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A Finite Element Analysis of Cold-Formed Z-purlins Supported by Sandwich Panels

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Abstract. Nowadays buildings based on lightweight steel skeletons are widespread in civil and industrial engineering. The trapezoidal sheet or roof sandwich panels fastened to thin-walled cold-formed purlins can be used as the building envelopes. In this paper the questions of numerical analysis of thin-walled Z-purlins in the coverings made of sandwich panels are studied. Numerical analyses are performed in the program MSC.NASTRAN. A full scale model of the roof with purlins and sandwich panels is considered. Numerical analyses are based on the laboratory experiments. Results of described analyses are compared with the results of tests. These researches are done to investigate a behavior of the roof system consisted of Z-purlins and sandwich panels and to develop a correct finite element model for the design of cold-formed purlins supported by sandwich panels.

Introduction

Nowadays Z-, C- and Σ-purlins are widely used as supporting elements in a roof coverings of a modular buildings based on the light steel skeletons. Sandwich panels can be used to cover the building envelopes. A purlin-sheeting interaction plays a great role in the work of these structures.

Due to loading the structure by distributed load a thin-walled cold-formed purlin undergoes a restrained torsion because of the eccentrically load application. Sheeting does not allow the free rotation of the purlin and supports it. The bearing capacity of the purlin is significantly different for cases when purlin is considered as free beam and as beam which is attached to sheeting because of such complex interaction of the purlin with sheeting. That's why the purlin cannot be considered separately from the sheeting fastened to it.

The trapezoidal sheet or the roof sandwich panels fastened to thin-walled cold-formed purlins can be used as the building envelopes. In Eurocode [1] the restraining provided by sheeting to purlin recommended to model as the spring with some rotational stiffness C_{DA} . Well-known that sandwich panel and trapezoidal metal sheet are completely different systems and rules for trapezoidal sheeting can't be used for sandwich panels [2]. Also the type of fasteners plays a great role in the work of the system. Today self-tapping screws are widely used as fasteners of the sheeting to purlin. Alternatively rivets can be applied [3].

In this paper the studies of cold-formed purlins supported by sandwich panels is carried out. Self-tapping screws are used as sandwich panel fasteners to purlin. Full scale model represents a part of roof structures consisted of Z-purlins and sandwich panels is considered.

Background

Many researchers have studied the work of similar systems.

Author of the papers [4,5] has observed the total absence of Eurocode provisions for the cases of sandwich panels supported by Z-purlins. There are recommendations only for the case of trapezoidal sheeting.

In the paper [6] the numerical calculations were carried out with use of the MSC.Marc program. For the modeling of purlin authors used the plate elements. Also the laboratory tests were carried out. The test model was a section of the load-bearing construction of a roof covering being in use for instance in lightweight single-store buildings. Three purlins Z250 with the length 6 m were applied. Trapezoidal steel sheet was fixed to each purlin.

The comparison of the experimental and numerical results was done. The numerical results showed that the analyzed beam-sheet structure effectively modeled as a whole with use of shell finite elements for steel profiles and sheet roof and brick elements for insulation blankets. The elaborated FEM model of a roof covering is appropriate for simulating the behavior of a true structure of the type.

In the articles [7, 8] stability analysis of thin-walled purlins restrained by sheeting for different beam lengths and type of the cross-section was carried out. Special attention is focused on modeling the restrained purlins in general purpose finite element program ABAQUS. The comparison of results obtained with the use of analytical and numerical models is carried out. The examples illustrate the importance of proper modeling the laterally restrained purlins.

So, a behavior of a described type of systems is still not fully understood and requires further researches.

Finite Element Model

In the frames of this study finite element analyses are carried out with the use of MSC.NASTRAN program and were based on the laboratory tests [2]. A model (Fig. 1) consists from purlins Z200x2 and sandwich panels SPC120/80PU fastened to them by screws GT6 175-5.5/6.3 mm. Outer purlins are two free-ends beams with the span of 6 m and interior purlin is continuous double-span beam with the length of 12 m. The boundary conditions are as follows. Displacements are prevented in directions of Y- and Z-axis in the ends of the beams and in X-, Y- and Z-axis directions in middle support. A gravity load is modeled. The load is uniformly distributed by panel, its total value is q=1800 kg (17658 N).

A geometrically and physically nonlinear finite element analyses are performed. Yield stress of steel in this case is 350 MPa. This approach allowed us to study a process of purlin buckling and occurrence of the yield stresses in the points of purlin cross-section.

