external loads on floating structures, it is necessary to take into account the operation of the mooring system. Floating structures are subject to time-varying loads from waves and wind. Anchor fastening systems hold the structures at a given installation point and limit their movements, taking up loads. At the same time, the connections must avoid sagging, which can lead to sudden jerks and damage to the structure [22].

The working and ultimate indicators of the state of the anchor device of pontoon berths are characterized by a number of possible defects: rupture of anchor chains/ropes, shift of anchors, mechanical and corrosive wear of anchor chains/ropes and fastening elements. At the same time, to ensure a working condition, rupture of anchor connections is not allowed; the ultimate state is characterized by rupture of one element [23].

This research is highly relevant due to the increasing need for reliable coastal infrastructure in areas exposed to intense natural and anthropogenic forces. Pontoons, a key focus of this research, offer unique advantages in such variable conditions. Their mobility, adaptability to water level fluctuations, and ease of installation make them particularly suitable for berthing and protective structures in dynamic coastal environments. Consequently, a detailed study of their anchoring systems is essential to ensure the structures can withstand these conditions while minimizing maintenance and damage over time.

The main goal of the research is to develop a reliable and scientifically validated anchoring system for pontoons, specifically tailored to the conditions of the Neva Bay. This system must ensure the stability and durability of the pontoons under diverse environmental stresses, thereby supporting safe and effective berthing options for small vessels. To achieve this goal, the research is organized around the following tasks:

1. Develop a numerical model for wave load calculations and conduct detailed numerical calculations of wave loads and dynamic characteristics of anchor ties using modern modeling approaches to enhance hydraulic engineering applications for pontoons.
2. Utilize model data to develop strategic placement plans for floating structures, enabling accurate prediction of their behavior under varying conditions, such as irregular waves and currents.
3. Create a tailored information model that reflects the unique hydrodynamic and climatic characteristics of the Neva Bay, ensuring reliable and safe operation of moorings for small vessels.
4. Implement advanced methods, such as the spatial radiation source method, to predict wave loads and optimize anchor system parameters in complex water areas like the Neva Bay.
5. Perform calculations to establish different external impact scenarios, such as wave heights of 1.1 m and 0.5 m, to identify suitable water areas for placing ship berths within the Neva Bay.
6. Design and test the anchor fastening system for pontoons in a protected part of the Neva Bay under maximum wave height conditions, ensuring it holds the structure securely and absorbs loads effectively.
7. Define specific operational conditions for the protected part of the Neva Bay to support reliable mooring functionality based on the anchor system testing.
8. Assess the suitability of Kupecheskaya harbor as a mooring site for pontoons, focusing on its protection from high waves.
9. Develop a generalized design framework for floating structures that can be adapted to other coastal sites, accounting for site-specific hydrodynamic conditions and environmental impacts.

The development of fastening systems is an important task to ensure the reliability and safety of the structures. This problem is solved within the framework of the development of an information model that makes it possible to assess and take into account changes in the natural and climatic characteristics and geometric parameters of the Neva Bay. A forecast of the wave regime of the water area, taking into account the location of protective and berthing structures, allows one to select a location for the mooring of small vessels and conduct further mathematical modeling using the example of a specific structure in a harbor determined in advance by calculations.

2. Methods

In order to solve the set problems of hydrodynamic and climatic loads on hydraulic structures in the protected part of the Neva Bay water area, a comprehensive methodology was used, including the collection of data on the wave regime, during which data on the wave activity of the water area was collected based on observations, model tests and calculations. Spectral wave models can be used to represent irregular waves with two calculated wave heights in the fairway area. Wave load modeling was carried out in software packages capable of taking into account irregular waves. For this purpose, numerical methods of hydrodynamic modeling (finite element method or spatial radiation source method) were selected. Based on the wave spectrum using superposition of harmonic components, wave loads were calculated in six degrees of freedom for each element of the structure. Temperature expansion of the ice cover was determined based on climatic and temperature conditions of the region. The calculations were based on stresses from a solid ice cover formed during its thermal expansion, taking into account its strength and adhesion to the structure. Ice freezing to the structures and its effect during water level fluctuations were taken into account. The wind load was calculated taking into account the length of the object and for several heights of the above-water part. The calculation was performed for the wind speed acting on the surface of the object in the worst position. The wind load was estimated using the flow resistance formula for the calculated section, based on the aerodynamic characteristics and the general projection of the vessel. To analyze the impact of the ice cover on the outer mole, a method for calculating ice loads for a flat ice field interacting with the outer southern mole of the Coastal harbor was used. Based on the strength characteristics of the ice and the contact area of the mole, the maximum load was determined. The calculations were performed taking into account the possibilities of ice destruction and the resistance of the mole material. Verification dynamic calculations of wave loads were made for two variants of wave action in order to take into account different directions and amplitudes of waves. Two scenarios were used to test the stability of the structures: one for typical wave conditions of the water area, the second for extreme ones. Based on the data obtained, the required strength and stability of the piers and pontoons under maximum wave conditions were estimated. Mathematical modeling is carried out in the Anchored Structures PC, according to the methodology proposed by the authors [24]. The software package calculates loads from external influences. An irregular wave is represented as a set of elementary harmonic waves. After setting the wave spectrum, the wave loads from each harmonic of the wave spectrum were calculated (taking into account its direction, magnitude and phase).

