ANALYSIS AND COMPARISON OF A JOINT CONNECTING MEMBERS IN A ROOF TRUSS

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K e y   w o r d s: truss, membrane forces, node, gusset plate.

A b s t r a c t

A truss as a planar structure consisting of joined members is dimensioned on certain assumptions which simplify the computational procedure. This paper presents an analysis of a randomly chosen node in a truss. Two cases have been considered. The first one concerned a node in a double-trapeze truss, where gusset plate was used. In the second case, the analyzed truss node consisted of a vertical member and a cross brace connected directly to the bottom chord. Our analysis has demonstrated that, as the references and the design experiments suggest, joining truss members directly does not cause any increase in the membrane forces or stresses.

ANALIZA I PORÓWNANIE POŁĄCZENIA PRĘTÓW W WĘŹLE WIĄZARA KRATOWEGO DACHOWEGO

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S ł o w a   k l u c z o w e: kratownica, siły membranowe, węzeł, blacha węzłowa.

A b s t r a k t

Kratownicę jako ustrój prętowy płaski wymiaruje się z pewnymi założeniami upraszczającymi procedurę obliczeniową. W pracy przedstawiono analizę losowo wybranego węzła kratownicy. Rozpatrzono dwa przypadki. W pierwszym przeanalizowano węzeł kratownicy dwutrapezowej, w którym zastosowano blachę węzłową. W drugim przeanalizowano węzeł kratownicy, w którym słupek i krzyżulec był połączony bezpośrednio do pasa dolnego. Analiza dowiodła, że zgodnie z zaleceniami w literaturze oraz doświadczeniami projektowymi bezpośrednie łączenie prętów nie powoduje wzrostu sił membranowych oraz naprężeń.

Introduction

A truss is a structure consisting of members connected at joints called nodes, which has a geometrically constant shape. It is among the most often designed and made constructions to support steel roofs of industrial buildings. A truss owes its popularity to a relatively light weight of the construction of truss supports, which means highly competitive costs of such roofs. Engineers are keen on designing trusses because of the ease of calculating the internal forces. A wide variety of trusses has found many uses in civil engineering.

Calculating dimensions of trusses

Calculating dimensions of trusses, according to BOGUCKI (1976) and ŻÓŁTOWSKI et al. (2000), is done based on the following assumptions:

1. Members are connected in nodes as hinged joints although in reality these joints are rigid or nearly rigid. For the sake of making the calculations simpler, the effect of stiffness is usually omitted – bending moments in nodes are absent and only axial forces appear in the members.

2. All members are rigid.

3. Axes of the members, passing through the members' centre of gravity, coincide with the geometrical outline of the truss – the node's balance. However, when the axes of the joined members are shifted by no more than 3% of the member's height, the shift need not be included in the calculations (Fig. 1).
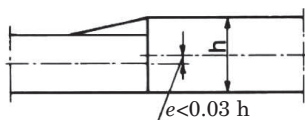

Fig. 1. Negligible shift of axes of truss members
Source: own work based on ŻÓŁTOWSKI et al. (2000).

4. There are no eccentricities or additional bending moments in a node – that is the members are joined concentrically in a node, i.e. axes of gravity intersect in one point.

When this condition is not met while designing a truss, an additional moment of the value $M = N \cdot e$ will appear in the node (Fig. 2). In accordance with the principles of statics, this moment divides itself between all the members meeting in a given node in proportion to their stiffness.
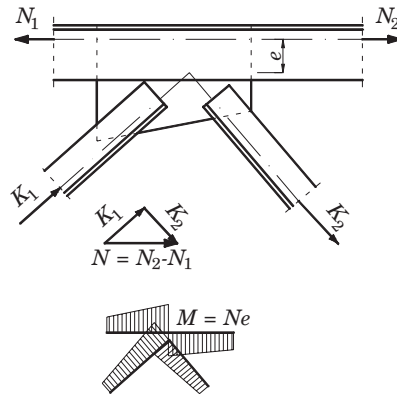
Fig. 2. Including additional moments in a truss node
Source: own work based on ŻÓŁTOWSKI et al. (2000).

