Program implementation of methodology for calculating and estimating residual life of frame of single-storey industrial building

T Zolina

Civil Engineering Department, Astrakhan State University of Architecture and Civil Engineering, 18, Tatischev Str., Astrakhan 414056, Russia

E-mail: zolina.asuace@gmail.com

Abstract. The paper presents a description of the software and calculation complex that allows evaluating the reliability, strength and stability of load-bearing structures of industrial buildings equipped with overhead cranes. It is built on the implementation of a consolidated algorithm aimed at the numerical solution of successively direct, inverse, and predictive problems of structural mechanics in a probabilistic formulation. The advantage of the complex is the possibility of forming for each design situation a large number of downloads, as well as the implementation and analysis of various schemes for their application with simultaneous action of components of the generalized load. The developed software and calculation complex acts as a tool for solving problems of computer processing of data obtained during a series of full-scale surveys of an industrial building equipped with bridge cranes aimed at determining the amount of residual life and the period of its trouble-free operation. Automating the calculation of indicators of reliability and durability in the dynamics of changes in their values, including in subsequent periods of operation of the facility, it becomes possible to predict emergencies and take timely measures to prevent them.

1. Introduction

For a wide range of tasks related to the assessment of reliability, strength and stability, as well as risk analysis of accidents of industrial buildings subject to various internal and external influences, developed software and settlement complex «DINCIB-NEW». It is aimed at overcoming the difficulties associated with the numerical solution of problems that have a probabilistic formulation, while fully realizing the presented summary algorithm for estimating the residual resource [1], which is based on the spatial computational model [2] of a one-storey industrial building equipped with a bridge crane (Figure 1). The choice of this model is due to the fact that it allows us to describe in the formalized form the overwhelming majority of design solutions for the construction of such objects and to obtain a numerical solution of the problem under consideration.

The created software package is written in Delphi language and can be implemented on computers compatible with the IBM PC class [3-6].

Advantage of using computer hardware is the possibility of forming a large number of downloads for each design situation, as well as implementing and analysing various schemes of their application while simultaneously acting as components of the generalized load. With this approach, the main criterion for the reliability of a building object is its achievement during a given service life under the
influence of the most unfavorable combination of loads of the first or second maximum permissible conditions [7-10].

![Spatial design scheme of a single-storey industrial building equipped with a bridge crane](image)

This design scheme is offered only as an example of demonstration of the software capabilities of the DINCIB-NEW complex. The main menu of the program includes a large number of options for entering and editing initial information on the object of study, such as:

- geometric features of a constructive design scheme;
- stiffness characteristics of frame elements;
- layout option boards and the quality of embedment of joints in the coating;
- parameters of operating crane equipment and its placement;
- the need to take into account the seismic component in the magnitude of the generalized load, etc.

2. Methods, results and discussion

The presented software complex (Figure 2) allows to solve both direct and inverse problems [11], which is very actual in evaluating the resource of structures, especially for industrial buildings that have been in operation for a long time. In the constructions of buildings and structures that were in long-term operation, latent defects may develop, reducing their rigidity and, as a consequence, strength and stability [12-18]. To estimate the resource of such structures, it is expedient to determine experimentally the resulting behavior of the structure [19,20], then to solve the inverse problem to find real stiffness characteristics.

To determine the average values and indices of the variation in the design parameters of the stability and reliability of the construction design, a multiple execution of the algorithm is required, caused by deviations in the values of the input parameters of the model relative to the corresponding mathematical expectations. By using a random number generator in a known range, a selective set of values of the sought parameter is formed, which allows finding its statistical characteristics at a given level of significance.
Figure 2. Consolidated algorithm for estimating the residual life of an industrial building.
To implement algorithms aimed at finding eigenvalues and eigenvectors of linear transformations defined by large-dimensional matrices, borrowed functions are used. Solving systems of linear equations and finding inverse matrices for known high-order initial matrices is made possible by connecting to the code of the program already known procedures and functions. All specified software implementations are publicly available and are part of the ALGLIB numerical analysis library supporting several programming languages.

The author developed an algorithm for the analytical solution of the inverse problem of compiling the stiffness matrix of the spatial framework of a single-storey industrial building equipped with a bridge crane for the case of a plane-parallel operation of the coating element, as well as its software implementation, presented as a separate module of the automated calculation system DINCIB-new.

