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Development of Maritime Mix-Type Structures

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Abstract: Mixed-type structures combining the advantages of pile constructions (low material consumption and possibility to erect on weak soils) and gravity walls (high bearing capacity and stability, good reliability and durability) are considered and improved. The sphere of application, main peculiarities, and practical technological aspects of these structures' implementation are analyzed.

Key words: Mixed-type structures, maritime engineering, quay wall, bearing capacity.

1. Introduction

Some ideas for the use of gravitational-pile structures were proposed in the last quarter of the 20th century and covered some design/technological solutions [1-5], as well as physical and numerical modeling and experiments [6-8]. Theoretical and applied approaches to develop effective methods for calculating and designing gravitational-pile structures and applying them in construction practice were proposed in the works of M. P. Doubrovsky, M. B. Poizner, M. I. Dranenko, D. A. Schwartzman, and others.

The main idea of gravitational-pile modules was to use the gravitational component of the structure above the level of the base of the structure as a retaining wall, perceiving lateral loads from the pressure of the backfill, and to use pile supports structurally connected to the bearing elements of the retaining wall to transfer the vertical load to the deep layers of the soil base.

2. Main Solutions for Maritime Engineering

Some of the proposed design solutions developed for use in port engineering are presented in Fig. 1. A typical gravitational-pile module of this type of structure consists of pile support 1 (Fig. 1a) driven in the soil base and equipped with a foot 2, placed at the bottom level, as well as reinforced concrete blocks 3 mounted on a pile [1, 2, 6].

The weight of the blocks and the possible operational load are transferred by the pile support to the layers of the soil base. In this case, possible horizontal loads are perceived by friction forces on the contact between the blocks, as well as between the lower block and the foot.

Such a separation of the functions of the structural elements of the gravitational-pile module makes it possible to significantly expand the nomenclature of the soils of the base on which the construction of this type of structure is permissible, up to the inclusion of all sandy and many clays (with a consistency index close to one) soils.

To simplify pile driving, the foot can be made not around the entire perimeter of the pile, but along some part of it, which allows the use of piling equipment available to the contractor.

There are various design options for the port engineering structures using considered gravitational-pile modules as a typical one.

The quay wall presented in Fig. 1b is a continuous massive wall of gravitational-pile modules, in the rear part of which a soil backfill 5 is made, and a monolithic or prefabricated superstructure 4 is arranged on the surface of the berth. Vertical loads (from the weight of blocks and surface operational loads), as well as lateral

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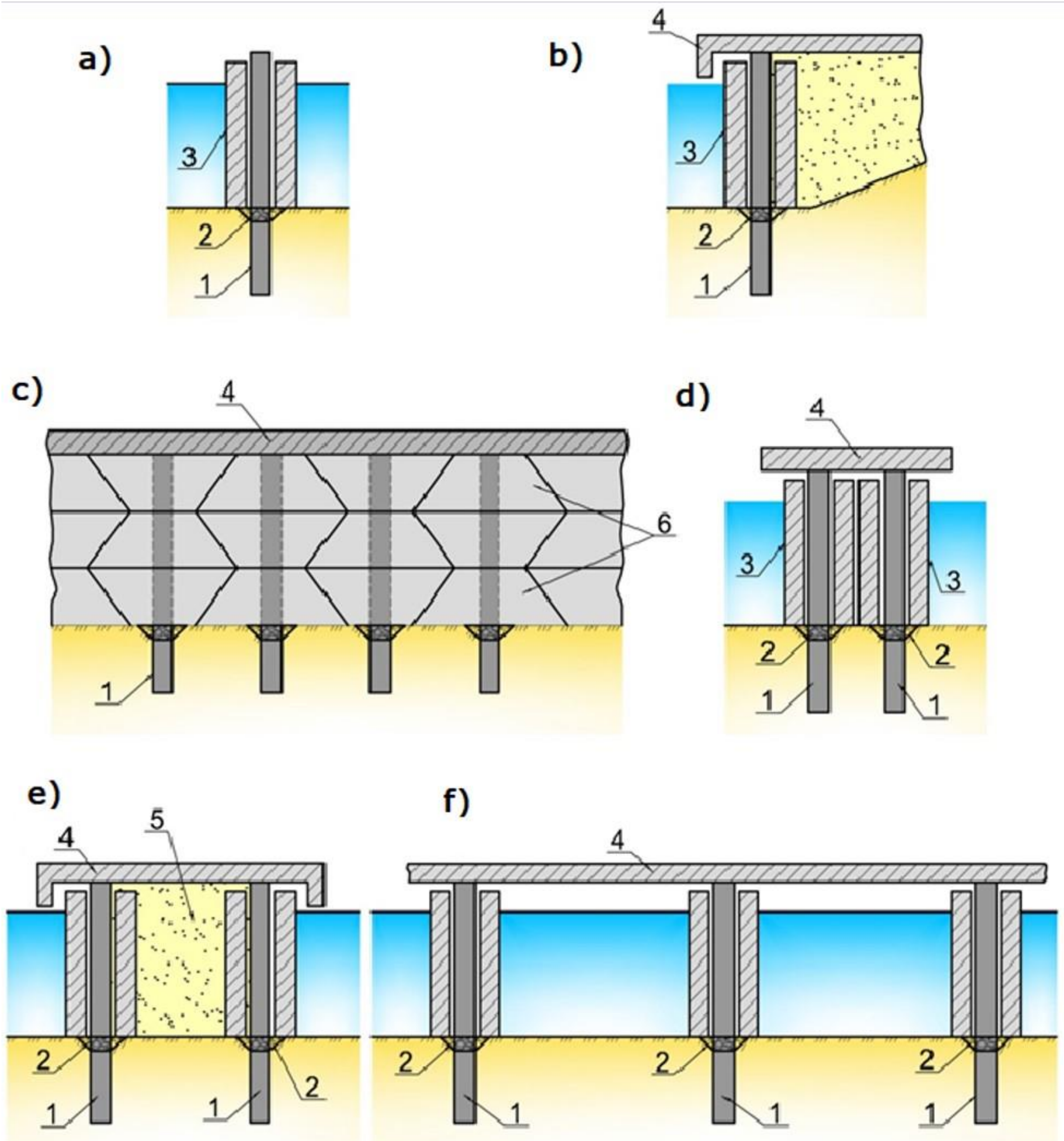

