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# RESEARCH OF THE DESIGN OF A T-SHAPED NODE OF COLD-ROLLED PROFILES, THE CONNECTION OF WHICH IS MADE BY A PLATE USING A BOLT CONNECTION

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**Abstract.** The supporting structures of mezzanines and platforms in warehouses are used to accommodate cargo and move personnel. The connection nodes(joints) of the beams of the structures are designed as hinged. The design of a conditional hinged joint is proposed, which ensures the absence of transmission of bending moments between the elements of the joint due to the design of the corner, which operates within the limits of plastic deformations. Numerical modeling of the design of the conditional hinged joint was performed and the values of stresses in its elements were obtained. It was confirmed that under working loads, all elements of the joint, except the corner, operate at the yield point of the materials from which they are made and their destruction does not occur. The design of the corner ensures the absence of transmission of bending moments between the elements of the node due to plastic deformations.
**Keywords:** finite element method; verification; equipment design; schemes; approaches, numerical modeling and calculation, conventional hinge joint; connection

## Introduction

The need to create new structures of mezzanines and platforms for performing operations within warehouse complexes and distribution centers is only growing due to the ever-expanding list of services provided in the logistics. At the same time, each center or complex is essentially unique, since it has completely different solutions both for the placement of work zones (reception and shipment zones, transport zones, placement (storage) zone, etc.), as well as for the planning of these zones and the placement of certain elements in them. The creation of new structures of mezzanines and platforms that will satisfy the technical task, as well as the requirements of low material consumption, ease of assembly and reliability of their operation is a pressing task. Currently, engineers design such structures using special calculation tools, such as Abacus, MSC Nastran and other common software tools. Such software tools allow obtaining fairly accurate data on the movement of structural elements, stresses and wear resistance of elements of these structures. Verification of structural calculations is an important stage that allows for comparison of the results obtained in such calculation tools with real tests in laboratory conditions.

## Analysis of recent research and publications

The main reason for the widespread use of the numerical method of structural modeling in computational tools when solving the problems of developing and manufacturing new structures is, first of all, the reduction of financial and time resources spent on conducting full-scale tests of structural models. On the other hand, this does not eliminate the need for conducting full-scale tests on reduced structural models in order to verify the calculations. In this case, the advantage of numerical methods allows you to analyze from several units to several dozen structural variants, assess the distribution of loads in joints, calculate the stress-strain state of structural elements and determine the most effective structural variants from the point of view of the selected evaluation criteria, thus narrowing the list of structures that will be subject to full-scale tests.

In products formed from thin-walled elements (plates or shells) fixed to supporting structures, the most loaded areas with a large number of local stress concentrators are joints(attachment of thin-walled elements to supporting structures). Modern systems in which joint modeling is performed allow solving a wide range of tasks, including the task of determining the moment of failure of the joint [8].

The work [1] is devoted to performing a semi-analytical analysis of the joint of the fuselage shell with supporting stringers. The shell in this case is made of a composite material with reinforcements at the connection points. The Classical Laminated Plate Theory (CLPT) is most often used for analytical description, which allows to accurately determine the behavior of plates and shells (their bending, deflection, vibration). However, at the junction of stringers and frames with fuselage skins, stresses often arise in three dimensions, which this theory cannot accurately describe. In addition, due to local bends of the skins at the junction, stresses often arise between the layers of composite materials, which are directed in a direction perpendicular to the fiber arrangement. The use of classical theory (CLPT) in the calculation of plates and shells in the aerospace industry leads to an increase in the weight of the structure, due to the need to design structures with a "margin". The authors in this work presented a new approach to analysis based on a semi-analytical method using the layer-by-layer theory of laminated plates. During the calculations, the behavior of the layers of the skin made of composite materials is taken into account, on the one hand, and on the other hand, the junction of the skin and the lower surface of the stringer. The bending moments in the skin at the junction points are the initial data for the semi-analytical method for determining three-dimensional stresses and the singular stress field in the connection zone.

The approach consists of two stages. In the first stage, a global modeling of the shell behavior at the point of its connection with the stringer is performed based on CLPT, and in the second stage, the shell is divided into separate mathematical layers. Their modeling is based on the layer displacement approach. The displacement values of one layer relative to another remain unknown. Interpolation between the distribution boundaries in the thickness direction is performed based on linear polynomial shape functions. This allows determining the interlayer stress concentrations in the shell made of composite materials. It is worth noting that this approach works well in the case of connecting load-bearing structures and shells without using fasteners (rivets, welding), but only based on a connection based on adhesive elements.

In various types of literature, bolted joints can be modeled in a simplified form as a point-to-point connection between parts [3], in others, bolted joints are modeled as continuous solid elements [4], and in some, accurate modeling of all structural elements, including the bolt and nut with threads on them [5, 6].

The Eurocode [7] clearly defines the procedure for analyzing prestressed bolted joints, in which friction forces arise due to the pressure. However, the issue of determining the rotational stiffness of a bolted joint is still a relevant problem, since in such joints everything depends on the surface of the connected parts (flatness, roughness and waviness), the material of the parts (elasticity, plasticity, strength, frictional properties, etc.), as well as changes in the stiffness of the joints depending on the number of cycles of application and removal of loads.

In the work [2], the stress fields in the joint formed by a prestressed bolted joint were investigated, determining their rotational stiffness and the ability of such joints to transmit bending moments. Often in the literature, depending on the industry, one can find two opposite statements. In mechanical engineering, the connection of two plates by a single prestressed bolted connection is considered rigid. In the construction industry, the situation is the opposite and such connections are considered as those that allow mutual rotational movement of the two parts relative to each other, with the axis of rotation being the axis of the bolt (hinge joint). In any case, in the case of using a prestressed bolted connection, friction occurs between the parts, which suggests that there is rotational rigidity that will not allow the parts to rotate freely relative to each other.

The authors of the work performed analytical calculations of the parameters of the rotational stiffness of the joint, determined its experimental values in a special model installation and conducted a numerical analysis of a similar design.

In experimental studies, a check of the joint of two parts was used, namely a C-shaped profile and a plate. Before testing, the friction coefficient of the surfaces was determined by the devices and their roughness was measured. The profiles are made of galvanized steel.

Based on these studies, an equation was derived that allows taking into account the action of the shear force and bending moment acting on the joint, as a result of which it is possible to determine the total shear stresses in the joint under the action of loads.

