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APPLICATION OF INNOVATIVE MATERIALS IN MODERN HYDROTECHNICAL ENGINEERING

[1]**Khoneliia N.N.**, PhD, Associate Professor,
khonelianatela@gmail.com, ORCID: 0009-0000-4323-0293
[1]**Bugaeva S.V.**, PhD, Associate Professor,
s.bugaeva2408@gmail.com, ORCID: 0009-0000-3805-3720
[1]**Lopatin K.O**., graduate student,
SLodessa80@gmail.com, ORCID: 0009-0002-0794-8366
[1]*Odessa National Maritime University*
34, Mechnikova st., Odessa, 65029, Ukraine

Abstract. When designing of berthing structures (quay walls), the determination of the pressure of reinforced backfill soil plays an important role. The ability of berthing structures to withstand loads depends on many factors, including their age, mode of operation, changes in the characteristics of construction materials, soil bases over time and others. In some cases, the ability to withstand loads decreases significantly over time, while in other cases it increases significantly. Sometimes, the ability of the structure to withstand loads increases during the first period of operation, and then decreases. In some cases, on the contrary, it decreases in the initial period, but then increases. Therefore, it is not possible to establish the actual value of the bearing capacity of structures only theoretically due to the lack of information about the technical condition at this stage of operation, as well as the difficulty of identifying the actual picture of the interaction between the structure and the grounded medium. This task can be solved through experimental and theoretical studies.

It is essential to investigate the stages of development and market introduction of innovative materials in the field of hydraulic engineering, to justify the possibility of increasing the reliability and the load-bearing capacity of corner-type structures with a buttress during reconstruction with the use of geotextile materials. These structures were built in the past and require modernization and reconstruction. The issue of reconstruction of corner-type structures with a buttress is relevant for Ukraine ports. Currently, there are no unequivocal methods of determining the effectiveness of berths reconstruction due to the complexity of the task given to the number of variables.

The article describes the determination methods of the reinforcement effect by geotextile material; developed models taking into account not only the structure and characteristics of the geotextile materials but also its location in the ground mass. Therefore, the model considers both the parameters of the backfill soil and the geomaterial characteristics and the depth of their embedment.

Keywords: berthing structures, reconstruction, geotextile materials, the backfill soil, the reinforcement effect, corner-type structures with a buttress.

Introduction. Ports are a connecting link between sea and land transport. To fulfil their purpose, ports must have facilities that meet the requirements of various means of transport, be equipped with powerful transshipment machinery, and boast modern routes from the sea and the land.

The National Transport Strategy of Ukraine for the period of up to 2030 [1] says that seaports located on the territory of Ukraine in the Black Sea-Azov Basin and the Danube Delta have a total capacity of more than 230 million tons per year.

The document underlines that the Strategy implementation needs tasks in the main areas to be carried out, including: competitive and efficient transport system; innovative development of the transport industry and global investment projects.

Most investment funds for infrastructure improvement are expected from external sources, primarily from international financial institutions, private investors and public-private partnership projects. Attracting investment funds from such sources to innovative transport projects is a condition for developing the transport industry, national security, and the country's competitiveness.

The Strategy also indicates general issues that need to be solved. They include lack of transport industry funding, low level of resource management and insufficient measures for the stable development of enterprises in the transport industry, high level of wear and tear of fixed assets (the degree of wear and tear of fixed assets of transport and warehouse enterprises in 2014 amounted to 97.9 per cent), technological backwardness of transport and infrastructure, low level of introduction of modern technologies and implementation of innovative policy in the transport sector.

The results of ensuring the actual depths in seaports and approach channels in compliance with the established passport characteristics, development of deep-sea seaports, etc., are expected for the modernization of river transport and deep-sea seaport infrastructure.

Statement of the problem. One of the main active factors for the development of water transport in Ukraine is the state of waterways and hydraulic facilities and structures, which are the most important components of the industry's transport infrastructure.

Hydrotechnical structures include engineering and technical structures (quay walls, mooring structures, piers of all categories and designations, enclosing and protective hydraulic facilities) designed to ensure safe approach, maneuvering, mooring and departure of vessels and to protect the water area of the port or coastal strip.

