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Dynamic tests and monitoring of the dynamic state of buildings and structures based on microseismic vibrations

E.A. Khoroshavin
Krasnoyarsk Institute of Railway Transport - branch Irkutsk State Transport University, Krasnoyarsk, Russia
** E-mail: zkpd2007@ya.ru*

Keywords: method of standing waves, dynamic testing of buildings, dynamic characteristics of buildings, geophone, analog signal recorder, microseismic vibrations recording, building dynamic behavior monitoring

Abstract. The article considers organizing and conducting dynamic testing of a multi-story residential panel building in Krasnoyarsk. For dynamic testing, a hardware-software complex was developed that implements the standing wave method, allowing to determine the dynamic characteristics of a building by registering microseismic vibrations of building structures. The dynamic test results determined actual natural (resonant) frequencies and their oscillations modes for the building structures. From the analysis of the distribution of the peak values of the amplitudes of natural vibrations, we determined the dangerous zones of the occurrence of destructive processes in the soil of the base of the building, affecting its safe functioning.

1. Introduction

The study of the technical condition of building structures is an independent area of construction activity, covering a number of issues related to the creation of normal working and living conditions of people in buildings and structures and ensuring the operational reliability of buildings and structures. Assessment of the technical condition of buildings and structures on the basis of the standard[2] is determined by instrumental examination methods that allow obtaining objective and sufficient information about the properties of materials, the behavior of structures and the actual operation of the structure [1–4]. Known methods of non-destructive testing and diagnostics of the state of building structures of buildings and structures (mechanical, ultrasonic, etc.) make it possible to determine the physic mechanical properties of concrete, reinforced concrete or metal structures, as well as the state of foundation of foundations of structures in a limited measurement area and to carry out defectoscopy of building structures. To determine the integral strength characteristics of building structures of buildings and structures, these methods are generally unsuitable.

Existing systems for assessing and monitoring buildings and structures in the Russian Federation and abroad, created by individual ministries and departments on a sectoral basis, also do not satisfy the modern security requirement. They do not provide the necessary accuracy in determining the parameters of the technical condition, do not allow combining the monitoring of technical condition with the registration of earthquakes at objects located in seismically dangerous areas. Currently there is no single system for assessing and monitoring the technical condition of buildings and structures to ensure their safe operation [5–16].

Experimental methods for studying the vibrations of buildings and structures (dynamic tests) have been and continue to be an effective research tool for modern building science [17–26], since the parameters determined during these studies are it is an individual set of parameters of the dynamic characteristics of natural vibrations inherent in each building and structure. They depend on the properties of the soil at the base of the building, on the structural design of the building, workmanship, characteristics

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of the material and structures, on existing defects, i.e. from the set of components that determine the bearing capacity of structures and allow to evaluate its technical condition.

Research methods for the natural vibrations of buildings can be divided:

1. Impact testing;
2. Testing by pulling (quick release of load);
3. Tests of buildings and structures with powerful vibrators mounted on the roof;
4. Vibration testing of buildings and structures with a source located outside of buildings and structures;
5. Studies of fluctuations of buildings and structures under the influence of industrial explosions and special explosions in lakes;
6. Studies of the reactions of buildings and structures to earthquakes;
7. The study of buildings and structures based on the study of microseismic vibrations.

Each of the mentioned methods has its advantages and disadvantages and with one degree or another solves the tasks assigned to it [27–39].

The study of buildings using microseismic noise has always been attractive because there is no cost to excite vibrations. The cheapest method, however, it was commonly believed that the results obtained with microseismic noise are inferior in accuracy to all other methods. With the advent of high sensitivity sensors (from 100 mV/(m/s²)) and digital signal processing, it became possible to register and isolate building vibrations arising from the action of a load applied to its structures, the intensity of which is comparable to the background from natural microseisms. This stimulated the development and creation of modern mobile diagnostic systems [40–44]. Such diagnostic complexes of the All-Russian Research Institute of Civil Defense and Emergencies as “Struna” and “Strela”, which are actively used to assess seismic resistance and diagnostics of buildings and structures. A distinctive feature of dynamic tests using these complexes is the registration of microoscillations of the objects under investigation (from fractions of millimeters to several millimeters), which has been known for a long time, but until recently its use was limited both by the capabilities of the recording equipment and sensors and by the level of processing the received signal. This method was called the method of free oscillations.

The methodology for determining the dynamic characteristics of building structures by their free vibrations excited by the action directly on the structure external pulse load, includes the following operations:

- arrangement of measuring sensors on structures;
- excitation and registration of oscillations;
- calculation of their Fourier spectra;
- analysis of Fourier spectra in order to isolate resonant peaks corresponding to various forms of free vibrations;
- obtaining, using the inverse Fourier transform, pulsed implementations of the selected resonant peaks for each form of free oscillations;
- identification and graphic representation of various forms of vibrations.

Roughly speaking, this technique is a measurement of the characteristics of a linear system as a result of a reaction to a broadband effect in the form of a δ-function or step. The idea is reasonable, widely used in practice in the study of linear systems [2, 3, 11, 13, 26]. The disadvantage is the low detail of the data and the low accuracy of the results.

Another method, called the standing wave method, was developed by the Geophysical Service of the Siberian Branch of the Russian Academy of Sciences (GS SB RAS, Doctor of Engineering A.F. Emanov) [17–19, 45] for a detailed study of the physical condition of buildings and structures at the level of structural elements. Unlike other methods, this method uses the natural vibrations of many frequencies. The only method that determines the phase parameters of the field of standing (natural) waves. Studying the field of standing waves with any detail makes it possible to obtain information about local hidden defects in the structure.

The idea of the method is that a small number of sensors moving in space that record microseismic vibrations determine their own (standing) waves with the required detail in buildings or engineering structures of any complexity. In other words, using small-channel equipment (using ten sensors), large engineering structures (hydroelectric power stations, bridges, high-rise buildings, etc.) can be examined [43, 47–51].

