THE CONCEPTION OF MAKING DECISION SUPPORT SYSTEM INTRODUCTION INTO BUILDING STRUCTURES DESIGN PRACTICE

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ABSTRACT: *The paper discusses introduction of artificial intelligence into structural engineering practice. The necessity of this paper is accelerated by the information base (IB) and decision support systems exigency, as some standards are not completely designed and there is no statistical information on faults, defects and damage to various buildings. The article suggests creating a decision support system for the optimal structural design of buildings that takes into account a risk of a propagating rupture. The article describes possibilities of a decision support system, the stages of its development and structure. Conceptual solution of the proposed decision support system for the analysis of structures is illustrated by designing trade and business centre high-rise building. The system is based on a knowledge base, which is created during its development and can be updated and expanded with the advent of new codes of practice and new structural design recommendations. Expert system will be built on the basis of clear rules and recommendations from foreign and Russian codes of practice, as well as European standards, and international occurrences of buildings accidents. Optimization of structural elements is performed on the basis of a genetic algorithm. The effect of various genetic operators on the performance of the algorithm is investigated. A model of a genetic algorithm for optimization of steel structural elements is developed. The work is the attempt to create a complex approach to the structural design: the user can not only study the normative documentation, get advice, study the examples of calculation, but also take advantage of the proposed programs for the optimization of the design decisions. It is expected that expert's knowledge on the analysis of buildings incorporated in expert system will improve the quality of the design, and as a consequence, the reliability of structures.*

KEYWORDS: *decision support systems, expert systems, optimum design, propagating rupture, genetic algorithm*

1. INTRODUCTION

The problem of safety and efficiency of buildings and structures is one of the main problems highlighted by continuously increasing volume of construction. The research in the design of reliable and at the same time, the optimal building structures indicates the relevance of creating expert systems in design. It is necessary to solve the problems that structural engineers are facing today. An urgent need for an information base (IB) and decision support systems is escalated. This paper proposes the creation of decision support expert system (ES), which will provide access to necessary information and suggest ways to solve problems effectively. In the U.S.A., Germany, Japan and other developed countries, hundreds of decision support systems of intellectual type (based on the ES) have been already designed and are used in various areas of construction. In Russia, expert systems are mainly used in the construction investment process.

2. BACKGROUND OF THE ES CREATION

The reference article (Gurjev and Dorofeev, 2006) states that in order to make effective decisions on reducing the occurrence of accidents in areas subject to natural and anthropogenic hazards, objective information about the technical state of objects can be obtained by monitoring the strength resources of buildings and structures. Currently the technology that monitors existing structures in the world is in a conceptual development stage, although some recent unexpected collapse of buildings in our country and abroad brought this problem to the foreground of preventive measures that ensure the safety of the population, especially in major cities. This information database is created by studying technical conditions of actual structures serving various purposes

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and by analyzing the conditions of their performance. In addition, the use of statistical information on faults, defects and damages received as a result of technical inspection of objects of the same type, will help to develop a structural reliability model and solve the problem of minimizing total expected costs, namely the cost of construction and maintenance of the structure.

In recent years, our industry discussed actively the design of structures taking into account a risk of cascade collapse. However, the design standards on this issue are not fully developed, while engineers need an improved methodology for assessing the vulnerability of structural systems and their improvement to mitigate damages from cascading collapse in various collapse scenarios. A very relevant issue is the optimal design of structures based on their joint work with the foundation.

One of the prerequisites for creating an ES is a decision-making under uncertainty. The creation of databases which will contain design examples, patents, books, containing solutions to overcome difficulties, is proposed.

3. CONCEPTUAL SOLUTION OF THE PROPOSED EXPERT SYSTEM

The concept of rapid prototyping was used for the development of expert system. The essence of this concept is to develop an ES's prototype in a short time, which is designed to implement a limited number of tasks. A prototype of expert system was created on the basis of the typical ES structure (Fig.1).

