ANALYSIS OF A SELECTED NODE OF A TRUSS MADE OF COLD-ROLLED SECTIONS BASED ON THE FINITE ELEMENT METHOD

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Abstract. *The study presents a comparative analysis of displacements and reduced stresses that occur in the selected node of a truss made of cold-rolled sections. Computations were based on the finite element method using the Autodesk ROBOT Structural Analysis and ANSYS Academic Research Mechanical software. Analysis of the status of the selected node was performed for permanent and variable loads.*

Keywords

Numerical analysis, finite element method, cold-rolled sections, light steel framing technology.

1. Introduction

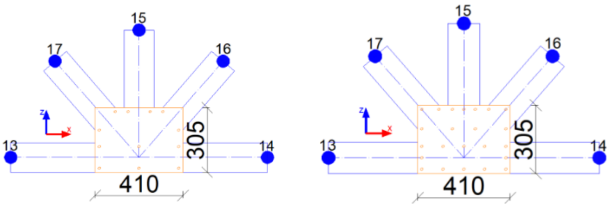
At the stage of the choice of materials, designers aim to reduce the mass of the components while maintaining or improving their strength properties. One of the groups of systems that are characterized by such features are the structures made of cold-rolled sections. In the construction sector, cold-rolled products have been used as construction materials (spans, pillars, trusses) and wall and roof claddings (e.g. components of shell walls) [1].

The study analysed the static state of stress of a selected node of the truss subjected to permanent (self weight of roof structure) and variable (wind and snow) load. This was achieved by the analysis of the truss of a detached house built using the light steel framing technology.

Two various pieces of software were used for the analysis, based on the finite element method. The displacements that were used in the further part of the study for determination of boundary conditions were evaluated using the Autodesk ROBOT Structural Analysis software [2]. Furthermore, the analysis of stresses was performed by means of the ANSYS Academic Research Mechanical software [3, 4].

2. Object of analysis

The case study presents the structure of a detached house constructed using the light steel framing technology (Sunday System) [5]. Node connections, which varied in terms of the number of screws, were separated from the structure (Fig. 1).

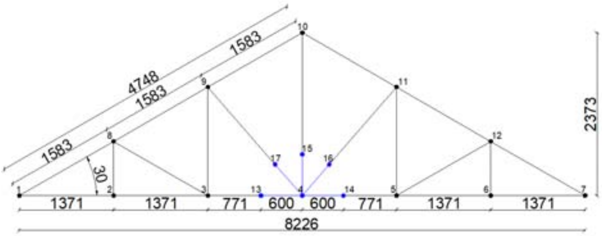


a) gusset plate with fewer screws b) gusset plate with fewer screws

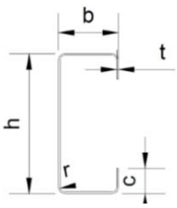
Fig. 1: The dimensions of the gusset plates and the number and method to distribute screws: (a) gusset plate with lower number of screws, 12 pcs. (b) gusset plate with higher number of screws, 23 pcs.

It has been assumed that the building is located in the first wind load zone and located in the city center at an altitude of A = 200m above sea level with the category IV area. [6, 7]. Furthermore, snow load was computed bases on the location of the object in the 2nd zone of snow load [6, 8].

Building height in the roof ridge beam was 8.62 m and the roof pitch for the roof covered with the asphalt shingle 30°. The beam span was 8.226 m at the height of 2.373 m (Fig. 2a). The truss was made of thin-walled sections (C140) with its dimensions according to Fig. 2b: h = 140 mm, b = 38 mm, c = 18 mm, t = 1.5 mm, internal radius r = 3 mm and cross section area of A = 3.591 cm^2. The sections were made of S185 steel with Young's modulus of 210 GPa and Poisson's ratio of 0.3 [9].



a) truss



b) cold-rolled section

Fig. 2: The computational model for a truss made of cold-rolled sections:
(a) truss with area denoted for further analysis of stresses that occur in the analysed node, (b) dimensions of a C140 cold-rolled section.