As a result of the experiments, it was determined that the increase in the bending moment depending on the angular displacement of the plate occurs nonlinearly. After a rotation angle of 0.060 radian, the increase in the bending moment does not occur at all. This is due to the fact that the prestressed joint during loading exhausts its rotational stiffness due to exceeding the ultimate shear stresses in the friction zone. Further rotation occurs due to sliding. In this case, the bending of the plate is absent.

The results of the research were further verified by numerical analysis in the ABAQUS system, while the model used similar values of the coefficients of surface friction, yield strength, strength and plastic elongation as in the experimental model, and the "bolt load" function in ABAQUS set the prestressing force of the connection. And the modeling was performed using nonlinear elastic-plastic analysis of large displacement.

It is worth noting that the position of the bolt relative to the center of the profile was also a variable in the analysis process. This made it possible to model the distribution of stresses in the profile that it perceives when transmitting the bending moment from the plate. The ultimate moment in this case, as well as the ultimate stress that arises in the joint, remain unchanged.

As a result of the comparison, the authors determined that there are discrepancies in the rotational stiffness of the connection (in the experimental model it is 30% higher than in the numerical model). In addition, it is obvious that such joints of profiles and plates cannot be modeled as completely rigid, therefore, the use of models with a semi-rigid connection is relevant when analyzing such structures. It is worth noting that the authors of the work [2] performed only the determination of the rotational stiffness of the joint, while important direction is the search for solutions that will reduce or eliminate the effect on such joints of bending moments that may arise as a result of plate torsion.

A large number of different types of truss structures are used to install wind turbines on them. In this case, the joints of round profiles are performed by two methods: 1) by the welded method with reinforcement with steel flange plates; 2) by the method of reinforcing welded joints with composite materials. In [9], researchers proposed a new type of connection of round truss profiles at nodes using composite materials without the use of welding. The problems of modeling the behavior of unwelded composite X-nodes of trusses, which are wrapped around round profiles, where the predominant load action is tension, were solved. The biggest problems are modeling thick composite reinforcement with complex geometry, as well as composite-steel connections. The authors created full-scale models of the nodes and subjected them to experimental tensile tests. At the same time, using a digital image correlation system, the expansion between the ends of the samples and the distribution of deformation of the connections were measured to track cracks.

In numerical modeling, the cohesive contact approach was used to simulate the composite-steel connection surfaces and their interaction under load, and the explicit method in the Abaqus PC was used to analyze the fracture of the connections, while the modeling is performed in a quasi-static manner.

As a result of the research, the authors compared the obtained results of the initial stiffness of the node, loads at the elastic limit and limit loads. The deviations between the values of the stiffness of the node and loads at the elastic limit obtained in experimental and numerical studies are 5 and 7%, respectively, which indicates a high convergence of the results. The result of the research is a formula for determining the average shear resistance that can withstand similar connections at the interface of materials.

It is worth noting that such studies allow for more accurate calculation of structural elements with a combination of steel and composite materials.

The authors performed numerical modeling of columns made of cold-rolled steel C-profiles[10], which are interconnected at the ends by means of two plates and a bolted joint. The methodology for analyzing the axial bearing capacity of such structures under longitudinal compression is given in Eurocode 3 (EC3). The authors searched for faster and simpler methods for analyzing such structures compared to the results obtained using the methodology from Eurocode 3.

To more accurately obtain the results of the behavior of vertical columns under loading, the structural imperfection factor (1) is taken into account by applying an equivalent force in the horizontal direction [11]

$$e_0 = L/500, \tag{1}$$

where $L$ - is the height of the column, m.

The value of the equivalent force is determined from the equation of equilibrium moments:

$$q = 8\frac{Ne_0}{L^2}, \tag{2}$$

where $N$ - is the axial force acting on the column, N.

The force is calculated so that the moment at the center of the column is equal to the moment taking into account the imperfection coefficient of the column.

The first study was performed by the authors using the ARSA program and nonlinear static analysis tools.All component connections are fixed.

The second study was performed based on the model imperfection tool, by importing the bending shape of the column with maximum displacement, which was performed within the framework of the first study.The initial deformation based on the calculations is added to the model.

As a result of comparing the three methods with the same axial forces applied to the ends of the columns, it can be seen that the results of the calculations by numerical methods are similar.However, in the case of using the study with the application of an equivalent force, the bending moment in the connection is greater due to the method of load application.

The Eurocode methodology assumes that the moments arising on both sides of a curved column are equal, which means that the moment at the connection to the plate is twice the moment in the C-section.The maximum moment arises at the point in the section where the connection begins and the entire moment is transferred to the plate without doubling.

The authors of [10] state the need to clearly introduce into the Eurocode the procedure for conducting nonlinear numerical studies of columns (for models built on the basis of beam-type elements and surface-type elements), since according to the results obtained, the procedure described in the Eurocode is most accurately suitable for calculating the bending resistance of a column to loads. Therefore, there is a need to compare the results obtained on the basis of numerical calculations and calculations using standardized methods based on experimental models of structures.

To increase the bearing capacity of columns of steel structures, it is necessary to increase the moment of inertia of their cross section, which is achieved by using prefabricated elements. This allows creating structures with maximum bearing capacity with a minimum amount of material consumed.

In the following work [12], the authors compare three types of finite element analysis in order to determine the inaccuracy of calculating the bearing capacity and stability of columns made of cold-rolled steel C-profiles, which are interconnected at the ends with two plates and a bolted joint.

Numerical studies were carried out on columns of 9 types, with different lengths L , the distance between the connection of C-profiles (braces) A and the different distance between the centers of moments of inertia of C-profiles H.

The models for the study were performed on the basis of surface four-node elements with six degrees of freedom in the node. The mesh size of the finite elements is 5 mm, the shape of the mesh is close to a square. The connection of the plates with C-profiles was carried out by connecting the contact surfaces of C-profiles and the brace plates (one profile node is connected to one node of the brace plates).

A comparison of three types of analysis was performed (static general with load control, static general with displacement control and static RIKS (arc length method).

All three methods showed good agreement in the results of the obtained values of normal forces applied to the end of the columns and deformations in the axial direction, as well as in the speed of calculations. Therefore, in the future, the authors used the method of static research with load control.