5. All members of a truss should lie in one plane and their cross-section is symmetrical relative to the truss's plane. When this condition is not fulfilled, an additional moment from the bending depending on:

$$\sigma = \frac{N}{A} + \frac{N \cdot e^2}{I},$$

N – the force acting in the ith member of the truss [N],
A – the ith member's cross-section area [mm^2],
e – eccentricity [mm],
I – moment of intertia [mm^4],
should be included in the calculations (Fig. 3a, b).

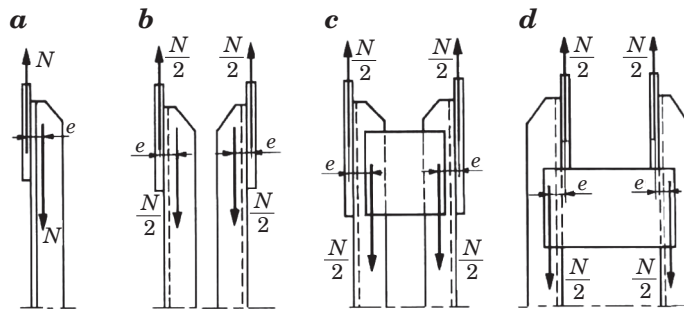Additional stresses can be omitted when batten plates are placed between gusset plates (Fig. 3c, d).

Fig. 3. Connection of members with gusset plates
Source: own work based on ŻÓŁTOWSKI et al. (2000).

6. Members in joints should be placed symmetrically relative to each member's axis, as this will enable us to avoid additional bending moments in a node.

7. The most important assumption is that external load on a truss is applied to the nodes – this means that only axial forces will appear. If some external load is applied to a member (outside the nodes), bending moments (their approximations) should be included in the calculations and members should be dimensioned as compressed or tensed eccentrically.

When analyzing the above assumptions, and especially the ones concerning hinged joints of truss members, it can be concluded that this is a gross oversimplification, which seems all the more unjustified because construction engineers often use gusset plates in truss member joints. An essential condition for determination of exclusively axial forces in truss members is that all the members are rectilinear, which is not always the case (production flaws, deformation during transport). Additional reasons why node moments should not be omitted is the non-axial connections of members in nodes (Fig. 2). The fact that joints are non-axial causes the appearance of residual moments, which should also be included in the calculations. The non-axiality of truss members often originates from technological or design-related considerations, such as the intention of designing nodes that will be easiest to make. BIEGUS (2003) claims that joints without gusset plates are technologically the easiest type of connection (Fig. 4).
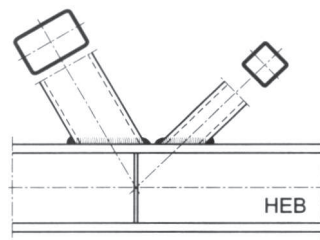

Fig. 4. A truss node without a gusset plate
Source: own work based on ŻÓŁTOWSKI et al. (2000).

The bending moment $M = N \cdot e$ (Fig. 1) which appears in a node with non-axially connected members divides itself among all the members proportionally to their stiffness (BOGUCKI 1976, ŻÓŁTOWSKI et al. 2000).

Planar trusses can be designed as:
– externally statically determinate -simple-supported trusses,
– statically indeterminate trusses – continuous trusses, frames.

The assumption that truss members are connected axially in a node is made because of the ease of calculating internal forces in the members. This ease is due to the assumed internal static determinancy of the truss's structure. It is then possible to apply well-known, classic methods for calculation of internal forces (Ritter method, nodes equilibrium method, Culmann method, and others) (JASTRZĘBSKI et al. 1974). In reality, the structure of a truss is a multiply statically indeterminate construction and assuming its internal static determinancy is far-reaching approximation, which disagrees with the actual work of a designed construction.

Truss members are connected in a node, which can be fitted with a gusset plate or not. Nodes are designed according to an analytical and geometrical method. Both members connected in a node and gusset plates should fulfill several conditions. Both ŻÓŁTOWSKI (2000) and BIEGUS (2003) suggest that vertical members as well as cross braces should be connected directly to the chords and using gusset plates should be avoided.

