Corrosion of Valves in Precast Piles

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Abstract. The article presents the results of experimental studies of the influence of dynamic stresses, similar in their parameters to those occurring during pile driving, on the degree of violation of the structure of concrete and the subsequent corrosion of the reinforcement. The experimental samples were subjected to dynamic effects with the help of a special laboratory unit, followed by the control of the degree of micro-destruction by ultrasonic and resonance methods. After repeated cyclic effects, the samples were installed in a semi-compressed state in solutions of different salinity and, according to potentiostatic measurements, monitored the state of the reinforcement. After a certain period (from 20 to 180 days), the samples destroyed and further assessed the condition of the reinforcement in terms of area and depth of corrosion. During the experiments, the parameters of dynamic pulses, salinity of the solution and the type of concrete were changed within a wide range. Based on the results of the performed experiments, graphical dependences of the influence of the studied factors on the corrosion process of the reinforcement are constructed, their significance is determined and the main conclusions are formulated, which allow to make the necessary technical decisions to ensure the safety of the reinforcement in piles under different operating conditions.

1. Introduction
Corrosion of reinforcement is most often manifested in reinforced concrete structures operating in the area of aggressive environment [1, 2, 3, 4]. This is, first of all, the zone of variable water horizon of marine hydraulic structures, as well as the zone of intersection of the structure with the surface of saline soil. These zones are characterized by the possibility of simultaneous penetration of the liquid aggressive medium and air oxygen components to the valve [5, 6, 7]. Most often it is prismatic piles or piles-shells of sea berths. Durability of piles in the zone of variable horizon is determined primarily by the type of concrete [8, 9, 10], the use of corrosion inhibitors [11], as well as the thickness of the protective layer of concrete. In areas affected by negative temperatures, the concrete must also meet the necessary requirements for frost resistance.

Long-term experience of operation of sea pile berths and the performed researches [12, 13] show that corrosion of armature often begins almost immediately after pile driving. This is accompanied by cracks along the reinforcing bars and layers of the protective layer in the areas of corrosion. Forced repair of such structures is carried out in difficult, often cramped conditions that require the use of divers and special boats at significant labor costs. The cost of repair is sometimes 30-40% of the cost of manufacturing and installation of the structural element.
2. Relevance of the topic
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3. Theoretical part
Studies carried out earlier in TsNIIS [14] showed that as a result of the action of dynamic stresses during piling in concrete micro cracks are formed, which increase the permeability of concrete and contribute to reducing its frost resistance. On the basis of the results obtained in the SNIP was made to the requirement to limit dynamic pressure to a value of \( \sigma = 0.7 \) and \( R^* \), and the method of calculation of dynamic stress [15], which was presented in the manual to SNiP 3.02.01. However, the studies performed were not reflected in the performance of piling works in industrial and civil construction and were used only in the construction of berths in the Barents and Okhotsk seas.

The calculations of the values of dynamic stresses acting in piles with the use of modern hammers show that these values remain close to the limit of the strength of concrete and the destruction of pile heads when hammered occurs on a significant number of construction projects. The performed ultrasonic measurements before and after piles immersion [16] show that concrete piles in most cases receive significant micro-failures, which accelerate the destruction of concrete under the action of alternating freezing and thawing and contribute to the subsequent corrosion of the reinforcement. [17, 18, 19.]

Leading firms of foreign countries (USA, Germany, Japan, etc.) involved in the design and manufacture of pile work, the selection of piling equipment mandatory to determine the value of the maximum dynamic stresses resulting from the immersion of the pile (the method of Smith [20]), to prevent damage to the piles during the dive.

To explore the impact of dynamic effects on subsequent preservation of rebar in concrete the experimental work carried out using laboratory installation, allowing to create in experimental models of shock pulses from the control of their main parameters. Micro-failures resulting from dynamic actions were evaluated by measuring the dynamic modulus of elasticity of samples by resonance method and ultrasonic measurements. After dynamic effects, the samples were placed in seawater (half-sunk condition) and potentiostatic measurements monitored the change of state of the valve. After a certain period (from 20 to 180 days), samples were extracted from seawater, destroyed and further assessed the condition of the reinforcement in terms of area and depth of corrosion.

* \( R^* \)-prismatic strength of concrete.

4. Problem statement
The program of experiments was compiled on the basis of mathematical planning methods. As the main factors of influence adopted: the value of the maximum dynamic compressive stress arising from the pile driving; number of dynamic effects and the salinity of the water in which was placed the samples after dynamic effects.

The following variation limits are set for the three selected factors:
- the maximum voltage \( \sigma \) - from 0.3 to 0.7 \( R \). It can be expected that the value of the factor beyond the lower limit will be negligible. The upper limit corresponds, approximately, to the level of stress at which there are visible damage at the top of the piles PRN their immersion.
- the number of dynamic effects – from 250 to 750-approximately covers the actual range of the number of beats in the piles;
- salinity of water - from 0 to 8%.

With a minimum number of experiments with different combinations of factors equal to 17, three twin samples were produced for each of 17 cases. For the construction of "zero points" control
samples were provided, tested in solutions of different salinity without the application of dynamic effects. A batch of prototypes manufactured from the same batch, was 66 pieces. All were tested by three batches of concrete of different compositions the total number of 200 pieces.

