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**ARTIFICIAL INTELLIGENCE IN TASKS OF TEACHING STUDENTS  
CALCULATIONS AND DESIGN OF METAL STRUCTURES**

**Abstract.** Various applications of artificial intelligence for design tasks and modeling of metal structures are being explored. Options for integrating artificial intelligence tools into calculations and principles of designing metal structures are considered. It is demonstrated that the integration of artificial intelligence technologies can both enhance students' understanding of engineering design concepts and structural analysis and lead to errors or misinterpretation of results. Directions for improving the outcomes of solving engineering tasks using artificial intelligence are discussed.

**Keywords:** artificial Intelligence, design of metal structures, improving ai outcomes in engineering words.

**Introduction**

This work analyzes the possibilities of using artificial intelligence to solve the problems of calculating and designing metal structures.

The use of artificial intelligence technologies in the development of construction projects and automation of construction processes have been discussed for a very long time [1].

Artificial intelligence can be used to automate modern complex tasks in the process of designing structures [2]. The use of artificial intelligence can optimize the processes of data analysis, modeling, forecasting, and automation in tasks of calculating and designing structures [3-5]. This allows engineers to make more accurate and informed decisions, considering various factors and risks.

**Problem statement**

There are many in such tasks uncertainties associated with creating descriptions of existing the object and, especially, the design of a new object [6-8]. There is a need to agree on conflicting criteria for ensuring strength and reliability, cost-effectiveness, safety, installation speed and other factors, as well as the probabilistic nature of loads, material characteristics and geometric characteristics of cross-sections. The limit state method used to solve this problem has its limitations, related to the analysis of the limit states. Since the main

operation of structures occurs between the limit states. There is always uncertainty in the engineer starting from the choice of the calculation scheme, as the process of allocating «main» factors of modeling the real design and discarding «insignificant» factors «in reserve». The construction experience confirms that this approach is valid for standard constructions, assemblies and materials.

**The aim of research**

The aim of this study is to analyze and apply artificial intelligence technologies to automate the design and calculation processes of metal structures. Particular attention is paid to increasing the accuracy, efficiency, and reliability of engineering solutions, taking into account the multifactorial and probabilistic nature of loads, materials, and geometry of structures.

**The main material**

Python with machine learning and data analysis libraries (such as TensorFlow, scikit-learn, pandas) can simplify the design and calculation of structures. It can provide guidance, such as suggesting to assume a calculated force of "50 kN" for connection elements without detailed calculation. Suppose you're analyzing the stress distribution in a beam structure. Starting with a simple model that considers only the main components of the beam (such as the beam itself and the supports) may provide sufficient

accuracy for initial calculations. Adding intricate details such as bolt connections, welds, and material imperfections might lead to unnecessary complexity without significantly improving the accuracy of the results. Additionally, it can use reference recommendations or databases to select nodes and sections for simple beam structures (fig. 1).

ChatGPT can explain the fundamental concepts and principles associated with modeling of structures. Will provide calculation results using simplified methods. This approach is used for preliminary analysis and exclusion of unexpected errors. As calculations using construction mechanics methods are not performed, standard diagrams and formulas are utilized.

However, such idealization of the structural scheme (replacing the actual structure with an axial design), boundary conditions (ideally hinged or fixed supports), and loads (ideally uniformly distributed load) is not typical for real structures. Moreover, it contradicts the principles of construction mechanics. It is known that each additional connection (considered as "insignificant" factors) contributes to load resistance.

For example, when considering hinge-fixed supports in trusses, there will be a redistribution of forces with partial compression appearing in the stretched area and stretching in the compressed area. In this case, the distribution of forces will not correspond to the "classical" scheme.

"It is difficult to get a definitive answer from ChatGPT as to when and why detailed modeling may be useful or undesirable."

For example, in the simplest calculations of roof or building structure, questions arise as to whether to consider the movement of roofing and roof, wall trims, and wall fillings only as loads or as additional connections? "Can the flat frame be separated from the spatial frame, as well as individual structures and nodes? How should the models of various finite elements be detailed?"

The correct answers to these questions are not always straightforward. It all depends on understanding the function of specific structural elements in the collaborative operation of the structural system. In any

case, there should be an understanding of the design scheme, that is, to some extent, forecasting the calculation results.

Specialized tools for engineering modeling will help in such tasks. Autodesk Revit, Ansys, Tekla Structures use artificial intelligence methods for modeling and analysis of building structures.

The use of a highly detailed model and a powerful computing complex will not always lead to the correct result. Artificial intelligence suggests that it's better to proceed from simple to complex, predicting calculation results and refining them during the detailing of the design in the next stage. First, a flat diagram is created, followed by a spatial one. Then, consideration is given to wall fillings, as well as interaction with adjacent subsystems of the foundation, structures, and load areas (see Fig. 2).

