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DETERMINATION OF SCOPE OF GEODETIC SURVEY DURING THE OPERATION OF BUILDINGS AND STRUCTURES SUBJECT TO EFFECTS OF MAN-CAUSED GEODINAMIC PROCESSES

Introduction. *Forecasting the dynamics of the progressing of building deformations with the use of the data of instrumental measurements should take into account the influence of geodynamic processes and other factors of the external environment on the operational suitability of buildings. The duration of the life cycle of buildings depends on the timely consideration of the damage threats and forecasting of changes in their technical condition under the influence of natural, man-caused, constructional, and operational factors.*

Problem Statement. *Untimely detection and elimination of defects is the cause of damage and deformation of buildings.*

Purpose. *The purpose of this research is to forecast the progressing defects and damage by the methods of timely assessment of the technical condition of buildings, with the use of instrumental measurement data on the influence of environmental factors on the mechanism of destruction and wear of buildings during their construction and operation.*

Material and Methods. *The methods of analysis and generalization have been used to substantiate the relevance and to formulate the purpose and objectives of the research. The retrospective method for studying the objects over time has been used to collect statistical information and analytical materials on the main parameters of their construction and operation. To forecast the parameters of instrumental measurements at the stages of the life cycle, there have been employed the following empirical research methods: survey, monitoring, generalization of experience, expert surveys, expert evaluations, and forecasting.*

Risks of damage have been assessed based on the materials of engineering studies, given the possibility of hazard activation, the power and remoteness of the threat source, the technical condition of buildings, and the compaction. The initial data for choosing an effective system are: the stability of the slopes where the building is located, their steepness, the condition and geological composition of the soil base, sources of possible flooding and vibrations.

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Results. *The authors have proposed choosing an effective system of instrumental observation of landslides during the construction and operation of buildings given the vulnerability criterion. The developed method allows choosing an effective system of landslide observations, during the construction and operation of buildings, given the mentioned criterion, i.e. the property of the building to lose serviceability as a result of its possible damage under the influence of negative factors.*

Conclusions. *The proposed method can be used to determine the scope of instrumental observations of landslides and the periodicity of landslide control during the construction in complex geodynamic conditions.*

Keywords: geodetic survey, scope of measurements, efficiency of measurements, technology and arrangement of measurements.

Studying the effects of construction works on the surrounding territory and neighboring developed areas is an urgent problem that requires the investigation of different-scale natural and man-caused geodynamic processes and ways to deal with them. Defects and damages of buildings that have not been timely detected and rectified cause deformations of buildings. In addition to material expenses related to the rehabilitation of operating properties of the structures, the consequences of such deformations results in social injuries and environmental losses. Therefore it is very important to estimate the operating conditions of buildings, to forecast a possible development of defects and damages and to work out measures for their stabilization and elimination. To this end, it is necessary to have a clear idea of a mechanism of wearing out and destruction of structural components during their operation and effects of environmental factors on them. This is impossible without obtaining the actual data by geodetic measurements.

Building deformations depend on the properties of base soils, with types of deformation depending on their structural features. Under effect of the building weight the soils are compacted, which results in subsidence of the foundation. The soils have various properties. Therefore, the subsidence is irregular and causes deformations of the building, with horizontal loads increasing them additionally.

Natural, combined natural and man-caused or pure man-caused geological processes affect the occurrence of emergencies. Variations of composition and quantity of ground water and changes in the temperature conditions facilitate intensification of geodynamic processes. Geological dangers are also affected by man-caused factors: static or dynamic effects of enterprises, buildings, transport, mechanisms, man-caused underfloodings, pumping of groundwater, thermal or electromagnetic fields [12]. These changes result in increased geological risks in such places where their development was impossible before a man-caused interference. Let us characterize the main factors of natural and man-caused effects on the serviceability of buildings and developed areas.

