SUSTAINABILITY OF TONGUE-AND-GROOVE WALLS WITH BUT-TRESSES

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Abstract: The development of ports requires the construction of more and more deep-sea berthing facilities or the reconstruction of existing ones for servicing modern large-capacity ships. Traditional design solutions for deep-water berths are labor-intensive and material-intensive.

The article describes the design of a deep-water berth in the form of tongue-and-groove wall with buttresses. Buttresses can be rectangular, trapezoidal with the extension downwards and trapezoidal with the extension upwards. The use of buttresses in the construction reduces the lateral pressure of the soil, increases the rigidity of the structure, and also increases the stability of the structure as a whole. The rational distribution of materials along the length of the structure and the unification of the elements leads to cheaper construction and a fast pace of construction. This solution can be used both in the construction of new berthing facilities and in the reconstruction of existing ones.

The development of the calculated justification of the stability of the tongue-and-groove wall with buttresses, which optimally reflects the specificity of the structure, is carried out. Buttresses are an additional factor affecting the stability of the tongue-and-groove wall. Then, the stability of the structure as a whole depends on the resistance forces of the soil, arising in the plane of contact with the front wall and the resistance forces of the soil within the width of the buttress and involved, due to friction forces, in the joint work of the adjacent soil volumes.

In order to determine the holding forces of the buttresses, experimental laboratory studies were conducted. Analysis of the results of the experiments shows that the trapezoidal buttresses with extension downwards have the greatest holding power. As a result of the mathematical modeling, the displacements of the wall and bending moments are plotted depending on the height of the buttresses.

Thus, the design of the mooring structure of the innovative type can be used to create an economically deep-water berth with increased bearing capacity, which will be able to perceive modern ships with a large deadweight.

Keywords: deep-water berth, tongue-and-groove wall, buttresses, stability, rigidity, holding forces of buttresses.

1. Introduction

Scientific and technical progress in the field of maritime transport, due to the intensive growth in cargo capacity and the size of ships, as well as new ways of transporting and handling cargo at berths, is putting forward new technical requirements for port hydraulic structures. Analysis of the exploitation of berths in the ports indicates the rapid onset of their moral depreciation, which is significantly ahead of the physical [1].

All this leads to the need for the construction of deep-water berths or the reconstruction of existing ones. The absence in the country of such a mooring front leads to significant economic losses, and to inefficient cargo handling. Analysis of the structure of the world fleet and, in particular, ships that can visit the ports of Ukraine, shows that in order to increase cargo turnover, the maximum depths at the berths should be increased to approximately 20 m.

The most quickly built and economically feasible are the bulwark-type structures. Traditional constructive solutions of berths in the form of thin walls in cases of their use at great depths require special technical measures that reduce the pressure of the backfill soil on the front wall and, accordingly, bending moments. The use of bunk anchoring, shielding systems [2, 3], dumping unloading prisms, or the use of elements of increased rigidity [4], allow to expand the range of depths for their use [5, 6]. Nevertheless, such technical measures will lead to a sharp increase in the material intensity of the berthing facilities and the timing of their construction. Therefore, at present there is a need to develop new designs for deep-sea berths.

The aim of this research is improvement of the design and technological solutions of deep-sea berth structures of metal tongue-and-groove, and assessing their sustainability.

To achieve the aim, the following tasks are set:

– to develop an innovative constructive solution for a deep-water berth (such as a tongue-and-groove wall) with a high bearing capacity;

– to conduct experimental studies of the stability of the retaining wall with buttresses.

The solution of the set tasks is an important link in the study of a new type of design, which will allow to introduce it into engineering practice.

2. Methods

Experimental and theoretical methods were used in the work.

Experimental laboratory studies were carried out to study the operation of the “tongue-and-groove walls with buttresses – soil environment” system. Also, calculation methods were developed, on the basis of which mathematical modeling was carried out.

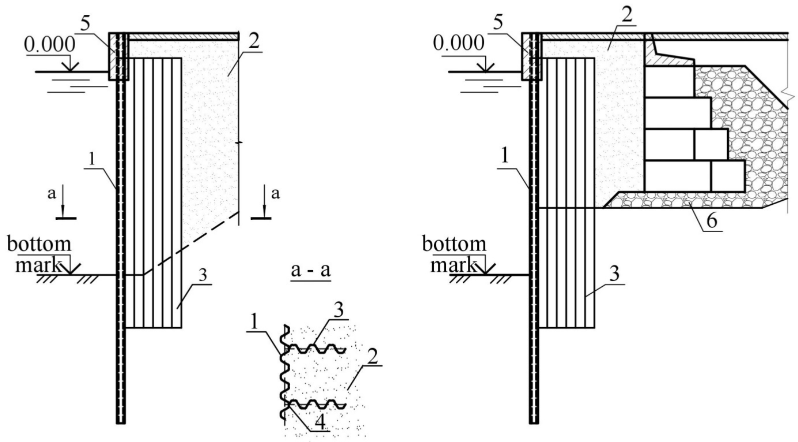
3. Results

Improvement of tongue-and-groove structures with the aim of rational distribution of material, reducing labor intensity and increased stability with increasing bearing capacity was achieved by developing combined tongue-and-groove walls.

