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Experimental investigation of torsional restraint provided to thin-walled purlins by sandwich panels under uplift load

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Abstract

Sandwich panels, usually used as members of wall or roof cladding, can provide lateral and torsional restraint to metal members of the substructure along their spans. They can positively influence the buckling resistance of the metal members. Lateral restraint given by sandwich panels can be considered for downward as well as uplift load applied on the surface of the panels. Torsional restraint can normally be utilized in case of downward load only. The uplift load causes the reduction of the contact area between the panels and metal members which is assumed to result in small (or conservatively zero) values of rotational stiffness which corresponds to the torsional restraint. There is a lack of data regarding torsional restraint under uplift load. Certain values of torsional stiffness can be considered when metal members of cold-formed cross-sections are utilized.

The paper focuses on experimental verification of torsional restraint given to steel purlins of thin-walled cold-formed cross-sections by sandwich panels under uplift load. As the test setup for verification of the torsional restraint provided to metal members by planar members according to the actual standard for design of steel structures does not cover the influence of external load applied on the surface of the panels, a special test setup taking the external load into account had to be used. The paper describes the specimens, the test setup and the procedure of testing and summarizes selected relevant results of the series of performed tests.

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Keywords: buckling; experiment; sandwich panel; stabilization; thin-walled beam; torsional restraint

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1. Introduction

Steel members of thin-walled cold-formed cross-sections have been widely used in civil engineering (purlins or girts supporting planar members of cladding, e.g. sandwich panels). The connection of the planar members to a thin-walled member results in continuous restraint of the member which fully or partially prevents its deformation (lateral deflection and rotation) and positively influences its buckling resistance [1,2]. If the continuous restraint is correctly considered, higher efficiency of the structural design can be achieved. The adjacent planar members can provide lateral restraint (effected by the shear stiffness given by the planar members) and torsional restraint (effected by the rotational stiffness) for the thin-walled member [3,4]. The lateral restraint provided by the sandwich panels to both hot-rolled and cold-formed members can be utilized for downward as well as uplift load applied on the surface of the sandwich panels. The torsional restraint can normally be considered in the case of the downward load only. The uplift load (e.g. wind) causes the reduction of the contact area between the panels and supporting metal members between the fasteners which is assumed to result in decrease of the rotational stiffness given by the sandwich panels [5]. Certain values of the rotational stiffness can be considered when cold-formed members are used and should be determined by experimental research [6]. As the test setup for determination of the rotational stiffness given by planar members according to the standard [7] does not take the external load applied on the surface of the planar members into account, a more complex test setup has to be used.

The rotational stiffness which characterizes the torsional restraint is defined as torsional moment causing the unit rotation of the flange of the restrained member. It is influenced by the stiffness of the connection of the adjacent planar members and thin-walled members, bending stiffness of the planar members and by the stiffness corresponding to the distortion of the cross-section of the thin-walled member [7,8]. It depends also on the orientation of the external load [9]. Due to lack of data regarding values of the rotational stiffness provided by the sandwich panels under uplift load, further research in this field is necessary.

Nomenclature

C_D	rotational stiffness
E	modulus of elasticity
F	force applied at midspan of the flange of the purlin
F_T	force on lever arm causing the rotation of the purlin
K	total lateral spring stiffness per unit length
K_A	lateral spring stiffness corresponding to the rotational stiffness of the connection
K_B	lateral spring stiffness due to distortion of the cross-section of the purlin
K_{adj}	adjusted total lateral spring stiffness
K_{obs}	total lateral spring stiffness obtained from a test
L	length of the purlin
R	lever arm
a	distance of the fastener and the web of the purlin
b	width of the flange of the purlin
h	depth of the purlin
h_Δ	distance of the point of the lateral displacement measurement from the bottom flange of the purlin
l_A	width of the planar member adjacent to the purlin
l_B	length of the purlin
p	uniform areal load
t	thickness of the purlin
δ	measured displacement of the purlin
μ_R	ratio between actual and nominal purlin thickness
ν	Poisson’s ratio

2. Experimental verification of the torsional restraint

2.1. Specimens

Two tests of the torsional restraint given to thin-walled purlins by the sandwich panels under uplift load were performed at the Testing Laboratory of the Institute of Metal and Timber Structures, Faculty of Civil Engineering, Brno University of Technology. Steel purlins of the cold-formed Z-sections (depth h = 150 mm, thickness t = 3 mm, length L = 2.4 m) and sandwich panels with thin steel facings (slightly profiled) and polyurethane insulating core of the thickness of 40 mm were used. The width of one panel was 1 m, the length was 4 m and the self-weight was 8.6 kg/m^2. The cross-sections of the purlins and the sandwich panels and the scheme of the fastening are in Fig. 1.

