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DEVELOPMENT OF THE TECHNIQUE OF EXPERT ASSESSMENT IN THE DIAGNOSIS OF THE TECHNICAL CONDITION OF BUILDINGS

Об'єктом дослідження є інформаційні методи та технології діагностики будівель з використанням інструментарію теорії нечітких множин. Одним з найбільш проблемних місць є відсутність системи інтелектуальних методів діагностування на базі накопичених знань експертів і поточних відомостей про стан будівель. В ході дослідження використовувалися експертні оцінки обстеження технічного стану об'єктів, як основи для прогнозування їх надійної експлуатації. Отримано методику експертного оцінювання при обстеженні технічного стану будівель. Запропонована методика має структуру, яка передбачає формування ознак пошкоджень через ранжування, формування експертної групи, формування правил роботи експертної групи, оцінювання ступеню узгодженості думок експертів, кількісне оцінювання ознак пошкоджень. При такому підході з'являється можливість отримання обґрунтованих результатів про наявність та ступінь пошкоджень та можливість співставлення результатів із початковими, що характеризують раніше проведені обстеження технічного стану. Запропонований підхід сприяє визначеності при розпізнаванні станів конструкцій будівель в умовах обмеженості статистичних даних з інструментальних обстежень та неточності інформації, яка ґрунтується на директивних методах обстежень. У порівнянні з імовірнісними підходами та методами теорії нечітких множин розглянутий підхід використовує теорію вимірювань та математичної статистики та додає впевненості експерту при обґрунтуванні необхідного оцінювання стану конструкцій. У розробленій методиці ступень та глибина експертного оцінювання конструкцій будівлі з метою приведення усієї системи в нормальний технічний стан проводиться через інтуїтивно-логічний аналіз проблем з якісним та кількісним оцінюванням суджень і формальним обробленням результатів. Забезпечується можливість вирішувати завдання оцінювання в умовах відсутності частини важливої інформації.

Ключові слова: *діагностика технічного стану будівель, комп'ютеризація методів діагностики, експертне оцінювання.*

1. Introduction

Forecasting of the deterioration of the building and determining the timing of repairs is a complex multifactorial task. In connection with the presence in the building of a large number of different in strength and durability of structures and materials, it is difficult to predict the service life as a combination of the service life of each element separately. Supervision of the object, reduced or operated, is designed to obtain information about its technical condition. Supervision measures are continuous observations and periodic technical inspections of the facility, which track:

– compliance with the rules of technical operation, technical condition of the structural system, individual structures and engineering systems;
– periodic planned and unscheduled inspections of the facility;
– instrumental (periodic or permanent) monitoring of the state of an object, its individual elements or systems. In modern construction, when diagnosing a technical condition, a large array of information methods is used to create a system for a comprehensive assessment of this state.

A special place in information technology is occupied by content on the diagnostics of buildings, where along with the operations of obtaining, accumulating, searching and managing of information flows, the most knowledge-intensive processes are being maintained-the actual creation of information products. Among many applications of these technologies is the computerization of intelligent diagnostic methods based on the accumulated knowledge of experts and current information on the state of buildings. When building and operating a building it is important to assess the nature and risk of damage. This diagnosis is the basis for a rational choice of means to maintain the building stock of Ukraine in the state. Crucial to ensure the reliability of the results of expert assessment is their processing. Therefore, now it is relevant to study the theory and practice of probabilistic statistical modeling of expert methods for predicting the state and parameters of building structures.

2. The object of research and its technological audit

The object of research is a system for assessing the properties and parameters of buildings when monitoring the technical condition of buildings.

One of the most problematic places is the presence of design flaws, which arise as a result of incompleteness of engineering surveys, inaccuracies in the initial data, errors in calculations, acceptance of unreasonable design decisions. The possibility of taking into account all factors when establishing the effectiveness of means and methods of geodetic work is not obvious. Since the factors affecting it are fuzzy, decisions depend on technological, technical, metrological criteria, on the subjective approach of the executors of work and even on the natural factors in which geodetic work is performed. As a result, it is necessary to decide on the choice of the most suitable methods for performing geodetic work.

