Operating Conditions and Damage to the Concrete of Port Facilities on the Southern Coast of Sakhalin

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Abstract. The article examines the winter operating conditions of the concrete of various port facilities in the area of variable water level on the southern coast of Sakhalin Island. It analyzes the climatic conditions of the south of Sakhalin being under influence of the cold Sea of Okhotsk and the warm Sea of Japan. The peculiarity of the climatic conditions predetermines various factors of the frost exposure on the concrete structures in the area of variable water level. The article describes the specifics of the port construction on Sakhalin and the factors that determine the concrete durability. It presents the results of surveying the structures with different service life. It has been established that under modern conditions of the construction of port facilities, the concrete destruction may be possible after the first winter period of operation. The processes of the concrete freezing in different sections of the area of variable water level as well as the distinctive types of concrete damage are considered.

1. Introduction

World practice shows that the economic need for the rational use of resources causes new requirements for the design process of facilities – the design for the life cycle [4, 12]. There is also a need to develop a new approach to the design - the design for durability [10]. Since 2000, the United States and the European Union have an increased interest in study of the concrete durability in aggressive environments. RILEM develops special programs for the study of mathematical models of the concrete durability [12]. The shortage of research and the need for research in this field are stated in the works of national experts [1-3, 5, 10]. This determines the particular importance of examining the real work of the concrete in a structure, the accumulation of data on the kinetics of corrosion processes during the concrete operation in aggressive environments.

This article shares some results of field surveys of offshore structures built on Sakhalin Island from 1930 to 2018. Regular surveys of transport facilities have been carrying out on Sakhalin since 1970, when the Sakhalin Research Laboratory (SakhNI TsNIIS), a structural subdivision of the USSR Scientific Research Institute of Transport Construction (TsNIIS), was set up. The laboratory introduced new technologies of concreting operations during the construction of marine and transport facilities in the harsh climatic conditions at the coasts of the Far Eastern seas, conducted studies of the durability of the concrete in real operating conditions. After the closing down of the USSR Ministry of Transport and Construction in 1990, the TsNIIS Institute and its peripheral subdivisions were closed as well. Since then, the budget funding for field studies of the concrete durability has been ceased in Russia. However, experts of Transstroy-Test LLC, who previously worked at the Sakhalin laboratory of TsNIIS, continue...
the research on their own. The study of the durability of concrete in harsh climatic conditions is one of the priority areas for Transstroy-Test LLC among many other areas of activity, like laboratory tests, inspection of buildings and structures, designing, and construction control. Such studies are necessary for an objective expert assessment of the causes of the concrete degradation in structures.

2. Techniques
The pattern of damage of the concrete in a structure is an important source of information to assess the bearing capacity of the structure and possible causes of the concrete degradation. Those were the observations of the road surface concrete fracture patterns and the failure analysis that made it possible to establish one of the important factors, an artificial air entrainment particularly, which increases the resistance of the concrete under frost exposure, as far back as the 1930s. This is an example showing that the pattern of the concrete fracture can give an important information explaining the causes of the material degradation, and this may be the grounds for the conclusion about the need for and ways to increase its durability.

The article gives the results of concrete condition assessment by external signs, which are an integral part of the planned further studies of durability of the concrete under the frost exposure. At the stage of the preliminary examination, it is important to collect all possible information about the operating conditions of the structures, their manufacturing technology, design requirements for the structures and actual concrete quality indexes at the start-up and during operation [8]. This information determines the degree of objectivity of the conclusions drawn and the relevance of recommendations that can be developed to improve the technology of the concreting operations.

In the area of variable water level of offshore facilities, as a rule, the severity of external exposures is assessed by the freezing temperature and the number of freeze-thaw cycles. Of the wide range of processes occurring during the freezing [5], the process of repeated freezing and thawing of the concrete in the area of variable water level of port facilities is considered to be the main factor of the severity of external exposures.

This article presents the results of surveys of three representative types of port structures operating in the southern coast of Sakhalin:
- massive structures of berthing facilities,
- protective structures,
- monolithic reinforced concrete structures of the embankment.

The structural elements of the facilities were selected due to the difference in the processes of the concrete freezing in these facilities.

