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Research paper

Features of Computer Automation Technology for Building Structures Calculations

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Abstract

Recently, the issues of evaluating the quality of building structures and predicting their reliability are becoming increasingly important, especially for the construction of industrial facilities of the old fund. At the moment, powerful mathematical methods are being developed to evaluate the performance of structures and predict their reliability, but there are no automated computer systems for such analysis. At present, programs for the determined calculation of structures have been developed, which implement methods for the resistance of materials, theoretical and construction mechanics, but they do not provide an opportunity to determine and predict reliability, especially objects of the old fund. The methods of the classical reliability theory combined with the methods of statistical modeling are used in the work, which requires the use of modern IT technologies methods with the development of appropriate software systems.

Keywords: *construction, reliability, automated computer systems, software complex, stress-strain state.*

1. Introduction

Nowadays, there is an urgent problem of many objects with conditions appointment reconstruction. Under a large number of abandoned buildings, there is an urgent need to evaluate the current quality of structures of these objects in order to predict their strength and reliability, as well as in the development of engineering recommendations for their further exploitation. Considering the necessity of the abandoned buildings reconstruction for bringing them into line with the planned activities, the assessment of their residual bearing capacity, real quality at the time of evaluation and reliability prediction during further possible exploitation becomes extremely [8, 10]. Under such terms, the actual question is a detailed study of the structures quality and their reliability prediction in possible further exploitation. In order to assess the quality and predict the reliability of such objects, one must have a clear idea of structures current state, their ruin degree, the materials used in the construction, and the type of activity planned after the reconstruction [9].

2. Main body

The stress-strain state analysis of structures, buildings and structures is an integral part of the design process, the quality assessment and prediction of reliability in construction. Structural mechanics classifies two types of constructions from the kinematic analysis point of view, in particular by dividing the statically distinguishable and statically obscure hinged-rod systems. Calculation of the first one, does not cause particular problems for engineers, but the second type systems calculation can cause considerable difficulties.

It occurs to the necessity of compiling and solving, in addition to the static equilibrium basic equations of so-called additional equations of deformations or displacements compatibility.

One of the most powerful modern methods of calculating complex building constructions is the finite element method, which involves the overlay on the finite-element grid construction, that is, structure decomposition into elements within each, other known as functions of displacements and stresses [1-7].

The finite element method also involves a system of linear algebraic equations formation and solution, the order of which is caused by the number of unknown nodal displacements.

In this case, such concepts as the freedom of the node finite-element grid degree of, considered as the vector of external loads, the supporting reactions vector. Another important factor that causes a real stressful condition is the rigidity of the cross section of the structure to the bend, shear and stretch. The above features of the calculation of such structures for predicting their strength and reliability determine the constant need to use the capacities of modern PCs, which in turn requires automation of settlement processes in the form of complete software complexes and systems [11-13].

According to the Poltava National Technical Yuri Kondratyuk University Department of Structural and Theoretical Mechanics of the, a number of software tools that implement interrelated tasks for assessing the strength and building structures and their elements reliability were developed [8, 10].

Figure 1 shows the global decomposition scheme, which displays that our system consists of four integrated modules: a statistical simulation module of the Monte Carlo method, a module for evaluating the stressed-deformed state under the numerical-iterative finite element method, a module for determining the reliability parameters by statistical processing methods and a module for developing engineering recommendations for the further construction exploitation possibility. The latter module is intended a recommendation issue for the reinforcement projects development of in the case of the construction emergency.

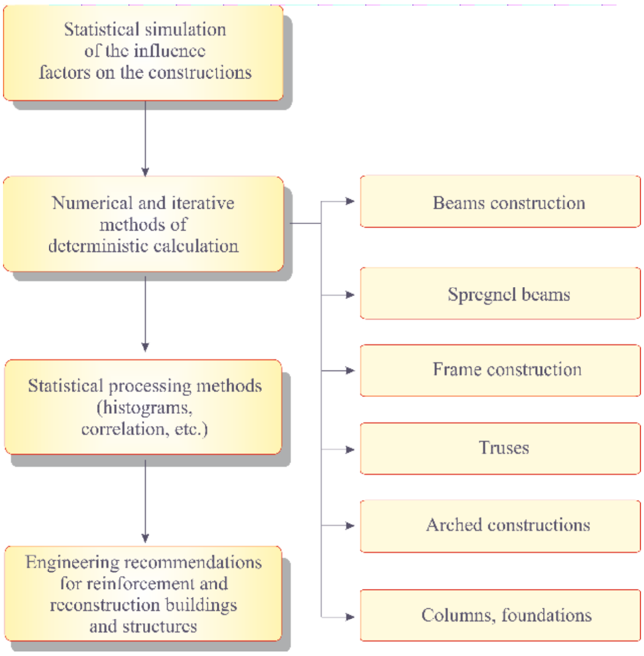

Fig. 1: Diagram of decomposition of the developed software main modules complex for analysis of the strength and reliability of different types structures