To solve this problem, let's apply elements of fuzzy logic, expert assessments and define:

– possible methods and means of performing geodetic work for each installation operation;
– factors affecting the choice of methods and means of geodetic work;
– the degree of belonging of these factors to a specific method and means of performing geodetic work;
– the degree of importance of the influence of these factors on the choice of methods and means of geodetic work;
– the truth value for each method (this is the value characterizing the correspondence of all factors of the geodetic work method for each installation operation). That is, for each installation operation, one value is defined that characterizes the total degree of belonging of all factors to a particular method.

If possible methods and means of geodetic work and the factors influencing this choice can be fairly clearly determined from the experience of surveying, then the degree of belonging and the degree of importance can only be determined subjectively. To increase the reliability of the choice of these quantities, it is necessary to use expert opinions of experts in the field of geodetic and installation works for this purpose.

3. The aim and objectives of research

The aim of research is building an expert assessment methodology for diagnosing the technical condition of buildings.

To achieve this aim, it is necessary to perform the following tasks:

1. To determine the sequence of formation of damage signs for assessment.
2. To determine the principles for the formation of an expert group and create an assessment structure for each expert on all signs of damage.

4. Research of existing solutions of the problem

Among the main ways to solve the problems of extending the term of reliable operation of buildings are the questions of assessing their technical condition by various methods. From the world scientific periodicals found in the resources, the following can be singled out:

– managerial issues of ensuring the stability of object indicators throughout the life cycle [1–3];
– tasks of increasing the effectiveness of expert systems through the integration of expert assessment in the dynamic structures of instrumental and information monitoring of buildings [4–7];
– methodological aspects of the functioning of information systems for diagnosing and forecasting technical condition through information management [8–10].

In particular, the paper [1] is devoted to the integration of the management systems of the technical characteristics of the building during the operation phase using the applications of the visual interactive model (VIM) design system.

The need to create a structure of virtual expert testing of buildings with impact on the management of environmental and energy indicators is reflected in [2]. At the same time, it is pointed out that the input parameters relating to the historical value of objects are important. Prognostic methodology for managing the energy efficiency parameters of a building is developed in the article.

The possibility of using VIM visualization to diagnose the condition of buildings and planning measures to improve their operational reliability is stated in [3]. Integration of expert data into the VIM system is provided, as a source of knowledge, a tree of failures is proposed.

The authors of [4] show that the effectiveness of expert systems depends on the dynamics of decision-making by experts. Classes of experts are classified: with a high and low level of participation in updating their own professional

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knowledge. The influence of possible changes regarding the initial assessment is considered, while taking into account the expert opinion, which changes the initial judgment, depends on the degree of professional authority.

An alternative solution to the problem, as described in [5], justifies the need to combine databases designing objects, monitoring data and expertise in a dynamic model with the evolving and expanding environment. And the authors use the method of discrete modeling of complex hierarchical control systems.

In the opinion of the authors of [6], in order to assess the building parameters, it is possible to use methods for designing control systems for aircraft. The proposed model is used to more effectively manage technical parameters that ensure reliable operation of the building.

Work [7] is an attempt to show the results of studies on the assessment of building systems and components for intelligent buildings. It is proposed to introduce intellectual indicators for eight basic intellectual systems. A systemic intellectual indicator has been introduced to unify the opinions of experts.

In the scientific papers [8–10], the methodological foundations of the construction of an information system for diagnosing and forecasting a technical state from the perspective of strategic information management are considered, where the main part is represented by methods for increasing the effectiveness of instrumental observations of the state of buildings.

Thus, the results of the analysis allow to conclude that improving the methods of expert appraisal in diagnosing the condition of construction sites is a promising task in construction, and new management solutions increase reliability in the operation of buildings.

5. Methods of research

There are several approaches to solving problems, based on expert data processing and the construction of an algorithm for the hierarchical structure of properties obtained during the design of various systems.