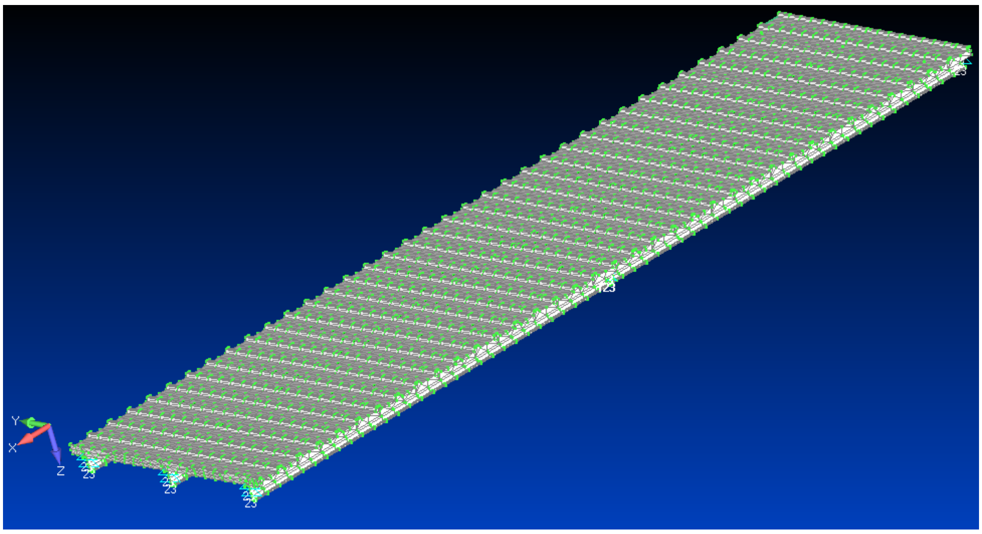
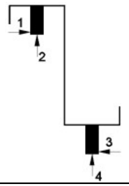
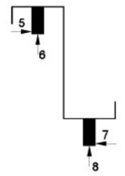


Figure 1. Model for numerical analysis.

Results of Finite Element Analysis

Displacements. Displacements are measured in the points of the interior purlin in two cross-sections (in the middle of span and in the middle support). The results for total value q=1800 kg are shown in Table 1.

Table 1. Displacement of purlin points

Load	Position	Direction	Displacement, [mm]	Scheme
1800 kg	In the middle support, mm	1	-0.40	
		2	-0.20	
		3	-1.11	
		4	0.43	
	In the middle of span, mm	5	-0.43	
		6	-5.82	
		7	2.83	
		8	-6.33	

Stresses. Maximum VonMises stresses 198 MPa are observed on the web of outer purlins in the middle support. Also big stresses are occurred in the interior purlin in the middle support in the place of web to bottom flange connection.Distributions of normal stresses over the cross-section occurred when load q=1800 kg applied are shown on Fig. 2.

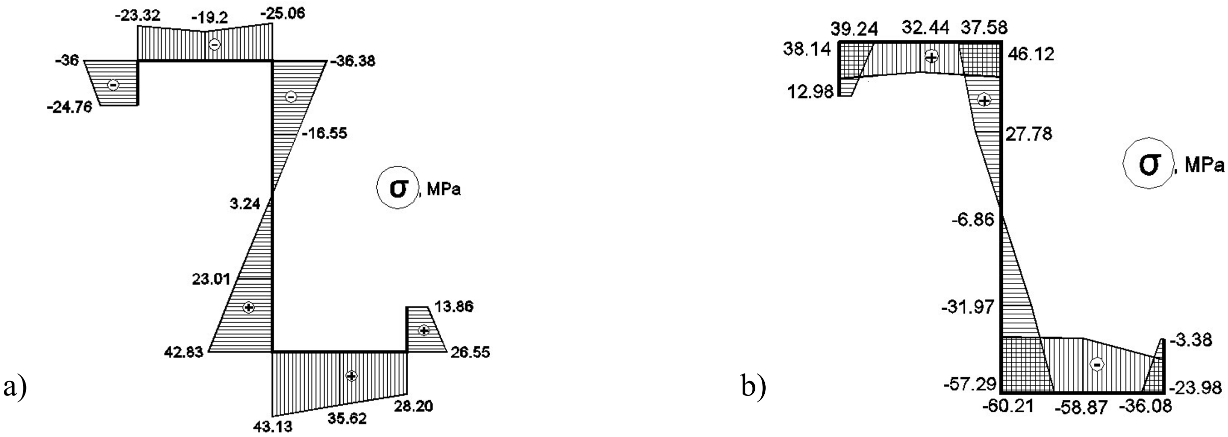


Figure 2. Diagrams of the normal stresses distribution over the cross-section (a – in the middle of span; b – in the middle support)

Buckling analysis. Total value of load q=14400 kg. During the increasing acting load value from 0 up to 14400 kg (24 steps) we can observe the process of plastic deformations occurrence.

