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Cast-in-situ piles encasements based on oil-bituminous rocks (kirs) in saline soils

Key words: corrosion, foundation, protective shell (encasement), mastic

Introduction

The SN RK 2.01-01-2013 standard (Komitet tekhnicheskogo regulirovaniya i metrologii Ministerstva torgovli i integratsii Respubliki Kazakhstan [KTRM MIR RK], 2013) regulate anti-corrosion protection of piles in aggressive soils with optimally viscous and maintaining continuity materials (bitumen, polymer materials, petrolatum, fuel oil). The use of these recommendations is hampered by the inevitable decreasing of the bearing capacity of the pile along its lateral surface when arranging the coating. So, for example, when coating with bitumen piles immersed to the depth of 13.3–22.7 m, their bearing capacity decreases from 30 to 80% de-

pending on fluctuations in soil and the air temperature. In addition, over time, bitumen so-called aging is observed, which is accompanied by delamination, crumbling and loss of the coating waterproofing (Ongarbayev, Imanbayev, Tileuberdi, Krivtsov & Golovko, 2019).

The specifics of manufacturing cast-in-situ and bored pile foundations using traditional technologies makes it difficult to solve the issues of their anti-corrosion protection, because in the course of arranging it is difficult to maintain the continuity of the coating and concrete of the structure or sufficient density of concrete and the integrity of the film protection along the barrel of the cast-in-situ bored pile.

The construction of buildings and structures (BS) on territories composed of saline silty-clayey soils (SSCS) (Imanbayev et al., 2017; Tileuberdi, Akkazy, Ongarbayev, Imanbayev & Mansurov,

2018), in accordance with the current regulatory and legislative framework, is accompanied by inevitable increasing the costs by 5–25%, which are dictated by the danger of SSCS manifestation and the absence of reliable and effective constructive-technological solutions (CTS) within the framework of construction and operation of the geotechnical system “base–foundation–structure” (BFS) in changing conditions under the impact of natural and man-made factors. Consequently, construction and operation of the gas station on SSCS is not provided with a proper quality. This is confirmed by the numerous emergency subsidence of BS on SSCS in the cities of Yerevan, Volgodonsk, Novy Uzen, Zhezkazgan, Balkhash, Karaganda, etc. The expenses for restoration, repair and reinforcement of emergency facilities are often 1.5–2 times higher than the initial estimated cost of construction.

To increase the bearing capacity and durability of the pile foundation in SSCS, there were developed a number of new geotechnologies based on combining well-known but fundamentally different approaches to solving the problem (Fig. 1), namely:

- formation of a protective and supporting shell (encasement) around the pile (Zaharov, 1999; Unaibayev & Zhussupbekova, 2001; Unaibayev, Arsenin & Unbayev, 2018; Unaibayev & Unbayev, 2018);
- compaction or consolidation of saline soil around the pile in order to increase its strength and deformation characteristics, structural and suffusion resistance, water resistance, etc. (Gimmerling, 1986; Komitet po delam stroitel'stva, zhilishchno-kommunal'nogo khozyaystva i upravleniya zemel'nymi resursami Ministerstva national'noy ekonomiki Respubliki Kazakhstan [KDSiZhKKh MNE RK], 2011);
- increasing the density and corrosion resistance of the pile structure concrete by means of using modified additives in concrete, etc. (Gavshin & Dzehtser, 1982; Unaibayev & Unbayev, 2019).

The proposed CTS, in addition to increasing the bearing capacity and corrosion resistance of the pile foundation on SSCS, are also relatively economical solutions, since they suggest the use of substandard materials (kirs, natural bitumen, fly ash, etc.).

