Описано технологію управління базою правил, за допомогою якої побудовано базу знань параметрів деградації залізобетонних будівельних конструкцій. Встановлено, що діагностування конструкції із застосуванням апарату нечіткої логіки дозволяє автоматизувати оцінювання в умовах невизначеності. Алгоритм налаштування параметрів та правил користувачем і покрокова експертна підтримка прийняття рішення в процесі діагностики реалізовані в програмному середовищі MATLAB

Ключові слова: база знань, будівельна конструкція, інтелектуальна інформаційна технологія діагностування, нечітка логіка, технічний стан

Описана технология управления базой правил, с помощью которой построена база знаний параметров деградации железобетонных строительных конструкций. Установлено, что диагностирование конструкции с применением аппарата нечеткой логики позволяет автоматизировать оценивания в условиях неопределенности. Алгоритм настройки параметров и правил пользователем, а также пошаговая экспертная поддержка принятия решения в процессе диагностики, реализованы в программной среде MATLAB

Ключевые слова база знаний, строительная конструкція, интеллектуальная информационная технология диагностирования, нечеткая логика, техническое состояние

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IMPLEMENTATION OF INTELLIGENT INFORMATION TECHNOLOGY FOR THE ASSESSMENT OF TECHNICAL CONDITION OF BUILDING STRUCTURES IN THE PROCESS OF DIAGNOSIS

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1. Introduction

At all stages of the life cycle of building objects (BO), the main task is to ensure their safe and reliable operation under the influence of random loads and impacts, which may lead to significant deviations in the actual indicators of reliability from those calculated in the process of design. After the introduction of BO into operation, a significant share of uncertainty to the actual state of these structures may be added by occasional errors in design solutions, deviations from the technology at the stages of manufacturing, transportation and construction. In addition, intensive development of modern cities and violations in the modes of operation over a long time of existence could lead to unpredicted changes in the complex of loads and impacts of the environment that were considered significant in the process of design. That is why i is not enough to predict the reliability of structures or BO in general only based only on the calculations during the stage of design [1].

Timely implementation of efficient measures for the adaptation of a building structure (BS) implies the use of reliable models and methods of diagnosis taking into account the impact of dynamic stochastic factors of the environment and subsequent adjustment of input conditions of a problem at the stage of operation. Under such conditions there remains a relevant task to increase the level of automation of the process of diagnosis, the solution of which requires the development and implementation in the process of BO lifecycle management of simple to use and economically grounded information technologies and tools for evaluation of technical condition (TC) of structures that are capable of taking into account dynamics of the processes of destruction under contemporary conditions of uncertainty [2, 3].

2. Literature review and problem statement

Modern scientific methods that provide for the possibility of solving the problem of safe and reliable operation of BO are divided into three groups [4–6].

The methods of the first group are applied only after the current test reveals that there are no cracks in the material of the structure. The methods of this group are designed for the cases of occurrence of possible accident not as a result of occurrence and development of cracks but due to the weakening in the bearing cross section of the structure. In these tasks, a probability approach is the most efficient and enables obtaining the adequate evaluation of the technical condition of BO even under conditions of partial uncertainty [1].

The probabilistic models are used for the implementation of calculations for the boundary states of the first group when predicting the "scripts" of progressive destruction. The choice of the most likely scenarios of emergency destruction is carried out by experts with regard to the location and factors of reduction in the bearing capacity. As the input data, they use expert assessments of probabilities of a–priori hypotheses about the cause of occurrence of certain states [6, 7].

A posteriori hypothesis are found by formula [8]:

$$\left(Dj/X\right)=\frac{P\left(D_j\right)P\left(X/D_j\right)}{\sum_{j=1}^{m}P\left(D_j\right)P\left(X/D_j\right)}, \quad (1)$$

where $P(D_j)$ is the a priori probability of the object of diagnostic's being in a state that is characterized by the diagnosis D_j, j=1, ..., m, m is the number of possible states; $P(X/D_j)$ is the conditional probability of the object's occurrence with the parameters of state $X=(x_1, x_2,..., x_n)$, which are inherent to the diagnosis D_j; $P(D_j/X)$ is the a posteriori probability of the object's transition to the state that is characterized by the diagnosis D_j.

The task of diagnosis is the evaluation of probability of a posteriori hypothesis about the technical condition of the facility and in conducting diagnosis based on these estimates.

The transition of the object of research from one state to another one at the stage of operation is described by Markov processes with discrete states (Fig. 1).

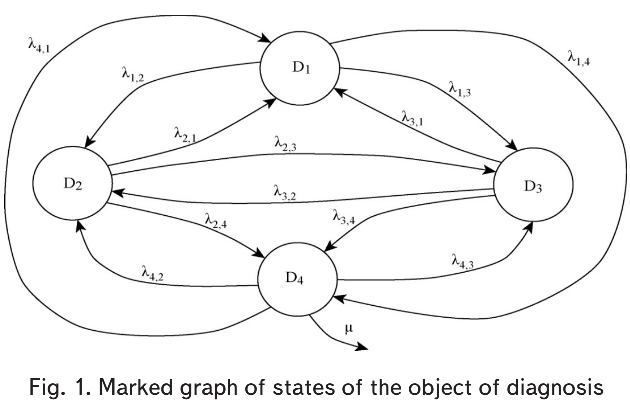


Fig. 1. Marked graph of states of the object of diagnosis

In Fig. 1: D_1 – normal condition – all the requirements of existing norms and standards are met, there are no damages and defects that indicate a decrease in the operational quality of the bearing structures; D_2 –satisfactory condition – the requirements of existing norms and standards with regard to the strength by the boundary conditions of the first group, taking into account the actual strength of materials, are met; not met by the boundary conditions of the second group; normal conditions are not provided in the given period of time under particular conditions; defects and damages that indicate a decrease in the bearing capacity are absent; but there are defects and damages that indicate a decrease in the protective properties of materials; D_3 –the condition does not allow for normal operation – the requirements of existing norms and standards in strength in terms of the boundary conditions of the first group are not met; the defects and damages that indicate a decrease in the bearing capacity and operational suitability are present; but there is no threat of brittle fracture, nor a threat to the safety of people; D_4 – emergency condition – the occurrence of a boundary state by strength and destruction of constructions is possible; there are defects and damages that indicate a threat to the people in the area of location of the facilities; λ_{ij} is the density of the course of events that transfer the object from the state i to the state j – parameter of distribution determined by the terms of operation; μ is the recovery parameter.

