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TESTS OF THE LOCAL RESISTANCE OF THIN-WALLED Z-PURLINS CLIP CONNECTION TO THE SUPPORTING STRUCTURE

Premysl Parenica, Miroslav Rosmanit, Jakub Flodr and Oldrich Sucharda
VSB-Technical University of Ostrava, Faculty of Civil Engineering, Czech Republic
E-Mail: premysl.parenica@vsb.cz

ABSTRACT

The local resistance of thin-walled cold-formed steel Z purlin clip connection with the additional bolt connection thought the bottom flange of the purlin to the supporting structure was studied. Overall behavior of this purlin and its connection is highly influenced by the local stability problems. Twelve experimental tests with four different widths of the bearing structure were performed together with advanced numerical finite element study. The numerical model was verified by the experiment performed. Finally, the experimental and numerical results are compared; typical failure mode is discussed in the conclusions. Future planed research activities are presented.

Keywords: connection, steel, overlap, crippling, thin-walled purlins.

INTRODUCTION

Nowadays, thin-walled steel sections are often used in industrial and civil building as a part of the roof structure (trapezoidal sheeting, purlins and claddings) [1, 2]. Because of their smart and economical sections in the combination with very good mechanical properties of steel [3, 4], this profiles can be used also for large spans in the design of halls. Effective design can lead to the considerable cost savings.

On the other hand, the disadvantages of designing thin-walled profiles are inadequate and difficult design methods [5, 6 and 7] which mainly describe local and global stability problems and design of connections [8]. Therefore, more advanced methods for design and analysis of civil structures are needed. Typically, finite element method [9, 10] and non-linear analysis [11, 12 and 13] are used for numerical models of steel constructions behavior.
A few types of thin walled profiles and their connections are used. Typical cross-sections used in the practice are Z- and C-profiles [14, 15 and 16]. Because of wide variety of the possible cross-sections and connections of this beams with the superstructure, the design coded do not give complex design solution which can cover all cases. Only typical and some recommended simplified solutions are given. Therefore the design of these structures is usually done using a design tables based on full-scale experimental test results. Those tests can simply be done for different cross-sections, but much harder for variety of connections (end and intermediate supports on simple and multiple beams). Typical connections are for example: i) direct bolt connection thought the bottom flange of the purlin without additional stiffener, ii) with stiffener created by the overlap or sleeve, using a clip connection (additional connection element) realized only in the web area - a gap between the flange and the superstructure is leaved out, iii) combinations of those or similar types of connections [6]. The connection should ensure the overall stability of the thin-walled profile at the support and enable axial (ideal) transfer of the internal forces to the superstructure.

Laboratory tests for some of the connection cases and numerical calculation models are available in the literature [17, 18 and 19]. For example, at the [20, 21] detailed description of simply beam model is shown. Using the clips seems to be very important possibility designing these connections [22], because the direct bolt connection thought the bottom flange of the purlin should not be sufficient for higher profiles.

This paper is focused on a problem of the roof purlin connections to the bearing structure and assembly joints. Local stress concentration occurs in connection area mainly. These stresses can have a significant impact for load bearing capacity of whole thin-walled profiles. Undue stress concentrations can be avoided using stiffening of beams in the areas which are loaded by local forces (supports). Doubling of the section in places above support is the mostly used stiffening (overlap, sleeves). Many different clips are used in practice. For higher beams, such as Z300 and Z350, the overlap reinforcement with additional stiffening clip connection seems to be one of the best solutions. The enhancing effect of the clip connection for whole bending moment capacity of the thin-walled profile in the support area is subject of this research.

Presented article shows a parametrical study for chosen type of connection of thin-walled Z-profile. The study is based on results from experiments and advanced numerical studies. Software ANSYS was used for numerical calculations [23].

Design of thin-walled members

Analytical models using traditional beam theory is most often used in the design of steel structures. Approaches of the beam theory are not always ideal for beams of thin-walled cross-sections, because the capacity of those profiles is affected also by the local stability problem such as local buckling and distortional buckling. Load bearing capacity of the section is exhausted when yield strength in any part of the cross-section is reached. Typically, load bearing capacity of thin wall section is calculated with reduced (effective) cross-sectional characteristics (A_{eff}, I_{eff}), which can be used for calculation of internal forces also in the simple beam model with limitations.