Underflooding is a process of natural or man-caused nature, which is dangerous for buildings [12; 14]. The artificial (man-caused) causes of underflooding are as follows: changes in the conditions of surface flows during earthworks on vertical grading or backfilling of natural drains and ravines; leaks from water utilities and storm sewages, artificial ponds; disturbances of surface water and groundwater flows, significant breaks between earthworks and construction works; infiltration of process water; decreased evaporation under buildings and pavements; groundwater damming in coastal or riverside areas; barrage effects during construction of buried underground structures.

The negative consequences of underfloodings are related with the following: subsidences and cavities of the earth's surface, which are formed due to compacting of wetted soils at the bases of buildings; hydrodynamic rarefaction of soils, which becomes apparent as soil removals on slopes or in construction excavations; the formation and intensification of sliding, karst, karst-suffusion, erosion and other geologic dangers with corrosion destruction of building foundations and basements, flooding of cellars, hoist ways, underground structures and utilities, terrain swamping.

Slides occur when the stability of slopes is disturbed by man-caused or natural processes and a force of soil adhesion is less than the gravity force. The slipping down of earth masses may be hardly noticeable or reach some dozens of meters per second [10]. At that intensification and formation of deep block slides of squeezing and slipping, development of smallest surface slides of slipping, visco-plastic flow, hydrodynamic destruction and sudden rarefaction are possible.

Karst is one of the widespread geologic processes, which may lead to slides and subsidences of buildings. Such a danger becomes apparent as rapid local subsidences and collapses of the earth's surface due to falling of roofs of karst cavities and carry-over of water-saturated rocks into them. The intensification of karst development is accompanied by an increased zone of intensive water exchange, deformations of terrains, destruction of buildings, and ruptures of buried lines.

The life cycle of buildings depends on timely accounting of risks of damages and forecasting of changes in the operating conditions of buildings under the effects of external (natural or man-caused) and internal (construction or operational) risks. The risks of damages shall be estimated on the basis of engineering survey data subject to a possible intensification of dangers, capacity and remoteness of a threat source, operating conditions of the building and vulnerability conditions. In addition, the vulnerability of the building and surrounding territory shall be estimated [7].

Vulnerability means a building property to lose serviceability due to a possible damage of the building under effects of negative factors. The degree of vulnerability depends on the conditions of the building, its soil base and surrounding territory.

To perform a quantitative estimation of risk effects, let us estimate the degree of danger. An "ideal" version of vulnerability K_y is hypothetic and characterized by no danger from the total effect of risks. In this case $\{\min k_y\} = 0$. Given the normalization principle for the characteristics, we assume that $\{\min k_y\} = 1$ corresponds to the maximum danger for the territory. That is $0 \leq K_y \leq 1$.

The parameters that characterize the vulnerability are summarized in Table 1 with the designations of parameters, their conventional codes y_i and subcodes for values of parameters y_{i1}, y_{i2}, y_{i3}, which has small influence, medium influence and maximum influence on the building. If the parameters are given in the numerical form, the vulnerability is defined as a linear function of the parameter.

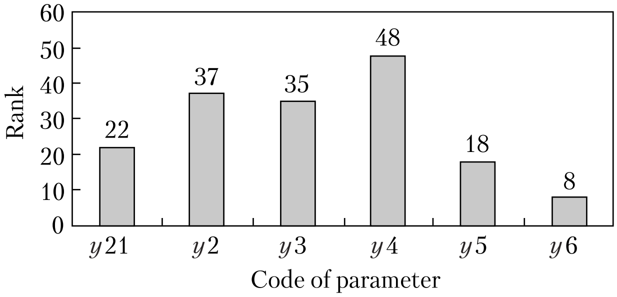

Fig. 1. Example of graphic interpretation of data obtained by the expert polling

Given that at the present stage the databases for effects of external and internal risks have not been sufficiently elaborated, we estimate the effects of the parameters on the vulnerability of buildings with the use of the method of expert evaluation [1; 15; 6] with specialists who have experience in the design and operation of building involved. The typical result of the expert evaluation is shown in Fig. 1. This result is based on the data obtained by expert polling. Henceforth, we use only those parameters that have maximum values. To determine the factor of building vulnerability we use reduced estimated value. The reduced value of these estimates is the maximum factor of vulnerability to the specific parameter y_{i3}.