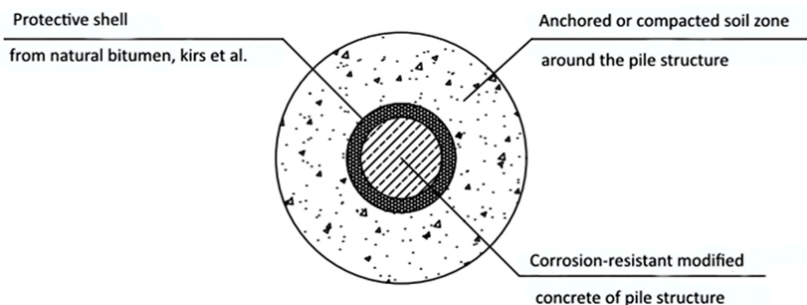
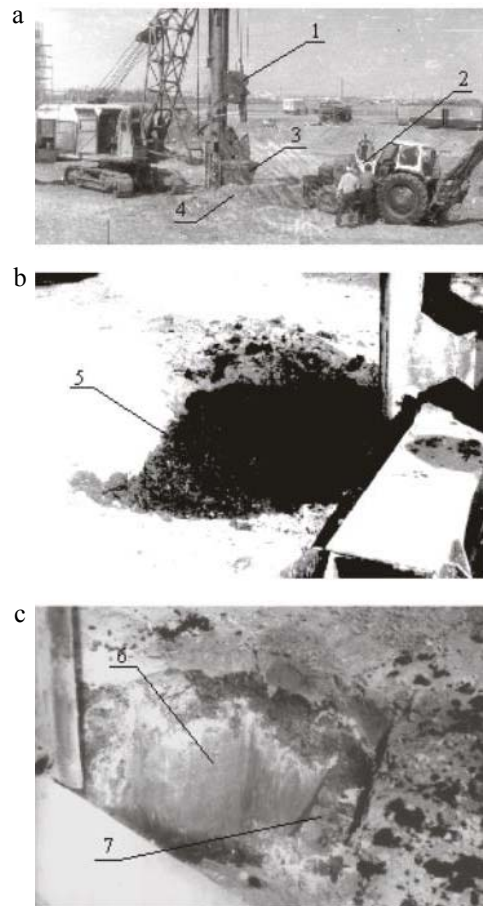


FIGURE 1. Working hypothesis for solving the problem of increasing the bearing capacity and durability of the pile in SSCS

Methods

It seems efficient to arrange a protective and load-bearing shell for cast-in-situ piles in punched and drilled wells and foundations in rammed pits (Figs. 2 and 3). So when driving a well or foundation pit by periodically dropping the dredge, in contrast to drilling a well with an auger, soil compaction is observed around the structure. Compaction leads to improving the physical and mechanical properties of the soil, and consequently to increasing the bearing capacity of the foundation. In this case, water permeability of the compacted soil layer around the structure, depending on the type of compacted soil, decreases tens and hundreds times.

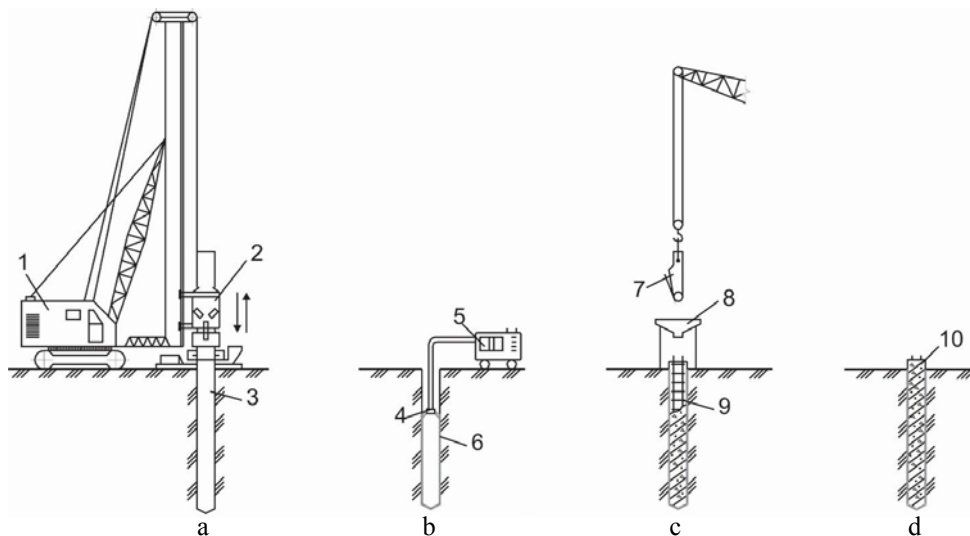
It should be noted that when arranging a bored pile, soil compaction around the structure does not occur; at best, its natural structure is preserved, and at worst, if the technology is violated, the filtration and mechanical properties of the soil around the pile deteriorate, because during “dry” drilling or construction widening, loosened soil crumbles into the well face. In this case, in the well face and therefore, under the bored pile a highly compressible soil layer with increased permeability is formed, which leads to decreasing the bearing capacity of the foundation. It seems efficient the proposed formation of a protective shell of the foundation in the rammed foundation pit and a punched hole by additional ramming into the walls and base of the punched hole or foundation pit of waterproof and corrosion-resistant materials (kirs) or applying heated natural bitumen to their surface by spraying for additional protection of the structure



