MODELING OF DAMAGES OF STEEL STRUCTURES OF INDUSTRIAL BUILDINGS

N A Buzalo, A S Alexeeva and B A Chernykhovsky
nastja3post@gmail.com
buzalo_n@mail.ru

Abstract. In this paper, the most common types of damage to metal structures were considered. Their mathematical models were specified in Ansys. In the framework of the problem under consideration, the stress-strain state of the samples in the elastic zone and beyond is studied, i.e. beyond proportionality, in this case it is necessary to perform non-linear analysis. Nonlinear mechanical properties of the material were set in the program. As a result of the calculation, the authors obtained curves of the dependence of the maximum strain in the middle of the rack on the magnitude of the applied force. The calculation results show satisfactory convergence with the experimental results. Thus, it is possible to perform a similar assessment of the decrease in the bearing capacity of the rack for damage not studied in the full-scale experiment.

1. Introduction
Since the second half of the 19th century, supporting steel structures have become the most frequently used for the frames of industrial buildings, both in world construction practice and in Russia. Then, advanced standards and technical conditions for the design of steel structures were developed and implemented. Standardization of structures was carried out, which allowed to reduce the cost of their manufacture. Enterprises were built to produce modern steel structures, mastered high-speed installation methods. Research has also begun on the mass production of new steel grades. Gigantic industrial buildings and structures using metal structures were built.

The advantages of steel structures traditionally include the possibility of disassembly, maintainability, the relative simplicity of reinforcement, which is important if necessary, the technical re-equipment of enterprises, when carrying out repairs and reconstructions of technological equipment, changing the profile of production.

To conduct an examination of industrial safety of industrial buildings and structures, it is necessary to determine the category of their technical condition [1,2]. For this, it is necessary to carry out a comprehensive inspection of the building, during which various defects and damage to individual building structures are detected. Based on the data obtained, a conclusion is made about the technical condition of both individual structures and the entire building as a whole. Despite the apparent similarity of the tasks, the assessment of the technical condition of individual building structures and the entire building as a whole have fundamental differences [3]. While the assessment of the technical condition of individual building structures is carried out on the basis of directly obtained information, the assessment of the technical condition of the entire building is the result of statistical processing of data on the state of individual elements based on certain criteria of their significance.
2. Materials and methods
At present, the concept of “category of technical condition” is used to assess the damage to building structures [4], with the wording: “Category of technical condition - the degree of operational suitability of a building structure or a building and the structure as a whole, established depending on the percentage of reduction in bearing capacity and operational characteristics constructions. " At its core, this is a certain range of values of the physical and mechanical properties of building structures, as well as the parameters of defects and damages identified during the examination, which makes it possible to assess the possibility of further safe operation of a building or structure. Depending on the goals and objectives facing the survey, regulatory documents are allocated from three to six categories of technical condition of building structures [5-8].

During the inspection, deviations of the actual state of the structures from those provided by the project, standards and norms are revealed. There are deviations of design decisions and deviations of the actual state of structures [9-10]. Deviations of design decisions are defined as the differences between the design decisions adopted in the design of the examined structures from the requirements of modern standards and the modern design form.

Deviations of the actual state of structures are defined as a difference from those envisaged by the project: spatial position, geometric dimensions, shape and continuity of structures and their elements (figures 1-3); the presence of mechanical damage (figures 4-5), the quality, size and placement of connecting elements, the properties of steel structural elements and joints [11-12].

To determine the bearing capacity of steel structures elements in the presence of damage received in service, it is necessary to make a calculation scheme taking into account the features of the structure, which is a very important task that requires deep professional knowledge [13].
3. Modelling and solving a problem

The authors of the article studied an eccentrically loaded I-section strut in several variations (figure 6): “C-0” - an intact strut, “C-1” - a strut with a section with a shelf cut out in the center, “C-3” - a strut with a crumpled shelf and a cut-out wall in the central part, “C-4” - a stand with corrosion of shelves in the central part (the thickness of the destroyed layer is 4 mm).

Figure 6. Design case variations

These types of injuries are widespread and occur everywhere. The mechanical properties of the steel struts are assigned in accordance with the results of mechanical tests conducted by the laboratory of destructive control methods of OJSC “ERP Rostovskoye”. Models of damaged struts are made in accordance with the samples used in a series of laboratory tests performed in [14-15].

It is possible to perform a geometric model of building structures of this kind in the form of one-dimensional rods with a given stiffness, in the form of a thin-walled profile with a given wall thickness and in the form of a full-size three-dimensional model. The choice of any of these options depends on the problem statement, desired results, and computer computing resources. The numerical model of the test stand is made in a volume formulation, since: in the framework of the study, the maximum stresses in the loaded strut go beyond the limit of proportionality; studied structural defects form a complex geometry, and therefore, the implementation of the strut in the form of a rod or thin-walled model can give incorrect results [16-17]. The modeling steps described below are valid for most CAD programs.