The essence of the method is to determine the field of its own (standing) waves of the structures of the structure. It is these vibrations that characterize the internal structure of the building and the state of its structures. The natural vibrations of a building are a set of standing waves, the dynamic characteristics of which are individual for each building and do not depend on time or on external influences. They are the reaction of the object to any external influences that come to it through the foundation (microseisms) or walls (wind load). The dynamic properties of buildings and structures are determined by the properties of the underlying soil and foundation, the mass and elastic characteristics of structures, the type and quality of the connection of individual blocks, parts and elements of buildings and structures. A change in these properties over time during operation leads to corresponding changes in the parameters of the dynamic characteristics of vibrations of buildings and structures. An analysis of the obtained frequency, amplitude and phase characteristics of the wave field of the object allows us to establish the presence of changes in the properties of the soil of the base and defects in the structure of the object that arise during its operation, and also allows you to get estimates of the technical condition of the object. This technology is unique and has no analogues abroad.

The purpose of this study, as a result of dynamic testing of a building based on the standing wave method, is:

- Determination of the main dynamic characteristics of the building (frequencies and forms of natural vibrations, amplitudes and phases, characteristics of the damping of oscillations) on a dense measurement system;
- Obtaining a distribution of the dynamic characteristics of natural vibrations among structural elements of a building;
- Identification of hazardous areas and weaknesses (defects and cracks) in the building;
- Obtaining a detailed (with the required degree of detail) reliable picture of the technical condition of the building.

The technology for conducting dynamic tests of a building based on the standing wave method requires solving the following problems:

- Definition of the arrangement of recording sensors;
- Conducting sequential registration of seismic micro-noise with low-channel equipment on all load-bearing structural elements of the building. Registration is carried out continuously in one or more reference points;
- Processing of registration data of microseismic vibrations of building structures, which is performed on the basis of the standing wave recalculation methodology (GS SB RAS, A. F. Emanov) [19, 22]. As a result of processing the micro-noise records, for the object being examined, simultaneous records of standing waves are obtained from simultaneous consecutive observations with reference points;
- Building a 3D geographic information system (GIS) - a model for representing the amplitudes and phases of the natural oscillation fields of a building and its structural elements;
- Construction of coherence spectra and error spectra to highlight the natural frequencies of the parameters of the field of standing (natural) waves and their modes of vibration, allowing to identify defects and weaknesses in the building structures;
- Analysis of the distribution of the dynamic parameters of the wave field over the structural elements of the building to assess the technical condition of the building.

2. Methods

The studies were conducted in the hostel No. 22 of the Siberian Federal University. The dormitory building consists of four reinforced concrete panel sections and a monolithic public block connecting interconnected panel double sections. In the first section of the hostel, during its operation, cracks appeared in the interface nodes of structural elements along the entire height of the building. Dynamic tests were carried out as part of the inspection and monitoring of the technical condition of the building to assess the possibility of its further trouble-free operation or the need for its restoration and strengthening of structures. For dynamic testing, a hardware-software complex was developed that implements the standing wave method [25, 42, 43, 51].

Microseismic vibrations of the dormitory building structures were recorded using the Standing Waves Method (MSW-1) mobile diagnostic complex, which is a multi-module system of 10 three-component recorders of the Baikal-ASN8 extended frequency range (Figure 1). Table 1 presents its technical characteristics.

Table 1. Technical characteristics of the Baikal-ASN8 microseismic oscillation registration system.

No	Characteristic	Units rev.	Value
1	The number of channels of one module		3
2	Data capacity	Bit	24
3	Input Type		differential
4	Input impedance	Ком	20
5	Max. sampling frequency	Hz	16000
6	Working frequency band (- 3 dB)	Hz	4000
7	Reference Generator Stability		2*10-8
8	Power consumption	Wat	<0.5
9	Диапазон рабочих температур	°C	-30 + +60
10	Weight	kg	4.5

Figure 1. Baikal-ASN8 recorders with A1637 sensors.

The recorders have time synchronization via GPS and a USB 2.0 channel for communication with a computer for programming and data transfer. The recorder is powered by built-in batteries. Data microseismic oscillations are recorded on the built-in drive (SD card), followed by transfer to a computer via USB.

The software runs on WindowsXP. The controls allow manual control of the registrar. Three-component accelerometers A-1637 are used as geophones.

The three-component accelerometer (seismic receiver) A1637 (Figure 2) is designed to convert vibrational acceleration into a proportional electrical signal. The seismic receiver is used as a primary transducer in the composition of seismic and vibration measuring systems and complexes, and can also be used in various fields of science and technology when measuring (recording) low-frequency low-level vibration parameters.

Figure 2. General view of the A1637 seismic receiver.

The scope of the A1637 seismic receiver: seismic exploration, control of vibrations of buildings and structures, as well as vibration of turbines and shafts of power plants.

Normal conditions for the use of a seismic receiver:

- ambient temperature from 18 to 25 °C;
- relative air humidity from 45 to 80 %;
- atmospheric pressure from 84 to 106.7 kPa;
- sound pressure level of acoustic fields no more than 60 dB;
- power supply voltage of the seismic receiver ± (12 +0.5) V;
- instability of supply voltage no more than 0.5%;
- voltage ripple no more than 1 mV.

Operating conditions for use:

- ambient temperature from minus 40 to plus 50 °C;
- relative air humidity up to 90% at 30 °C;
- atmospheric pressure from 84 to 106.7 kPa;
- power supply voltage of the geophone + (12 ± 2) V;
- instability of supply voltage no more than 0.5%;
- voltage ripple no more than 1 mV.

Microseismic oscillations were recorded in two stages. The first stage in 2014. Microseismic vibrations of the dormitory building structures were recorded in two sections, in axes I-III (Figure 3) at the attic floor mark and on the floors of the building with a pitch of geophones 3 meters apart.