Wave load vector on a structure in six degrees of freedom $F_w(t) = \left(F_{w1},\ \ldots F_{wj},\ \ldots F_{w6}\right)$, time-dependent, is defined in this case as a superposition of the loads of individual components of the wave spectrum [25]:

$$F_w(t) = \sum_{i=1}^{N} F_{wi}(\omega_i)\sin\left(w_i t + \varphi_i\right), \tag{1}$$

where F_{wi} is vector of amplitudes of loads and moments from the i th harmonic of the wave spectrum; t is time; ω_i is the circular i th harmonic; φ_i is the phase of the i th harmonic of the load spectrum; N is the number of harmonics.

Thus, to simulate the dynamic behavior of a structure in waves in the Anchored Structures software package, it is necessary to determine the wave load vector F_w and hydrodynamic parameters of the structure (λ – matrices of added masses and B – matrix of wave resistance coefficients) for each specific frequency of the wave spectrum. To obtain theoretical values of these parameters for different spectrum frequencies, a variation of the widely known method of hydrodynamic features was used – the method of spatial radiation sources. This method is based on obtaining the reflected and incident wave potentials and integrating the resulting liquid pressures over the wetted surface of the structure. Calculation of stresses in the anchor ties was performed by a quasi-static method, the tension and trajectory of the line are a function of the position of the hawse point of the structure. When calculating the anchor ties, their stretching is taken into account, as well as the possibility of laying part of the tie on the bottom of the water area.

To calculate the rigidity characteristics of the anchor ties, an analytical solution of the equations of a freely sagging flexible heavy and stretchable tie was used. This method was developed by the authors of the Anchored Structures software package, was widely tested in the calculations of anchor ties of floating structures and showed high accuracy and reliability of the calculations [24]. The method allows calculating the vertical and horizontal components of the tie tension at an arbitrary position of the hawse point. The software package constructs the rigidity characteristics of all ties; the general multidimensional piecewise linear rigidity characteristic of the entire retention system is presented as:

$$F_R\left(X_c, L_1\right)=\sum_{j=1}^{N} C_j\left(T_j\left(B_{jx}\left(X_c\right), B_{jz}\left(X_c\right)\right)\right), \tag{2}$$

where X_c is vector of displacements of the structure in six degrees of freedom; $B_{jx}\left(X_c\right)$, $B_{jz}\left(X_c\right)$ are operators that allow based on a vector X_c calculate the vertical and horizontal coordinates of the hawse points of an arbitrary j^{th} connection; L_1 is vector of lengths of the first (upper) sections of connections; T_j is an operator that calculates the reaction of each connection based on its stiffness characteristics and the coordinates of the hawse point; $C_j\left(T_j\right)$ is operator that transforms the reaction of the j^{th} link into a reaction vector relative to the center of gravity of the structure; N is number of connections. Thus, the operator of the connection reaction allows us to obtain a reaction relative to the center of gravity of the structure in six degrees of freedom at an arbitrary position of the center of gravity with the ability to control the reaction using the vector L.

