Infilled Shells Constructions in Hydraulic Engineering

N Ya Tsimbelman¹, N M Malkov², T I Chernova³, M A Selivanova⁴

¹candidate of engineering sciences, associate professor, engineering school, Far Eastern Federal University (FEFU), Sukhanov St., 8, Vladivostok, 690091, Russia
²candidate of engineering sciences, associate professor, engineering school, Far Eastern Federal University (FEFU), Sukhanov St., 8, Vladivostok, 690091, Russia
³senior lecturer, engineering school, Far Eastern Federal University (FEFU), Sukhanov St., 8., Vladivostok, 690091, Russia
⁴assistant, engineering school, Far Eastern Federal University (FEFU), Sukhanov St., 8., Vladivostok, 690091, Russia

E-mail: selivanova.ma@dvfu.ru

Abstract. Filled shells are built for the needs of various industries. Made from a variety of materials, the shells retain the inner filler as a storage medium or as a structural material. The work considers constructions in which the filler has the function of a structural material that ensures the operational qualities of the entire construction, although in most cases the operating conditions of shells with a filler make it possible to set and use general approaches to the calculation and modeling of the construction. The main types of hydraulic structures, in which shells with soil filler are used or can be used, are grouped into several main groups.

1. Introduction

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2. Application of filled shell structures in hydraulic constructions projects
Shells with a filler are used to solve various engineering problems in hydraulic engineering, primarily in the construction of berthing facilities (embankments, bollards, piers) and protective structures (breakwaters and cutwaters). On the basis of the involvement of the surrounding soil in ensuring the strength and stability of the structure, the filled shells occupy an intermediate position between massive gravitational structures (box caisson) and thin walls pinned into the ground (bulwarks).

A significant effect of using filled shells is achieved when building quay embankments. Installed in a row, reinforced concrete or metal shells form a solid wall: tied at the top by a monolithic superstructure, they form a reliable extended construction capable of absorbing both the pressure of the soil retained from the shore and significant loads from mooring ships, port technological equipment, stored materials (figure 2, 3). The ability to absorb significant horizontal loads from ships makes it possible to use filled shell structures in the design of piers and roadstead berths (bollards).

The ability to achieve the required massiveness of the structure by using the weight of the soil retained by the shell led to the emergence of technical solutions for protective structures (breakwaters, cutwaters) made of filled shells. At the same time, constructive techniques aimed at increasing the reliability of the filled shells as a part of protective structures can be divided into two main areas: the
first one includes technical solutions introduced in order to increase the massiveness of a construction (for example, partial concrete filling - Figure 4a), and the second one - solutions, allowing to reduce the wave load on a construction (for example, the device of wave-damping chambers and wave-break walls - Fig. 4b).

**Figure 2.** Scheme of a partially recessed shell as a part of the embankment in Riga (Latvia); a - view of the embankment in plan; b - cross section of the shell; 1 - reinforced concrete shell, 2 - topside construction, 3 - filler (sandy soil), 4 - anchor rods, 5, 6 - elements of the topside construction, 7 - fenders.

**Figure 3.** Scheme of a gravity shell with a filler as a part of the quay wall in the port of Vladivostok (Russia); a - a fragment in plan; b - cross section; 1 - steel shell, 2 - filler (soil), 3 - rubble base, 4 - loamy soil of the base.

When building structures on a shallow continental shelf, filled shells can be used to enclose alluvial artificial territories [1], including artificial islands (Figure 5).

A wide range of technical solutions for constructions using filled shells is combined into a separate group of "support blocks" (figure 1), containing a description of the use of shells as the main supporting (foundation) parts of a construction. Here, stand-alone supports of significant size (monoblocks) are distinguished, forming support (including ice-resistant) foundations - filling structures of special constructions located off the coast: for example, exploration and oil and gas production platforms (figure 6), other offshore complexes for various purposes (figure 7), as well as structures for navigational conditions (beacons, leading signs, etc.).
Figure 5. Scheme of an artificial island enclosure made of shells: 1 - shell (sheet pile cell), 2 - filling, 3 - reinforced concrete belt, 4 - island body.

Figure 6. Scheme of an ice-resistant foundation (designed by Tokyo Boeki Ltd.) [2].

Figure 7. Scheme of the supporting structure of a marine complex [3].

Other structures of the supporting foundation parts of stand-alone constructions on the shelf are thin shells fixed in the ground, filled with soil by complete immersing the shell into the base (bucket foundations, suction caissons). This is a relatively young trend in the use of filled shells as foundations and is currently used mainly to hold point eccentrically loaded objects in the design position (for example, wind generators, power transmission line supports, etc. - figure 8).
Structures of filled shells are also used to protect supporting structures and soil foundations of other constructions to ensure their strength and stability. An example of such an application is stand-alone cylindrical shells designed to protect bridge supports (figure 9), as well as shells that ensure the stability of the foundations of mixed-type protecting constructions (for example, deep-water breakwaters - figure 10).

Filled shells can be used for the construction of bridges in river beds, as well as for the formation of marine protective and berthing structures. For this purpose, shells of various shapes are used, as a rule, formed by immersing groove of various cross-sections into the ground: cofferdams (figure 11).
Figure 11. Process of construction of a filled-shell cofferdam on the Ohio River (Willow Island, USA) [6].

3. Conclusion
Based on the analysis of the possibility of using filled shells in projects of hydraulic structures, a classification of hydraulic constructions made of shells with a filler according to their functional purpose was compiled.

The analysis of the experience of using the main types of shell structures in hydraulic engineering was carried out in view of the urgency of the task of expanding the capacity of ports and the construction of new coastal infrastructure facilities.

The factors on the basis of which, at an early stage of design, preference is given to solid shells or groove shells, can be combined into three main groups:

- experience of the company, availability of the necessary equipment;
- financial justification related to the remoteness of the facility and the availability of the necessary infrastructure;
- optimal compliance of the project with the conditions of construction and operation. For engineers, the third group of factors is most interesting, reflecting the features of the operation of a construction as a building structure, and allowing to choose the optimal solution depending on the conditions of the construction site and the operating parameters of the future facility. These factors determine the "niche" of conditions for which one of the design options will be more preferable than the other.

4. References
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