The system of linear differential equations to determine the probabilities of transfer of the structure from state to state at the stage of operation has the form [8]:

$$\begin{cases}\frac{dp_1(t)}{dt}=\lambda_{2,1}p_2(t)+\lambda_{3,1}\,p_3(t)+\lambda_{4,1}p_4(t)-(\lambda_{1,2}+\lambda_{1,3}+\lambda_{1,4})p_1(t);\\ \frac{dp_2(t)}{dt}=\lambda_{1,2}p_1(t)+\lambda_{3,2}\,p_3(t)+\lambda_{4,2}p_4(t)-(\lambda_{2,1}+\lambda_{2,3}+\lambda_{2,4})p_2(t);\\ \frac{dp_3(t)}{dt}=\lambda_{1,3}p_1(t)+\lambda_{2,3}\,p_2(t)+\lambda_{4,3}p_4(t)-(\lambda_{3,1}+\lambda_{3,2}+\lambda_{3,4})p_3(t);\\ \frac{dp_4(t)}{dt}=\lambda_{1,4}p_1(t)+\lambda_{2,4}\,p_2(t)+\lambda_{3,4}p_3(t)-(\lambda_{4,1}+\lambda_{4,2}+\lambda_{4,3})p_4(t),\end{cases} \quad (2)$$

where $p_i(t)$ is the probability of the condition i at the specified time t.

The constraints that complicate formalization of probabilistic process of forecasting in the case of diagnosis of technical condition of BO under real operating conditions include [8]:

– hypotheses about facts of violations of the operating conditions that may lead to changes in TC category in future, do not form full groups of events;

– the condition of the independence of hypotheses in totality is not met;

– subjectivity of expert assessments.

This means that the application of the probabilistic approach is justified and efficient if there is a sufficient reason to believe that the information about the input data is described by the known probabilistic laws or characterized by representative statistics. In this case, an analysis of experimental studies and field observations under real conditions revealed that the metal and reinforced-concrete structures more often pass into emergency condition due to the workload under the influence of aggressive environment rather than collapse when the loads reach the limiting levels [9, 10].

The deterioration of properties of reinforced concrete that is operated under conditions of modern cities is caused by the penetration of aggressive environment inside the structure, which contributes to the degradation of protective layer of concrete and corrosion of reinforcement. Corrosion results in the reduction of cross-sectional area of reinforcement and the character of adhesion between concrete and reinforcement, which significantly decreases reliability and bearing capacity of BO.

The described process of destruction depends not only on the concentration of aggressive environment but on the conditions of loading. Thus, during prolonged action of cyclic stresses and strains, in addition to corrosion, there is the process of changing the physical properties of materials, which is defined as the fatigue. In addition, all long-term processes of destruction of metals are accompanied by their aging. Studying the processes of degradation enables professionals to consider a possible mechanism of destruction with taking it into account during designing, while the second group combines methods that are based on general laws of mechanics of materials destruction [11, 12].

The methods of the second group are based on the following procedure of forecasting [1, 4, 13]:

– performance requirements and criteria for damage are defined;

– critical characteristics of the suitability of material are defined;

– the expected type and extent of factor of destruction are defined;

– characteristics of the material, for which the forecast is conducted, are set;

– possible mechanism of destruction is determined;

– design is carried out and quick tests are conducted with the purpose of realization of rapid destruction and determining its mechanism;

– long-term testing is run under operational conditions;

– a mathematical model of destruction is built and the speeds of changes are compared under laboratory and field conditions;

– forecasting of durability of the design is performed.

The methods of calculation of structures based on the above-mentioned procedure have the character of partial solutions, as the developed in each case formula contain empirical coefficients that meet specific conditions of the experiments [14].

Development of a mathematical model of destruction, according to the theory of structural parameters, includes:

– modeling a constructive element with regard to the character of its deformation under the action of a specified load;

– modeling a support, simulation of loading;

– simulation of the interaction between the aggressive environment and the element.

The mathematical models of destruction developed in this way are the boundary problems of second and higher orders with different boundary conditions. Such models adequately reflect reaction of materials to loads under examined conditions, but are difficult to use.

An alternative to the above-described methods are those based on the application of apparatus of fuzzy logic and which make up the third group [7, 8, 15–17]. The methods of fuzzy mathematics are used in this paper to assess technical condition of BO that function under conditions of uncertainty. Under such conditions, there is a growing demand for intelligent information technology (IIT) and the systems that are able to perform not only the assigned sequence of actions with the determined data but are capable to analyze dynamic information by themselves, to find regularities in it and perform forecasting [8, 11]. To solve such problems, there are artificial neural networks that can perform the function of an expert in the intelligent decision support systems (DSS). The application of artificial neural networks significantly increases the level of automation of the process of diagnosis, but their training implies the existence of reliable database (DB) for various combinations of factors of influence from the environment [11, 17]. The approach which is based on the models and methods of fuzzy mathematics provides a possibility to build a dynamic knowledge base for intelligent DSS based on the comparison of results of the BO inspection with the results of monitoring the environment in real time.

3. Aims and objectives of the research

The aim of the work is to develop the IIT assessment of building structures using the apparatus of fuzzy logic for the formalization of the expert knowledge with its further implementation by the State Enterprise "Scientific and Research Institute of Building Production» in Kyiv.

To achieve this goal, the following tasks were formulated:

– to explore the information processes of diagnosis of technical condition of BO;

– to design a fuzzy knowledge base, which will be the basis of information provision of intellectual technology of diagnosis of technical condition of building structures under conditions of uncertainty;

– to propose reliable and economically substantiated practical implementation of the developed technology of assessment of technical condition of the building structures.

4. Design and application of the technology of assessment of technical condition of BS

4. 1. Research into the process of diagnosis of technical condition of BO

An analysis of information processes and methods of examination and assessment of TC of buildings and facilities revealed a number of peculiarities associated with the uncertainty of input information of different nature which are displayed at the stages of decision-making [11]. In each particular case the definition and approval of the rules according to which the decisions are made, and the development of recommendations regarding their application are passed on to experts. In this case, the experts may receive information for considering additional operations and places to locate appropriate measurement devices, using the automated design systems (CAD), which perform construction of information model of buildings (BIM) and calculate loads on separate BS. The BO information model contains necessary information about the elements that are in the areas of increased risk of destruction: their location, the points of the highest load, material they are made of, etc. [3, 13].

The main stages of diagnosis of technical state of BO are shown in Fig. 2.

The illustration of integration of contemporary systems of calculation and design into the process of diagnosis of BO of intellectual information technology based on the expert knowledge using fuzzy logic is demonstrated in Fig. 3.

When designing a model of management of diagnostic parameters of TC, they distinguish between the notions of degradation of elements of the structure and the structure's materials. The degradation of element is the accumulation of corrosive and mechanical and corrosion-mechanical defects that cause the decline in its bearing capacity. Later, some of them are eliminated during repairs while the others are taken into account when determining the stressed-strained state (SSS) of the element of the structure with defects and its resource according to the original mechanical characteristics of materials. Element's degradation is characterized by a specific set of direct parameters of defects and damages, which include geometrical parameters of cracks and other structural parameters that directly characterize TC of the structure (Table 1).