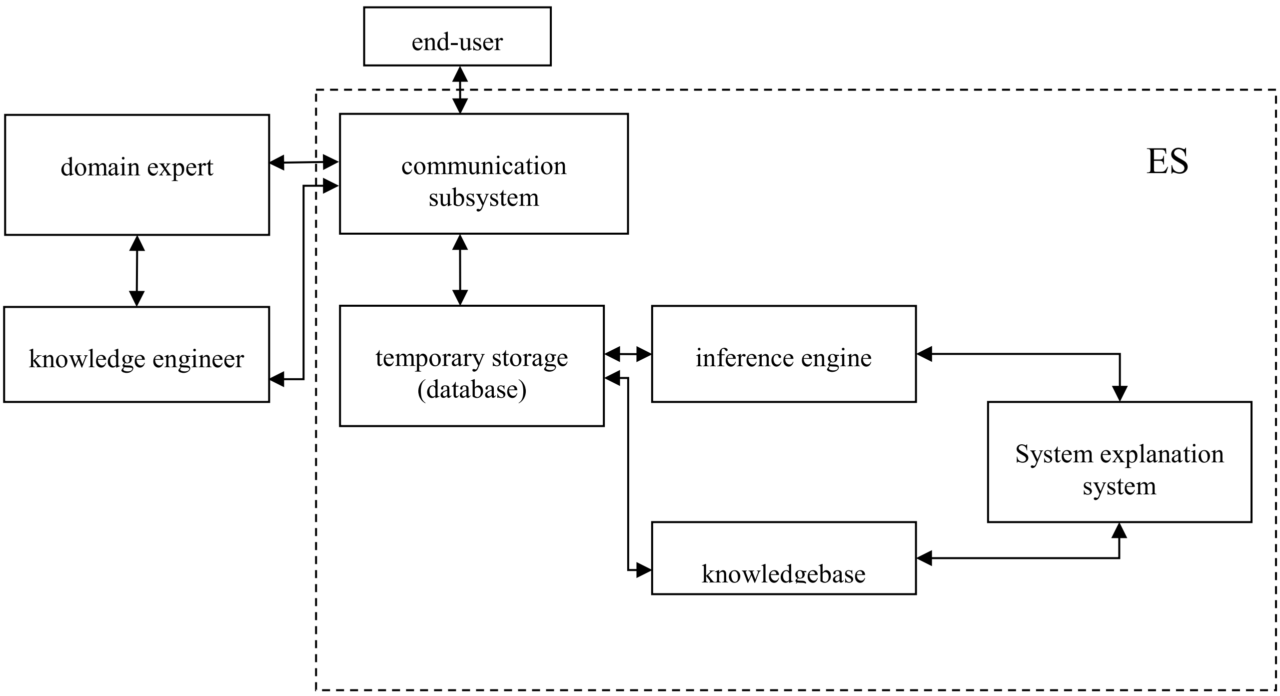

Fig. 1: The structure of the expert system

Numerous works were studied (Chris Naylor, 1991; Jean-Louis Lauriere, 1991; Peter Jackson, 1998 and others). The program was created similar to Leonardo expert system. Software was written in Delphi. Knowledge can be represented as both rules and frames. A frame represents an object or situation by describing the collection of attributes that it possesses. It does this by listing all the attributes of a typical case, and by providing a slot for each one. This description of the typical case then can be used to capture any individual case by placing the value of its attributes in the respective slots. Each frame has a standard set of slots into which information about the object can be entered. The slots are as follows (LEONARDO Revision 3.20, 1990):

- Name: name of the object;
- LongName: more descriptive name;
- Type: text, list, real;
- Value: value assigned to the object;

during last consultation

- Certainty: between 0 and 1 expressing the certainty with which the value is believed to be true;
- DerivedFrom: Source of the value in the Value: slot;
- DefaultValue: value assigned to the object if the user responds to user query with unknown or user query is suppressed;
- FixedValue: Specifies an initial value for an object.