Fig. 1 Port structures of gravity-pile type.
(a) a typical gravitational-pile module; (b) a cross-section of the quay made as a retaining wall; (c) construction using trapezoidal concrete massifs; (d, e) two-row structures (narrow and wide piers); (f) bridge-type pier.

pressure of the backfill act on the structure. The weight of the blocks is determined according to the stability condition of each of them and the entire column against shifts. The cross-section of the pile support is calculated to satisfy the following conditions:

- perception of vertical compressive pressure
- withstanding the bending moment which is transmitted by friction forces to the level of the supporting foot
- providing the required bearing capacity of the pile regarding its interaction with the soil foundation

As calculations have shown when using reinforced concrete blocks weighing up to 1 MN, steel pipes with approx. diameter of 1 m can be applied as tubular piles.

If it is necessary to reduce the pressure on the supporting foot 2, it is possible to ensure the interaction of blocks of adjacent pillars by applying blocks 6 (Fig. 1c) with the trapezoidal shape of the cross-section

Table 1 Consumption of construction materials per 100 m of construction length for comparable design options.

Design option	Steel (t)		Concrete (m^3)		Stone (m^3)	Gravel (m^3)
	Pipes	Ties	Plates	Blocks		
Sheet piling	251.1	52	48.7			
Gravity type wall				4,000	1,800	495
Gravitational-pile structure	35.7			1,390		

The volume of sandy backfill and the area of quay surface pavement are the same for these construction options and therefore excluded from comparison.

in a plane parallel to the boundary line of the berth. The interaction of blocks along inclined contact faces contributes to the redistribution of forces, which is favorable for the operation of the structure.

The pier, mole, or breakwater (Figs. 1d and 1e) are made of two or more of the rows of gravitational-pile modules, united by a common superstructure 4. The width of the structure, that is, the number of rows, depends on its technological purpose and perceived external loads. If necessary, pile rows 1 can be pushed apart and the space between them is filled with soil 5.

The design of bridge-type mooring structures (Fig. 1f) consists of separate supports made of gravitational-pile modules 1, and span elements of the upper structure 2, connecting the heads of piles of adjacent modules. When changing the depth of the bottom along the structure, the length of the piles and the number of reinforced concrete blocks placed on them can be adjusted accordingly.

Summarizing the advantages of the considered design solutions based on the use of gravitational-pile modules, it should be noted their benefits in comparison with traditional structures: a wide scope of application (for any non-rocky soils that allow the driving of piles); the absence of stone bedding, which significantly reduces the material consumption and labor intensity in the construction of the structure; manufacturability, and processability.

Of undoubted interest are the results of a technical and economic comparison of this new type of port facility with traditional structures, carried out when choosing the option of reconstruction of the shallow-water cargo berth in the Ukrainian commercial seaport.

