Materials Science Forum
ISSN: 1662-9752, Vol. 1006, pp 130-135

Submitted: 2020-03-23
Revised: 2020-03-29
Accepted: 2020-03-30
Online: 2020-08-07

On Providing an Assessment Monitoring System for Especially Essential Structures

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Keywords: concrete, construction, structure, emergency situations, condition, assessment, properties, electroconductivity.

Abstract. The article deals with the assessment problems of especially essential structures. Increased demands on prevention of emergency situations and minimizing the consequences in the event of their occurrence require constant determination of especially essential structures condition. Achieving the goal of reliability and continuity of information is possible by coating the structure surface by a layer of electroconductive concrete, working as a monitoring system sensor. The study of the electrical properties of concrete was performed using the voltmeter – ammeter scheme. After the measurements had been made, the conditional electrical resistance of the electrode pair was calculated. The analysis of the above dependencies found that the change in the electrical resistance of the material from its stress approaches the linear law at lower values of W/C over a larger section of the studied interval. Processing of the obtained data showed that the measurement results were significantly affected by the shape and size of the electrodes used during the experiments.

1 Introduction

Increased demands on prevention of emergency situations and minimizing the consequences in the event of their occurrence require constant determination of especially essential structures condition. Most of these structures are massive reinforced concrete structures that take significant loads during operation or when project accidents are localized. These are primarily protective and localizing systems of nuclear power plants, hydroelectric dams and hydroelectric power plants, destruction of which leads to heavy-duty technogenic impacts on the environment and humans.

According to the current regulations [1-3], the technical condition assessment is presented as a discrete process that is implemented using a specific algorithm. Monitoring the condition of such buildings and structures was provided by systems that were installed during construction. But over time, these systems partially failed [4] or became obsolete. This situation reduces the monitoring system reliability and may lead to delayed response during emergencies. Restoration of the necessary level of reliability of monitoring systems is provided by current means on the modernized base of control devices. An example of such a solution can be a system that uses modern means of automated strain monitoring [5]. As a part of such systems, the vast majority of devices are high-precision electronic total stations, GPS, levels, inclinometers, accelerometers, and so on. The structure assessment is based on calculations that use data about the properties of materials of construction, level of impacts and loads, as well as the results of the identified damage and defects. Determination of the properties of the structure materials is based on the use of regulated non-destructive testing methods [6-8]. Damage detection is performed by visual inspection [9] and using modern research methods and tools [10-12]. However, the reliability of the results of determining the state of structures is also affected by changes in the properties of materials, which is associated with various factors. The influence of technological and operational factors on the results of determining the properties of concrete in structures using non-destructive methods is given in [13]. Usually, calculation systems are used to determine the technical condition of complex buildings and structures. One of these is the "Lira–Windows" software package (PC), which relies on the finite element method in moving parts when determining the technical condition of a building [14]. This software package allows creating a system for monitoring the condition of buildings and structures. The formation of the system is provided by a combination of a PC with a system for automatic determining the properties of materials, loads and impacts. The methodology of the state enterprise "Ukrainian Research and Design Institute of Building Materials and Products" requires the establishment of supervision over the behavior of local zones of construction [9]. However, the existing common tools and methods for determining the properties of concrete in operated structures do not allow correct reflecting possible changes in its characteristics. Other tools and methods are too expensive.

2 Unresolved Issues

Changes in the properties of concrete structures are usually determined as the result of measuring deformations in the local area. For this purpose, various types of strain gauges are used, both direct-acting (direct measurements of the movement of rappers fixed on the concrete surface) and indirect-acting (strain gauges, fiber-optic sensors, etc.) with additional converters of the received information [15]. In the first case, the system is more difficult to adapt to the automation of measurements. In the second case, there are problems with preserving the sensors during the structure operation.

The purpose of the study is to improve and increase the reliability of the means of reflecting changes in the properties of concrete in structures during their operation.

3 Main Part

Achieving the goal of reliability and continuity of information is possible by coating the structure surface by a layer of electroconductive concrete, working as a monitoring system sensor.