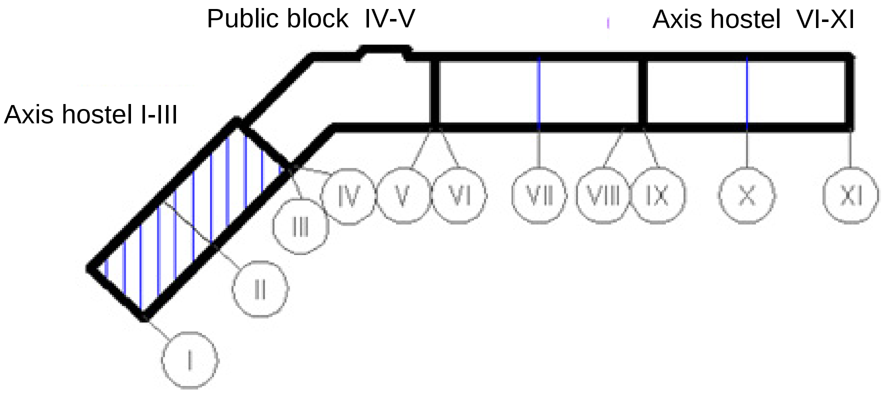


Figure 3. Scheme of the investigated object.

At the attic floor mark, the registration of microseismic vibrations with small-channel equipment was carried out at 120 observation points (Figure 4).

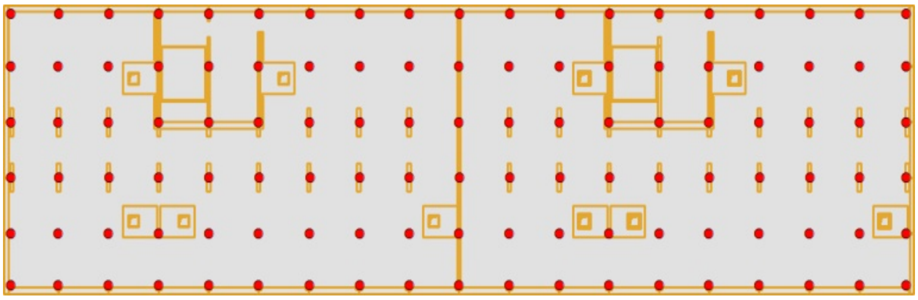


Figure 4. Observation points of microseismic noise at the attic of the hostel in 2014.

Microseismic vibrations with small-channel equipment on the floors of two sections of the hostel were recorded at 180 observation points (Figure 5).

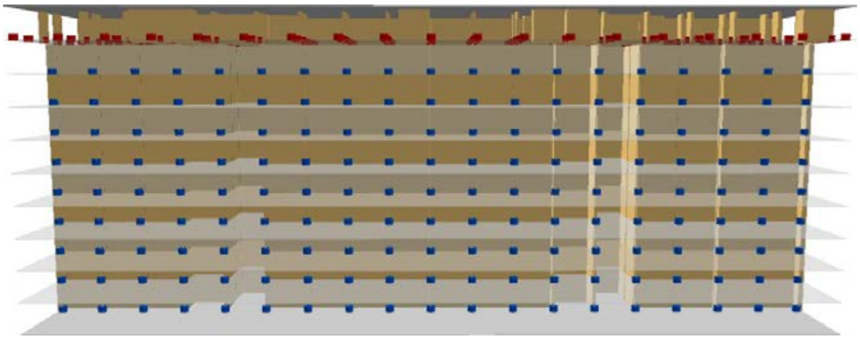


Figure 5. Observation points of microseismic noise on the floors of the hostel in 2014.

The second stage was held in 2015. Re-registration of microseismic vibrations of the dormitory building structures was carried out in axes I-II (Figure 6) at the attic floor mark.