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The numerical models using the shell and volume elements are better for advanced design and analysis of steel elements of thin-walled profiles. Geometrical, physical and constructional non-linearity can be taken into account in the calculation as well as the effect of the large deflections. This can ensure the right non-linear behavior of the model (the local buckling, shear lag, contact pressure between the clip and the purlin, and loses of stiffness due to the large deformations in stability problem. Namely, our research is focused on the design of the new type of Z-purlin's connections with the superstructure by the combination of the direct bolt connection of the purlin and using the overlap with clip. The work is concentrated to creation of semi-analytical design method, recommendations for advanced numerical modelling, and parametrical study of the effect of chosen variables (thickness and height of the thin-walled profile, width of the bearing structure and number and spacing of the bolts) to total load bearing capacity. The results will possibly spread the database of optimized details.

EXPERIMENTS AND NUMERICAL MODELING

The parametric study is comprises a pair of Z-beams, which are duplicated across the length and reinforced by a clip. The Z-profile beams have the height of 300 mm and a thickness of 1.90 mm. Doubling is done in reason the weakest point of the beam area was support region under the load element, instead transition overlap for a continuous profile. End of overlap is bolted in web with three bolts. Scheme assembly and connections is shown in Figure-1. The entire assembly works like a simple supported beam loaded in the middle of the range (3-point bending). Distance between supports is 3.0 m. The moment-reaction ratio (M/R ratio) for this assembly in middle of span under crossbeam location is 1.5.

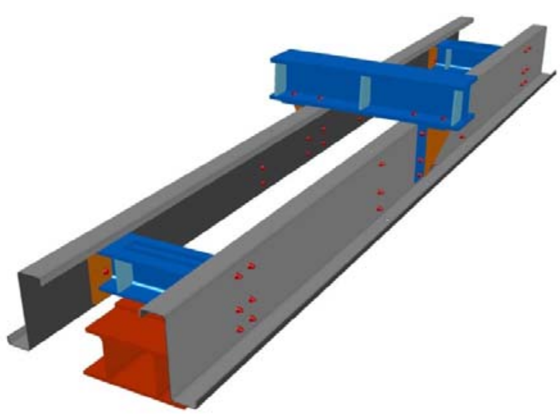

Figure-1. Setup of the experiment - visualization.

Two opposing beams eliminate transverse forces caused by bending moment on nonsymmetrical Z-profiles. Detailed view of transversal distribution of crossbeam and clip connection is shown in Figure-02. There is also seen bolt distribution in the clip supported area. The clip is attached to the crossbeam by two bolts. Connection between clip and Z-profile is realized by six bolts in three rows. The Z-profile flange is connected to crossbeam by two bolts. All used screws are dimension M12 without washers and class 4.6 according to [1].

Experiments were focused on the overall behavior of the Z-purlin and its overlap clip connection with the bearing structure and determination of the total load capacity and failure modes. The test setup corresponds to the real connection used in practice; it is just turned upside. Twelve experiments were performed with four different widths of the bearing structure (180, 200, 250 and 300 mm).

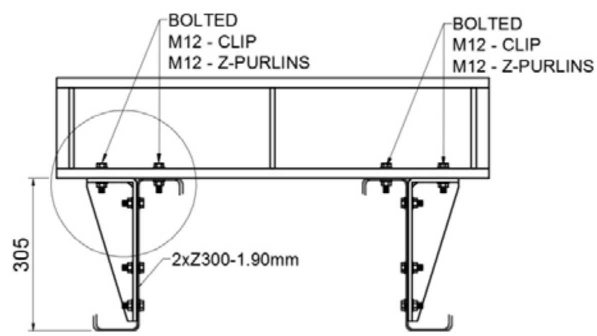

Figure-2. Setup of the experiment - cross section of the specimen.

Physical experiments

Tested assembly is formed by crossbeam, on which are placed symmetrically two doubled Z-purlins with a reinforcing clip and bolted to the bottom of the load element. This cross member is used for applied the load. Supports on the ends of the Z-purlins are implemented using end plates with supported thresholds, which are designed as pinned support. Between support and crossbeam there were screwed additional crossbars which stabilize the Z-profiles laterally and torsionaly.