The Strategy for the development of seaports of Ukraine for the period up to 2038 [2] provides for the creation of capacities for processing in seaports of at least 250 million tons of cargo per year and ensuring the effective development of port infrastructure facilities, the introduction of innovative activities by seaports through the application the recent technologies, increasing the efficiency of the use of transshipment complexes of seaports to 75 – 80 per cent.

Over the years, starting from the second half of the 20th century, the quay front increased in two directions: due to the reconstruction of existing ports and wharves of the old structure and due to the construction of new ports, including two largest ports – Chornomorsk and Pivdennyi, which were created precisely at this time period. The construction of new ones and repeated reconstruction of existing ports ensured the availability of loading and unloading capacities, which mainly meet the country's needs. However, a significant part of the quay front remains unsatisfactory and needs reconstruction, technical re-equipment, and significant repairs. Therefore, the number of the old fund quays in Ukraine amounts to 30 – 35% of all existing quays; this is a good foundation for introducing innovative technologies and new materials to increase the carrying capacity and raise cargo turnover.

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 corner-type structures with a buttress. The share in the total the waterfront is not large. They were built in the past and require modernization and reconstruction.

The successful development of commercial seaports is impossible without constant engineering and scientific research related to the functioning of hydro-technical structures and equipment, movements and deformations of structures, and determination of the possibility of their further operation under increased cargo turnover of ports. An important issue in hydraulic engineering implies also determining the expediency of reconstruction of existing structures or the construction of new ones and modernization of existing facilities based on modern innovative technologies. This finds its practical application in the form of the development and implementation of relevant, innovative projects. One of the promising innovative ways in this direction is the use of geotextile materials. The effectiveness of the evaluation of any project is determined by the methods chosen for its implementation, i.e. a set of techniques and operations used for project evaluation. Under conditions of competition, there are always three components of justification – cheaper, faster, and better quality. Therefore, in modern conditions, highly effective projects of modernization of quays with innovative materials, which are a way to increase investments in ports, occupy a rather important place.

The analysis of many years of experience in scientific research, design and construction shows various ways of achieving effective results: the refinement of calculation methods, changes in the structural forms and profile of buildings, and the development of a more progressive technology for their construction. Thus, it is important to determine the effectiveness of using innovative materials that lead to cheaper construction or reconstruction of marine berthing structures and to increase the reliability and bearing capacity.

Currently, there are no unequivocal methods of determining the effectiveness of berth reconstruction due to the complexity of the task given to the number of variables. In particular, marine berthing structures are in a constant state of stress, operate under aggressive environmental conditions, and are characterized by reduced maintainability.

Analysis of research and publications. In most practical applications, reinforced soils are obtained by incorporating continuous reinforcement inclusions (for example, strip, bar, sheet, mat, or net) within a soil mass in a definite pattern. The literature has explained the reinforcing mechanisms for such reinforced soils in different forms since Henry Vidal developed the first modern form of soil reinforcement in 1966.

Later on, such scientists as R.H. Basset [3], K.Z. Adraves [4], Yu.V. Feofilov [5], M.F. Drukovanyi [6], Yu.B. Balashov [7, 8], O.A. Ruban [9] and others studied the issues related to soil reinforcement. The results of studies on field applications of reinforced soils show that much care is required. Since the influences of engineering properties of soil and geotextile, and the scale effects on the stress-strain characteristics of reinforced soils have not been investigated fully on a large scale, the actual behavior of reinforced soils is not yet sufficiently studied.

Various small-scale laboratory experiments were performed on sand soils (e.g., V.A. Guido, A.V. Sweeny [10]; K.H. Khing, B.M. Das et al. [11]; T. Yetimoglu, Wu, A. Saglamer [12]) using single or multilayered of geomaterial. It was confirmed by most researchers that there was a significant increase in bearing capacity and a decrease in settlement of soil reinforced with geomaterial. The increase in bearing capacity of reinforced foundation is defined in terms of bearing capacity ratio, which is defined as the bearing capacity of reinforced soil to that of unreinforced soil.

A layer of geomaterial reduces the outward horizontal stresses transmitted from the overlying soil backfill to the top of the underlying soil. This action of geomaterials is known as shear stress reduction effect. This effect results in a general-shear, causing an increase in the load-bearing capacity of the foundation soil (R.D. Espinoza and J.D. Bray [13]; M.T. Adams and J.G. Collin [14]).

