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Ensuring chemical resistance of pile foundations when they are installed in permanently and seasonally frozen soils with aggressive environments

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Abstract. The analysis of soil and groundwater chemical composition in Kazakhstan has showed that they contain soluble salts of various concentrations. Therefore, one of the problematic tasks in constructing pile foundations on seasonally frozen soils with aggressive media is not only about to ensure proper pile driving, but also to ensure their chemical resistance against soluble salts. The main factors affecting the pile foundations when driving their permanently and seasonally frozen soils have been identified. It was established that as the main factors in the technology of driving pile foundations in frozen soils are the depth of freezing soil and appropriate method of driving piles. It has been established that in many cases construction is carried out in soils with aggressive environments, which raises new challenges for ensuring the chemical resistance of pile foundations. To ensure the chemical stability of pile foundations, new chemically active additives are proposed in the form of siliceous rock - flask and thermolitic sand. The results of the studies, it has been found that the use of siliceous rock-flask in the form of a filler in the composition of cement binder and thermolithic sand increases the chemical resistance of concrete in conditions of high-intensity salt and acid aggression by almost 1.5-3 times, respectively, in comparison with concrete on quartz sand.

1. Introduction

The installation of pile foundations in the winter is one of the laborious processes of construction.

In Kazakhstan, the winter period of construction in the northern regions is up to almost six months, and in the southern regions up to 3 months. At the same time, the depth of soil freezing in the northern regions reaches up to 1.5–2 meters, and in the southern regions on average up to 1 meter. Therefore, for construction work in the winter, for the immersion of piles, preparatory work is required before the freezing soil begins. Preparatory work for driving piles includes careful planning of the construction site, preparation work for storing piles and prefabricated elements of the underground part of the building. In addition, special work is carried out to warm up and thaw the soil, to drill leader wells. In this case, the selection of a specific method of work is carried out on the basis of technical and economic calculations at the stage of development of the project of work.

The analysis of the chemical composition of soils and groundwater in Kazakhstan showed that they contain soluble salts of various concentrations. Therefore, for the construction of underground structures in the conditions of salinization of soils and groundwater, it is necessary to carry out additional technological studies to ensure resistance and corrosion protection of the foundations of buildings and structures [1].

Therefore, one of the problematic tasks in constructing pile foundations for seasonally frozen soils with aggressive media is not only to ensure proper pile driving, but also to ensure their chemical resistance against soluble salts. The analysis of construction work on driving piles in winter in frozen ground with a depth of more than 0.3 m shows that when punching a frozen layer of considerable thickness, the pile body is in some cases damaged by hammer blows.

Therefore, there is a need to thaw the soil in order to exclude damage to the protective layer of concrete when driving a pile foundation. As a rule, soil thawing is currently carried out by electric heating with special devices. At the same time, to install the electric heating apparatus, it is necessary to pre-drill holes in frozen soil. To do this, use special equipment. As a result, when immersing piles in winter, soils need to perform construction operations that increase the complexity and duration of pile work [2].

The task of designing reinforced concrete pile foundations which are resistant to sulfate and chloride environments is relevant for foundations in aggressive soils and groundwater. In addition, it is also important for bridges, offshore structures, structures of various industrial buildings. One of the ways to increase the resistance of reinforced concrete pile foundations to chloride and sulfate environment is to use new unconventional aggregates and additives in concrete, which reduce the permeability of concrete and reduce the rate of corrosion processes in aggressive environment.

In the studies of scientists [3], it is argued that concrete and reinforcement used for the manufacture of reinforced concrete foundations can be subjected to various aggressive influences of soil environment. In result, reinforced concrete material is prone to destruction over time.

Therefore, there are developed methods that to some extent prevent damage to reinforced concrete foundations.

This work describes some methods, such as: the correct choice of foundation depth, strengthening the foundations by using gravel and crushed stone, the construction of drainage systems, waterproofing and proper care of concrete hardening.

At the same time, the authors of research indicate the need for mandatory consideration of concrete exposure degree to external influences.