The studies of the bearing capacity of columns based on the imperfection factor of the structure according to Eurocode (EC3), as well as for imperfection factors for two other cases (bending between the column straps, as well as with the simultaneous formation of bends both along the total length and the formation of bends between the straps along the length of the column) based on shell (surface) elements do not allow obtaining results that would correspond to the results of experimental strength tests (the calculated bearing capacity of the column could be both higher and lower than the values obtained as a result of the experiments).

The main problem is identified as the inaccuracy of the model, which arises due to the lack of rigidity in the connection of the nodes of the shells (surfaces) of the plates and profiles. It is worth noting that in the studies [10,12] an assumption was made about an absolutely rigid connection (fixed) of the strapping plates together with the C-profiles, despite the fact that they are connected by a pre-stressed bolted joint. That is, there are no mutual movements in the bolt-hole pair, which leads to the complete transfer of bending moments from the C-profiles to the strapping plates. Such an assumption does not allow for accurate modeling of structures, which ultimately leads to errors in their design and subsequent problems during operation.

**Research objective**

The joint of load-bearing beam structures formed using metal profiles of various shapes is usually carried out using special joint nodes that allow the rotation of the beams and at the same time do not transmit bending moments from one beam to another. A node has been developed that consists of a corner of a special design, which is fixed to the walls of the profiles using a bolted connection with uncontrolled tension. The possibility of mutual rotation of the beams and the absence of transmission of bending moments is realized using the flexibility (bending plasticity) of the connecting corner. The purpose of the study is to verify the correctness of the schemes and approaches that are used in the design of the node by conducting numerical modeling and calculation of the structure using the finite element method, for the further use of such schemes and approaches in the creation of modern projects.

**Description of the design of the T-shaped joint**

When creating structures from different types of profiles (T, C and others), the most critical places are the joint where one profile is connected to another [15]. The best joints of two profiles are the use of nodes that allow rotation and do not transmit bending moments from one profile to the wall of the other, namely conditionally hinged [13]. In this case, such nodes should have maximum flexibility in both vertical planes.

The design of the joint to be calculated is shown in Figure 1.

Fig. 1. View of the node of the T-shaped joint of the joint of cold-rolled profiles using a corner and a bolted connection with uncontrolled tension

The node includes two C-shaped single profiles of open section cold forming from pre-galvanized strip steel (S390GD-Z275MA) with a wall thickness of 4 mm. The yield strength of the steel from which the profiles are made is 390 N/mm$^2$. The angles of bending of the steel into the profile and the radii of the roundings are made in accordance with Eurocode 3 [7]. The transverse profile is C+450x4, and the longitudinal profile is C+350x4 [16]. The cross-section diagram of the profiles is shown in Figure 2, and the dimensions are in Table 1.

The profiles are connected to each other using an L-shaped plate (corner) with holes and a bolted connection with uncontrolled tension. The corner is made of pre-galvanized steel sheet (S350GD+Z275) with a thickness of 3 mm. The yield strength of the steel from which the angles are made is 350 N/mm$^2$. To connect the profile to the corner, M12 bolts of strength class 8.8 and M12 nuts of strength class 8 were used. The hole in the profiles and corner has a diameter of 13 mm, as a result of which a gap is formed between the cylindrical surfaces of the bolt and the hole. The gap is necessary to compensate for the inaccuracy of drilling the holes. The nuts and bolts are tightened with an initial torque that is not regulated for this design, however, the presence of an initial torque leads to the fact that this connection has an initial rotational stiffness[2], which is why it cannot be considered as conventional hinge.

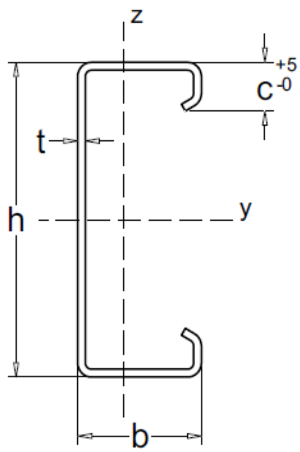


Fig. 2. Cross-section scheme of the profiles of the supporting beams

The way to overcome this challenge is to use such a design of the connecting corner that would give the connection sufficient compliance (rotational plasticity) to eliminate the possibility of transmitting bending moments to the wall of the supporting profile. In this case, the strength and plasticity of the connecting plate must be sufficient to withstand the working loads in the node and at the same time allow the occurrence of inelastic deformations in it that are able to compensate for the rotation of the beam end.

Table 1

Dimensions and parameters of the cross-section of the profiles used in the design

| Profile number | *h*, mm | *b*, mm | c, mm | *t*, mm | *G*, kg/m | *A*, cm$^2$ | $I_y$, cm$^4$ | $W_y$, cm$^3$ | $I_z$, cm$^4$ | $W_z$, cm$^3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| C+450x4 | 450 | 120 | 35 | 4 | 23.52 | 29.66 | 8604 | 385.8 | 550.7 | 63.95 |
| C+350x4 | 350 | 100 | 30 | 4 | 18.77 | 23.67 | 4181 | 241.7 | 309.1 | 44.12 |

**Calculation diagrams of the design of the T-shaped joint**

Figure 3 shows the support reaction R, which arises in the node from the application of loads to the longitudinal profile. Local bending moments M1 and M2, arising in the node of the connection of two profiles, respectively, in the longitudinal and transverse vertical planes under the action of the support reaction and eccentricities (force arm) e1 and $e_2$, respectively.

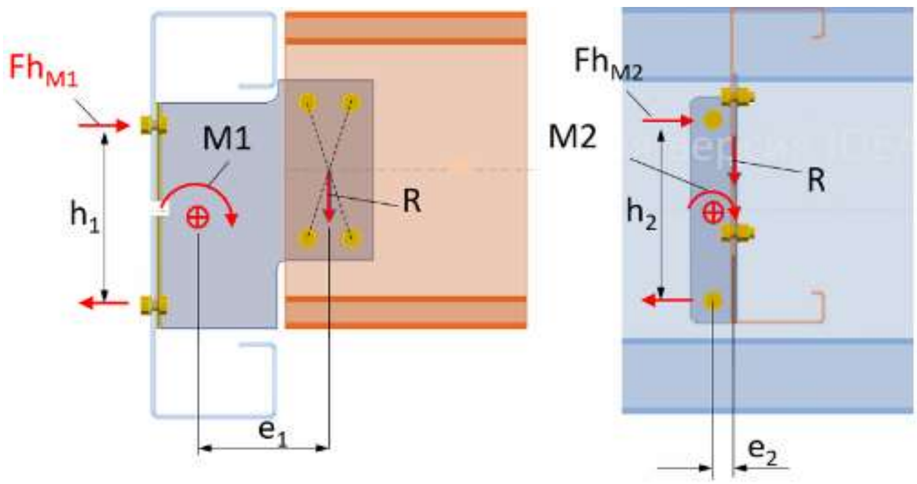


Fig. 3. Design scheme of the joint of two C-shaped profiles and local bending moments in their design

Bending moments in such joints are relatively small compared to the forces acting on the shear, so these moments are often neglected [2].