P.L. Bourdeau et al. [15], J.P. Giroud et al. [16] performed research that showed that a layer of geomaterial redistributes the applied surface load in the backfill soil. This leads to a decrease in pressure and a reduction of stress in the foundation soil. They have proven that the friction mobilized between the soil and a layer of geomaterial plays an important role in decreasing soil pressure. The results of experimental studies of soil reinforcement with geotextile materials are devoted to works by S.V. Bugaeva and A.A. Baranova [17, 18], which demonstrated the effectiveness of their use for reinforcing the soil bases of structures.

Based on the above, it should be noticed that so far maximum use of soil reinforcement technology has been made in the construction of Retaining walls. Due to limited awareness among practicing engineers and the high cost of reinforcing materials the technology of soil reinforcement for berthing structures has not found its widespread in our country. A literature review has been done that has given the idea to research issues of determining the stability coefficient of berthing structures when reinforcing the backfill soil.

The purpose of the research is to perform theoretical and experimental studies to evaluate the use of geotextile materials in hydraulic engineering.

The tasks of the research are as follows:

– to determine the effectiveness of using innovative materials in the field of hydraulic engineering;

– to carry out experimental studies to establish the effect of reinforcement on the wall when using geotextile materials located in the backfill soil and the most effective placement;

– to substantiate the possibility of increasing the reliability and bearing capacity of the berthing structure during construction and reconstruction with the use of geotextile materials in the backfill soil;

– to compare the results of experimental studies with the results obtained in the PLAXIS software package;

– to apply the research results to a corner-type structure with a buttress to analyze the preliminary reconstruction options.

The research methods:

– the theoretical method – to determine the reliability and bearing capacity of berthing structure with the use of geotextile materials;

– the experimental method – to establish the effect of reinforcement on the wall and determine the most effective placement of the geotextile materials in the backfill soil.

The results of the research. In the last 20 – 30 years, an exciting and promising material called "geotextile" or "geosynthetic" appeared in the construction domain. The root "geo" indicates the field of application of these materials: they are used as reinforcing nets or waterproofing membranes in structures and buildings whose foundation is loose rock such as soil, sand, gravel mixtures, etc. "Synthetics" and "textiles" reflect the composition of materials, the method of their manufacture and appearance: fabrics, felt, films and other relatively thin, light materials of a large covering area.

Synthetic polymers give geotextiles specific favourable properties for polymers: water and frost resistance, universal corrosion resistance, low weight (density of polymers is about 1 g/cm^3), and high tensile strength.

Disadvantages of polymers (such as rapid ageing under direct solar radiation (UV component), a sharp drop in strength when heated to 80˚– 120˚C and flammability) when used in structures where the bulk of the volume is made up of loose rocks that protect polymers from light and temperature effects, are blocked.

Currently, the term geosynthetic materials (GM) is used more often, so attention will be paid to it in the future. The field of application of geosynthetic materials is quite broad: road, hydrotechnical, underground, and nature protection construction; it is also advisable to use GM in landscape design.

The use of geosynthetic materials in construction has fundamentally changed the nature of works related to the fastening of slopes, construction of retaining walls, and road foundations. Large volumes of concrete and earthworks become unnecessary, so sand and reinforcing geogrids, geotextiles, and geolattices are used to obtain the desired result.

Fig. 1. Application of geotextile in environmentally friendly construction

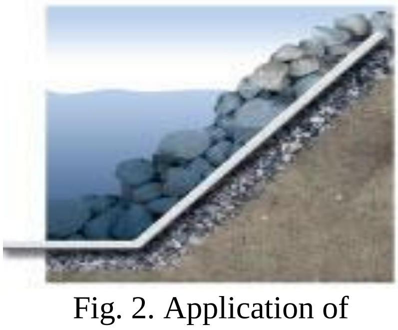

Fig. 2. Application of geotextile in hydraulic engineering

In the case of arranging water reservoirs or storages, film geosynthetic materials, nets and, again, local soil are used. Thus, the use of geosynthetic materials has a considerable economic effect, reducing and even eliminating the use of such materials as concrete, steel, and imported natural stone and facilitating the work. All this leads to a minimum environmental intervention, making geosynthetic materials ecologically effective, which is the most crucial advantage and necessary quality these days.

GM is widely used to prevent soil erosion and protect the shores of reservoirs and their landscaping (Fig. 1). Anti-erosion mats are an alternative to traditional methods of anti-erosion protection made of concrete, stones or wooden gratings. Another significant advantage of these materials is that even before the formation of the vegetation layer, the mats prevent the occurrence of erosion processes.