One of such solutions of a deep-water berth is the construction of a raised rigidity of a tongue-and-groove wall, for which a patent was obtained for an invention [7] and a patent for a utility model (a method for constructing a structure) [8]. It consists of a traditional front tongue-and-groove wall. Along the length of the front wall, transverse rows of piles (buttresses) are provided, which are immersed in the base soil and fixed to the rear part of the sheet pile wall with the help of special locking joints. The shape of the buttresses can be rectangular, trapezoidal with the extension downwards, trapezoidal with the extension upwards. The width and spacing of the buttresses should be assigned a multiple of the width of the sheet pile or the width of the package. The proposed design can be used in the construction of new and in the reconstruction of existing berths of various structural types (**Fig. 1**).

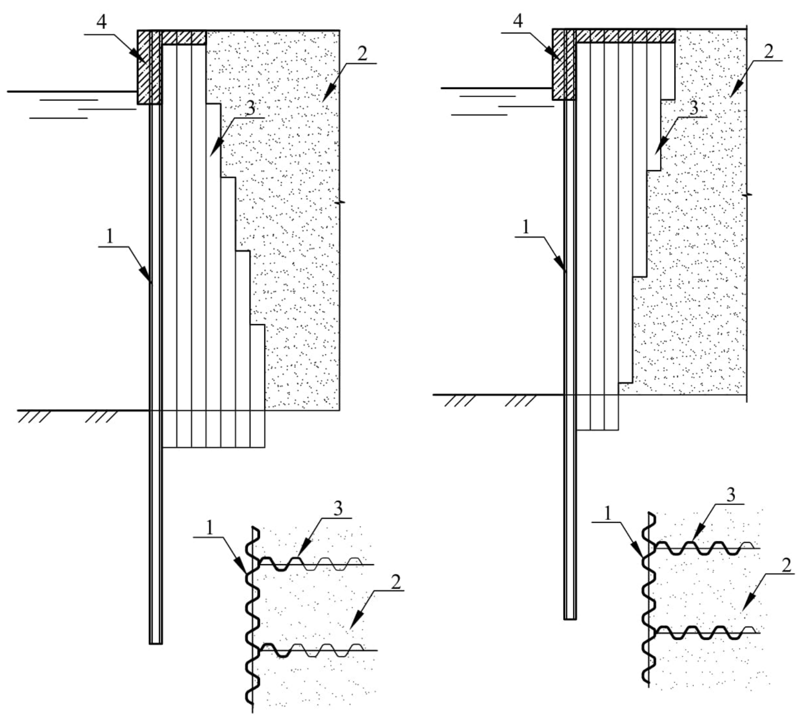
The introduction of such a technical solution will lead to an increase in the rigidity of the front wall without the installation of time-consuming and busy traditional anchor rods. When carrying out reconstructive measures, the advantages of such a solution are the absence of the need to disassemble or use the existing structure. Also, the minimum removal of the border line, limited only by the planned size of the buttresses, which can be varied.

The shape of the buttresses can be trapezoidal with the extension downwards or trapezoidal with the extension upwards. When creating trapezoidal buttresses with extension downwards (**Fig. 2, *a***), it is possible to achieve a maximum reduction in the ground strap pressure, and when creating trapezoidal buttresses with extension upwards (**Fig. 2, *b***), increasing the rigidity of the structure in the upper part, which contributes to move the top of the wall.



a *b*

Fig. 1. Tongue-and-groove wall with buttresses: *a* – building a new berth; *b* – during the berth reconstruction; 1 – front tongue-and-groove wall, 2 – backfill, 3 – transverse rows of piles, 4 – lock joints, 5 – cap beam, 6 – existing design



a *b*

Fig. 2. Tongue-and-groove wall with buttresses: *a* – trapezoidal shape with extension downwards; *b* – trapezoidal shape with an extension upwards; 1 – front tongue-and-groove wall, 2 – backfilling, 3 – transverse rows of piles

It should be noted that the building of structures can be carried out by traditional methods with the exception of the operations on the installation of buttresses, which are mounted using lock joints and pile inserts.

In previous works, methods were developed for calculating the lateral pressure of the soil, taking into account the relieving action of the buttresses [9–11]. The next step is development of a design justification for the stability of the tongue-and-groove wall with buttresses, which optimally reflects the specificity of the structure. The design scheme in a simplified form in the vertical plane is represented as a cantilever beam, clamped in an elastic base (below the bottom level) and the filling soil loaded with an extension pressure. According to this approach, a planar problem is solved, but a beam with different stiffness in height (section with buttress and without) is considered, which is determined by the buttress step.

