Vibration Monitoring
Of Building Constructions

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ABSTRACT:
Vibration monitoring of the defective and unimpaired constructions, in particular beams with loop joints and elements of brickwork with concrete inclusions are carried out. The research of main dynamic informative parameters of technical state of structures of loop joints and elements of brickwork are submitted. Internal defects and changes in structures of joints of precast and cast-in-situ reinforced concrete are analyzed. Presented analysis based on determination of the frequencies of characteristic resonance oscillations using spectral method. Results of dynamic tests of building constructions - diagrams of dependence of vibration displacement from frequency are presented.

Keywords: Vibration monitoring, dynamic tests,beams, loop joints, elements of brickwork with concrete inclusions

1. INTRODUCTION

Commissioned buildings undergo a continuous process of functional obsolescence. During the reconstruction of existing housing is planned to strengthen existing structures and putting them in line with new technological and moral requirements. In addition, currently there are a certain percentage of buildings exposed to external factors which have an adverse effect on the structural strength. These factors include the effects of earthquakes, fire, ground movement and operation of construction equipment in the immediate vicinity of the building. At the current stage of construction, when the bulk of the constructed buildings are high-rise, the special attention should be paid to the level of quality control of the structures, in particular the indices of their integrity. Timely and continuous analysis of these indicators helps to diagnose a technical condition of building structures, prevent the occurrence of accidents and hence will increase their service life.

Visual and instrumental technical surveys sometimes do not fully determine the actual state of constructions. This is due to the fact internal defects of existing structures can be determined only by means of special non-destructive methods for diagnosis, for example, acoustic or ultrasonic. Analog of such non-destructive control methods of structures is also vibration-based monitoring - detection of internal defects and changes in structures based on determination of the frequencies of characteristic resonance oscillations using spectral analysis. According to the obtained spectra of recorded signals from vibration sensors the forms and frequencies of characteristic oscillations of structures and buildings are determined, as well as the logarithmic decrement, which allows to evaluate the quality of structures.

Dynamic testing of structures in the mode of oscillation frequencies or forced oscillation are one of the constituent elements of a comprehensive non-destructive quality control of the finished product. Most widely used vibration tests on the enterprise manufactures precast concrete. Tests are performed for quality control of flexible products, including pre-stressed products. In most cases, the main dynamic informative parameters of technical state of structures are the frequency and damping rates of the natural oscillations in the main tone, which are the most sensitive to the existing building structures defects and damage. In order to investigate these informative parameters in the laboratory a series of experiments was set to determine the dynamic characteristics of building constructions: reinforced concrete beams with loop and splined joints of precast and cast-in-situ structural system (type of Uniform girderless framework -2.5) and elements of brickwork with concrete inclusions (Figure 1).

