Structures of Berthing Facilities Recommended for Erection in Severe Climatic Conditions of the Arctic (Review)

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Abstract. The article gives an overview of the constructions of berthing facilities recommended for erection in severe climatic conditions. The main conditions for the application of each type of structure are singled out. Features of operating conditions of structures on the Arctic shelf are analyzed. Recommendations are given for choosing the optimal type of structures when there are weak soils at the base of the construction site, as well as under ice and seismic influences. The berthing facilities constructed in severe climatic conditions, both in Russia and abroad, are analyzed. The expediency of using shells of large diameter, which are thin metal or reinforced concrete casings (usually cylindrical shells), whose cavities are filled with coarse ground, have been substantiated in the harsh climatic conditions of the Arctic. The main advantages of this type of structures are described, and a number of problems are emphasized that are primarily related to the interaction of the shell and the filler material. The difficulties in organizing the transfer of the load from the shell structure to the ground base are singled out.

1. Introduction

In recent years the Arctic has become a prior territory for development. Its industrial development is associated with mining, the development of transport routes and transport infrastructure.

The Northern Sea Route which is the only route linking all Arctic regions of Russia, plays a huge role in the further development of the Arctic. However, for its full use, modernization and, in some cases, the construction of port infrastructure along the NSR are necessary.

The key problem in increasing the competitiveness of the Northern Sea Route is the physical and moral deterioration of the fixed assets of the ports along the route. A significant part of the port hydraulic structures has reached thus standard service life. On inland northern waterways, the state of port transshipment facilities is a problem. Most of the berthing facilities operating on shelf zone waterways have been operating for 50–70 years or more [1].

Due to the harsh climatic conditions, the structures and repair of infrastructure in this Arctic area is becoming more complex.

Under the conditions of relatively weak compressible soils of the Arctic seas of the base of the shelf zone, the construction of specially prepared stone beds is difficult and the production and transportation of massive precast concrete structures are impossible due to the remoteness of construction objects.
That is why the problem of finding an optimal engineering solution to this problem becomes very topical.

2. Features of the operating conditions of the structures on the Arctic shelf

The Russia’s Arctic shelf in natural climatic, bathymetric, engineering-geological, geological, seismic and other conditions is characterized by the following features [2]:

- its considerable length small depths (less than 100 m) prevail, under these conditions wave transformation occurs, which leads to a significant increase in wave loads;
- severe ice conditions (large fields of drifting ice, hummocks, and other ice phenomena) are observed on the most part of the history;
- a high level of seismic effects;
- difficult natural-climatic and engineering geological conditions (as a result of numerous transgressions and regressions of the sea);
- sporadic distribution of eternally frozen and frozen soils.

The conditions for the construction and operation of hydraulic structures on the Arctic shelf of Russia are characterized by specific features. These features should be taken into account in the design and construction of hydraulic structures. [2]:

- distance from construction sites and lack of infrastructure;
- difficult conditions and a short period of time acceptable for transportation, assembly and installation of hydraulic structures;
- severe (in terms of loads and impacts) operating conditions.

3. Types of berthing structures recommended for construction in seismic areas with weak soils at the base

In seismic conditions in the presence of weak soils on the construction site, it is recommended to apply the following hydraulic structures [3]:

- berth anchor walls made of steel sheet piles (pan, t-shaped, pipe-sheet, etc.) (Fig. 1);
- berthing ramps on steel tubular and box piles, on centrifuged reinforced concrete piles-shells and prismatic piles (Fig. 2);
- berthing facilities of large-diameter shells (Fig. 3).

If there are weak soils at the base of the anted bolverk, the latter should be completely or partially replaced by better coarse-grained soils, or strengthened. The need to replace or strengthen the soil is determined on the basis of calculations of strength and stability, taking into account seismic effects. Replacement soil or fixed soil is recommended to be placed on dense underlying soils behind the front wall and in front of it. The width of the site for replacing or reinforcing the soil is determined by calculating the stability of the structure, taking into account seismic effects. Behind the front wall, it is recommended to replace or reinforce the soil in the entire area between the front and anchor walls.