Table 1. **The Parameters Characterizing the Building Vulnerability**

Group code	Subgroup code	Designation and value of parameter
y_i		Parameter *i*
	y_{i1}	Value of parameter *I*, which has the minimum influence on vulnerability
	y_{i2}	Medium value of parameter *i*
	y_{i3}	Value of parameter *I*, which has the maximum influence on vulnerability

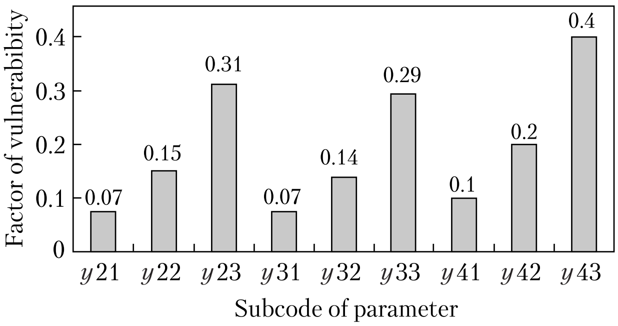

Fig. 2. Example of determination of the reduced factor of vulnerability to a parameter on the basis of the data obtained by the expert evaluation

The reduced maximum factor of vulnerability y_{i3} to a parameter is defined as the ratio of the value of rank r_i obtained by the expert evaluation to the sum of all ranks applied, that is:

$$y_{i3} = \frac{r_j}{\sum_{i=1}^{n} r_i}, \tag{1}$$

where *j* is the number of the vulnerability value; *i* is the number of the vulnerability value to be applied; *n* is the total number of values to be applied.

The degree of lesser vulnerability is defined as $y_{i2} = 0.67 \cdot y_{i3}$ and $y_{i1} = 0.33 \cdot y_{i3}$ if the parameters are specified by specific expression (Figs. 1—2).

When the parameters have numeric values (Fig. 3), the factor of vulnerability to a certain parameter can be found with the use of expressions:

$$y_i = \begin{cases} (x \cdot \frac{0.33}{x_{i1}}) \cdot y_{i3}, x < x_{i1} \\ (0.33 + (x - x_{i1}) \frac{0.67 - 0.33}{x_{i2} - x_{i1}}) \cdot y_{i3}, \quad x \geq x_{i1}, \\ y_{i3}, y_i \geq y_{i3}. \end{cases} \tag{2}$$

Table 2. **The Characteristics of the Threat Sources**

Parameter of threat sources	Degree of threat		
	high	medium	low
	Parameter value, coefficient of significance, k_d		
Parameter *i*	value $k_d = 1.1$	value $k_d = 1.0$	value $k_d = 0.9$

$$y_i = \begin{cases} (1 - x \cdot \frac{0.33}{x_{i1}}) \cdot y_{i3}, x \prec x_{i1}, \\ (1 - (x - x_{i1}) \frac{1.0 - 0.33}{x_{i2} - x_{i1}}) \cdot y_{i3}, x \geq x_{i1}, \\ 0, y_i < 0, \end{cases} \tag{3}$$

where y_i is vulnerability to the i^th parameter; *x* is the parameter's value; y_{i3} is the reduced maximum factor of vulnerability to the i^th parameter, x_{i1}, x_{i2} are the parameter's values that separate low, medium, and high vulnerabilities

To estimate the vulnerability to factors that threaten with damages, let us apply the factor of vulnerability to all factors k_y as maximum probability of influence exerted by a specific factor. It is determined as a sum of the factors of vulnerability to some parameters of the factor for a specific building

$$k_y = \sum_{i=1}^{n} y_i, \tag{4}$$

where y_i is the reduced numeric value of the i^{th} parameter of influence, *n* is the number of parameters that affect this object.