For the manufacture of prototypes used Portland cement M400, Belgorod plant, quartz sand with a fineness modulus of 2.3, crushed granite being delivered, the fraction of 3 – 5 mm concrete mix 1:1:2.5 At/C = 0.4 – 0.45. The composition of the first batch did not contain additives; the second – superplasticizer s-3 additive; the third – corrosion inhibitor NaNO2. Reinforcement steel of a-600 class was used for reinforcement of samples. The concrete mixture was compacted on a standard vibration platform and after 2 hours of exposure steamed mode 4+8+4 at 60°C. After steaming the samples were stored in normal-humid conditions for at least 30 days.

5. The results of experimental studies
Before and after the dynamic load application, the dynamic modulus (e) was measured in all samples and the strength was determined from the twin sample tests. The measurement results are shown in figures 1 and 2 *

**Figure 1.** Dependence of the value of reduction of the dynamic modulus of elasticity on σ.
1 – n = 250 pulses; 2 – n = 500 pulses; 3-n = 750 pulses.

**Figure 2.** Dependence of the value of reduction of the dynamic modulus of elasticity on the number of dynamic effects.
1-σ = 0,3 R; 2-σ = 0,5 R; 3-σ = 0,7 R.

* * E0; E1-modulus of elasticity before and after load application.

It is seen that the significance of the maximum compressive stress factor is higher than the importance of the number of dynamic effects. When the maximum compressive stress σ = 0,7 R microseminoprotein is progressive in nature with increasing number of impacts.

Immediately after applying the dynamic load, the samples were installed in solutions of different salinity in a semi-loaded state and, according to the measurement of potentials in the valve, monitored the development of the corrosion process. During the full period of testing in the solution – 120 days electrode potential (the potential difference between the test rods and the electrode comparison) increased in different samples by the size of 40 to 200mV.
After extraction from the solution, drying, measurement of the dynamic modulus of elasticity and strength, all samples destroyed and determined the degree of corrosion by the size of the area of the rod exposed to corrosion.

Based on the results of the data processing, graphical dependencies are constructed (Fig. 3-8), allowing to judge the significance of the considered factors on the degree of corrosion of the reinforcement.

**Figure 3.** The dependence of corrosion from salinity of water (the composition without the additives). 1- $\sigma/R=0.3$; 2- $\sigma/R=0.5$; 3- $\sigma/R=0.7$.

**Figure 4.** The dependence of corrosion from salinity (composition with the addition of superplasticizer C-3). 1;2;3 – $\sigma/R=0.3$; n=250;500;750. 4;5;6 – $\sigma/R=0.5$; n=250;500;750. 7 – $\sigma/R=0.7$; n=500.

**Figure 5.** The dependence of corrosion from salinity (composition with the addition of NaNO2). 1;2;3 – $\sigma/R=0.3$; n=250;500;750. 4 – $\sigma/R=0.5$; n=500. 5;6;7 – $\sigma/R=0.7$; n=250;500;750.
**Figure 6.** The dependence of the corrosion from $\sigma$ (the composition without the additives). 1;2;3 – NaCL=0; n=250;500;750. 4 – NaCL=4%; n=500. 5 – NaCL=8%; n=500.

**Figure 7.** The dependence of corrosion from $\sigma$ (the composition of the additive superplasticity C-3). 1;2;3 – NaCL=0; n=250;500;750. 4 – NaCL=4%; n=500. 5 – NaCL=8%; n=500.

**Figure 8.** The dependence of corrosion from $\sigma$ (composition with the addition of NaNO$_2$). 1;2;3 – NaCL=0; n=250;500;750. 4 – NaCL=4%; n=500. 5;6;7 – NaCL=8%; n=250;500;750.

6. **Conclusion**

1. Among the factors studied, the salinity of the solution and the maximum compression stress are of the greatest importance. The influence of salinity of the solution is manifested most strongly by increasing from zero to four percent. In the range from 4 to 8%, this effect becomes less noticeable.
For rice, 3, 4, 5 the growth of corrosion has a fading nature. As the value increases, the effect of salinity on the corrosion process in the range of 0 – 4% also increases.

2. The dependence of corrosion on the value of $\sigma$ in all experiments has a progressive nature (Fig. 6, 7, 8). The influence of $\sigma$ is evident, starting with the value of 0.3 R if the use of the composition with the plasticizer and composition without the additives in the saline solution 4 to 8% (Fig. 6, 7). In freshwater, the influence of $\sigma$ can hardly be seen (Fig. 6, 8) and is manifested only when using a composition with a plasticizer, starting with a value of 0.3-0.4 R (Fig. 7). When using a composition with a corrosion inhibitor, the influence of $\sigma$ is manifested only, starting with a value of 0.5 R, regardless of the salinity of the solution (Fig. 8).

3. The number of dynamic effects has the least impact on the size of corrosion in all tested batches. This result is correlated with the data shown in figure 1.2. Measurements of the dynamic modulus of elasticity indicate that the bulk of micro-failure sample receives during the first dynamic effects. The accumulation of micro-defects by increasing the number of impacts is very slow, especially when $\sigma = 0.3$ R and has little effect on the amount of corrosion.

4. The use of superplasticizer S-3 in the manufacture of samples of composition 2 led to increased corrosion of the reinforcement in any combination of the factors under study. The greatest increase in corrosion occurs at $\sigma = 0.5$ and 0.7 R, including testing in fresh water (Fig. 7). The use Of NaNO2 corrosion inhibitor additive in the manufacture of samples of composition 3 led to a decrease in the size of corrosion and smoothed the influence of other factors (Fig. 8). A significant increase in the size of corrosion (compared with non–loaded samples) was observed here only at $\sigma = 0.7$ R and at the salinity of the solution 4-8%.

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