Figure 1. Berthing facilities of anchored bolverk from pile shells and also from tongue and groove; 1 - anchor thrust; 2 - anchor plate (wall); 3 - tongue; 4 - shell column.
Figure 2. Berthing facilities of the overpass type; 1 - pile; 2 - upper structure; 3 - supporting sheet pile.

Figure 3. Landing facilities of large-diameter shells; 1 - stone bed; 2 - sand backfill; 3 - superstructure; 4 - shell of large diameter.

The construction method of the anchored bolverk (sequence of soil dumping) should exclude the displacement of the weak soils left when working on the formation of the territory and their accumulation at the front wall. In order to do this, it is necessary to dump soil from the side of the wall deep into the territory. It is also advisable to provide consolidation of dumped soils in front of the front and anchor walls.

Shells of large diameter should be supported on dense underlying soils. Weak soils inside the shells should be replaced with stronger ones, or they strengthened should be them.

Pile supports should be immersed in strong, seismic resistant soils [3].

In order to increase the horizontal stiffness of the pier-type piers, it is recommended to: pour sandy pillow and a layer of coarse-grained soil successively over weak soils and compact this soil. It is also recommended to install expander on piles in this layer, involving a larger amount of soil in the work under horizontal loads. The installation of gantry supports is also advisable [3].

4. Types of berthing structures recommended for construction in ice conditions

Hydrotechnical structures of seaports with a freezing water area, operated during the ice period, must meet the following basic requirements [4]:

- berthing hydraulic structures must withstand the stresses arising from the impact of ice and the conduct of mooring operations in ice conditions;
- berthing facilities must be used at negative air temperatures and in ice conditions;
- berthing facilities must be equipped with special means to ensure the safety and speed of the mooring operations.

The front walls of the engulfed berthing facilities for the conditions of the Arctic should be made of steel sheet piles or pipes, shielding elements - of reinforced concrete piles and shells. It is possible to use shielding elements for the front walls [3].

It is recommended to use the following structures of hydraulic structures [5]:

- berthing facilities from ordinary concrete massifs, massifs of giants from hollow concrete massifs (Fig. 4);
- shell mooring facilities (Fig. 3);
- mooring structures of the bolverk type (Fig. 1);
- embankments and piers of the overpass type (a) on prismatic reinforced concrete piles, with ice thickness in the water area up to 0.25 m; (b) on tubular reinforced concrete piles, ice thickness in the water area being up to 0.4 m) (Fig. 2).
5. Berthing facilities in arctic conditions

At the end of the twentieth century while designing berthing facilities in the harsh conditions of the Arctic, various types of structures became widespread in our country. For example, in the port of Tiksi (Russia), a berth of a shell structure made of steel sheet piling (eight-ball seismic area) is being operated.

Shell structures have a very high seismic resistance. The earthquake of 1968, which affected the ports of the southern part of the island of Hokkaido and the northern part of the island of Honshu, the cellular structures were not damaged [6].

Sheath structures of steel sheet piling are being built in Greenland, Canada, USA (Alaska) (Fig. 5) [6].

Oil berths in the Gulf of Cook and the pier in Anchorage (USA, Alaska) have been built out of tubular piles. The berths of the pile structure in Anchorage have proven themselves well in the 1964 earthquake. The pier moved about 0.3 m horizontally, while the port area was displaced by almost 0.9 m [6].
Gravity-type structures of giant arrays have been built in some ports of Canada (Quebec, Cartier, Seven Islands) and are located in conditions close to the Arctic. In the port of Quebec, the giant massifs are made of cylindrical reinforced concrete with a height of 27.5 m and a diameter of 24.5 m, installed on the stone dumping and equipped with ice-cutting devices. It is worth noting the complexity of the natural conditions of this sea-port. The winter period in this area is characterized by drifting ice fields. During the spring flood, ice is carried by a strong current into the Atlantic Ocean, ice fields reaching gigantic sizes and weights. The adopted technical decision of the berth took into account the local conditions [6].

