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Analysis of Remote Monitoring Methods of Cracks and Joints in Rigid Structures

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Abstract

The article analyzes the appearance of deformations in structures. Arithmetic expressions and calculations of such types of prefracture as absolute or total settlement, average and uneven settlement, relative heel, horizontal displacement and average strain rate are given. The analysis of research results of monitoring for joints or cracks in structures, as well as devices for remote monitoring.

Keywords:deformation of structures, monitoring of structures, cracks, joints, displacement sensors, GSMmodule

1. Introduction

Technical inspection is a process that includes control, testing, analysis and evaluation of various structures, including buildings and structures. The main purpose of the technical inspection of structures is to determine the current technical condition, to identify the degree of physical wear and tear, defects, to clarify the performance of structures, to predict their behavior in the future. [1]

2. Deformation of structures

In the general case, the term deformation is understood as a change in the shape of the object of observation. In geodetic practice, it is customary to consider deformation as a change in the position of an object relative to some initial position. In most cases, the following types of deformations are determined:

- vertical displacements (precipitation, subsidence, rises);
- horizontal displacements (shifts);
- rolls.

Draft - displacement of the structure in the vertical plane; subsidence - a rapidly flowing structure undergoing radical changes in the structure of porous and loose soils; shift - displacement of the structure in the horizontal plane; roll - uneven draft of the structure. To determine deformations, points are first fixed in characteristic places of the structure. Next, the change in the spatial position of the fixed points is determined for the selected time interval relative to the initial position of the object.

The absolute or total draft S is the difference between the absolute heights (marks) of the initial (H_{ini}) and current (H_{cur}) observation cycle (Fig.1), determined relative to the initial point:

$$S = H_{ini} - H_{cur} \quad (1)$$

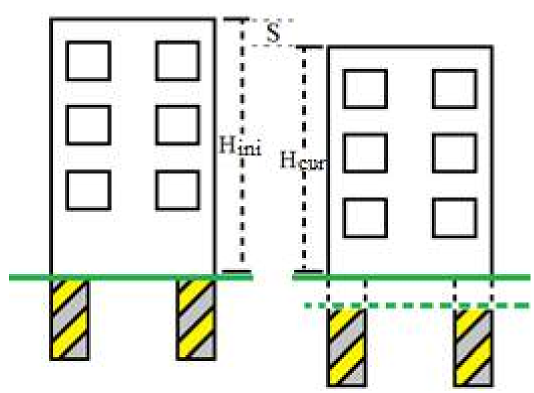

Fig.1. Absoluteorfulldraft

The average draft S_{ave} of the entire structure or its individual parts is calculated as the arithmetic mean of the sum of the draft of all n points of it (Fig.2), i.e.

$$S_{ave} = \frac{\sum_1^n S}{n} \qquad (2)$$

where, S -is the sediment of individual grades; n - is the number of stamps.

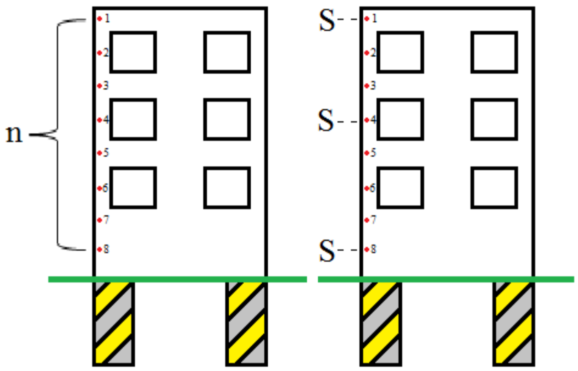

Fig.2. Average structure draft

Simultaneously with the average draft, for completeness of the general characteristics, indicate the largest and the smallest settlement of points of structures.
The uneven settlement (Fig.3.) can be determined by the difference in the settlement ΔS of any two points 1 and 2, i.e.

$$\Delta S_{1,2} = S_2 - S_1 \qquad (3)$$

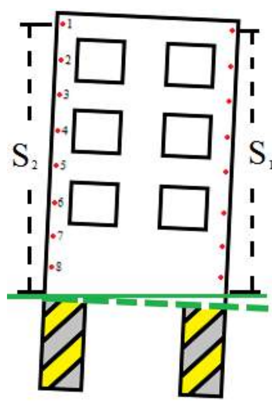

Fig.3. Uneven settlement

The roll or inclination of a structure is defined as the difference between the settlement of two points located on opposite edges of the structure, or parts of it along the selected axis. Inclination in the direction of the longitudinal axis is called a blockage, and in the direction of the transverse axis - skew.