1 – OVK-2 equipment in combination with EO-2621; 2 – loader based on MTZ-80; 3 – rammer; 4 – crushed stone; 5 – kirs; 6 – rammed foundation pit; 7 – the protective shell made of kirs

FIGURE 2. Fragment of testing the technology of arranging a foundation structure with a protective and supporting shell made of kirs in SSCS of the Kulsary urban-type settlement, microdistrict 3: a – general view of the work production; b – filling the rammed pit with kirs; c – a type of the protective shell

from corrosion (Figs. 2 and 3). In this case, after placing and shaping the concrete, the protective coating turns out to be hermetically packed between the reinforced concrete monolithic foundation



1 – pile driver; 2 – tip; 3 – dredge; 4 – nozzle; 5 – unit for applying bitumen mastic; 6 – protective shell; 7 – vibratory tub; 8 – receiving funnel; 9 – reinforcing cage; 10 – pile

FIGURE 3. Technological diagram of the arranging cast-in-situ piles in drilled wells with the use of a protective shell made of natural bitumen to the well walls: a – immersion and extraction of the dredge; b – applying natural bitumen mastic to the borehole walls; c – reinforcing and concreting the well; d – finished pile

structure and the dense waterproof layer of soil around it compacted by ramming. The latter contributes to the continuity, long-term preservation and durability of the protective coating and consequently, durability and corrosion resistance of the concrete foundation structure.

Protection of a pile foundation structure in contact with an aggressive water-salt soil environment (AWSSE) in the base made of SSCS, by using for this purpose various corrosion-resistant coatings and materials made on the basis of substandard oil-bituminous rocks and natural bitumen extracted from it, significantly reduces the material consumption. The use of natural bitumen as a coating, which in comparison with industrial bitumen has a higher chemical resistance, adhesion value, low cost

and non-scarcity, as well as good adhesion, penetrating ability, etc., can significantly increase the structure durability (Mahsimov, 1986). The technology of extracting bitumen from kirs and technical specifications for the use of kirs for construction purposes were tested by us in industrial conditions and proved to be positive (Ahmetov & Zhurikov, 1988).

Experiments on the extraction of natural bitumen from kirs for construction purposes were carried out with oil-bituminous rocks: kirs from the Munayly-Mola field of the Atyrau region in Kazakhstan with the organic content of 14–22%. The mineral part of the kirs is mainly represented by fine-grained sand with the fraction of 0.1–0.25 mm. The initial raw materials (kirs) were ground in an aqueous medium, and the concen-

tration of the pulp with modifiers and flotation of the organic component was carried out at an elevated temperature. Grinding the feedstock was carried out by mixing the pulp in a Na_2CO_3 solution at an elevated temperature.

In contrast to the traditional technologies of grinding kirs based on impact, compression, rupture or cutting, there was used the ability of kirs in aqueous salt solutions to self-grind or disintegrate into small pieces at elevated temperatures. This process is especially intense with stirring in aqueous solutions of salts. The experiment has shown that in solutions the self-grinding of kirs proceeds 5–6 times more intensely than in water, and the grinding speed increases with the increased concentration.

The process is carried out as follows. Oil-bituminous rock and Na_2CO_3 are loaded into the pneumo-mechanical laboratory flotation machine with the chamber capacity of 1.0 l, filled with water in the required proportions at an appropriate temperature and mixed within 20–30 min; the organic component of kirs (natural bitumen) is floated. The process is controlled by the organic matter content in the sands (tailings) and in the organic component (bitumen concentrate), which is determined by the combustion method after drying the samples at the constant temperature of 85°C.