However, for the design of a plate structure that will compensate for the rotation of the profiles within the limits of inelastic deformations, taking into account these moments is important, since on the one hand it is necessary to ensure sufficient rotational plasticity, and on the other hand, sufficient bearing capacity for shear forces. If sufficient plasticity cannot be achieved, this can also lead to premature failure of the node. Therefore, it is important that connections affected by shear forces are designed taking into account the requirements for both strength and plasticity [14].

Such a node is used as part of the internal structures of a warehouse complex and serves to accommodate equipment for storing raw materials and materials, moving personnel, and moving lifting and transport equipment. The general model of the premise is shown in Figure 4.

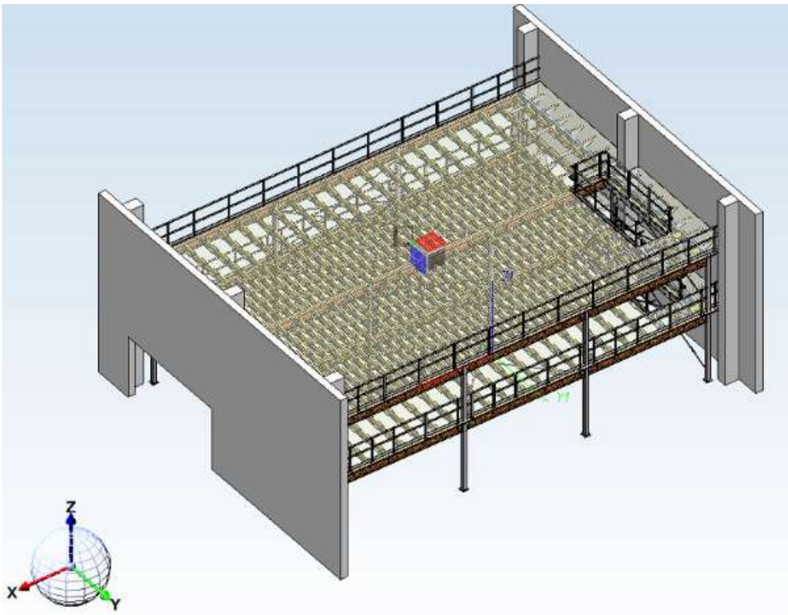



Fig. 4. General view of the structures arranged in the premises

Figure 5 shows the beam-bearing structure of one of the warehouse levels. The node to be calculated is located at the junction of the longitudinal beam and the transverse profile of this structure.

Fig. 5. General view of the beam supporting structure of one of the warehouse levels

**Numerical modeling of the behavior of a T-shaped joint under operating loads**

To simulate the behavior of the T-shaped node, an model was developed (Fig. 6). The analog model is a version of a part of the original structure turned 180° relative to the longitudinal axis. It consists of two transverse load-bearing C-shaped profiles 1, which are rigidly attached to support posts 2 with plates using a bolted connection with uncontrolled tension. Support posts 2 act as vertical columns of the structure. Longitudinal C-shaped profiles 3 are placed between the transverse load-bearing profiles 1, which are fixed using a connecting corner of a special design and a bolted connection.

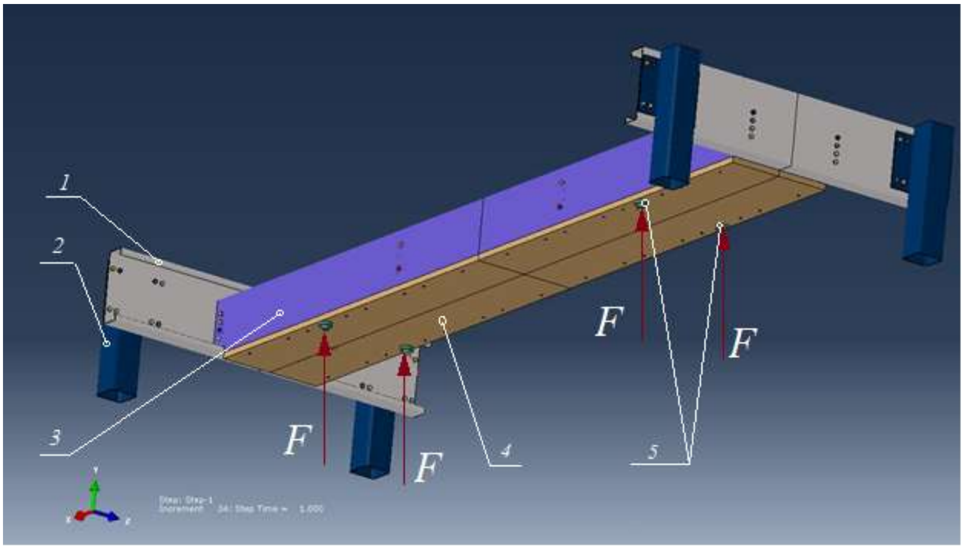



Fig. 6. Model of the structure to be studied and the points of application of forces $F$

Bolt connections, as in the case of the developed structure, are made with a gap between the cylindrical surfaces of the bolt and the hole. The nut with the bolt is pre-tightened with an initial moment. The design of the corner, which is made of sheet steel, has a compliance (rotational plasticity) sufficient to eliminate the possibility of transmitting bending moments to the wall of the supporting profile, due to the occurrence of inelastic deformations in it, which are able to compensate for the rotation of the end of the beam.