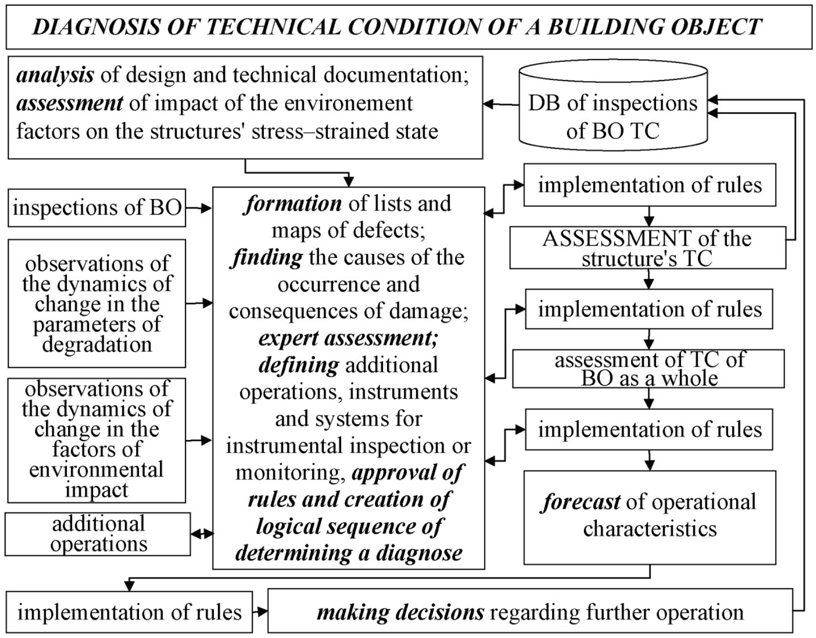


Fig. 2. Main stages of diagnosis of technical condition of building objects

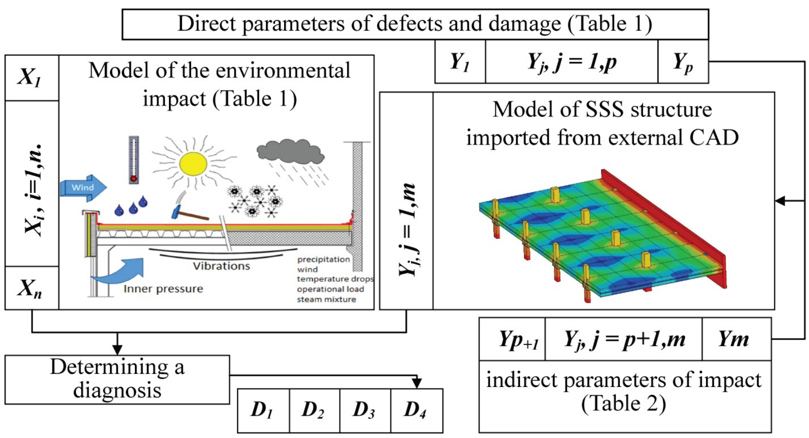


Fig. 3. Model of management diagnostic parameters in the process of creation of the logical sequence of determining a diagnosis

Table 1

Example of formalization of direct parameters of degradation of reinforced concrete floor slabs

Defects and damages	Terms for linguistic assessment
y_1 – crack type	longitudinal (lt); transverse (tv); slanted (sl); shrinkable (shr);
y_2 – opening width	small (sm); developed (dv); large (lr);
y_4 – crack's length	short (sh); medium (m); long (l);
y_5 – crack location	near supports (ns); in the shelves of slabs (shs); along armature (aa); in the seams between slabs (sbs);
y_6 – displacement	absent (ab); insufficient (is); considerable (c);
y_9 – slab sagging	(ab) absent; (is) insufficient; (c) considerable;
y_{10} – traces of wetting or freezing	(ab) absent; (is) insufficient; (c) considerable;
y_{11} – peeling surface of concrete	(ab) absent; (pr) present

Another reason of change in the operational characteristics of structures is the degradation of materials – change in their original structural-phase state in the course prolonged operation. To account for the degradation of materials, the set of direct diagnostic parameters is complemented by a set of indirect parameters that reflect impact of the environment on the kinetics of degradation (Table 2).

Table 2

Example of formalization of indirect parameters of impact of the environment on the speed of destruction of a structure

Parameters of impact	Terms for linguistic assessment
y_{12} – effect of vibrations	(ab) absent; (ne) non-essential; (c) considerable;
y_{13} – effect of humidity	(ab) absent; (sw) slow; (m) medium; (c) considerable
y_{14} – effect of wetting	(ab) absent; (sw) slow; (m) medium; (c) considerable
y_{15} – effect of temperature	(ab) absent; (sw) slow; (m) medium; (c) considerable
y_{16} – effect of corrosion	(ab) absent; (ne) non-essential; (m) medium; (c) considerable

A diagnosis of environment is carried out according to the loads and effects that cause degradation processes, which lead to changes in the structure's SSS.

Determining a diagnosis is performed by developers of analytical software based on the expert knowledge. The rules of determining are built according to the infologic formalization of the process of assessment that is provided in [11] in the form of conditional operator:

if <logical expression> **then** <operator>, (3)

where <logical expression> is the expression that is built based on logical operations with fuzzy values; <operator> is the resultant solution.

The first question that arises in the course of development of a fuzzy model and selection of an algorithm of fuzzy determination of diagnosis, – substantiation of the set of parameters that form the vector of input data.

4. 2. Information provision of IIT with fuzzy logic

The base of information provision for intelligent information technologies is the DB of inspections of TC of BO (Fig. 2) and the knowledge base.

The DB of inspections reflects:

– information arrays and data streams about BS and BO in general that function under different conditions starting from installation and to the current inspection;

– regulatory and reference information;

– templates for incoming and outgoing documents and instructions regarding conducting inspections;

– control cards of quality characteristics and other documents and standards required for the analysis of uniformity of structures' TC and the project data and information model.

The knowledge base contains a database and a database of rules. The database stores:

– classification features of categories of structures' TC with the list of relevant linguistic terms and possible causes and consequences of their degradation;

– the data of field inspections and scientific-experimental studies;

– an atlas of standards and analogues with descriptions of conditions of their operation.

The database of rules accumulates the rules that have already been applied and conditions of their application.

Table 3 presents an example of fuzzy knowledge base of diagnostic parameters of TC of reinforced concrete floor slabs [11].

Each column (Y_j) of the table corresponds to certain terms of linguistic variables that describe diagnostic parameters of degradation, which were detected during the diagnosis; the degree of damage to the structure is assessed by terms of condition: normal (N); satisfactory (S); unfit for normal operation (UN); emergency (EM). A fuzzy knowledge base for the structure that is diagnosed, is composed of the set of fuzzy rules that reflect interrelation between the input and output variables. Each line in the table corresponds to one rule. Connection between linguistic variables inside one rule is carried out with the involvement of the logical operation & (AND). Within the limits of one knowledge base, linguistic rules are the lines related to the logical operation OR.