First plastic deformations are observed in the middle support in the ends of external beams (load q=3600 kg). Then plastic deformations occur in a place of web to free flange connection of interior purlin in the middle support (q=7200 kg). The load when buckling of purlin occurs is q=10886 kg.

Comparison of Test and Finite Element Analysis Results

In this section a comparison of test [2] and finite element analysis (FEA) results is performed. Values of displacements and stresses are considered.

Displacements. In the Table 2 a comparison of the results of displacements obtained by testing (Test) and numerical analysis (NASTRAN) is represented. This data is also shown on graphs (Fig.3). Displacements were measured in middle of a purlin span (points and directions – see fig. 3). Evidently, a dependence "displacement-load" is nonlinear. It means that plastic deformations are occurred on the some level of load.

As we can see from table and graphs the results of numerical and laboratory researches are quite similar especially regarding a behavior of dependence "displacement-load". However, sometimes there are obtained big differences between test and FEA results (up to 45%). More rapid increasing of the displacements observed in the results of experiment than of numerical analysis.

Table 2. Displacements of purlin cross-section points

Load, kg	Displacement "6", [mm]		Error Δ, %	Displacement "7", [mm]		Error Δ, %	Displacement "8", [mm]		Error Δ, %
	Test	NASTRAN		Test	NASTRAN		Test	NASTRAN	
600	-1.06	-1.94	45.36%	1.05	0.97	8.25%	-1.70	-2.12	19.81%
1200	-4.25	-3.88	9.54%	1.75	1.91	8.38%	-3.30	-4.23	21.99%
1800	-5.45	-5.82	6.36%	2.15	2.83	24.03%	-4.70	-6.33	25.75%
2400	-6.95	-7.76	10.44%	2.85	3.71	23.18%	-6.10	-8.42	27.55%
2800	-8.75	-8.56	2.22%	3.25	4.03	19.38%	-7.90	-9.01	12.36%
3000	-9.42	-8.72	7.99%	3.55	4.15	14.46%	-8.63	-9.46	8.74%
3400	-10.75	-9.37	14.77%	4.15	4.40	5.74%	-10.10	-10.15	0.53%
3600	-11.68	-9.69	20.57%	4.45	4.58	2.84%	-10.93	-10.50	4.13%
4000	-13.55	-10.43	29.98%	5.05	4.90	2.97%	-12.60	-11.29	11.63%
4200	-14.22	-10.67	33.24%	5.25	5.02	4.58%	-13.10	-11.55	13.42%
4600	-15.55	-11.01	41.18%	5.65	5.27	7.18%	-14.10	-12.05	17.02%
4800	-16.55	-11.66	41.94%	6.10	5.46	11.72%	-15.55	-12.61	23.31%
5000	-17.55	-12.88	36.22%	6.55	5.91	10.78%	-17.00	-15.40	10.39%
5200	-18.58	-13.70	35.64%	6.45	6.38	1.10%	-17.87	-14.78	20.88%
5600	-20.65	-14.48	42.59%	6.25	6.73	7.18%	-19.60	-4.79	25.48%
5800	-21.39	-14.78	44.71%	6.47	6.86	5.64%	-20.30	-15.94	27.35%
		Mean value of error	26.42%		Mean value of error	9.84%		Mean value of error	16.90%