In the practice of hydrotechnical engineering, GM, namely bentonite geomembranes, are used as waterproofing when installing anti-filtration curtains, dams or water walls, as well as for the organization of waterproofing screens of reservoirs, ponds, and reservoirs (Fig. 2). The use of geomembranes provides guaranteed long-term waterproofing (several tens of years), even in aggressive environments.

There are other areas of application of geosynthetic materials. When choosing one or another GM, it is necessary to consider its properties, largely determined by the type and structure of polymers used for their production. The type of polymer the material is made of determines its resistance to temperature effects, short-term and long-term strength, resistance to ultraviolet rays, aggressive environments, etc. In addition, it is very important to strictly follow the recommendations on the production technology of works using geosynthetic materials.

As for the facilities and structure reconstruction, the use of geomaterial is very relevant. This material is easy to install and lay, it does not have a large weight, and, in terms of its characteristics, is not inferior to traditional materials. It can be used in the reconstruction of facilities in conditions of limited space or where reinforcement is required without a substantial weighting of the existing structure.

The results of experimental studies. The experimental studies were conducted to establish the effect of reinforcement on the front wall when using geomaterial located in the backfill soil and its most effective placement. Innovative geomaterial – Typar SF – was considered.

To determine the most effective placement of the geomaterial, several studies (minimum of 3 experiments in each series of studies) were carried out, such as:

1. Tray with sand and load located on the backfill surface.
2. Placement of geomaterial in 2 layers for 1/3 and 2/3 of the entire height of the wall.
3. Placement of geomaterial in 1 layer for 1/3 of the entire height of the wall.

The experimental tray has the following dimensions: length 81 cm, width 69 cm, height 48 cm. The load is located on the surface in the form of an evenly distributed load and is applied at levels of 60 kg, 120 kg, 180 kg, and 240 kg.

Sensors were calibrated before conducting experiments. Movements are measured using clock-type sensors. Graphs are drawn for 3 sensors (Fig. 3).

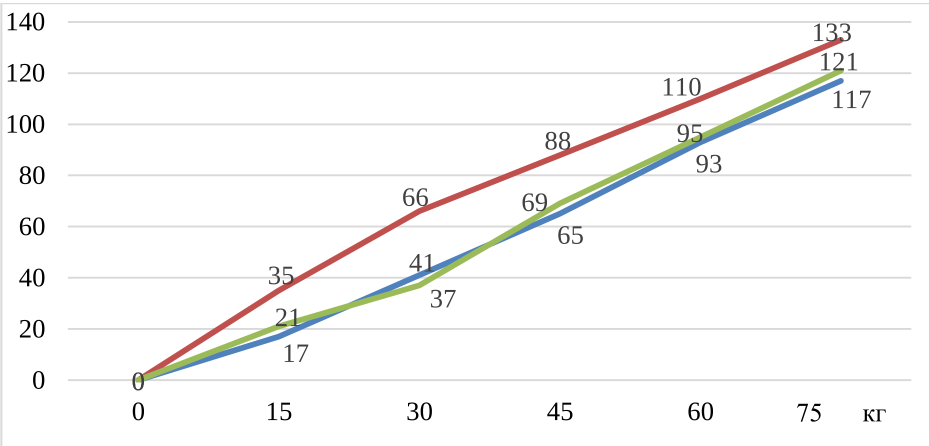

Fig. 3. Calibration curves:
sensor 1; sensor 2; sensor 3

When moves are received, a reverse operation will be performed for the loaded tray. Further, the effect of reinforcement in % and the comparison of the results are determined.

The results of experimental studies (Sensor indications and pressure of the backfill soil on the wall) depending on the placement of the geomaterial are shown in Tables (1 – 6).