3. Results and Discussion

The parking of small vessels is regulated by Russian State Standard GOST R 58736-2019 “Moorings of small vessels. General requirements”. According to paragraph 6.1.8 of GOST R 58736-2019: “The creation of wave protection structures is recommended in cases where the normal average annual wave height in an unprotected water area exceeds 0.3 m.” At the same time, according to the calculations carried out by the authors, in the considered protected part of the Neva Bay water area, only the Kupecheskaya harbor is suitable for the parking of small vessels. In the Kabotazhnaya harbor, according to the calculations performed, the maximum waves are 0.4–0.6 m. Verification dynamic calculations of wave loads and wave amplitude was 0.7 m, the full wave was 1.4 m. The calculations are made for waves from ships that are sailing along the fairway. These waves are the maximum and spread in the direction of the Kabotazhnaya harbor, since the fairway is in close proximity to the harbor.

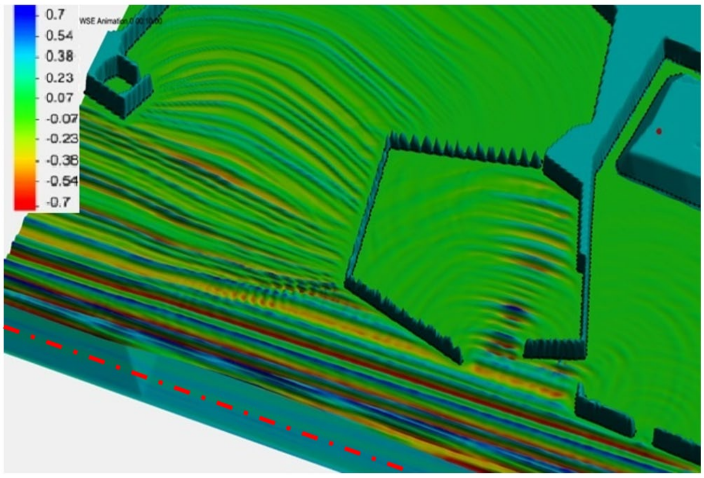

Figure 1. Result of wave height calculation in Kabotazhnaya and Kupecheskaya harbors (option 1).

The wave height in the Fig. 1 consists of two wave amplitudes, since the zero axis is taken as the water level in the Baltic system. The fairway axis is shown in the figure with a dashed line. The color scale corresponds to the wave height (m). For detailed examination, a fragment of the figure in the Harbor behind the protective mole is presented. The wave completely fades toward the shore. The recommended wave height is 0.3 m according to clause 6.1.8 of GOST R 58736-2019.

The wave calculation is performed for the wave direction from the vessel's passage along the fairway. The points of output of the results are presented in Fig. 2, which shows the results of the calculation of the wave height and loads in the Kabotazhnaya and Kupecheskaya harbors. Fig. 2 shows 11 calculation points, in which the wave height in meters (ETA) and the wave load in kN/m are determined for a calculation period of 600 s.

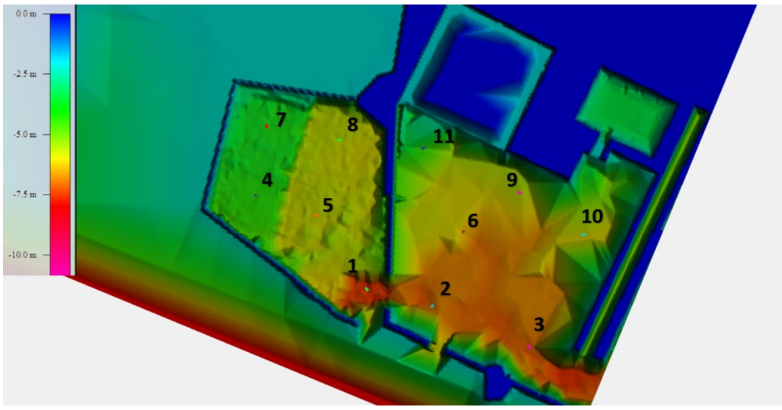

Figure 2. Layout plan of settlement points in Kabotazhnaya and Kupecheskaya harbors.

Table 1 shows the maximum values of wave height and the force of its impact at each calculation point. The given load values do not take into account the streamlining of the object.

Table 1. Maximum values of wave height and force at the moment of time at the calculated points.

No. of calculated point	Maximum wave height, m	Maximum force from wave, kN/m	Time, s
1	0.41	748	280
2	0.4	600	280
3	0.28	600	470
4	0.27	140	520
5	0.28	363	480
6	0.28	470	480
7	0.16	99	490
8	0.22	347	360
9	0.25	371	499
10	0.22	326	360
11	0.4	150	325

A pontoon for mooring small vessels is located in the Kupecheskaya harbor of Kotlin Island. The depth of the water area at the mooring point is 10 m.

