Analysis of the hardness of node connections of metal constructions using modern CAE-systems

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Abstract. In classical structural mechanics, there are two types of nodal connections – rigid and simple joints. This separation is used to simplify the calculations of building structures. Such simplification is called the idealization of the model [1–15]. The above simplification is convenient for describing many complex aspects of the work of building structures, for example:

- for mathematical description of the interfaces of elements of the design scheme (description of boundary conditions);
- for mathematical description of the scheme of deformation of elements of the design scheme;
- for mathematical description of the form of the compressed rod buckling;
- to determine the calculated length of the compressed rod.

1. Introduction
In classical structural mechanics, there are two types of nodal connections – rigid and simple joints (Figure 1, a, 1, b). This separation is used to simplify the calculations of building structures. Such simplification is called the idealization of the model [1–15].
Methods of calculation of building structures were created based on idealized models. These methods were successfully used for the calculation of structures both manually and with the help of modern calculation complexes [16–24]. The accuracy of the solution obtained by these methods depends, among other things, on how accurately the physical nodal connection corresponds to its simplified model [25]

To obtain reliable solutions in the calculation of building structures should pay special attention to the correct idealization of nodes [25, 26]. It is known that any idealization leads to a loss of solution accuracy. The loss of accuracy can be allowed only in the direction of the security of the solution. Therefore, some margin of safety, which compensates for the inaccuracies of the calculation, is initially laid during calculating building structures. Such a statement of the issue leads to unreasonable overspending of materials. In addition, the safety margin assumed by the designer for compensation of inaccuracies in the calculation model is not able to be quantified. Therefore, we should abandon the practice of maximum idealization of the model. Modern software systems for the calculation of structures allow performing calculations of higher complexity task. With the help of modern computers it is possible to take into account more specific features of designs in their design models [25, 27]. Therefore, it is possible to abandon the maximum idealization of the model, in particular for the nodes of the elements connection.

In nature the ideal hinge or perfectly rigid clamping doesn’t exists. All existing nodal mates have finite stiffness (Figure 1.c). This means that each specific node should be studied and evaluated for its rigidity. For well-studied constructions, researches of the rigidity of the nodes show compliance with the well-known ideal model. For example, trusses, assembled from a corner profile, can be considered hinged. For other units, a simple visual assessment of its design may not provide a clear definition of its rigidity. Therefore, the authors propose to assess the rigidity of the nodal conjugation before making a decision on the design model of the structure. Evaluation of node stiffness can be performed by experimental methods. The authors highlight the use of numerical studies of nodes in modern CAD as the most simple and promising way to assess their rigidity. The resulting value of the final stiffness of the node can later be used for static and dynamic calculation of the structure, to determine the calculated lengths of the building elements and so on. The resulting design solution will have greater reliability and, as a result, have greater reliability and cost-effectiveness.

2. Materials and methods
The approach proposed by the authors to assess the stiffness of the nodes was implemented in the calculations of various structures [28–30].

For the metal frame, consisting columns and beams, the authors performed a numerical analysis of the connection (Figure 2). The described node was made by welding the beam wall with the support edge of the column. A distinctive feature of this unit is the presence of a pair of separated vertical joints in the weld joint. This pair of seams is able to perceive the bending moment. It gives certain rigidity to the node even in the presence of gaps in the beam belts. To clarify the influence of such a joint stiffness on the stress-strain state (SSS) of the node, its numerical studies were performed. Numerical studies of this node were performed by the finite element method using the CosmosWorks calculation complex (Figure 3).
Figure 2. Node connection of a beam to column.

Figure 3. Beam deformation scheme.

For the column support unit on the Foundation, the authors performed numerical studies of two variants of the structural design of the units. The first option is a node consisting of only one base plate (Figure 4). The second is a node consisting of a base plate and low traverse (Figure 5). In the first case, the rigidity of the node depends on the thickness of the base plate. In the second case the rigidity of node depends on thickness of the plate and the rigidity of the traverse. Numerical studies of the nodes were performed by the finite element method using the CosmosWorks calculation complex.

During the research, the analysis of the deformation value of the nodes and the analysis of internal stresses were performed. The purpose of the research was to determine the nature of deformation of the joint, that is, the possibility of classifying the node to the hinge or rigid type.

The results of studies of the beam-column interface showed a small stiffness of the nodal connection. The presented unit without loss of accuracy of the solution can be attributed to the hinge.

The results of studies of the column support unit on the Foundation with only one support plate showed a strong dependence of the stiffness of the node on the thickness of the plate. The authors identified three possible results (Figure 6). When a thin base plate is used, the node operates as a hinge (Figure 7). When a very thick plate is used the knot works like a hard one (Figure 8). In the case of a support plate of medium thickness, the unit operates as a spring, that is, it has a finite stiffness.
Figure 4. Base of the column consisting only of a base plate.

Figure 5. The base of the column, consisting of a base plate supported by low traverses.

Figure 6. Diagram of deformation of the column base depending on the thickness of the base plate.

The results of the studies of the column support unit on the foundation with the help of a support plate reinforced with low traverses showed the similarity of the work of such a unit to a node with only one plate. The difference between these nodes from each other is the thickness of the base plate, which provides a manifestation of the nature of the rigid pinching of the node. In other words, the presence of low traverse increases the stiffness of the support plate. Traverses allow achieving the effect of rigid pinching of the node when using a base plate of lower thickness (Figure 9).
3. Conclusions

- All nodes have a finite stiffness;
- In practical calculations, the rigidity of the node can be neglected, provided that the computational justification, for example, using a numerical study of the node;
- The node coupling of the beams to the column, which is performed only through the wall of the beam, has a small stiffness and is actually hinged;
- The column support unit on the Foundation only through the base plate can be adopted hinged, rigid or occupy an intermediate value between them. The rigidity of such a unit depends on the thickness of the plate and the ratio of the bending moment to the clamping force;
- The column support unit on the Foundation through the base plate, reinforced with traverses, can be adopted hinged, rigid or occupy an intermediate value between them. The rigidity of such a unit is less dependent on the thickness of the plate. The rigidity of such a node depends more on the rigidity of the traverse.

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