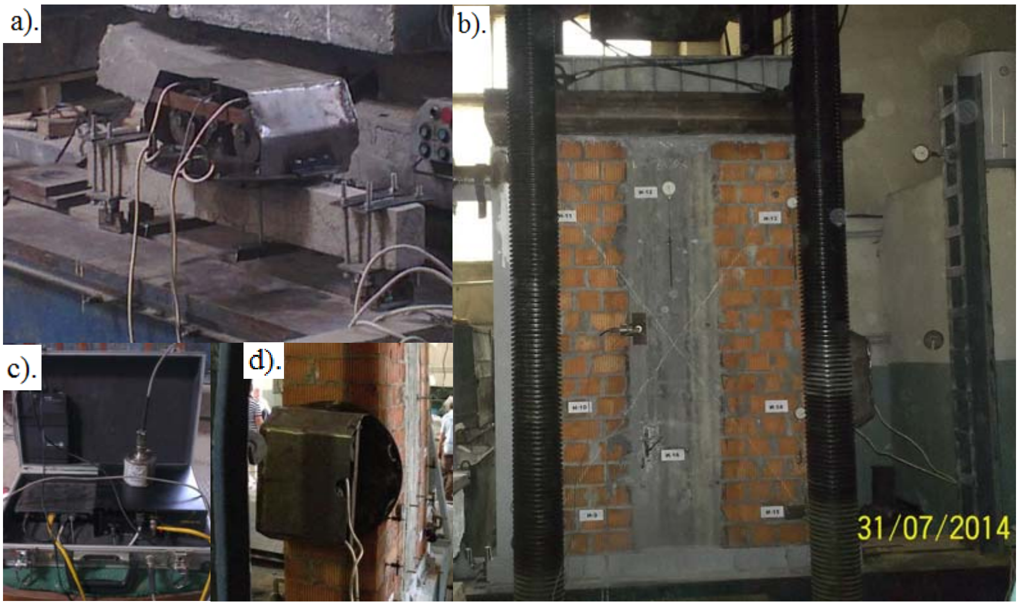


Figure 1. a). experimental reinforced concrete beam with loop joint with vibrator in testing;
b). element of brickwork with concrete inclusion mounted on experimental stand;
c). local workstation with seismic accelerometer (model 731A firm Wilcoxon, USA);
d). vbrator mounted element of brickwork with concrete inclusion.

1. DYNAMIC TESTS OF BEAMS WITH LOOP JOINTS

First part of the series of experiments was testing reinforced concrete beams with loop joints. Types and marking of experimental samples are shown in Table 1. Previously, all samples were tested by static load, resulting to defects which appeared in the form of cracks in the tension zone of the samples. To determine the frequencies of characteristic and the attenuation ratio of the oscillations of beams the method of instantaneous removal of the load and the subsequent processing of damped oscillations was used. Low frequency seismic accelerometer (model 731A firm Wilcoxon, USA) was used as the vibration sensor. Record of vibrosignals was performed from local workstation using a portable eight-channel measuring system "Seismomonitoring" (Figure 2). To determine the oscillation frequencies of the experimental reinforced concrete beams with loop joints the narrowband spectral analysis was produced in the frequency range 1-1000 Hz. By results of dynamic tests temporary signals of vertical vibration accelerations were registered and its spectrum was calculated for reinforced concrete beam at the instantaneous load shedding.

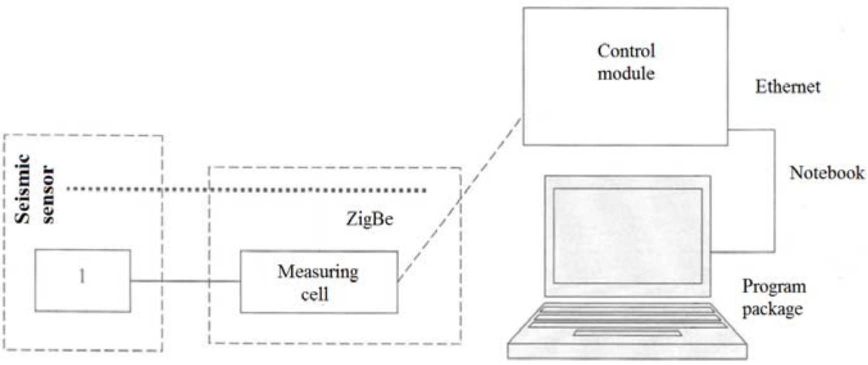
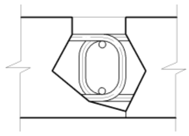
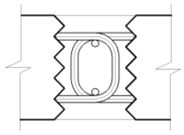
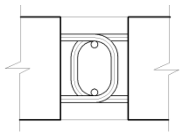
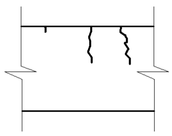


Figure 2. Seismic monitoring system.