When designing the algorithm of assignment of rules, it is necessary to take into account that the hydrogeological, climatic, environmental, technological and other factors of the environmental impact display different degree of influence even on standard BO depending on the peculiarities of their location and operating conditions. In such cases, fuzzy system sorts the diagnostic parameters that form the input vector, in descending degree of influence and, in the absence of other rules, would recommend making a decision by the criterion with a smaller serial number.

Table 3

Fragment of fuzzy knowledge base of the degradation parameters

Type of structure	Rule number	Number of elements	Operation	Parameters of condition						Term of condition
				Y_1	Y_2	Y_4	Y_5	Y_9	Y_{10}	
1	2	3	4	5	6	7	8	10	11	12
k_1 (slab)	1	5	&	lt	sm	sh	shs	ab	ab	N
	2	5	&	tv	sm	sh	sbs	ab	is	N
	3	5	&	sl	sm	m	ns	ab	–	N
	5	5	&	lt	dv	m	aa	ab	ab	S
	7	5	&	lt	sm	m	shs	is	is	S
	8	5	&	tv	dv	m	aa	is	is	S
	10	5	&	lt	lr	l	aa	is	c	UN
	11	5	&	tv	lr	m	shs	c	is	UN
	12	5	&	tv	dv	l	aa	c	ab	UN
	14	5	&	lt	lr	l	shs	c	c	EM
	15	5	&	tv	lr	l	ns	c	c	EM

Note: the sign "–" denotes the variables that can take arbitrary values without breaking the truth of the appropriate rule, the functions of belonging of these variables can be removed from logical equations

For example, according to (3), the sorting rule has the form:

*if <**slow** effect of humidity on the speed of destruction* AND ***considerable** effect of vibrations on the speed of destruction> **then** <y_1 – effect of vibrations on the speed of destruction, and y_2 – effect of humidity on the speed of destruction>*

But the cases are possible of occurrence of conflicting sets of rules (Table 4).

Table 4

Examples of the conflict of rules, which lies in the fact that various factors of the environment are characterized by the same level of influence

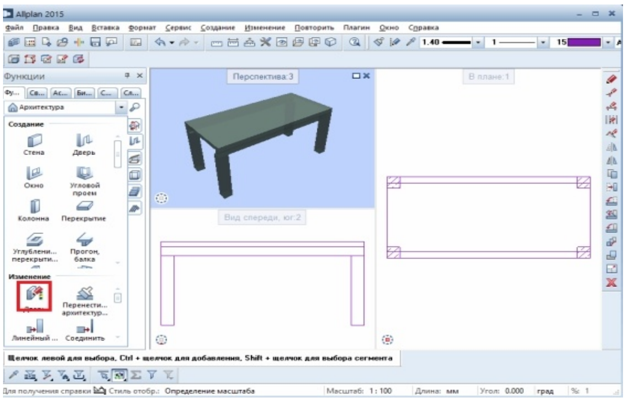
No.	Primary event		Order of factors
1	A_1	non-essential effect of vibrations	1 – effect of temperature; 2 – effect of corrosion; 3, 4 – effects of wetting, humidity OR 3, 4 – effects of humidity, wetting, 5 – effect of vibrations
	A_3	slow effect of humidity	
	A_5	slow effect of wetting	
	A_7	considerable effect of temperature	
	A_9	medium effect of corrosion	
2	A_2	considerable effect of vibrations	1–3 – effects of vibrations, wetting, temperature OR 1–3 – effects of temperatures, humidity, vibrations OR 1–3 – effects of humidity, vibrations, temperature OR ... 4 – effect of wetting; 5 – effect of corrosion
	A_4	considerable effect of humidity	
	A_5	slow effect of wetting	
	A_7	considerable effect of temperature	
	A_8	non-essential effect of corrosion	

The given examples are enough for understanding another problem – the order of diagnostic parameters that form the vector of input data with the automated assessment of the TC category affects the choice of the standard for comparison and leads to an increase in the risks of incorrect specification of the model. In any case, these and other issues related to uncertainties or inconsistencies in information are addressed by the experts at the stages of "rules implementation" (Fig. 1).

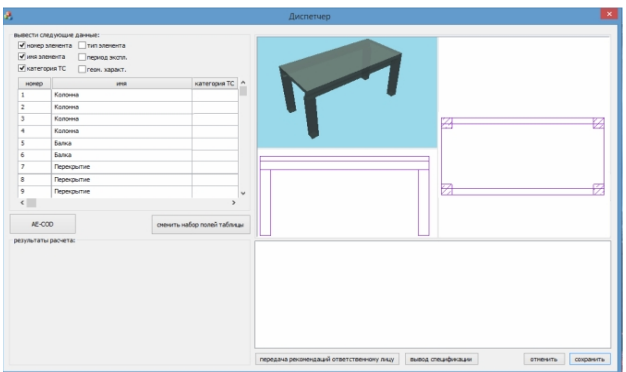
4. 3. The application of universal software systems for setting parameters and rules for diagnosing

A model of stressed-strained state of the structure is downloaded in the form of a plate-rod model from any CAD that supports the data transfer format of IFC (Industry Foundation Classes). In this example, we use the software complex Allplan 2015 (Fig. 4, *a*).

An external CAD automatically transfers all the necessary information regarding testing data of calculation elements in accordance with the type of production, factory, etc. to the dispatcher (Fig. 4, *b*). In this window one may edit, delete, sort out the elements from the list of inspections. The elements that were not included in the list of those calculated do not affect technical condition of BO or their effect is insignificant. The elements that require assessment will be highlighted in yellow. To assess their TC, the user must select the objects in the table and configure the necessary parameters and rules from the knowledge base. When changing the field set, the settings are automatically saved. Below we describe functions which are used to control parameters and rules.



a



b

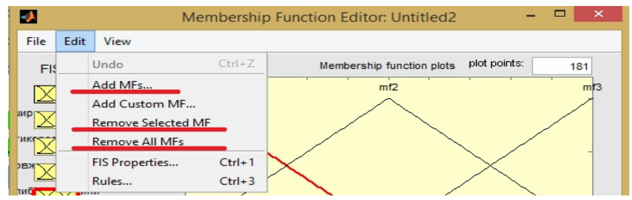
Fig. 4. Windows of programs: *a* — Allplan 2015; *b* — Dispatcher

The FIS Editor displays the algorithm of fuzzy determination of diagnosis: input and output linguistic variables; intervals for calculations, types of distribution of functions of belonging and setting the rules (Fig. 5, *a*). The Membership Function Editor is designed to control such characteristics of the input variables, as a set of terms and choosing the membership functions (Fig. 5, *b*).

The Edit feature provides the possibility to add, select, or delete parameters in any term (Fig. 6, *a*). For each of the terms, the scale of calculation of variables is determined; intervals for displaying and for carrying out the calculations are specified (Fig. 6, *b*). The type of membership function and characteristic points of each variable are set when setting the terms (Fig. 6, *c*).

After the terms setting (Ctrl+1), the Editor is used to navigate to setting the rules (Ctrl+3).

The Rule Editor is used to perform such operations when setting the rules as: to add, to delete, to assign weight, etc. (Fig. 7).