3. Operating conditions for port facilities on sakhalin
Sakhalin's climate is unique. The southern part of the western coast of the island is washed with the Sea of Japan, and the rest of the coast is washed with the Sea of Okhotsk [11]. The latter is one of the cold subarctic seas and the coldest one among the Far Eastern seas. The simultaneous influence of the cold Sea of Okhotsk and the warm Sea of Japan is especially evident in the southern part of the island. The extreme southern part of the sea never freezes, however, there are the conditions for the icing of offshore structures there. The hydro-meteorological conditions of the southern Sakhalin are characterized by the following indicators [11]:

In winter, the sea is the roughest - an average frequency of waves is 35%-50%, the wave height reaches four to six meters.

The tides are of two main types there: diurnal tides and mixed tides. In the southern part of the island, the height of tides is 0.8-2.5 meters.

In winter, the water temperature on the sea surface is about 0°C.
Salinity of water on the surface is 31‰ -33‰.
The usual wind speed is 10-11 meter/second.
The estimated winter temperature of the outside air ranges from -17°C to -19 °C [7].
The southern coast of Sakhalin is an area with severe hydro-meteorological operating conditions [6], the aggressiveness of the environment for concrete structures at the area of variable water level comes under class XF4 [7].

4. Findings and discussion
Berth concrete structures and protective facilities in the area of variable water level are subjected to freeze-thaw cycles and the icing in winter. Figures 1 - 3 show the typical operating conditions for the concrete in the variable water level area. It can be seen that there are two characteristic sections - a section of the tidal motion and a section of the wave splash - in the area of variable water level.

In the section of the tidal motion, the freezing of the concrete occurs in air during the low tide, and the thawing occurs in water during the high tide. An ice layer does not appear on the concrete surface (Fig. 2, b, c) in this section.

Since in winter the height of waves near the structures reaches four to six meters, a layer of ice appears on vertical and horizontal surfaces and remains there during the coldest winter months. Based on the existing working hypotheses about the mechanisms of the concrete destruction under the frost exposure [13], these two sections of the variable water level area may have different concrete destruction mechanisms. To classify the types of destruction and further explain the causes of destruction in the area of variable water level, it is reasonable to specify two sections: a section of the tidal motion and a section of the wave splash.

Example 1. Offshore hydraulic structures on Sakhalin Island have been under intensive construction since the 1930s. Many structures built at that time are still in operation. Among them are the piers of the Korsakov seaport in the south of Sakhalin Island (Fig. 1).

Figure 1. General view of the pier structures (built in 1930) in the area of variable water level, which have been in operation for 90 years; winter operating conditions of southern structures (a) and northern ones (b) (01/25/21).

The main structural elements of the facility are prefabricated units – concrete caissons, which were made in dry conditions at the casting yard, and then were lowered into the water by a slip, transported afloat to the construction site for subsequent sinking through flooding. A caisson is a hollow cellular structure with plan dimensions 5m x 6m and 7m high. The authors have no data on the concreting operation technology, which was used to make the caissons. However, they believe that the regular
(classic) concrete was used without structure-forming agents with a long hardening period in natural conditions. The latter is due to the need to have the high strength concrete for transportation of the structure and its installation in the pier site. The concrete operating conditions in winter can differ significantly in the height of the variable water level area and in the location of structures in the facility. In the area of tidal motion, a slow one-sided freezing of the caisson concrete occurs at the low tide with a gradual moving of the freezing front into the depth of the concrete. The surface area is covered with a layer of ice due to the splash of waves, which persists during the three coldest winter months (December, January, February), on structures facing north (Fig. 1, b). The ice layer on structures, the front surfaces of which are facing south (Fig. 1, a), periodically disappears under the influence of sunlight. The ice layer on the north-facing side can melt during a thawing period. The difference in freezing conditions is the following: in the first case the concrete freezing time is determined by the type of the tide and it is much shorter than the concrete freezing time for the icing area.

The survey found that after 90 years of operation, the concrete in the area of variable water level has localized damage to concrete from mechanical and frost exposures. This suggests that the regular concrete is able to provide high long-term resistance in harsh operating conditions.

