Збірник наукових праць. Серія: Галузеве машинобудування, будівництво

Academic journal. Series: Industrial Machine Building, Civil Engineering

http://journals.pntu.edu.ua/znp
https://doi.org/10.26906/znp.2019.52.1678

UDC 624.04:41

Calculation of building structures and features of its automation technology

Shkurupiy Oleksandr [1]*, Mytrofanov Pavlo [2], Pashchenko Andrii [3], Kozichko Ivan [4]

[1] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0003-1487-1037
[2] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0003-4274-1336
[3] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0002-6562-0046
[4] Head of production and technical department ALC «Poltavtransbud»
Corresponding author E-mail: shbm@ukr.net

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. 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

Розрахунок будівельних конструкцій та особливості технології його автоматизації

Шкурупій О.А.[1]*, Митрофанов П.Б.[2], Пащенко А.М.[3], Козічко І.В.[4]

[1] Полтавський національний технічний університет імені Юрія Кондратюка
[2] Полтавський національний технічний університет імені Юрія Кондратюка
[3] Полтавський національний технічний університет імені Юрія Кондратюка
[4] Начальник виробничо-технічного відділу ТзДВ «Полтавтрансбуд»
*Адреса для листування E-mail: shbm@ukr.net

Останнім часом питання оцінки якості будівельних конструкцій і прогнозування їх надійності стають все більш актуальними, особливо для будівництва промислових об'єктів старого фонду. Розробляються потужні математичні методи для оцінки експлуатаційних характеристик конструкцій і прогнозування їх надійності, але немає автоматизованих комп'ютерних систем для такого аналізу. На даний час розроблені програми для детального розрахунку конструкцій, в яких реалізовані методи опору матеріалів, теоретичної та будівельної механіки, але вони не дають можливості визначати і прогнозувати надійність, особливо об'єктів старого фонду. В роботі використовуються методи класичної теорії надійності в поєднанні з методами статистичного моделювання, що вимагає використання сучасних методів IT-технологій з розробкою відповідних програмних систем. Наведено особливості моделі та алгоритмічна база задачі прогнозування міцності та надійності будівельних конструкцій. Виконано декомпозицію та модульне представлення програмної системи розрахунку конструкцій. У ракурсі задачі оцінювання напружено-деформованого стану конструкцій розроблене програмне забезпечення у вигляді драйвера прошивки для електронно-комп'ютерного пристрою лабораторного обстеження елементів конструкцій, що дає змогу визначати стан аварійності елементів конструкцій та отримувати числові значення фактично діючих навантажень на конструкції та їх елементи. Показано особливості поєднання окремих утиліт визначення параметрів надійності з метою прогнозування роботи конструкцій різних типів, які можуть працювати у аварійному та передаварійному станах.

Ключові слова: конструкція, надійність, автоматизовані комп'ютерні системи, програмний комплекс, напружено-деформований стан.

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. In order to assess the quality and predict the reliability of such objects, there must be 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].

Review of research sources and publications

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, 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 structure cross section 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].

Definition of unsolved aspects of the problem

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 in the context of the kinematic analysis, 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.

Problem statement

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 issue is a detailed study of the structure's quality and their reliability pre-diction in possible further exploitation.

Basic material and results

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

The decomposition principle has been used as a scientific method, which uses the structure of the problem for development and enables 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 enables 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 utility software form are such as beam structures, reinforced beams with sprengel, frame structures, frames, arched constructions, etc. For such types of structures, solved evaluation tasks of the stress-strain state main components, based on which the parameters of the construction's reliability are evaluated as the characteristics of failure-free operation. These subsystems division and some of the other lead to the subsystem's 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 are 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, a diagram of usage options, namely the activity diagram, is adopted that explains 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 has been given.

In the case where the reliability analysis is performed on the criterion of bearing capacity, the algorithm of determination of the loads boundary value 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 complex activity diagram is terminated by the activity end-node (terminal activity).

To automate the determination of possible emergency work of structures and to obtain numerical data for further numerical-iterative statistical modeling, the task iss to develop an electronic system of digital fixation of deformations and computer control of laboratory researches of building constructions elements.

In the laboratory of Poltava National Technical Yuri Kondratyuk University a developed tool for analyzing the damage to the elements of the truss farm has been applied.

For the task, a software utility was developed that enables to determine, based on the evidence of deformation sensors, whether the design is in a problem condition. That is, it works in regular mode or it is needed to be reconstructed and strengthened.

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 it is known, the essence of this method is to minimize the squares sum of deviations between experimental data and data based on theoretical dependence.

