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THE RESULTS OF THEORETICAL STUDIES FOR DETERMINING OPERATIONAL LOADS ON GRAVITY-TYPE BERTHING STRUCTURES

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Abstract. The current waterfront of Ukrainian ports includes structures that have been developed in the past and have over 50 years of experience. Open-piled quay walls and sheet-pile quay walls are the most common types of quay walls used for berths in Ukrainian ports. However, there are gravity-type quay walls. The share in the total the waterfront is not large. They were built in the past and require modernization and reconstruction. Most of these berthing structures have defects in concrete and reinforcement, which reduce the durability and bearing capacity.

Furthermore, the development of freight and passenger maritime traffic and the construction of modern ships led to the need to increase the depths at existing berths and define the operational loads meeting modern requirements.

Thus, the issue of reconstruction of gravity-type quay walls is relevant for many ports of Ukraine. The choice of the reconstruction method depends on the correct estimation of the actual technical condition of an existing structure. Gravity-type structures are those that rely primarily on their weight and grip on the foundations to resist any possible adverse load combinations. The requirements for such structures lead to the solution of one of the main tasks – the determination of the reactive capacity of the soil base.

The reactive capacity calculation of the soil bases for considered structures is essential. The purpose of the calculation is to provide both strength and stability of soil bases. An improved method for determining the reactive capacity of the soil base of gravity-type quay walls has been developed. This method allows determining the reactive capacity of the soil base in conditions of the mixed stress state (limit and sublimit stress state zones in the soil base are considered).

This paper reviews some results of applying the proposed method for the reactive capacity estimation of the soil base of gravity-type quay walls. The obtained results have been used to analyze the preliminary reconstruction options for the mentioned structures and determine operational loads.

Keywords: the reactive capacity, gravity-type quay wall, limit and sublimit stress state, reconstruction and operational loads.

Introduction. The sea ports are the most important component of Ukraine's transport infrastructure and export potential. The transport complex competitiveness in the world market depends on sea ports functioning efficiency, the level of their technological and technical equipment, the management system and the development of infrastructure with modern international requirements.

The main conditions for the development of sea ports are the reconstruction and renovation of existing ones and also the construction of new deep-water transshipment complexes that allow the serving of large sea vessels. The current waterfront of Ukrainian ports includes structures that have over 50 years of experience. Open-piled quay walls and sheet-pile quay walls are the most common types of quay walls used for berths in Ukrainian ports. However, there are gravity-type quay walls. The share in the total waterfront accounts for approximately 10%. They have been built in the past and require modernization and reconstruction.

The constantly growing cargo turnover affects the size of the marine fleet. Construction of modern vessels with drafts 12.0-17.0 m leads to the necessity of increasing the depths at existing berths and updating operational loads. Thus, the issue of reconstruction of gravity-type quay walls is relevant due to the growing number of berths that do not meet modern requirements as well as having an exceeded design life and physical deterioration.

Statement of the problem. For the development of Ukraine as a transit state in the global transport system, it is necessary to take measures to increase transit cargo flows and solve the problem of the functioning and development of seaports.

Seaports of Ukraine have an advantageous transport and geographical position to strategic directions of cargo flows and proximity to European and Middle Eastern markets. Ports with developed infrastructure, sufficient depths, and a high level of mechanization of loading and unloading work make it possible to consider seaports of Ukraine as convenient transshipment points for transit cargo flows. Thus, the reconstruction of berths and dredging works for the renewal and development of Ukrainian port infrastructure will solve some key issues that are relevant and need to be resolved. The reconstruction method depends on the constructive scheme of the existing structure and its actual technical and deformable states.

As mentioned above, a great variety of gravity-type quay walls has been developed in the past and require modernization and reconstruction. Gravity-type structures are those that rely primarily on their weight and grip on the foundations to resist any possible adverse load combinations. The requirements for such structures lead to the solution of one of the main tasks – the determination of the reactive capacity of the soil base.

Analysis of research and publications. The traditional design method of foundations of gravity-type structures is based on the concept of bearing capacity. The fundamental basis of methods for the bearing capacity assessment of the soil bases is limit equilibrium theory. It should be noted that the practical significance of the solutions of limit equilibrium theory is used until now despite the widespread use of different elastic-plastic deformation analysis methods of soils. Static solutions of limit equilibrium theory are repeatedly tested in practice and allow reliably determine limit load value on the soil bases [1]. Therefore, the results of these solutions are included in the regulatory documents for performing calculations of the soil bases of structures [2].

