Acta Technica *62* No. 4B/2017, 1–8

Geotechnical monitoring of the objects based on the method of inclinometric control of own frequencies[1]

Oleg R. Kuzichkin[2,4], Anastasia V. Grecheneva[2], Nikolay V. Dorofeev[3], Vadim V. Mishunin[2]

Abstract. This article presents analysis and proves the use of phase indicating method of the inclinometric control in geotechnical monitoring systems based on analysis of own frequencies of the construction. It is proved that use of accelerometers for control of own frequencies of construction oscillations as integral parameter of the construction condition gives frequency shift towards low frequencies. And this shift depends on the place where initial converters are located, and gives system mistake of definition of real own frequencies of controlled construction. Algorithms of analysis of the recorded data are suggested and proved. The algorithm has been developed and tested. This algorithm is based on the use of the composite demodulation method which allows to carry out spectral and time analysis without Fourier transformations at the real time scale. Calculating experiment was made base on the experimental data of the geotechnical control of the real object.

Key words. Deformation, accelerometer, own frequency, spectral and time analysis.

1. Introduction

The system of the geotechnical monitoring is one of the security system components of any projected buildings and constructions of the high responsibility level and must work before the beginning of construction [1]. Moreover, geotechnical control has to be carried out both during construction and during operating period [2]. One of the most informative monitoring methods of the building condition is

[1]The work was carried out as part of the research on the project, supported by the Ministry of Education and Science of the Russian Federation No. 5.3606.2017/PCH.

[2]Belgorod State University, 85 Pobedy St, Belgorod, 308015, Russia

[3]Vladimir State University, 87 Gor'kogo St, Vladimir, 600000, Russia

[4]Corresponding author; e-mail: kuzichkin@bsu.edu.ru

control of own frequencies of construction oscillations as integral parameter of the construction condition [3]. In the analysis of obtained data external impacts on an object and its reaction to the influence must be separated. This allows to increase the reliability of the geotechnical analysis and accuracy of projections. Use of inclinometric control based on accelerometer phase indicating method is proved in works [4–6]. That gives an opportunity to connect incilometric measurements with control of own frequencies during organization of the geotechnical monitoring. Use of the phase indicating method allows to mark direct values of the dominating own frequencies of controlled objects without integrate operations in the processing algorithms as when using traditional sensors of vibrospeeds.

The aim of the work is proving the use of the phase indicating method of the inclinometric control in the systems of the geotechnical monitoring of construction condition, based on the analysis of building own frequencies, and algorithm development of control data processing.

2. Realization peculiarity of inclinometric control based on phase indicating method

Phase indicating method realization of the angle of rotation measurement in systems of the inclinometric control bases on the algorithm of collecting dynamic data. This algorithm is based on the direct signal transformation from accelerometers into phase of sine wave oscillation.

For making angle model of the phase indicating control model of construction own frequencies separate kinematic links have to be marked. These links potentially have their own technogenic rhythms. In this case, if an object of control is building or construction, m-link model will look as it is depicted in Fig. 1.

Primary accelerometer transformers after initialization of measurement system are focused on basis vectors of the general measuring basis

$$a_{xi} = G\sin\varphi_{xi} + \ddot{x}_i \approx \frac{G}{l_i}x_i + \ddot{x}_i,\ a_{yi} = G\sin\varphi_{yi} + \ddot{y}_i \approx \frac{G}{l_i}y_i + \ddot{y}_i\,. \tag{1}$$

With use of phase measurement indicating method output signal of primary transformers looks this way: (K being the transformation coefficient)

$$u_x(t) = K\left(\varphi_x + \frac{\ddot{x}(t)}{G}\right),\ u_y(t) = K\left(\varphi_y + \frac{\ddot{y}(t)}{G}\right)\,. \tag{2}$$

According to ratios (1)–(2) for monoharmonic oscillation with a frequency ω, communication between the registered signals and amplitudes of horizontal replacement of a monitoring object in observing points as follows:

$$x_{mi} = \frac{u_{xi}l_i}{K(1-\omega^2 l_i/G)},\ y_{mi} = \frac{u_{yi}l_i}{K(1-\omega^2 l_i/G)}\,. \tag{3}$$

According to the depicted ratios use of accelerometers for control of own frequen-

