Non-destructive methods of determining the properties of materials as a component of the "SMART HOUSE" system

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Abstract. Adequate reflection of material properties by modern methods and devices is difficult. In addition, standardized methods do not allow to build an automated system for monitoring material properties during operation. Developing a monitoring system based on proper determination of the physical and mechanical characteristics of structural materials while the structure is in use could ensure the trouble-free operation, as well as determine the residual life buildings and structures. The research results allow us to establish the compliance of the methods for determining the properties of concrete with the control tasks and determine the limits of applicability of research methods. It is necessary to improve the accuracy of determining the physical and mechanical characteristics of reinforced concrete structures. This can be implemented by improving the method of non-destructive testing, taking into account the influence of significant factors. Systems for monitoring the properties of materials based on improved non-destructive testing methods allow to provide the SMART HOUSE system with sufficient stability and durability.

1 Introduction

The existing level of the regulatory and technical framework and proposals for creating a comprehensive system to assess reliability, durability and to predict the variability of the materials and structures properties allows us to outline the ways to prepare the prerequisites for creating a system for monitoring the properties of building structures during operation in real time.

Such a system should consist not only of theoretically grounded probabilistic and statistical methods for processing the received information, but also of a hardware and research complex of non-destructive testing equipment that reflects modern ideas about the structure and properties of concrete and reinforced concrete.

Adequate reflection of material properties by modern methods and devices is difficult. In addition, standardized methods do not allow to create an automated system for monitoring material properties during operation.

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The construction of a system for monitoring the building structures of buildings and structures based on the adequate determination of the physical and mechanical characteristics (PMC) of materials in operation will ensure trouble-free operation, as well as determine the residual life of buildings and structures [1, 2].

Objective. To substantiate the concept of increasing the accuracy of determining the PMC of the material in the structural element while operation and to establish the compliance of methods for determining the properties of concrete with the tasks to control and determine the limits of applicability of research methods with its subsequent addition to the "SMART HOUSE" system.

2 Results

Currently, monitoring systems are installed only at specially responsible facilities (Fig. 1, 2). Such systems are installed only during construction. During operation, part of the sensors of these systems fail, but their replacement causes many problems. In addition, the current methods do not allow to adequately reflect the PMC of concrete structures using the systems that could be installed during the operation of buildings.

Fig. 1. Hydroelectric power plant

Fig. 2. Nuclear power plant

The improvement of non-destructive methods will allow to expand the monitoring of particularly responsible objects to ordinary objects of civil infrastructure and high-rise residential buildings (Figs. 3, 4).

Fig. 3. Overpass above the railroad

Fig. 4. High-rise residential building

To improve the methodology, the impact was determined:

• factors related to the technology of concrete mix production and the technology of production of concreting works on structures;

• operating conditions of the structure and the level of the stress-strain state;
• measurement conditions.

The results of the conducted studies [3-9] allow us to establish the compliance of methods for determining the properties of concrete with the tasks of control and determine the limits of applicability of research methods. Unfortunately, most modern methods of non-destructive testing cannot be used in monitoring systems because they are indirect and require the determination of concrete properties using control samples. Obtaining such samples is usually a problem for structures that are in operation, and in some cases, it is impossible.

Most building structures are statically indeterminate. Changes in the constraining conditions for such structures lead to a redistribution of forces between their elements, and within the element to a redistribution of internal stresses in them. In some cases, it is even possible to form localized areas with zero stress, i.e., we can talk about “unloading” such a region of the structure.

The appearance of a zone with no stress will necessarily be accompanied by the appearance of a “transition” zone from the existing stress level to zero, as well as the appearance of a zone with increased stress caused by the redistribution of stress within the system. Thus, by changing the conditions for imposing restrictions on the movement of structural elements, it is possible to create a local, specially organized heterogeneity of the stress field in the structure. By measuring the deformations within such a specially organized area, information about the deformation properties of the structural material can be obtained. At the same time, the parameters of the structure disturbance should not lead to a significant increase in stress in the structural element outside the unloading zone.