Table 1. Types and marking of experimental samples

Position	Marking series of experimental samples	The Loop joint scheme of series	Notes
1	2	3	4
1	A		Loop joint by UGF-2.5 technology (Uniform Girderless Framework -2.5)
2	B		Splined loop joint
3	C		Keyless loop joint
4	D		Samples without joint

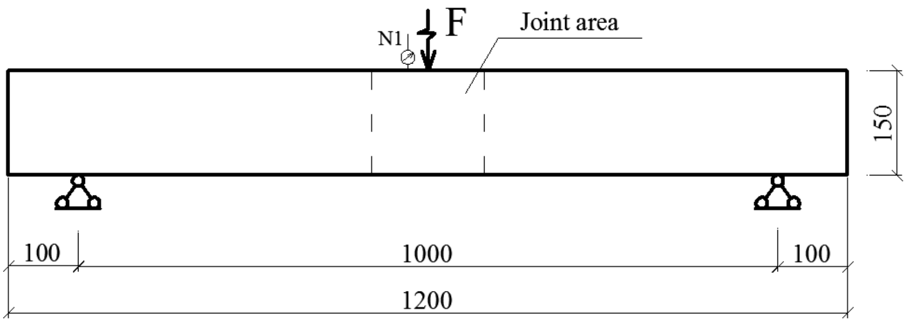


Figure 3. Scheme of the dynamic testing of samples beams (F- amplitude of vibrator dynamic force; N1-accelerometer)

The theoretical natural frequency of reinforced concrete beams without the cracks with a given rigidity was determined before the start of the experiment, and it was $f_{theor}=204,9\ Hz$

All results were compared with the values of the frequencies of the first form of natural vibrations experimentally obtained for each beam individually before testing it by static loading. These values were taken as 100%.

After static loading-unloading at the load rate of 0.5 from breaking load, tests of beams of the series A showed decrease in the natural frequency values to 69-85% of the original. After static loading-unloading at the load rate of 0.9 from breaking load, natural frequency decreased to values in the 55-58% of the initial indications. Absolute values of natural frequencies before static loading tests for such beams ranged from 202 Hz to 211 Hz.

At dynamic tests by the method of instantaneous load shedding after static loading-unloading at the load rate of 0.5 from breaking load natural frequency of the beams of the series B ranged from 64% to 72% of the initial indications. At dynamic tests after static loading-unloading at the load rate of 0.9 from breaking load, natural frequency values decreased to 45-51% of the similar values obtained before static loading-unloading of the experimental samples.

After static loading-unloading at the load rate of from breaking load natural frequencies for the first form of vibration mode of beams series C decreased to 71-86% of the initial indications. After static loading-unloading at the load rate of 0.9 from breaking load these values already reached 64-73%. Test of beams performed without loop joint, show a decrease in the resonance frequency of the first form to 81-94% for the second stage (after loading the samples at the load rate of 0.5 from breaking load and the subsequent unloading). Values of the natural frequencies of vertical oscillations at the third stage of such beams in percentage was 54-56% of the initial values. The overall picture of decline of natural frequencies for beams on the series is displayed on the fig.4.

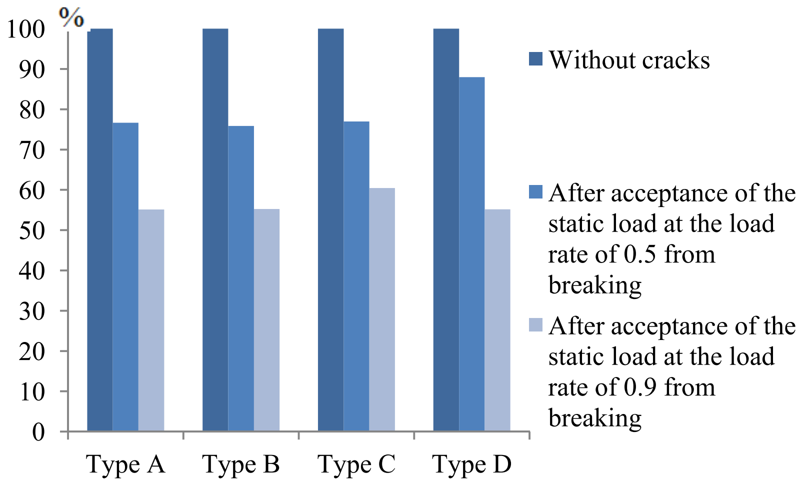


Figure 4. Dynamics of decrease of natural oscillation frequencies of beams in researched series by the results of dynamic tests