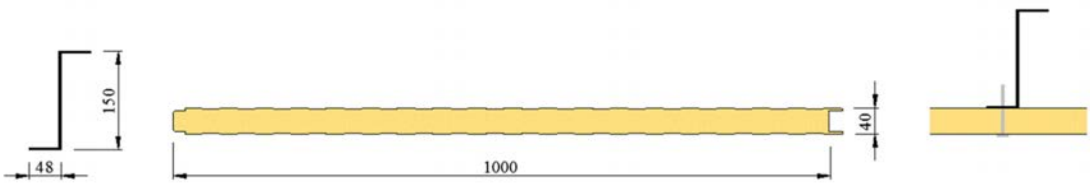

Fig. 1. Cross-sections of the tested purlins and panels and fastening of the members.

2.2. Selection of the suitable test setup

The standard [7] provides a relatively simple test setup for verification of the torsional restraint given to thin-walled members (purlins) by planar members. A purlin of a depth of h is fastened to the planar member and loaded by a force F at midspan of the top flange. The applied force should induce lateral displacement of the top flange of a magnitude of h / 10.

The test gives the combined lateral spring stiffness K which comprises the component K_A and K_B. The combined lateral spring stiffness per unit length is obtained from (1).

$$\frac{1}{K} = \frac{1}{K_A} + \frac{1}{K_B} = \frac{\delta}{F} \qquad (1)$$

The component K_B can be calculated using (2) and the rotational stiffness C_D using (3).

$$K_B = \frac{E \cdot t^3 \cdot l_B}{4 \cdot (1 - \nu^2) \cdot \left[\frac{h_\Delta^2}{2} \cdot (3 \cdot h - h_\Delta) + b_{mod} \cdot h \cdot h_\Delta \right]} \qquad (2)$$

$$C_D = \frac{K_A \cdot h \cdot h_\Delta}{l_A} \qquad (3)$$

The formula (2) was derived using the method of the virtual work for the case when the lateral displacement is measured in an arbitrary point in a distance of h_Δ from the bottom flange of the purlin. In (2), the value of b_{mod} is taken as a if the load causes the contact of the purlin and planar member at the purlin web or $2 \cdot a + b$ if the load causes the contact of both members at the tip of the purlin flange.

As the test setup according to the standard [7] does not take the external load applied on the surface of the planar members into account, it is not suitable for verification of the torsional restraint under uplift load. The test setup based on [6] was used instead. Its scheme is in Fig. 2.

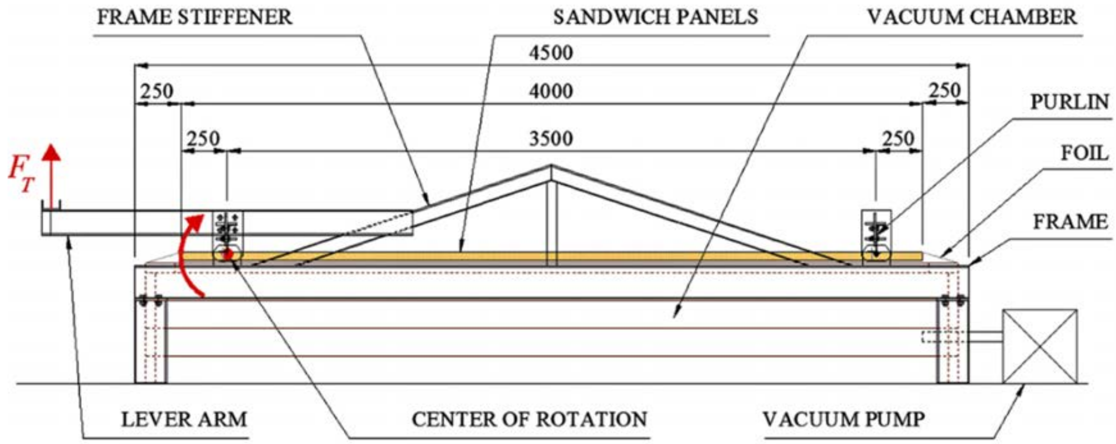

Fig. 2. The test setup taking into account the external load applied on the sandwich panels