A rectangular concrete pontoon in plan is adopted for mooring small vessels. Vessels are moored directly to the pontoon. The characteristics of the pontoons are presented in Table 2.

Table 2. Characteristics of pontoons.

Type of pontoon	Dimensions, L×W×H m	Freeboard height, m	Displacement, t
1	**9 × 2.4 × 1.07**	**0.49**	**10.1**
2	12 × 2.4 × 1.07	0.54	15.0
3	15 × 2.4 × 1.07	0.56	19.7
4	12 × 3.16 × 1.07	0.58	21.3
5	15 × 3.16 × 1.07	0.61	27.9
6	**15 × 4.2 × 1.07**	**0.64**	**38.8**

The pontoon is attached to the bottom of the water area using four 19 m long synthetic ropes on dead anchors. The characteristics of the anchor connections are presented in Table 3.

Table 3. Characteristics of pontoons.

Type	Quantity	Linear weight, kN/m	Breaking strength, kN
Anchor connections (rope)	4	0.159	1307

Dead reinforced concrete anchor with a vertical holding force (anchor weight) of at least 200 kN – 4 pcs.

Mathematical modeling for the design cases was carried out in the Anchored Structures PC. The software package calculated loads from irregular waves. The Anchored Structures PC allows you to calculate: ballasting, stability; anchoring and positioning systems; wind, current, wave and ice loads; structure dynamics; floating object dynamics during offshore operations; anchor and mooring tie dynamics. After calculating all the necessary hydrodynamic parameters of structures, the program begins directly modeling the dynamics in the frequency domain. Next, a static problem is solved for structures with anchor or mooring tie (the rest are in the initial position). After that, the tie calculations (if any) are performed. Then, the problem is solved in the frequency domain for each harmonic. Next, the static problem is solved taking into account the real force of wave drift in a given wave mode. Then, an iterative solution of the problem is performed in the frequency domain for each harmonic of the real wave spectrum taking into account the viscous quadratic resistance approximated by a linear one for a given oscillation amplitude for each degree of freedom.

Modeling was carried out for two situations: calculating a floating structure for a wave height of 1.1 m, as well as for a wave height of 0.5 m. Accordingly, the impact of waves was modeled: 1) the height of waves with 3 % probability is 1.1 m, the average wave period is 4.7 s and 2) the height of waves with 3 % probability is 0.5 m, the average wave period is 2.8 s.

The calculated directions of wave propagation: 90°, 135°, 180° are shown in Fig. 3.

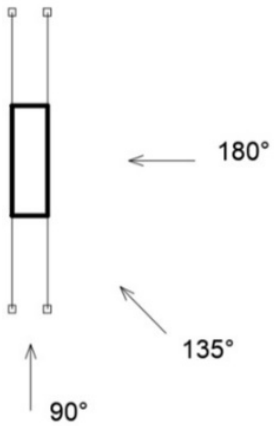

Figure 3. Directions of propagation of excitement.

The model of a floating structure with an anchoring system, defined in the Anchored Structures PC, is shown in Fig. 4.

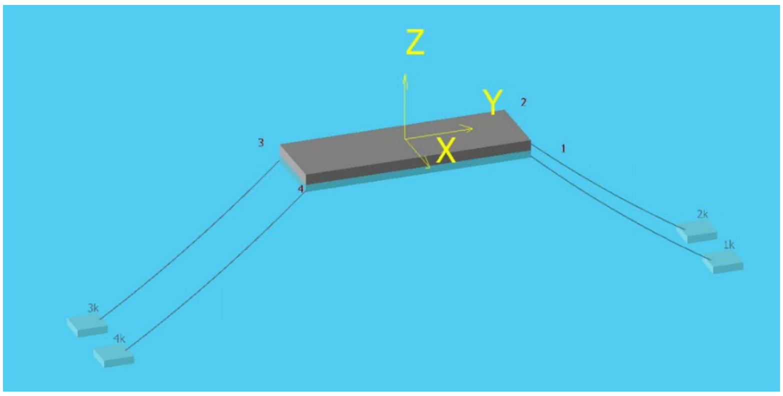

Figure 4. Model of a floating structure. General view.