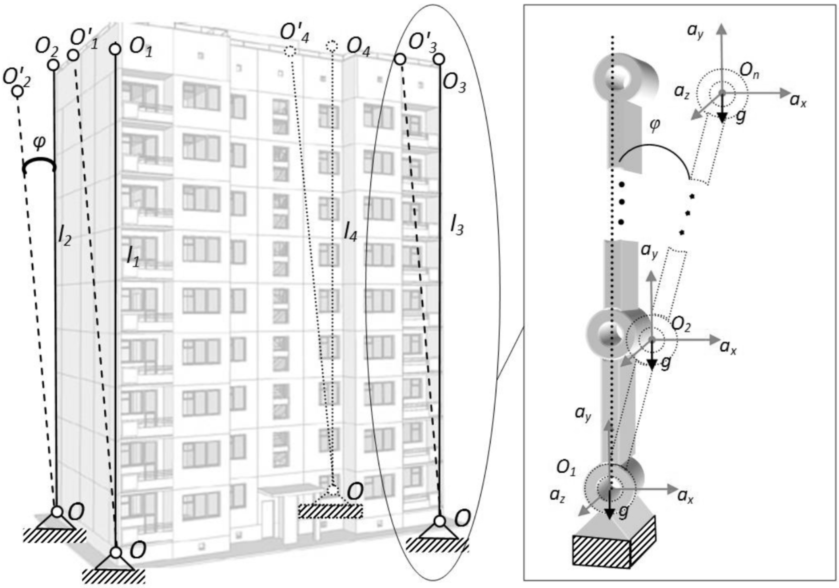

Fig. 1. Left–principle of the phase indicating control, right–angle model of the control object

cies of construction oscillations as integral parameter of the construction condition gives frequency shift towards low frequencies.

3. Task positing of allocation of main natural object frequencies

According to the settlement scheme (Fig. 1,) in every observing point signal from the phase indicating sensors which are located on a vertical alignment of the building, can be written in the form

$$\varphi_{xi}(t) = \varphi_x^*(t) + \Delta\varphi_{xi}(t) + \xi_{\varphi x},\ \ \varphi_{yi}(t) = \varphi_y^*(t) + \Delta\varphi_{yi}(t) + \xi_{\varphi y}\,, \tag{4}$$

where φ_x^* and φ_y^* represent the signal which is defined by own frequencies of the controlled construction, $\Delta\varphi_{xi}$ and $\Delta\varphi_{yi}$ stand for frequency deviation of separate constructive parts of an object, $\xi_{\varphi x}$ and $\xi_{\varphi y}$ denote the casual stationary processes characterizing forming hindrances factors. For defining the distribution angle parameters on vertical alignments of control object on phase signals, and own frequencies of the controlled building we will use the following criterion function for creation of regression:

$$\Psi(\Delta\omega) = \sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{k=1}^{K}\left(\varphi_{\mathrm{m}}(l_{ij},\Delta\omega_k) - \varphi_{(}l_{ij},\Delta\omega_k)\right)^2\,, \tag{5}$$

where φ_{m} and φ denote the model and measured phase parameters of signals, N is the quantity of controlled vertical alignments of an object, M stands for the quantity of placement points of primary phase converters in an alignment and K is the number of registration frequency ranges of phase signals. The offered algorithm (5) assumes determination of vibration amplitudes of a controlled subject in the frequency ranges of measurement with the minimum value of target function. It leads to computing expenses increase at data processing and the performance decline of system, and to assessment shift owing to distinction of measurements dispersions on different points of control. This defect can be eliminated by means of statistical parameters processing of a signal, on condition of sufficient redundancy of the obtained measuring information. The offered algorithms are based on preliminary frequency selection of the phase indicating data and space-time processing of signals, recorded in the marked frequency range on the distributed system of registration points of phase signals. The result of preliminary processing of phase signals in control points can be written down in the form of vector-matrix expression: ($\boldsymbol{W}_n(\lambda, \omega_n)$ being transfer characteristic of the filter and T_{P} the time interval of a search window).

