Method of determining electrotechnical characteristics of concrete

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Abstract. The main characteristics of concrete working under the influence of electricity are considered. In this regard, concretes can be divided into two main groups: electrically conductive and electrically insulating. Both of them have the right to exist, as the development of science and technology predetermines their necessity. Various attempts were made to determine the electrotechnical properties of concrete. The article presents a fundamentally new way to study the electrotechnical properties of concrete and mortars: the "voltmeter-ammeter" method. It is proved that the measurement of the specific resistance at frequencies of 1 ... 5 kHz should be considered the most appropriate for carrying out the measurements. The experiments showed that this method has the right to exist, and is one of the simplest and does not require expensive equipment.

1. Introduction
When studying the basic characteristics of heavy concrete - strength, frost resistance, and water resistance, the electrical characteristics are often underestimated, especially for reinforced concrete structures. Their specific electrical resistance as well as the production of electrically conductive concrete should be assessed.

2. Relevance
An increase in the moisture content of a concrete increases its electrical conductivity, while a decrease in moisture (drying) increases its electrical resistance. The presence in the concrete of a large number of components with different physicochemical properties, as well as its complex capillary-porous structure, determined the specific requirements for methods for evaluating its electrical properties.

In particular, they require additional experimental verification of the permissible range of measurement frequencies on alternating current, materials applicable for electrodes, and the degree of influence of the moisture content of a concrete. Not enough attention has been paid to the methods of measuring the electrical properties of concrete in the literature [1-5], and although a large amount of experimental data has been published, serious complications arise when comparing the results (some conclusions are diametrically opposite). In addition, the evaluation of the electrical conductivity of the mixture and the stone also has significant differences. During cold weather concreting, the determination of the electrical properties of a mixture and a stone plays a significant role when using the method of electrical curing of a concrete mixture and electric heating of concrete.
3. Theoretical part

The exclusion of coarse aggregate from the composition of concrete changes the absolute value of electrical resistance, but does not affect the nature of its change [1].

If the specific electrical resistance of the concrete mixture increases immediately after tempering water, then in the cement-water paste in the initial period its decrease is observed, and after 20 days of intensive growth stabilization is observed. At the same time, in the initial period of hardening of the cement-water paste, there are two lows of specific electrical resistance [2].

The electrotechnical characteristics of concrete can be regulated in various ways. For example, Lambert's insulating concrete was tempered with water-bitumen emulsions, ion-exchange resins were injected into concrete, the cement bond was replaced with a polymer resin, etc. [3]

In order to obtain insulating concrete, special attention is paid to the study of the properties of its components. And to get electrically conductive concrete, special attention is paid to the use of conductive additives. But in each case, the question arises about the methods for measuring the electrical characteristics of concrete.

A number of papers provide information to answer some important questions of methodological support, however, validation of the methods used in each specific study is required.

Analysis of the existing methods of conductometry showed that to measure the specific electrical resistance of concrete is most appropriate to use the contact method of measuring alternating current using the "voltmeter-ammeter" method. The use of this method with the use of modern equipment and carefully graduation provides the minimum measurement error that meets production requirements [6-8]. At the same time, this method is characterized by simplicity and accessibility of the equipment used.

4. Experimental part

The GZ-33 generator was used as a source of alternating current to study the electrical properties of concrete by the “voltmeter-ammeter” method. The generator voltmeter and the combined device Ts-4341 were used as indicators of voltage and current.

The electrical properties of samples from a mortar with a composition of 1:1 at W / C = 0.4 and samples from concrete with a composition of 1: 2.30: 3.22 at W / C = 0.57 were studied. When measuring on alternating current, the influence of the polarization of the electrodes on the results is insignificant, but the correct choice of frequency is needed. With increasing frequency, the relative resistivity decreases, which is explained by a decrease in the polarization of the electrodes, molecular complexes, and molecules of the components in the material under study. A noticeable change in the nature of the dependence of resistivity on frequency (at low frequencies due to polarization of free water, and at high frequencies due to the increasing influence on the results of capacitive and inductive resistance of the measuring circuit) at the edges of the considered frequency range is observed.