In the case of a comprehensive review of the construction, the buttresses not only increase the flexural rigidity of the structure and reduce the lateral pressure of the soil, but also are additional factor affecting the wall stability. Then the total stability of the structure as a whole consists of the soil resistance forces arising in the plane of contact with the front wall and the soil resistance forces within the width of the buttress and involved, due to friction forces, in the joint work of adjacent soil volumes, that is, the spatial problem is solved.

In order to determine the holding forces of the buttresses, experimental laboratory studies are conducted. The frictional force that develops along the lateral surface of the buttresses, as the prism of the collapse creeps in, has a significant effect on the pressure distribution along the wall height. The horizontal component of this force is defined as the holding force of the buttresses. In the study of the carrying capacity of the buttresses, the holding force of the buttresses of various configurations with no load applied and with the load applied is determined. The results are listed in the **Table 1**.

Table 1
Holding power of buttresses of various configurations

Shape of buttresses	Holding power of buttresses, kN	
	Without load	With load
Rectangular b=300 mm	0,186	0,266
Trapezoidal shape with extension downwards b_1=180 mm, b_2=420 mm	0,216	0,296
Trapezoidal shape with extension upwards b_1=420 mm, b_2=180 mm	0,171	0,256

An analysis of the results of the experiments shows that the trapezoidal buttresses with extension downwards have the greatest holding power. The retention force of the trapezoidal buttresses with an extension downwards is 13.9 % more than a rectangular shape and 20.8 % more than the trapezoidal buttresses with an extension upwards.

As a result of the mathematical modeling, displacements of the wall and bending moments are plotted depending on the height of the buttresses (**Fig. 3**). In modeling, the relative height of the buttress is considered as the ratio $\frac{d}{H}$=(0.84; 1.0; 1.1), where d – buttress height, H – height of the wall above the bottom level.

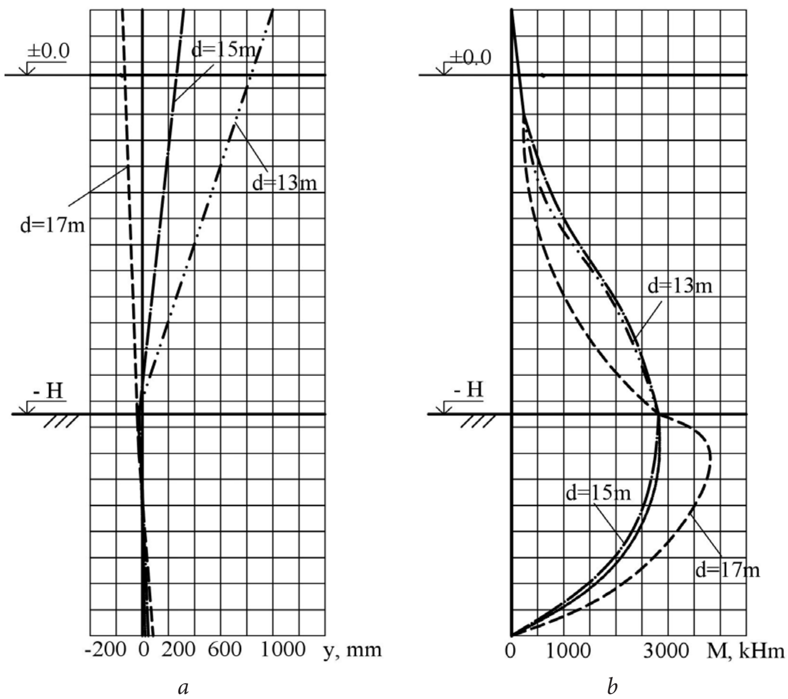


Fig. 3. Schemes for the calculation of the wall when the buttress height is changed: *a* – diagrams of wall movements; *b* – diagrams of bending moments in the wall

The analysis of the obtained plots shows that compliance with the allowable deformations is observed at the height of the buttress (1.0÷1.15) N.

4. Discussion of results

The proposed construction of a combined tongue-and-groove wall can be used as a new construction of a , shore protection, protective structure, in dry docks and locks of a split structure as a wall, as well as in reconstruction of hydraulic structures by building of a border in front of any type of structure. The new type of border is not constructively connected with the old structure, which ensures the independent operation of both structures. Construction work can be performed without decommissioning of the territory (rear area) of the berth. At the same time, the construction of the considered type will speed up the process of construction of the structure due to the unification of structural elements, which will lead to cheaper construction costs.

An analysis of the results of the experiments shows that the trapezoidal buttresses with extension downwards have the greatest holding power.

Thus, the design of the berth structure of an innovative type can be used to create an economical deep-water berth of increased bearing capacity that can be received by modern ships with a large deadweight.

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