Can be changed later;

- AllowedValue: Contains the permitted values for an object;
- ComputeValue: Contains the name of a procedure. A procedure is a piece of executable code that will derive a value for the object;
- OnError: Defines a message which appear if the user supplies a value which is outside the specified AllowedValue;
- QueryPromt: Contains a text promt used when the user is asked for a value;
- Commentary: Slot for system builders notes;
- Introductions: Appears when the application is started;
- Conclusion: Screen format which is displayed when the object is instantiated;
- Ruleset: This slot contains a set of rules in similar format as the Main Ruleset for instantiation of the object. These rules can be used to derive a value for the object.

Knowledge can be represented with rules of the general form: IF condition (or consequent) THEN action (or antecedent).

However, there is a fundamental difference. The developed program feature consists of two independent modules: knowledge base editor and expert system shell. The system is based on a knowledge base, which is created during its development and can be updated and expanded with the advent of new codes of practice and new structural design recommendations. Knowledge base is being developed in cooperation with leading experts; it presents a set of qualified opinions (rules) and a constantly updated directory of the best methods and strategies used to solve specific problems. Expert system will be built on the basis of clear rules and recommendations from foreign and Russian codes of practice, as well as European standards, and international occurrences of buildings accidents. The main window of the editor of knowledge base is shown in Figure 2. Editor is designed to create, edit and save the files of knowledge-base on drive. Database files created in the editor at any time can be downloaded to add new information or edit an existing one. Files of database which were created in the editor can be uploaded at any time to add new information or edit an existing one. Knowledge-base editor user - is the knowledge engineer.

The prototype of ES was created by the example of consultation on the issue of disproportionate collapse. The expert system shell is designed for the end user. Expert system shell window is shown in Figure 3.

