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# PARAMETRIC STUDY OF HIGH THIN-WALLED Z-PURLINS STRUCTURAL CONNECTION WITH ADDITIONAL CLIP

Premysl Parenica, Oldrich Sucharda and Petr Lehner
Department of Structural Mechanics, Faculty of Civil Engineering, VSB-Technical University of Ostrava, Czech Republic
VSB-Technical University of Ostrava, Czech Republic
E-Mail: premysl.parenica@vsb.cz

## ABSTRACT

The article deals with the possibilities of connecting thin-walled purlins and supporting structures. The presented research is part of it the designing of large-scale halls field. For this type of construction the using of thin-walled purlins of higher structural heights is recommended. The behavior of the structure is highly influenced by different types of joints, by their number and also by other things. For example, geometrical and physical non-linearity must be including in numerical analysis. Experimental testing is also highly required. The main aim of the article is demonstration of parametric studies of a comprehensive series of experiments. The experiment results are presented in the context of the current design code. The evaluation is performed in the form of interaction (M/N) diagrams. Parametric study includes different thicknesses of steel, selected Z-purlins heights and several connection methods. The paper also contains a detailed determination of material properties of steel by tensile tests.

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

## INTRODUCTION

Thin-walled profiles structures as a part of the roofs are being used much more frequently in civil engineering [1], [2]. It is caused by several major pluses. Thin-walled profiles in combination with good mechanical properties of steel leads to reduction of weight and lower price on these structures [3], [4].

However, there are some disadvantages too. The designing of thin-walled profiles can be problematic due to complicated design methods [5], [6]. Also the important factors are loosing of stability of an element or buckling [7]. Thus, more advanced methods of designing and use laboratory tests are needed.

From the perspective of numerical modeling the finite element method [8], [9], [10] and nonlinear analysis are usually used [11], [12], [13]. For example software ANSYS can be used for numerical calculations [14].

Normative rules are usually issued using internal experiments. Their use is often limited to typical cases. Thus, the design of these structures is usually done using a design tables based on full-scale experimental test results. It is possible to perform tests for different cross sections, but different types of connections are difficult to prepare. A wide range of profiles must be considered. Similarly, different types of joints need to be evaluated. A large number of possible combinations bring complexity. Therefore, focusing on the most typical options is required. Typical cross-sections used in the practice are Z-profiles [15], [16].

For high beams, such as Z300 and Z350, overlapping with additional steel reinforcement appears to be the best solution. The effect of this clip on the total bending moment capacity above the support is the subject of this research.

## THIN-WALLED Z-PURLINS STRUCTURAL CONNECTION

The connection of thin walled purlins on the support structure has several possible solutions. The selection of the variant depends on the required spacing of the load-bearing structures and on the supporting structure type. Design of continuous beam along the entire length of the roof for higher distances of the main carrier frames and the larger dimensions of the roof purple structures is the most appropriate. This solution is statically more efficient and economical.

The typical variants of the solution for connecting the thin-walled roof purlins to the main supporting structure are shown in Figure-1.

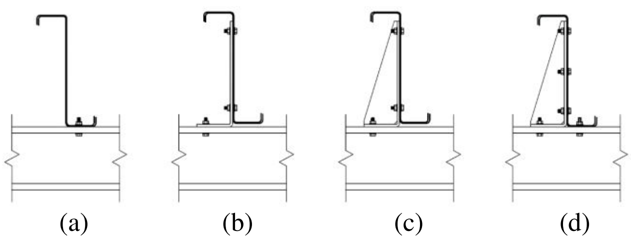


**Figure-1.** Types of connection Z-purlins to frame: (a) simple without clip, (b) with clip, (c) with stiffening clip, (d) with stiffening clip and with bolted on Z-purlins.

The figure shows four types of Z-purlins connection to frame. Variant (a) is simple joint by bolt without any clip. Against it variant (b) have not bolt in Z-purlins, but simple clip. Variant (c) uses stiffening clip. It must be said that in variant (b), and (c) is always a gap between the Z-purlins and frame, to prevent buckling and unwanted force transmission. Last variant (d) is combination of stiffening clip and classic simple joint by bolt on Z-purlins. The entire research presented here also focuses on this version of the connection.

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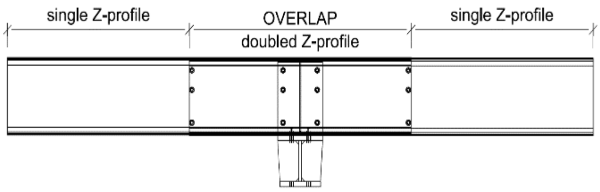
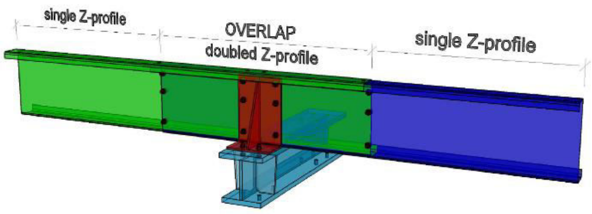
The connection should ensure the overall stability of the thin-walled profile at the support and enable axial (ideal) transfer of the internal forces to the superstructure. For all types of connection the common cross-sectional duplication over the support it is so-called overlap [2].