The resulting natural bitumen was used to prepare a bitumen emulsion paste. Mastics are a mixture of bitumen emulsion pastes with mineral powdered fillers and various additives. Thus, a bitumen paste serves as the main component of the protective composition manufactured at the factory. The mastic

itself is prepared at the construction site immediately before its application.

Bitumen emulsion pastes consist of the main organic binder, natural bitumen, an emulsifier, a finely dispersed mineral powder and various additives to water as a dispersed medium in which natural bitumen is dispersed. To prepare a bitumen paste, a laboratory paddle mixer is used.

At first, the emulsifier suspension heated to 80–90°C is loaded into the paste-mixer, and then natural bitumen and water are alternately fed: at first natural bitumen until the mixture thickens, and then water to liquefy it, and so gradually there is introduced the estimated amount of bitumen and water. Bitumen should be evaporated or dehydrated, cleaned of dirt and debris and heated to the operating temperature of 150–160°C. Quicklime, screening from the Temirtau Electrometallurgical Plant and carbide powder lime, waste of the same plant were used as emulsifiers. Before use, the quicklime lump was slaked into powder lime.

The compositions of bitumen pastes based on this lime do not meet the requirements to bitumen pastes for waterproofing purposes, namely, the pastes are not stable and quickly exfoliate, there is no complete emulsification of bitumen. In lump quicklime there are many impurities in the form of unquenched grains, clay inclusions, etc. To obtain high-quality bituminous pastes based on such lime, additional processing of lime is needed, increasing its dispersion by additional grinding, vibration grinding, or introducing additives of highly plastic clays. All these activities require additional costs, so we refused working with this emulsifier. Another emulsifier

used in the work was carbide fluff lime, waste of the Temirtau Electrometallurgical Plant JSC.

When selecting the compositions of bitumen pastes based on natural bitumen, the known paste compositions that are widely used in practice were taken as the base. Since we used waste as an emulsifier, we had to adjust the compositions of bitumen pastes. The results of this work are shown in Table 1.

Table 1 shows that the most high-quality bitumen paste based on natural bitumen is composition number 7. Since the paste of composition number 7 is stable, homogeneous, does not delaminate. Carbide powder lime is the waste that has some impurities, the activity of lime does not exceed 70% therefore, to obtain a stable paste and to increase the bitumen content in the paste, the emulsifier is taken in a larger amount than is needed theoretically.

In the future, the optimal composition of the paste will be marked as follows: BL-42 (bitumen–lime paste with the 42% content of natural bitumen.

BL-42 lime–bitumen paste has the following characteristics:

- cone mobility according to Stroy-CNIL – 13–15 cm;
- the paste density – $1.42 \text{ g}\cdot\text{cm}^{-3}$;
- the ability to dilute with water – 10 times the amount;
- water absorption of dried paste – 5–7%;
- swelling of the dried paste by volume – 3–5% by weight.

Cold bitumen mastics prepared by mixing bitumen paste with fillers are recommended for applying to the surface of punched and drilled wells for piles, coating strip prefabricated foundations and grillage on pile heads. Lime powder was used as fillers, fly ash of KarGRES-1, Portland cement M-400.

The method of selecting the compositions of cold asphalt mastics was as follows. First, the composition of the bitumen paste was selected, on which base the mastic was prepared. The finished mastic in the liquid and solidified form was tested according to the known technique.

TABLE 1. Characteristics of the bitumen pastes compositions based on natural bitumen

| Composition | Natural bitument [%] | Powder lime [%] | Water [%] | Note |
|-------------|----------------------|-----------------|-----------|--|
| 1 | 45 | 12 | 43 | Water separation 1 h after preparation |
| 2 | 48 | 15 | 37 | Delamination of the paste, not all bitumen has been emulsified |
| 3 | 50 | 16 | 34 | Coagulation of bitumen has occurred |
| 4 | 48 | 18 | 34 | Partial delamination |
| 5 | 40 | 20 | 40 | Water separation |
| 6 | 35 | 25 | 40 | Water separation |
| 7 | 42 | 24 | 34 | The paste is stable, homogeneous, does not delaminate |
| 8 | 40 | 25 | 35 | Partial delamination |

In the liquid state cold asphalt mastics are tested like bituminous pastes: their density, cone mobility according to the StroyCNIL, and heterogeneity are determined. However, when selecting the composition of the mastic, it is necessary to test them additionally for stability during storage. In the plastic state for cold asphalt mastics the bulk density, porosity, water absorption and swelling are determined. In addition, when selecting the composition of the mastic, the samples dried to constant weight at 40°C within 5 days were subjected to all the above tests.