The berth, located on loamy soils, after reconstruction, should have a depth of 6 m and perceive the operational load of category 1 (general cargoes). As competitive (while ensuring the conditions for the overall stability of the structure and the strength of its structural elements), the indicators of the following structures were analyzed:

- the basic design for the quay walls of the considered port, e.g. an anchored sheet piling made of steel pipes of diameter 426 mm and web 8 mm driven into the bottom soil (driving depth: 5 m)
- gravity-type structure of pillar masonry made of concrete blocks (5 m width in cross-section of the berth) placed on a stone bed
- gravitational-pile structure corresponding to Fig. 1b. Steel pipes of diameter 426/8 mm were used as pile supports, the width of the concrete blocks in the cross-section of the berth was 2 m; the horizontal elements of the supporting heel were designed from I-beam No. 22, the span of the tubular supports in the longitudinal direction was 3 m.

Some economical parameters for the compared design options are shown in Table 1.

As can be seen from the considered indicators, the berth made of gravitational-pile modules turned out to be significantly economical in comparison to berths of traditional designs.

3. Further Development of Mixed-Type Structures

Considered innovative solutions do not avoid some technological and technical shortcomings, which include:

- the problematic nature of ensuring the location of the supporting elements at the same height after the immersion of the pile supports (piles in different places along the length of the structure can be driven to different depths due to the heterogeneity of the properties of the soil base), which complicates the technology of erecting the retaining wall
- limitation on the diameter of pile supports and the need to tie their diameter with the dimensions and design of reinforced concrete blocks, which reduces the bearing capacity of the structure as a whole, and also leads to an increase in the length of pile supports (that is, the material consumption and cost of construction increase).

Gravitational-pile structures, the supporting heel of which is rigidly connected to the pile support, should meet the following main requirements for the piles:

(1) ensuring the conditions of strength of pile supports during the joint action of force and moment loads (the most loaded sections of the pile are the cross-section at the place of clamping of the support in the bottom ground and the cross-section at the place where the pile is embedded in the support heel);

(2) providing the necessary parameters for the deformability of the pile (on the one hand, limiting deformations/movements at the place where the pile is embedded in the supporting heel since the latter serves as a support for the retaining wall; on the other hand, ensuring deformations/movements of the retaining wall, sufficient to realize the active lateral pressure of the backfill on the wall);

(3) ensuring the required bearing capacity of the pile support in the perception of both the weight of the retaining wall and the operational load.

A good opportunity to increase the efficiency of structures made of gravitational-pile modules is the application of modern technologies for arranging piled supports, particularly bored piles. Indeed, almost throughout from the base of the quay wall to the target depth of driving, piles are in a soil media. It indicates the expediency of considering the conditions and effectiveness of using the appropriate technology that ensures the arrangement of bored piles (Fig. 2).

The possibility of varying the degree of reinforcement of the pile along its length (corresponding to the reinforcement of the armature carcass in specified places) allows the most optimal perception of maximum forces in the zones where the pile is embedded in the supporting heel and the bottom soil.

In addition, the upper part of the pile, which is adjacent to the zone of location of the supporting heel, can be made of a larger diameter, and, accordingly, with a greater bearing capacity regarding the perception of force and moment loads.

Modern equipment for the arrangement of bored piles [1-5, 8-11] allows providing almost any design diameter of pile supports (at least in the range from 0.6 m to 3.0 m).

Depending on the planned location of the marine structure under construction, drilling of wells for bored piles can be carried out both from the shore (for example, from an existing berth or jetty, breakwater, etc.) and from a floating facility (barges, pontoons, etc.) anchored in the appropriate position. Usually, drilling below the level of the bottom of the reservoir is performed in a casing, which is progressively removed from the soil as the concrete mortar supplied to the well sets.

The solid lower end of the bored pile provides a significantly greater bearing capacity under the action of axial compressive loads than when using steel tubular supports or reinforced concrete shells. Finally, the possibility of varying the rigidity of the bored pile (both due to the proper design of the reinforcement frame and the variation of the pile diameter) allows us to provide design requirements and limitations for the deformation/movement of the whole structure.

Fig. 2 shows the main stages of the quay wall construction. First, bored pile supports 1 are installed (stage 1), then supporting elements (foundation slabs 2) are placed at the bottom level (stage 2). Further, the