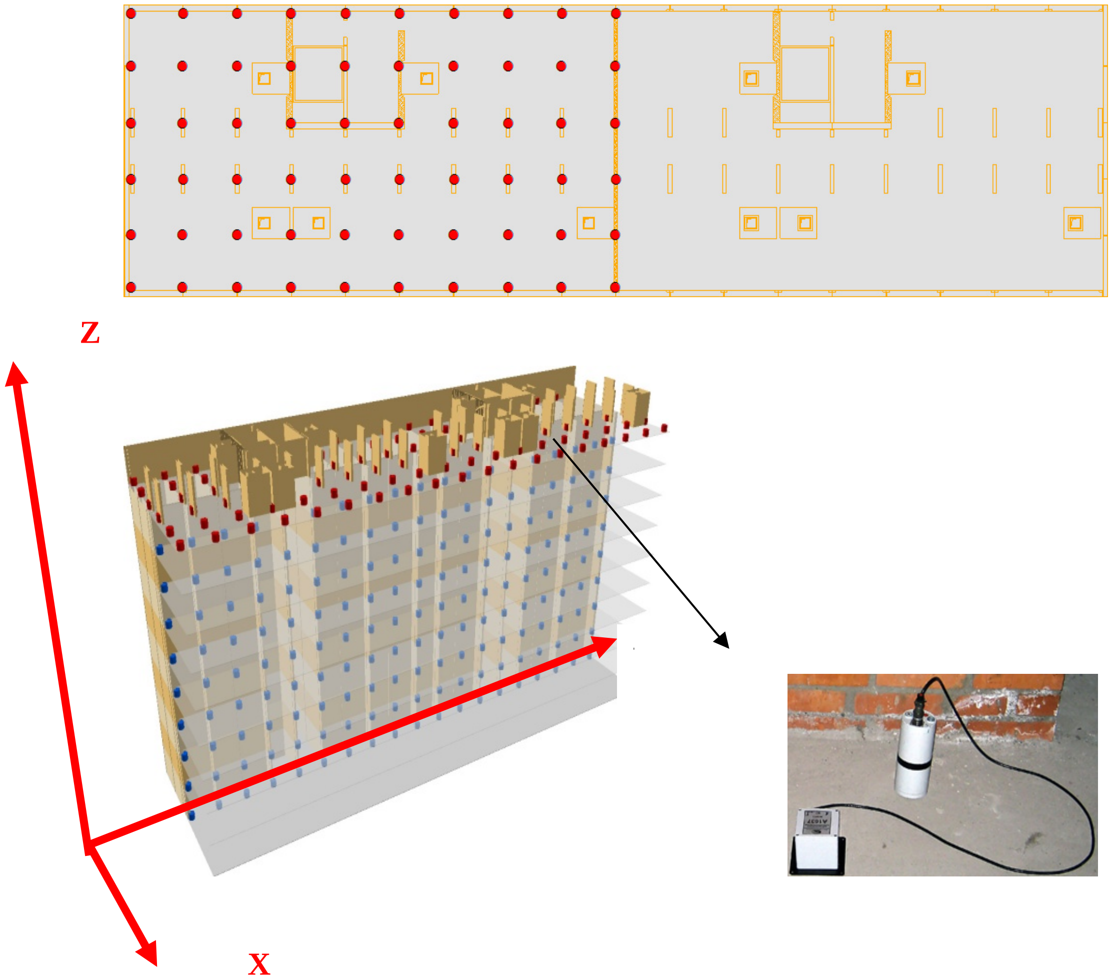


Figure 6. Observation points of microseismic noise at the attic of the hostel in 2015.

To record microseismic noise with small-channel equipment, 10 seismic detectors were used. The registration time was 15 minutes, after which the equipment moved to the following observation points. The sensor at the reference point remains in place during the entire measurement cycle.

As a result of the processing of micro-noise records, obtained simultaneous records of standing waves from different-time, sequential observers with reference points. The processing procedure is reduced to the following operations:

- Primary processing of micro-noise records, open input data for calculating functions between observer points;
- Calculation of vibration functions at reference points with oscillations at each observation point;
- Recalculation of standing waves from reference points to all points of the object being examined.

The oscillations are recorded simultaneously at two reference points and at each i-th (or group of i-x) points in turn. Obtaining simultaneous recordings of standing waves from different time observations with two reference points is reduced to the following operations. Simultaneous recordings are divided into separate intervals (implementations) with a recording length of ~ 16 seconds. The frequency characteristics of the Wiener two-channel filter are estimated using the formulas:

$$L_{1i}(\omega)=\frac{\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{i,j}^{*}(\omega)\left[1-\frac{\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{2,j}^{*}(\omega)\sum\limits_{j-1}^{n}\bar{F}_{2,j}(\omega)\bar{F}_{i,j}^{*}(\omega)}{\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{i,j}^{*}(\omega)\sum\limits_{j-1}^{n}\left|\bar{F}_{2,j}(\omega)\right|^{2}}\right]}{\sum\limits_{j-1}^{n}\left|\bar{F}_{1,j}(\omega)\right|^{2}\left[1-\frac{\left|\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{2,j}^{*}(\omega)\right|^{2}}{\sum\limits_{j-1}^{n}\left|\bar{F}_{1,j}(\omega)\right|^{2}\sum\limits_{j-1}^{n}\left|\bar{F}_{2,j}(\omega)\right|^{2}}\right]} \qquad (1)$$

$$L_{2i}(\omega)=\frac{\sum\limits_{j-1}^{n}\bar{F}_{2,j}(\omega)\bar{F}_{i,j}^{*}(\omega)\left[1-\frac{\sum\limits_{j-1}^{n}\bar{F}_{2,j}(\omega)\bar{F}_{1,j}^{*}(\omega)\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{i,j}^{*}(\omega)}{\sum\limits_{j-1}^{n}\bar{F}_{2,j}(\omega)\bar{F}_{i,j}^{*}(\omega)\sum\limits_{j-1}^{n}\left|\bar{F}_{1,j}(\omega)\right|^{2}}\right]}{\sum\limits_{j-1}^{n}\left|\bar{F}_{2,j}(\omega)\right|^{2}\left[1-\frac{\left|\sum\limits_{j-1}^{n}\bar{F}_{1,j}(\omega)\bar{F}_{2,j}^{*}(\omega)\right|^{2}}{\sum\limits_{j-1}^{n}\left|\bar{F}_{1,j}(\omega)\right|^{2}\sum\limits_{j-1}^{n}\left|\bar{F}_{2,j}(\omega)\right|^{2}}\right]} \qquad (2)$$

These formulas allow you to connect two reference points with two-channel Wiener filters, recalculating standing waves, with all points of the observation system. Thus, for each observation point, we obtain the coupling functions L_1 and L_2 that allow us to obtain the wave field parameters in it from simultaneous recordings at reference points.

Choosing any implementation F at the reference points, we recalculate it into a simultaneous wave field at all observation points using the following formula:

$$F'_{i}(\omega)=L_{1,i}(\omega)\bar{F}\ (\omega)+L_{2,i}(\omega)\bar{F}\ (\omega) \qquad (3)$$

To build the relationships between the points of the building and build a model of propagation and transmission of wave effects, coherence spectra and error spectra are calculated. The coherence spectrum $\gamma(\omega)$ is a measure of the linearity of the coupling of vibrations between two points of an engineering structure. The values of the coherence spectra increase at the frequencies of normal modes and decrease between them. In the error spectrum, on the contrary, $\sigma(\omega)$ - the values decrease at the frequencies of the normal modes and increase between them. The ratio of these spectra allows us to select the eigenfrequencies.