One of the directions based on expert data processing in the implementation of the complex tasks for the safe operation of buildings and structures is the methodology for constructing an expert assessment of their technical condition. The advantage of this approach is:

– in the task of creating expert methods and models for assessing technical condition;

– in the study of intellectual technology in the implementation of the information system of survey and assessment of technical condition;

– in conducting research within the framework of a separate expert system.

At the second stage of the survey of the technical condition of buildings, it is necessary to group design solutions, characterized by major defects and damage to individual building elements.

In this regard, let's consider the following approach of peer review technical condition survey. With it, it becomes possible to obtain the results of the signs of damage in different variants and for different characteristics and to compare the results relative to those given initially. This allows to conduct the monitoring process and make timely decisions on safe and reliable operation of buildings and create normal conditions for the attendants, taking into account the results of the survey of buildings.

When building an expert assessment, an expert group is formed which, after carrying out a preliminary inspection of the building and determining the required scope of work at the second stage of the survey, determines the defects and damages of the main structural elements of the building.

The main stages of the construction of the expert assessment methodology for the inspection of the technical condition of buildings:

1. Formation of signs of damage (ranking) – m.

2. Formation of an expert group:

– the number of experts (h);

– depending on the answers (opinions) of experts, a matrix is formed – a line for each j-th sign of damage:

$$Y_j = \left| a_{1j}, a_{2j}, \ldots, a_{hj} \right|; \quad (1)$$

– let's find the average value of the group's estimate for the j-th sign of the damage:

$$A_j = \frac{\sum^{h} a_{tj}}{h}; \quad (2)$$

– determine the deviation of the estimates of each expert from the average value of the group's estimates for all j-signs of damage $\Delta_{tj} = |a_{tj} - A_j|$, a matrix of deviations is formed as a result:

$$D = \left\| D_j \right\| = \left\| \begin{matrix} \Delta & 11\ \Delta_{21} & \cdots & \Delta_{h1} \\ \Delta & 12\ \Delta_{22} & \cdots & \Delta_{h2} \\ \ldots & \ldots\ \ldots & \cdots & \ldots \\ \Delta & l_m\ \Delta_{2m} & \cdots & \Delta_{hm} \end{matrix} \right\|; \quad (3)$$

– let's find the average deviation of the estimates of each expert for all signs of damage from the average value of the group's estimates:

$$\bar{\Delta} = \frac{\sum_{j=1}^{m} \bar{\Delta}}{m}; \quad (4)$$

as a result let's obtain the row matrix:

$$\bar{D} = \left| \overline{\Delta 1},\ \overline{\Delta 2},\ \ldots,\ \overline{\Delta h} \right|; \quad (5)$$

– experts are numbered as their estimates are removed from the average value of the group's estimates. As a result, a tuple of expert competence is established:

$$\bar{D}^* = \left| \overline{\Delta 1}^*,\ \overline{\Delta 2}^*,\ \ldots,\ \overline{\Delta h}^* \right|; \quad (6)$$

– let's determine the average value of the confidence coefficient, depending on signs of physical depreciation and rules for assessing the technical condition of the main structural elements of the building. As a rule, it is taken equal to 0.5 ($\Phi = 0.5$). At $\Phi < 0.5$, the expert group is re-formed by excluding experts from the list of recent issues, in which there is a sharp deviation of responses from the group's average opinion.

3. Formation of the work rules of the expert group (Table 1):

– order signs of damage, starting with the least important:

$$x_1 < x_2 < \ldots < x_m; \qquad (7)$$

– the ranks a_i are attributed:

$$(a_1 = 1;\ a_2 = 1;\ \ldots\ a_m = 1); \qquad (8)$$

– weight coefficients of signs of damage are determined $a_j\ (j = \overline{1,m})$:

$$a_j = \frac{\sum_{t=1}^{h} a_{jt}}{\sum_{j=1}^{m}\sum_{t=1}^{h} a_{jt}}. \qquad (9)$$

