The technical state experimental studies of construction with free support in the non-stationary oscillations’ analysis

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Abstract. An algorithm for the experimental determination of the defective zones of the construction with free support is presented. A reinforced concrete floor plate freely supported on both sides is studied as an example. The oscillation method is used as a diagnostic method. Impact loading is used as the excitation of non-stationary oscillations. The studies were carried out using an oscillation measuring setup. The research is based on the analysis of oscillation modes under non-stationary dynamic loading of an object. The analysis of oscillation modes makes it possible to detect the conditionally defective zones of floor plate.

1. Introduction

It is well-known, any actual constructions lose its performance over time. This is due to the loss of the operational properties of materials under the external negative factors’ influence, the creation of emergency situations and further construction destruction. Technical diagnostics require for preventing the critical state of the object and for its technical conditions’ analysis for further operation.

Floor plates are the research objects in the study. Restoration of the integrity and reliability of floor plates is carried out during the repair and restoration works. Carrying out these works in practice should be accompanied by planned technical monitoring. With this aim, at the first stage, it is required to conduct construction and technical examination, one of the algorithms of which is proposed in [1]. The paper presents a draft of schedule for the comprehensive technical monitoring of industrial building constructions. The features of construction and technical monitoring of industrial building constructions are described. The algorithm scheme is presented. During the analysis, the object is divided into zones, where various research methods and specialized equipment can be used.

In the research process, different procedures, the examples of which have been presented in various publications, could be applied:

(i) visual and technical detection of defects in the structure [2];
(ii) description and establishment of the object’s technical conditions category [3];
(iii) development of repair technology procedures (the creation of a map of technological preparation of the construction surface [4]; the selection of repair, the connection and restoration of structural integrity [5, 6]);
(iv) quality control of repair works (the establishment of a criterion for assessing the quality of work performed; verification tests and calculations of structural elements [7]; development of methods for testing and preliminary calculations [8]).
For instrumental examinations of floor plates, specific examination methods can be used, for example, oscillation diagnostics. Some approaches to oscillation diagnostics have been developed in [9-11].

Some approaches of the authors of that use algorithms for solving problems based on assessing the influence of damage parameters on the change in natural oscillation frequencies and modal characteristics of signals are known [12-14]. In these studies, both analytical and numerical methods of calculation can be used.

Application of specialized calculation methods, evolutionary algorithms and neural networks can improve the constructions analysis accuracy [16-18]. In these studies, an experimental approach can be used to determine the criterion-based assessment of the applied theory and to minimize the time of mathematical operations by calculating the object’s characteristics.

2. Formulation of the problem

The basic aim of the research is to draw up a technique for oscillation diagnostics of floor plates and its experimental testing.

3. Description of experimental research

The research was carried out in the Don State Technical University, Rostov-on-Don by using the hollow floor plates (with dimensions of \( h \times b \times l = 220 \times 1190 \times 6000 \text{ mm}^3 \)) of one of the university buildings. The oscillation analysis of floor plates is based on the natural frequencies and oscillation modes’ analysis. The use of modeling and comparison of results makes it possible to restore the missed parameters of the construction. The calculation of the stress state can be performed on the base of the previously obtained data on the structure oscillations by comparing the numerical analysis of the floor plates’ deflection and experimental data.

At the first stage, the oscillation diagnostics system was assembled, tested and the sensors were placed on the floor plate. The frequency of the analog-to-digital converter (ADC) was chosen equal to 100 kHz. The number of accelerometer sensors simultaneously interrogated by the ADC was 16. The distance between the sensors was fixed and equal to 38 cm. Thus, the sensors covered an area of 5.7 m.

*Figure 1* shows an example of the measuring setup arrangement.

Oscillations were grouped at a fixed impact loading for a group of floor slabs. The fixed impact loading was applied by using a weight on a tripod, dropping from a certain height at a point located at the edge of the slab near to the sensor No. 1. A significant signal level was recorded in the far registration zone. Thus, the most optimal effect on the plate in the force terms was selected. In this case, a series of floor plates oscillations’ indications were recorded on a computer. A sampling of a representative signal was made. Acceleration diagrams were built (*Figure 2a*) for a group of points and the comparative analysis production. The natural frequencies of plate oscillations were calculated based on the fast Fourier transform of the signal. Using Fourier transform and accelerations \( a(t) \) oscillations integration, the velocity \( v(t) \) and displacement \( u(t) \) were calculated for the measured data.