The modeling task is to calculate the anchoring system for a floating berth structure and the pontoon movements. For this purpose, the calculation of external wave loads on the floating berth was performed in the Anchored Structures software package.

The results of modeling the structure's behavior under the influence of waves from the adopted directions of load propagation are presented in Table 4 (the worst cases for each direction). The results are presented for pontoons with dimensions of 9 × 2.4 × 1.07 (type 1) and 15 × 4.2 × 1.07 (type 6).

Table 4. Security values for pontoon types 1 and 6 (the worst values for each direction are indicated).

Calculation of a floating structure for a wave of 1.1 m						
Type of pontoon	1	1	1	6	6	6
Direction of excitement	135	180	90	135	180	90
Pontoon displacement, m	1.03	1.7	1.3	4	6.2	5.1
Vertical displacement, m	0.48	0.43	0.35	1.9	1.9	1.3
Roll, degree	2.5	0.5	2.5	9	2	9
Trim, degrees	9.03	13.02	4.5	34.02	50	18.1
Yaw, hail	5.6	1.8	3.4	22	7	13
$K_з$ anchor ties (worst)	2.9	3.8	5.04	10.2	15	20.01
Tie No.	3	2	4	3	2	4
$K_з$ mooring ties (worst)	1.46	1.9	3	5.6	7.2	11.8
Tie No.	1	1	1	1	1	1
Horizontal force on anchor, kN	120	101	80	470	400	320
Anchor No.	4	3	3	4	3	3
Calculation of a floating structure for a wave of 0.5 m						
Type of pontoon	1	1	1	6	6	6
Direction of excitement	135	180	90	135	180	90
Pontoon displacement, m	0.5	1.08	0.42	2	4	1.6
Vertical displacement, m	0.21	0.21	0.12	0.84	0.84	0.84
Roll, degree	0.7	0.7	1	2.8	2.8	4.1
Trim, degrees	4.42	6.23	2.09	17.6	24	8.1
Yaw, hail	4.5	5.5	2.6	18	22	10.4
$K_з$ anchor ties (worst)	7.7	5.8	60.3	30.8	23.2	240
Tie No.	1	1	4	1	1	4
$K_з$ mooring ties (worst)	3.1	2.4	5.5	12.4	9.6	22
Tie No.	1	1	1	1	1	1
Horizontal force on anchor, kN	52	60	8.5	208	240	34
Anchor No.	1	1	4	1	1	4

For comparison and juxtaposition, it is possible to select similar structures and methods, since the structure in question has not previously been calculated using the method in question. Mostofi & Bargi (2012) focused on new analysis concepts for floating piers' response to ship berthing impact [12]. Both studies highlight that robust anchoring systems are vital to maintain stability in areas exposed to wave loads, but this research specifically modeling wave impacts of 1.1 and 0.5 m for protected harbors like Kupecheskaya. Lamei, Li, & Hayatdavoodi (2023) explored wave-current interactions for floating objects with square and circular waterplane areas, discovering that shape plays a critical role in dynamic stability [13]. This research corroborates these findings by focusing on rectangular pontoons and analyzing their response to wave conditions typical of Neva Bay, suggesting that customized pontoon design can reduce instability in complex hydrodynamic environments. Tajali & Shafieefar (2011, 2008) performed hydrodynamic analyses of multi-body floating piers, focusing on wave actions in complex marine conditions [15]. Their results suggest that multi-body interactions and spatial wave action analysis improve structure resilience. Claus & Lopez (2022) [14] and Zeng & Bi et al. (2023) [22] examined floating structures in renewable energy settings, noting that durable mooring systems and wave-resistant designs are crucial for long-term stability in marine environments. This research supports the relevance of these findings by demonstrating that the Kupecheskaya harbor's sheltered location and tailored pontoon design make it suitable for small vessel parking, mitigating wave impacts and enhancing durability. Chen et al. (2022) [17] and Huang et al. (2023) [20] conducted numerical simulations to predict wave dissipation and dynamic responses for floating structures under long-period waves, noting that such modeling can anticipate wave impacts effectively. In the current research, similar numerical simulations were conducted with the Anchored Structures software, offering tailored insights for the Neva Bay's specific wave conditions, which also address dynamic wave behaviors and maximum load conditions. Garibin, Egorov & Butsanets (2023) explored floating berths' practical deployment in yacht marinas, emphasizing site-specific mooring requirements. Similarly, this research verifies the suitability of Kupecheskaya harbor for small vessel parking [23].