The analysis of change of the quantitative dynamic characteristics of the experimental samples consisted also in determination of the actual logarithmic decrement (fig. 5). The diagrams of the absolute and relative (concerning values of logarithmic decrements for beams to their static loading) values of the decrements were drawn on the results of tests.

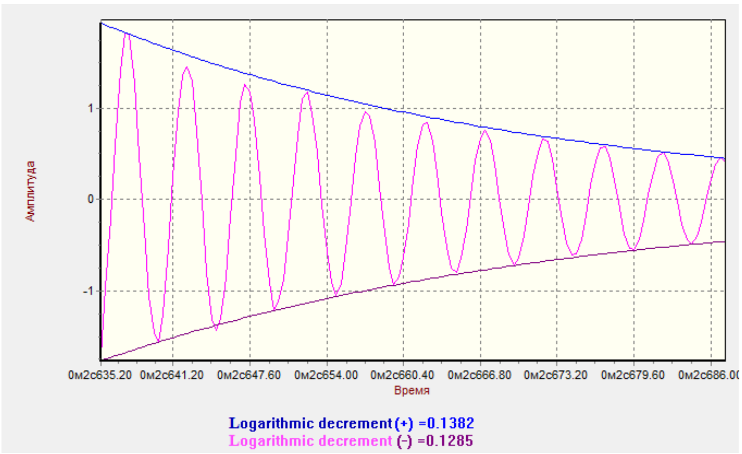


Figure 5. Logarithmic decrement is defined by a system of seismic monitoring.

The average value of the logarithmic decrement made up 0,1475 for beams of a series A and it appeared the least. It should be noted, that value of logarithmic decrement for beams of a series A remained minimal compared with similar values of decrements for beams of other series by results of the subsequent stages of tests. The maximum value of the logarithmic decrement was obtained in the tests of beams series C. Logarithmic decrement for such beams increased after perception a static loading by them at a rate of 0,9 from breaking load from value 0.1885 at the first stage to 0.4430, that are more than values of logarithmic decrements 0.4120 and 0.3840 for beams of series A and B respectively. Logarithmic decrement for series D beams perception after them by a static loading at a rate of 0,9 from the failure load was 0.4165. However, having taken into consideration the relative values of oscillation damping rates, we note an increase in decrements for series A beams in 1,91 times after perception beams of dead loads at a rate of 0,5 from breaking load and in 2,6 times after by the experimental samples perception of loadings at a rate of 0,9 from breaking load. Decrement increased in 1,79 and in 2,39 times for series "B" beams, and in 1,65 and in 2,35 times for series C beams, respectively. Logarithmic decrements increased in 1,83 times after static loading-unloading at the load rate of 0.5 from breaking load and in 2,86 times after static loading-unloading at the load rate of 0.9 from breaking load for beams without joints.

As could be seen from fig. 6, the test of reinforced concrete beams of A series showed the smallest increment of the logarithmic decrement in absolute values and at the same time the greatest dynamics of its increase in relation to the initial values. Decrement values in the beams with splined loop joint (Series B) and in the beams without joints (Series D) were comparable with each other. At the same time as the result of experimental researches the absolute values of the logarithmic decrement in beams with keyless loop (Series C) were maximal.