The basis of the formula is the centrifugal compression of the material resistance:

$$\sigma = \sigma_N + \sigma_{Mx} + \sigma_{My} = \frac{N}{A} + \frac{Mx}{Jx} x + \frac{My}{Jy} y, \qquad (1)$$

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 1-5 show the form of a software utility for entering the geometric characteristics of the section and the main form of the program.

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 square's 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

$$\begin{aligned} a &= \frac{N}{A}[kN/m^2]; \\ b &= \frac{Mx}{Jx}[kN \cdot m/m^4]; \qquad (2) \\ a &= \frac{My}{Jy}[kN \cdot m/m^4]. \end{aligned}$$

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 is 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 have developed an electronic device based on the microprocessor ATmega328, which has been 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.

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 has been developed and tested.

For example, here are some screenshots of the forms of utility interaction with a user for assessing the degree of the truss rods damage.

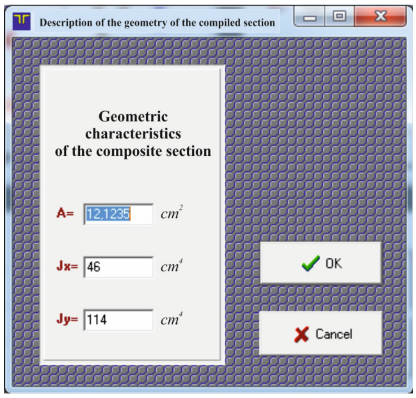

Figure 1 – Modal form for describing geometric cross section of structures

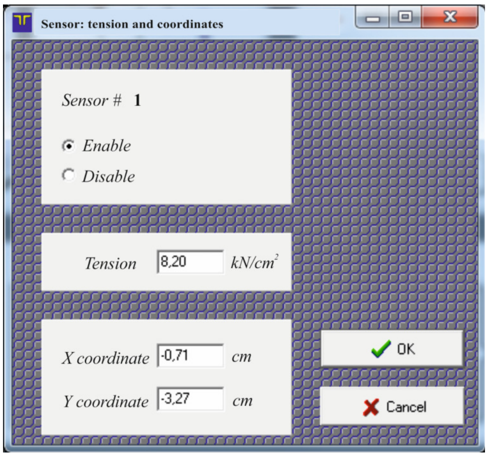

Figure 2 – Modal form for the control of the selected deformation sensor and fixed voltage by electronic-digital device

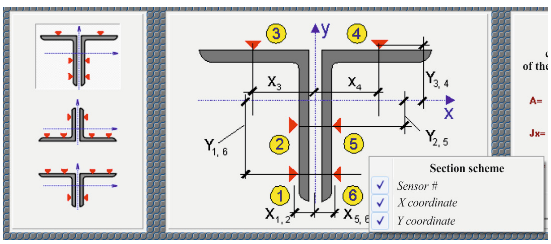

Figure 3 – Section scheme properties

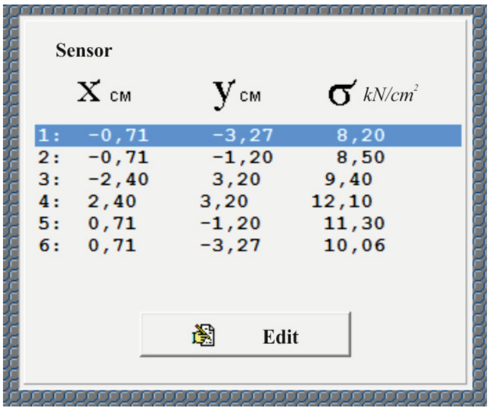

Figure 4 – Sensors data – X, Y and tension data

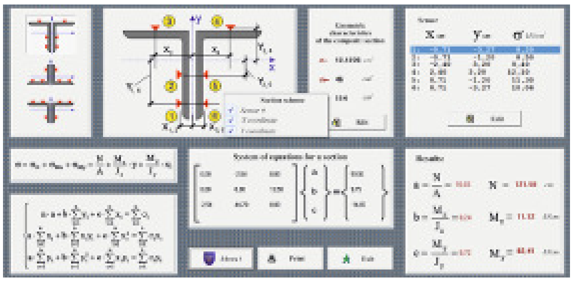

Figure 5 – The electronic computer system form for the sensors processing of structural deformation

Conclusions

The program algorithm realization peculiarities, which considered various factors of the actual work of structures and determined their stress-strain state have been presented. Software has been developed as a firmware driver for electronic structural elements of computer device laboratory testing, which enables to determine the state of structural elements emergency and obtain numerical values of actual loadings on structures and their elements. The separate utilities combination features have been presented for reliability parameters determination in order to predict the work of various structures types that can work in emergency and pre-crash states.