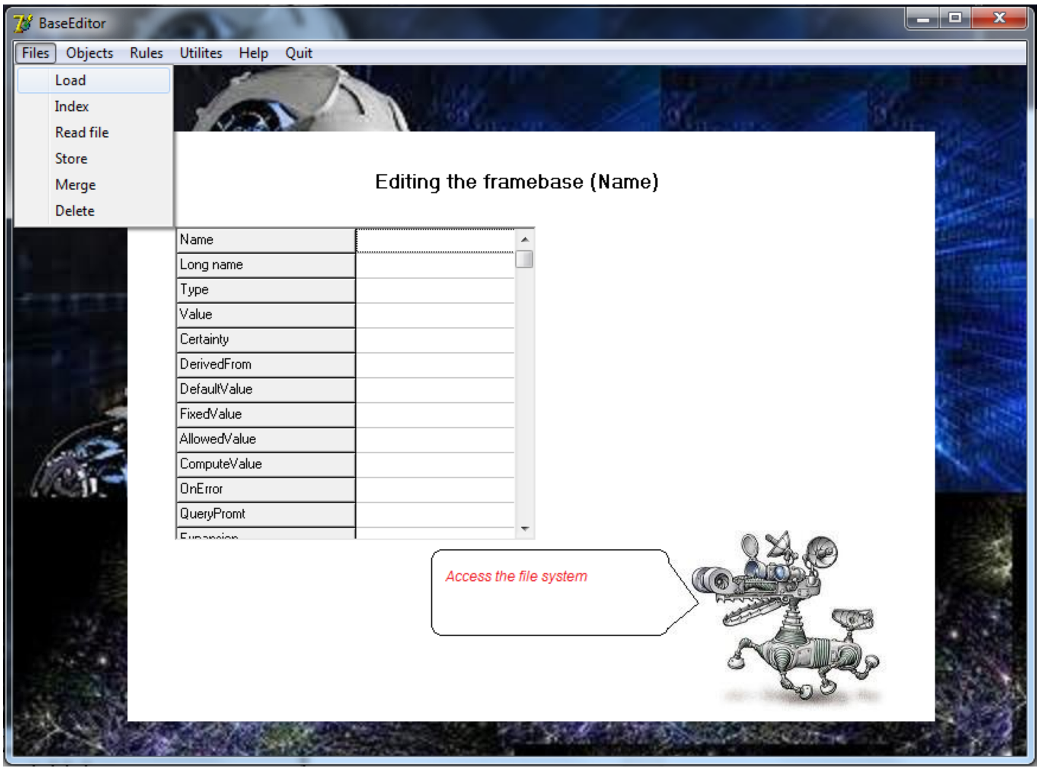

Fig. 2: The main editor window of knowledge base

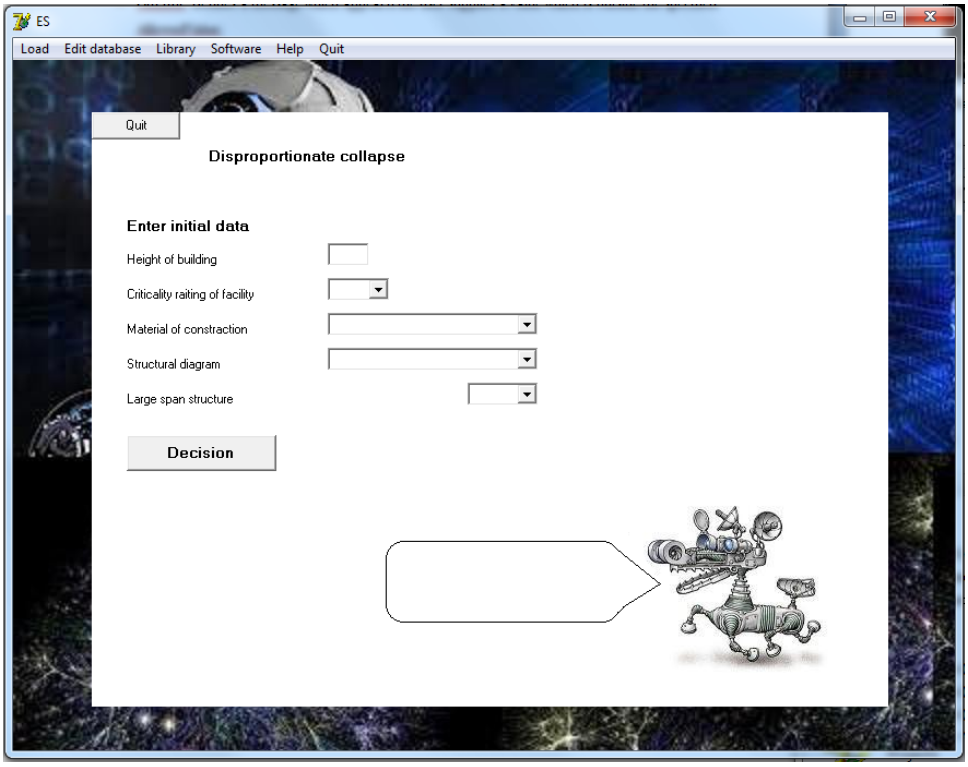

Fig. 3: Expert system shell window

Expert System will help to assemble and categorize the required initial information on an object: type, size, number of stories, level of responsibility, functional purpose, the specifics of the processes which will take place in it, location, soil conditions, location, etc. If necessary, IB will be defined. The problem is formalized by the dialogue with the user on the scenario approach and knowledge of ES base. As fairly pointed out in (Perelmuter and Slivker, 2007), if a structure is small, e.g. its dimensions are comparable with the size of the "local" damage, then it will not make sense to check the possibility of progressive failure. According to the classification of buildings and structures, the selection of objects for analysis is carried out based on:

- Objects of class 1, for which the design does not consider a possibility of accidents
- Objects of class 2, in which all structural components can be protected from accidental damage by increasing the carrying capacity or the use of protective devices;
- Objects of class 3, in which some structural elements cannot be protected from accidental damage, which would require assessment on the progressive destruction (Perelmuter and Slivker, 2007).