The amount of roll referred to the distance l between two points 1 and 2 (Fig. 4.) is called the relative roll - K, which is calculated by the equation:

$$K = \frac{S_2 - S_1}{l} \qquad (4)$$

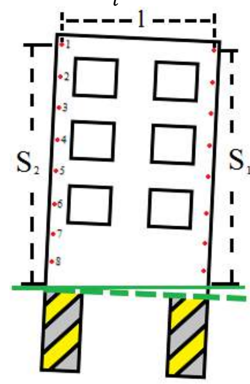

Fig.4. Relative roll

The horizontal displacement q of an individual point of the structure is characterized by the difference of its coordinates x_{cur}, y_{cur} and x_{ini}, y_{ini}, obtained in the current and initial observation cycles (Fig.5.).

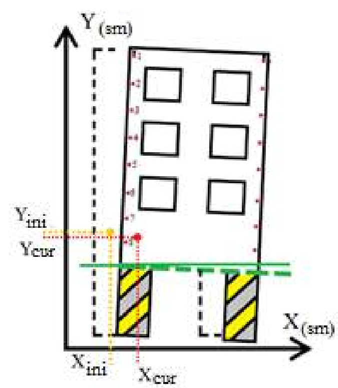

Fig.5. Horizontal offset

The position of the coordinate axes, as a rule, coincides with the main axes of the structure. Calculate the displacement in the general case by the equations

$$q_x = x_{cur} - x_{ini}\,;\ q_y = y_{cur} - y_{ini}\,. \qquad (5)$$

Similarly, you can calculate the displacement between the previous and next observation cycles. Horizontal displacements are also determined along one of the coordinate axes.
Torsion about the vertical axis is typical mainly for tower-type structures. It is defined as a change in the angular position of the radius of a fixed point, drawn from the center of the investigated horizontal section.

The change in the magnitude of the deformation over the selected time interval is characterized by the average deformation rate υav. So, for example, the average rate of settlement of the point under study for the time interval t between two cycles i and j measurements (Fig. 6) will be equal to:

$$\upsilon_{\text{cp}} = \frac{(S_j - S_i)}{t} \qquad (7)$$

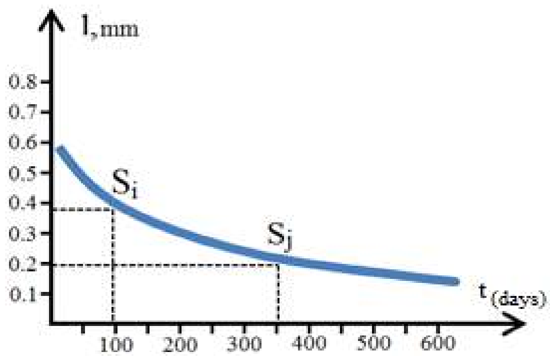

Fig.6. Average strain rate

A distinction is made between the average monthly rate, when t is expressed by the number of months, and the average annual rate, when t - is the number of years, etc.

3. The technical inspection of structures

The technical inspection of structures is carried out in 4 stages.

1) Preliminary examination of structures:

The preliminary survey includes:

- general inspection of structures;
- collection of general information about the structure (construction time, service life);
- general characteristics of space-planning and constructive solutions of engineering equipment systems;
- identification of the features of production technology in terms of their impact on the structure;
- determination of the actual parameters of the microclimate or industrial environment, temperature and humidity conditions, the presence of aggressive technological emissions to structures, collection of information on anti-corrosion measures;
- hydrogeological conditions of the site and general characteristics of the soils of the foundations of structures;
- familiarization with the archival materials of the survey;
- study of materials of surveys of the production environment and the state of structures previously carried out at this facility.

At the stage of preliminary visual inspection, the categories of the technical condition of structures are established by external signs, depending on the existing defects and damages.

2) Detailed instrumental examination of structures:

Detailed examination includes:

- Visual inspection of structures (with photographs of visible defects);
- Measurement work - the configuration, dimensions, position in plan and vertical of structures and their elements are determined;
- instrumental examination;
- measurement of deflections and deformations;
- determination of material characteristics of supporting structures;
- settlement of foundations and deformation of soils of the foundations of structures.

3) Determination of the physical and technical characteristics of the materials of the examined structures in laboratory conditions.

4) Generalization of research results.

Based on the survey results, the following are compiled:

- technological report containing the results of the survey (plans and sections of structures with geological profiles, design features of structures, foundations and their geometry);
- layouts of benchmarks and marks; description of the adopted measurement system; photographs, graphs and diagrams of horizontal and vertical displacements, rolls; crack development; a list of factors contributing to the occurrence of deformations;
- assessment of strength and deformation characteristics of soils of foundations and materials of structures;
- a technological conclusion on the category of the technical state of the structure with assessments of the possibility of perceiving additional deformations or other influences caused by new construction or reconstruction, and, if necessary, a list of measures to strengthen the structures and strengthen the foundation soils.