The recording coherence spectrum at the i point relative to one of the reference points is calculated by the formula:

$$\gamma^{2}(\omega)=\frac{\left|\sum\limits_{j-1}^{n}\bar{F}_{i}(\omega)\bar{F}_{0}^{*}(\omega)\right|^{2}}{\sum\limits_{j-1}^{n}\left|\bar{F}_{0}(\omega)\right|^{2}\sum\limits_{j-1}^{n}\left|\bar{F}_{i}(\omega)\right|^{2}}, \qquad (4)$$

where $F_i(\omega)$, $F_0(\omega)$ are the spectra of simultaneous recordings of standing waves at the i-th point of the object being examined, and the base point

Taking into account that in the filter for recalculation of standing waves the phase spectra are averaged over n independent realizations, it can be argued that the variance of the random error will decrease n times. With this in mind, the standard error of the phase characteristic (error spectrum) of the eigenfrequency separation is calculated by the formula:

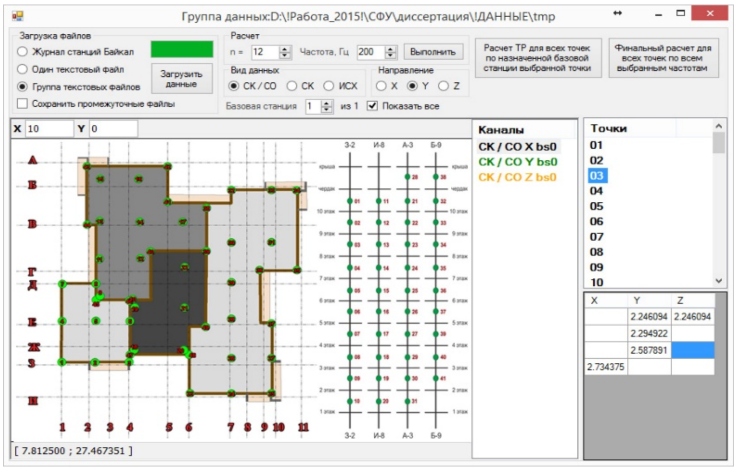
$$\sigma_\theta(\omega) \approx \frac{\sqrt{1-\gamma_{oi}^2(\omega)}}{|\gamma_{oi}(\omega)|\sqrt{2n}}. \quad (5)$$

3. Results and Discussion

To process the data of dynamic tests, a software package "Standing Waves Method" was developed [25, 42, 43, 51], which makes it possible to determine the dynamic characteristics of an object, select natural frequencies and visualize test results in a three-dimensional geoinformation system (GIS) – a model of the object under study (Figure 7–11).

The program provides:

1. Binding of sensors to the building plan and registration time (Figure 7);
2. Import of microseismic vibration logs (Figure 8);
3. Storage of initial, intermediate and output information;
4. Construction of coherence spectra, normalized to spectra of errors of microseismic vibrations to identify natural frequencies of the building (Figure 9);
5. Determination of natural frequencies and modes of vibration of the building. Determination of phase and amplitude characteristics of the wave field of natural oscillations of the building (Figure 10–11);
6. Ability to work within the program with a three-dimensional model of the building;
7. Possibility of constructing various types of diagrams using the standing wave technique.



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n = 12 Частота, Гц 200

Вид данных
● СК / СО ○ СК ○ ИСХ

Направление
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Базовая станция 1 из 1 ☑ Показать все

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Каналы
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Точки
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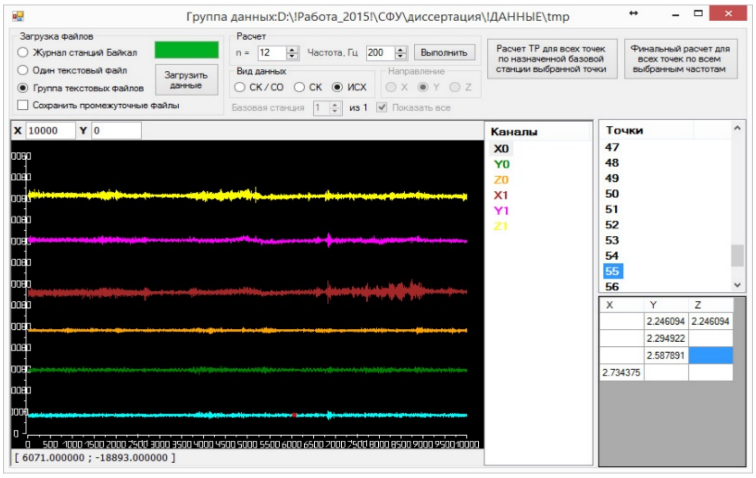
[7.812500 ; 27.467351]

Figure 7. Interface of the “Standing Wave Method” program. Arrangement diagram of the recording sensors.



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n = 12 Частота, Гц 200

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○ СК / СО ○ СК ● ИСХ

Направление
○ X ● Y ○ Z

Базовая станция 1 из 1 ☑ Показать все

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Точки
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X	Y	Z
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	2.294922	
	2.587891	
2.734375		

[6071.000000 ; -18893.000000]

Figure 8. Interface of the “Standing Wave Method” program. Primary data of monitoring of microseismic vibrations recorded by Baikal-ASN8 stations.

Figure 9 shows the calculation of the coherence spectra.