We use decomposition principle as a scientific method, which uses the structure of the problem for development and allows us to replace the solution of one large reliability task assessing of structures by solving a series of smaller ones in the volume of interconnected tasks.

Thus, decomposition as a separation process allows us to consider the complex system of the software complex as consisting interrelated separate subsystems which, in turn, can also be divided into parts, in particular, part of the simulation factors, a part of the deterministic calculation and a part of the probabilistic construction calculation.

The output system of the developed software complex consisting of the four modules described above is located at zero level. After its division, the first level subsystems are released. This is a subsystem for describing the modules of deterministic various calculations constructions.

Among the main types of constructions, the calculation of which is realized in the utilities software form are such as beam structures, reinforced beams with sprengel, frame structures, frames, arched constructions, etc. For such types of structures, solved the tasks of evaluation of the main components of the stress-strain state, on the basis of which the parameters of the constructions reliability are evaluated as the characteristics of failure-free operation. These subsystems division and some of the other leads to the subsystems appearance of the second level.

Software formulas of random number generator are used to calculate stochastic factors such as wind and snow load, steel constructions corrosion and tolerances of rolled various types of cross sections, crane loads in industrial shops, temperature fluctuations as well as material strength and precision of structures construction. Models are developed on the basis of mathematical interpretation, in which the description of the main dependencies is carried out on the equations of building engineering, in particular under the Hooke law, the Zhuravsky formula, the Moor formula, used the general principles of finite elements method, as well as methods of numerical integration and functions approximation.

The software package is represented by a structure that links the levels with the mandatory elements of the structure with the levels of variations of all or part of these elements. Depicted the hierarchical structure is in the form of a tree, that is, a graph without closed routes, with the arrangement of vertices at certain levels. The upper level top is the root. The levels combination and their number is determined by the requirements of the visibility and ease of received hierarchical structure perception.

As for the subsystems lower elementary level we have taken such a subsystem where the understanding of their nature and description is available to the executor, in our case, the developer. Hence, the hierarchical structure for the program is subjectively oriented, but for our system it is quite definite.

Here is an activity diagram description for the developed software complex to explain its logical structure and to describe its physical implementation. As a graphical software system main functions representation, we adopt a diagram of usage options that gives us an idea of what our system provides to us, namely the activity diagram, explain how these features are used.

Thus, in accordance with the activity diagram, the initial activity node "activity initial node" describes the construction design study beginning, that is, laboratory studies conducted to identify imperfections or damage.

For example, for trusses elements characteristic it is the presence of only longitudinal types of internal efforts, while in the real situation, other types of efforts can be recorded, indicating the accidental operation of the structural element. In this work a description of the utility definition of the structural elements for a farm accident rate was given.