The paper also provides scientific information on the use of various additives providing water resistance and frost resistance.

Moreover, as an additional protection of the concrete surface, various coating chemicals can be used, such as: hydrophobic impregnation silica, epoxy resins, bituminous sealing or self-adhesive tapes, bitumen emulsions, synthetic films, and waterproofing cement mastics.

The authors of the work emphasizes that when building foundations, special attention should be put to the thickness of the protective layer of concrete, as well as the choice of reinforcement resistant to corrosion.

The issue of protecting the foundations from corrosion is especially relevant in the construction of high-rise structures, where reinforced concrete with metal structural elements are combined as load-bearing structures. The work [4] provides case studies on the study of 51 defective bases of self-supporting and guided antenna towers. Based on the research results, the main factors that influence the durability of the supports and foundations of the towers are determined. These include corrosion of parts of the tower in direct contact with the ground, insufficient detailing of the foundations of the tower and insufficient design of the concrete composition against corrosion of the foundations.

Given that virtually no access to piles during operation of the facility for inspection and repair is excluded, ensuring chemical resistance and maintaining the integrity of pile foundations is a priority at the stages of their manufacture and immersion.

Recently, for the installation of pile foundations in the conditions of permafrost and seasonal frozen soils, they began to use antifreeze chemical additives to thaw them. The use of such technology for driving piles poses new challenges for the anticorrosive protection of pile foundations not only from the aggressive environment of soils, but also from the negative impact use of antifreeze chemical additives in soils.

The analysis of the studies shows that one of the effective methods of protecting reinforced concrete driven pile foundations is to optimize the material composition of concrete components at the stage of their manufacture. In [5-6], this problem was achieved by the correct choice of the type of cement and the use of chemically active aggregates that interact with the cement matrix by one mechanism or another and grow together with it, which reduces or completely eliminates the contact zone conductivity for aggressive environmental components.

Therefore, conducting scientific and experimental research in this direction is an urgent task, since the climatic conditions of construction, the physicomechanical properties of soils, the chemical composition of groundwater, and other factors are constantly changing factors. Moreover, for each building under construction, specific actual research is necessary, taking into account the factors above.

2. Materials and methods

Silica rock-flask of the West Kazakhstan deposit was selected as the main raw material.

X-ray phase analysis (XRD) was carried out on a DRON-3 diffractometer with CuKa radiation in the range of angles 80-640. The sensitivity of the method is from 1 to 2%. Powder flasks passed through a 0.315 sieve were subjected to X-ray phase analysis.

The chemical and mineralogical composition of the studied raw materials was determined using a JSM-6390LV scanning electron microscope with an energy-dispersive microanalysis system, an X'Pert PRO MPD X-ray diffractometer, and an ICP-MS Agilent 7500cx inductively coupled plasma mass spectrometer (JEOL, Japan).

According to the results of the study, the siliceous rock, the flask of the West Kazakhstan deposit, is a light dense micro-porous rock of gray color, composed mainly of the smallest particles of opal - cristobalite silica. The content of opal - cristobalite silica is 82-87%. The particle size is less than 0.005 mm. Bulk mass is 1.2–1.4 t / m3, porosity is in the range of 35–40%. The strength of natural samples is 7.0 - 10.0 MPa.

3. Results

In order to achieve this goal, we have developed a technology for producing finely dispersed filler based on siliceous flask and artificial sand and gravel (thermolitic sand and gravel) in order to replace quartz sand in concrete [7].