### **Discussing**

But the question remains: how to perform the breakdown of the structure into finite elements during modeling?

Different schemes of finite elements may result in different calculation outcomes (either meeting or not meeting the requirements of the first group of limit states).

Additionally, different methods of modeling joints and connections pose a problem, such as resting beams on columns. Rigid inserts, solids, etc can be applied. For instance, rigid inserts move the flexible part of the element away from the node, creating an infinitely rigid insert between the flexible part and the node. This helps model eccentricities and allows for additional moments, reducing beam span and moments within the span, and adjusting the transverse force. The difference in moments can range from 10% to 15%.

When modeling sheet hinges, transmitting forces in specific directions - only vertical, or only horizontal can be used to "combine movements".

Different ways of modeling floor structures will result in different outcomes:

1) Elements of type «beam-wall» have an important feature - they do not work on bending and work only on the displacement of stretching and compression and in cases

when, that they will take over part of the tensile or compressive force can be neglected they can be used to model rigidity, however, the type elements «beam-wall» do not transfer

the load from the plane, so to transfer the loads from the plane, it is possible to "stick" elements «shell» of the type of zero stiffness on them (the modulus of elasticity is zero).

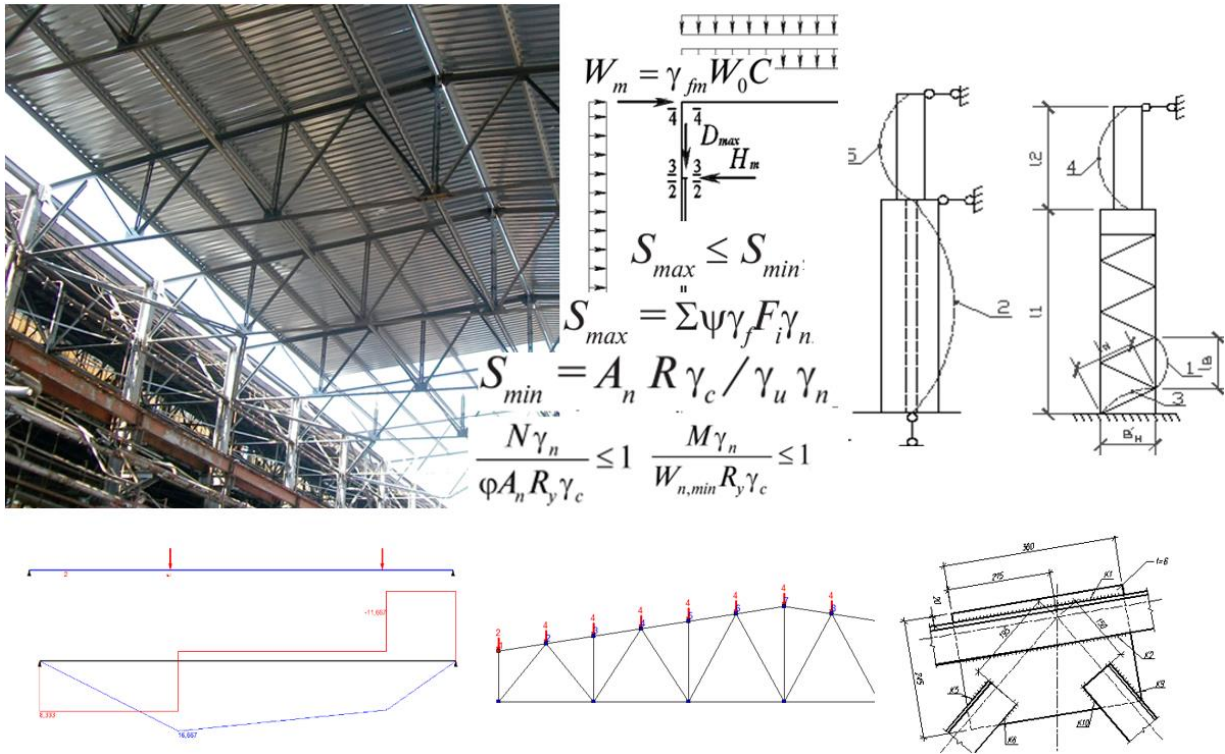


Fig. 1. The spatial structural scheme, the calculation schemes of structures and nodes

