Method of Protection of Foundations in Rammed Foundation Pits against Aggressive Groundwater and Frost Heaving

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Abstract. The article presents the results of experimental studies of strength and adhesive characteristics for coatings that protect the foundations in rammed foundation pits against aggressive groundwater or industrial water and increase the resistance of such foundations against frost heaving. The studies were carried out on model foundations in rammed foundation pits with different compositions of protective coatings.

1. Introduction
Protecting foundations from aggressive groundwater and industrial water is an important part of the design and construction of underground structures. This problem has been covered in many papers [1–12].

Practically all the papers studied the protection of foundation blocks and offered the various types of adhesive and paste waterproofing as protective measures.

However, not only the foundation blocks are exposed to corrosion due to aggressive groundwater and industrial water, but also piles and foundations in rammed pits, which are widely used in construction, are.

The solution of this problem is of particular importance to the construction conditions of the south of the Far East, where the foundations, for the most part, are composed of composite soils with a liquidity index \( J_L \) often more than 0.5. Another feature of the region’s soils is the formation of top watering, which leads to additional watering of the bases. Besides, anthropogenic waterlogging of foundations is often observed in the built-up areas. All the above-stated proves the need to develop effective ways to protect the foundations in rammed pits against groundwater and frost heaving arising in winter period.
2. Conducted research
A group of DalNIIS researchers (Yu.S. Tonkikh, N.A. Falaleeva, V.P. Reshetko and others) carried out the experimental studies to select a composition for protective coating and develop a method of its applying on the foundations made in rammed pits.

The research method was based on modeling [13, 14] a process of interaction of special compositions applied to the walls of an excavation with freshly laid concrete mixture. The researchers studied the strength and adhesive characteristics of coatings, the influence of coatings on the resistance of foundations in the rammed pits to frost heaving force and developed a recipe and method of producing polymer-silicate (slag alkaline) compositions to protect foundations in rammed pits.

Slags from the Dalnegorsk Coal Mine and waste ashes from Artem TPP were used as raw materials to produce protective compositions. To increase the crack resistance, the fine ground siftings of local rock crushing (slags and siftings mixture grinding) were introduced into the compositions made on Dalnegorsk slags, while quartz-feldspar sand and unground waste ash were added to the compositions made on Artem ashes.

When selecting the ingredients for polymer-silicate compositions, the quantity of cement, amount of dry mineral components, dosage of polymeric additive (latex, resin) and volume of sodium silicate (liquid glass) solution were varied. Protective compositions on cement were prepared for comparison with alkaline compositions.

Solution of low-module liquid glass (at l/h 0,40-0,50) and a polymer additive (dispersion) in the amount of 0,15-0,25 from the mass of dry mixture were used for mixing. Silicon fluoride sodium was introduced at the rate 15% of the liquid glass mass in terms of dry substance.

Protective compositions were kept for 28 days under normal hardening conditions and 28 days in water. The start time of the dough setting was recorded. After keeping the samples, the following characteristics were determined: the sample density \( \rho_{об} \) g/cm\(^3\), compressive strength \( R_{см} \) MPa, water resistance coefficient \( K_{в} \), water absorption \( V_{нагр}, \% \).

According to the experimental data, it was determined that the proposed polymer silicate compositions are of sufficient high strength and water-resistance. Additives of polymer dispersions slightly reduced the strength of the samples, but increased their elasticity and water resistance characteristics. Of the 14 formulated compositions, the following one (in % by mass in the dry mixture) was selected for further study: cement 15-20 %; ground ash 15-30 %; sand, non-grounded ash-and-slag mixture or stone dust (sifting) 55-65 %.

To check the adhesion of polymer-silicate layer to concrete, a series of samples was made in the form of cubes 10 * 10 * 10 cm with layer placement of materials: the bottom layer - clay (soil), the middle layer - polymer-silicate composition, the top layer - concrete.

Clay moisture was \( W \) 25%.

The polymer-silicate composition (kg/m\(^3\)) content: cement - 240, ground ash - 320, non-ground ash - 240, liquid glass (\( \text{Mc} = 1,8; \rho_p = 1,33 \text{ g/cm}^3 \)) - 360, dispersion of DE-20 resin - 88; of plastic consistency, the beginning of the setting - 16-20 minutes.

The composition of concrete (kg/m\(^3\)): cement - 370, crushed stone - 1250, sand - 625, water - 230.

The strength of adhesion \( R_{адг} \) (MPa) of the polymer-silicate composition to concrete was determined by the tensile strength at splitting [15] and was calculated by the following formula:

\[
R_{адг} = \left( \frac{P_p}{S_c} \right) * 10^{-1}
\]

Where \( P_p \) is the destructive load, kg;

\( S_c \) is the adherence surface area, cm\(^2\).

The 3-day adhesion strength of the concrete and polymer-silicate composition was 1.2 MPa, and the contact strength of the clay and polymer-silicate composition was 0.5 MPa. At the same time, the characteristic tensile strength of concrete at splitting was 2.0 MPa, of a layer of a polymer-silicate composition — 0.6 MPa, and of a layer of clay — 0.1 MPa.