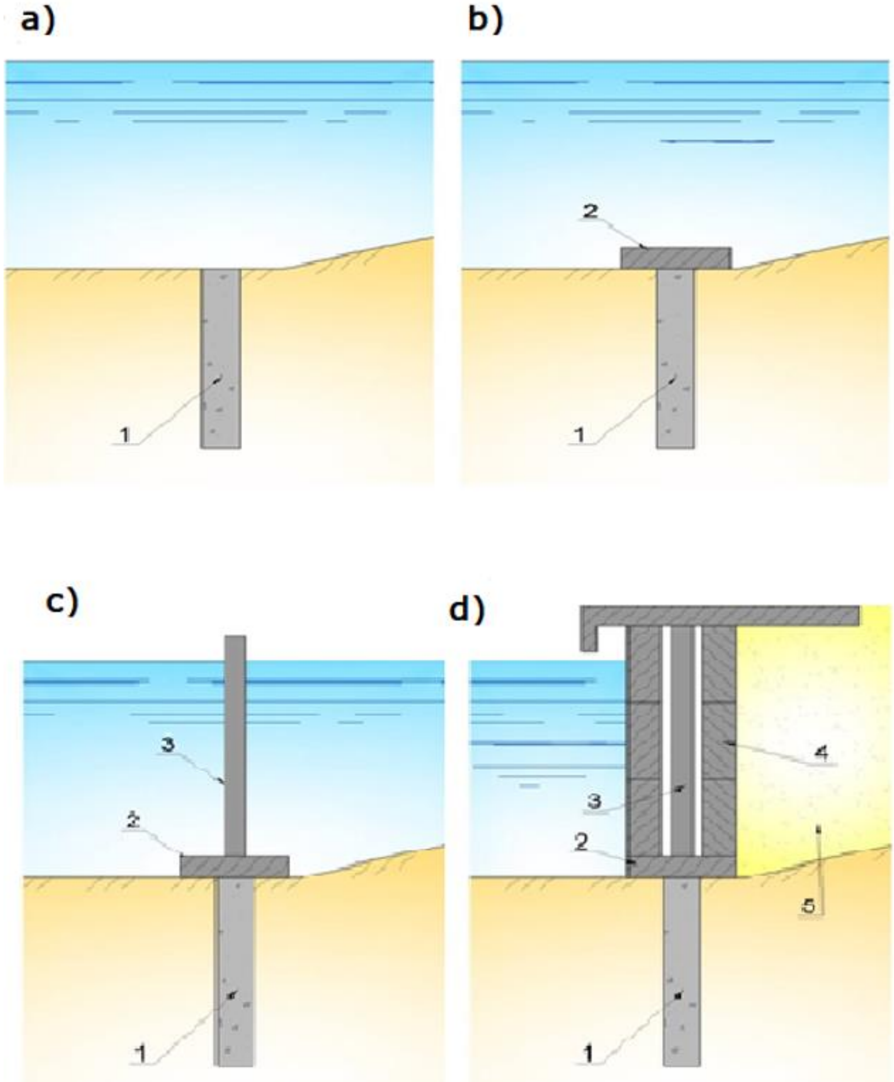

Fig. 2 Innovative solution of gravitational-pile structure using bored piles.
(a) stage 1 (installation of bored piles); (b) stage 2 (mounting of foundation slabs); (c) stage 3 (coupling of bored piles and load-bearing columns); (d) stage 4 (installation of the gravitational wall and backfilling of the territory); (1) bored piles; (2) supporting elements (foundation slabs); (3) load-bearing columns; (4) reinforced concrete blocks; (5) backfill.

upper ends of the bored piles 1 and the lower ends of the bearing vertical columns 3 are connected via the supporting element 2 (stage 3). Reinforced concrete blocks 4 are installed on column 3 (stage 4) and vertical seams are laid between the blocks to ensure soil insulation of the retaining wall. Finally, sandy backfill 5 is fulfilled and the superstructure is mounted.

The technological advantage of such a solution [12] is the possibility of placing all supporting elements at the same design height (since they are placed and fixed after the installation of bored piles). It simplifies the assembling of the structure and reduces the cost of a quay wall construction. At the same time, there are no restrictions on the diameter of the bored piles because their diameter should not be associated with the dimensions and design of the concrete blocks of the wall. It simplifies ensuring the necessary bearing capacity of the structure and decreases the length of pile supports.

It should also be noted the flexibility in making and implementing the optimal design solution because bored piles and bearing supporting columns can be of different diameters and materials.

When designing such quay walls, the specificity of the structure is reflected in the application of external actions at the stage of its operation. Thus, vertical loads—from reloading mechanisms (in the case of the location of crane beams along the heads of the supporting columns), from the weight of the gravitational part of the structure (through the foundation slabs)—are transmitted using bored piles to the soil base. At the same time, the dimensions (cross-sectional dimensions and length) of the piles are determined by the condition of ensuring their required bearing capacity.

Horizontal loads (lateral pressure of the soil, shiploads, etc.), perceived by the gravitational quay wall, are transformed into friction forces on the contact of the lower concrete block of the wall with the foundation slab, and the bending moment, which affect the pile supports of the structure.

4. Conclusions

Developed mix-type marine structures may be widely implemented in various port and coastal protection projects providing the possibility of construction on weak soils and maintenance of the facilities under essential operational and natural loads. Besides such a kind of design leads to a reduction of materials consumption and, correspondingly, to budget cuts.

Proposed further improvement of mix-type marine structures based on bored piles application in the foundation part of the facilities provides some new advantages: design flexibility and better adaptation to local conditions, particularly for deep-water constructions.

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