Four sheets 4 of chipboard are attached to the longitudinal profiles, which in this case are only a visualization of the surface along which personnel move. To simplify the model, the uniformly distributed load q, which would be appropriate to model the placement of equipment for transporting and storing products on the span surface, is reduced to a concentrated force F, which is applied at four points, namely two points on each of the span beams. The protruding elements 5 in the amount of four units act as points of application of the load F.

It is assumed that the structure must withstand a uniformly distributed load equivalent to the concentrated force applied at each of the four points $F_{\text{work}}$=38000 N. To detail the behavior of the node, the load F is variable in magnitude during the simulation time from 0 to the maximum value that the node can withstand before failure, namely 80000 N.

Figure 7 shows a side view of the model.

When calculating the model, a contact problem was also solved. The corner and C-profiles are connected to each other not using rigid clamping, as is customary to perform modeling of such structures, but as structures that are connected by contact of the finite element nodes of the cylindrical surface of the hole and the bolt. This allows you to model the mutual movement of the finite element nodes of the bolt and the hole relative to each other for a more accurate account of the behavior of the node. As a result, it is possible to determine local stresses and deformations in the profiles along their length, as well as determine local stresses and equivalent plastic deformations that arise at the points of contact, namely at the point of tightening the corner and the wall of the profile using a bolted connection.

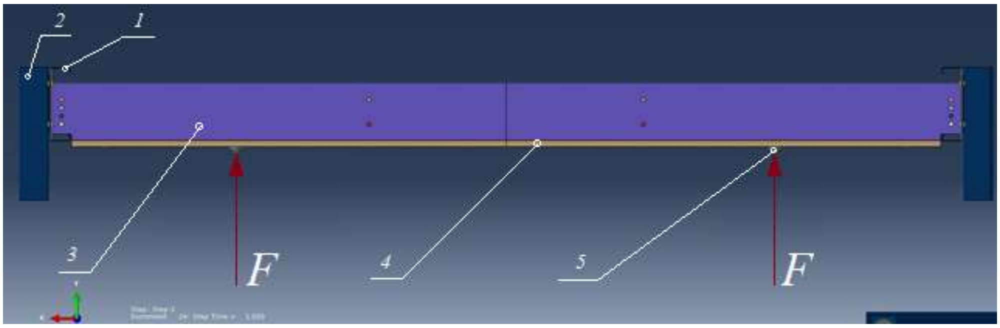



Fig. 7. Side view of the model of the structure to be studied and the points of application of forces F

Further, in the work, the adequacy of the flexibility of the joint to compensate for the rotation of the beam and, on the other hand, to prevent its premature destruction due to loads, is checked.

Figures 8-12 show the results of the study. Figure 8 shows the values of the stresses in the longitudinal beam according to Mises, and Figure 9 shows the equivalent plastic deformation, which shows the relative deformation of the structure within the inelastic section of the strength curve.

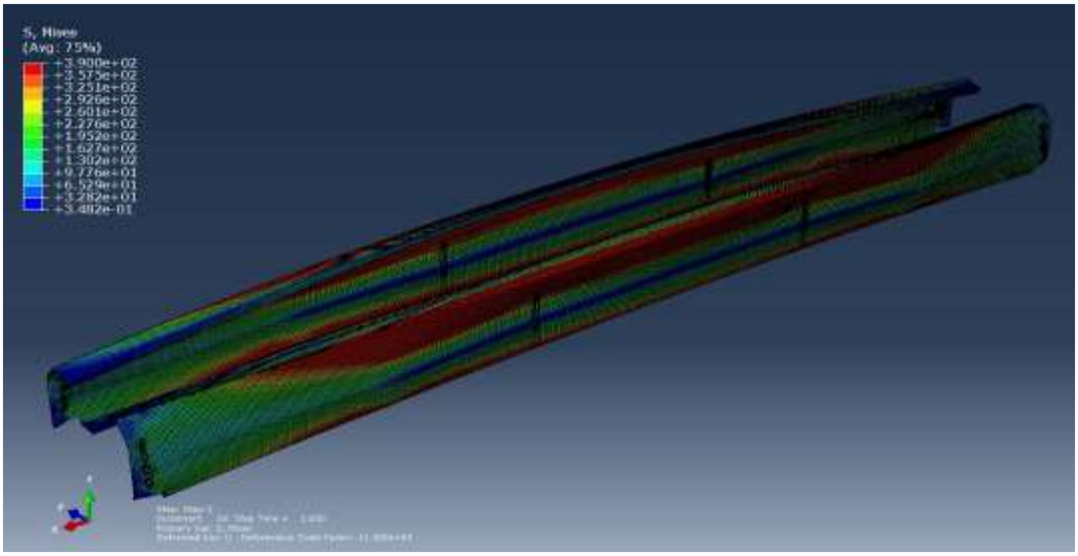



Fig. 8. Obtained values of stresses in the span of the longitudinal beam under load

According to Figure 8, the highest values of stresses in the span are recorded in the upper and lower shelves of the C-profiles and in the corresponding adjacent sections of the vertical wall in the central part of the span of the longitudinal beam, namely 390 N/mm$^2$, which does not exceed the values of the yield strength of the profile steel. When approaching the ends of the beam, where the designed conditional hinge node is located, the stress decreases and approaches the minimum value – 32 N/mm$^2$. This demonstrates that the design of the node performs the task of not transmitting bending moments.

According to Figure 9, the distribution of equivalent plastic strains corresponds to the zones with the highest Mises stress, i.e. in the central part of the span. The highest value of equivalent plastic strains is up to 3.51%.

Figure 10 provides a more detailed overview of the stress values (a) in the C-profile structure near the holes, namely at the contact points that connect the longitudinal beam with the corner using a bolted connection and the corresponding equivalent plastic strains (b).

The magnitude of the stresses in the cylindrical surface of the holes has the greatest value in the lower zone and is in the range from 357 to 390 N/mm$^2$, which does not exceed the yield strength of the material. In other zones of the holes, the stress value varies from 162 to 292 N/mm$^2$. The equivalent deformation in the zones with the greatest stress value is from 1 to 3.5%.