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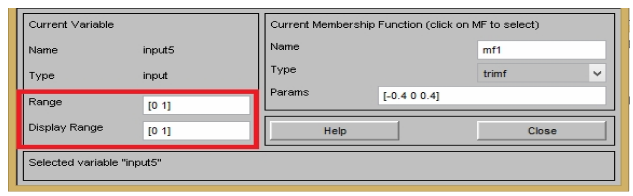

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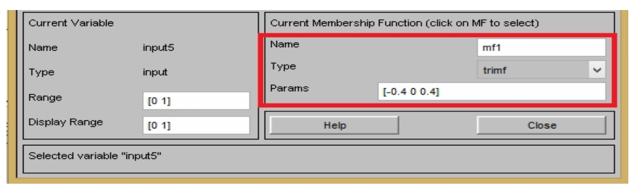
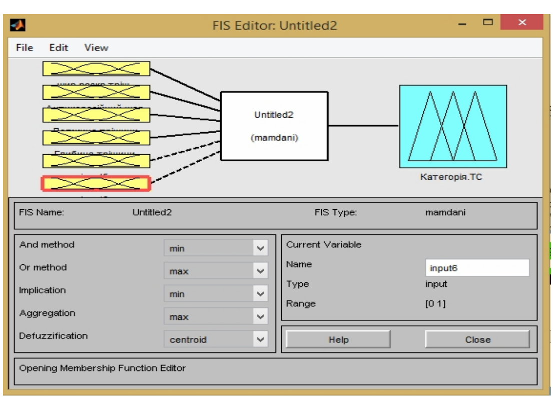


c

Fig. 6. Setting parameters and rules: *a* — formation of the structure of the input vector; *b* — determining the intervals of the scale of calculation; *c* — terms setting

The fields of rules management are shown in Fig. 8. Removal, adding or changing the rules are shown in Fig. 8, *a*). The fields of configuration of logical operations are marked in Fig. 8, *b*). The diagnostic features of degradation parameters are configured using the fields that are shown in Fig. 8, *c*).



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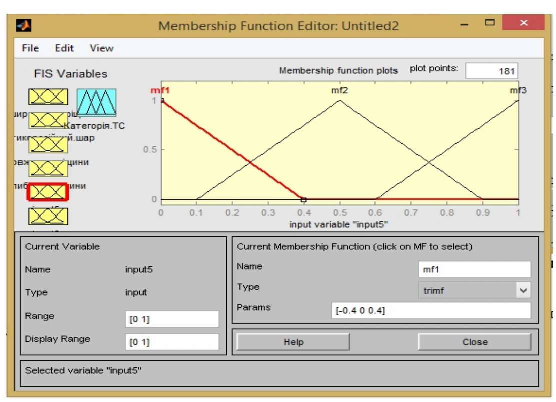


b

Fig. 5. FIS Editor and Membership Function Editor: *a* — settings and rules in a general form; *b* — control of parameters of the input variables

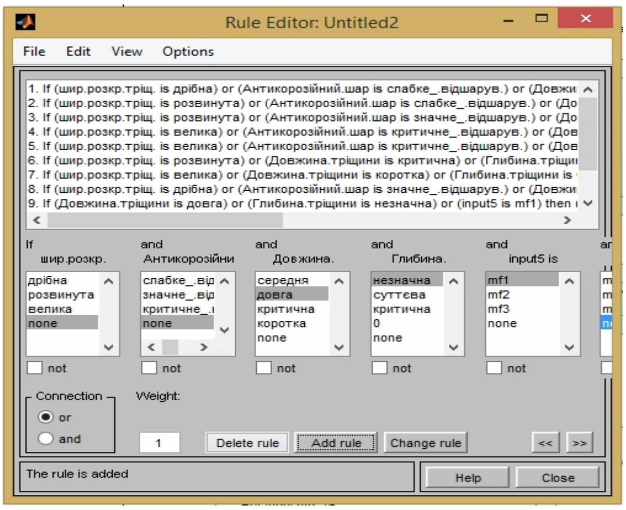
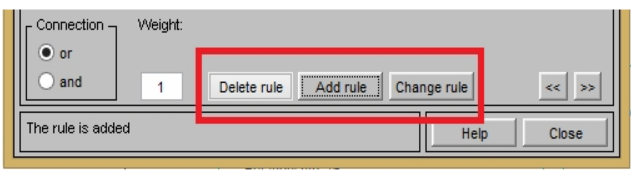


Fig. 7. Setting the rules of fuzzy logic

For the implementation of expert decision making support when diagnosing the TC of structures, we propose the following algorithm of control of the base of rules.



a

b

c

Fig. 8. Fields of setting: *a* – rules; *b* – logical operations; *c* – diagnostic features of parameters of degradation

4. 4. Implementation of expert decision making support

To carry out the following steps using the package Fuzzy Logic Toolbox of the Matlab software.

Step 1. Download a file with the rules for BS, the technical condition of which is estimated. To do this: click on the context menu File, select the line Import, click on From File (Ctrl+O), as shown in Fig. 9.

Step 2. Select Read FIS (Fig. 10, *a*). Using the Open command, select and download appropriate rules (Fig. 10, *b*).

Step 3. Go to Rule Viewer: open View tab; in the menu that will appear choose the line Rules or use Ctrl+5 (Fig. 11).

Step 4. Assess the category of TC of the object of diagnosis using display of terms of linguistic variables in Rule Viewer (Fig. 12). The number above the last column is a clear value of the degree of belonging of the original rule.