Load was applied by hydraulic cylinder, which was situated in the middle of crossbeam. The pressure in the cylinder was recorded. Crossbeam displacement and support deflection were measured by the extensometers. Two extensometers were placed on crossbeam and two above threshold on both ends of beam, four in total. In Figure-3 is shown whole test assembly during testing.

Figure-3. Setup of the experiment - loading by the hydraulic cylinder and measuring by extensometers.

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Numerical models

Numerical model of tested specimen was created in the finite element software ANSYS [23]. Finite elements used for creation of the model were volume elements SOLID185 (cross member, clip and screws) and BEAM188 (pinned support elements). Shell finite elements SHELL181 (4-node) were chosen for modelling of the Z-profile. Summary of elements, nodes and equations represents computational demands of each numerical model is presented at the Table-1.

Screws are modeled with embedded prestress which simulates screw tightening during assembly; therefor the prestress element PREST179 was used. The contacts between all individual parts of the model (clip, Z-purlins, bolts, cross-beam) are ensured using the contact elements TARGET170 and CONTA175.

The geometry of the specimen in the numerical model is simplified. Due to the symmetry in the longitudinal direction only half of the specimen was modeled, while additional boundary conditions were applied using CP coupling algorithm. The computational cost of the task was also reduced by replacing pinned support on both ends of beams with MPC algorithm [23], see Figure-4. Forces and deformations on the end shell nodes are tied to the pilot node situated in the middle joint of the rotation.

Figure-4. Numerical model; mesh and simplified supports (using the MPC algorithm) are displayed.

Four numerical models simulating the experiments and varying by widths of the bearing structure were created. A computational demand of all numerical models represented by summary of elements, nodes and equations is presented in the Table-1.

Table-1. Computational demands of numerical models represented by summary of elements, nodes and equations.

Model	Flange width (mm)	No. of elements		No. of nodes	No. of equations (in total)*
		SOLID185	SHELL181		
Fin_01	300	19 623	22 502	100 284	500 655
Fin_02	200	16 319	22 502	100 284	488 443
Fin_03	180	19 928	22 502	100 166	500 671
Fin_04	250	23 754	22 502	105 905	517 018

*Summary includes all type of elements used in the models.

The numerical model takes into account constructional, geometrical and physical nonlinearities. Systems of nonlinear equations are solved by Newton-Raphson iteration algorithm. Geometrical nonlinearity is taken into account by large displacement solver settings (NGEOM, ON).

The numerical models were also improved using the multilinear material model. Real material properties and thickness of Z-purlins, based on tensile tests, were implemented into the numerical models. These values were determined on the samples taken from negligibly loaded parts of already tested beams. Final multilinear model of the basic material used in the numerical models is shown on the Figure-05, so also the physical nonlinearity [24] was considered.

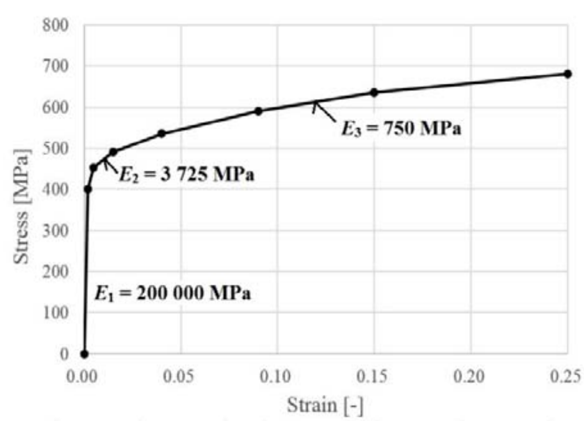

Figure-5. Multilinear material model of steel used in FEM analysis, based on tensile tests of real samples.

RESULTS

Twelve tests for four different widths of crossbeam flanges were performed, three tests for each width. Experimental results are plotted in graphs (see

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Figure-06 to Figure-09). It can be seen good conformity between the experiments and numerical models, mainly the stiffness and partially the total capacity of the specimen.

The load bearing capacity of the specimen was determined at each test; the results are shown in the Table-02. Measured load capacities of all test specimens were in range from 71 to 78 kN, surprisingly independently to the width of the bearing structure. The test A3 (with the load bearing capacity 66 kN only, was probably negatively influenced by the large initial imperfection at the clips connection or by some other error due to the testing. Therefore this test result is not giving great importance of the final evaluation.