4. Conclusions

1. The numerical calculation of wave loads and the dynamic characteristics of anchor ties using modern approaches is a significant advancement for hydraulic engineering technologies applied to floating pontoons.
2. The data presented enable informed planning for the placement of floating structures and provide a basis for predicting their behavior under irregular waves and currents.
3. Introducing a model adapted to the specific conditions of the Neva Bay and detailing wave impact parameters ensures reliable operation of moorings for small vessels, enhancing both the safety and durability of these structures.
4. The modeling and calculation methods considered, allow for accurate prediction of wave loads and optimization of anchor system parameters, which is especially crucial for complex water areas like the Neva Bay.
5. Calculations performed as part of the Neva Bay information model identified suitable areas for placing ship berths and allowed for two modeling scenarios: one with a wave height of 1.1 m and another with a wave height of 0.5 m.
6. The anchor fastening system for a pontoon in a protected part of the Neva Bay was tested under two modeled scenarios, taking into account maximum wave heights; the anchor fastening reliably secures the structure and absorbs the acting loads.
7. Operational conditions for the selected protected part of the Neva Bay water area were formulated based on these tests.
8. The study confirms that Kupecheskaya harbor is a suitable location for a pontoon due to its protection from high waves.
9. The proposed approach to the design of floating structures is adaptable to similar projects, especially those requiring detailed analysis of hydrodynamic conditions specific to the installation site.

References

1. Ryabchuk, D.V., Nesterova, E.N., Zhamoida, V.A., Kotilainen, A., Vallius, G., Sukhacheva, L.L., Spiridonov, M.A. Dynamics of Sedimentation Processes in the Neva Bay (the Gulf of Finland) under Influence of Anthropogenic Factors. Proceedings of the Russian State Hydrometeorological University. 2014. 35. Pp. 102–118.
2. Rodionov, V.Z. Kompleks zashchitnykh sooruzheniy Sankt-Peterburga ot navodneniy: istoriya i ekologicheskiye problem [Complex of protective structures of St. Petersburg from floods: history and environmental problems]. Regional Ecology. 2016. 4. Pp. 13–23.
3. Badenko, V.L., Zotov, D.K., Kozinets, G.L., Kozinets, P.V., Chernov, P.V. Digital models for retrospective analysis of the structure of currents in Neva Bay. Magazine of Civil Engineering. 2023. 124(8). Article no. 12411. DOI: 10.34910/MSE.124.11
4. Kozinets, G.L., Badenko, V.L., Zotov, D.K. The influence of anthropogenic load on changes in the morphology of the Neva bay bed in the XIX–XXI centuries. Power Technology and Engineering. 2024. 1. Pp. 43–52.
5. Andreeva, S.A., Sharapov, D. Hoek–Brown model for ice breaking simulation. Magazine of Civil Engineering. 2023. 123(7). Article no. 12303. DOI: 10.34910/MCE.123.3
6. Sharapov, D.A., Sumtsova, A.S. Rockfill Stability to Ice Shearing by the Finite Element Method. Power Technology and Engineering. 2023. 57. Pp. 228–232. DOI: 10.1007/s10749-023-01646-1
7. Pryanichnikov, K.N., Sharonova, M.I. Designing moored floating berths for the operating conditions in the Black Sea. Bulletin of VSAWT. 2013. 34. Pp. 68–74.
8. Dai, J., Wang, C.M., Utsunomiya, T., Duan, W. Review of recent research and developments on floating breakwaters. Ocean Engineering. 2018. 158. Pp. 132–151. DOI: 10.1016/j.oceaneng.2018.03.083
9. Blagovidova, I.L., Tertyshnikova, A.S., Babak, A.S., Balagurak, A.V. A floating breakwater design for the protection of LNG terminal and FLNG. The Hydrotechnika. 2024. 2(75). Pp. 28–33.
10. Alkarem, Y.R., Ozbahceci, B.O. A complemental analysis of wave irregularity effect on the hydrodynamic responses of offshore wind turbines with the semi-submersible platform. Applied Ocean Research. 2021. 113. Article no. 102757. DOI: 10.1016/j.apor.2021.102757