The base plates are primitive box-type geometry. Such geometry, as a rule, is created by one command (like similar primitives - sphere, cylinder, cone, torus, prism). To do this, you need to specify the coordinates required for the selected method of creating a box-type primitive, for example, the coordinates of two diametrically opposite vertices of a box.

The strut, which is a beam of an I-section, is modeled in two actions: creating a sketch of the section and extruding the section to a given length.

More interesting in this model is the modeling of the body of the weld. To do this, you need to build a sketch of the cross section of the weld, and “stretch” it along the trajectory of the contour of the I-beam, using the “sweep” command.

The difference between “sweeping” and “extruding” is that the “extruding” means stretching the section exclusively along a straight path, when a command “sweep” allows you to stretch the section along any curve, be it a circle, arc, spiral, etc.

The design scheme of the model corresponds to Figure 7.
The stops Z limit the displacement of the base plates in the direction of the Z axis, while not preventing the rotation of the base plates with respect to the Y axis. Symmetrically positioned stop restricting the movement of the bottom end of the rack along the X axis and the loading element are set with given eccentricity equal to 10 mm. In order to correctly assign the above boundary conditions, small round surfaces corresponding to the contact surfaces of the stops and strut in the natural experiment were added to the geometric model. It should also be noted that in the authors' model of the weld body, the support plates and the beam itself are separate bodies that do not interact with each other by default. In order for the details to correctly interact with each other during the calculation process, it is necessary to add boundary conditions of another type – contacts (Figure 8).

Contact interaction is assigned between selected geometry elements. For example, curve-curve, curve-surface, surface-surface. Contacts in a general sense are divided into glued and non-glued (frictional, frictionless, etc.) types. The glue contact maintains the mutual arrangement of the nodes associated with the geometry chosen for the contact interaction, taking into account elastic or plastic deformations of the material. Non-glued contact allows the displacement of nodes, the magnitude of
which depends on a large number of properties of contact interaction, such as friction coefficient, sample parameters of gaps or intersections, etc. The interaction between the bodies of the welds and the welded parts are suitable for the glued type. The interaction between the ends of the beam and the support plates can either not be assigned at all (to reduce the required computing resources), or assigned by non-glued contact (frictional). In different CAE programs, the assignment of boundary conditions can occur at different stages. For example, in Ansys PC, finite element modeling is oriented to geometry, which makes it possible to set boundary conditions before creating a mesh [18]. In Femap PC, the finite element model is less dependent on geometry, and in most cases boundary conditions are assigned to existing nodes (for example, forces and constraints).

In modern CAE programs, the creation of a finite element model is somehow tied to geometry objects [19]. This greatly simplifies the work of an engineer when working with complex models such as a car body, engine block, engine systems, agricultural machinery functional systems, atypical structures of unique buildings, etc. This approach does not exclude the possibility of creating elements in a pure form without reference to geometry. Moreover, the “combined” approach is quite common in engineering practice, where rigid, beam, mass, spring and other elements appear in the form of elements that are not attached to geometry, which are necessary to simplify the model and to accurately model the interaction of the components of the model. In the process of performing the finite element model, it is necessary to monitor the quality of the elements obtained. There are a number of parameters that in one way or another reflect the degree of correctness of an element. For the most part, they relate to geometric features [20], such as:

- the ratio of the smallest and largest angles relative to the edges;
- the ratio of the length of the smallest edge of the element to the largest;
- the ratio of the length of the largest rib to the radius of the circle inscribed in the geometry of the element;
- the ratio of the radius of the described sphere to the length of the largest rib.

It is also necessary to evaluate the overall quality and rationality of the set of elements - the finite element mesh. To do this, it is first of all important to understand the physics of the process under study and to be able to predict the location of geometric areas to which special attention should be paid. This is expressed in the "overall" dimensions of the finite elements and their uniform filling of the existing geometry. Based on the working practice of some engineering areas, the following rules for modeling a volume finite element mesh were adopted in the framework of this study:

- for those areas of the object where the smallest size is much smaller than the overall dimensions of the cross section (for example, the wall of an I-beam), at least 4 finite elements must be provided throughout this size (Figure 9);
- in places of smooth transition between surfaces, at least 2-6 elements should be provided, depending on the radius of fillet (Figure 10);
- in the areas of the object located far from the studied zones and having a monotonous character, ensure large overall dimensions of the grid elements;
- item size provides at least 2 mm.

Figure 9. Mesh quality in an I-beam’s wall
All of the above requirements are met by applying the partitioning rules to selected individual geometry objects. These rules prescribe the number and size of the created finite elements on the selected geometry object (curve, surface or body), and behavior of the distribution – bias factor (Figure 11). With the correct implementation of such measures, the calculated calculation results can be obtained from the created finite element model, and this model itself will also be relatively less resource intensive.