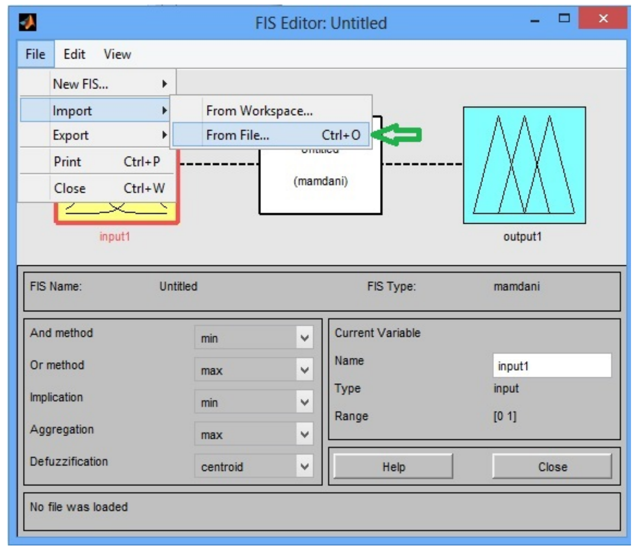
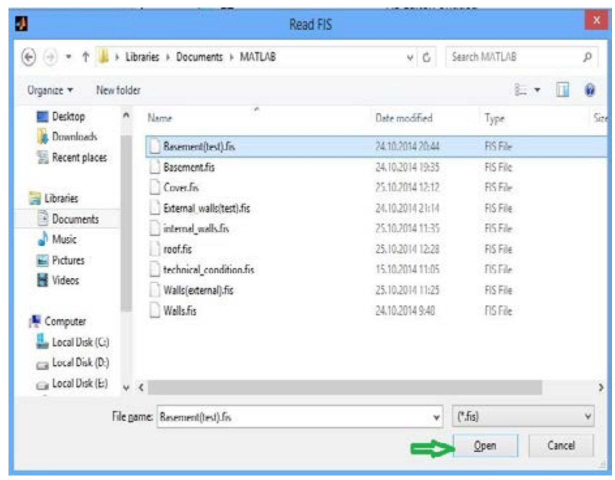
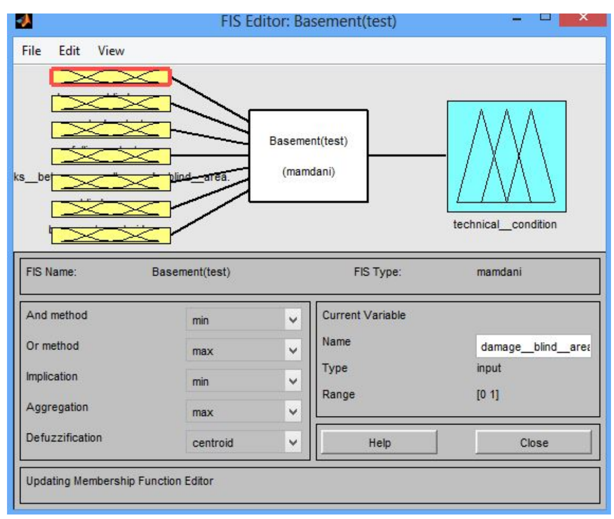


Fig. 9. Starting window of settings and rules



a



b

Fig. 10. Downloading the rules from the database: *a* – selecting the file with the rules; *b* – display of the downloaded rules in the window Read FIS

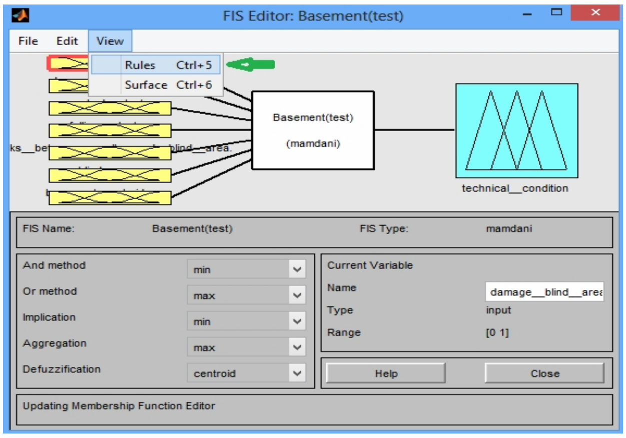


Fig. 11. Transition to the window Rule Viewer

The results of diagnosis and recommendations for further operation are given through the Dispatcher of the integrated CAD (Fig. 13).

Category of technical condition – IV.

Level of fitness – emergency.

The reason of occurrence of the IVth condition – long developed crack of critical depth.

The list of possible causes:

1) overload of structure;

2) displacement of position of the stretched armature during manufacturing;

3) insufficient effort of the armature stretch (for preliminary stressed structures).

The decisions regarding further exploitation of BO are taken at the appropriate level according to current regulations governing the compilation of conclusions.

All values of parameters and rules that are set by using the described technology and applied by the expert or the user are collected and stored in the DB of inspections of TC of BO (Fig. 2).

5. Discussion of results of approbation and possibilities of implementation of IIT for assessing TC of building structures

To test the adequacy of fuzzy models that formed analytical provision of this IIT, the technology of management of the base of rules built as a result of the conducted research was proposed to specialists and verified when assessing technical condition of such facilities in the city of Kiev as:

– building No. 36, Volodymirska Street, building No. 11, Zolotovorotska Street;

– building No. 42, Gonchar Street, building No. 17, Novovokzalna Street.