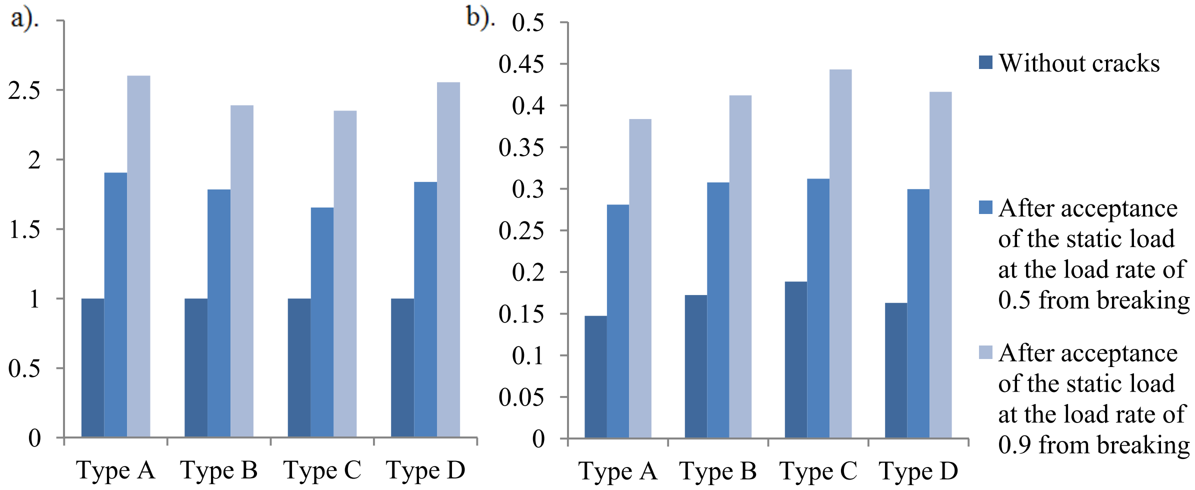


Figure 6. Changing the logarithmic decrement in the experimental beams during testing:
a- the relative increase in values of decrements;
b – the absolute values of decrements.

Dynamic tests of beams were held in two stages. In the first phase, all test samples were tested by vibration load before the static loading. In the second stage the dynamic test of the specimens were carried out after static load reaching a value of 0.5 and 0.9 of the breaking load. Vibration frequency of dynamic effects was increased stepwise from 2 Hz to 16 Hz (step 2 Hz). According to the results of dynamic tests of beams we defined the amplitudes of vibration accelerations, velocities and displacements. When processing of vibration signals the digital filtering was performed with the help of "Seismic monitoring" (fig.7).

For all tested beams the increase in values of amplitudes was registered at low frequencies (from 1 Hz to 6 Hz). The reason of this fact can be the natural frequency of fluctuations of all test set, consisting not only of experimental beams with vibrator, but also of the metal frame mounted on rubber vibration dampers which serve as a support for the test samples. In this case, it is necessary to speak not about the behavior of the experimental sample with loop joint as a whole but about the behavior of the loop joints of various configurations in the perception of vibration loads. For this reason, the values of vibration

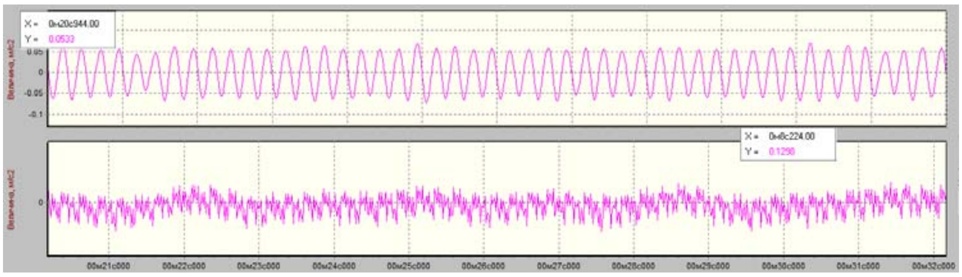


Figure 7. Vibrating beam acceleration signal after filtering (on the top) and the recorded signal (bottom).

displacement, vibration speed and vibration accelerations at low frequencies were not taken into consideration in the analysis of the experimental data.