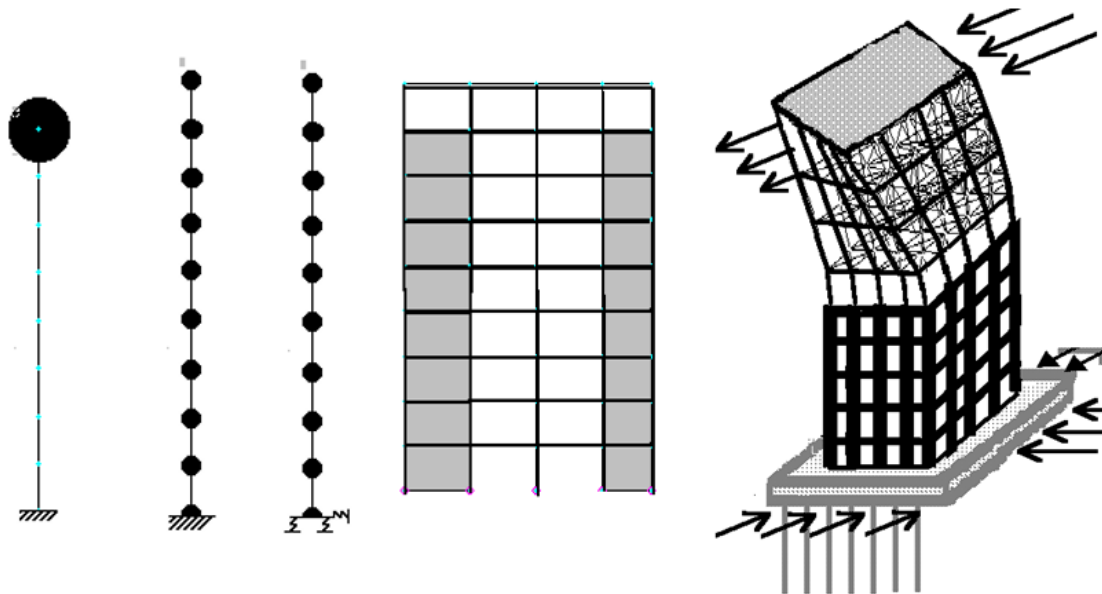


Fig. 2. Options for modeling multi-story frame buildings

2) Conditional cross or diagonal ties in addition to shear work are included in the work for stretching-compression.

3) "Elastic" coupling elements – "rigidity only in the direction perpendicular to the axis" of the element allow you to simulate a net shift. It's a relatively complex and time-consuming method, but for modeling a net shift the most correct.

4) The "shell" type for modeling steel flooring at low thickness of the elements of the type will not distort the bending moments in the beams.

It becomes even more complicated when calculations are required for progressive collapse, when optimizing the life cycle processes of manufacturing, installation, operation, and application of effective methods of analysis and forecasting the behavior of structures under the influence of external factors. Additionally, it is complex during the development of more accurate and faster methods of diagnosing the technical condition of structures, increasing safety, and durability of engineering structures.

A separate group of questions concerns interpretations by artificial intelligence of a specific formula for calculating steel structures.

From communication with the neural network:

- Me: - Do I understand correctly, in the formula for calculating steel columns for stability, the coefficient  $\xi$  in the denominator takes into account geometric nonlinearity and initial imperfections?

Neural network:

- Yes, you understand correctly. The factor  $\xi$  in the steel column stability calculation formula accounts for geometric nonlinearity and initial imperfections. These factors can lead to a reduction in the critical load that a column can support before lateral buckling or displacement occurs. The coefficient  $\xi$  accounts for these effects and provides more accurate stability estimates for steel columns.

- Me: - Then, if the coefficient  $\xi$  accounts for the forces arising from initial imperfections and geometric nonlinearity, and in the design scheme geometric nonlinearity is accounted for directly using nonlinear finite

element geometry, then it turns out that the steel column stability design formula is not applicable because it already accounts for the effects of geometric nonlinearity and initial imperfections? Neural network: - If geometric nonlinearity is accounted for directly using geometrically nonlinear analysis methods, then the coefficient  $\xi$  may not be applicable in the stability calculation of a steel column. However, formulas with the  $\xi$  coefficient can still be used in calculations if it is necessary to perform a preliminary assessment of column stability without the use of complex analysis methods such as the finite element method.

- Me: - So the coefficient  $\xi$  should be taken equal to one? Neural network: - If the geometric nonlinearity and initial imperfections are directly accounted for in the design scheme, then the coefficient  $\xi$  can be assumed to be equal to one. However, if all factors affecting the column stability have not been taken into account in the calculations, the coefficient  $\xi$  can be applied to account for possible effects of geometrical nonlinearity and initial imperfections. Note, however, that the factor  $\xi$  may vary depending on the specific situation and the calculation methods used. Therefore, if you are in doubt about the necessity of applying the phi coefficient in a particular case, it is recommended to consult specialists in the field of design and calculation of structures.

Communication with Gpt-4.