Analysis of the measurement results showed that the measurement of the specific resistance at frequencies of 1 ... 5 kHz should be considered the most appropriate for carrying out the measurements. As the frequencies change in one direction or the other, a sharp change in the measurement results is observed due to the lack of reliability. As the system hardens, the error increases. This is determined by the composition of the material and especially its free water content: with a decrease in the specific electrical resistance of solid components and with a decrease in the amount of moisture, a tendency to narrow the frequency range and increase the effect of frequency on the measurement results is observed.

For concretes and mortars based on portland cement in cases where the current frequency is not limited by the specific conditions of the material and by the need to study the state of moisture in it, a frequency range for measuring 0.15 ... 5 kHz and the standard frequency of 1 kHz can be recommended.

After molding, the samples from the mortar were kept for 7 days in metal forms, and then stored for 2 months in air-humid conditions. During this time, the specific electrical resistivity increased by more than 3 orders of magnitude.
With water saturation, the resistivity sharply decreased to the initial value (section B of Figure 1). During subsequent hardening in air, the specific resistance increases (section C in Fig. 1), i.e. it is in accordance with the water content of the sample (Figure 2).

It is noteworthy that the decrease in the amount of free water in the samples by 7% caused an increase in the resistivity by almost 2 orders of magnitude. At the same time, the relationship between the content of free water and specific electrical resistance is non-linear in nature (Figure 3) and the more it differs from the direct one, the smaller the free water in the sample.

Thus, when the material is kept in air for a long time, the measurement results are increasingly influenced by fluctuations in the ambient humidity. Also when determining the electrical properties of concrete, it is necessary to specify the conditions of hardening and moisture of the material at the time of measurement, and when the specific resistance is reached 100 Ohm.m to increase stability results it is advisable to provide measures that eliminate fluctuations in humidity.

The value of specific electrical resistivity is also influenced by the temperature. With increasing it to 80° C, the specific electrical resistivity decreases due to a change in the mobility of electrolytes (Figure 4).
Figure 4. The effect of temperature on the specific electrical resistivity of concrete (resistivity at 18 °C is taken as 100%): l.e. - laid-on electrodes, s.e. - submersible electrodes.

It is possible to use both submersible and laid-on sensors in the contact method of determining the electrical conductivity of concrete. However, submersible sensors, which are two electrodes, can be installed in the volume of concrete only when it is molded. A small measurement error is provided due to good contact with the material. Electrodes must have sufficient mechanical strength, low polarization resistance, and be inert with the components of concrete. Due to the high cost, the use of noble metals, as well as aluminum, copper and alloys based on them due to chemical activity, is excluded [9-11]. All the above results were obtained using submersible sensors having galvanized steel electrodes. The cost of such electrodes is small, they do not interact with the components of concrete, and the relatively high polarization resistance was compensated by increasing the current frequency to 1 ... 5 kHz.

Laid-on sensors should be used to study the electrical properties of concrete structures. Electrodes of that sensors can be used many times. But the use of such sensors requires a smooth concrete surface to create a reliable contact.

The laid-on non-polarizable copper-sulphate sensor is devoid of these disadvantages. The contact between the concrete and the measuring electrode is made through an intermediate electrolyte solution in that sensors [12]. Experimental verification showed that with a contact surface area of 15 mm², the scatter of results does not exceed 20%.

5. Conclusions
Analysis of the literature [13-20] and the obtained data allowed us to draw the following conclusions:
- The results of measuring the electrical properties of concrete are significantly influenced by the sample moisture and temperature, current frequency, sensor design, and electrode material. Therefore, the comparison of data obtained by various researchers is possible only if all these parameters coincide or after finding the corresponding transition coefficients.
- In order to reduce the measurement error, it is necessary to pay special attention to the stabilization of moisture and temperature, since even a slight change in them leads to a large measurement error. Measurements should be carried out at a frequency of 1 kHz, using submersible sensors with electrodes made of materials that do not interact with concrete (titanium, zinc, etc.).

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