As an analogue of such concrete, the development of the Research Institute of Concrete and Reinforced Concrete of the USSR Gosstroy was used [16], in which the electrical conductivity of concrete was provided by adding coke to the concrete.

In order to improve the electrical properties of electroconductive concrete, only an electroconductive conductive aggregate was used. Soot and graphite crushed in different fractions were used as such aggregate.

Concretes with the components ratio providing the densest structure were used for the study. To do this, pieces of graphite were crushed and sifted through a standard set of sieves. Varying the residues on the sieves (0.314; 0.63; 1.25 and 2.5) in different ratios and adding soot, various mixtures for the aggregate of electroconductive concrete were obtained. Changing the ratio between the components was aimed at obtaining the most dense structure. For further research, an aggregate with a weight ratio of Soot: Graphite (0.63): Graphite (2.5) = 1: 2: 4 was adopted. Taking into account the specific rheological properties of concrete with an electroconductive aggregate (a mixture of graphite and soot), experiments were made with concrete at a water-cement ratio of more than 0.6. Only with this W/C it was possible to form both experimental samples and an electroconductive layer on the surface of concrete structures. The use of plasticizing additives was rejected a priori in order to reduce the influence factors on the properties of electroconductive concrete.

The concrete compositions, used during the research, are shown in Table 1.

Samples with a size of 40x40x160 mm (Fig. 1a) were made. 4 graphite electrodes were installed in each sample to study the properties of electroconductive concrete. The layout of electrodes in the samples is shown in Fig. 1b.

The study of the electrical properties of concrete was performed using the voltmeter – ammeter scheme.

Table 1. Ratio between components of electroconductive concrete of different compositions

Composition №	Cement	Water	Aggregate	W/C
1	2.619	1.667	1	0.636
2	3.095	2.143	1	0.692
3	3.095	2.381	1	0.769
4	3.333	2.381	1	0.714
5	3.333	2.619	1	0.786

a) 

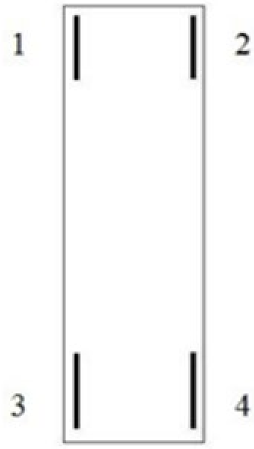
b) 

Fig. 1. Experimental samples from electroconductive concrete:
a) samples; b) layout of electrodes

Measurements were performed sequentially for each pair of electrodes. During the measurement, we tried to ensure that the voltage and current parameters were within the middle part of the device measuring range. The measurements were repeated up to 10 times to obtain statistically reliable results. Statistical processing was performed using EXCEL. The calculation results are shown in Table 2.

Table 2. Measuring results of electrical resistance for concretes of various compositions

Comp. №	Electrical resistance between pairs of electrodes, [ohm]					
	1-2	2-4	4-3	1-3	4-1	3-2
1	3.05±0.18	25.14±1.89	2.33±0.21	23.91±1.70	26.37±2.05	26.33±1.93
2	4.57±0,37	30.19±2.41	2.67±0.26	27.56±2.09	36.97±2.32	35.63±2.58
4	7.84±1.18	36.41±2.19	4.44±0.34	32.09±2.79	39.64±2.74	40.08±2.57
3	25.76±1.87	89.64±5.07	16.30±1.87	83.24±6.70	101.64±8.13	102.90±7.13
5	44.09±3.36	205.36±11.37	28.47±2.18	209.29±15.37	211.18±14.26	217.39±12.12

The distance was measured for each pair of electrodes. After the measurements were made, the ratio of the electrical resistance of concrete between this pair of electrodes R to the distance between them L was calculated.

The analysis of the obtained results shows that the dependence of the electrical resistance on the distance for different W/C is almost linear for experimental compositions of electroconductive concretes. Depending on the W/C, each dependency has its own proportionality coefficient. There are deviations in the resistance changes at short distances between the electrodes, which can probably be the result of the influence of the shape of the used electrodes and their size ratio with the distance between them.