In 7 days, these values were as follows: the adhesion strength of the concrete - polymer-silicate composition 1.4 MPa, the contact strength of the clay - polymer-silicate composition — 0.3 MPa, the...
characteristic tensile strength of concrete at splitting 4.0 MPa, of a layer of a polymer-silicate composition — 0.9 MPa, and of clay layer - 0.1 MPa.

Upon subsequent hardening, the clay layer cracked and moved away from the layer of the polymer-silicate composition. The adhesion of concrete with a protective layer remained stable and without damage through all the tests.

To compare the corrosion resistance of cement and alkaline compositions, samples of two compositions were made in the form of cubes 10*10*10 cm. The first composition included cement, ground ash, sand, crushed stone siftings at the consumption of cement 490 kG/m³ in cement composition, mixed with water. The second composition included cement, ground ash, sand, crushed stone siftings at the consumption of cement 200 kG/m³ in alkaline composition, mixed with low-modulus liquid glass solution (Mc = 1.8; ρρ = 1,35 g/cm³). The consistency of the composed fine-grained mixtures was plastic; vibration resistance accounted to 5-15 seconds.

The samples were placed for testing in different conditions: “normal hardening”, air-dry condition, fresh water, sea water, 5% sodium sulfate solution and variable humidity condition (1 cycle - 16 hours in water and 8 hours in the open air at temperature of 60-70°C).

The experimental data showed that alkaline compositions lagged behind cement ones in terms of intensity of strength gain by 28 days. However, at the subsequent hardening, regardless of the external environment, there was an intensive set of strength of alkaline compositions there. Moreover, the greatest increase in strength of alkaline compositions was observed just in aggressively active environment - in sea water, sodium sulfate and water, which confirmed the expediency of the studies.

Comparison of the characteristics of cement and alkaline compositions showed a higher efficiency of the latter in aggressively active environment.

Comparison of protective polymer-silicate compositions with a control protective composition based on cement showed that the compositions did not give cracks and had good adhesion to concrete, while the cement composition had deep cracks and did not give adhesion to concrete.

The research of protective compositions was carried out simultaneously with the development of the technology of protective coatings [16].

To assess the technical condition of the protective coating after the deformation of the soil massif from the operating load, a test was carried out on the model of a foundation in a 1/3 scale pit of a full-scale rammed pit.

The research was carried out in a large earthen tray with dimensions of 4.0 * 7.0 * 5.0 m.

The soil in the tray was the normally compacted bulk clay with the following characteristics: dry soil density ρρd = 15.1 kN/m³, humidity W = 25%, porosity coefficient e = 0.71, specific cohesion C = 0.025 MPa, angle of internal friction φ = 21°, modulus of deformation E = 16 MPa, coefficient of water saturation Sr = 0.85-0.95.

The pits for the foundation models were rammed out with a mobile experimental unit according to the technology [17].

A layer of protective coating with the thickness of 1.0-1.5 mm was manually applied to the walls of foundation pits15 minutes prior to laying concrete. Its composition (in mass % was as follows): cement - 15-20, ground ash - 15-30, unground ash - 55-65, liquid glass (Mc = 1.8 = ρρ 1,32-1,35 g/cm³).

After the 30-day long hardening of the concrete mixture under normal conditions, the foundation models were tested with a pressing load in accordance with [18]. Under the load of 175 kN on the foundation, the 38.6 mm settlement was recorded.

After removal of the load, the tested foundations were excavated and inspected. The inspection showed that the entire lateral surface of the foundations was uniformly covered with a durable protective layer of polymer-silicate composition. The protective coating had no cracks or breaks.

Stability of natural foundations in rammed pits without any load under conditions of frost heaving of clay soils was checked at a kindergarten construction site in the city of Khabarovsk. In October, the foundation construction was stopped and the majority of the finished foundations were in an unloaded
condition. In the winter, levelling observations were made to monitor the shifting motion of the foundations heads during the soil freezing.

The researchers monitored the shifting motion of two control foundations in the rammed pits without protective coating and two foundations with a protective polymer-silicate composition. Vertical shift of the foundations began in the third decade of November, when the soils had frozen to a depth of 80 cm.

The control foundations were raised by frost heaving forces by 30 and 36 mm. After the soil thawing, they lowered by 14 and 15 mm. The residual deformations accounted to 16 and 21 mm. The foundations with the protective polymer-silicate composition raised by 5 and 10 mm, and during soil thawing, they lowered to almost original position.

3. Conclusion
Thus, the research gave the results as follows:

1. The proposed polymer-silicate compositions have high enough strength, water resistance, good adhesion to concrete, they are sufficiently plastic and have no cracks.
2. The comparison of compositions on cement and liquid glass showed a higher efficiency of the latter with respect to aggressive environment.
3. To ensure high adhesion to concrete, polymer-silicate coatings must be applied to the soil immediately before placing concrete into the foundation body.
4. The coatings made of the proposed polymer-silicate composition provide reliable protection of the base body working under load in aggressive environments.
5. Polymer-silicate composition coatings reduce the effect of frost heaving forces on foundations in rammed pits.

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