The methods of the bearing capacity calculation of the soil bases based on limit equilibrium theory are described in well-known works by M.V. Malyshev [3], P.I. Yakovlev [4], S.G. Kushner [5], Yu.K. Zaretskiy [6], V.G. Fedorovskii [7], N.K. Ameta [8], J.M. Raut et al. [9].

A Literature review has been done that gives the idea of new methods for the bearing capacity calculation of the soil bases. Y. Guang-hua et al. [10] proposed a new method for determining the bearing capacity of the soil base that considers the size, buried depth, and settlement of the foundation. New solutions for the bearing capacity calculation of the soil bases with the use of modern numerical methods based on limit equilibrium theory have been analyzed by A.M Karaulov et al. [11]. However, the use of the finite element method to describe the limit state of soils remains understudied, despite its widespread use in geotechnical calculations. Researchers [12] provided information about the significant impact of soil inhomogeneity on the reactive bearing estimation of the soil base.

Based on the above, it should be noticed that a number of fundamental issues related to the development and improvement of practical methods for the reactive capacity estimation of the soil bases of gravity-type quay walls remain unresolved.

The purpose of the studies is to apply the proposed method of the reactive capacity calculation of the soil base for some gravity-type quay walls [13, 14]. Special attention is given to the reconstruction issues of gravity-type quay walls and clarification of the scheme of permissible operational loads.

The research method is theoretical with the development of a calculation model of the "structure – soil base" system, which allows determining the reactive capacity of the soil base of a gravity-type berthing structure as well as estimating the reserves of its bearing capacity.

The results of the research. According to the instruction of the document [15], one of the important factors affecting the choice of reconstruction scheme of a gravity-type quay wall is the reactive capacity estimation of the soil base. The strength and the reactive capacity of soil bases of mentioned structures during the operation depend on operational load values.

Based on the above, the method of the reactive capacity calculation of the soil base has been developed [13, 14]. The method is based on the theory of limit stress state but compared to other approximate methods, considers two zones of stress state (limit and sublimit) and the friction on the contact of the base of the foundation structure and the soil base. In the paper, concrete blocks quay wall with the immersed stone bed in the soil is considered. Here, the friction on the contact of the stone bed and the base of the foundation structure is taken into account (Fig. 1).

Where b_e – the width of the contact zone of the stone bed interacting with the base of the foundation structure in limit stress state; B – the width of the base of the foundation structure interacting with the stone bed; $f_{fr}^{\lim}$ – the intensity of the friction forces on the contact of base of the foundation structure within the width of limit stress state zone; f' – the intensity of the friction forces on the contact base of the foundation structure within the width of sublimit stress state zone; E – the lateral backfill pressure.

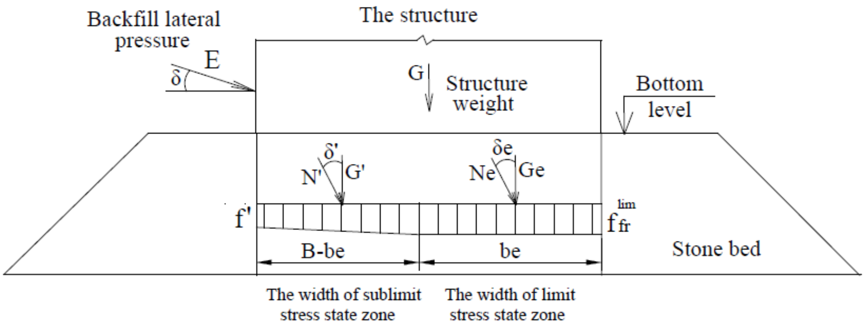

Fig. 1. The calculation scheme for determining the width of limit and sublimit stress state zones of the soil base

The resultant of the reactive capacity of the soil base N can be determined as the vector sum of two components: limit N_e acting within the wide b_e and sublimit N' acting within the wide B-b_e. In this case, the resultant of the reactive capacity of the soil base N can be expressed by the equation $N=\left[N_e^2+N'^2+2\cdot N_e\cdot N'\cdot\cos(\delta_e-\delta')\right]^{1/2}$.