Table 1

Formation of the work rules of the expert group

Number of signs of damage	Legend of signs of damage	Number of the expert					Weighting factors
		1	2	…	…	j	
1	m_1	h_{11}	h_{12}	…	…	h_{1j}	a_1
2	m_2	h_{21}	h_{22}	…	…	h_{2j}	a_2
…	…	…	…	…	…	…	…
n	m_i	h_{i1}	h_{i2}	…	…	h_{ij}	a_j

4. Assessment of the degree of consensus among experts (Table 2):

– results of ranking are represented in the form of a matrix of ranks;

– the sum of the ranks for each j-th sign of the damage and the average sum of ranks for every j-th sign are determined:

$$Q_j = \sum_{t=1}^{h} a_{jt}, \qquad (10)$$

where Q_j – sum of the ranks;

$$T = \frac{\sum_{j=1}^{m}\sum_{t=1}^{h} a_{jt}}{m}, \qquad (11)$$

where T – the average sum of ranks.

– the sum of squares of deviations is calculated:

$$S_E = \sum_{j=1}^{m} \delta_j^2 = \sum_{j=1}^{m} \left(Q_j - T\right)^2; \qquad (12)$$

– the confidence coefficient is determined:

$$\Phi = \frac{12 S_E}{\{h^2(m^3 - m)\}}. \qquad (13)$$

If $\Phi > 0.5$, then there is a sufficient degree of consistency between the opinions of experts. If $\Phi < 0.5$, then the group is corrected by excluding the last expert in the tuple, the confidence coefficient is listed, and so on until the necessary degree of consistency is obtained.

Table 2

Assessment of the degree of consensus among experts

Number of signs of damage	Legend of signs of damage	Number of the expert					Rank sum	Deviation of the sum of ranks	Deviation square
		1	2	…	…	j			
1	m_1	h_{11}	h_{12}	…	…	h_{1j}	Q_1	Q_1-T	$(Q_1-T)^2$
2	m_2	h_{21}	h_{22}	…	…	h_{2j}	Q_2	Q_2-T	$(Q_1-T)^2$
…	…	…	…	…	…	…	…	…	…
n	m_i	h_{i1}	h_{i2}	…	…	h_{ij}	Q_j	Q_j-T	$(Q_j-T)^2$
Average sum of ranks							T		
Sum of deviation squares									S_E

If the expert can not specify the order of decrease of two or more signs of damage, he assigns to each of them the same rank.

In this case, the confidence factor is calculated from the relationship:

$$\Phi = \frac{S_E}{\frac{1}{12}h^2\left(m^3 - m\right) - h\sum_{t=1}^{h} T_t}, \qquad (14)$$

$$T_t = \frac{1}{12}\sum_{j=1}^{m}\left(Z_j^3 - Z_j\right), \qquad (15)$$

where Z_j – the number of identical ranks in the t-th ranking.

6. Research results

When developing the method of expert assessment, technical objects can be subject to civil (housing, hotels, hostels, multifunctional centers, administrative and public buildings) and production facilities (industrial enterprises, production plants, factories, garages).

Let's consider an example of use of the offered technique of an expert assessment of inspection of a technical condition for a warehouse building (Fig. 1).

Let's use the common signs of damage that occur when examining any building:

– crack in the basement of the foundation (m_1);

– crack in the wall (m_2);

– crack in the slab (m_3);

– crack in reinforced concrete roof rafters (m_4). Let's take these signs of damage as input data for peer review.

When inspecting the technical condition of buildings in specialized organizations dealing with such issues, there are units in which, as a rule, an expert group of 2–5 people is formed. Such generally accepted order can be characterized as rational, therefore it is the basis for the formation of such group of five experts:

I – the expert – the head of the department, the candidate of technical sciences;

II – expert – chief engineer;

III – expert – engineer of the I category;

IV – expert – engineer;

V – expert – junior researcher.