Under potential risks damages appear depending on the vulnerability of buildings, the characteristics of a threat source, the operating conditions of buildings, and the soil compactness conditions. These factors may be estimated individually for every specific case on the basis of data taken from publications or by the method of expert polling. The result of such an estimation can be expressed as a coefficient of danger significance k_d for the net factor of vulnerability.

The characteristics of threat sources are listed in Table 2. For determining the building importance level, we use the coefficient of significance k_c corresponding to the importance level (see Table 3). For the building operating conditions, the coefficient of significance k_{oc} has been used (see Table 4). Then the factor of vulnerability of building k_{vb} to the specific risk factor can be expressed as

$$k_{vb} = k_d \cdot k_c \cdot k_{oc} \cdot k_y, \tag{5}$$

where k_d is the coefficient of significance (capacity) of the threat source; k_c is the coefficient of

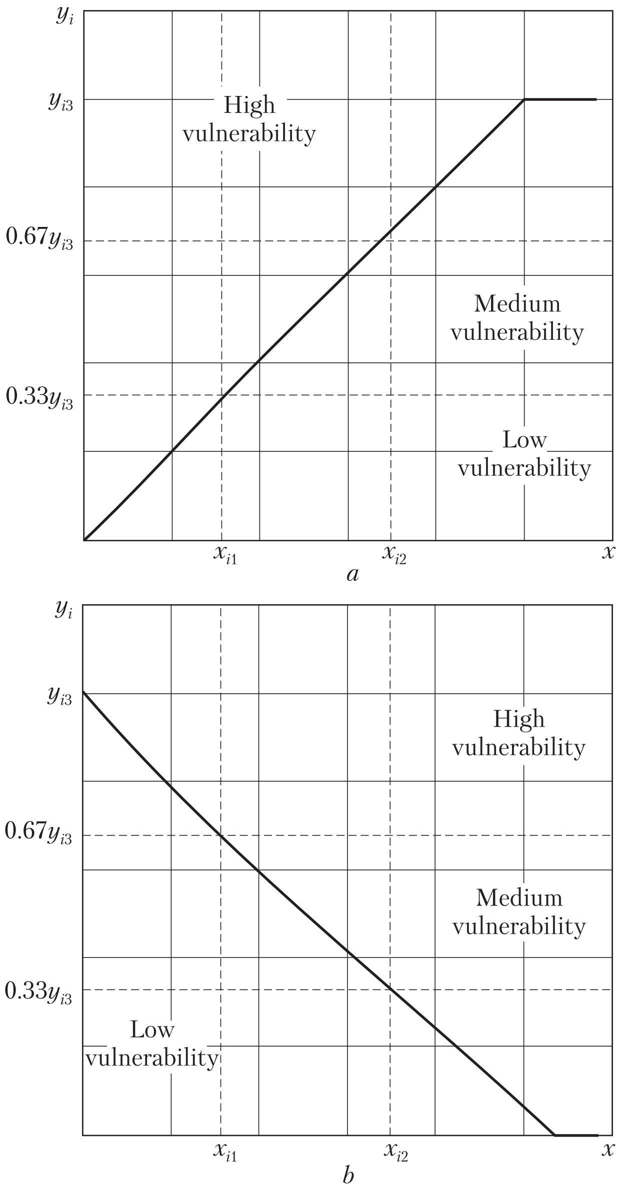

Fig. 3. Vulnerability function: *a* — for expression (2); *b* — for expression (3)

significance for the building importance level; k_{oc} is the coefficient of significance for the building operating conditions; k_y is the factor of vulnerability in formula (4).

The significance coefficients are determined on the basis of data taken from publications, results of experimental studies or by the method of expert polling. The most optimal values are listed in Tables 2—8. If there are several threat parameters, they shall be considered separately and the maximum value $k_d = k_d^{\max}$ shall be used for estimation. Survey shall be decided separately for every source. When the means of survey coincide they are combined for all sources.