Table 1 – Sensor indications without reinforcement

Sensors	Loads on the backfill surface				
	0	60	120	180	240
	Sensor indications				
Sensor 1	76	83	90	104	118
Sensor 2	76	84	93	102	115
Sensor 3	74	85	86	96	120

Table 2 – Backfill pressure without reinforcement

Backfill pressure on the wall for 3 experiments	Loads on the backfill surface				
	0	60	120	180	240
	Backfill pressure				
P1	51	55	58	67	76
P2	37	42	48	55	63
P3	48	54	55	61	74

Table 3 – Sensor indications with the laying of one layer of geotextile 1/2H

Sensors	Loads on the backfill surface				
	0	60	120	180	240
	Sensor indications				
Sensor 1	74	84	94	106	118
Sensor 2	72	83	94	104	114
Sensor 3	59	71	77	87	97

Table 4 – Backfill pressure with the laying of one layer of geotextile 1/2H

Backfill pressure on the wall for 3 experiments	Loads on the backfill surface				
	0	60	120	180	240
	Backfill pressure				
P1	50	55	61	68	76
P2	34	42	49	56	63
P3	40	46	50	55	61

Table 5 – Sensor indications with the laying of 2 layers of geotextile 1/3H i 2/3H

Sensors	Loads on the backfill surface				
	0	60	120	180	240
	Sensor indications				
Sensor 1	75	79	91	105	119
Sensor 2	74	79	89	97	108
Sensor 3	48	56	88	98	109

Table 6 – Loads with laying of 2 layers of geotextile 1/3Hi 2/3H

Backfill pressure on the wall for 3 experiments	Loads on the backfill surface				
	0	60	120	180	240
	Backfill pressure				
P1	50	53	59	68	76
P2	35	39	46	51	59
P3	35	39	56	62	68

Determining the effectiveness of reinforcement. Using formula (1), we determine the effectiveness of geotextile reinforcement.

$$E = \frac{P_{nr} - P_r}{P_{nr}} \quad (1)$$

P_{rn} – backfill soil pressure on the wall without geotextile reinforcement;

P_r – backfill soil pressure on the wall with geotextile reinforcement;

E – effectiveness of geotextile reinforcement.

The effectiveness of reinforcement depends on the geotextile layers and the load on the backfill soil surface, as is shown in Fig. 4, 5. The effectiveness of reinforcement is calculated as a percentage.

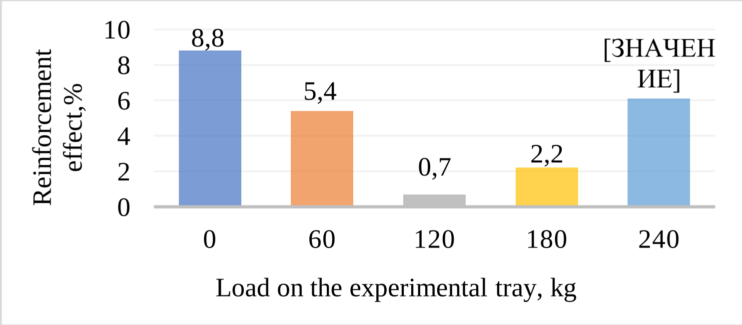

Fig. 4. Effect of reinforcement with laying of one layer of geotextile

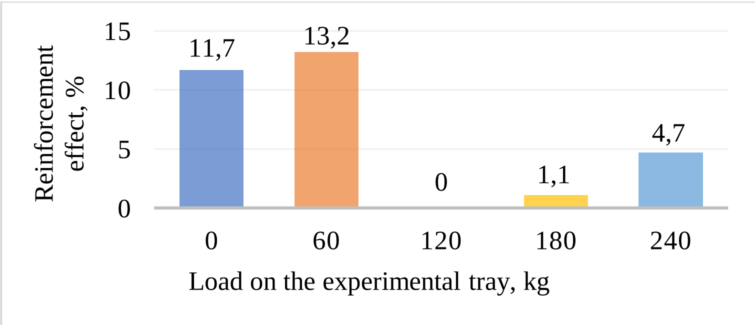

Fig. 5. Effect of reinforcement with laying of 2-layer geotextile

Thus, we can conclude:

– maximum effect of reinforcement in 2 layers was obtained from the beginning of the load after the effect decreased;

– after the penetration of soil particles into the pores of the geomaterial, the reinforced layer begins to work as a composite, which leads to an increase in the effect of reinforcement.

Calculation results in the software complex Plaxis 2D. Plaxis is a simple and convenient package of ordinary element programs for performing calculations of complex geotechnical projects in modern construction. In the process of two-dimensional and three-dimensional calculations available in Plaxis programs, stresses, deformations, and strength (stability) in complex geotechnical systems are determined, considering the joint work of engineering structures and their interaction with the soil at the construction, operation and reconstruction stages.The calculation scheme, with a uniformly distributed load, was created in the Plaxis 2D package. Fig. 6-8 presents the calculation results showing how the load located on the surface of the backfill is distributed along the wall.