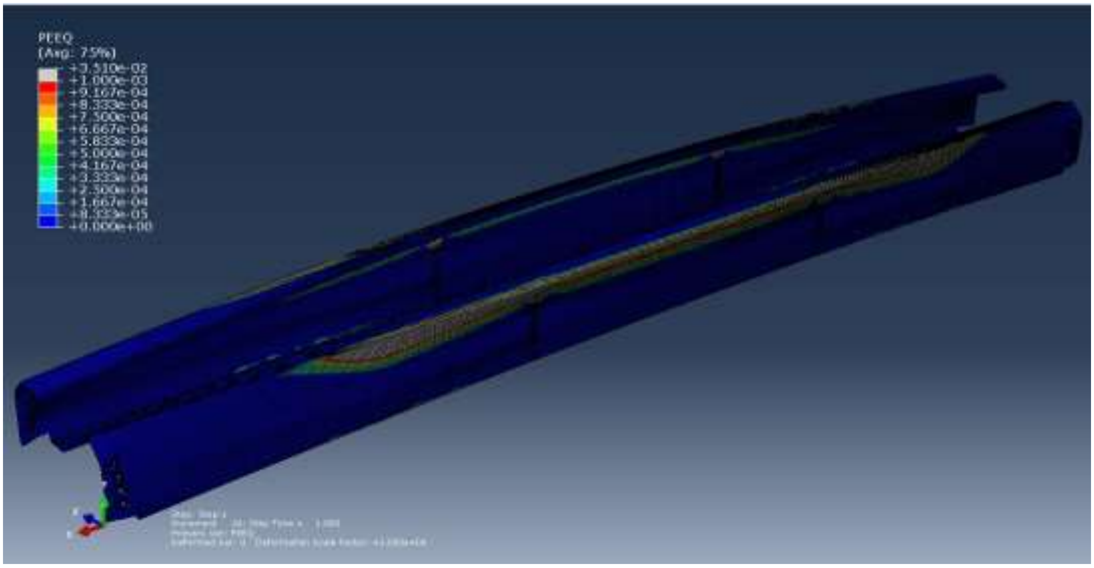
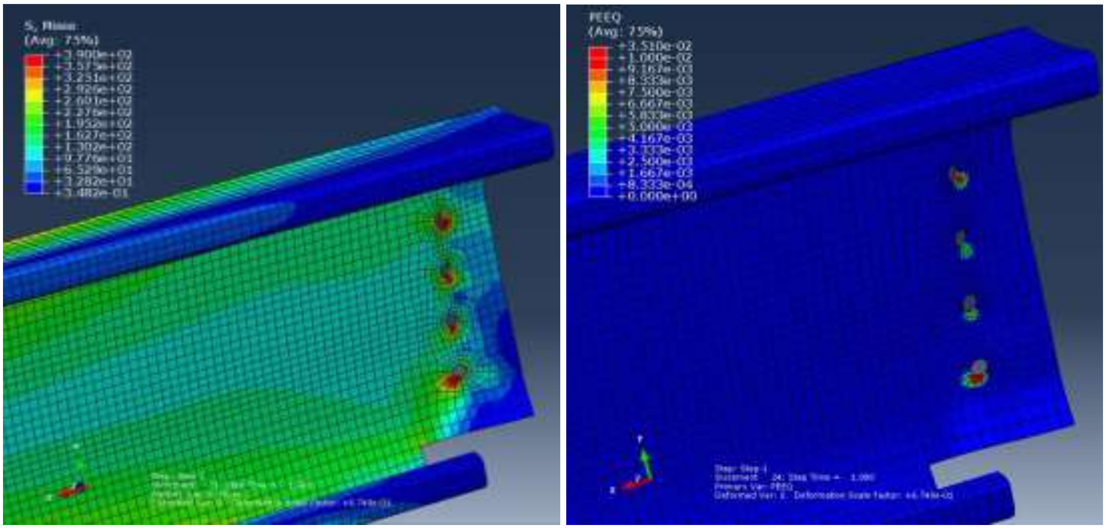



Fig. 9. Obtained values of equivalent plastic strains in the span of the longitudinal beam under load

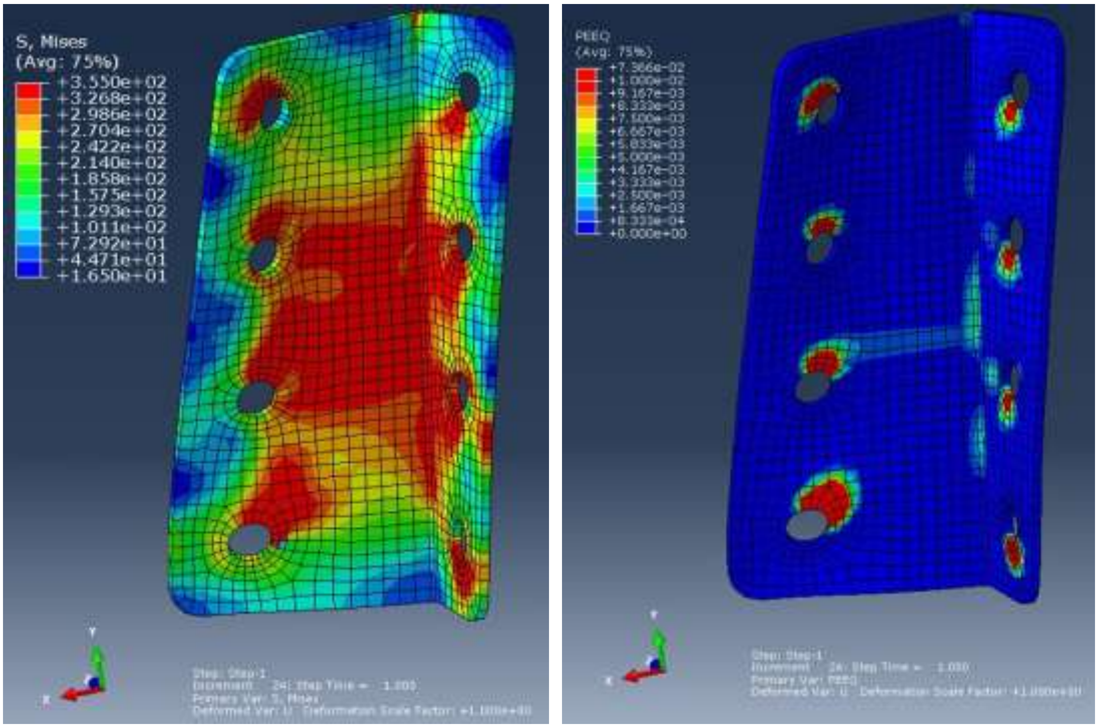



(a) (b)

Fig. 10. Obtained stress values at the connection node of the longitudinal beam with the corner (a) and equivalent plastic deformation (b)

The distribution of stresses in the structure of the corner, which is included in the connection node, is presented in Figure 11,a. The largest recorded values of the Mises stresses are from 326 to 355 N/mm$^2$, therefore, in some sections of the corner structure, stresses arise that exceed the yield strength for this material. The most stressed zones are the cylindrical bolt holes, namely the upper zone of the holes connecting with the corresponding part of the longitudinal beam and the lower zone of the holes connecting with the corresponding part of the transverse beam.