Monitoring during construction - systematic and (or) periodic monitoring (observation) of the construction process, deformations of structures in general or their parts, as well as the condition of soils, foundations and surrounding buildings, timely fixation and assessment of deviations from the project, regulatory documents, forecasting mutual influence of the facility and the environment in the future, providing adequate feedback for timely identification of actual changes, prevention of negative processes and elimination of their consequences. [1]

Let us consider in more detail the second stage of the technical examination of structures, namely the instrumental examination.

In order to implement the integrated safety of structures, it is necessary to consider monitoring the technical condition of structures as an element of a unified functional structure control system. The concept of intellectualization implies the creation of a single control center for intelligent construction systems, in connection with which it is necessary to consider the system for monitoring the state of structures and their parameters as remotely controlled. [2]

When examining structures, the most critical stage is the study of pre-fractures (for example, cracks), identifying the causes of their occurrence and the dynamics of development. In the presence of pre-failure on the bearing elements of structures, it is necessary to organize a systematic observation of their condition and possible development in order to find out the nature of deformations of structures and the degree of their danger for further operation. [3, 4]

It is especially important to conduct surveys followed by monitoring after various man-made and natural impacts, during the reconstruction of old structures, which is often associated with a change in the existing loads, the functional purpose of structures and the need to take into account modern design standards. Due to the fact that the deformation effects on structures as a result of changes in the state of the properties of the base are mainly of a long-term nature, today the most effective way to predict and prevent emergencies is to monitor their technical state, carried out in a periodic mode. [5]

In most cases, the dynamics of the disclosure of pre-fire and destruction is determined visually, using the following types of beacons: gypsum, plate, point beacons. [6]

The criterion for the development of a crack in this case is the rupture of the lighthouse or the displacement of the plates in relation to each other. However, the disadvantage of these devices is their high labor intensity during operation and the impossibility of automating measurements. It is especially time consuming and difficult to use these devices if the controlled crack is located in a hard-to-reach place or at a great height. [7]

4. Comparison of modern sensors

In [7], [8] technical solutions are given that allow transmitting measurements of controlled parameters, namely, the width of crack opening in structures using wireless information transmission systems.

In [7], a diagram of the device of a displacement sensor is shown (Fig. 7), which controls the width of the opening of each crack and notifies the user in advance of the intensive dynamics of the opening of any crack, transmitting the measurement data to a personal computer, where the data obtained at the object is automatically entered to the base for further analysis. Thus, a technical result is achieved, which consists in providing the possibility of automating measurements of cracks and joints, as well as preventing emergency destruction of structures.

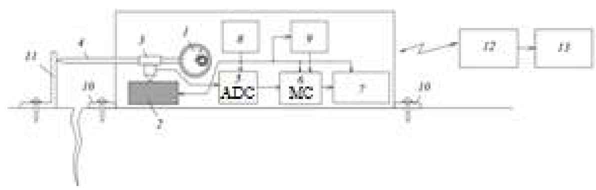

Fig.7. Diagram of the displacement sensor device:

1 - dial indicator, 2 - slidewire, 3 - slideableslidewire of slidewire, 4 - sliding indicator rod, 5 - analog-digital converter, 6 - microcontroller, 7 - transmitting radio module, 8 - chemical current source, 9 - alarm clock, 10 - sensor support, 11 - sliding rod stop, 12 - receiving radio module, 13 - recording device

The monitoring system consists of one or more displacement sensors and a recording device, which can be a computer or laptop. The displacement sensors include a reochord and a current collector, an analog-to-digital converter, a microcontroller transmitting a radio module with support for the Zigbee protocol, a chemical supply voltage source, and an alarm clock module (Fig.7).

The sensors are installed at the appropriate control points, which can be located in different parts of the structure. In this case, the receiving radio module, connected to the registration device, is connected via a radio channel to each transmitting radio module, which are part of the sensors (Fig.8).

The sensor works as follows. With the expansion of the controlled crack, the distance between the sensor and the stop of the rising stem increases. As a result, the sliding dial indicator rod moves after the stop, and the dial indicator shows the movement. The movement is due to the fact that the dial indicator contains a spring. The device can use a standard dial gauge such as, ИЧ-10 (-25, -50).

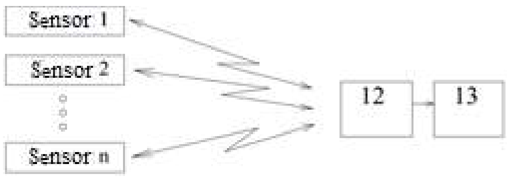

Fig.8. Structural monitoring system

If it is necessary to control several cracks in different parts of the structures, several sensors should be used, according to the number of controlled points. In this case, the receiving radio module alternately communicates with the transmitting radio modules that are part of each sensor. Each of them has its own number and transmits information over the radio channel to the recording device.