References

1. Hjelmstad K.D. (2005). *Fundamentals of Structural Mechanics.* Boston: Springer. https://doi.org/10.1007/b101129

2. Hartmann F. (1985). *The Mathematical Foundation of Structural Mechanics.* Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-82401-2

3. Hulse R. & Cain J. (1991). *Structural Mechanics*. London: Palgrave. https://doi.org/10.1007/978-1-349-11897-7

4. Киселев В.А. (1980). *Строительная механика. Специальный курс*. Москва: Стройиздат.

5. Lacarbonara W. (2013). *Nonlinear Structural Mechanics.* Boston: Springer. https://doi.org/10.1007/978-1-4419-1276-3.

6. Смирнов А.Ф., Александров А.В., Лащеников Б.Я., Шапошников Н.Н. (1981). *Строительная механика.* . Москва: Стройиздат.

7. Баженов В.А., Перельмутер А.В., Шишов О.В. (2008). *Будівельна механіка. Комп'ютерні технології.* Київ: «Каравела».

8. Shkurupiy O., Mytrofanov P., Masiuk V. (2018). Calculation of The Stability of the Form of Equilibrium of Discrete Systems. *International Journal of Engineering & Technology*, 7(3.2), 401-407. http://dx.doi.org/10.14419/ijet.v7i3.2.14561

9. Шкурупій О.А. (2015). *Стійкість форми рівноваги та динаміка дискретних систем*. Полтава: ПолтНТУ.

10. Severyn V., Pashchenko A., Mytrofanov P. (2018). Probabilistic Analysis of Structures Under Snow Load. *Intern. Journal of Engineering & Technology*, 7(3.2), 339-342. http://dx.doi.org/10.14419/ijet.v7i3.2.14431.

11. Smith P. (2001). *An Introduction to Structural Mechanics*. Palgrave Macmillan.

12. Фадеев Д.К., Фадеева В.Н. (1960). Вычислительные методы линейной алгебры. Москва: Физматлит.

13. Баженов В.А., Дехтярник В.А., Дехтярник Е.С. (1998). *Будівельна механіка. Динаміка споруд*. Київ: ІЗМН.

1. Hjelmstad K.D. (2005). *Fundamentals of Structural Mechanics.* Boston: Springer. https://doi.org/10.1007/b101129

2. Hartmann F. (1985). *The Mathematical Foundation of Structural Mechanics.* Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-82401-2

3. Hulse R. & Cain J. (1991). *Structural Mechanics*. London: Palgrave. https://doi.org/10.1007/978-1-349-11897-7

4. Kiselev V.A. (1980). *Structural mechanics. Special course*. Moscow: Stroyizdat.

5. Lacarbonara W. (2013). *Nonlinear Structural Mechanics.* Boston: Springer. https://doi.org/10.1007/978-1-4419-1276-3.

6. Smyrnov A.F., Aleksandrov A.V., Lashchenykov B.Y., Shaposhnykov N.N. (1981). *Structural mechanics. Dynamics and stability of structures*. Moscow: Stroyyzdat.

7. Bazhenov V.A. Perel'muter A.V., Shyshov O.V. (2008). *Structural Mechanics. Computer Technology*. Kyiv: Karavela

8. Shkurupiy O., Mytrofanov P., Masiuk V. (2018). Calculation of The Stability of the Form of Equilibrium of Discrete Systems. *International Journal of Engineering & Technology*, 7(3.2), 401-407. http://dx.doi.org/10.14419/ijet.v7i3.2.14561

9. Shkrupiy OA (2015). *Stability of equilibrium form and dynamics of discrete systems*. Poltava: PoltNTU.

10. Severyn V., Pashchenko A., Mytrofanov P. (2018). Probabilistic Analysis of Structures Under Snow Load. *Intern. Journal of Engineering & Technology*, 7(3.2), 339-342. http://dx.doi.org/10.14419/ijet.v7i3.2.14431.

11. Smith P. (2001). *An Introduction to Structural Mechanics*. Palgrave Macmillan.

12. Faddeev D.K., Faddeeva V.N. (1960). *Computational methods of linear algebra*. Moscow: Fyzmatlyt.

13. Bazhenov V.A. Dekhtyaryuk V.A.. Dekhtyaryuk Ye.S. (1998). *Structural Mechanics. Dynamics of structures*. Kyiv: IZMN