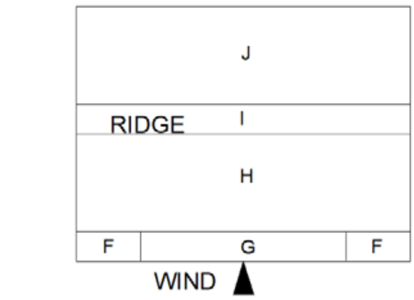
The node connections were made according to the guidelines for the technology. The nodes are covered on both sides with metal sheets with thickness of 1.5 mm and connected by means of self-drilling screws with diameter of 6.3 mm. The distance adopted between the screws and their distance from the section edge was not smaller than 19 mm (Fig. 1).

3. Case study

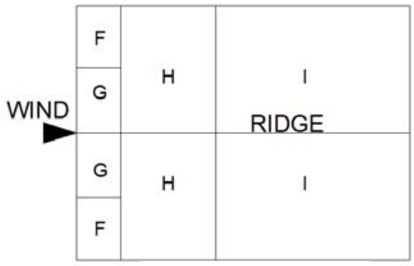
The analysis took into consideration wind load, snow load and weight of the truss sheathing. Densities of materials were adopted according to the "PN-EN 1991-1-1 Eurocode 1: Actions on structures. Part 1-1: General actions" [10] or according to the manufacturer's data. Permanent actions for the analysed case are 0.319 kN/m. The diagram of the snow load was determined according to the "PN-EN 1991-1-3 Eurocode 1. Actions on structures. Part 1-3: Snow loads" [7], which are:

- uniformly distributed snow load s_1 = 0.230 kN/m,
- not uniformly distributed snow load s_2 = 0.115 kN/m.

Wind pressure acting on the truss is presented in Table 1 according to the denotations presented in Fig. 3, which were determined based on the „PN-EN 1991-1-4 Eurocode 1. Actions on structures. Part 1-4: Wind actions" [8].



a) VARIANT I



b) VARIANT II

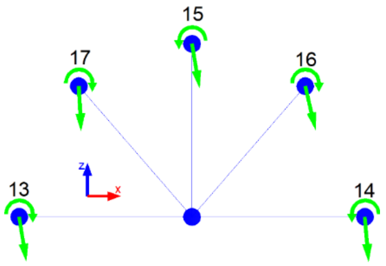
Fig. 3: Wind load field for the roofline: (a) VARIANT I: wind blowing perpendicularly to the roof ridge, (b) VARIANT II: wind blowing parallel to the roof ridge.

Tab. 1: Characteristic values for wind load for the analysed truss: roof pitch angle of 30°

VARIANT I Wind direction perpendicular to the ridge [kN/m]					
Field	F	G	H	I	-
$W_{net,10}$	-0.428	-0.526	-0.364	-0.230	-
VARIANT II Wind direction parallel to the ridge [kN/m]					
Field	F	G	H	I	J
$W_{net,10}$	0.329	0.329	0.300	-0.166	-0.169

According to the diagram presented in Fig. 1a, the static analysis was performed for the loads mentioned above using the Autodesk ROBOT Structural software. The presented truss was approached in the computations as a frame. For the purposes of further computations, the most unfavourable combination was chosen from automatic standard combinations. Next, displacements were read in nodes 13, 14, 15, 16 and 17 at the same distance of 0.6 m from the central node 4 (Fig. 4).

Modelling boundary conditions in ANSYS was possible by assigning the displacements read in the Autodesk ROBOT Structural software, applied to the symmetry axis of the C140's cross-section (Fig. 4). The main operation in computation of the states of stress and displacements was to perform correct discretization and assuming adequate contacts of the components of the analysed model. In the adopted model, Solid187 elements were generated, with 3 degrees of freedom in the node [11]. Degrees of freedom are the components of displacements and angles of rotation in the nodes. In the case of a node with lower number of screws, 41197 grid elements were assigned, whereas in the node with higher number of screws, this number was 65030. Contacts between gusset plate and sections were modelled as Frictional type, for which friction coefficient of 0.15 was introduced. Furthermore, for other contacts i.e. gusset plate - screw and C140 section - screw, the Bonded contact was generated.