Thus, for making a decision on the expediency of surveying and the survey scope, a classification of building vulnerability (low, medium or high) to a specific factor of risk has been proposed:

- the low vulnerability

$$k_{vb} \leq 0.33 \cdot k_{vb\,max} = 0.33, \qquad (6)$$

where $k_{vb\,max}$ is the maximum possible value of the factor of vulnerability, $k_{vb\,max} = 1$ irregardless of the coefficients for the risk factors;

- the medium vulnerability

$$0.33 > k_{vb} > 0.67; \qquad (7)$$

- the high vulnerability

$$k_{vb} \geq 0.67 \qquad (8)$$

Table 3. **The Coefficient of Significance for the Building Importance Level**

Designation	Value	Characteristic
k_c	0.9	Importance level CC1
	1.0	Importance level CC2
	1.1	Importance level CC3

Table 4. **The Coefficient of Significance for the Building Operating Conditions**

Designation	Value	Characteristic of conditions
k_{oc}	1.0	normal
	1.2	satisfactory
—	—	unserviceable — the building shall be inspected and a decision on overhaul shall be made
—	—	abnormal — the building shall be inspected and a decision on reconstruction or removal shall be made

k_{vb} can take values that exceed 1.0 when coefficients of threat significance or building importance level, etc. are taken into account.

The necessity of survey, its scope and periodicity are decided on the basis of the results obtained during the determination of factors of vulnerability:

Table 5. **The Degree of Building Vulnerability to Slidings**

Parameter	Coefficient of slope stability	Lithologic rock units	Slope steepness	Groundwater conditions
Parameter code	y_1	y_2	y_3	y_4
Degree of vulnerability	0.30	0.21	0.31	0.18

Table 6. **The Slope Parameters**

Code	Designation of parameter	Degree of vulnerability
y_1	Coefficient of slope stability	
	1.25	0.10
	1.20	0.20
	>1.15	0.30
y_2	Lithological rock units	
	Silicified claystones, siltstones, sandstones	0.07
	Marls with layers of marly siltstones, claystones, sandstones	0.14
	Marls with layers of sandstones, calciferous claystones with layers of sandstones	0.21
y_3	Slope steepness, degr.	
	0—2	0.10
	2—10	0.21
	10—15 and more	0.31
y_4	Groundwater conditions	
	Absence of underground water	0.06
	Sporadic expansion of underground water	0.12
	Constant level of underground water	0.18

Table 7. **Sliding Probability**

Construction works	Risk of sliding occurrence at which decisions on taking necessary measures are needed, %		
	Protection of structures	Protection of structures or slope survey	Slope survey
Large-scale construction works	>10	—	5—10
Works of higher significance	>5	5—10	1—5
Works of special significance	>1	1—5	0—1

- for the low vulnerability of building, the scope of survey is usual i.e. given the low probability of damages, no instrumental survey is necessary; visual survey is sufficient during planned inspections;
- for the medium vulnerability of building, the scope of survey is expanded i.e. given the medium probability of damages, in addition to planned visual inspections used for the usual level of survey, periodic instrumental survey shall be carried out to determine possible correlations between the building or foundation parameters and the dynamics of the recorded damages subject to subsidences, inclinations etc.;
- for the high vulnerability of building, the scope of survey is special i.e. given the high probability of damages, in addition to the expanded scope of surveying, the building shall be equipped with an automated monitoring system for the prevention of emergencies; the system composition and structure shall be determined individually, subject to the analysis of potential risks and damages.

With the use of the survey data the further development of processes may be forecasted. The control intervals shall be established subject to a maximum possible rate of the control parameter dynamics and the ratio of costs of such works to possible losses that may arise because of untimely detection of damages.

Below, the examples of the application of this procedure for the determination of the scope of instrumental survey of slidings and appropriate control intervals when construction is carried out under complex geodynamic conditions are considered.

When the scope of instrumental survey of slidings is determined, the input data for the selection of a system and design of measurement procedure are the stability of slopes and their steepness, the conditions and geological composition of the soil base, sources of floodings and vibrations, which threaten the stability of slopes. The risks of damages are estimated with the use of the data of engineering surveys provided for designing of measures to reduce negative effects of geological processes, natural or man-caused emergencies. In addition to the risks of damages, the vulnerability of the building and the surrounding territory shall be estimated.