Summarizes diagrams of vibration displacement depending on frequency of vibrator for each series of experimental samples are submitted in fig. 8. Diagram shows three experimental curves: dependence of vibration displacement on frequency for beams before tests by a static loading and dependence of vibration displacement for the same experimental beams after a static loading of beams loading in 0.5 and 0.9 from breaking load.

It is established, that at tests of the reinforced concrete beams vibration displacement after static loading-unloading at the load rate of from breaking load were above the similar values received on

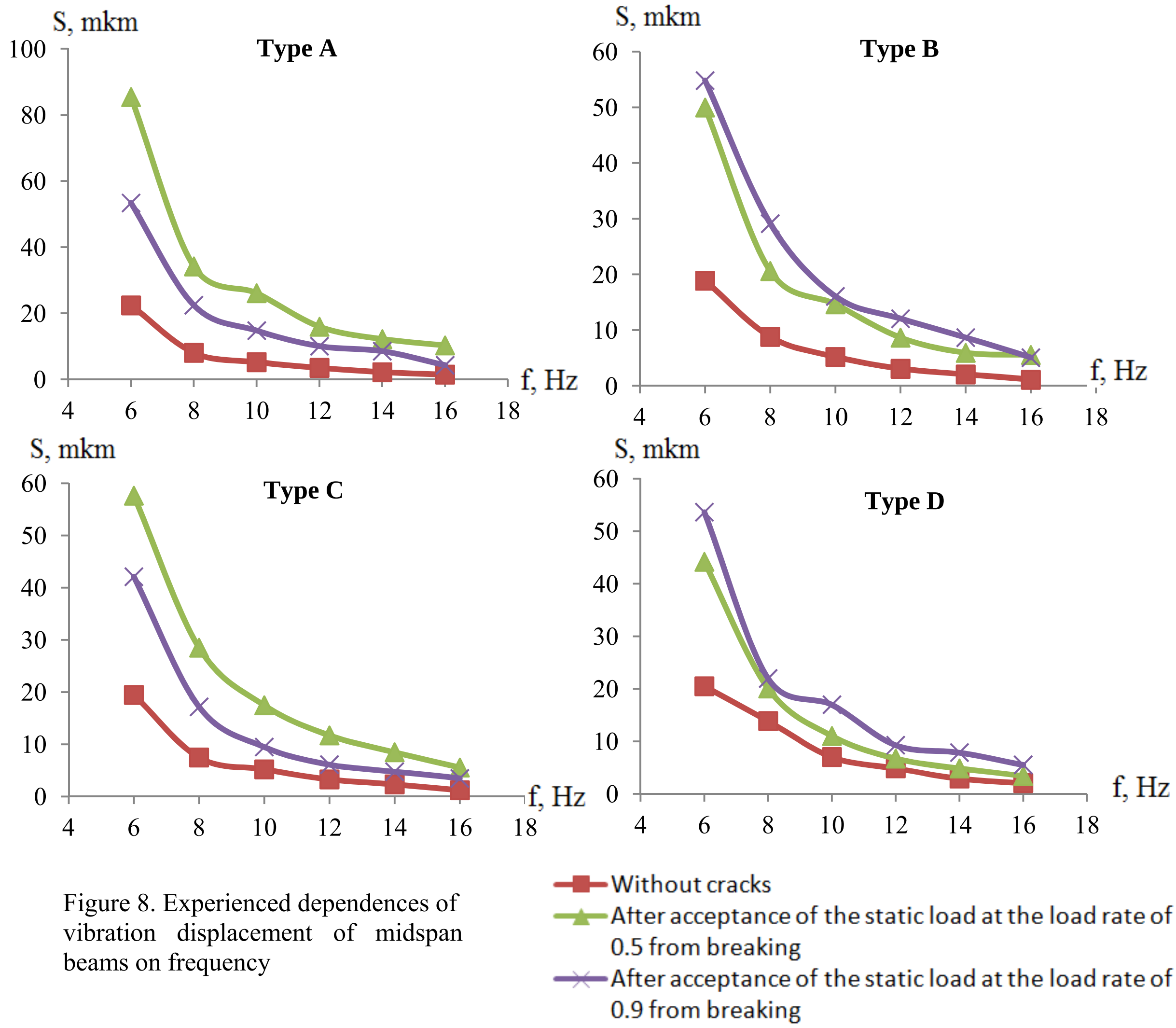


Figure 8. Experienced dependences of vibration displacement of midspan beams on frequency

beams before test by a static loading. The significant differences in the perception of vibration load by loop joints manifested in tests of experimental reinforced concrete samples after static loading-unloading at the load rate of 0.9 from breaking load.

At this stage displacement in beams with splined loop joints became even higher than the similar values obtained at the previous stages. The same dependence was observed and at the tests of the experimental beams of a series D executed without a joint. At the same time, at test of beams with the loop joint made by the Uniform Girderless Framework - 2.5 technologies and beams with a splined loop joint vibration displacement appeared much less than the same values obtained at tests of the same samples after static loading-unloading at the load rate of 0.5 from breaking load.

3. CONCLUSIONS

Comparing the diagrams of vibration displacement depending on frequency of vibrator for beams with loop joints of series A, B, C and beams without joints of series D for each stage experimental research (before loading the static load and after static loading-unloading at the load rate of 0.5 and 0.9 from breaking load) with the help of multiple repeating vibration loading showed the following (fig.9):