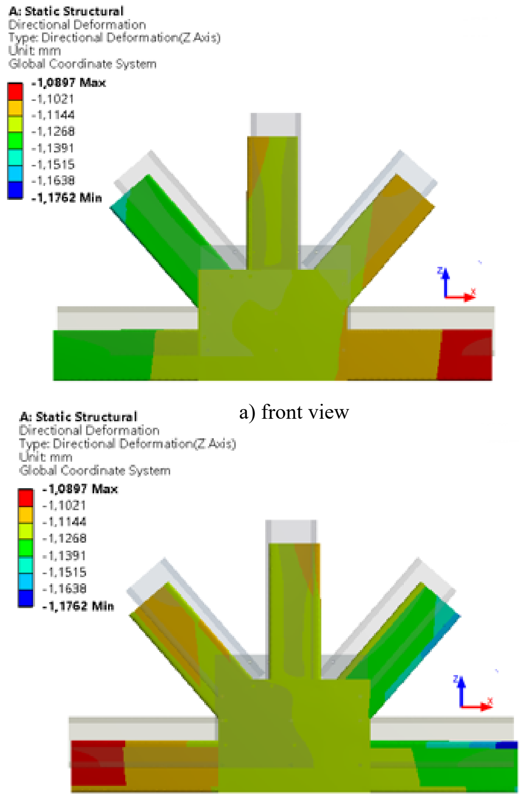


NODE	DISPLACEMENT		
	UX [mm]	UZ [mm]	RY [rad]
13	-0.237474	-1.493571	0.000120
14	-0.106395	-1.211914	0.000198
15	-0.297278	-1.273341	0.002494
16	-0.382812	-1.205065	0.000033
17	-0.075205	-1.457643	0.000465

Fig. 4: The analysed part of the truss with values of displacements which were used for determination of boundary conditions for the analysis performed in ANSYS Academic Research Mechanical.

4. Results

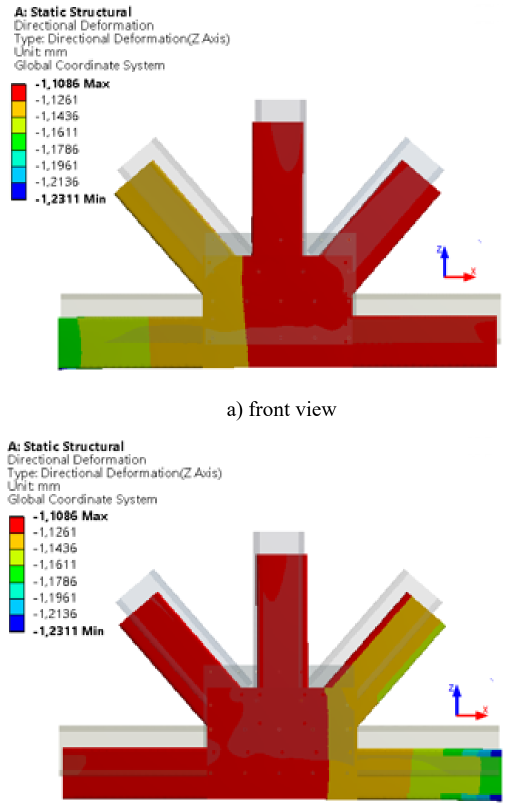
Values of von Mises reduced stresses and changes in displacements were determined during the analyses. A linear static analysis was used for the description of the node connection described above. Fig. 5 and 6 present the behaviour of the node with respect to vertical displacements. The displacements illustrated in Fig. 5 and 6 reflect the behaviour of the structure with respect to the adopted boundary conditions. Differences in the reactions of nodes to forced displacement could be observed for different numbers of screws. Higher number of screws led to insignificant changes in general behaviour of the node model. The displacements computed in the area of the gusset plate were nearly the same in both cases, with the difference of ca. 0.2%. The biggest displacements were documented in the area of applied displacements, i.e. at the distance of 0.6 m from the node centre.



a) front view

b) rear view

Fig. 5: The vertical displacements UZ of the analysed node with lower number of screws: (a) front view, (b) rear view.