To obtain sand and filler, siliceous rock - flask was first crushed using a laboratory jaw crusher DSCH 80-150. The crushed fractions were screened using a set of laboratory sieves to obtain a fraction of 0, 14 - 5.0 mm. After sieving, the fractions were subjected to high-speed firing in laboratory rotary kilns of the RSR120 / 1000/13 brand according to a specially developed regime. The maximum firing temperature was 1100 ° C. The fine fractions remaining (after sieving) (less than 0.14 mm) were milled together with Portland cement grade M 400 in a laboratory ball mill grade MShL 250x100 to a specific surface of 3000 g / cm2. The content of the siliceous flask was 25%. The resulting cement composition was used as a binder for the preparation of concrete mix. The heat-treated fractions of siliceous flask rock were used as a fine aggregate instead of sand in the concrete mix. (Figure 1)

For experimental work, a fine-grained concrete mixture was prepared in the cement system: fine aggregate in a ratio of 1: 3. From the prepared mixture, cubes with a size of 10 x 10 x 10 cm were poured. For comparative analysis, samples of concrete based on quartz sand were prepared in parallel without the addition of chemically active fillers. Samples of concrete for complete hardening were stored in a bath with a water seal for 28 days.

Studies of concrete samples to determine chemical resistance were carried out in 1% solutions of sulfuric acid (H2SO4) and salt medium (MgSO4) for 12 months.

Figure 1. General view of a chemically active filler, thermolitic sand and concrete sample based on them for a pile foundation.

As the main criterion for assessing the chemical resistance of concrete samples, the compressive strength (Rczh) was chosen, since pile foundations, as a rule, mainly absorb compressive forces.

The results of scientific and experimental studies are presented in table 1.

Table 1. Comparative analysis of the chemical resistance of concrete using active components based on siliceous flask of the West Kazakhstan deposit

Chemical environment	Chemical resistant, Rczh, MPa Quartz sand concrete		Chemical resistance, Rczh, Mpa Concrete using active ingredients	
	Test period 6 months	Test period 12 months	Test period 6 months	Test period 12 months
$MgSO_4$	29,2	26,3	40,7	42,4
H_2SO	10,4	5,6	38,2	41,1

According to the results of this work active components based on siliceous rock - flask increase the chemical resistance of concrete under conditions of high intensity salt and acid aggression by almost 1.5-3 times, respectively, compared to concrete on quartz sand.

This is due to the following factors:

- silica flake rock in its composition is mainly active silica SiO2, which is able to bind calcium hydroxide formed during cement hardening into water-insoluble calcium hydrosilicate by the reaction of Ca (OH) 2 + SiO2 = CaO • SiO2 • H2O;
- the active aggregate in the form of thermolitic sand obtained by high-temperature processing, has a crystallized sintered structure. As crystalline phases, tridymite (SiO2) albite (Na, Ca) Al (Si, Al) 3 O8,) alumina silicates (Al2 SiO5) are formed, which have high chemical resistance.
- heat-treated thermolitic sand has an increased porosity of the surface layers, which contributes to the penetration of the most dispersed fractions of the binder into the surface layers of the aggregate with the formation of additional bonds of the cement matrix. This factor provides enhanced adhesion and significantly reduces the permeability of the concrete contact layer.

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4. Conclusion

As a result of an analytical analysis of modern technologies for the construction of pile foundations in permanently and seasonally frozen soils, the main problems have been established to ensure their integrity and resistance to aggressive environments in soils;

The main factors affecting the pile foundations when driving their permanently and seasonally frozen soils have been identified. It was established that as the main factors in the technology of driving pile foundations in conditions of permanently frozen soils is the depth of freezing of the soil, the choice of the appropriate method of driving piles;

The most rational methods of driving piles in the conditions of permanently and seasonally frozen soils have been identified. In this case, one of the effective methods can be distinguished preliminary warming of the place of driving piles with heat-insulating materials and the use of antifrosty additives in soils that exclude freezing soil;

It has been established that in many cases construction is carried out in soils with aggressive environments, which raises new challenges for ensuring the chemical resistance of pile foundations;

An analytical review of ongoing research in this area has shown particular effectiveness in the use of chemically active additives in concrete for the manufacture of pile foundations;

To ensure the chemical stability of the pile foundations, new chemically active additives in the form of siliceous rock - flask and thermolitic sand based on them;

It was found that the use of siliceous rock-flask in the form of filler in the composition of cement binder and thermolithic sand based on them increases the chemical resistance of concrete in conditions of high-intensity salt and acid aggression by almost 1.5-3 times, respectively, compared to concrete on quartz sand.

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