The degree of building vulnerability depends on the properties of the building, the characteristics and conditions of the soil base. The parameters of buildings and developed areas, which affect the degree of vulnerability are as follows: the type of underground structure, the degree of wear of building, the type of foundation, the coefficient of slope stability, the lithologic rock units, the slope steepness, and the groundwater conditions. The expert polling establishes the maximum possible degree of vulnerability to slidings (Table 5).

The main parameters of buildings and bases that affect the degree of vulnerability to slidings are shown in Table 6. To estimate the building vulnerability to the factors that threaten with slidings, the factor of building vulnerability k_y, which is expressed as a sum of the degrees of vulnerability to specific factors, has been used. To determine the building importance level, the coefficient of influence on vulnerability is taken from Table 3. The factor of building vulnerability k_{vb} to a specific risk factor may be determined in accordance with (5). If there are several threats, they shall be

Table 8. **Recommended Approximate Intervals of Slope Monitoring**

Coefficient of slope stability	Survey intervals, days	
	Type of stability failure and slope deformation (types of slidings)	
	squeezing	slipping
0.7	7	10
0.8	12	18
0.9	20	25
1.0	40	60
1.1	60	100
1.2	180	300
1.35	360	500

considered individually and the maximum value $k_d = k_d^{max}$ shall be assumed.

Underfloodings and vibrations may cause an increase in the probability of slidings. It should be kept in mind that all antisliding measures shall be foreseen at the stage of design. The data that characterize the parameters of underflooding sources caused by water utilities and the parameters of vibration sources have been presented in [3]. The factor of building vulnerability to slidings is calculated in accordance with (4) with the use of values from the works and Tables 5—6 [3, 8, 9]. A decision on the necessity to make a survey and its scope shall be made given relations (6—8).

Further development of slidings may be forecasted on the basis of the survey data. The control intervals are determined on the basis of the data on maximum rates of slidings subject to the ratios of costs of these operations and the losses induced by untimely detection of the sliding processes.

When determining the sliding control intervals, we consider the following main types of slidings: slipping, squeezing, upfloating, subsiding, and rarefying. In the developed areas, the most prevalent are slipping and squeezing slidings. Slidings in the areas of development and economic activities result in negative consequences. Table 7 shows the probabilities of slidings and the measures that shall be taken, subject to the building importance level, in the area of sliding.

Slopes shall be considered as stable ones if the coefficient of stability is $k_c > 1$. The value $k_c = 1$ relates to the equilibrium limit. When buildings are to be located on a slope, the coefficient of slope stability shall comply with the following requirement

$$k_c \geq k_{c.ad}, \tag{9}$$

where $k_{c.ad}$ is the permissible value of stability coefficient, which is determined subject to loads, reliability and operation conditions at the stage of design.

In the areas where slidings are probable and the coefficient of stability complies with the requirement $k_c > 1$, horizontal displacements, underground water table, and pore pressure shall be surveyed. The periodicity of horizontal displacement monitoring ($T_{mon.max}$) can be determined by (10).

$$T_{mon.max} = 5\sigma_{det}/V. \tag{10}$$

For slipping sliding, the maximum rate of sliding is defined [Bugrov, 2002] by the following formula:

$$\nu_c^{max} = \frac{\rho \cdot g \cdot H^2 \cdot \sin\alpha}{2\mu}, \tag{11}$$

where ρ is the density of soil, t/m³; H is the maximum thickness of sliding soil mass, m; α is the slipping angle, degree; μ is the soil viscosity.

The average rate across the whole cross section is

$$V_c^{av} = \frac{2}{3} \cdot V_c^{max}. \tag{12}$$

The recommended approximate intervals of slope survey for the various types of slidings and various values of the stability coefficients are shown in Table 8. The values have been determined based on the experience of surveying.