**Example 2.** Protective structures made of shaped blocks (tetrapods and geksabits [reinforced concrete units of complex shape]) are usual hydraulic structures on Sakhalin (Fig. 2) built after the 1970s. The main task of these structures is to protect the water areas of the ports and the open coast from waves. The operating conditions of these structures in winter, on the one hand, are comparable to the conditions of berthing massive structures, on the other hand, they are different as the structures are much smaller in size and weight. It should be noted that only a small part of the structures of protective constructions, as a rule, is placed in the area with two well-defined sections of variable water level (Fig. 2 a). In major, the structures are located in both the area of the tidal motion and the wave splash. However, the facilities with structures, which are simultaneously exposed to the tidal motion and the icing (Fig. 2, c, d) are of interest for research.
Beginning the 1970s, the widespread use of complex agents, both air-entraining and plasticizing [9], has become a distinctive feature of the concretes used for structures of offshore constructions on Sakhalin. Neutralized air-entraining resin [CHB (SNV)] was mainly used as an air-entraining agent. Various monofunctional agents like sulfite waste liquor [CCB (SSB)], sulfite-cellulose liquor [СДБ (SDB)], technical lignosulfonate [ЛСТ (LST)], superplasticizing agent С3 (S3) and polyfunctional agents of the ПФМ-НЛК (PFM-NLK) (polyfunctional concrete modifier) type were used to plasticize the concrete mixture.

An earlier research [9] on assessing the durability of concrete structures of offshore constructions, which were in operation for 40 years, showed two characteristic types of concrete destruction in tetrapods - surface and volumetric - from the frost exposure. However, the observed destruction was detected only in 7% of the constructions. In winter, the tetrapods were factory made with heat treatment, and in summer - at the casting yard with hardening in natural conditions. The tetrapods were made of hydraulic concrete М300, Мрз300, В6 in accordance with the National Industry Standard GOST 4795-68 with the use of complex agent CHB + СДБ [neutralized air-entraining resin [(SNV)] + sulfite-cellulose liquor [(SDB)]. The air content in the concrete mixture was ensured within 3% to 6%. Tests of samples drilled out of these structures showed that the actual performance of the concrete corresponds to its design performance: the concrete strength was within 350-500 kp/cm\(^2\), the water absorption in the surface layer was up to 2.5%, the frost resistance was as much as F\(_{300}\) [9].

The overwhelming majority of tetrapods being in operation for over 40 years have not suffered from the frost exposure. The above mentioned cases of the concrete destruction are associated with violations of the production cycle of the structures manufacturing.

**Example 3.** Cast-in-place and precast concrete structures are used for construction of berthing facilities on Sakhalin. In this example, specifics of the construction of a structure made of monolithic concrete is considered (Fig. 3).

The facility was under construction from 2017 to 2019. The embankment superstructure has three characteristic structural elements: a vertical quay wall, a superstructure slab and a breakwater wall with a parapet. The reinforced concrete structures are made of in-situ concrete with design requirements - B25 F\(_{2}300\) W6. To improve the technological properties of the concrete mixture and ensure at least 4% content of the air in the concrete a complex agent П1 (P1) + CHB (SNV) was used.

After the first year of operation, all structural elements had signs of the concrete surface destruction. The most significant destruction was observed on the surface of the quay wall - the concrete layer was destroyed to the depth of 50 mm (Fig. 3 a, d). The concrete destruction of the surface layer of the slab and the breakwater wall was mainly in the form of scaling (Fig. 3 b, d).
Figure 3. General view of the embankment (built in 2018) after the first year of operation (d); the nature of concrete destruction on the horizontal (a) and vertical surfaces (b) of the variable level zone in the wave splash area (c); general view of the embankment in winter (d).

The winter operating conditions of the concrete in structures (Fig. 3, d) are characterized by a long icing period. This means that under certain conditions, the concrete in an area of the variable water level can be destroyed, when there is no exposure of repeated freeze-thaw cycles there.

These examples show that the process of the concrete freezing in different structures of the same construction can be different. To determine the causes of destruction, the concrete qualities should be carefully examined with paying attention to the used technology of concreting operations.
5. Conclusion
Severe hydro-meteorological conditions for the operation of berthing facilities on the southern coast of Sakhalin Island are most apparent in winter. Specific weather conditions caused by the influence of the cold Sea of Okhotsk and the warm Sea of Japan create, on the one hand, mild conditions for navigation - the port areas do not freeze, on the other hand, they create harsh operating conditions for the concrete: during four winter months, concrete structures of port facilities in the variable water level area are subject to different freezing conditions. A significant difference in the operating conditions of the concrete in different sections of the area of variable water level makes it possible to monitor the exposure of two of the four main classified types of the processes that occur during the freezing. The main goal of the research of the concrete resistance in natural conditions is to present an argument for designing patterns to modeling the durability of the concrete taking into account the mechanisms of the freezing and destruction of the concrete.

6. References
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