At present, two berths are being built in the seaport of Sabetta (Russia). Berth constructions are anchored bolverk and are made of metal piping. According to the characteristics and timeframe of the project, these facilities are unique and are being implemented in Russia for the first time, since the design load on the floor when unloading the modules is 10 t / m2, and construction time is only one and a half years (Fig. 6) [8].

As part of the development of the Salmanovsky (Russia) oil and gas condensate field and the implementation of the construction of plants for the shipment of liquefied natural gas, the construction of berths in the northern part of the Ob Bay of the Kara Sea was completed. The design of the pier is anchored bolverk and is made of metal piping [8].

Several berths of the type anchored bolverk built in the city of Pevek (Russia). The operation of these berths for a long time showed their sufficient reliability [6]. Anchored bolverks have been erected in a number of other points, including the port of Magadan, where the ice conditions are rather severe.

In Arkhangelsk (Russia), three sea berths have been built in the form of a shielded anchored bolverk using pre-stressed reinforced concrete shells.

Figure 6. The mooring of the port of Sabetta [9].

The embankment of the overpass type was built on Spitsbergen (Norway). Its total length is 195 m, on the seabed there are vertical piles with a diameter of 80 cm and steel skirts connecting the piles (Fig. 7) [7].
6. Large diameter shells
The authors propose shells of large diameter as one of the promising types of structures for the construction of berthing facilities in the harsh climatic conditions of the Arctic (Fig. 8).

This type of construction has several advantages:

- efficient design. As a rule, expensive structural material is used only for the shell: reinforced concrete structures occupy up to 10% of the total volume of the shell structure with aggregate, for steel structures is this volume up to 1% of the total volume. The filler material is in most cases relatively cheap compared to the shell material.

- “vitality” of the structure. That means that the shell is able to redistribute forces that make it possible to maintain the strength with significant deviations from the design position

- it is possible to use structures made of shells of large diameter in conditions of relatively weak compressible soils of the base of the shelf zone of the Arctic seas.

Figure 8. Examples of structures of large-diameter shells: 1 – shell made of steel; 2 – shell made of reinforced concrete [4].

It is worth emphasizing a number of problems, mainly related to the interaction of the shell material and the filler material, as well as the difficulties in organizing the transfer of load from the shell structure to the subgrade: contact area of the shell, filler and soil base; the complexity of the description of the stress-strain state of the “shell – elastic filler” system, taking into account the physical and mechanical properties of the filler, the conditions of contact of the filler with the shell and edge effects; the lack of an automated integrated method for calculating shell structures with
elastic filler; limited set of design solutions to improve the efficiency of the filler as part of the structure in various operating conditions; the need to develop solutions for the technology of erection of shell structures with elastic filler for various materials and construction conditions [11].

These problems are the result of the insufficient knowledge of the nature of the stress-strain state of shell structures with elastic filler both in natural conditions and on models. In this connection, studies of the stress-strain state of shells with an elastic filler remain relevant.

6. Conclusion

Cost-effective combined designs that make the most effective use of the positive properties of their constituent elements are increasingly applied in construction practice. In hydraulic engineering during the construction of quay quays and piers it is often cost-effective to use thin steel or reinforced concrete shells with a soil filling.

The shells allow the technological capabilities of the manufacturer of construction work to be taken into account. The shells themselves can be made both solid and composed of sheet piles immersed in the ground.