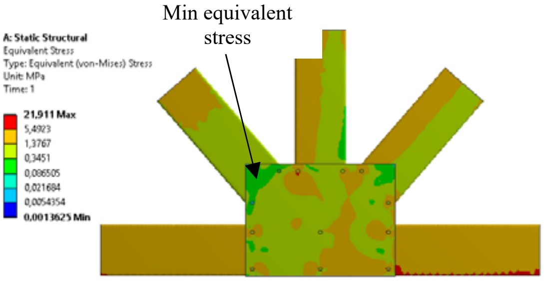


a) front view

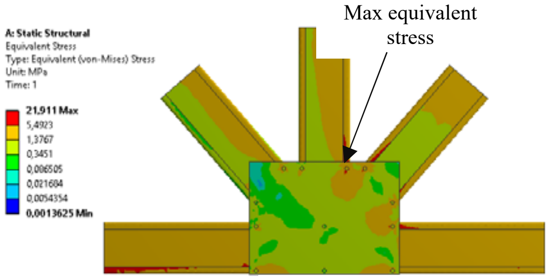
b) rear view

Fig. 6: The vertical displacements UZ of the analysed node with higher number of screws: (a) front view, (b) rear view.

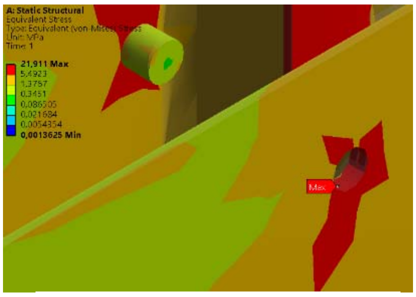
In both cases, maximal stresses occur in the place of contact of the gusset plate with the brace member (Fig. 7c and 8c). Higher reduced stresses could be observed in the component with lower number of screws in the lower area (Figs. 7a, 7b). For the second case, this distribution was more uniform (Figs. 8a, 8b). The analysis revealed insignificant changes in displacements and distribution of reduced stresses.



a) front view

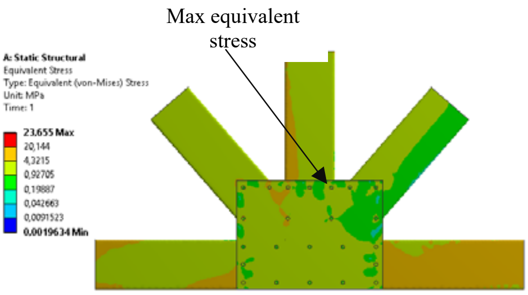


b) rear view

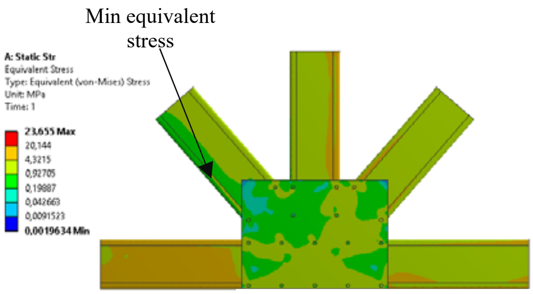


c) location of the highest stresses

Fig. 7: The map of reduced stresses for the node with lower number of screws: (a) front view, (b) rear view, (c) location of the highest stresses.



a) front view



b) rear view

c) location of the highest stresses

Fig. 8: The map of stresses for the node with higher number of screws: (a) front view, (b) rear view, (c) location of the highest stresses.

5. Conclusion

Displacements and stresses are the basic values which have to be verified at the stage of design of nearly any structure. According to standard guidelines, boundary states have to be met in order for a design element to be considered as safe.

This study presents the analysis of the behaviour of the selected node of the truss made of cold-rolled sections. The FEM analysis was used to predict the behaviour of connections and describing the results computed depending on the number of screws. Based on the computations one can conclude that the changes in the number of screws used for gusset plate connection with the truss did not lead to substantial differences. However, this does not mean that the number of screws should be minimized. Similar studies with the use FEM method to the analysis of thin-wall profiles to verify calculations was made in [12].

It should be emphasized that in order for numerical computations to reflect the behaviour of a structural component in reality, one needs a detailed technical knowledge concerning the solved problem and knowledge of the software. It often occurs that the analytical solution of the problem based on known computational methods is impossible, whereas simplified models can lead to elevated risk of making a mistake that has an effect on final results.

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