This wireless monitoring system fits perfectly into an "intelligent system", since the personal computer, which receives all the measurement results, controls the width of each crack opening and notifies the user in advance when there is an intense dynamics of any crack opening. This monitoring system allows you to remotely determine the cause of defects and prevent emergency destruction of structures. [7]

In [8], the results of the development of a wireless system device for monitoring the state of cracks and structures using dual-processor Wi-Fi transmitters are presented (Fig.9)

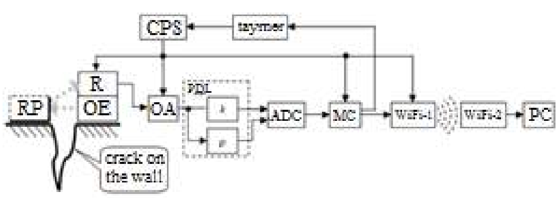

Fig.9. The structure of a wireless device for monitoring the state of cracks and joints of structures

The general structure of the monitoring device (Fig.9.) includes an optical sensor, consisting of a reflective panel (RP), an optical emitter (OE) and a receiver (P), an operational amplifier (OA), an analog-to-digital converter (ADC), proportional - differentiating link (PDL), microcontroller (MC), Wi-Fi transmitter (Wi-Fi-1), Wi-Fi receiver (Wi-Fi-2), personal computer (PC), controlled power supply (CPS) and timer.

A distinctive feature of this device is the availability of information about the expansion rate of the measured crack, which gives the most complete picture of the degree of destructive activity in structural elements and allows you to quickly respond to emerging threats, and the organization of wireless signal transmission and the developed algorithm, including limiting the transmission time of the useful signal, allow significantly save power consumption and use an autonomous power source. [8]

5. Proposed solution

However, the main disadvantage of these measuring systems is the small measurement range of the controlled parameters. In addition, the technology of taking measurements from these sensors excludes the possibility of wireless data transmission to a computer, which significantly reduces the scope of its application.

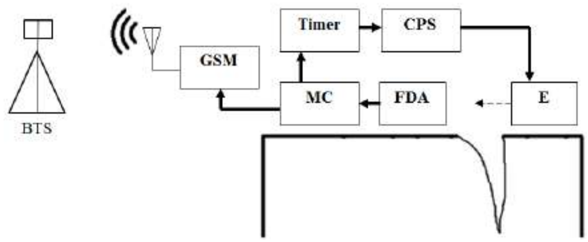

Fig.10. Block diagram of a wireless monitoring system for cracks in structures, using a mobile communication network

The general structure of the monitoring device (Fig.10) includes a photodiode array (FDA), an emitter (E), microcontroller (MC), a GSM module (GSM), a controlled power supply (CPS), a timer.

The emitter forms an intermittent beam at the output, the radiation of which hits the photodiode matrix of the FDA. Initially, the emitter and the FDA are installed so that the beam from the output of the emitter is concentrated in the center of the FDA. The displacement of the surfaces of the controlled crack leads to a change in the distance or plane between the photodiode array and the emitter. Thus, by the deviation of the emitter beam in two coordinates (vertical and horizontal), it is possible to determine changes in the position of the crack in two planes.

A distinctive feature of this device is the ability to obtain information on the rate of change in the size of the controlled crack, which gives the most complete picture of the degree of destructive activity in structural elements and allows you to quickly respond to emerging threats, and the organization of wireless data transmission using mobile communication networks allows monitoring the state of the crack at a distance

6. Conclusion

The analysis showed that the technical examination of various structures, including buildings and structures, is an important process for identifying physical wear, defects, deformations of structures, ascertaining the performance of structures, as well as predicting their behavior in the future, which is also one of the objectives of the survey.

It was also shown that when examining structures, the most critical stage is the study of pre-fractures (for example, cracks), identifying the causes of their occurrence and the dynamics of development. In the presence of pre-failure on the bearing elements of structures, it is necessary to organize systematic monitoring of their condition and possible development in order to find out the nature of deformations of structures and the degree of their danger for further operation.

A distinctive feature of wireless devices for monitoring and observing joints and cracks of structures, which were shown in this article, is the presence of constant information about the expansion rate of the observed (measured) cracks in real or in a certain time interval, which gives the most complete information about the degree of destructive activity in structural elements and allows you to quickly respond to emerging threats.

The analysis revealed a common drawback in all the above methods for observing joints and cracks - these methods or devices do not have the ability to measure changes in crack sizes in three coordinates.

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