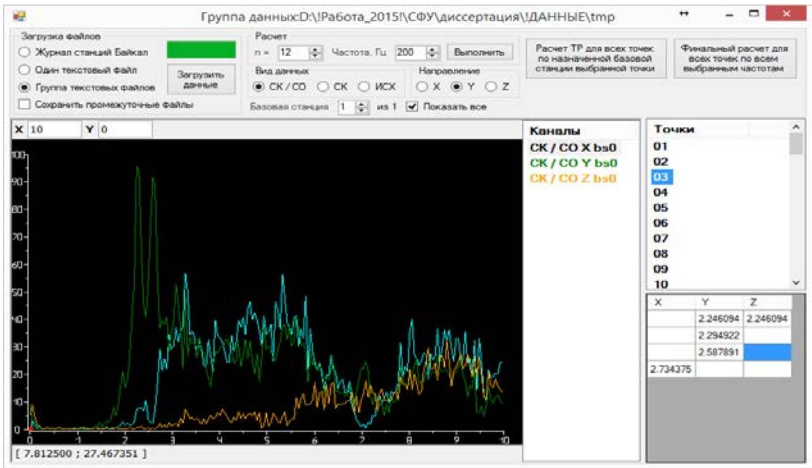


Figure 9. Interface of the "Standing Wave Method" program. Construction of coherence spectra normalized to error spectra.

Figure 10. Interface of the "Standing Wave Method" program. Construction of phase diagrams of natural vibrations. Forms of natural vibrations.

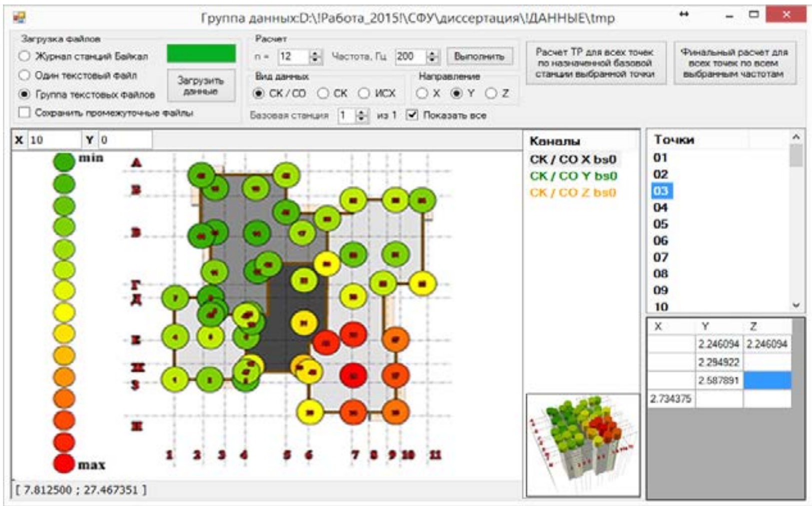


Figure 11. Interface of the "Standing Wave Method" program. Construction of diagrams of natural vibration amplitudes.

As a result of dynamic tests of the dormitory building at the first stage in 2014. the actual frequencies of the first and second modes of natural vibrations were obtained (Figure 12).

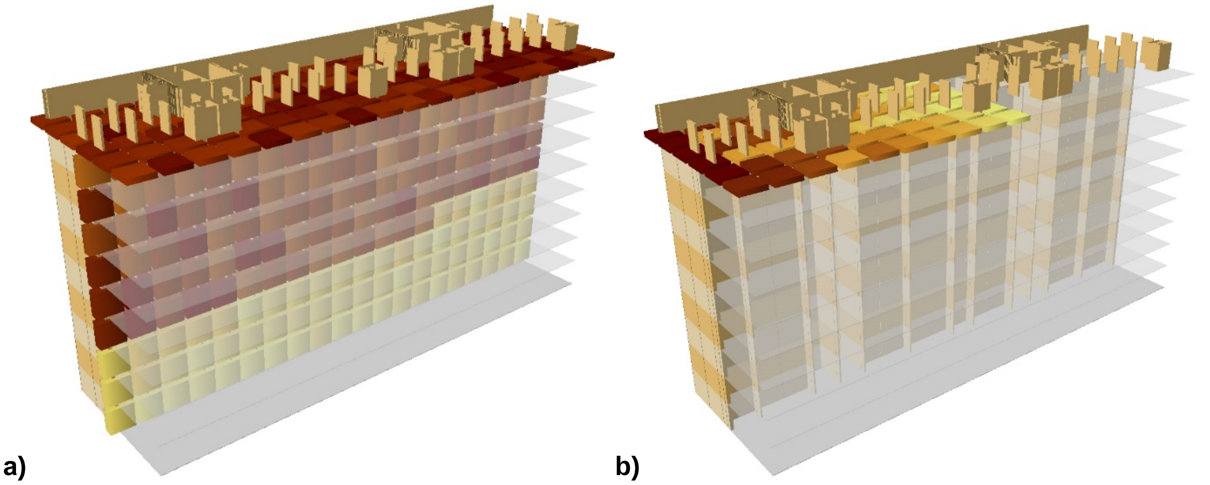


Figure 12. 3D GIS-model of the studied object. a) Maximum amplitudes of the 1st form of natural vibrations at a frequency of 2.34 Hz along the Y-component in 2014. b) Maximum amplitudes of the 2nd form natural vibrations at a frequency of 2.67 Hz along the Y-component in 2014.

Figure 13 shows the isolines of the maximum amplitudes on the plan of the attic space obtained in 2014.

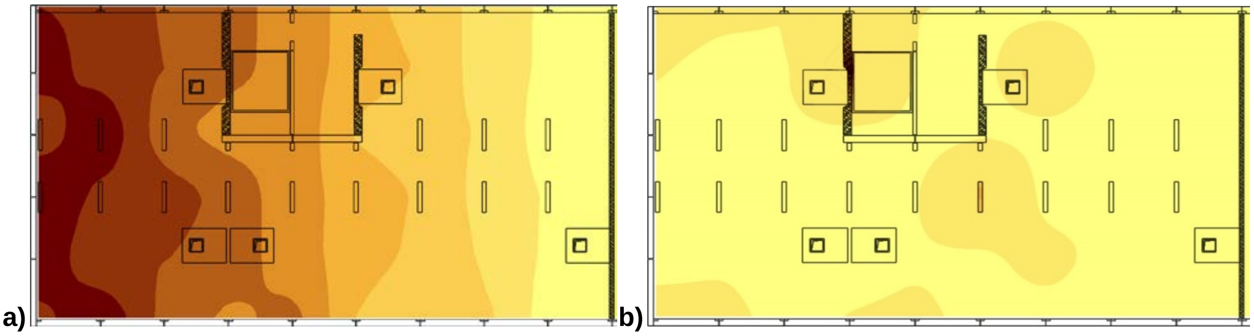


Figure 13. Isolines of maximum amplitudes on the plan of the attic space obtained in 2014. a) Maximum amplitudes of the 2nd form natural vibrations at a frequency of 2.67 Hz along the Y-component. b) Maximum amplitudes of the 2nd form natural vibrations at a frequency of 2.67 Hz along the Z-component.