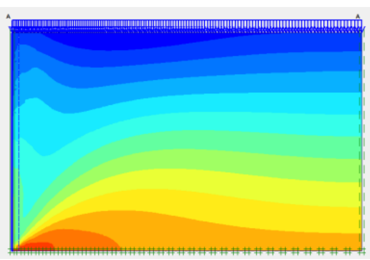

Fig. 6. Load distribution on the wall without reinforcement

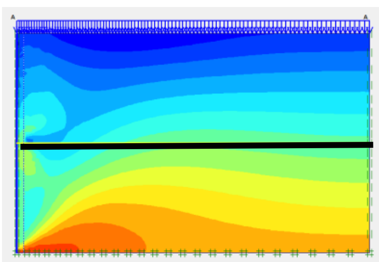

Fig. 7. Load distribution on the wall with laying of one layer of geotextile

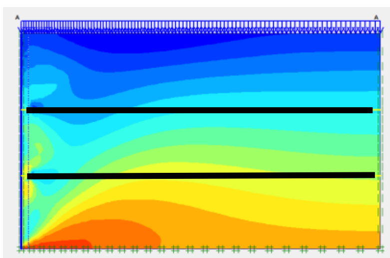

Fig. 8. Load distribution on the wall with laying of 2-layer geotextile

In order to find out that the software complex Plaxis can be used for the correct calculation of full-scale structures, the results (on a tray in the laboratory and simulated in the program) must be identical or have acceptable differences.

For this purpose, a soil tray was simulated in the software complex and loaded with a similar load. It was reinforced and the forces in the front wall were determined.

The backfill soil characteristics in the software complex and the backfill of the soil tray are similar. A comparison of the results was performed. The results of the conducted studies are presented in Fig. 9.

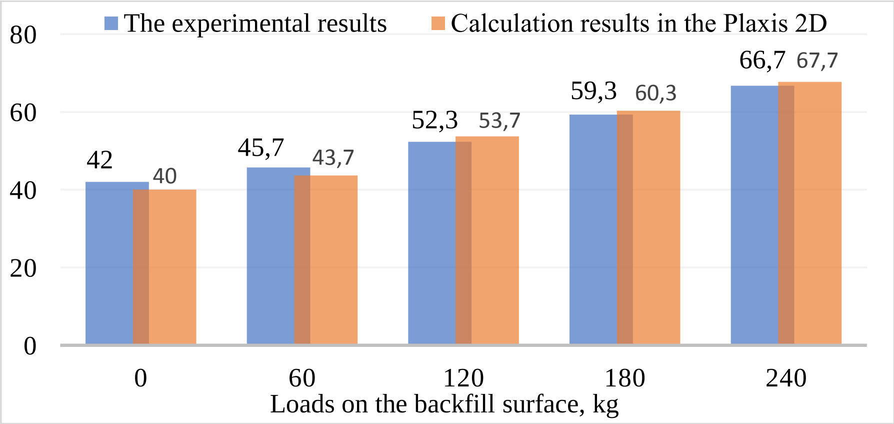

Fig. 9. Comparison of the obtained results. Backfill pressure with the laying of one layer of geotextile 1/2H

A comparison of results have shown that the differences in results is about 5%. Given these results, it can be concluded that the use of the Plaxis 2D software complex for calculations of full-scale structures using innovative geotextile material in the future is feasible.

The calculation results of the berthing structure in the software complex Plaxis 2D. The research results have been applied to a corner-type structure with a buttress to estimate the correctness of the obtained results and to analyze the preliminary reconstruction options.

The mentioned structure has been calculated in the software complex Plaxis 2D. Stability coefficients have been determined depending on the location of the geomaterial. The research results are presented in Fig. 10-12.