The design scheme for determination of the resultant of the reactive capacity of the soil base N is shown in. Fig. 2. It should be noted that the equilibrium conditions of each zone of strain stress should be consistently considered for the determination of limit N_e and sublimit N' components of the reactive capacity of the soil base. The definition of all necessary components of the design scheme is described in the work [14].

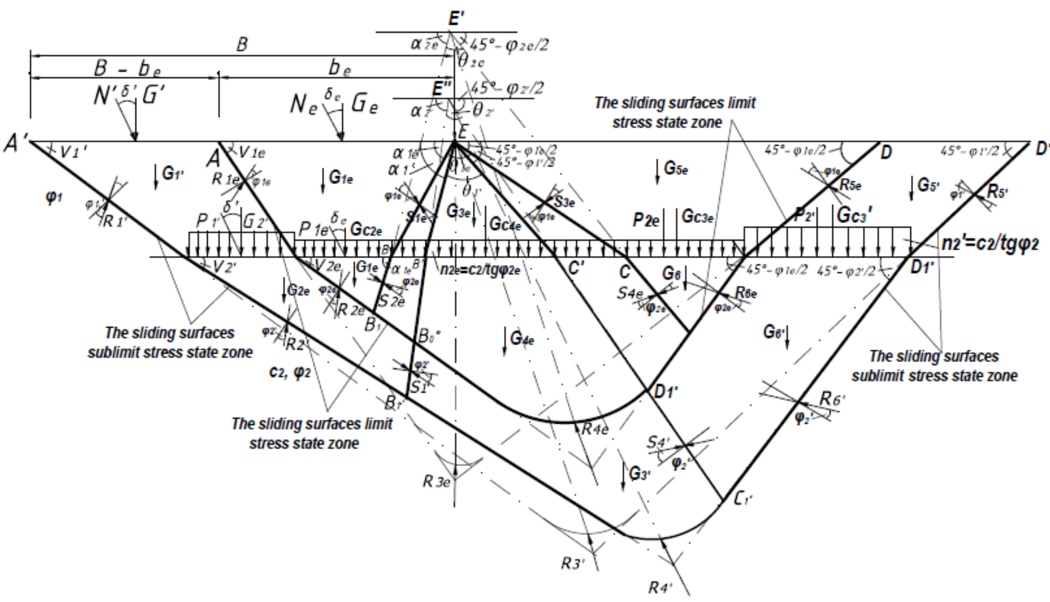

Fig. 2. The sliding surfaces and the outlines of limit and sublimit stress state zones

The cohesive soil characterized by specific cohesion c can be taken into consideration by loading of an uniformly distributed load acting downward on the top surface of the soil base. The intensity of the load within limit stress state $n2e = c2/tg\varphi2e$ the intensity of the load within sublimit stress state $n2' = c2/tg\varphi2$ as shown in Fig. 2. The angels $\delta^{'}$ and δ_e, determine as $tg\delta' = E^{'}/G^{'}$ and $tg\delta_e = E_e/G_e$ where E_e, G_e and $E^{'}, G^{'}$ horizontal and vertical components of the resultants N_e and N' accordingly in the range of limit and sublimit stress state zones.

There are two phases of the interaction of a gravity-type quay wall and the backfill. First is the phase of structure construction. It includes the process of formation of the backfill. Second, is the operation phase. The paper studies the second phase. In this case, the growth of a uniformly distributed load q leads to an increase of the lateral backfill pressure and a decrease of the reactive capacity of the soil base (due to the appearance and development of limit stress zone in the soil base). This process will continue until the reactive capacity of the soil base does not reach of limit value. Further increase of load q will lead to loss of stability of the structure due to the exhaustion of the bearing capacity of the soil base.

This paper reviews the results of reactive capacity calculation of the soil base of some gravity berthing structures for the choice of the reconstruction scheme and determination of operational loads. The design of the reconstructed gravity-type quay wall is shown in Fig. 3. The quay wall comprises four courses of concrete blocks on a stone bed and a superstructure made of reinforced concrete elements of an L-shaped type. The backfill material – stone and gravel filter.

The reconstruction scheme of the berth has been chosen based on the reactive capacity of the soil base calculation of the existing berth. The reconstruction of the existing berth provides the construction of a new high pile grillage structure on the seaward side and carrying out dredging works.