The largest values of the equivalent plastic deformations (Fig. 11,b) in such zones have values from 1 to 7.3%. The structure thus operates within the limits of plastic deformations and plays the role of a conventional hinge node. Destruction does not occur.




(a) (b)

Fig. 11. Obtained stress values in the corner structure (a) and equivalent plastic deformation (b)

It is worth noting that at values of equivalent plastic deformation that do not exceed 5%, the structure operates mainly in the elastic deformation zone. It is this value of equivalent plastic deformation that the vast majority of engineers take as the limiting values for checking joints. This is due to the fact that the stresses in the structures of the connection elements do not exceed the yield strength of the material, which allows to ensure the reliability of the connection on the one hand, but on the other hand, this can often lead to excessive material consumption. In practice, exceeding the limiting value of equivalent plastic deformation during modeling does not mean the destruction of the connection elements. Within these limits, plastic deformation of the structural elements continues to occur [17].

Figure 12 below shows a graph of the dependence of displacements on the magnitude of the force applied to the structure.

On the abscissa axis, the value of the time interval 1.00 corresponds to the load F=80000 N. Elastic deformations before reaching the proportionality limit occur up to and including the 6th increment, which corresponds to the load of 52800 N. After that, the corner structure operates within the limits of plastic deformations.

According to the above results, it can be assumed that the longitudinal and transverse profiles of the structure can withstand the load F, at each of the application points, greater than that determined by the study (80000 N). However, as can be seen from Figure 8, even with the current load, the profiles twist, which can affect their bearing capacity due to loss of stability. To confirm or refute this assumption, it is necessary to further check the structural elements for loss of stability, which was not performed in this work. The design of the corner is also subject to detailed verification, as even under the loads determined by the study, it operates within the limits of plastic deformations and is an element in which stresses and equivalent plastic deformations greater than the maximum permissible occur.

**Conclusions**

Based on the work performed, the following results were obtained:

- the design of a conditional hinged joint of the T-shaped connection of the longitudinal and transverse C-profiles was developed using a bolted connection with uncontrolled tension and a corner of a special design;

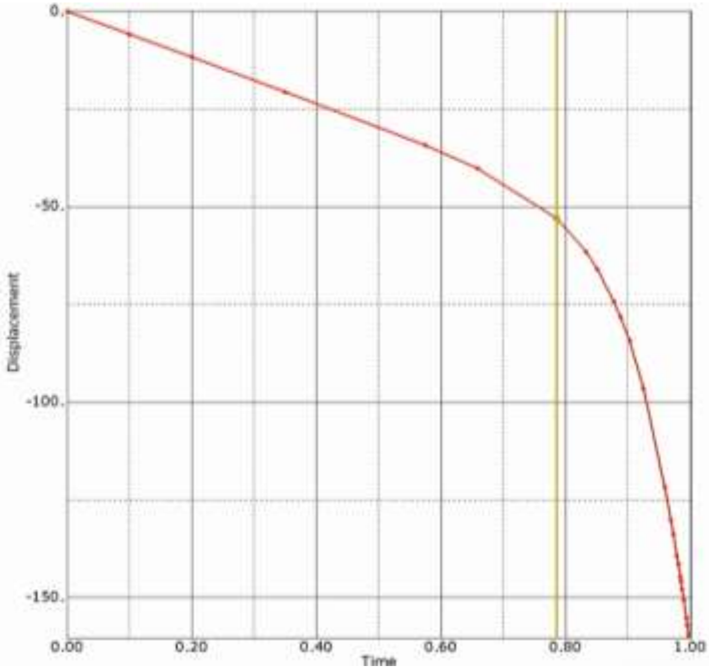



Fig. 12. Graph of the dependence of the displacements of the structure on the magnitude of the load

- the design of the developed corner does not transmit bending moments from the wall of the longitudinal to the wall of the transverse corner. This is achieved due to the operation of the corner design within the limits of plastic deformations;
- as a result of the finite element analysis of the joint, it was confirmed that under working loads in all elements of the joint, except for the corner, the stresses do not exceed the yield strength of the materials from which they are made;
- the highest values of Mises stresses are recorded in the center of the span of the longitudinal beam and in the zones of cylindrical sections of the holes (from 357 to 390 N/mm2), which is on the border of the yield point of the S390GD-Z275MA steel, from which the longitudinal beam is made. The equivalent deformation in the zones with the highest stress values is from 1 to 3.5%. The beam has some flexibility, but irreversible destruction does not occur;
- the stresses in the connecting corner have values from 326 to 355 N/mm2, so some zones of the structure work beyond the yield point for S350GD+Z275 steel. The highest values of equivalent plastic deformations in such zones have values from 1 to 7.3%. The structure thus works in the zone of plastic deformations and plays the role of a conventional hinge joint;
- the design of the profiles allows for a greater load than determined by the study, however, to verify these assumptions, it is necessary to conduct additional studies to check the structural elements for loss of stability.

Such studies allow us to obtain detailed information about the magnitude of stresses in all structural elements and predict their behavior in real operating conditions, which ultimately provides the opportunity to develop modern structures with low metal consumption that are capable of operating throughout their entire service life without premature failure.