In accordance with the developed algorithm for compiling the corrected stiffness matrix, a direct problem is first solved to search for displacements of the system at each individual point of the framework, with known global stiffness matrices, inertia characteristics of the building, and design values of the loads. Then, when accessing the "Inverse problem" module of the software-calculation complex, the load is selected, the amount is specified, and the numbers of the calculation points of the framework, in which the movement changes occurred due to the action of one of the load types, and also the displacements obtained during the experimental study. The multivariate implementation of the initial model of the object is caused by the fact that when developing the design of an industrial building equipped with bridge cranes, a number of internal technological factors that significantly affect the performance of the structures and the duration of their safe operation are taken into account. As the result of the operation of the algorithm is an adjusted stiffness matrix that takes into account the introduced displacements.

The newly obtained corrected stiffness matrix can be used in further studies in solving both direct and inverse problems of the operability of structures under the influence of other external influences. In this case, the stiffness matrix of the transverse frame containing the load application point also tolerates changes determined by the principle of proportionality of its constituent parts.

Having experimental data on the displacements at the anchor points of the framework, fixed at various intervals of time, using the above-described module "Inverse problem" becomes possible:

- to monitor the dynamics of changes in the rigidity characteristics of the framework of industrial buildings;
- to construct a functional dependence of the load, taking into account the dynamics of stresses in the elements of the frame of the building, arising from the joint impact on the system of several factors;
- to build a forecast of changes in the stability of the building to external and internal influences at a particular time of operation of the object on the basis of the derived regression dependencies.

The developed software package "DINCIB-new" adapts the consolidated algorithm of calculation to the current loads (Figure 3) for a specific object of research.

The proposed software also provides tools for automating the search for numerical characteristics of such random variables as: conditional and full seismic risk, system dynamism level, total variance, effective oscillation period, average number of emissions for the billing period [21, 22, 23]. The implementation of embedded algorithms by means of the option "Seismic effects" allows obtaining results for each specific object and analyzing its operation under the action on the seismic wave system.

Algorithms of the module "Seismic effects" provide opportunities:

- decomposition of oscillations of an industrial building at its own frequencies;
- constructing the curve of the earthquake spectral density;
- determination of the maximum values of displacements and the dynamic coefficients of the system;
- finding the numerical characteristics of the forms of oscillations: the total variance, the effective period, the average number of emissions for the billing period;
establishing the value of conditional, external and full seismic risk depending on the life of the building at a given level of significance.

Figure 3. Consolidated algorithm for calculating an industrial building for operating loads.

In the course of the study, the reliability of the obtained results and conclusions was estimated with the approbation of the developed methods, which are the basis of the software complex. Comparison of possible deviations of calculated values of separate elements of similar algorithms, previously
implemented in applied mathematical packages MathCAD and Maple, in the computer-aided design SCAD [24-27]. Comparative analysis showed a deviation in the results in the range not exceeding 2%.

3. Conclusions
Thus, the implementation of the PC "DINCIB-new" allows you to step-by-step solve problems:

- registration of large volumes of input information and analysis of results at the output from the system;
- accumulation of statistical information on the behavior of the structure of the framework when varying the parameters of the load characteristics in a given range for the purpose of constructing dynamic images of the system;
- carrying out static and dynamic calculations of an industrial building under the action of crane and seismic loads with multiple implementation of algorithms;
- solution of the inverse problem, which allows to correct the stiffness matrix as a function of the change in the displacements at the design points of the framework;
- constructing a forecast on the degree of decrease in the operability of the facility in future periods;
- estimate $\gamma$ - resource and the remaining service life to achieve the maximum permissible state of the technical system;
- analysis of the calculated data and their comparison with the experimental;
- planning of current and capital repairs of structural elements of a building.

It acts as a tool for solving the problems of computer processing of data obtained during a series of full-scale surveys of an industrial building equipped with bridge cranes aimed at determining the amount of residual life and the period of its trouble-free operation. The use of this tool expands the circle of users of the proposed research concept. The construction of a forecast on the change in the stressed-deformed state of the object under examination in future periods of operation is the basis for the formation of a repair program with the establishment of their orientation and the degree of complexity.

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