A high pile grillage with steel sheet pile wall and back steel pipe piles is shown in Fig. 3. The wall and steel pipes are rigidly embedded in the grillage. The grillage is a monolithic reinforced concrete element. The front crane rail is designed on a pile foundation and consists of one row of vertical and inclined steel pipe piles. The rear crane rail is laid along a reinforced concrete beam on piles.

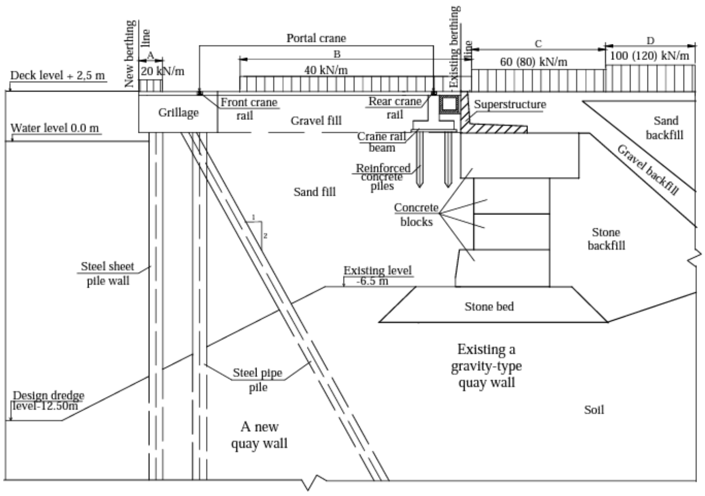

Fig. 3. Cross – section of reconstructed berth

The reactive capacity calculation of the soil base of concrete block quay walls by two methods (the traditional method accordingly [1, 2] and the proposed method described above [13, 14]) have been performed. The calculations have shown that the value of the reactive capacity of the soil base obtained by the proposed method is 1.35 times greater than the value obtained by the traditional method. It allowed increasing the uniformly distributed load intensity in the rear zone of the berth: in zone C from 60 to 80 kN/m^2 and in zone D from 100 to 120 kN/m^2. The scheme of operational loads is shown in Fig. 3.

Berths 24 and 21 of Odessa Commercial Sea Port are considered. Cross-sections of berths are shown in Fig. 4, 5. The berth design is an open-piled quay wall with a concrete block gravity wall on the coastward side. The reactive capacity calculation of the soil base of a concrete block gravity wall made it possible to clarify the values of operational loads on the berthing structures. The reactive capacity of the soil base has been calculated by the methods described above.

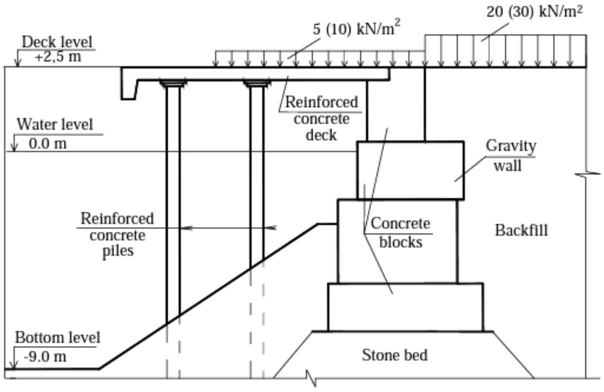

Fig. 4. Cross-sections of Berth 24

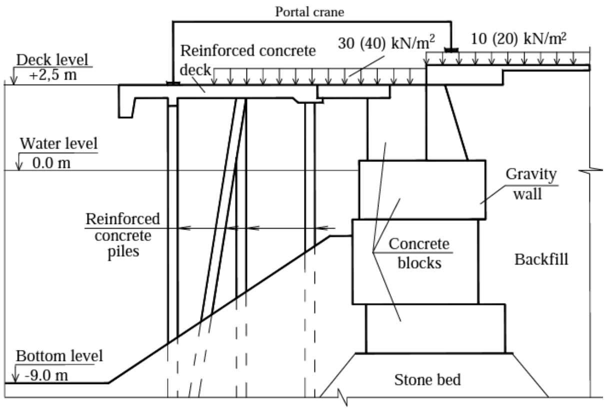

Fig. 5. Cross-sections of Berth 21

For berth 24, the calculations have shown that the value of the reactive capacity of the soil base obtained by the proposed method is 1.36 times greater than the value obtained by the traditional method. It allowed increasing the uniformly distributed load intensity within the superstructure of an open-piled quay wall from 5 to 10 kN/m^2, behind a concrete block gravity wall from 20 to 30 kN/m^2.