In the next step block solver ES classifies the building based on the size of the considered structures, and potential emergencies, according to data entered by the user. ES in consultation with the user selects one of three possible options: design of the structure without considering disproportional collapse; design of structure without considering the disproportional collapse with indication of possible preventive measures to protect the structure or design of the structure in view of the emergency situation, but preserving the integrity of the structure; and the third alternative is calculation accounting for the disproportional collapse of the structure, i.e. by removing some elements from the design model. Deleted elements are selected depending on the background information about the object. It means that, for example, if explosives are placed in a building, elements closest to the explosive location will be more vulnerable. Design of the structure is carried out with regard to the possible destruction of these elements.

All directions to correct initial design model that are received from the ES (emergency impact load, exclusion of certain elements from the model) can be used by user and applied to calculate the structure in one of the available computational software systems.

The prototype of the proposed decision support system for the analysis of structures has been considered and tested on the example of designing a high-rise building for trade and business center (e.g. Figure 4) with regard to the risk of its progressive collapse.

Fig. 4: The general shape of the building trade and business center in Yekaterinburg

Load-bearing frame for the 38-story section is a supported framework, with the external shank in the form of a truss. The overall stability of the building is provided by the columns, non-divided floor structure plates and vertical space truss, which is a system of vertical cross braces of auxiliary bars, and is placed on the perimeter of the building. Vertical load is carried by the columns; horizontal load is transmitted to the truss through floor structure.

At the first stage, which is the stage of identification, the tasks were defined: establishing recommendations for design of the structures with regard to the risk of the propagating rupture, and issuing reinforcement recommendations for the structure. The process of expert system prototype development was planned, necessary sources of references (books, design standards, methodology), resources, similar expert systems, goals, etc., were identified.

At the second stage, the stage of conceptualization, the structure of the identified information about the subject area has been revealed. Terminology, a list of the main concepts and their attributes, the structure of the input and output information, decision-making strategy, etc., were defined. At this stage the main concepts and the relationship between the concepts of the subject area were also defined.

At the stage of formalization the attempt was made to express all the key concepts and the relationships identified at the stage of conceptualization by some formal language. The main component of the knowledge base is a set of rules. As a base of procedural knowledge, the system has a set of products (rules) of the type IF A, THEN B.

At the stage of implementation, the prototype of expert system was created, which included a knowledge base and other subsystems. The fourth stage of expert systems development, to some degree, is the key, as it is the stage of bundled software creation, which is demonstrating the viability of the approach as a whole.

At the fifth stage, the stage of testing, the prototype was tested for usability and appropriateness of the I/O interface, the effectiveness of management strategies, the quality of the test examples, and the correctness of the knowledge base.

According to the logic of the expert system, the low stylobate part was classified as the object of class 1, meaning it was not taken into account when calculating an emergency situation. It was designed without measures to impede the propagating rupture. Since the high-rise part was of the level I importance and was more than 75 meters in height, it was assigned an object class 3. It had to meet special requirements on the stability against a propagating rupture, and structural calculations considered the probability of failure in any of the load-supporting elements.

As a result of consultation with the ES, were received the following recommendations. The building contained no explosive manufactures, accumulation of combustible materials, or other hazardous substances. Therefore, types of local structural failure should be defined as usual, according to (Shapiro et al., 2006). As the most dangerous types of local structural failure, the failure of any free-standing column and the collapse of floor plate with the area of 80 m2 should be considered. Only dead-loads and long-time temporary loads should be taken into account while computing against the propagating rupture.

