Integrated monitoring the technical condition of large-scale building structure

Victor Gaidaychuk[1], *Konstantin Kotenko*[1,2], *Ivan Tkachenko*[3]

[1] Kyiv National University of Construction and Architecture
Povitroflotskyy prosp., 31, Kyiv, Ukraine, 03680
viktor_gaydaychuk@bigmir.net, orcid.org/0000-0003-2059-7433
[2] 1969box@mail.ru, orcid.org/0000-0002-3181-3819
[3] International exhibition center
Brovarskoy prosp., 15, Kyiv, Ukraine, 02660
ivan-t@iec-expo.com.ua, orcid.org/0000-0001-7923-1319

Summary. The results of the equipping of the International exhibition center (IEC) building with comprehensive technical condition monitoring system are given. The characteristic features of the existing systems are formulated.

The first three basic frequency magnitudes and the natural modes of vibrations corresponding to them are the most informative.

The basic magnitudes of natural frequencies and the building vibration directions are determined by means of the calculation method using established adequate finite-element model and experimental verification. The directors of improvement suggested monitoring system were noted.

Key words: static monitoring, dynamic monitoring, frequencies and modes of vibrations, finite-element model.

INTRODUCTION

The building of International Exhibition Center was designed by the project of V.M. Shimanovsky Ukrainian Institute of Steel Construction, and the second phase of its construction was completed in 2006. The main purpose of the building is to show industrial and scientific achievements of domestic and foreign enterprises, to arrange summits, conferences, meetings, mass cultural events and more.

The total area of the building (57,477 m^2) and the service equipment allow staying there over 15 thous visitors simultaneously. In this respect, the building construction is the largest object of the corresponding function in Ukraine.

The works on further improvement and development of the center's infrastructure are performed. The documentation of the third construction stage of its facilities is elaborated. The service equipment is improved in accordance with modern European standards.

BUILDING STRUCTURE

IEC is a large-scale engineering structure of the 5th difficulty category, CC3 (SS3) importance class. In regard to architectural and constructive issues, the building is a combination of three blocks (А, Б, В (A, B, C)), the coating of blocks Б (B) and В (C) are integrated by «Khvylia».

The metal frame of the building is made of shaped iron. Reinforced concrete solid-cast foundations. The roof is a classic pie: profiled sheeting, vapor barrier, insulator PAROC-AKL, EPDM and PVC roofing membrane. Walls of three-layer panels of "sandwich" type with ROCKWOOL mineral wool insulation.

PURPOSE OF WORK

According to the safety requirements the buildings and structures of CC3 (SS3) importance class to which the IEC building be longs are subject to mandatory system monitoring [1, 2] and must be equipped with the automated systems of monitoring and management [3, 4].

WORKING DATA

In 2012, when the implementation of the decree of public services [5], the IEC building was equipped with an automated system of static monitoring of metal structures and foundations (ASM). A technique developed by French company SOLDATA and the National Geographic Institute of France (IGN) is the basis of the system implemented.

The system working principle is based on the determining of the spatial position of observation checkpoints with the use of laser guidance technology which is implemented by means of the appropriate surveying high-precision equipment and a special software package.

The structure and interaction of the system components and its communication with other systems is shown in Fig.1.