For berth 21, the calculations have shown that the value of the reactive capacity of the soil base obtained by the proposed method is 1.42 times greater than the value obtained by the traditional method. It allowed increasing the uniformly distributed load intensity within the superstructure of an open-piled quay wall from 30 to 40 kN/m^2, behind a concrete block gravity wall from 10 to 20 kN/m^2.

Conclusions. The development of foreign trade and the export orientation of strategic sectors of the Ukrainian economy lead to the development of maritime transport infrastructure. The rational direction for its development is the construction of new ports and cargo terminals, as well as the reconstruction of existing ones. The results of the research have been used to evaluate the developed method for the reactive capacity calculation of the soil base of a gravity-type quay wall for particular operating conditions. The most important conclusions are:

1. For the selection of a reconstruction scheme of gravity-type quay walls, it is necessary to evaluate its actual technical condition, considering the results of the reactive capacity calculation of the soil base. The safe operation and the durability of the operated berthing structures depend on the values of the operational loads.

2. The method of the reactive capacity calculation of the soil base of a gravity-type quay wall is proposed. The method is based on the theory of limit stress state but compared to other approximate methods, considers two zones of stress state (limit and sublimit) and the friction on the contact of the base of the foundation structure and the soil base.

3. The application of the proposed method for the reactive capacity calculation of the soil base of gravity-type quay walls made it possible to consider reconstruction schemes and clarify permissible operational loads.

4. The calculation results can be used for the assessment of the bearing capacity reserves of operated berthing structures.

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РЕЗУЛЬТАТИ ТЕОРЕТИЧНИХ ДОСЛІДЖЕНЬ ЩОДО ВИЗНАЧЕННЯ ЕКСПЛУАТАЦІЙНИХ НАВАНТАЖЕНЬ НА ПРИЧАЛЬНІ СПОРУДИ ГРАВІТАЦІЙНОГО ТИПУ

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Анотація. Аналіз особливостей причального фронту морських портів України свідчить про застосування, головним чином, споруд які зведені, в основному, у період після Другої світової війни. При цьому найпоширенішими конструктивними рішеннями були пальові естакади, включаючи облямівки і больверки зі шпунта. Однак є споруди гравітаційного типу, які були побудовані в минулому та потребують модернізації й реконструкції. Частка у загальному причальному фронті таких споруд складає приблизно 10%. Більшість таких причальних конструкцій мають дефекти бетону та арматури, що знижує довговічність і несучу здатність. Крім того, розвиток вантажних і пасажирських морських перевезень та будівництво сучасних суден призвели до необхідності збільшення глибин біля причалів і визначення експлуатаційних навантажень, що відповідають сучасним вимогам. Важливими й актуальними напрямами подальших досліджень, спрямованих на вдосконалення і розвиток причального фронту морських портів України, є розробка і впровадження в практику портового гідротехнічного будівництва вдосконалених методів проектування, будівництва і реконструкції традиційних конструкцій причальних споруд.

Вибір методу реконструкції залежить від правильної оцінки фактичного технічного стану реконструйованої споруди. Для забезпечення міцності та стійкості споруд гравітаційного типу важливим є розрахунок відпорної здатності ґрунтових основ. Пропонується розрахункова модель «споруда – ґрунтова основа». На основі цієї моделі розроблено метод розрахунку відпорної здатності ґрунтових основ причальних споруд гравітаційного типу. Цей метод дозволяє визначити відпорну здатність грунтової основи у рамках моделі змішаного напруженого стану (облік граничного та дограничного напруженого стану ґрунту основи).

Розглядаються деякі результати застосування запропонованого методу для оцінки відпорної здатності ґрунтової основи причальних стінок гравітаційного типу. Отримані результати використані для аналізу попередніх варіантів реконструкції та уточнення експлуатаційних навантажень.

Ключові слова: відпорна здатність, ґрунтова основа, споруда гравітаційного типу, граничний та дограничний напружено-деформований стан, реконструкція, експлуатаційні навантаження.

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