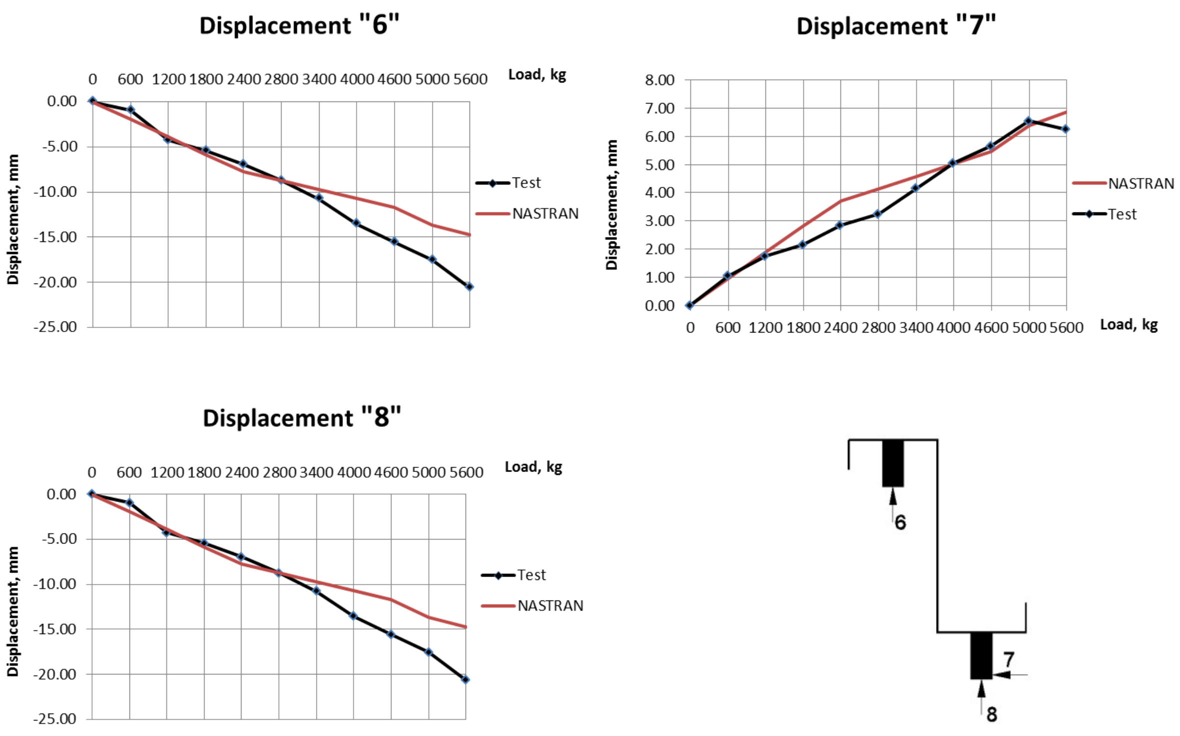
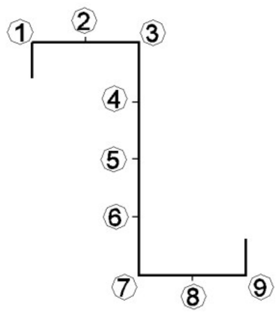


Figure 3. The graphs showing the dependence “displacement-load” in the middle of span

Normal stresses. In the Table 3 a comparison of the values of normal stresses obtained by testing (Test) and numerical analysis (NASTRAN) is represented. Diagrams of a stress distribution over the purlin cross-section are represented (Fig.4,5). Stresses are measured in the points of cross-section in the middle of purlin span and in the middle support.

Table 3. Normal stresses in the points of purlin cross-section

Point	Stress, [MPa] Middle of span		Error Δ, %	Stress, [MPa] Middle support		Error Δ, %
	Test	NASTRAN		Test	NASTRAN	
1	-32.93	-29.17	3.03%	39.87	39.24	0.40%
2	-31.63	-19.20	12.23%	43.67	32.44	7.38%
3	-23.93	-25.06	1.15%	55.97	46.12	4.82%
4	-11.23	-16.55	9.58%	29.47	27.78	1.48%
5	1.17	3.4	23.47%	-9	-6.86	6.75%
6	13.33	23.01	13.32%	-20.97	-31.97	10.39%
7	27.5	43.13	11.06%	-55.03	-57.29	1.01%
8	25.73	35.62	8.06%	-46.3	-58.87	5.98%
9	28.23	28.2	0.03%	-51.73	-36.08	8.91%
		Mean error	9.1%		Mean error	5.23%