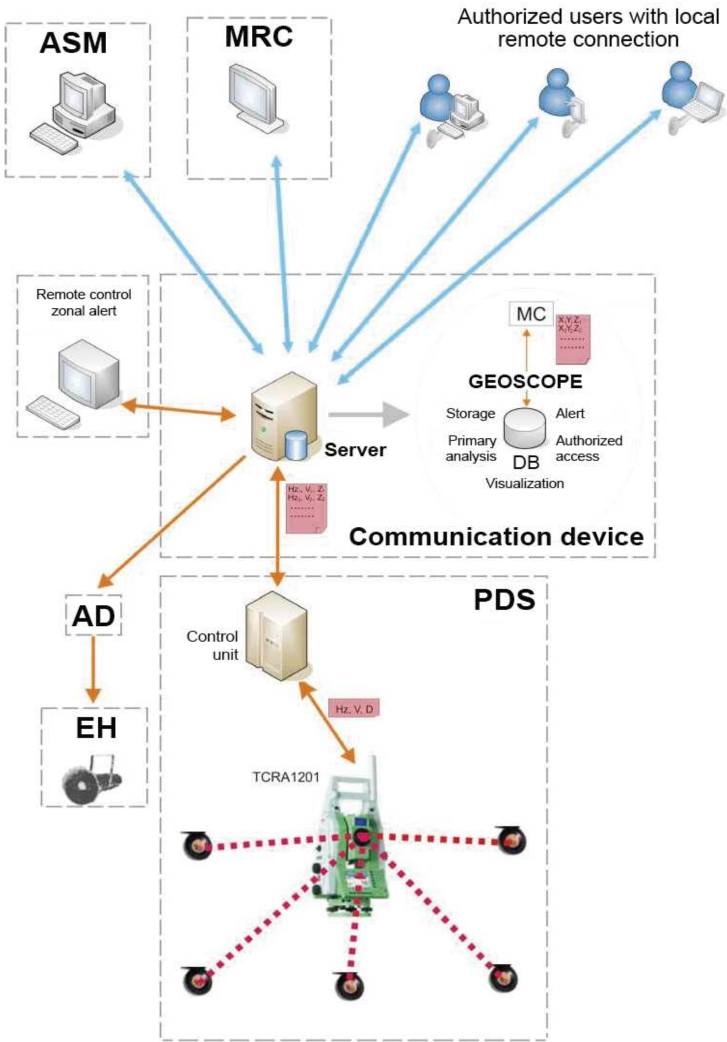

Fig.1. The structure and interaction of the ASM components:
ACMS (ASM) – automated central monitoring system;
MRC – maintenance remote control; AD – alert device;
EH – end hardware; PDS – primary data sources

The target reflectors of special design (reference standard and monitoring) are used for remote measurement of the position of a checkpoint. The reference standards are placed outside the influence of possible deformation of the structures, and observation targets are mounted on the structural elements. The displacement values are measured using high-precision geodetic TCRA tachymeters of Leica production.

These measured data are stored in the minicomputer of the control unit and are transmitted via LAN channels to the ASM server for further calculations, and the checkpoint position calculations are performed using the ASM software.

ASM implemented allows for the observation of possible spatial displacements and deformations of various structural elements of buildings and the visualization of the results of measurements in a three-dimensional coordinate system. The monitoring is performed for 85 observation points.

ASM operates in continuous mode and provides a measurement of vertical deflections and horizontal displacements with an accuracy of ±1 mm. Since the introduction of the system, it was found no irregularities in its work, and the observation results indicate a generally satisfactory state of the structures observed. However, some shortcomings in the constructions of the building are revealed; these shortcomings linked to faulty installation works during construction. For example, in 2012, in a case of significant snow load, the bottom chord of a secondary truss ПФ-6 (PF-6) is elastically deformed in the horizontal plane, as shown by analysis, because of the absence of deformation expansion joints in the form of oval holes of bolted-type connection which was promptly corrected.

However, the system specified displays the stress-strain behavior of the specific observed structures when they are exposed to static load and characterizes only its local situation, despite the considerable importance of these structures in the construction. The system indicators do not provide the information on the dynamic effects on the structure such as e.g. microseismic transients in the earth's surface, wind impulses, background impacts associated with the movement of subway and other vehicles that make the diagnosis of the buildings poorly effective.

Therefore, in view of a large scale and structural fullness of the building (more than 200 groups of structural elements) and dynamic background effect on it, the finding ways to improve the monitoring efficiency was aimed at the monitoring globalization. The expediency of the preparation of a computational building model and the use of the dynamic characteristics in the monitoring system were provided.

There is a point of view according to which tool monitoring without support and comparison with a set of adequate mathematical models of objects have random-senseless nature, represents no practical value and does not reflect the reality of a problem [6 − 10], and a mathematical model implements the actual physical and mechanical properties of the material, geometrical forms of structural elements, actually characterizes the work of nodes and connections, and thus is an effective diagnostic tool of a technical condition of the building.

Based on this approach, the experts of Kyiv University of Construction and Architecture, National Transport University, and IEC performed preprocessor treatment and a finite-element model of the IEC building was created taking into account its structural and operational features [11 − 13].

NASTRAN and SCAD software systems were used. Further, the use of the NASTRAN finite element model which was proofed for adequacy and has been refined for possible calculations of dynamic characteristics including the addition of non-structural masses is envisaged.

The model created is universal and globally reflects the stress-strain behavior of the building structures. Provides the information according to static and dynamic characteristics, including axial forces, bending moments, shear forces, displacements, buckling, frequencies and modes of natural vibrations at different combinations of actual loads.