For application of the uniformly distributed load on the surface of the panels, the vacuum test method was used [10,11]. The suction in the timber vacuum chamber caused by the vacuum pump simulated the uplift load applied on the panels. The tightness of the vacuum chamber was ensured by a foil. One test setup consisted of two sandwich panels and two purlins supported by a steel frame. The connection between the panels and the purlins was effected by four self-drilling screws per one sandwich panel. At the ends of one purlin, steel lever arms were attached and connected by a transversal girder at their ends.

Fig. 3. (a) The test setup; (b) rotation of the purlin.

2.3. Procedure of testing and evaluation

Using the transversal girder fixed to the ends of one purlin, the torsional moment was applied as the force F_T on the lever arm R. The force was applied using the bridge crane and measured by a force transducer. The purlin was equipped with sensors of displacements. The rotation of the purlin by the torsional moment was performed under no suction load and under five different levels of the suction load. Within the frame of each level of load, three cycles of rotation were conducted. The magnitude of the last level of the suction was chosen in such a way that it exceeded the maximum tabled allowable load for the panels of 25 %. As the force was not applied directly to the top flange of the purlin, the appropriate value of the force F (for the calculation of the combined lateral spring stiffness) was derived using a mechanical model. It resulted in (4).

$$F = 1.125 \frac{F_T \cdot R}{h} \tag{4}$$

Using the force F and the displacement at midspan δ the combined value of the lateral spring stiffness K_{obs} was obtained for each level of the suction as the slope of the line approximating the force-deformation curve. The adjustment of the test results was performed according to [7] using the ratio between actual and nominal purlin thickness μ_R. Using the adjusted value K_{adj} and the value of K_B, the component K_A was calculated and used for the calculation of the rotational stiffness C_D.

2.4. Results of the tests

The typical relationship between the force F and the deformation δ (measured in a distance of h_Δ from the bottom flange of the purlin) is in Fig. 4 (for the first and the last level of the suction load). The relationships for other levels were similar as the ones shown. The complete results for all levels of the suction load for both tests performed are summarized in Table 1 and Table 2 and graphically presented in Fig. 5.

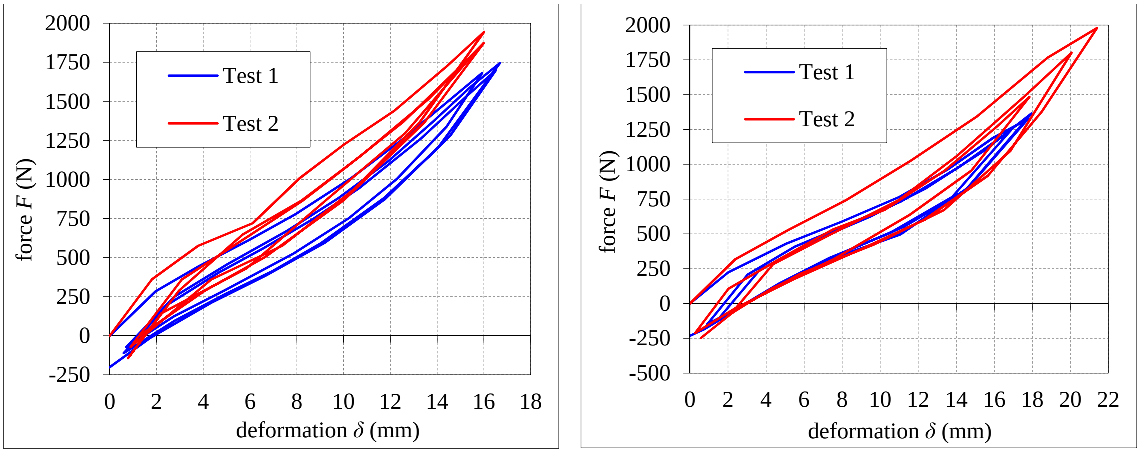

Fig. 4. (a) Test results of the first level of the suction load; (b) test results of the fifth level of the suction load.