In the light of the above suggestions and considerations as well as the results of some experimental designs, the usability of gusset plates in trusses has been analyzed.

A computer model

This paper compares values of external forces in a double-trapeze truss in which all the nodes are rigid. It has been assumed that truss chords are stiff and rigidly connected with cross braces and vertical members. Our analysis involved one, randomly selected node, in which non-zero cross brace and vertical member are connected with the bottom chord.
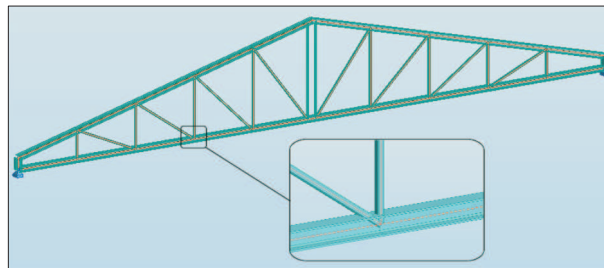

Fig. 5. The analyzed model of a truss with a selected node
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

The cross brace and vertical member are connected directly to the chord by welding (case I) or via a gusset plate (case II). In order to determine the values

of membrane forces in the members connected in the analyzed node, the latter was isolated by the so-called "rigid connection". At the same time, in the isolated node, walls of members were replaced by panels, treated as coating, of the thickness equal the thickness of the walls of members connected in the analyzed node. Creating the panels was possible by introducing additional nodes (slave nodes) connected to the main node (master node). Thus, it is possible to analyze maps of any internal forces in the node.
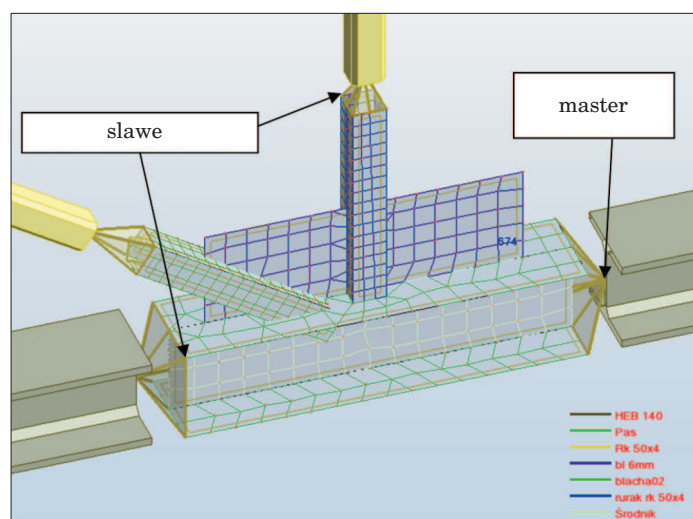

Fig. 6. A computer model of a node – the way of isolating nodes
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

In one case, a panel simulating a gusset plate was introduced to the node (Fig. 7a); in the other case, the members reaching the node were connected to the chord directly (Fig. 7b).
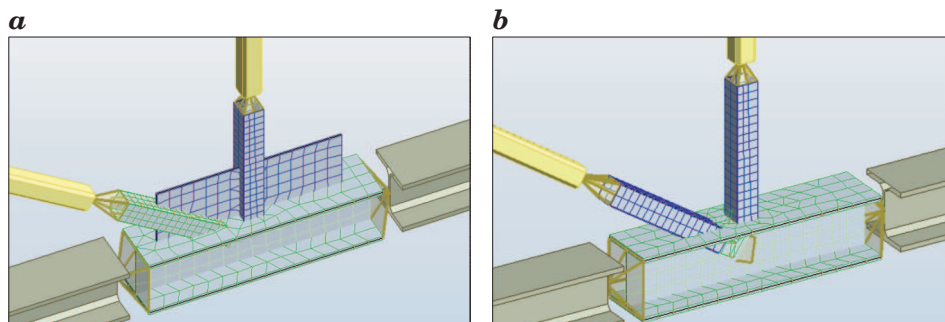

Fig. 7. A computer model of the analyzed node: *a* – with a gusset plate, *b* – without a gusset plate
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

In both cases, the truss was subjected to a force applied uniformly to the top chord of the truss. This way of loading a truss can simulate loading a purlinless roofing construction. The value of the load was identical in both analyzed cases (with and without a gusset plate) and equalled q=10kN/ Both models were submitted to an analysis according to the Finite Elements Method. The gusset plate is marked as element 247 in our analysis.