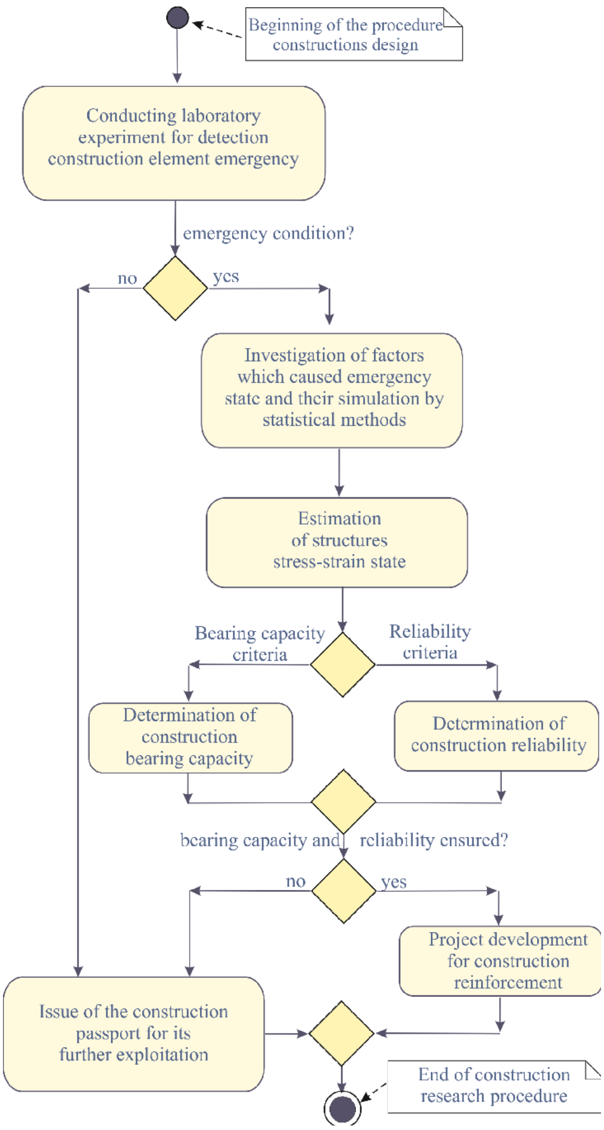

Fig. 2: Diagram of decomposition of the developed software main modules complex for analysis of the strength and reliability of different types structures

Figure 2 shows an enlarged activity diagram. The entrance to the next stage is the conclusion of the structural element emergency work of the. In the case when the construction element is not in an emergency condition, the output is the issuance of the passport to the construction for its further exploitation.
Another possible option is to conclude an emergency condition, then factors which influence the work of the structure and uses a mathematical apparatus for statistical simulation of the constructions in real conditions are examined.
For each factor, the statistical law of density distribution, which determines the so-called statistical modeling of the constructions is studied.
Further, in accordance with the activity diagram, a deterministic design calculation is performed for a given set of random variables that simulate the structures work.
The next stage of activity is the definition of what criteria is used for the analysis of reliability of the construction before further exploitation.
In the case where the reliability analysis is performed on the criterion of bearing capacity, the algorithm of determination of the boundary value of loads is accordingly activated, which is further compared with the actual load on the structure. In the case when the reliability analysis is performed according to the reliability criterion, the algorithm of the probabilistic calculation of the design accordingly is activated.
Further, the send signal action occurs before the performance check of the load bearing capacity or reliability.
The result of the latter is the conclusion on the basis of which a project for the reconstruction and reinforcement of building construction elements is being developed or a design passport is issued for its further exploitation. The activity diagram of our complex is terminated by the end-node of activity, the so-called terminal state of activity.
To automate the determination of possible emergency work of structures and to obtain numerical data for further numerical-iterative statistical modeling, the task was to develop an electronic system of digital fixation of deformations and computer control of laboratory researches of elements of building constructions.
In the laboratory of Poltava National Technical Yuri Kondratyuk University has been applied a developed tool for analyzing the damage to the elements of the truss farm.
Figure 3 shows photos of a laboratory farm with deformation sensors, which assesses the stresses and solves the inverse problem of determining the existing efforts.
For the task, a software utility was developed that allows determining, based on the evidence of deformation sensors, whether the design is in a problem condition. That is, it works in regular mode or needs to be reconstructed and strengthened in case no.
The utility algorithm is based on the basic notions of material resistance, that is, from the sensors obtained by deformation values, they pass to the values of normal stresses according to Hooke's law, after which they decompose these stresses on the values of the forces acting in the experimental section of the construction.
The decomposition procedure is based on the method of least squares, which has shown itself well in such tasks.
As you know, the essence of this method is to minimize the sum of squares of deviations between experimental data and data based on theoretical dependence.
The basis of the formula is the centrifugal compression of the material resistance:

$$\sigma = \sigma_N + \sigma_{Mx} + \sigma_{My} = \frac{N}{A} + \frac{M_x}{J_x} \cdot y + \frac{M_y}{J_y} \cdot x; \quad (1)$$

where *N* – longitudinal effort,
Mx, My - the desired bending moments relative to the x and y axes,
A – sectional area of the structure,
Jx, Jy - the moments of inertia of the cross section with respect to the x and y axes.