In the framework of the problem under consideration, the stress-strain state of the samples in the elastic zone and beyond is studied, i.e. beyond proportionality. In this case, a nonlinear analysis is necessary. Nonlinear analysis implies an iterative solution, where, at each new iteration, a decision is made according to the initial data, which is the solution of the previous iteration. Nonlinearity is physical and geometric. Physical nonlinearity is a change in the elastic modulus of the material with increasing stresses that go beyond proportionality. Nonlinear mechanical properties of the material are set in the program and shown in the figure 12. Geometric nonlinearity implies a disproportionate change in the deformation of the body with increasing stresses. As the decision is made, the geometry of the calculation model changes sequentially, and the value of the applied load rises to its nominal value.
4. Results
As a result of the calculation, the authors obtained curves of the dependence of the maximum strain in the middle of the rack on the magnitude of the applied force (Figure 13). Also, on this graph, the dashed line shows the curves obtained during a natural experiment. As can be seen, the calculation results show satisfactory convergence with the experimental results.

Based on these results, it becomes possible to evaluate the effect of each type of rack damage on its bearing capacity. Moreover, taking into account the errors caused by the assumptions when choosing a design scheme and the conventions of the finite element method as a whole, one can perform a similar assessment of the decrease in the bearing capacity of a strut for damage not studied in a natural experiment.
To determine the bearing capacity of steel structures elements in the presence of damage received in service, it is necessary to make a calculation scheme taking into account the features of the structure, which is a very important task that requires deep professional knowledge.

5. References

[1] Rekomendacii po ocenke nadezhnosti stroitel'nych konstrukcij zdanj i sooruzhenij po vneshnim priznakam/CNIIPromzdanij. – M.: Gosstroj, 2001.
[2] Rekomendacii po obshledovaniyu staj'nnych konstrukcij proizvodstvennyh zdanj/CNIIProektstal'konstruciya. – M.: Gosstroj SSSR, 1988.
[3] Buzalo N.A., Kanunnikov A.V. Opredelenie koefficienta znachimosti stroitel'nych konstrukcij pri ocenke tekhnicheskogo sostoyaniya zdanj//Stroitel'stvo i rekonstruktsiya. Orlovskij gosudarstvennyij universitet im. I.S. Turgeneva (Orel) – 2018 - №3(77) – s.3-11
[4] SP 13-102-2003. Inspection rules for load-bearing building structures of buildings and structures. Code of rules for design and construction. - M.: Gosstroy of Russia. GUL CPP, 2003.
[5] GOST R 53778-2010. Buildings and constructions. Rules for inspection and monitoring of technical condition. General Provisions - M.: Standartinform, 2010.
[6] RD 22-01-97. Requirements for assessing the safety of operation of industrial buildings and structures of supervised industrial production and facilities (inspection of building structures by specialized organizations). - M.: Central Research Institute "Projectstalkonstruktsiya", 1997.
[7] TSN 13-311-01 Territorial building codes. Inspection and assessment of the technical condition of buildings and structures. Samara Region. - Samara: Administration of the Samara region, 2001.
[8] ODM 218.4.001-2008. Guidelines for the organization of inspection and testing of bridge structures on roads. - M.: Rosavtodor, 2008.
[9] Recommendations for assessing the reliability of building structures of buildings and structures by external signs / Central Research Institute of Industrial Buildings. - Moscow: Gosstroy, 2001.
[10] Recommendations for the inspection of steel structures of industrial buildings / Central Research Institute of Steel Construction. - M.: Gosstroy of the USSR, 1988.
[11] Recommendations for the examination and assessment of the technical condition of large-panel and stone buildings / TSNIIISK them. V.A. Kucherenko - Moscow, 1988.
[12] ODM 218.4.001-2008. Guidelines for the organization of inspection and testing of bridge structures on roads. - M.: Rosavtodor, 2008.
[13] Gorshtkov A.S. Model of physical deterioration of building structures // Building materials, equipment, technologies of the XXI century. - 2014. - No. 12. - S. 34-37.
[14] Buzalo N. A., Gontarenko I. V. An experimental study of the stress-strain state of eccentrically compressed struts with damage // Internet Journal of Science. - 2014. - No. 1 (20).
[15] Gontarenko I.V., Buzalo N.A. Determination of force resistance of eccentrically-compressed racks of an I-section with damage // Internet Journal of Science. - 2014. - No. 2 (21).
[16] Glushakov S. V. Mathematical modeling: a training course / S. V. Glushakov, I. A. Zhakin, T. S. Khachirov. - M.: Publishing house ACT, 2001. - 524 p.
[17] Gorodetsky A. S. Computer models of structures / A. S. Gorodetsky, I. D. Evzerov. - K.: Fact, 2007. - 394 p.
[18] Kaplun A. P. ANSYS in the hands of an engineer: a practical guide / A. P. Kaplun, E. M. Morozov, M. A. Olf'eva. - M.: URSS editorial, 2003. - 272 p.
[19] Study of the work of frame structures / A. V. Gemmerling, V. I. Trofimov, I. E. Mileikovsky [et al.] // Scientific communication. - M.: TSNIPS, 1955. - Issue. 21. - 140 s
[20] Rzhansyn A. R. Calculation of structures taking into account the plastic properties of the material / A. R. Rzhansyn - M.: Gosstroyizdat, 1954. - 288 p.