Nevertheless, objectivity of information may be inadequate due to possible changes in the technical condition of the building associated, for example, with the change of joints in the junctions (cropping of bolts, the appearance of flexible joints), sinking soil base under the foundation of load-bearing elements of the structure, vibration of the working process equipment and more [14 − 16].

Therefore, a preliminary assessment of the building integrity is a prerequisite. The dynamic monitoring [17 − 21] which characterizes the total (integral) state of the building using dynamic characteristic parameters (natural frequencies and modes of vibrations) seems effective in this regard.

The preliminary analysis gives preference and focuses on high priority of the evaluation of the building integrity. In a case of positive results of such evaluation the use of finite-element model is effective, and in a case of negative signals it is necessary to inform promptly the services responsible for the building safety.

This approach has been used in the development of dynamic monitoring methods for the IEC building. The certain provisions of the specified method were analyzed and refined according to the design and operational features of this building. The following dynamic characteristic parameters were used: the magnitude of frequencies and modes of natural vibrations, the parameters describing a low-frequency range of vibrations (the first three basic frequencies). The modes of vibrations were shown by means of directions and magnitudes of the amplitudes corresponding to the specified frequency range. The range of natural modes of vibrations was taken with regard to permanent non-structural mass: process duty and a load of building envelope.

EXPERIMENTAL RESEARCH

The calculations were performed using SCAD and NASTRAN software, and full-scale frequency magnitudes were measured by an instrumental method of Kyiv National University of Construction and Architecture using ZET-048C seismograph (Table 1). The vibration accelerations of load-bearing structures were experimentally measured in real time with their further processing and determination of the natural vibration building frequency data. The registered vibrational records were processed using ZETLAB SEISMO software with spectral analysis by the discrete Fourier transformation method.

The resulting spectra (Fig.2) were analyzed in order to determine the frequencies of natural vibrations that correspond to the main peaks on the spectrograms and are the results of a response of the structures to external sources of dynamic action.

The spectral analysis allows filtering natural frequencies of the building and other effects of background. The spectral analysis is necessary, especially in the dynamic monitoring system of large-scale structures. But the using of natural frequencies can be ineffective if the construction defects do not violate its integrity. For example, subsidence of the soil base under the foundations of structures that did not cause cracks and other irregularities, local buckling of certain elements, a lateral tilt of a framework and so on. In this case, it is appropriate to use their natural modes of vibrations.

Table 1. Specifications of ZET-048C seismograph

Sensor type	differential
The number of measured coordinates	3 (*X*, *Y*, *Z*)
Measurement parameter	vibration acceleration
Operating range, Hz	from 0,3 to 400
Responsivity	less than 10^{-5} m/s^2
Intrinsic relative error, %	less than ±10
Operating temperature, °C	from −30 to +50

Fig. 2. The spectrum of natural vibrations of the IEC building

CONCLUSIONS

The dynamic monitoring of the total (integral) state using parameters of frequencies and modes of natural vibrations is quite an essential element of the diagnosis of the building technical condition.

The first three basic frequency magnitudes and the natural modes of vibrations corresponding to them are the most informative.

The basic magnitudes of natural frequencies and the building vibration directions are determined by means of the calculation method using established adequate finite-element model and experimental verification.

REFERENCES

1. **Sukach M. K., 2015**. First international scientifically-practical conference «Underwater technologies, 2015». Underwater technologies, Vol.01, 3-12 (in Ukrainian).
2. **Sukach M. K., 2016**. Second international scientifically-practical conference «Underwater technologies, 2016». Underwater technologies, Vol.04, 4-15 (in Ukrainian).
3. **DBN B.1.2-14-2009.** System reliability and safety of construction projects. General principles of reliability control and constructional safery of buildings, structures and supports. Ministry of Regional Development of Ukraine. Kyiv, 43 (in Ukrainian).
4. **DBN B.1.2-2:2006.** System reliability and safety of construction projects. Loads and impacts. Design standards. Ministry of Construction of Ukraine. Kyiv, 75 (in Ukrainian).
5. **DBN B.2.5-76:2014** National Structural Rules and Regulations The automated systems of the early detection threats of the origin emergencies and notification the population. Ministry of Regional Development of Ukraine. Kyiv, 38 (in Ukrainian).
6. **Belostotsky A.M., Kalychava D.K., 2012.** Adaptive finite element models as the base of dynamic monitoring of tall buildings. Part 1: Theoretical basis of the developen technique: The basis of the developed computational and experimental methods. International Journal for Computation Civil and Structural Engineering, Vol. 8, 19-27 (in Russian).
7. **Belostotsky A.M., Kalychava D.K., Novikov P.I., Ostrovsky K.I., 2015.** Adaptive Finite Element Models as a Basis of Monitoring Systems of Load Bearing Structures of Unique Buildings. Strength of Materials and Theory of Sructures, Nr.94, 202-216 (in Russian).