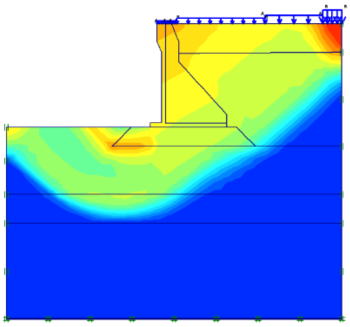

Fig. 10. Sliding surfaces without reinforcement. The stability coefficient is 1.19

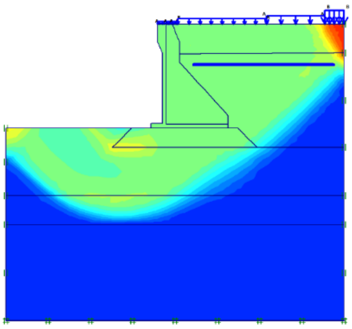

Fig. 11. Sliding surfaces when reinforcement in one level. The stability coefficient is 1.25

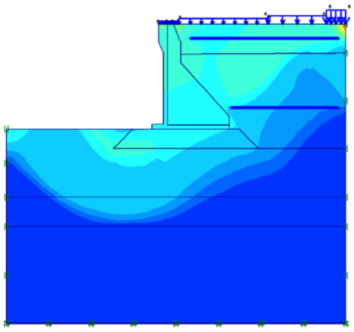

Fig. 12. Sliding surfaces when reinforcement in two levels. The stability coefficient is 1.37

A comparison of calculation results shows that the stability coefficient significantly increases with using geotextile materials for reinforcement. When reinforcement is in two layers horizontally, plastic and elastic-plastic zones practically do not appear behind the structure. This makes it possible to increase the load on the surface of the berthing structure without reducing operational reliability.

Possible reconstruction options of a corner-type structure. The study's results applied to a corner-type structure with a buttress to analyze the preliminary reconstruction options. Possible reconstruction options of a corner-type structure when geomaterial is located in 1 level at 1/3 of the entire height of the wall and 2 levels at 1/3 and 2/3 are shown in Fig. 13.

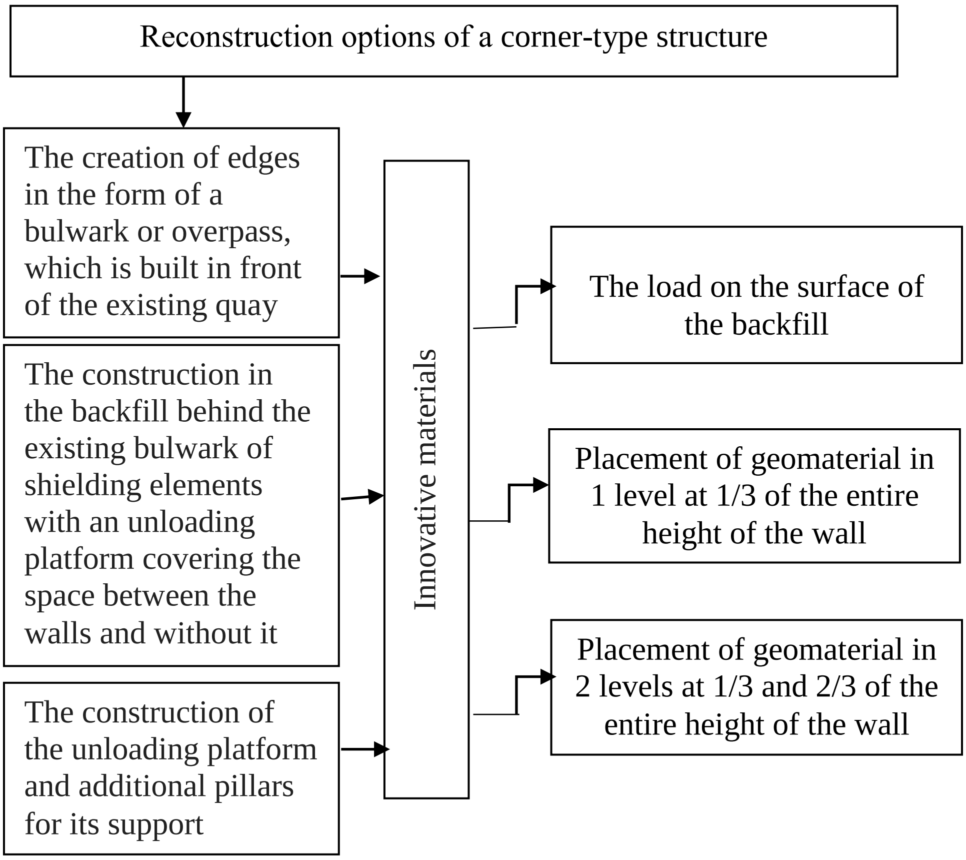

Fig. 13. Possible reconstruction options of a corner-type structure

Conclusions:

– when using geotextile materials in the backfill soil the stability coefficient of the structure increases. This reduces the forces and deformations in the elements of the structure. Using geotextile material leads to a reduction in material consumption and cost. The research has confirmed the reduction of pressure in the backfill soil;

– the research result has confirmed that geotextile material reduces pressure in the backfill soil. Experiments have shown that the reinforcement of the backfill soil behind the structure with geotextile material is a promising type of reinforcement or "strengthening" of structures. Vertical reinforcement in the form of two screens showed that displacements decreased without load;

– the calculations have shown a lower efficiency in the reinforcement of the backfill soil in comparison with the results of the experiments. This is because the Plaxis does not consider the force of friction of the soil against the vertical wall of the structure. However, even with this shortcoming, the calculation results showed a reduction of pressure on the wall of the structure;

– innovative projects make it possible to solve complex problems of attracting financial resources for modernization. The value of such projects lies in the fact that using modern methods in the field of hydraulic engineering with geotextile materials significantly reduces the necessary capital investments. This leads to cheaper construction or reconstruction of existing structures while increasing the reliability and the strength of the objects.

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ЗАСТОСУВАННЯ ІННОВАЦІЙНИХ МАТЕРІАЛІВ В СУЧАСНОМУ ГІДРОТЕХНІЧНОМУ БУДІВНИЦТВІ

[1]**Хонелія Н.Н**., к.т.н., доцент,
khonelianatela@gmail.com, ORCID: 0009-0000-4323-0293
[1]**Бугаєва С.В.**, к.т.н., доцент,
s.bugaeva2408@gmail.com, ORCID: 0009-0000-3805-3720
[1]**Лопатін К.О**., аспірант,
SLodessa80@gmail.com, ORCID: 0009-0002-0794-8366
Одеський національний морський університет
вул. Мечникова, 34, Одеса, 65029, Україна

Анотація. Визначення тиску армованого ґрунту засипки на причальну споруду відіграє важливу роль. Навантажувальна спроможність причальних гідротехнічних споруд залежить від багатьох факторів: їх віку, режиму експлуатації, зміни характеристик матеріалів конструкцій, ґрунтів основи та засипки в часі та ін. У деяких випадках з часом вона значно знижується, а в інших – значно зростає. Іноді навантажувальна спроможність споруд у перший період експлуатації збільшується, а надалі знижується. У ряді випадків навпаки – на початковий період знижується, а згодом – зростає. Тому встановити фактичне значення навантажувальної спроможності споруд лише теоретичним шляхом не є можливим через недостатність інформації про технічний стан на даному етапі експлуатації, а також складності виявлення дійсної картини взаємодії споруди та ґрунту основи. Це завдання може бути вирішене лише в результаті комплексних експериментальних та теоретичних досліджень.

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 й больверки зі шпунта. Однак є споруди кутового типу з контрфорсом, які були побудовані в минулому та потребують модернізації й реконструкції. Частка у загальному причальному фронті таких споруд складає приблизно 10%. 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 будівництва і реконструкції існуючих причальних споруд.

У статті розглянуто методи визначення ефекту армування геотекстильним матеріалом, розроблено моделі, що враховують не лише структуру та характеристики геотекстильних матеріалів, а і їхнє розташування в ґрунтовому масиві. Таким чином, модель враховує як параметри ґрунту засипки, так і характеристики геотекстильного матеріалу та глибину їх розташування. Описано результати експериментальних досліджень з встановлення ефекту армування на лицьову стінку при застосуванні геотекстильних матеріалів, розташованих в засипці. Обґрунтовано можливість підвищення надійності та несучої здатності причальних споруд при реконструкції з використанням геотекстильних матеріалів у ґрунтовій засипці. Для оцінки коректності отриманих результатів виконано порівняння експериментальних даних з даними, отриманими в програмному комплексі Plaxis. На основі одержаних результатів досліджень виконано аналіз попередніх варіантів реконструкції для споруди кутового типу з контрфорсом.

Ключові слова: причальна споруда, реконструкція, геотекстильний матеріал, ефект армування, споруди кутового типу з контрфорсом.

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