Table-2. Summary of experimental results.

No. of test	Flange width (mm)	Maximal force (kN)	Moment* (kNm)	Deformation (mm)
A1	180	71.7	50.55	14.10
A2	180	75.0	52.88	16.15
A3	180	66.0	46.53	13.82
B1	200	72.4	50.68	14.46
B2	200	77.6	54.32	14.82
B3	200	73.8	51.66	14.26
C1	250	77.7	53.42	14.84
C2	250	78.0	53.63	14.03
C3	250	73.3	50.39	14.27
D1	300	77.2	52.11	13.97
D2	300	73.8	49.82	13.45
D3	300	77.1	52.04	14.56

*Bending moment is calculated in the edge of crossbeam flange (failure section). Distance from the specimen support center varies from 1350 to 1410 mm (depending to the width of the crossbeam flange).

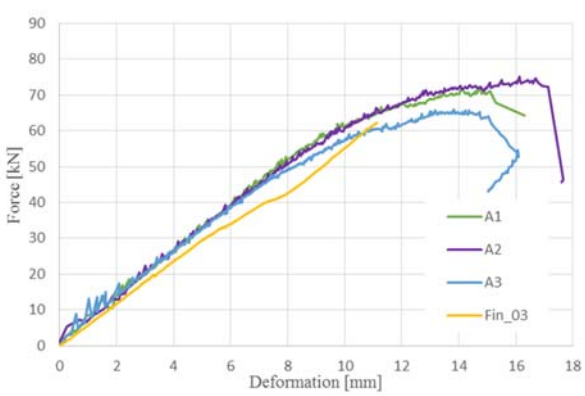

Figure-6. Results of experiments A1, A2, A3 and numerical model results Fin_03 - flange width 180 mm.

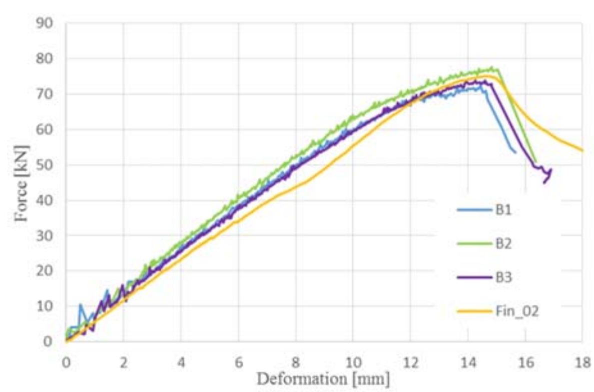

Figure-7. Results of experiments B1, B2, B3 and numerical model results Fin_02 - flange width 200 mm.

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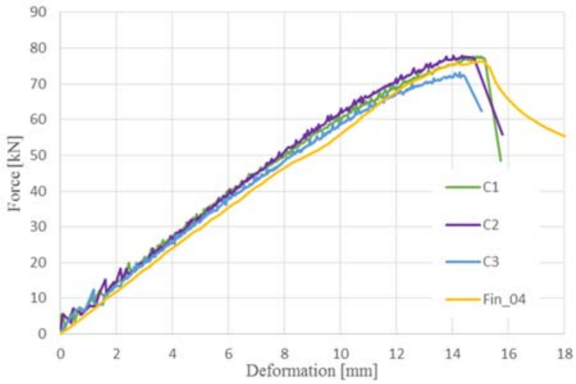

Figure-8. Results of experiments C1, C2, C3 and numerical model results Fin_04 - flange width 250 mm.

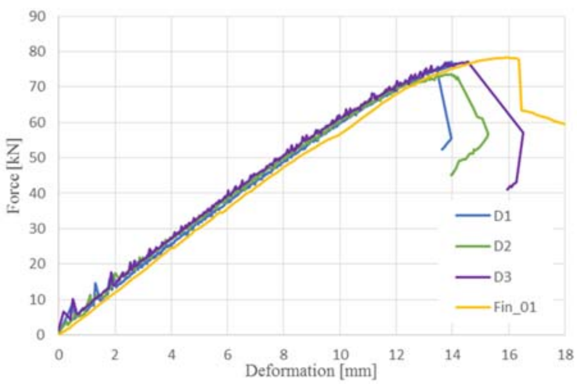

Figure-9. Results of experiments D1, D2, D3 and numerical model results Fin_01 - flange width 300 mm.