8. **Gaydaychuk V.V., Kotenko K.E., Tkachenko I.A., 2016.** Dynamic monitoring of building structures of International Exhibition Center. Science and construction, Nr.3, 20-25 (in Ukrainian).
9. **Balagas D., Frizen C.P., Guemes A., 2006**. Struktural Healh Monitorig, London, Publ. ISTE Ltd, 496.
10. **Kotenko K., Tkachenko I., 2016**. Means to enhance the diagnosis of technical condition in building constractions. «Build master class 2016». Proceedings of the International scientific-practical conference of young scientists. Kyiv, KNUCA, 123-124 (in Ukrainian).
11. **Perelmuterd A.V., Slivker V.I., 2002.** Computational models of structures and the possibility of their analysis. Kiev, Steel, 597 (in Russian).
12. **Szymanowski A.V., Ogloblya A.I., 2002.** Theory and Design of bearing elements span spatial structures. Kiev. Steel, 368 (in Russian).
13. **Vashchilina O.V., Borshch O.I., Kotenko K.E., Tkachenko I.A., 2014**. Finite-element monitoring of structures of International exhibition center. Visnyk National Transport University. Kyiv. National Transport University, Vol.31, 43-49 (in Ukrainian).
14. **Patrikeev A. V., 2007.** Improvement of Safery of Engineering Structures Exemplified by the Main Monument of Victory Memorial on Poklonnaya Hill in the city of Moscow. Problems of Urban Environment Quality Management. Collected works of 11-th Scientific Conference. Moscow, RAGS Publ., 82.
15. **Patrikeev A.V., Salatov T.K., 2011.** Dynamic Monitoring of Building and Structures as One of the Criteria or Their Safe Explotation. Technological Problems of Strength. Collected works of XVIII International Seminar. Podolsk, 78-81.
16. **Skoruk O, 2016.** The strength and crack resistance fiber concrete slabs supported on four sides on repeated loads, Underwater technologies, Vol.03, 83-93.
17. **Ana Paula Camargo Larocca, Jorge Alves Trabanco, Joao Olympio de Araújo Neto, André Luiz Cunha, 2014.** Dynamic Monitoring vertical Deflection of Small Concrete Bridge Using Conventional Sensors And 100 Hz GPS Receivers, Preliminary Results., Vol.04, Nr.9, 9-20.
18. **Savin S.N., 2012.** Dynamic monitoring of building structures by the example of the ramp of Pushkinskiy concert hall in Moscow. Magazine of Civil Engineering, Vol. 7, 58-63 (in Russian).
19. **Savin S.N., Demishin S.V., Sitnikov I.V., 2011.** Monitoring of unique buildings with using of dynamic parameters according to GOST R 53778-2010. Magazine of Civil Engineering, Nr.7, 33-39 (in Russian).
20. **Patrikeev A.V., 2014**. Dynamic monitoring of engineeing structures as a key elevent of its technical security.Vestnik MGSU, Nr.3, 133–140 (in Russian).
21. **Doebling S.W., Farrar C.R., Prime M.B., Shevitz D.W., 1996.** Damage identification and health monitorig of structural and mechanical system from chages in their vibration characteristics: a literature review, Los Alamos, N M, Los Alamos National Laboratory, Report Nr. LA-13070-MS, 136.

Комплексный мониторинг технического состояния большеразмерного строительного сооружения

Виктор Гайдайчук, Константин Котенко, Іван Ткаченко

Аннотация. Приведены результаты оборудования сооружения Международного выставочного центра комплексной системой мониторинга технического состояния. Сформулированы характерные особенности действующих систем. Наиболее информативными являются величины трех первых частот основного тона колебаний и соответствующие им формы собственных колебаний.

Расчетным методом, при помощи создания адекватной конечно-элементной модели и экспериментальной проверкой установлены базовые величины собственных частот и направления колебаний сооружения. Отмечены пути усовершенствования предложенных систем мониторинга.

Ключевые слова: статический мониторинг, динамический мониторинг, частоты и формы колебаний, конечно-элементная модель.