The dependence of the relative electrical resistance (R/L) of electroconductive concrete on the W/C is shown in Fig. 2. This dependence (for the entire definition interval) can be approximated by third- or fourth-degree polynomials with approximation confidence close to 1. In both cases, the dependencies have an inflection point in the range 0.72<W/C<0.76. That is, changes occur in the structure of electroconductive concrete within this interval. Such changes may be associated with the beginning of sliding the aggregate grains with a cement paste. Confirmation of this is a sharp change in the electrical resistance in concrete within this interval.

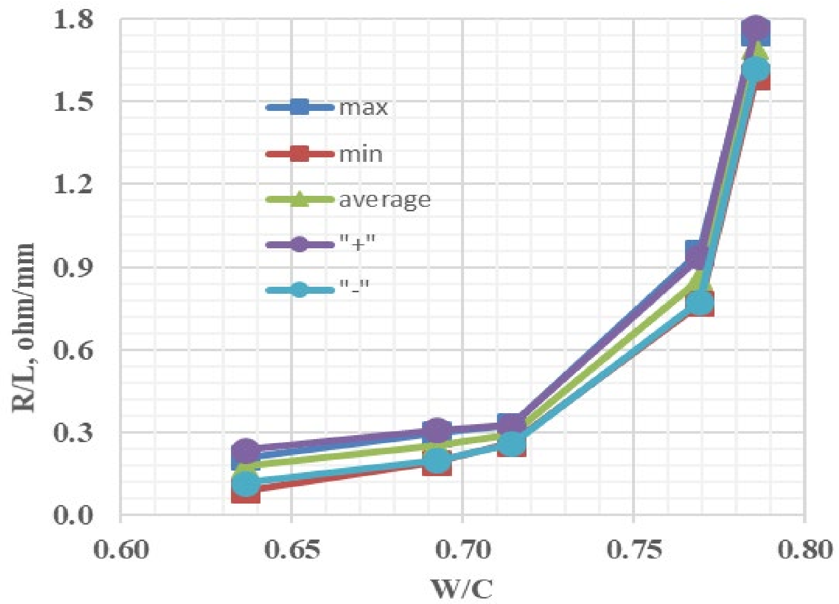


Fig. 2. Results of statistical processing of data on the change in the ratio of electrical resistance to the distance between the electrodes (R/L) in electroconductive concrete, depending on the W/C

Consider in more detail the interval in which the parameter R/L changes slowly (Fig. 3).

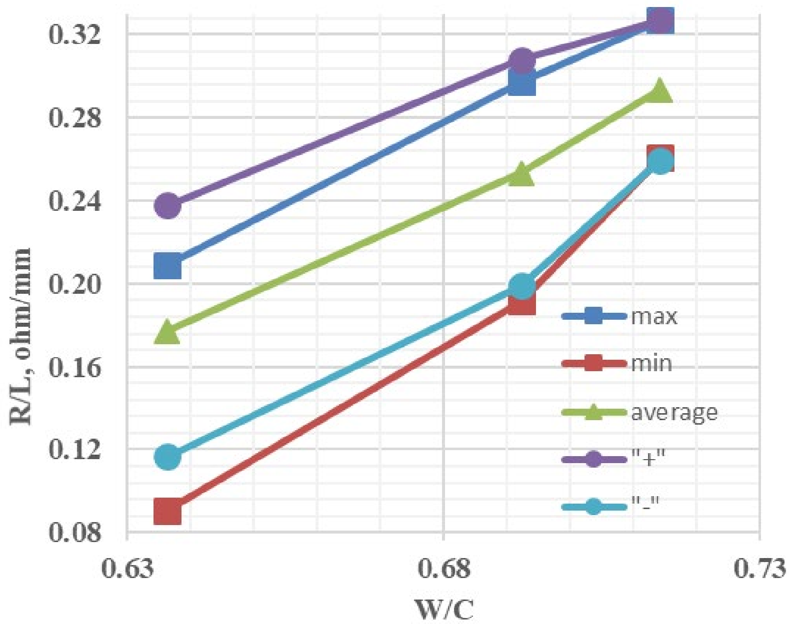


Fig. 3. Results of statistical processing of data on the change in the ratio of electrical resistance to the distance between the electrodes (R/L) in electroconductive concrete, depending on the W/C