At the second stage in 2015. as a result of dynamic tests of the dormitory building, the actual frequencies of the first and second forms of natural vibrations were re-obtained (Figure 14).

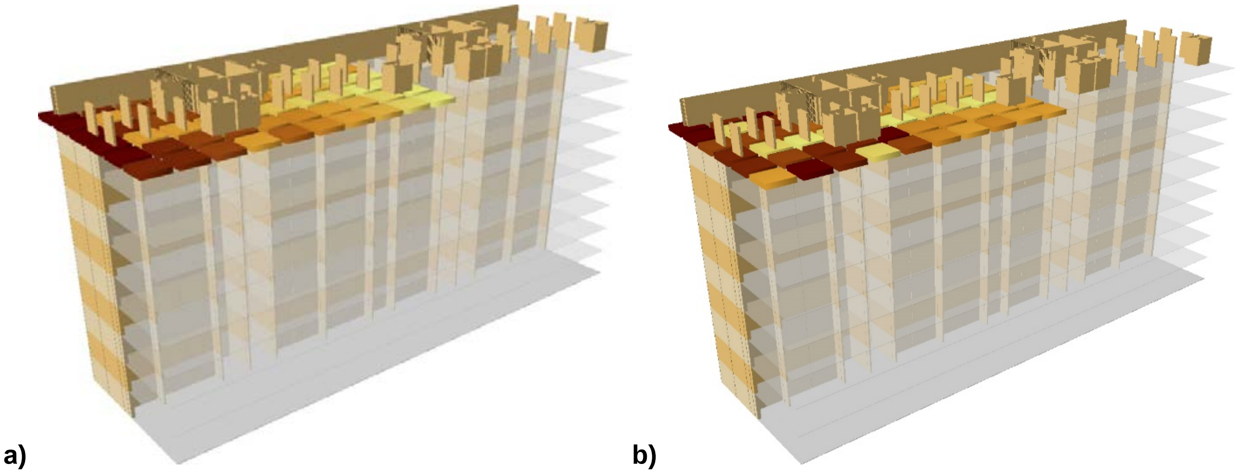


Figure 14. 3D GIS-model of the investigated object. a) Maximum amplitudes of the 1st form of natural vibrations at a frequency of 2.29 Hz along the Y-component in 2015. b) Maximum amplitudes of the 2nd form natural oscillations at a frequency of 2.59 Hz along the Y-component in 2015.

Figure 15 shows the isolines of the maximum amplitudes on the plan of the attic space obtained in 2015.

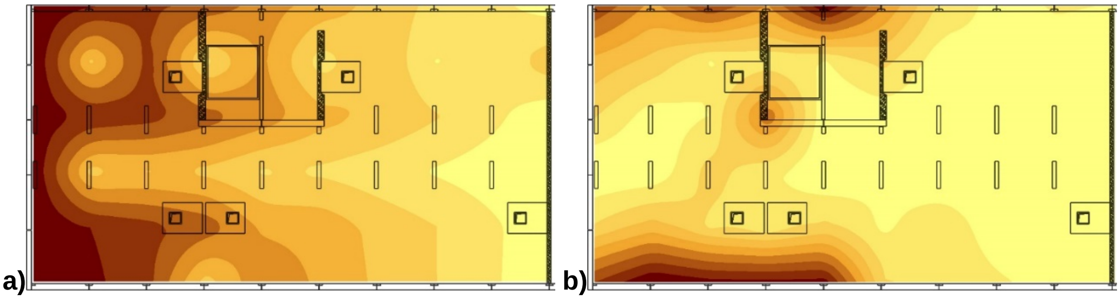
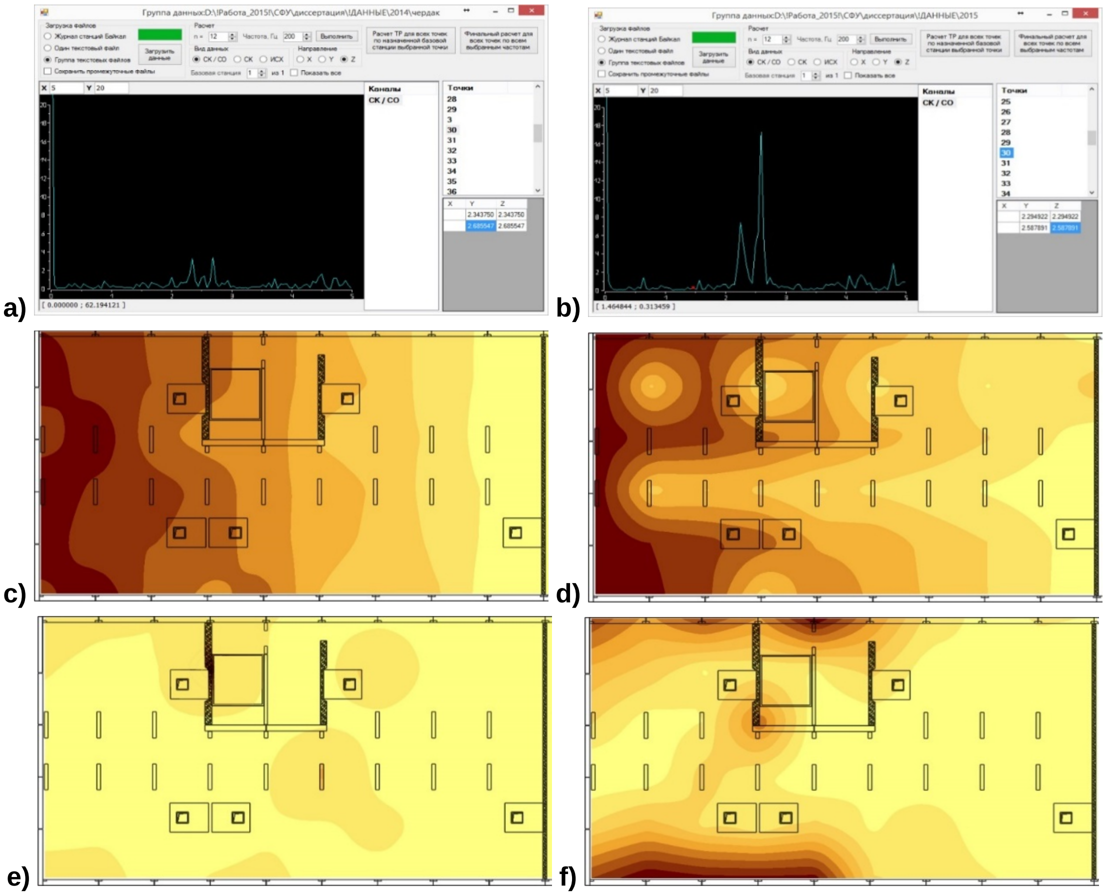