Types of floors, where destruction should to be modeled: all different floors with a reasonable classification. The most dangerous locations of local damage are: the destruction of the corner columns, the destruction of the all four corner columns of the building, several middle columns and columns at the extreme perimeter of the building in areas of largest cantilevers of floor structures. Collapse of the overlying floor area should be at the end bay and in places of the greatest floor cantilevers. Loads for the computation of the building in an emergency phase should take the following: according to (Shapiro et al., 2006), analysis taking into account the local destruction must be performed on special combination of loads, which includes the permanent loads with their design value, long time temporary loads (temporary loads with low design values) and one emergency impact. Combination coefficient of all the loads is equal to 1.

Computation of framework on the resistance against the disproportionate collapse was performed with the help of the bundled software "Lira 9.4". Stresses in separate elements of the structure, obtained on the basis of static calculations with the account of the local collapse were compared with the stresses from static calculation results without regard to local collapse. The results of the calculations revealed that the local collapse did not lead to a structural failure of the neighboring vertical structures and the disproportional collapse of a building. The most adverse schemes of local collapse for the vertical supporting elements were the destruction of columns at the perimeter of the building, especially the corner columns.

The computations showed that the collapse of overlying floor structures with area of 80 m2 was not a dangerous scheme of local collapse. Stresses in the floor structure elements did not exceed acceptable values. It was revealed, that the design of the floor structure was not protected from the propagating rupture when the collapse of the separately standing columns occurred. However, beams inflexibly connected with the columns could continue to work effectively with formation of large bays and cantilevers in the system.

In accordance with the expert system concept, the design of structure reinforcement was developed to protect the floor structures from a propagating rupture. According to (Shapiro et al., 2006) it allowed for rigid connections of beams to columns. In addition, it was required to increase the reinforcement in the flat part of the floor. Originally, the project was designed with the upper background reinforcement continuous throughout the floor area Ø5 V500 (Bp-I) at 400 mm in both directions. It was replaced with a Ø10 A400 (A-III) at 200 mm in both directions. The spacing of the lower concrete reinforcement was also reduced to 200 mm from the initially designed Ø10 A400 (A-III) 400 mm on center, since the failure of any column or relative settlement in the area of a column would require more lower reinforcement. At the corner areas of floor structures, the local reinforcement was also strengthened. A number of design solutions, impeding to the propagating rupture was also included. For example, anchoring lower reinforcement in the area of concrete reinforced beams is carried out by welding.

Thus, in the process of the user's work with the ES, the decision support system summarizes existing knowledge in its database and offers the user the rational way to solve problems, displaying a chain of reasoning and references to sections of regulatory documents. By using the module-based optimization of genetic algorithm, the problem of finding optimal or near optimal settings of the optimized cross-sections of the structure can be solved.

Once the prototype was tested on the suitability of the system to work in this domain, the correctness of the code, the encodings of the facts, links and strategies reasoning of the expert, in the ES were included the following sections: library, consultation, the design approaches on the progressive collapse, examples of the analysis, analysis and optimization of structures. "Library" includes domestic and foreign requirements documents relating to the protection of buildings against progressive collapse (e.g. Figure 5).