Figures 4-5 show the form of a software utility for entering the geometric characteristics of the section and the main form of the program (Figure 6-8).
As can be seen, this formula considers the off-center compression of the cross-section of the design in two directions - relative to the x-axis and with respect to the y-axis.
Thus, knowing the normal stress at the cross-section can be subjected to the equation and considering the value of the section's geometry and the sensor's binding relative to the center of gravity of the section, determine the components of the equation - the longitudinal force and the bending moments relative to the two axes x and y.
Several sensors can be installed in the cross section to improve the accuracy of such calculations, each of which can produce results with different accuracy. Hence, the use of the least squares method is fairly rational and appropriate in view of one of the important properties, in particular the fact that this method tends to mitigate possible errors and inaccuracies in experimental research.
The method of least squares for the considered problem involves the formation of a system of three equations, which solves the coefficients a, b, c. The indicated coefficients represent the relation of the desired force factors to the known geometric characteristics of the cross section:

$$a = \frac{N}{A}\left[kH / м^2\right]; \; b = \frac{M_x}{J_x}\left[кH \cdot м / м^4\right]; \; c = \frac{M_y}{J_y}\left[кHм / м^4\right]. \quad (2)$$

As you know, the function of several arguments will have an extremum if the derivatives behind each variable are zero, so we can write down the system of equations of the least squares method for our task:

$$\begin{cases} n \cdot a + b \cdot \sum_{i=1}^{n} y_i + c \cdot \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \sigma_i \\ a \cdot \sum_{i=1}^{n} x_i + b \cdot \sum_{i=1}^{n} x_i y_i + c \cdot \sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} \sigma_i x_i \\ a \cdot \sum_{i=1}^{n} y_i + b \cdot \sum_{i=1}^{n} y_i^2 + c \cdot \sum_{i=1}^{n} x_i y_i = \sum_{i=1}^{n} \sigma_i y_i \end{cases} \quad (3)$$

Thus, it is possible to determine how the section of the construction works not in a project mode, which affects the probability of exhaustion of the bearing capacity of the section and the structure in general and, as a consequence, the reliability of further exploitation.
On the basis of the above mathematical substantiation of the estimation of the accident rate of building constructions elements in a laboratory a special electronic-computer device was developed, the indicators of which determine the non-project work state, which the emergency state.
The main physical devices of the developed system include the following: a system of glued in characteristic points of cross sections for the tensonometric sensors construction, a system of servo-devices for controlling the laboratory load on a construction, an analog-digital converter and an operational amplifier. The results of deformation measurements are used to obtain the values of internal forces that act in the sections of structural elements.
The obtained values of internal efforts give the investigator-engineer an accurate picture of the stress-strain main components distribution in the sections of structural elements, on the basis of which the influence of various factors may be modeled in the future.
The following is a description of the software utility for conducting such laboratory studies.
In the design research lab, a developed utility for working with various types of constructions was introduced.
This construction cross-section is a compiled section of the two rolled steel cubes profiles, each of which has three sensors at characteristic points, which guarantees the coverage of the entire cross-section and the results objectivity.

The advantages of the developed digital system are the possibility of automation of deformation detection in a large number of cross sections structures control with high frequency and with great accuracy.
To do this, the authors developed an electronic device based on the microprocessor ATmega328, which was developed on the Arduino Uno/Mega processor board.
This processor is a fairly common device in cases where it is necessary to combine analog and digital devices with modern computer systems, in our case - digital sensors of deformations with a PC.
Also, for this processor it is characterized the possibility of automating the various technological processes management, in our case – the control of servo-devices for switching-on / off the pump motors of the test loads station, depending on the degree of fixed deformations of the laboratory structure.

Fig. 3: Laboratory roof truss for analyzing the internal forces and displacements distribution

In laboratory for testing building constructions, an electronic device with software in the form of drivers for firmware microprocessor ATmega328 based on Arduino Uno/Mega was developed and tested.
For example, here are some screenshots of the forms of utility interaction with a user for assessing the degree of damage of the truss rods.