Analysis of the results

Figure 8 shows maps of membrane forces x-x in the analyzed node with a gusset plate whereas Figure 9 illustrates maps of membrane forces x-x in the analyzed node without a gusset plate.

Fig. 8. A map of membrane forces x-x in the analyzed truss node with a gusset plate
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

Maps of shear stresses in the analyzed node with a gusset plate are presented in Figure 10, while Figure 11 shows maps of shear stress in the node without a gusset plate.

In these figures, the blue colour indicates values of stresses in tangents in the planes of connections between the panels.
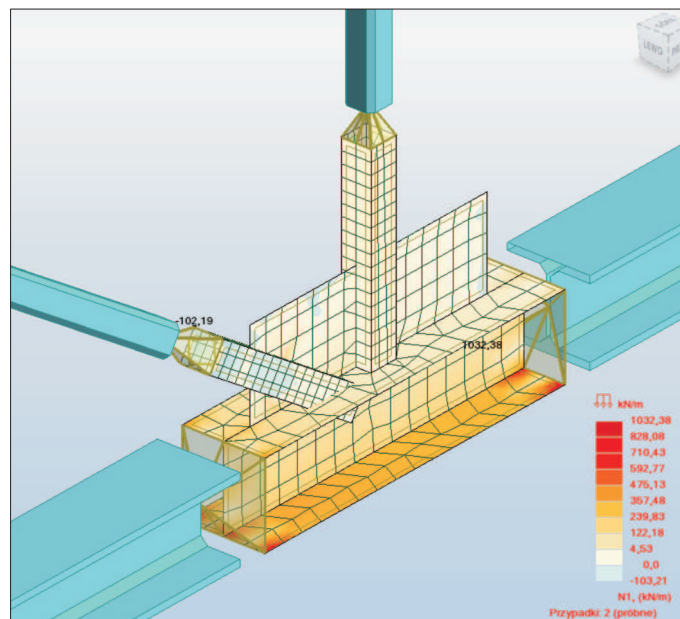
Fig. 9. A map of membrane forces x-x in the analyzed truss node without a gusset plate
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

Fig. 10. A map of tangent stresses in the analyzed truss node with a gusset plate
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.
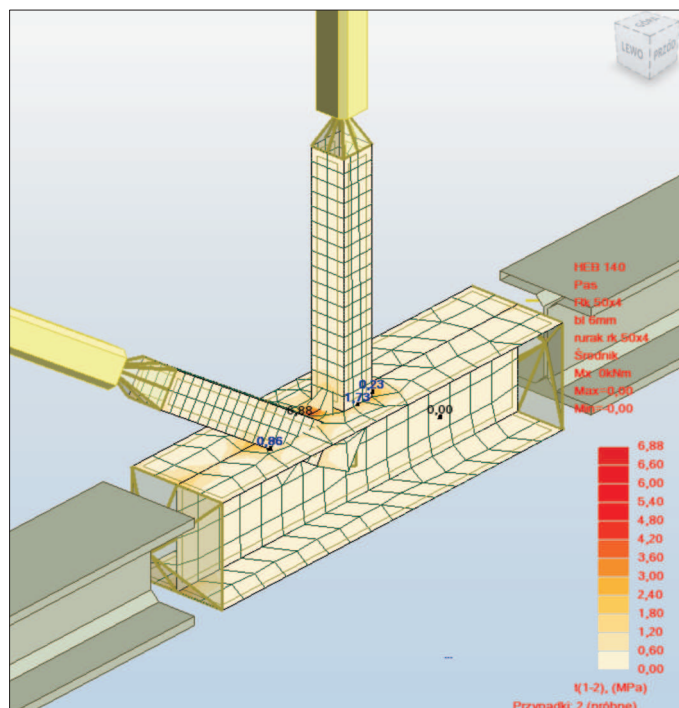
Fig. 11. A map of tangent stresses in the analyzed truss node without a gusset plate
Source: Autodesk Robot Structural Analysis Professional 2011, licence no 3251.