Figure 15. Isolines of maximum amplitudes on the plan of the attic space obtained in 2015. a) Maximum amplitudes of the 2nd form natural vibrations at a frequency of 2.59 Hz along the Y-component. b) Maximum amplitudes of the 2nd form natural vibrations at a frequency of 2.59 Hz along the Z-component.

As can be seen from Figure 14, there have been changes in the natural frequencies of the building during the observation period from 2014 to 2015, and in particular a decrease in the natural frequencies of the first form from 2.34 Hz to 2.29 Hz and the second form from 2.69 Hz to 2.59 Hz. This fact indicates a decrease in the overall stiffness of the building. The reason for the weakening of the stiffness of the building, as can be seen from Figure 15 b), was the peak amplitudes in the Z-component, which appeared at the second stage of testing in 2015. The occurrence of vertical components of relative displacements in the field of standing waves indicates a decrease in the bearing capacity of the building foundation in these zones.

Figure 16 shows the changes in the field of standing waves of the building obtained during the observation period from 2014 to 2015.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Каналы: СК / СО

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	2.685547	2.685547

[0.000000 ; 62.194121]

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X	Y	Z
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	2.587891	2.587891

[1.464844 ; 0.313459]

Figure 16. Changes in the field of standing waves of the building obtained during the observation period from 2014 to 2015. a) Construction of the coherence spectra normalized to the spectra of the error in the Z-component in 2014. b) Construction of the coherence spectra normalized to the spectra of the error in the Z-component in 2015. c) Maximum amplitudes of the 2nd form of natural oscillations at a frequency of 2.67 Hz along the Y-component in 2014. d) Maximum amplitudes of the 2nd form of natural oscillations at a frequency of 2.59 Hz along the Y-component in 2015. e) Maximum amplitudes of the 2nd form of natural vibrations at a frequency of 2.67 Hz along the Z-component in 2014. f) Maximum amplitudes of the 2nd form of natural vibrations at a frequency of 2.59 Hz along the Z-component in 2015.

As can be seen from Figure 16, during the repeated dynamic testing of the building, zones of the occurrence of peak amplitudes along the Z-component appeared, indicating a weakening of the bearing capacity of the soil of the pile foundation in these zones.

The obtained research results are unique and cannot be compared with the results of other authors. This is due to the features of the standing wave field, which is individual for each building. It should be noted that the results of studying the features of the standing wave field in buildings and structures obtained on the basis of the standing wave method were published in [6, 48, 50, 51].

4. Conclusions

The microseismic vibrations of building structures were recorded with the mobile diagnostic complex Method of Standing Waves (MSW-1). According to the results of dynamic tests of a residential multi-storey panel building, its dynamic characteristics are obtained. The natural frequencies, peak amplitudes and phase characteristics of the wave field of the building are determined. To distinguish the building's natural frequencies, a software package has been developed that implements the standing wave method. A GIS is built - a model for representing the amplitudes and phases of the natural oscillation fields of a building and its structural elements. An analysis of the frequency, amplitude, and phase characteristics of the wave field obtained as a result of monitoring a residential multi-storey panel building made it possible to establish the causes of cracks in the interface nodes of structural elements. The causes of cracks were the destructive processes of the soil in the pile foundation of the building, associated with a seasonal increase in groundwater. Defects of the building foundation identified as a result of diagnostics require measures to lower the groundwater level on the construction site.

Currently, the Standing Wave Method (MSW-1) mobile diagnostic complex has been used to diagnose large-span bridge structures, assess the earthquake resistance of a building with a stationary seismic isolation system, and monitor the technical condition of the Musical Theater and residential buildings. The complex can be used to solve the widest range of tasks:

- inspection of emergency buildings;
- assessment of earthquake resistance of buildings;
- audit of the quality of construction work;
- reconstruction and resumption of construction;
- scheduled inspections of industrial buildings and especially hazardous facilities;
- study of the impact of external influences on objects (explosions, construction work, etc.);
- inspection and monitoring of the technical condition of buildings and structures;
- determination of the parameters of the fundamental tone of natural vibrations for the building passport.

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Contacts:

Evgeny Khoroshavin, zkpd2007@ya.ru

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