Figure-10. Failure mode - experiment C2. Web and flange crippling near by the clip area. Maximal loading force F = 78.0 kN (top fig.), residual force F = 55.8 kN (bottom figure).

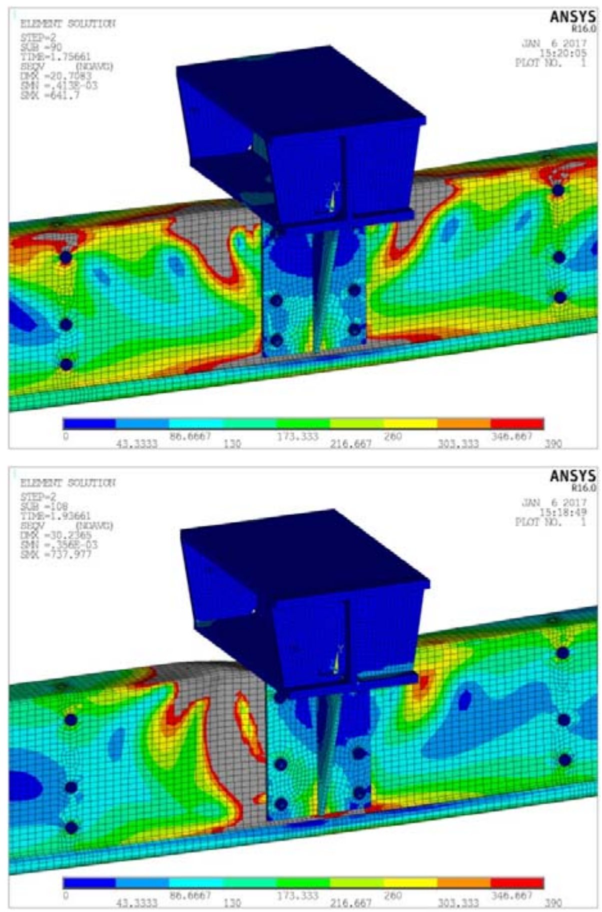

Figure-11. Failure mode - numerical model, represented by Von Mises stress (scaled 0 - 390 MPa) and by the deformation shape. Maximal loading force F = 76.2kN (top fig.), residual force F = 53.4 kN (bottom fig.).

Two representative cases of the failure mode and post critical residual behavior of the specimen C2, both from the experiment and numerical model are presented on the Figure-10 and Figure-11. There is a strong conformity of the results, shoving typical failure mode which is web and flange crippling near by the clip area.

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Also a value of stresses, represented by the maximal loading force and residual force is similar.

Comparing all experimental results, minimum influence of the bearing structure width to the total load bearing capacity was observed. In all specimens the failure occurred near by the clip connection. Failure modes were very similar in all experimentally tested cases. Post-critical behavior of Z-profile in clip area is represented by flange crippling initialized by web crippling (local) in early stage of loading, see Figure-10 and Figure-11.

CONCLUSIONS

The local resistance of thin-walled Z purlin (with the height 300 mm and thickness 1.90 mm) clip connection with the additional bolt connection thought the bottom flange of the purlin to the supporting structure was studied. The set of twelve experimental tests was carried out with four variable widths of the bearing structure (180, 200, 250 and 300 mm). The problem was solved also numerically, using non-linear finite element analysis. The numerical model takes into account constructional, geometrical and physical nonlinearities.

Both experimental and numerical results were compared; overall behavior of the samples was studied. There is a strong conformity of the results in all comparable outputs, namely the stiffness of the connection, overall deformation and especially the failure modes represented by web and flange crippling near by the clip area. Surprisingly, the influence of the bearing structure changing width was not significant. Similar failure of the Z-purlin occurred in all cases researched, also similar load bearing capacities were reached, varies between from 71 to 78 kN, independently to the width of the bearing structure.

The long term aim is of this research is to develop a design methodology for slender and tall Z-purlins connected by the clip to the bearing structure. Therefore, taking into account the results obtained in the experiments and numerical simulations, the research will continue for higher Z-profiles with different setup parameters. Because the numerical model well describes real behavior of tested samples, wide parametrical study will be performed based on those models.

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