$$\boldsymbol{u}_{x,y}(t,n) = \frac{1}{\pi}\int_0^\infty \left[\int_0^{T_{\mathrm{P}}} \mathrm{e}^{-\mathrm{j}\lambda t}\boldsymbol{u}_{x,y}(t)\,\mathrm{d}t\right]\boldsymbol{W}_n(\lambda,\omega_n)\mathrm{e}^{\mathrm{j}\lambda t}\,\mathrm{d}\lambda\,. \tag{6}$$

4. Processing of experimental data

For approbation of the offered technique at our disposal there were data of a deformation research of an inhabited 5-storey 5-access brick house which was built in the year of 1986. The building has the pile base and overlappings from combined reinforced concrete multihollow plates. Researches were conducted since the building is located in the karst-dangerous area and for many years the building sat the base owing to what numerous cracks were formed in the middle of the building in bearing walls. Production works for definition of installation sites deformation and the accelerometer of sensors were originally carried out. For this purpose for determination of frequency range of own oscillate of a building structure, dynamic characteristics of the building were recorded by three accelerometer sensors located in the garret. The system of monitoring contained two branches of the three-component LIS331dlh accelerometers, 6 sensors in each branch connected by the loop to the data-recording equipment.

Figure 2 depicts us STAN diagrams received as a result of preliminary processing of experimental data by means of the technique considered in the present article. In the course of monitoring system work fluctuations from sensors with the 3rd hour interval automatically were registered. In the case of failure data were restored by means of a Lagrange interpolation polynom of the 8th order. The revealed range of own frequencies is in an interval of 1, 6–4, 2 Hz. For accuracy support in this range of own frequencies determination $\Delta\omega/\omega \leq 3\,\%$ we will block frequency range by 30 STAN filters. Figure 3 depicts us the typical type of the signals which are removed with the accelerometer sensors. The data obtained during the researches at the different levels of observation height are provided in Fig. 2. By means of the tone values analysis of the STAN-ranges presented in this figure it is possible to select the steady dominating values in the range of frequencies from 2 Hz to 3 Hz, both for longitudinal and cross.

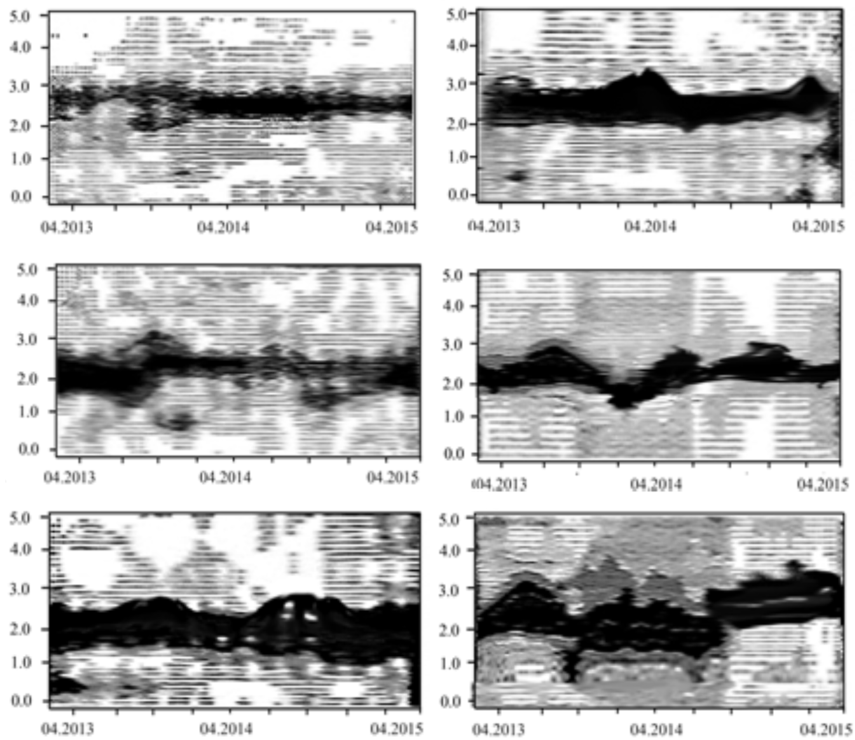

Fig. 2. STAN diagrams of phase indicating data of building geotechnical monitoring (f given in Hz)

5. Discussion of results and conclusions

Analyzing dynamics of the dominating frequency of a cross component of angular relocation (Fig. 3) it is possible to conclude, that in the range of 2–3 Hz frequencies, one frequency which is own is obviously selected. However apparently from STAN diagrams there is a dependence between dominating frequencies and height of sensor layout. What is explained by the fact that at preliminary processing the data phase-frequency correction wasn't carried out. Besides, it is possible to draw a conclusion that there is a dependence between own frequency and time. And the interseasonal temporary dependence which characterizes transition from summer value on winter and vice versa is characteristic. Most likely, freezing of soil and a snow load exerts impact on value of own frequency.