Values of the extreme external forces alongside the number of the element in which they appear are given in Tables 1 and 2.

Table 1

Values of the extreme stresses, membrane forces and shear forces in a node with a gusset plate

	σ_{xx} [MPa]	σ_{yy} [MPa]	σ_{xy} [MPa]	N_{xx} [kN/m]	N_{yy} [kN/m]	N_{xy} [kN/m]	τ_{xx} [MPa]	τ_{xy} [MPa]
Max	75.14	27.38	30.52	901.70	286.89	366.28	3.40	2.42
Panel	235	236	235	235	235	235	237	251
Node	421	309	408	421	421	408	661	146
Min.	-58.41	-21.53	-30.53	-233.65	-150.68	-366.34	-4.91	-2.26
Panel	248	236	235	248	236	235	237	251
Node	29	661	398	29	661	398	704	200

Source: the authors.

Table 3

Values of the extreme stresses, membrane forces and shear forces in a node without a gusset plate

	σ_{xx} [MPa]	σ_{yy} [MPa]	σ_{xy} [MPa]	N_{xx} [kN/m]	N_{yy} [kN/m]	N_{xy} [kN/m]	τ_{xx} [MPa]	τ_{xy} [MPa]
Max	74.73	119.95	103.21	896.77	286.68	365.14	1.41	1.07
Panel	235	251	250	235	235	235	249	238
Node	421	578	466	421	421	408	150	461
Min.	-262.12	-264.50	-109.59	-524.23	-529.00	-364.49	-3.46	-1.06
Panel	250	251	251	250	251	235	250	239
Node	463	463	463	463	463	398	76	316

Source: the authors.

Meanwhile, values of the efforts of truss members were compared for the following types of joints:

1. all the members connected in a joint are hinged.

2. the members of the inner truss structure are joined by hinges and connected with continuous truss chords (top and bottom chords)

3. all the members in nodes are connected rigidly.

The results for the both extreme conditions are contained in Table 3.

Table 3

Comparison of values of efforts of truss members

Comparison of bending moments and shifts between three types of joints in a truss		
all hinged joints	continuous chords. hinged vertical members and cross braces	all stiff joints
bending moments [kNm]		
0.3	51.4	79.3
excess of normal stresses [%]		
14.4	39.8	53.2
shift of nodes [m]		
0.04668	0.0433	0.04296

Source: the authors.

Summary

Based on the above analysis, it can be concluded that the recommendation found in many references, suggesting that gusset plates should be avoided in trusses, especially in truss roofs, is substantiated. This is demonstrated by the values of the membrane forces set in Table 1 and Table 2. When gusset plates are used, the value of membrane forces is $N_{xx,\mathrm{max}} = 901.70$ kN/m, but when no

gusset plate is fitted, this value is $N_{xx,\max} = 896.77$, which is comparable. In addition, the stresses, both tangent and normal ones, in the analyzed nodes yield comparable values.

An important conclusion to be drawn from the above tests is that the extreme values of the forces and stresses do not occur in panel number 247, which is a gusset plate used in the analyzed node.

Translated by JOLANTA IDŹKOWSKA

References

BIEGUS A. 2003. *Stalowe budynki halowe.* Arkady, Warszawa.

BOGUCKI W. 1976. *Budownictwo stalowe.* Arkady, Warszawa.

JASTRZĘBSKI P., MUTERMILCH J., ORŁOWSKI W. 1974. *Wytrzymałość materiałów.* Arkady, Warszawa.

PN-EN 1993-1-8:2006, *Eurokod 3: Projektowanie konstrukcji stalowych.* Część 1–8: *Projektowanie węzłów.*

ŻÓŁTOWSKI W., FILIPOWICZ A., ŁUBIŃSKI M. 2000. *Konstrukcje Metalowe.* Część I. *Podstawy projektowania.* Arkady, Warszawa.

ŻÓŁTOWSKI W., ŁUBIŃSKI M. 1992. *Konstrukcje Metalowe.* Część II. *Obiekty budowlane.* Arkady, Warszawa.