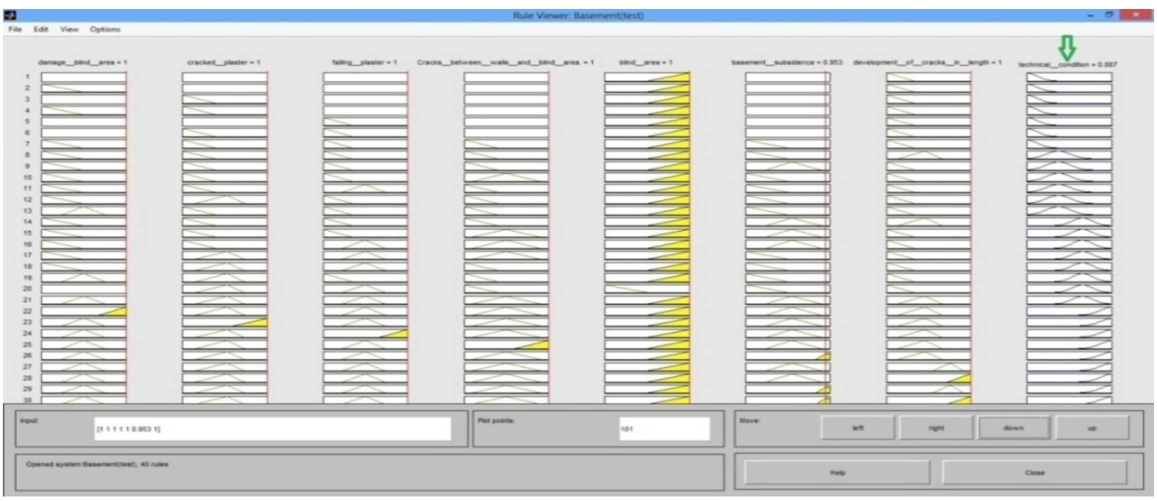


Fig. 12. Window of display of terms of linguistic variables Rule Viewer

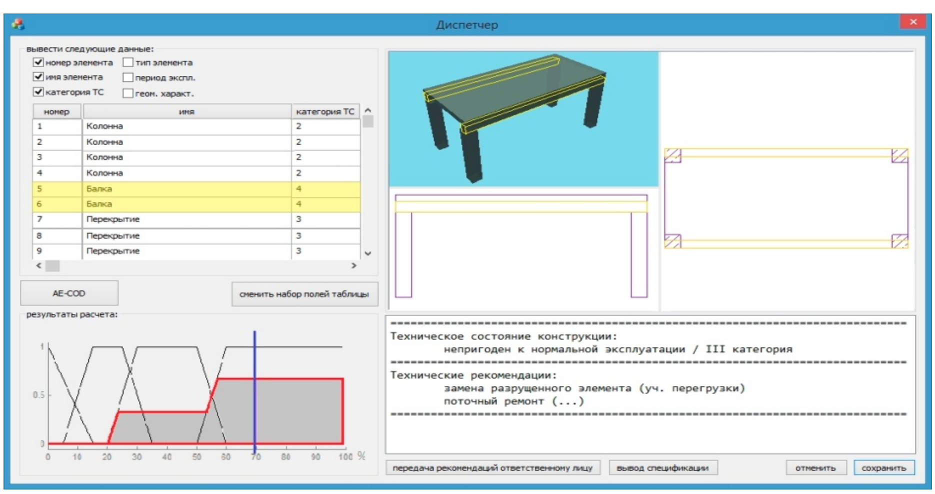


Fig. 13. The obtained result of calculation

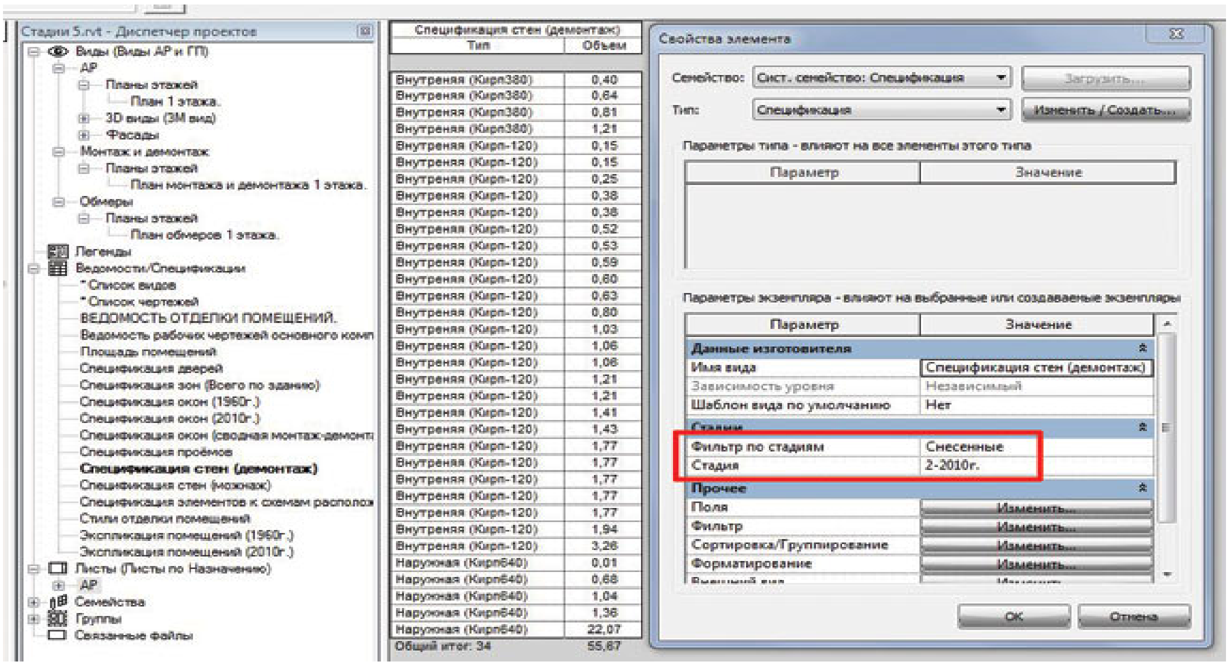


Fig. 14. Stages in Autodesk Revit

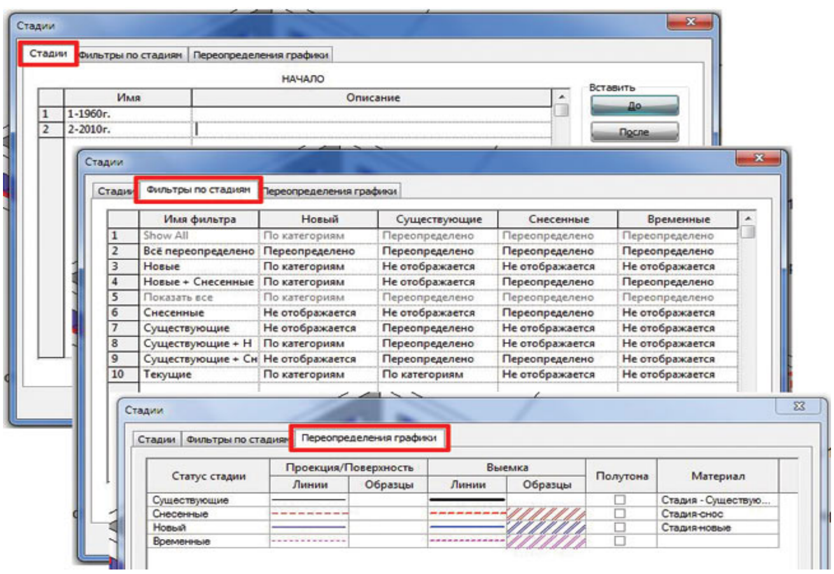


Fig. 15. Example of work in stages in Autodesk Revit

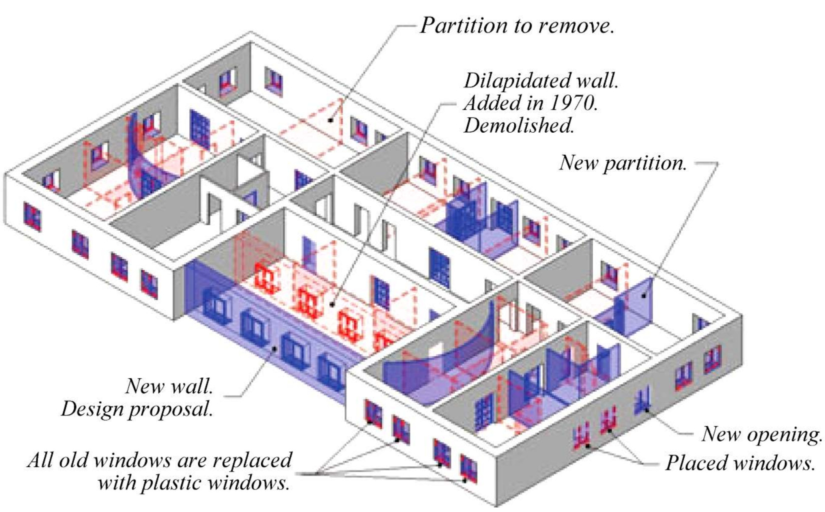


Fig. 16. Demonstration of changes in the facility by stages

The received conclusions about the diagnosis of TC of the specified BO are consistent with conclusions of the experts from the State Enterprise “Scientific and Research Institute of Building Production”, as confirmed by the certificate of implementation No. 210 a/01–14 as of 31 March 2015.

Thus, the testing of the knowledge base described in this work proved its adequacy and relevance of further development of the automated expert system of diagnosis of technical condition of BO based on the apparatus of fuzzy logic.