The choice of construction type depends on the following factors [12]:

- soil characteristics of the base. It is advisable to use cylindrical shells in complex engineering and geological conditions. Large-diameter casings are usually installed on a specially prepared, solid foundation (“bed”), which is not always possible to install due to the complexity of underwater work;
- availability of materials and equipment. The availability of materials and equipment is often a determining factor while choosing a project type. The metal sheath of solid sheet or its components is a unique type of construction, which is manufactured at the factory in accordance with the project and delivered to the construction site using large-sized land or water transport. The remoteness or absence of a nearby equipped assembly site increases the cost of production work and construction time. In this case, cylindrical shells from the tongue are the optimal solution: the component structural element - steel tongue - is selected according to the catalogues of the plant according to the calculation results and delivered to the construction site in a shorter time, since the transportation process is simplified;
- the size of the designed structure. Solid shells are made in most cases in the form of a cylinder: they are installed in a row, close, or at a short distance from each other, which is covered by a fragment of the shell of the same or smaller radius. The rest of the set of forms of solid shells is very limited. On the contrary, the cylindrical shells of the tongue can be arranged in a different order depending on the desired configuration of the future protective structures;
- construction conditions. It is rational to use barrier structures from OBD during construction “into the water”, in conditions when erection of shells from the dowel is difficult due to the impossibility of submerging sheet piles;
- presence of seismic load. In the case of a seismic load, one-piece shells should be supported on dense underlying layers of soil, which is not always possible due to a considerable depth of the structure. Shells from the tongue in this case can serve as the optimal solution.

Despite the difficulties that often arise during the design justification of the joint work of the shell and the filler, the building structures that they compiled are often the most economically preferable. At the same time, the lack of information on the design parameters of the models is compensated by laboratory tests and long-term observations of the erected structures.

References

[1] The development strategy of the sea port infrastructure of Russia until 2030 http://www.rosmorport.ru/media/File/State-Private_Partnership/strategy_2030.pdf (accessed 28 August 2019)
[2] Bellendir E N 2006 Scientific justification for the design of gravity support blocks of offshore
ice-resistant platforms and their interfacing with a soil base (Sankt-Peterburg)

[3] R 31.3.02-98 1998 Recommendations for the design of marine port hydraulic structures in seismic areas in the presence of weak soils in the base *publishing house AOOT "DNIIMF"* (Vladivostok), 50 p

[4] Tsimbel'man N Ya, Potyanikhin D A, Mamontov A I, Chernova T I, Kvon E V, Kuznetsov I G 2013 A mathematical model of a shell with a filler for the calculation of hydraulic structures *Bulletin TOGU* 4(31) pp 43-50

[5] SP 287.1325800.2016 Marine mooring facilities. Rules for design and construction http://docs.cntd.ru/document/456069590 (accessed 28 August 2019)

[6] Shtan'ko L F 1981 Development of design guidelines for berthing facilities for the Arctic, taking into account the effects of loads and frozen soil in the body of the structure (Moscow: Dal'morniiiproekt)

[7] Sheet piles and design solutions http://sheetpiling.arcelormittal.com/ (accessed 28 August 2019)

[8] Construction projects of Trest Zapsibhydrstroy LLC for the oil and gas industry http://www.s-ntng.ru/pdf/main_1939.pdf (accessed 28 August 2019)

[9] Yamal LNG Project in Sabetta https://sdelanounas.ru/blogs/95954/ (accessed 28 August 2019)

[10] Marchenko A, Shestov A, Sigitov A, Loset S 2011 Water-ice actions on the coal quay at Kapp Amsterdam in Svalbard *Proc. Int. Conf. Port Ocean Eng. Arct. Cond. POAC11-145* (Montreal, Canada) 11 p

[11] Bekker A T, Tsimbel'man N Ya 2010 The use of shell structures with elastic filler in construction *Bulletin of the Far Eastern State Technical University* 2(4) pp 27-34

[12] Chernova T I, Tsimbel'man N Ya 2016 Cylindrical shells with internal filler in the practice of geotechnical construction *Scientific Bulletin of Voronezh State Administrative University Construction and architecture* 1(41) pp 11-20