It is easy to see that the confidence interval narrows with increasing W/C. In addition, the R/L value at the end of the definition interval is within the confidence interval. The coefficient of variation from the initial value of 32.58% decreased to 10.99% at the end of the definition interval. That is, the structure will be more uniform in concrete samples from such concrete composition.

Determination of the dependence of the resistance of electroconductive concrete on the stress in the concrete was performed during press tests of sample halves formed after determining bending strength of electroconductive concrete (initial sample size 4x4x16 cm). Fig. 4 shows the results of determining the change in R for concrete samples when the stress level changes in relation to the destructive one. The results are given for samples with W/C equal to 0.64, 0.69 and 0.71, respectively.

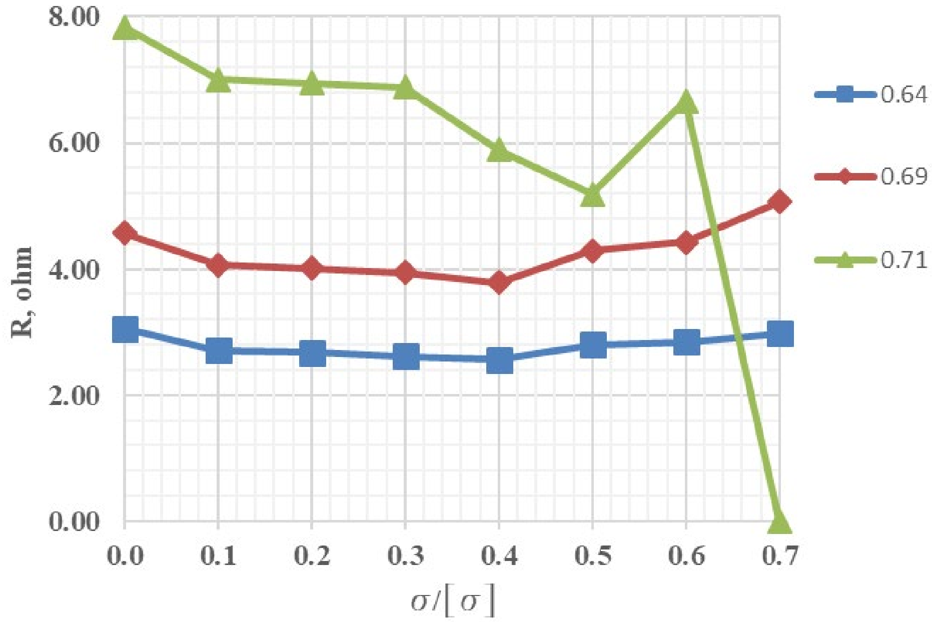


Fig. 4. The change in the electrical resistance in the samples with various W/C, depending on the ratio of the voltage in the sample at the test stage to the destructive stress

The voltage R decreases slowly up to a certain level and after reaching the level (within the ratio of the voltage in the sample at the test stage of the destructive stress, equal to 0.4...0.5) R begins to increase, which is associated with the beginning of destruction of the sample structure (microcracking). A sharp drop in R for a sample with a W/C of 0.71 is associated with the destruction of the measuring electrode.

Conclusion

The obtained results confirmed the possibility of using electroconductive concrete to reflect changes in the stress-strain state of the structure and material properties. In other words, the obtained results allow improving the system for determining the technical condition of buildings and structures [17], including using the "Lira" PC [18]. Processing of the obtained data shows that the measurement results are significantly affected by the shape and size of the electrodes used during the experiments. When comparing the distance between the electrodes with the size of the electrode itself, it is difficult to identify the conditions for the flow of electric current between the electrodes, which reduces the reliability of measurements.

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