A numerical model has been developed to study the parameters of changes in the stress-strain state of a structural element under conditions of controlled disturbance of the element structure at a limited intensity of action. This model is implemented by the finite element method. “Lira” and “SOLIDWORKS” computing complexes were used for modeling. Comparison of the simulation tests of both complexes showed comparable results. Analysis of the results in numerical experiment, when varying the parameters in a local disturbance of the element structure, allowed us to obtain the kinetic dependences when occurring the changes in the stress-strain state in the vicinity of such a local disturbance. These results provide us to the basis for developing a method for determining the stress level in structural elements. The results of one of the stages of the model's study are in figures 5 and 6.

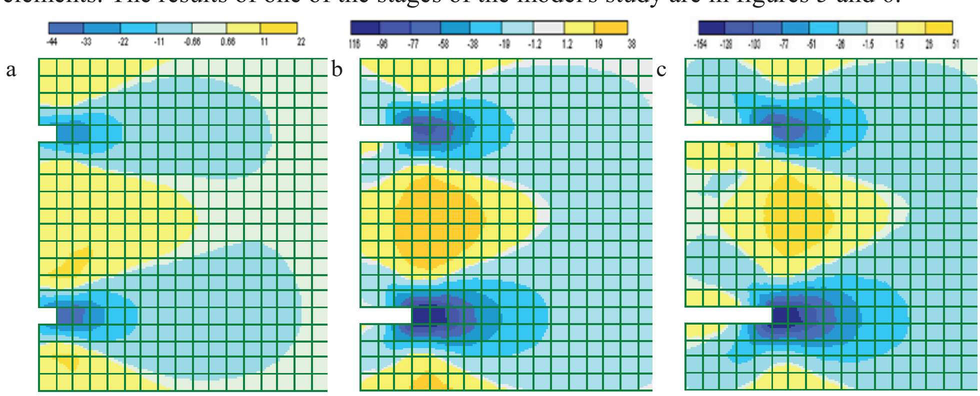

Fig. 5. Change in the normal stress of the local area near the created defects when their depth changes from 5 mm /0.05h cross-sections (a) to 25 mm /0.25h cross-sections (c), respectively, at the stress in the concrete of the structure. The calculations were made by the “Lira” complex

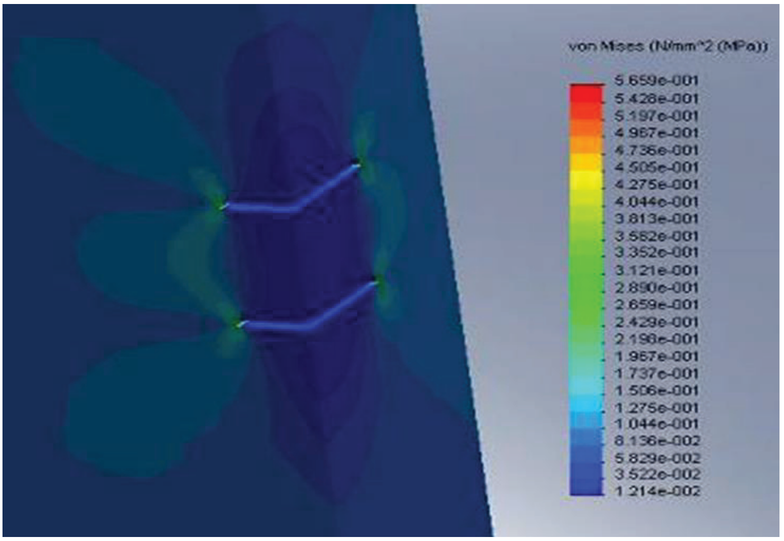

Fig. 6. The stress field in the vicinity of a local change in the structure of the element. Calculations were made by the "SOLIDWORKS" complex

The obtained results make it possible to form schematic solutions that can be built into the "SMART HOUSE" system as a component to ensure the assessment of the technical condition of the building's structures and predict the future functioning of the building and the "SMART HOUSE" system.