For these samples, water resistance is determined when they are kept in water within 30 days. Finally, by monitoring the composition of the cold asphalt mastic coating, its moisture and bitumen content are determined.

The bulk density of cold asphalt mastics is determined on samples 5 × 5 cm in size and 1–1.5 cm thick by weighing in air and water.

Determining the bulk density is the main method of the laboratory quality control of the finished coatings, mastic composition and coating density. Water absorption of cold asphalt mastic samples is determined in the accelerated way by saturating them with water during evacuation or keeping the samples in water within 15 days with the constant increasing of the water level within the first three days by one third of the sample per day.

Water resistance of mastics is determined only by a control test when selecting the composition of the mastic. The tests are carried out on standard instruments for determining water resistance of concrete. On the basis of the obtained

BL-42 lime–bitumen paste, the compositions of mastics with various types of fillers were selected.

The already known compositions of waterproofing mastics were taken as a base. Mastics based on lime–bitumen paste and II-20 lime filler have a dense structure after drying and stabilization. Testing the mastics has shown that their properties are not inferior to the mastics already used in construction practice.

To increase mechanical strength of the mastic, Portland cement M-400 and fly ash were introduced into its composition. The compositions of mastics IIC-20, IZ-20, IZC-20, IIC-25 were obtained.

Stabilization of mastics with Portland cement occurs faster due to the reaction of cement hydration with water that is a part of the bitumen paste. Indeed, these mastics with two binders, organic and hydraulic, are characterized by increased strength and elastic brittle properties.

Results and discussion

The results of experiments on extraction of natural bitumen from kirs indicate that in an aqueous medium without the addition of Na₂CO₃, the oil-bituminous rock separation into organic and mineral components is low in terms of the quality of the product being reduced. The optimal technological parameters were obtained experimentally and are as follows: the concentration of Na₂CO₃ is 7–10 g·l⁻¹, the stirring time is 20–30 min, the temperature with stirring is 80–85°C, the flotation time is 5 min. The ratio of solid to liquid is 1 : 20. It is undesirable to increase the time for more than 30 min, since the indicators of the qual-

ity of the extracted product do not improve, and increasing the time leads to decreasing the productivity of the process as a whole.

The improved protective properties of cold bitumen compositions based on natural bitumen extracted by the proposed method, when compared with compositions based on industrial bitumen, are explained by the fact that no paraffin was found in these bitumen, which is known to reduce the adhesion properties of the protective coating.

Due to the fact that bitumen mastics are the simplest and most effective traditional means of protecting reinforced concrete structures against corrosion in soils, one of the cold asphalt mastics proposed is a mixture of bitumen mastic based on natural bitumen with mineral powder fillers. Cold asphalt mastics fundamentally differ in their properties from traditional hot asphalts in that after preparing they have increased water absorption compared to the original bitumen or hot asphalt mastics. Long-term tests of bitumen mastics based on natural bitumen indicate that in these mastics the process of water absorption gradually fades over time, and after two to three years of operation these mastics become more waterproof than traditional mastics based on industrial bitumen.

Cold asphalt mastics based on natural bitumen due to good waterproofing properties, such as resistance to water, heat, frost, weather and corrosion, as well as sufficiently high strength under static and dynamic loads, reliable adhesion to concrete can be recommended for anticorrosive protection of concrete, building structures in the conditions of SSCS leaching, marine, sulfate, magne-

sian, carbonic and alkaline aggressiveness of water-environment, as well as for anti-corrosion protection of overhead metal structures.

The compositions of the obtained cold asphalt mastics and their main characteristics are shown in Table 2. The compositions of cold mastics were selected by the method of mathematical planning of the experiment.

Waterproofing coatings made of mastic based on natural bitumen were tested, applied by spraying onto the walls of drilled wells and rammed pits (Fig. 1) as the secondary protection of cast-in-situ piles in punched and drilled wells and foundations in rammed pits from the aggressive effects of saline soils and saline waters in Atyrau and Kulsary urban-type settlement.