In addition, it should be noted that the proposed technology supports the data transfer format of IFC, which is endorsed by such software developers as Graphisoft, Autodesk, Nemetschek, Robobat, Tekla, Bentley and SCIA and does not require a special interface to any of the existing universal automated systems of design. This means that the experts may select which particular CAD to integrate in the process of diagnosis.

The possibilities of implementation of the software Autodesk Revit in the process of diagnosis are shown in Fig. 14.

All the elements are being in one of two states: built or demolished and inextricably linked together (Fig. 15).

Filtration by stages eliminates the need for the user to control every element (Fig. 16).

The results of the diagnosis are passed on to the integrated CAD and can be used for modeling the processes of destruction and prediction of the stressed-strained state of bearing structures of building objects both at the planning stage of renovation and at the stage of formation of an adequate calculation model in the design process.

6. Conclusions

1. When developing the algorithm of assessment and organization of expert decision making support, we took into account such problems as unsatisfactory speed of estimation and the risk of making incorrect decisions related to the formalization of logic sequence of determining a diagnosis under conditions of uncertainty of the input data. The implementation of this IIT contributes to overcoming these challenges through gathering, accumulation, systematization and use of generalized expert knowledge.

2. The designed knowledge base was verified by the experts from Scientific-Research Institute of Building Production when assessing the technical condition of a number of facilities in the city of Kiev. The obtained conclusions confirm the adequacy of fuzzy models that formed its foundation.

3. The use of contemporary CAD for building an information model of a building and calculations of loads on separate BS contributes to the reliability of prediction and reduction of costs for conducting additional field tests and the risks of development of uncontrolled defects after conducting these tests.

References

1. Barabash, M. S. Metodika modelirovaniya progressiruyushchego obrusheniya na primere real'nyh vysotnyh zdanij [Text] / M. S. Barabash, M. A. Romashkina // Stroitel'stvo, materialovedenie, mashinostroenie. – 2014. – Vol. 78. – P. 28–37.
2. Lin, Y.-C. Developing construction defect management system using BIM technology in quality inspection [Text] / Y.-C. Lin, J.-X. Chang, Y.-C. Su // Journal of Civil Engineering and Management. – 2016. – Vol. 22, Issue 7. – P. 903–914. doi: 10.3846/13923730.2014.928362
3. Volk, R. Corrigendum to "Building Information Modeling (BIM) for existing buildings – Literature review and future needs" [Autom. Constr. 38 (March 2014) 109–127] [Text] / R. Volk, J. Stengel, F. Schultmann // Automation in Construction. – 2014. – Vol. 43. – P. 204. doi: 10.1016/j.autcon.2014.02.010
4. Ellingwood, B. R. Best practices for reducing the potential for progressive collapse in buildings [Text] / B. R. Ellingwood, R. Smilowitz, D. O. Dusenberry, D. Duthinh, H. S. Lew, N. J. Carino. – National Institute of Standards and Technology, 2007. doi: 10.6028/nist.ir.7396
5. Nasirzadeh, F. Integrating system dynamics and fuzzy logic modelling for construction risk management [Text] / F. Nasirzadeh, A. Afshar, M. Khanzadi, S. Howick // Construction Management and Economics. – 2008. – Vol. 26, Issue 11. – P. 1197–1212. doi: 10.1080/01446190802459924
6. Terenchuk, S. A. Informatsiyna systema otsinky efektyvnosti reklamnykh zakhodiv [Text] / S. A. Terenchuk, V. V. Hots, Kh. M. Shamshur // Upravlinnya rozvytkom skladnykh system. – 2010. – Vol. 1. – P. 43–45.
7. Yusong, P. A Simulation Based Expert System for Process Diagnosis [Text] / P. Yusong, P. Hans, M. Veeke, G. Lodcwijks // In Proceedings of EUROSIS 4 th International Industrial Simulation Conference (ISC 2006), 2006. – P. 393–398.
8. Terenchuk, S. A. Modeli i metody otsinky ryzykiv v investytsiynykh budivel'nykh proektakh v umovakh nevyznachenosti [Text] / S. A. Terenchuk, B. M. Yeremenko, D. B. Zhurybeda // Teoriya i praktyka budivnytstva. – 2009. – Vol. 5. – P. 49–53.
9. Kryvenko, P. Sulfate Resistance of Alkali Activated Cements [Text] / P. Kryvenko, S. Guzii, O. Kovalchuk, V. Kyrychok // Materials Science Forum. – 2016. – Vol. 865. – P. 95–106. doi: 10.4028/www.scientific.net/msf.865.95
10. Krivenko, P. Atmospheric Corrosion Protection of Metallic Structures Using Geocements-Based Coatings [Text] / P. Krivenko, S. Guziy, H. A. J. Al-Musaedi // Solid State Phenomena. – 2015. – Vol. 227. – P. 239–242. doi: 10.4028/www.scientific.net/ssp.227.239
11. Yeremenko, B. M. Design of intelligent system for diagnostics of technical state of building objects [Text] / B. M. Yeremenko // Technology audit and production reserves. – 2015. – Vol. 1, Issue 2 (21). – P. 44–48. doi: 10.15587/2312-8372.2015.37506
12. Kozachenko, Yu. V. Accuracy of Simulations of the Gaussian random processes with continuous spectrum [Text] / Yu. V. Kozachenko, A. A. Pashko // Computer Modeling and New Technologies. – 2014. – Vol. 18, Issue 3. – P. 7–12.
13. Borodavka, Ye. V. Model' rozshyryuvanoyi systemy avtomatyzatsiyi zhyttyevoho tsyklu budivel'noho ob'yekta [Text] / Ye. V. Borodavka // Upravlinnya rozvytkom skladnykh system. – 2010. – Vol. 4. – P. 69–71.
14. Tüysüz, F. Project risk evaluation using a fuzzy analytic hierarchy process: An application to information technology projects [Text] / F. Tüysüz, C. Kahraman // International Journal of Intelligent Systems. – 2006. – Vol. 21, Issue 6. – P. 559–584. doi: 10.1002/int.20148
15. Doukas, H. Intelligent building energy management system using rule sets [Text] / H. Doukas, K. D. Patlitzianas, K. Iatropoulos, J. Psarras // Building and Environment. – 2007. – Vol. 42, Issue 10. – P. 3562–3569. doi: 10.1016/j.buildenv.2006.10.024
16. Yeremenko, B. Statistical Simulation of Accidental Loads in the Problems of Constructional Mechanics [Text] / B. Yeremenko, A. Pashko, S. Terenchuk // Advanced Materials Research. – 2015. – Vol. 1122. – P. 249–252. doi: 10.4028/www.scientific.net/amr.1122.249
17. Castro, J. R. Building Fuzzy Inference Systems with the Interval Type-2 Fuzzy Logic Toolbox [Text] / J. R. Castro, O. Castillo, P. Melin, L. G. Martínez, S. Escobar, I. Camacho // Advances in Soft Computing. – 2007. – P. 53–62. doi: 10.1007/978-3-540-72432-2_7