Design features for Arctic ports berths for accepting the ships with a deep draft

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Abstract. Construction of new Arctic ports is a complex scientific and technical challenge. The experience extends to the berths that can accept the vessels with a small draft only during the summer navigation period. Commercial efficiency of shipping in the Arctic seas is possible only with year-round use of large-tonnage vessels of high ice class with a draft of 12 meters or more. The Arctic seas basin is mostly shallow, and the main transport task is the regular export of liquid natural gas and crude oil by shuttle ships. We analyze a currently used berth structures and their operational features. It has been revealed that the berths of the overpass type on piles of shells with a concrete grillage require additional ice protection structures in the port water area, since power loads from the vessel mooring and ice may be critical. The infrastructure of the modern marine port in the Arctic should combine with production and logistics capabilities, since the internal transportation of goods is labor intensive. A mooring structure from the arrays of concrete gravity caisson wharf is proposed, which can be quickly constructed and they can accommodate additional equipment for transporting or transferring cargo. The studies are performed at the Department of Hydraulic Port Construction in Admiral Makarov State University of Maritime and Inland Shipping.

1. Introduction
The development of Arctic shipping as an international transport system in the future will require the construction of a new polar ports infrastructure. Now in the Arctic two transport directions are actively developing, these are the export of crude oil and liquid natural gas (LNG) and transit shipping during the summer navigation period; transit through the Arctic is a shorter alternative route than that through the Suez Canal. In the Chapter [1] we gave a historical review and results of research about the features of the Arctic’s ports structures, including mooring devices. Perspective of developing the Arctic ports in the national regions of Russia, Canada, Norway, Iceland and the United States (Alaska), Greenland and Faeroe Islands as local and regional projects is presented in [2]. An idea of solving the local needs and logistics supply problems, which should become the main driving forces for development of the sea ports infrastructure in the Arctic, is highlighted.

In 2018, according to the Administration of the Northern Sea Route (Russia) [3], the cargo turnover amounted to 20 million tons, which is the maximum value for the entire period of Arctic shipping along the Northern Sea Route. The main cargo base is LNG from the port of Sabetta and crude oil from the port of Novy Port. The composition of the Arctic fleet has changed significantly, since 2015 the large-capacity vessels of high ice class Arc7 have been introduced (project 42K - Arctic oil shuttle with deadweight over 40 thousand tons, project YamalMax - LNG tanker with deadweight over 100 thousand tons). During the summer open water navigation period in the Arctic, the vessels like as Aframax,
AtlanticMax and MR-class are used, which take the project cargo and make the transit voyages. From 2017, it became clear that an intensive increase in cargo turnover would be possible only with the use of large-tonnage vessels with a draft of more than 12 meters with Arc7 ice-class. Such vessels do not require icebreaking assistance and can independently navigate in the ice up to 1.5-2.0 meters. All new projects on the Arctic shelf also include the use of vessels with a draft of more than 12 meters. An important problem for the operation of such vessels in the Arctic is the lack of ports capable to receive the vessels with a deep draft and mooring devices for cargo handling. The concept of maritime spatial planning for the Arctic zone, as a new scientific area [4], considers the areas of seaports as the functional zones with their own safety criteria. Therefore, an important component in the construction of the port is the development of technical means for monitoring the technical condition, which should cover the entire life cycle of the structure. Instrumental monitoring of the construction part of the berths in the arctic conditions is difficult, the shift method of personnel delivery and the lack of technical means make it almost impossible to assess the temperature effects, deformations from ice loads, the consequences of the bulk of the ships during mooring.

The objective of this work is to study the use of gravity structures and concrete gravity caisson wharf for the construction of the Arctic maritime ports and the methods for monitoring the technical condition of structures during their operation, this problem is relevant for designing berths for ships with a draft of more than 12 meters.

2. Methods and materials
The most of existing structures of the Arctic berths can be divided into two main groups:
- the construction is carried out from local natural materials for the vessels with a draft of no more than 5-6 meters, the type of construction is a bulk dam;
- the construction is carried out using pipe piling, sheet pile and concrete for the vessels with a draft of up to 9 meters, the type of construction is a pile ramp or anchored sheet piles.

The exception is the port of Sabetta in Ob Bay, which can receive the vessels with a draft of 14 meters, its construction is a double-row sheet pile wall with a concrete head and an approach ramp of large-diameter pipes, the port is equipped with the ice-shelter structures, an icebreaker operates on its territory. The approach channel in Ob Bay is ice and is served by a nuclear-powered icebreaker during the winter navigation period.

The “Gates of the Arctic” terminal in the Novy Port is a modern gravity structure, located 3 km from the coast and equipped with a flexible pipeline for pumping oil onto a tanker, the terminal can receive the ships with a draft of up to 9.5 meters. The construction of the berthing facilities in this place is impossible due to the small depths.

Additionally the information about the transit of ships through the NSR over the past 10 years according to the Centre of high north logistics (http://arctic-lio.com/) and NSR Administration, which publish annual reports, is studied. It is found that the ships with a draft of more than 12 meters are extremely rarely used for navigation and they do not have the ability to moor at the Arctic ports.