*Figure 2b* shows an example of accelerations \( a(t) \) oscillations diagrams and displacements \( u(t) \) for 16 points on the floor plate.
\[
\ddot{a}(\omega) = \int a(t) e^{-i\omega t} dt \\
\ddot{v}(\omega) = \int v(t) e^{-i\omega t} dt; \quad \ddot{v}(\omega) = \frac{\ddot{a}(\omega)}{i\omega} \\
\ddot{u}(\omega) = \int u(t) e^{-i\omega t} dt; \quad \ddot{u}(\omega) = \frac{\ddot{v}(\omega)}{i\omega}
\]

where \(\omega\) is the circular oscillation frequency, \(i\) is the imaginary unit, \(\ddot{a}(\omega)\), \(\ddot{v}(\omega)\) and \(\ddot{u}(\omega)\) are the Fourier vectors for acceleration, velocity and displacement, respectively, \(t\) is the time parameter.

The oscillations analysis shows that the accelerations \(a(t)\) are represented as a series of oscillations within a period of \(t = 0.03\) s. For a range equal to \(t = 0.1\) s, the velocity \(v(t)\) and displacement \(u(t)\) are calculated by integration.

In a comprehensive comparative analysis of natural frequencies and the largest oscillation amplitudes for the studied floor plates, a conclusion was made about the weakest floor slabs. Table 1 shows an example of comparing the first natural frequencies of some floor slabs at the same row. The maximum resonance frequencies obtained by Fourier analysis of the acceleration signal \(a(t)\) are investigated. Analysis shows that the lowest frequency is the first frequency for floor plate 3, which may be related to its most defective state.
Table 1. Natural frequencies of floor slabs

| Floor slab No. | Floor slab Natural frequency, Hz |
|---------------|---------------------------------|
|               | $w_1$ | $w_2$ | $w_3$ |
| 1             | 122   | 134   | 207   |
| 2             | 122   | 146   | 195   |
| 3             | 97    | 146   | 219   |

At the next stage, a comparative analysis of damped oscillation modes was carried out for all floor plates. The criterion was a modal sign about the maximum angles of the construction deflection during damping. The deflection angles were calculated by the formula:

$$\alpha = \arccos \left( \frac{(AB)(BC)}{||AB|| ||BC||} \right)$$  \hspace{1cm} (4)

where $AB$ and $BC$ are the vector representations of two segments between the corresponding points of the normalized oscillation mode for points $[i - 1, i]$ and $[i, i + 1]$.

Figure 3 shows an example of oscillation modes during impact loading of a floor plate at different times. Fractures of oscillation modes, expressed by the greatest curvature of oscillations, were revealed at the points 2, 7, 10, 15. Thus, the zones for which it is necessary to monitor the defect state of the floor slab in more detail, were identified.

![Figure 3](image)

**Figure 3.** Forms of the floor slab structure oscillations at some points in time $t$.

Summary

The problem of experimental analysis of oscillations and identification of defective zones in a reinforced concrete floor plate is considered. An analysis of damped oscillations was carried out under nonstationary action on the plate in the form of impact loading. The natural oscillation frequencies of a set of floor plate constructions were considered. The construction with the lowest first natural frequency was chosen as the most damping one. By analyzing the forms of damped oscillations, the criterion of the largest bends of the oscillation modes was applied, which may correspond to a loss of structural rigidity or the presence of defects in the form of cracks in concrete in the vicinity of this zone.

In accordance with the normative and technical base, the state of the existing monolithic plate could be classified as limited-workable. Reinforcement of the construction is required to restore the bearing capacity. Before reinforcement, it is necessary to limit the loads on the floor slab. A more detailed analysis requires calculations and additional studies of hazardous areas of the facility.
Acknowledgments
The authors acknowledge the support by the Southern Federal University, grant No. VnGr-07/2020-04-IM (Ministry of Science and Higher Education of Russia).

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