Since the main cause of slidings is saturation of soil masses by water, the pore water pressure shall be monitored. At the stage of design works, a possible rate of pore pressure dynamics shall be determined. Measuring devices shall be selected with the due account of the range of possible pressure dynamics and the required accuracy of measurements.

The periodicity of monitoring of pore water pressure may be defined as follows

$$T_{mon.pw} = \frac{\Delta_{sen}}{V_{p.w.}}, \tag{13}$$

where Δ_{sen} is the resolution of a pore pressure transducer; $V_{p.w.}$ is the possible rate of pore pressure dynamics, which shall be determined at the stage of designing.

CONCLUSIONS

1. Forecasting of dynamic building deformations with the use of instrumental measurements during the construction and operation stages shall

take into account the effects of geodynamic processes and other environmental factors on the serviceability of buildings.

2. The procedure allows the selection of an effective system of instrumental control of slidings during the construction and operation of buildings subject to the vulnerability criterion. During the operation of buildings, the basic data for the selection of a measuring system are the stability and steepness of slopes on which the buildings are located, the conditions and geological composition of the soil base, the sources of possible underfloodings and vibrations, which may threaten the stability of slopes.

3. Horizontal displacements and underground water table shall be monitored in the territories that are adjacent to new construction works and for which slidings are possible. Since the presence of ground water is the main cause of slidings in addition to horizontal displacements, the pore water pressure shall be monitored as well.

4. Measuring devices shall be selected subject to the ranges and rates of possible changes in the monitoredparameters.

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ВСТАНОВЛЕННЯ ОБСЯГІВ ГЕОДЕЗИЧНИХ СПОСТЕРЕЖЕНЬ ПРИ ЕКСПЛУАТАЦІЇ БУДІВЕЛЬ І СПОРУД З УРАХУВАННЯМ ВПЛИВУ ТЕХНОГЕННИХ ГЕОДИНАМІЧНИХ ПРОЦЕСІВ

Вступ. Прогнозування динаміки розвитку деформацій будівель з використанням даних інструментальних вимірювань має враховувати вплив геодинамічних процесів та інших факторів зовнішнього середовища на експлуатаційну придатність будівель. Тривалість життєвого циклу будівель залежить від своєчасного урахування загроз пошкодження та прогнозування зміни їхнього технічного стану під впливом природних, техногенних, будівельних та експлуатаційних чинників.

Проблематика. Несвоєчасне виявлення та усунення дефектів є причиною пошкодження та деформацій споруд.

Мета. Прогнозування розвитку дефектів та пошкоджень методами своєчасної оцінки технічного стану будівель з використанням даних інструментальних вимірювань впливу факторів середовища на механізм руйнування і зношення будівель у процесі будівництва та експлуатації.

Матеріали й методи. Застосовано методи аналізу та узагальнення, ретроспективний метод, статистичний та аналітичні методи. Використано емпіричні методи дослідження — обстеження, моніторинг, узагальнення досвіду, опитування фахівців, експертні оцінки, наукове прогнозування — для прогнозування параметрів інструментальних вимірювань на етапах життєвого циклу. Ризики пошкоджень оцінено за матеріалами інженерних досліджень з урахуванням можливості активізації небезпек, потужності та віддаленості джерела загрози, технічного стану будівель, умов ущільненості.

Результати. Вибір ефективної системи інструментальних спостережень за зсувами при будівництві та експлуатації будівель запропоновано виконувати з урахуванням критерію уразливості. Методика дозволяє обирати ефективну систему спостережень за зсувами при будівництві та експлуатації будівель з урахуванням вказаного критерію, тобто властивості будівлі втрачати експлуатаційну придатність в результаті можливості її пошкодження під впливом негативних факторів.

Висновки. Запропоновану методику можна застосовувати для встановлення обсягів інструментальних спостережень за зсувами та періодичності контролю зсувів при будівництві в складних геодинамічних умовах.

Ключові слова: геодезичні спостереження, обсяги, ефективність, технологія вимірювань, будівництво, експлуатація, уразливість будівель.