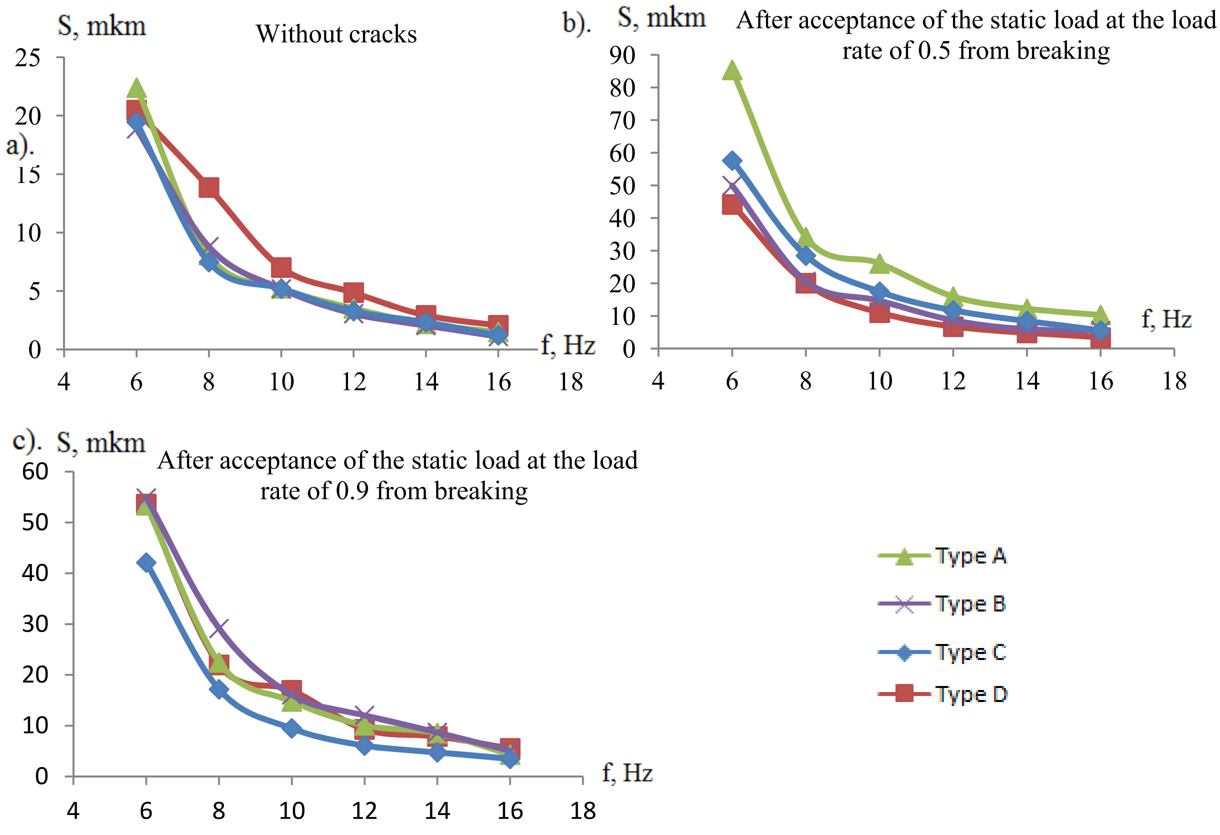


Fig.9. Results of dynamic tests - diagrams of vibration displacement depending on frequency. Stepwise overlay for all series:
a - without cracks;
b - after acceptance of the static load at the load rate of 0.5 from breaking;
c - after acceptance of the static load at the load rate of 0.9 from breaking.

1. The dispersion of values of vibration displacement of all beams with loop joints in the central zone of beams was small at test of the experimental samples without cracks by dynamic load. At the same time vibration displacement of beams of series D in the midspan differed considerably in a bigger way - by 30-40% from the similar values for the remaining beams.

2. Further tests of beams with loop joints by dynamic load after static loading-unloading at the load rate of 0.5 from breaking load showed the larger dispersion of absolute values of vibration displacement (fig.9.a-9.b). When comparing dependency diagrams it is visible that the D-series beams have the least amplitude of vibration displacement in the midspan. At this stage of experiment B-series beams with splined loop joint showed the closest to reference D-series beams values of vibration displacement. The difference between these indicators amounted to 22-32 %. Vibration displacements of C-series beams were already 58-75% higher than values of vibration displacement of beams without joints. It is possible to consider test of data for A-series beams a little unexpected. Vibration displacements of such beams were in 2.4-2.55 times and at 16 Hz in 3 times larger than vibration displacement of beams without joints.