The dominating STAN-range frequency for a longitudinal component of angular

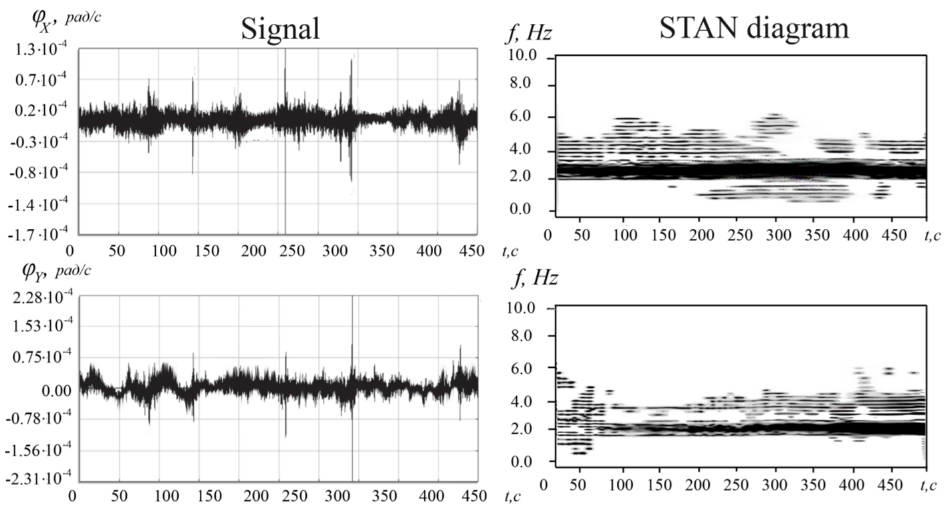

Fig. 3. Typical types of accelerometer sensor signals

shifts is in the range of 2–3 Hz, and as for cross components frequency dispersion is observed depending on the position of sensors. The size of dominating frequencies dispersion $\Delta\omega = 0.34\,\mathrm{rad}^{-1}$. During the winter period the shift of frequencies towards great values is also noticeable, and at the same time during the winter period two dominating frequencies in SEAN-ranges of a longitudinal component of angular relocation are more obviously selected. On the basis of the made measurement experiment it is possible to draw a conclusion that need of height accounting of an arrangement of primary converters on control subject at the organization of geotechnical monitoring is needed. Besides it is important to consider seasonality of observations and influence of climatic factors on value of the dominating construction frequencies.

References

[1] V. I. Bolshakov, V. E. Vaganov, T. A. Bier, I. A. Bausk, I. M. Matiushenko, O. A. Ozhyshchenko, M. Y. Popov, A. M. Sopilniak: *The usage of smart materials for skin-diagnostics of building structures while their monitoring.* Procedia Engineering *172* (2017), 119–126.

[2] N. Martins, E. Caetano, S. Diord, F. Magalhaes, Á. Cunha: *Dynamic monitoring of a stadium suspension roof: Wind and temperature influence on modal parameters and structural response.* Engineering Structures *59* (2014), 80–94.

[3] O. S. Salawu: *Detection of structural damage through changes in frequency: a review.* Engineering Structures *19* (1997), No. 9, 718–723.

[4] S. Musso, J. M. Tulliani, G. Ferro, A. Tagliaferro: *Influence of carbon nanotubes structure on the mechanical behavior of cement composites.* Composites Science and Technology *69*, (2009), 1985—1990.

[5] T. Lindeberg, A. Friberg: *Idealized computational models for auditory receptive fields.* Plos One *10* (2015), No. 3, paper e0119032.

[6] L. R. Rabiner, B. Gold: *Theory and application of digital signal processing*. Prentice Hall, USA, 1975.

Received October 12, 2017