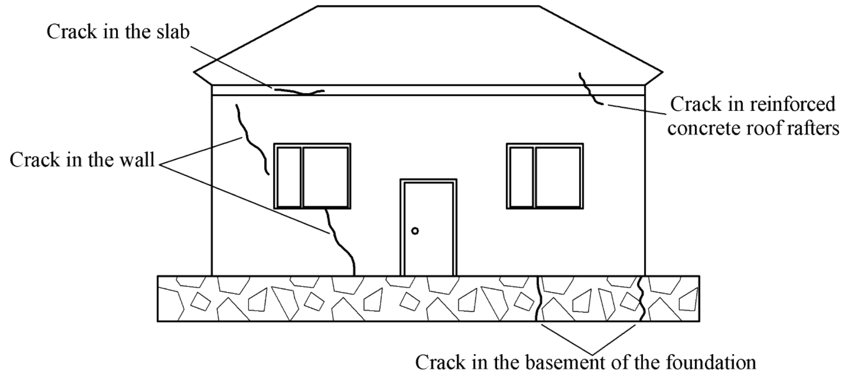

Fig. 1. Appearance of a warehouse building with signs of damage detected during inspection

The matrices of the expert assessment line for each j-th sign of damage of the form (1):

$$Y_1 = |0.41\ \ 0.37\ \ 0.05\ \ 0.44\ \ 0.33|;$$

$$Y_2 = |0.21\ \ 0.33\ \ 0.11\ \ 0.23\ \ 0.30|;$$

$$Y_3 = |0.10\ \ 0.08\ \ 0.33\ \ 0.13\ \ 0.05|;$$

$$Y_4 = |0.16\ \ 0.17\ \ 0.21\ \ 0.06\ \ 0.21|.$$

The average value of the group's estimates for each feature of the damage, respectively, will be according to the form (2):

$$A_1 = (0.41+0.37+0.05+0.44+0.33)/5 = 0.320;$$

$$A_2 = (0.21+0.33+0.11+0.23+0.30)/5 = 0.236;$$

$$A_3 = (0.10+0.08+0.33+0.13+0.05)/5 = 0.138;$$

$$A_4 = (0.16+0.17+0.21+0.06+0.21)/5 = 0.162.$$

After determining the deviations of the estimates of each expert from the average value of the group's estimates Δ_{tj} for each feature of the damage, a matrix of deviations is obtained according to the form (3):

$$\Delta_{11} = (0.41-0.32) = 0.09;\quad \Delta_{21} = (0.37-0.32) = 0.05;$$

$$\Delta_{31} = (0.05-0.32) = 0.27;\quad \Delta_{41} = (0.44-0.32) = 0.12;$$

$$\Delta_{51} = (0.33-0.32) = 0.01;\quad \Delta_{12} = 0.026;\quad \Delta_{22} = 0.094;$$

$$\Delta_{32} = 0.126;\quad \Delta_{42} = 0.006;\quad \Delta_{52} = 0.064;\quad \Delta_{13} = 0.038;$$

$$\Delta_{23} = 0.058;\quad \Delta_{33} = 0.192;\quad \Delta_{43} = 0.008;\quad \Delta_{53} = 0.088;$$

$$\Delta_{14} = 0.002;\quad \Delta_{24} = 0.008;\quad \Delta_{34} = 0.048;\quad \Delta_{44} = 0.102;$$

$$\Delta_{54} = 0.048.$$

$$D = \begin{Vmatrix} 0.090 & 0.050 & 0.270 & 0.120 & 0.010 \\ 0.026 & 0.094 & 0.126 & 0.006 & 0.064 \\ 0.038 & 0.058 & 0.192 & 0.008 & 0.088 \\ 0.002 & 0.008 & 0.048 & 0.102 & 0.048 \end{Vmatrix}.$$

The average deviations of the estimates of each expert for all signs of damage from the mean value of the group estimates have been calculated as follows according to the form (4):

$$\overline{\Delta}_1 = \frac{0.090+0.026+0.038+0.002}{4} = 0.039;$$

$$\overline{\Delta}_2 = \frac{0.050+0.094+0.058+0.008}{4} = 0.053;$$

$$\overline{\Delta}_3 = \frac{0.270+0.126+0.192+0.048}{4} = 0.159;$$

$$\overline{\Delta}_4 = \frac{0.120+0.006+0.008+0.102}{4} = 0.059;$$

$$\overline{\Delta}_5 = \frac{0.010+0.064+0.088+0.048}{4} = 0.052.$$

As a result, a row matrix according to the form is established (5):

$$\bar{D} = |0.039\ 0.053\ 0.159\ 0.059\ 0.052|.$$

The analysis of the obtained results allows to compose a tuple of experts' competence by the form (6):

$$\bar{D}^* = 1,5,2,4,3.$$

Experts of the ranking of signs of damage by importance and importance of the weight coefficients of signs of damage a_j are presented in Table 3 according to the form (7)–(9).