The traditional construction of marine berth is piles and concrete grillage, which is shown in Figure 1, for the Arctic this design is dangerous because it cannot withstand the load during movement of ice floes. The pile diving depth is up to 70 meters, the depth at the pier is 15 meters, and the height of the freeboard for the ships of the YamalMax type is 27 meters. Thus, when mooring a vessel, the total shoulder from the bottom of the bottom is more than 40 meters, and a total of more than 110 meters.
With such construction, the natural-ecological balance of frozen soils is always disturbed, which can lead to ambiguous changes in the entire pier. It is clear that any bulk of the tanker with a berth will cause its deformation, and the construction of a separate mooring device is an additional cost. The strength of the berth should correspond to the through passage of the ice field with a length of at least 1 km. However, in practice, the size of individual ice floes can be much larger, and crawling on piles will be dangerous. Other types of structures require the importation of a huge amount of building materials, which significantly increases the construction time and cost of berths.

3. Results
With the use of satellite imagery methods, we research and measure the linear size of ice floes in the winter period in Ob Bay and the Kara Sea.

The boundaries of cracks in ice are clearly visible on images; it is also possible to determine the movement of ice when viewing satellite images over a period of several days. An example of measurements is presented in Figure 2, where separate ice floes are circled along the contour of the cracks. The image corresponds to the heaviest ice period, when according to the various sources the ice thickness is up to 1.4 meters thick. In Figure 2, the individual ice floes are identified with an area of 1.12, 1.17, 1.9, 2.1, 5.1, 7.05, 18.7, 28.8 square kilometers and a linear dimension of 0.6 to 8 kilometers. Speed of movement of separate ice floes is also investigated on a series of space pictures; it can reach up to 0.5 meters per second at an ice drift.
Figure 2. Analysis of the size of ice floes by the satellite image in Ob Bay.

Obviously, the through passage of ice floes of this size through the pile field of the berth trestle with a height of 16-22 meters (for mooring the vessels with a draft of up to 14 meters) is dangerous. The solution of this problem is the construction of ice port facilities, however, such structures are very expensive for the Arctic, experience has also shown that in conditions of a closed port water area, when there is no current, broken ice actively accumulates and can reach a thickness of several meters, which makes navigation more difficult. Ice-protecting dams also reduce the water area of the Arctic port, and the large-tonnage vessels require a large operating area for self-reversal.

To reduce the construction time of the Arctic ports, the construction of structures from floating elements is promising. Gravity-type or concrete caisson berths from large blocks of gigantic massifs have found their use on the inland waterways close to the large industrial enterprises. However, the absence of developed bases in the Arctic regions for the construction of floating elements and a limited period of work on the installation of giant massifs (up to 2 months) hinders the development of this direction. In addition, in harsh climatic conditions, in order to ensure the standard durability of the berth, an increased thickness of facial elements of at least 20 cm is required.

A variant of the construction of a single section of a gravity pier is shown in Fig.3 (a), after installation on the prepared stone bed on the bottom, each cavity is filled with stone, which ensures the immovability of the pier, the next section is installed on top to reach the required berth height. There are a sufficient number of ways to fasten the sections together; they all give a good result. For the delivery of sections, modern semi-submersible icebreaking vessels Audax, Pugnax (Heavy Load Carrier) can be used, which have a cargo deck with a size of 43 by 175 meters; they are equipped with a heating system and can carry large blocks in overall dimensions of the deck.
4. The discussion of the results

The infrastructure of the modern marine port in the Arctic should combine with production and logistics capabilities, since the internal transportation of goods is labor intensive. A mooring structure is proposed from the arrays of concrete gravity caisson wharf, which can be quickly constructed and they can accommodate additional equipment for transporting or transferring cargo.

Criteria that are used in the design of marine ports in the Arctic are currently being actively developed, basic safety requirements were formulated in [5, 6] which were continued in work [7]. The codes of rules and technical regulations for the design of port facilities in the Arctic are being developed in Russia since the beginning of 2000. Construction of port Sabetta and “Gates of the Arctic” terminal has revealed some design advantages, but the experience of operating the ports is still insufficient.

The organization of continuous automated monitoring of the technical condition of the berths in the Arctic is important. For gravitational structures, this task is reduced to observing the deformations in height and measuring the temperature conditions in the structure and below the sea bottom level. Lotsberg in [8] suggested the main criteria for designing offshore berthing facilities that can be applied to the Arctic ports in terms of force interaction with ice fields and arrays, preliminary analysis for gravity facilities has shown their high stability when colliding with ice floes of 2-3 meters thickness, which is ensured by large mass and uniformity of berth. In [9] we proposed a system for automated monitoring of deformations, which with sufficient accuracy reveals all dynamic impacts on the berth, such as ship’s bulk or ice exposure. A promising direction for the design and operation of the Arctic berths is the use of information modeling technology - BIM, a digital model for the operation of berths in the Arctic was proposed by us in [10].

5. Conclusion

For the Northern Sea Route, an important task is the development of ports in the Eastern sector, the concept in [11] involves the use of ports in Dikson, Taimyr, Khatanga, Tiksi, Pevek and others. For their construction and reconstruction, new solutions are needed for large-capacity ships with a deep draft, which can be implemented in the short-term using gravity structures. The construction of such ports can be combined with the organization of production and logistics on the coast and carried out in broader options than only during the summer navigation period. At the same time, even temporary structures can be used for mooring ships and sending goods, as well as gravitational blocks have minimal impact on the natural and technical environment and ecology of the Arctic regions.
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