- Me: - In Eurocode 3 [6], formula 4.1 allows you to predetermine the stiffness of the node. In formula 4.1, the denominator contains the coefficient  $\xi$ . Since the coefficient  $\xi$  is in the denominator, the larger it is, the lower the stiffness of the node. For example, when joining a beam on one side,  $\xi = 11.5$ , if you put transverse ribs  $\xi = 5.5$ , and if you put a diagonal rib, then  $\xi = 3$ . And when the beams are joined from two sides, not everything is clear. So, when connecting beams without transverse ribs,  $\xi = 6$ , i.e. the resulting knot is stiffer than when the beams are joined on one side. But when the beams are connected from two sides and the transverse ribs are set,  $\xi = \infty$  (infinity). Therefore, since infinity is in the denominator, the stiffness of the node becomes infinitely small, i.e. when placing

transverse ribs, when connecting beams from two sides, does the node become hinged?

- Gpt-4: - Yes, you are right. When the coefficient  $\xi$  is equal to infinity when connecting beams on two sides and adding transverse ribs, this means that the stiffness of the node becomes infinitely small. Since infinity is in the denominator, this leads to the fact that the node becomes hinged, that is, it has no rigidity and can rotate freely.

- Me: - But when connecting the beams from two sides and setting the transverse ribs, the knot should be even more rigid?

- Gpt-4: - Sorry for the confusion in the previous answers. Let's figure it out. When connecting the beams from two sides and setting the transverse ribs, the factor  $\xi$  will be equal to 5.5, according to your data from the table. Since the coefficient  $\xi$  is in the denominator of the formula for determining the stiffness of the node, the smaller its value, the greater the stiffness of the node. Thus, when connecting beams from two sides and adding transverse ribs, the node becomes stiffer than when connecting beams from one side or when adding a diagonal rib. This means that the node will have higher rigidity and will be less prone to deformations under loads.

### **Conclusions**

At the moment, there are still limitations on the application of artificial intelligence in solving tasks related to the design of metal structures, which can complicate or restrict the capabilities of the designer in the absence or malfunction of these systems. Examples are given where the absence of human expertise in the use of artificial intelligence in structural calculations can lead to errors or incorrect consideration of certain factors.

We believe that the most effective applications of artificial intelligence can be implemented at the stages of calculation and design, both in educating students and in creating innovative design methods, monitoring the condition of structures in real-time, and simulating dynamic features of construction work.

Artificial intelligence can be integrated as a direction for the development of

advanced calculations and models aimed at enhancing the reliability and durability of designed buildings and structures (it should be noted that this need arises not only in the design of new buildings and structures, but also in the inspection, diagnosis, and reconstruction of existing facilities).

Comprehensive approach to specification (testing) of calculation models and their parameters. Artificial Neural Networks can be employed to refine and test calculation models, optimizing various parameters based on training data and real-world performance.

Application of spatial models taking into account actual modeling of nodes, boundary conditions, stiffening on different subsystems of constructions. Finite Element Analysis software, such as Abaqus or ANSYS, utilizes AI algorithms for spatial modeling, considering factors like node behavior, boundary conditions, and subsystem interactions.

Modeling of non-linear properties and characteristics (elastic and dissipative), taking into account structural non-linearities (gaps, one-sided connections, working, for example, only for stretching or compression, "included" or "off"). Machine learning algorithms, such as Random Forests or Gradient Boosting Machines, can be utilized to model non-linear properties and structural behaviors, adapting to complex relationships between variables and conditions.

Correct accounting of the interaction of structures with loads (mobile loads, loads from technological equipment, wind loads, seismic loads). Deep Learning models, including Convolutional Neural Networks or Recurrent Neural Networks, can analyze vast datasets to accurately predict and account for structural responses to various loads, including dynamic and environmental factors.

Consideration of static and dynamic models of the main structures of the site together with their foundations and bases. Reinforcement Learning techniques, combined with physics-based simulations, can help develop static and dynamic models of structures, considering foundational elements and their interactions with the environment.

Input into dynamic models of real records of dynamic disturbances (including random processes) obtained during field dynamic tests. Natural Language Processing algorithms, like recurrent neural networks or transformer models, can process textual data from dynamic tests and extract relevant information to input into dynamic structural models.

The development of directions of structural formation of metal structures with the solution of problems of energy saving, safety, and reduction of weight of construction structures, comfort, and economy of place. Genetic Algorithms can optimize the design process of metal structures by iteratively evolving solutions that meet specified criteria, such as energy efficiency, safety, and weight reduction, while considering spatial and material constraints.

Individual tasks and calculations with the use of artificial intelligence in the selection of technology in the manufacture of metal structures, in transportation, in installation and technological processes of construction production, in operation and repair, in tests of metal structures, in technical diagnostics. Robotics Process Automation combined with machine learning algorithms can automate various tasks involved in metal structure manufacturing, transportation, installation, and maintenance, improving efficiency and accuracy while reducing costs and human error.

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