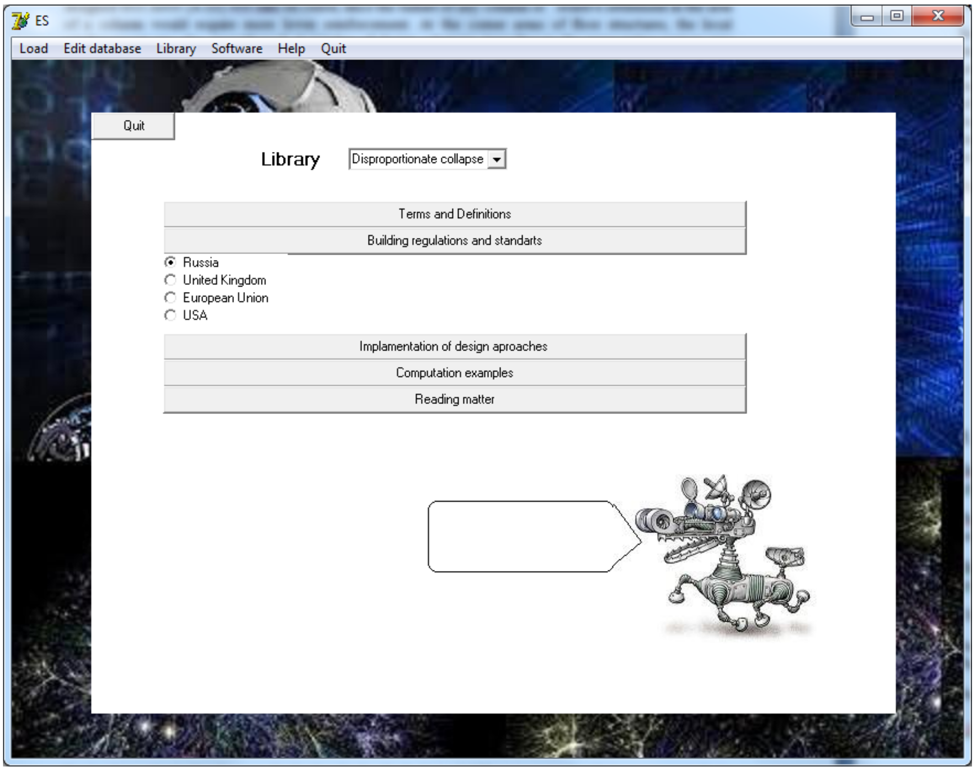

Fig. 5: Library of ES

Section "consultation" is the core. In the "methods of calculation" different ways of analysis are presented in schematic form, briefly it is described how these methods are implemented. In the section "Examples of analysis" one can see examples of computations by different methods of structural analysis. In the "analysis and structural optimization" the user can take advantage of the developed programs for the structural optimization, for example, program of optimization of constructions on the basis of a genetic algorithm (GA). GA is a well-reputed heuristic solutions search method. Definition of the optimization problem is expressed by determining design parameters {x1 ... xn} for elements of steel frame buildings using a minimum volume of structure criteria and complying with limitations on strength, stiffness, local and general stability.

Based on studied publications and tests of the algorithm, the following model of the GA is suggested: the initial population is randomly generated; population size and capacity of the genes are fixed. The selection is proposed as elitist, a method of parent-pair forming is a genotypic outbreeding. Crossover operator of individuals is encouraged to take a single point, and the mutation operator with probability of mutation is of the order of 3%.

4. CONCLUSION

In conclusion, the work is the attempt to create a complex approach to the structural design: the user can not only study the normative documentation, get advice, study the examples of calculation, but also take advantage of the proposed programs for the optimization of the design decisions. In future it is planned to create a database of statistical information on structural failure, defects and damages received on results of the technical examination of objects of the same type; to expand the circle of tasks, and add to the base constructive examples, patents, books, in which there will be a way of overcoming some of the difficulties. It is expected that expert's knowledge on the analysis of buildings incorporated in expert system, will improve the quality of the design, and as a consequence, the reliability of structures.

Here are a few possibilities of ES:

- optimization of the design decisions for buildings at the early stages of design, the choice of the basic space - planning decisions for buildings (configuration, column grid, structural solutions);
- making effective decisions to reduce the emergency situation occurrences in regions subjected to natural and man-made hazards;
- design in terms of reliability, taking into account the probability of structural failure after a certain operating duration and accounting for relevant maintenance;
- the possibility to use probabilistic methods of structure optimization;
- design of structures with regard to the risk of their disproportional collapse;
- decision-making in conditions of uncertainty; optimization of structures based on modern methods of optimization by genetic algorithms;
- competent user help, design standards reference.

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