11. Daniel, H.H., Haryo, D.A., Fandy, A.R. Geometric analysis of pontoon and mooring line towards hydrodynamic response. E3S Web of Conferences. 2024. 499. Article no. 01015. DOI: 10.1051/e3sconf/202449901015
12. Mostofi, A., Bargi, K. New concept in analysis of floating piers for ship berthing impact. Marine Structures. 2012. 25(1). Pp. 58–70. DOI: 10.1016/j.marstruc.2011.12.001
13. Lamei, A., Li, S., Hayatdavoodi, M., Riggs, H.R. Wave-Current Interaction With Floating Objects With Square and Circular Waterplane Areas. Proceedings of the ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering. 5. Ocean Engineering. Melbourne, 2023. Article no. V005T06A023. DOI: 10.1115/OMAE2023-105065
14. Claus, R., Lopez, M. Key issues in the design of floating photovoltaic structures for the marine environment. Renewable and Sustainable Energy Reviews. 2022. 164. Article no. 112502. DOI: 10.1016/j.rser.2022.112502
15. Tajali, Z., Shafieefar, M. Hydrodynamic analysis of multi-body floating piers under wave action. Ocean Engineering. 2011. 38(17–18). Pp. 1925–1933. DOI: 10.1016/j.oceaneng.2011.09.025
16. Tajali, Z., Shafieefar, M., Akhyani, M. Hydrodynamic analysis of multi-body floating piers. Proceedings of the ASME 27th International Conference on Offshore Mechanics and Arctic Engineering. 1. Offshore Technology. Estoril, 2008. Pp. 797–804. DOI: 10.1115/omae2008-57849
17. Chen, J., Zhang, J., Wang, G., Zhang, Q., Guo, J., Sun, X. Numerical simulation of the wave dissipation performance of floating box-type breakwaters under long-period waves. Ocean Engineering. 2022. 266(4). Article no. 113091. DOI: 10.1016/j.oceaneng.2022.113091
18. Barrera, C., Losada, I.J., Guanche, R., Johanning, L. The influence of wave parameter definition over floating wind platform mooring systems under severe sea states. Ocean Engineering. 2019. 172. Pp. 105–126. DOI: 10.1016/j.oceaneng.2018.11.018
19. Ozbahceci, B., Celik, H., Girgin, E. and others. Effect of tsunami induced currents on floating pontoons with the mooring lines. Coastal Engineering Proceedings. 2023. 37. Structures.20. DOI: 10.9753/icce.v37.structures.20
20. Huang, H., Chen, X., Ji, S., Miao, Y., Chen, X. Experimental and numerical study on dynamic responses of floating bridge under the shielding effect of a floating platform. Marine Structures. 2023. 89. Article no. 103379. DOI: 10.1016/j.marstruc.2023.103379
21. Loukogeorgakia, E., Lentsiou, E.N., Aksel, M., Yagci, O. Experimental investigation of the hydroelastic and the structural response of a moored pontoon-type modular floating breakwater with flexible connectors. Coastal Engineering. 2017. 121. Pp. 240–254. DOI: 10.1016/j.coastaleng.2016.09.002
22. Zeng, F., Bi, C., Sree, D., Huang, G., Zhang, N., Law, A.W.-K. An Adaptive Barrier-Mooring System for Coastal Floating Solar Farms. Applied Energy. 2023. 348. Article no. 121618. DOI: 10.1016/j.apenergy.2023.121618
23. Garibin, P.A., Egorov, S.V., Butsanets, A.A. Some issues of surveying floating berths of yacht marinas. Vestnik Gosudarstvennogo universiteta morskogo i rechnogo flota imeni admirala S.O. Makarova [Bulletin of the Admiral Makarov State University of Maritime and Inland Shipping]. 2023. 15(5). Pp. 783–797. DOI: 10.21821/2309-5180-2023-15-5-783-797
24. Bolshev, A.S., Frolov, S.A., Kuteinikov, M.A. Mathematical modeling of offshore floating facilities using “Anchored Structures” Software Package. Research Bulletin of the Russian Maritime Register of Shipping. 2013. 36. Pp. 68–90.
25. Bolshev, A.S., Mikhalenko, E.B., Frolov, S.A. Matematicheskoe modelirovanie povedeniya morskih plavuchih sooruzhenij [Mathematical modeling of the behavior of marine floating structures]. Trudy SPBGTU [Works of SPBGTU]. 2007. 502. Pp. 252–274.

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