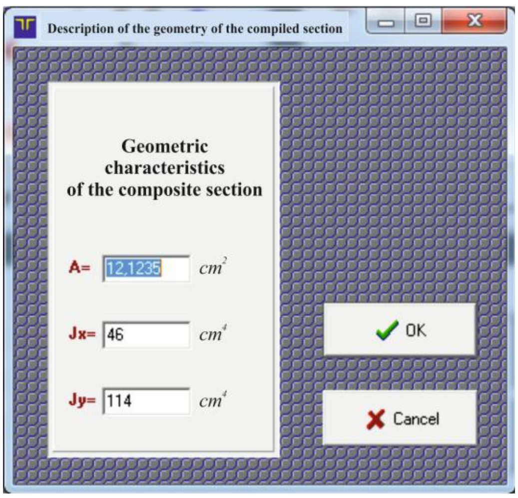

Fig. 4: Modal form for describing geometric cross section of structures

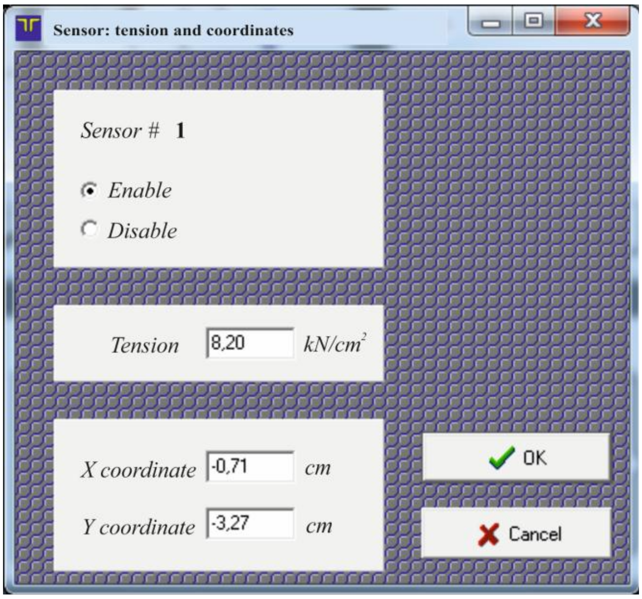

Fig. 5: Modal form for the control of the selected deformation sensor and fixed voltage by electronic-digital device

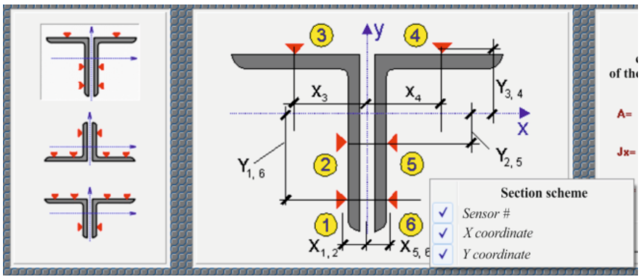

Fig. 6: Section scheme properties.

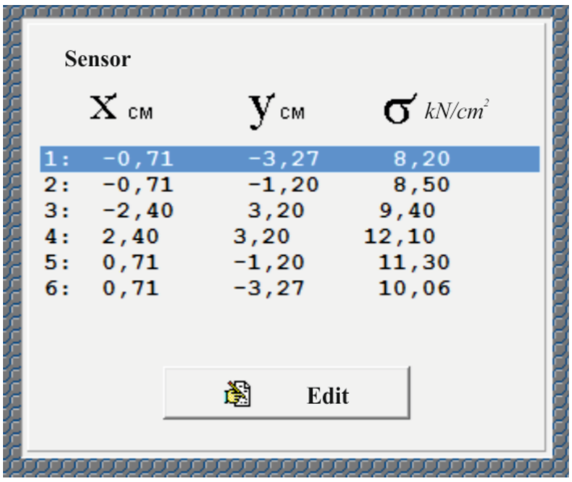

Fig. 7: Sensors data – X, Y and tension data

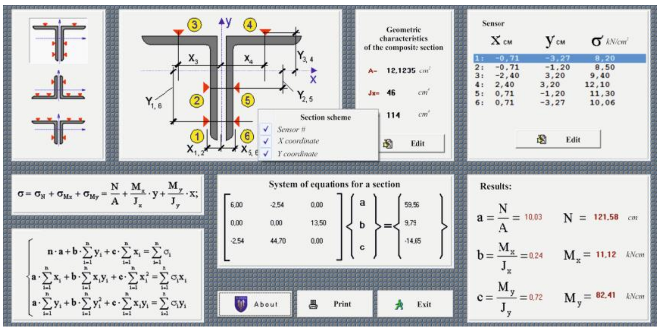

Fig. 8: The electronic computer system form for the sensors processing of structural deformation.

3. Conclusions

The features of the model and the algorithmic basis of the forecasting the strength and reliability of building structures problem were considered. Completed decomposition and modular presentation of the software system for structures calculation. The program algorithm realization peculiarities, which considered various factors of the actual work of structures, and determined their stress-strain state were presented. Software was developed as a firmware driver for an electronic structural elements of computer device laboratory testing of, which enables to determine the state of emergency structural elements and obtain numerical values of actual loadings on structures and their elements. The separate utilities combination features were presented for reliability parameters determination in order to predict the work of various structures types that can work in emergency and pre-crash states.

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