The following composition of cold bitumen mastic is recommended, in percentage by weight:

- natural bitumen – 40%;
- powder lime – 12%;
- asbestos, VI–VII grade – 8%;
- solar (diesel) – 40%.

The efficiency of the developed CTSs is confirmed by technical and economic calculations and experimental and industrial testing. However, the main criterion that determines the efficiency of the proposed CTSs is reducing the subsequent operating costs. Post-construction subsidence of BSs on traditional prefabricated strip foundations and driven piles without a protective shell exceed the subsidence of similar buildings on foundations and piles with a protective shell. This is due to the fact that BSs on strip foundations are not protected from suffusion and deformation processes and therefore, during operation, they require

TABLE 2. Compositions of cold asphalt mastics (based on natural bitumen extracted from kirs) and their main characteristics

| Mastic type | Mastic composition in percent by weight | Density [g·m ⁻³] | Residual moisture [%] | Water absorption [%] | Swelling [%] |
|-------------|--|------------------------------|-----------------------|----------------------|--------------|
| II-20 | Lime-bitumen paste BI-42 – 80 Limestone powder – 20 | 1.38 | 7.0 | 6.0 | 0.5 |
| IIC-20 | Lime-bitumen paste BI-42 – 70 Limestone powder – 20 Portland cement M400 – 10 | 1.4 | 5.0 | 3.3 | 1.1 |
| IZ-20 | Lime-bitumen paste BI-42 – 80 Fly ash – 20 | 1.1 | 4.0 | 10.0 | 2.5 |
| IZC-20 | Lime-bitumen paste BI-42 – 75 Fly ash – 15 Portland cement M400 – 10 Water (over 100%) – 5 | 1.3 | 6.0 | 8.0 | 0.6 |
| IIC-25 | Lime-bitumen paste BI-42 – 55 Limestone powder – 20 Portland cement M400 – 25 Water (over 100%) – 5 | 1.5 | 7.0 | 5.0 | 0.5 |

annual post-construction repairs. When using foundations and piles in punched and drilled wells with a protective and bearing shell, BSs do not practically undergo post-construction subsidence. This is evidenced by many years of experience in construction and operation of BSs on foundations and piles with a protective and load-bearing shell in Karaganda, Atyrau, Aktobe, Temirtau, Kulsary urban-type settlement, Tengiz and others.

The proposed list of technologically advanced (Figs. 1, 2 and 3) that have passed approbation in the industrial conditions allows reliable and efficient erecting BSs in the territories formed by SSCS.

Conclusions

1. A comprehensive technology of arranging foundations and piles in drilled wells in SSCS with a protective and

bearing shell based on natural bitumen-containing materials has been proposed, which makes it possible to increase the durability and bearing capacity of the foundation structure.

2. A method of extracting natural bitumen from kirs has been developed. The use of this method makes it possible to exclude the difficult operation of mechanical grinding the feedstock, which is expensive and energy-intensive, as well as to reduce the reagents consumption and to improve the quality of the extracted natural bitumen. The copyright, the novelty and efficiency of the technology are confirmed by A.C. No 16867550 dated 24 November 1988.

3. The compositions of cold mastics based on natural bitumen with the addition of industrial waste have been developed. The compositions of the obtained mastics based on natural bitumen are not inferior in their properties to the known

compositions of waterproofing cold mastics based on industrial bitumen, and the use of waste reduces their cost.

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Summary

Cast-in-situ piles encasements based on oil-bituminous rocks (kirs) in saline soils. A technology of building a pile foundation in saline soils with a protective and load-bearing shell based on bituminous rocks (kirs) is proposed that makes it possible to eliminate water permeability, to increase suffusion resistance and bearing capacity of the soil, as well as durability. The method of extracting natural bitumen from bituminous rocks (kirs) is based on the ability of kirs to self-grind or disintegrate into small parts at elevated temperatures in aqueous salt solutions. The proposed method excludes mechanical grinding and allows reducing the consumption of reagents and improving the quality of extracted natural bitumen. The compositions of the obtained mastics based on natural bitumen are not inferior in their properties to the known compositions of waterproofing cold mastics based on industrial bitumen at a lower cost.

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