Table 1. Results of test No 1.

Load level	p (kN/m^2)	K_{obs} (N/mm)	μ_R	K_{adj} (N/mm)	h_Δ (mm)	b_{mod} (mm)	K_B (N/mm)	K_A (N/mm)	C_D (Nmm/mm/rad)
0	0.00	98.95		102.82				112.09	1067.61
1	0.16	104.62		108.71				119.12	1134.66
2	0.32	98.85	0.96	102.72	127.00	21.00	1244.13	111.97	1066.47
3	0.48	90.47		94.01				101.69	968.59
4	0.64	82.58		85.81				92.17	877.93
5	0.80	77.19		80.21				85.74	816.63

Table 2. Results of test No 2.

Load level	p (kN/m^2)	K_{obs} (N/mm)	μ_R	K_{adj} (N/mm)	h_Δ (mm)	b_{mod} (mm)	K_B (N/mm)	K_A (N/mm)	C_D (Nmm/mm/rad)
0	0.00	112.61	0.95	118.00	130.00	21.13	1199.79	130.87	1275.98
1	0.16	118.01		123.66				137.87	1344.20
2	0.32	114.13		119.59				132.83	1295.11
3	0.48	111.35		116.68				129.25	1260.16
4	0.64	107.13		112.26				123.84	1207.48
5	0.80	89.56		93.84				101.81	992.63

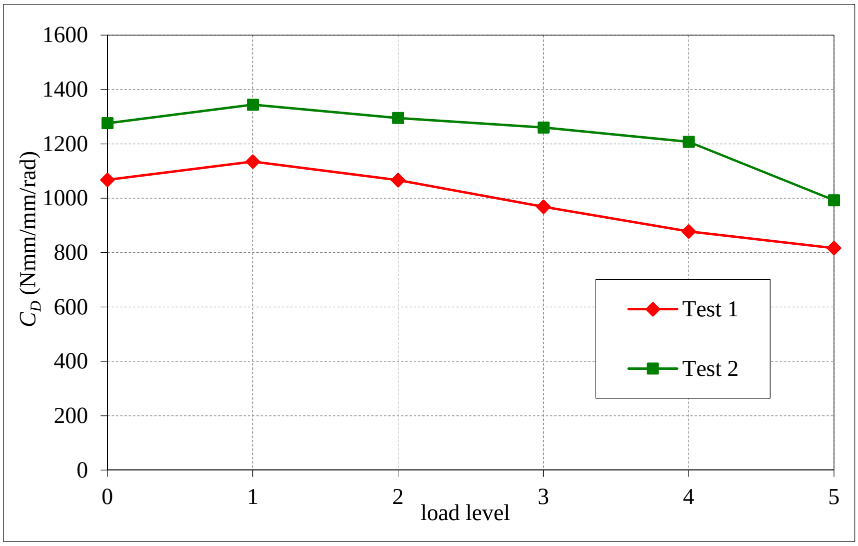

Fig. 5. Rotational stiffness in dependence on the load level.

3. Results and discussion

Although the rotational stiffness provided to the thin-walled members by the sandwich panels under uplift load is standardly not considered, the performed tests indicate that practically significant values of the rotational stiffness may be available. A slight decrease of the rotational stiffness with increase of the uplift load was observed. If a more extensive experimental research was performed and the results were generalized, it would be possible to adopt the values of the rotational stiffness into the calculation and reach more economic and efficient structural design of the steel members. The inconvenience of the testing is the complexity of the test setup taking into account the uplift load.

4. Conclusions

The paper summarizes the results of the series of tests of torsional restraint given to thin-walled members by sandwich panels under uplift load. For the tested specimens, a significant rate of torsional restraint under uplift load was observed. A more general conclusion regarding actual behavior of the thin-walled members with torsional restraint provided by the sandwich panels under uplift load could be brought by a more extensive experimental research.

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