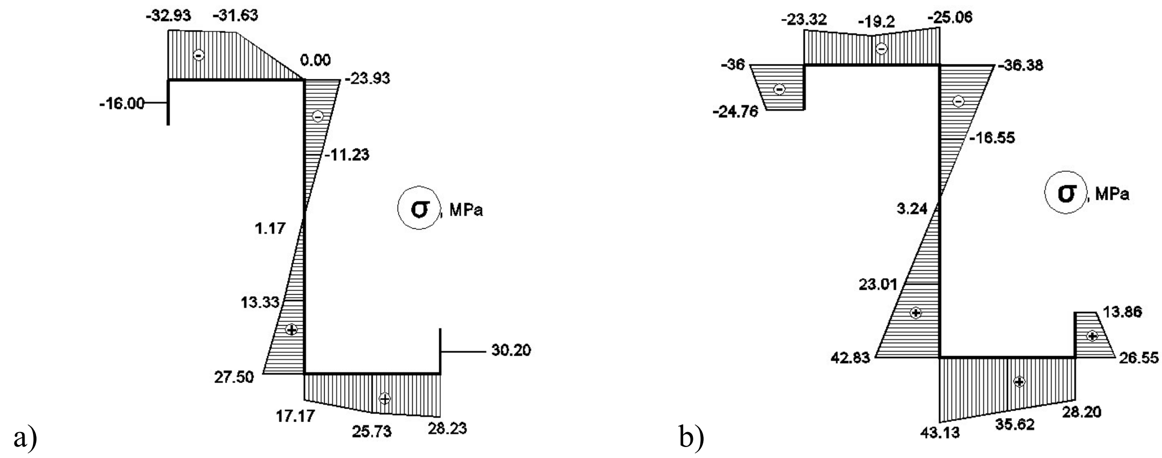


Fig. 4. Normal stresses in the middle of span (a – test; b – NASTRAN)

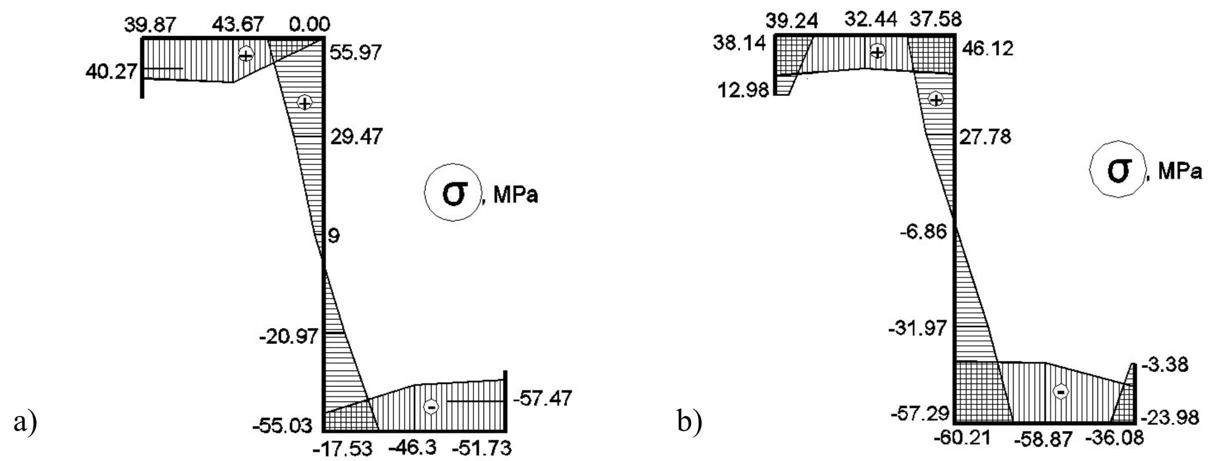


Fig. 5. Normal stresses in the middle support (a – test; b – NASTRAN)

The characters of normal stress distribution over a cross-section obtained by testing and finite element analyses are similar. Differences in stress values are varying from 0.4% up to 39%. The mean value of error between test and FEA results for the middle span cross-section is 9% and for the middle support cross-section is about 5%.

We can see a change of linear character of stress distribution on the top flange of purlin. It is related to the screw fastening of sandwich-panel to purlin in this point. A screw restrained free displacement of purlin in the longitudinal axis direction (prescribed boundary conditions allowed free displacements of purlin along its longitudinal axis). And this restraining cause a local axial force applied in the top flange connected to sheeting.

Summary

Roof structures consisted of cold-formed purlins and sandwich panels are very promising and widespread structures. Absence of any standard provisions for the case of sandwich panels necessitates their researches.

In the summary, it should be noted that actual studies of Z-purlins supported by sandwich panels lead to the following conclusions. On the basis of performed finite element analysis a picture of stress-strain state of Z-purlins supported by sandwich panels was obtained and described in this paper. Most stressful places of purlin web and flanges were revealed. Stresses and displacements were determined on the all stages of loading. As geometrically and physically nonlinear numerical analyses were carried out the processes of plastic deformations occurrence were studied.

Performed comparison of test and FEA results allowed us make a conclusion that developed finite element model in MSC.NASTRAN give us plausible results and can be used in future for further studying of such kind of systems.

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