Here is an example of a conceptual automated monitoring system for the technical condition of an overpass. The scheme was developed during the assessment of the technical condition of the overpass and highway construction on the street Livoberezhna in the city of Kramatorsk, Donetsk region.

During the implementation of the monitoring system in the zones of the structure with different levels of the stress-strain state, the formation of "research areas" (marked "V" in Fig. 7) is performed, which are equipped with measuring devices and subsequently combined with communication, calculation, and processing devices and storage of information.

Fig. 7. The scheme of the study areas in the system of monitoring the condition of overpass structures above the railway

The preparation of the structural study area begins with the installation of measuring electrodes, covering the study surface (including the electrode installation sites) with a layer of conductive material and ensuring contact between the surface and the measuring electrodes (Fig. 8).

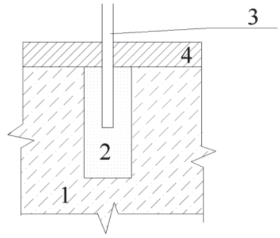

Fig. 8. Scheme of installation of the measuring electrode: 1 - concrete structure; 2 - insulating material; 3 - measuring electrode; 4 - conductive layer

After carrying out appropriate measurements of electrical resistance and specifying the coordinates of the measuring electrodes in the research area, grooves are formed in a certain way between the electrodes (the dimensions of the grooves are calculated in advance). The procedure for measuring the electrical resistance between the electrodes is repeated, after which the grooves are deepened to the calculated depth. The number of repetitions is calculated in advance. The results are used to determine the stress level in the local area of the structure and to compare the results with the design data.

The scheme of the monitoring system proposed for implementation on the highway overpass along the Livoberezhna Street in Kramatorsk, Donetsk region, is shown in Figure 9.

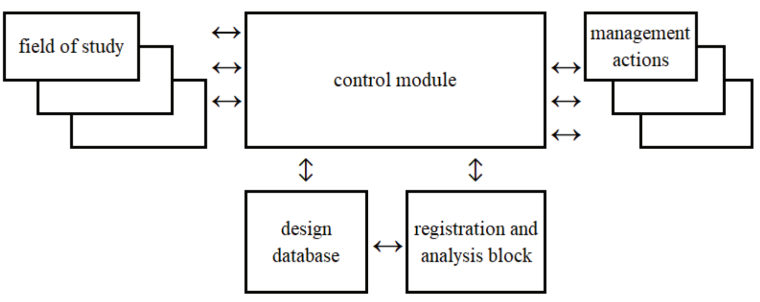

Fig. 9. Scheme of the monitoring system for the implementation on the highway overpass along the Livoberezhna street in the Kramatorsk city, Donetsk region

During the operation of the object, the control module conducts measurements in all research areas (according to a certain program), stores them in the database after comparing them with previous data. When receiving statistically significant differences, the registration and analysis unit performs a verification calculation of the design. The results of verification calculation (after comparing them with the design data) lead the control unit to the generation of appropriate control actions. All data and results are indexed and stored. The procedure is repeated at certain (predetermined) time intervals.

Such a monitoring system can also be used as a component of the “SMART HOUSE” system, adding stability and durability to it.

The identified differences provide information on the discrepancy between the declared material properties of the structure and those realized during construction, as well as identify changes that occurred during its operation.

3 Conclusions

According to the research, it was found that:

1. Standardized methods do not allow to build an automated system for monitoring material properties during operation.
2. It is possible to increase the accuracy of determining physical and mechanical characteristics of concrete structure, which can be achieved by improving the technique of non-destructive testing, taking into account the influence of significant factors.
3. Automated system for monitoring material properties based on improved non-destructive detection methods allow to provide the "SMART HOUSE" system with sufficient stability and durability.

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