3. It is possible to see the following changes on series in test data at tests after static loading-unloading at the load rate a component 0.9 from breaking load. When comparing dependency diagrams in fig. 9 it is visible that vibration displacement in the midspan of C-series beams with keyless loop joint 35-44% less than the values of vibrodisplacement of beams of a series D executed without joints. In turn, vibration displacement of beams with splined loop joint (series B) and with loop joints by Uniform Girderless Framework - 2.5 technology (series A) are comparable to values of displacement of beams without joints and differ from the last in 6-10%.

4. Tests of reinforced concrete beams with different configuration of sides of loop joints by a vibration variable sign load showed existence of advantages to each of a configuration of joints in specific conditions. A rigidity of loopback connections of beams with splined loop joints was maximal after static loading-unloading at the load rate of 0.9 from breaking load. This configuration of a joint at the final stage of researches is optimum on indexes of rigidity characteristics. Researches allow to make a conclusion on rationality of B-series beams with splined loop joints as well as joints in A-series beams (on the UGF-2.5 technology) in precast and cast-in-situ constructing.

5. Comparison of the results of vibration monitoring of_constructions and results of definition of the main dynamic characteristics by the method of instantaneous load shedding allows to make a conclusion on a correctness and reliability of the received results. In the future improvement of a complex of equipment for vibration monitoring, and also the software for processing of the received results is planned.

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