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**ДОСЛІДЖЕННЯ КОНСТРУКЦІЇ Т-ПОДІБНОГО ВУЗЛА ХОЛОДНО-КАТАНИХ ПРОФІЛІВ, З'ЄДНАННЯ ЯКИХ ВИКОНАНО ПЛАСТИНОЮ З ВИКОРИСТАННЯМ БОЛТОВОГО З'ЄДНАННЯ**

Складські комплекси і приміщення, що використовуються для розміщення устаткування для зберігання, переміщення вантажопідйомного обладнання і персоналу вимагають створення сучаснихнесучих конструкцій мезонінів та платформ. Такі конструкції мають одночасно відповідати вимогам низької металоємності, достатньої міцності, стійкості і витримувати велику кількість циклів прикладення і зняття навантажень. Вузли з'єднання балок подібних конструкцій проектують шарнірними. Вони дозволяють обертання балок і при цьому не передають згинальних моментіввід одного елемента на стінку іншого. У праці запропоновано конструкцію вузла, який складається з кутика спеціальної конструкції, що жорстко закріплений на стінках профілів з допомогою болтового з'єднання. Особливістю вузла є те, що він є умовно-шарнірним і забезпечує відсутність передачі згинальних моментів між елементами вузла. Це досягається за рахунок конструкції кутика, який маєподатливість (обертальну пластичність) необхідну і достатню для компенсації повороту кінців з'єднаних балок за рахунок його роботи в межах пластичних деформацій. З іншого боку міцність цього кутика повинна бути такою аби передача навантажень між елементами конструкції відбувалася без його руйнування. Виконано чисельне моделювання конструкції умовно-шарнірного вузла, отримані значення напруженьу елементах, що входять у вузол. Підтверджено, що при робочих навантаженнях в усіх елементах вузла, окрім кутика, напруження не перевищують границі текучості матеріалів з яких вони виконані,еквівалентні пластичні деформації не перевищують граничних значень(5%). Конструкція кутика працює у межах пластичних деформацій і виконує роль умовно-шарнірного вузла.У окремих зонах конструкції кутика при робочих навантаження виникають напруження, які перевищують границю текучості матеріалу, з якого він виконаний. Руйнування вузла при цьому не відбувається. Подібні дослідження дозволяють отримати детальну інформацію про величину напружень в усіх елементах конструкцій і передбачити їх поведінку в реальних умовах експлуатації, що у результаті надаєможливості розробки сучасних конструкцій з низькою металоємністю, що здатні працювати впродовж всього терміну експлуатації без передчасного їх виходу з ладу.

**Ключові слова:** метод скінченних елементів, верифікація, конструкція обладнання, схеми-підходи-чисельне моделювання і розрахунок, умовно-шарнірний вузол, з'єднання.

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**RESEARCH OF THE DESIGN OF A T-SHAPED NODE OF COLD-ROLLED PROFILES, THE CONNECTION OF WHICH IS MADE BY A PLATE USING A BOLT CONNECTION**

Warehouse complexes and premises used to accommodate storage equipment, move lifting equipment and personnel require the creation of modern load-bearing structures of mezzanines and platforms. Such structures must simultaneously meet the requirements of low metal consumption, sufficient strength, stability and withstand a large number of cycles of application and removal of loads. The nodes that connect the beams of such structures are designed as hinged. They allow the rotation of the beams and do not transmit bending moments from one element to the wall of another. The work proposes the design of a connection node(joint) that consists of a corner of a special design that is rigidly fixed to the walls of the profiles using a bolted connection. The peculiarity of the node is that it is conditionally hinged and ensures the absence of transmission of bending moments between the elements of the node. This is achieved due to the design of the corner, which has the necessary and sufficient flexibility (rotational plasticity)to compensate for the rotation of the ends of the connected beams due to its operation within the limits of plastic deformations at the plasticity limit of the material. On the other hand, the strength of this corner should be such that the transfer of loads between the structural elements occurs without its destruction. Numerical modeling of the design of the conditional hinged node was performed and the values of stresses in the elements included in the node were obtained. It has been confirmed that under working loads in all elements of the joint, except for the corner, the stresses do not exceed the plastic strain limit of the materials from which they are made, equivalent plastic deformations do not exceed the limit values (5%). The corner structure operates within the limits of plastic deformations and plays the role of a conventional hinge assembly. In certain zones of the corner structure, under working loads, stresses arise that exceed the limits of plastic strain limit of the material from which it is made. The destruction of the assembly does not occur. Such studies allow us to obtain detailed information about the magnitude of the stresses in all elements of the structures and to predict their behavior in real operating conditions, which ultimately provides the opportunity to develop modern structures with low metal consumption that are capable of operating throughout the entire service life without premature failure.

**Keywords:** finite element method, verification, equipment design, schemes-approaches-numerical modeling and calculation, conventional hinge joint, connection.

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*Вабіщевич М.О., Дєдов О.П., Дьяченко О.С., Литвин О.В.* **Дослідження конструкції Т-подібного вузла холодно-катаних профілів, з'єднання яких виконано пластиною з використанням болтового з'єднання** // Опір матеріалів і теорія споруд: наук.тех. збірн. – К.: КНУБА. 2025 – Вип. 114. – С. 62-75.
*У статті запропоновано конструкцію умовно-шарнірного вузла, що забезпечує відсутність передачі згинальних моментів між елементами вузла. Конструкція кутика працює в межах пластичних деформацій. Виконано чисельне моделювання конструкції вузла, отримані значення напружень у його елементах. Підтверджено, що при робочих навантаженнях в усіх елементах вузла, окрім кутика, напруження не перевищують границі текучості матеріалів, з яких вони виконані, еквівалентні пластичні деформації не перевищують граничних значень (5%). Кутик працює в зоні пластичних деформацій і виконує роль умовно-шарнірного вузла без його руйнування.*
Табл. 1. Іл. 12. Бібліогр. 17 назв.

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*Vabishchevych M.O., Dedov O.P., Diachenko O.S., Lytvyn O.V.* **Research of the design of a T-shaped node of cold-rolled profiles, theconnection of which is made by a plate using a bolt connection** // Strength of Materials and Theory of Structures: Scientific and technical collected articles – K.: KNUBA, 2025. – Issue 114. – P. 62-75.
*The article proposes a design of a conditional hinge joint that ensures the absence of bending moment transmission between the elements of the joint. The design of the corner works within the limits of plastic deformations. Numerical modeling of the design of the conditional hinge joint was performed, and the values of stresses in its elements were obtained. It has been confirmed that under working loads in all elements of the assembly, except for the corner, the stresses do not exceed the plastic strain limit of the materials from which they are made, equivalent plastic deformations do not exceed the limit values (5%). The corner works in the zone of plastic deformations and performs the role of a conditional hinge assembly without its destruction.*
Tabl. 1. Fig. 12. Refs. 17.

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