Table 3

Results of the ranking of signs of damage by experts and the importance of weighting factors

Number of signs of damage	Legend of signs of damage	Number of the expert					Weighting factors
		1	5	2	4	3	
1	m_1	5	5	5	5	1	0.350
2	m_2	4	4	4	4	2	0.300
3	m_3	1	2	1	2	2	0.133
4	m_4	3	1	3	3	3	0.217

In assessing the degree of consistency of expert opinions, the dependencies of the fourth stage are used. The results of the calculations are summarized in Table 4 according to the form (10)–(13).

Table 4

Assessing the degree of consistency among experts

Number of signs of damage	Legend of signs of damage	Number of the expert					Weighting factors	Deviation of the sum of ranks	Deviation square
		1	5	2	4	3			
1	m_1	5	5	5	5	1	21	9	81
2	m_2	4	4	4	4	2	18	6	36
3	m_3	1	2	1	2	2	8	–4	16
4	m_4	3	1	3	3	3	13	1	1
Average sum of ranks							12		
Sum of deviation squares							134		

Since none of the experts has assigned two or more signs of damage to the same ranks, then to find the confidence coefficient let's use an expression of the form (13):

$$\Phi = \frac{12 \cdot 134}{5^2 \cdot \left(4^3 - 4\right)} = \frac{1608}{1500} = 1.072.$$

Since $\Phi > 0.5$, there is sufficient consistency between the experts and obtained results are taken as finite.

The main signs of damage are quantified:

– crack in the basement of the foundation = 0.350 mm;
– crack in the wall = 0.300 mm;
– crack in the slab = 0.133 mm;
– crack in reinforced concrete roof rafters = 0.217 mm.

7. SWOT analysis of research results

Strengths. In comparison with analogues the proposed method allows to take into account the individual assessment of each expert in the overall structure of the assessment of the technical condition of the building. And the dynamics of changes in opinions in expert assessments is taken into account in accordance with fluctuations in regulatory requirements.

Weaknesses. The weaknesses include the influence of subjectivity in the personal assessment of the technical condition, the instability of the composition of the expert groups for individual areas of surveys in accordance with the designation of buildings.

Opportunities. The methodology is evolutionary, it is possible to expand it to development of the models for forecasting technical and economic parameters through the use of correlation-regression analysis.

Threats. It is necessary to take into account the possible additional costs due to the increase in the level of professional qualification of experts, as well as through its corresponding reduction simultaneously with the need to apply more costly tools and tools to survey buildings to neutralize this decline.

8. Conclusions

1. It is established that the sequence of formation of signs of damage provides for the inclusion in the database of the characteristics, in the first place, of the most common and those that most affect the load-bearing safe operation of the building (the main load-bearing structures of the underground and ground parts). The weight coefficients of the signs are thus an indicator for identifying the dominant features that can be used in the construction of multifactor models for forecasting technical and economic indicators.

2. It is shown that the principles for the formation of an expert group, the structure of assessment, the degree of agreement between experts' opinions, is a complex of providing valid data in diagnosing the technical condition of buildings. A tuple of expert competence and a confidence factor (at values greater than 0.5) affect the acceptance of survey results as final and credible, as well as the future composition and structure of the expert group.

A variant of using the proposed method for a warehouse building with common signs of structural damage is an example that demonstrates a simple sequence of its application. With a significant increase in the signs of damage (as a rule, at several existing facilities it is several dozen), it seems effective to enlarge the calculations for the blocks, depending on the working groups of experts and the scope of the survey.

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