The Figure-2 shows the schema and the model of this overlap. The main factors for using this are increasing the total bearing capacity of detail, and better behavior for different load types. Also, it is better transmission of the transverse forces from the plane of the roof, and resistance to the horizontal forces caused by the bending of the irregular cross-section. This connection is successfully used for low purlins. However, behavior of high purlins is not currently sufficiently verified.




(a)




(b)

**Figure-2.** Overlap system: (a) a typical scheme (b) and the model.

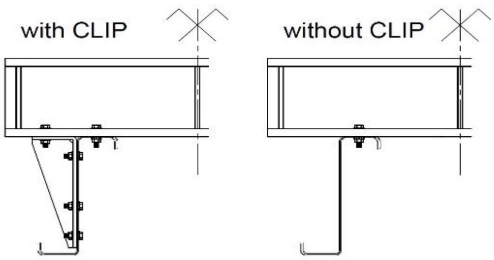
An advantage is the high variability of the overlap system. It is possible to use various highs of purlins, all types of clip etc. The design and assessment of these types of joints are not available into recommended design forms and normative regulations.

Thus, the area of design for the connection of thin-walled Z-purlin is chosen as the main field for this research. The assessment of these details is currently prepares on the basis of experience, internal tests and standard sheets of individual producer of these structures. Efficiency and economy is not sufficient and there are large reserves for optimization.

The paper is part of a long series that aims to gradually showcase the various possibilities of joints at different profile heights. The first results of the research have already been presented in [17], [18]. The article focused on several experimental tests that were made in the laboratories of the Faculty of Civil Engineering at VŠB-TU Ostrava. Real and calculated steel working diagrams are present and their use in numerical modeling of thin-walled structures is evaluated.

## DESIGN OF EXPERIMENTS

The set of experiments contained testing of the connection supporting between purlins and main frame. The configuration test was prepared from two thin-walled Z-purlins in symmetrical placement. The tests simulated the download and included type with a clip and without a clip (See Figure-3).




(a) (b)

**Figure-3.** Cross-section of the connection detail at the support point with clip (a) and without clip (b).

The overlap of the beams was used along the whole length. This eliminated the possible influence of the load bearing capacity exhaustion. This test arrangement ensures that capacity is exhausted directly in the detail of the connection. This phenomenon was desirable and one part of the research focuses.

Next, the symmetrical arrangement of the two Z-purlins were chosen, due better transmission of the transverse forces. The ends of the purlins were bolted to the thresholds, which were designed as articulated.

The static schema of the physical test corresponds to a simple supported beam with a point loads at the center of the span. Figures 4 and 5 shows a schematic view of one variation of test for example (Z300 profile).

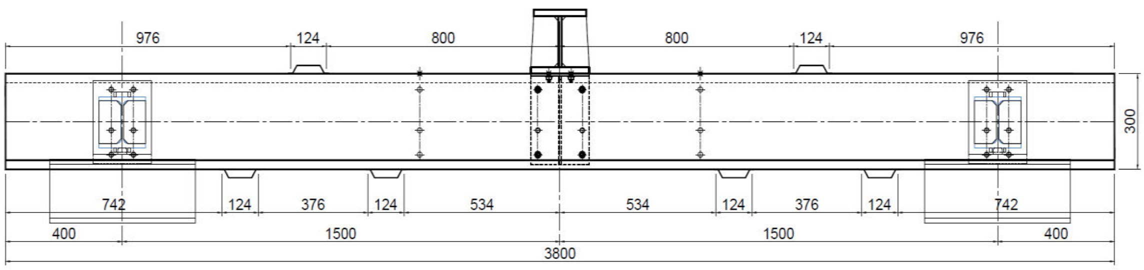



**Figure-4.** Scheme of the 3 points bending test at two Z-purlins (side view).

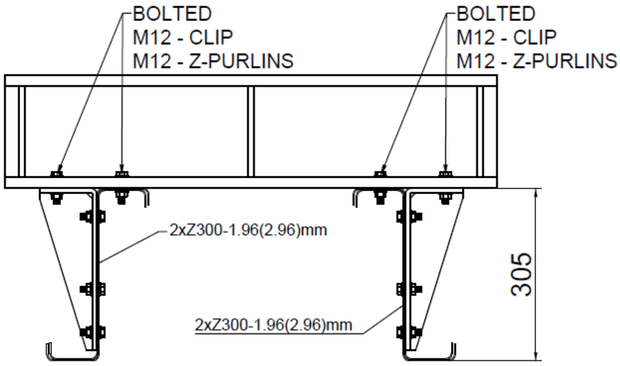



**Figure-5.** Scheme of the 3 points bending test at two Z-purlins (cross-section).

The loading was performed by a hydraulic press placed in the middle span. This transverse beam was the upper part of the main supporting structure.

The Z300 and Z350 purlins of 1.95 and 2.95 mm thickness were selected for testing. Selected details of thin-walled beams and transverse beam are shown on Figure-6.

(a)

(b)

**Figure-6.** Details of thin-walled beams and transverse beam from side view (a) and from bottom view (b).

The load from the hydraulic press and deformation by the extensometers at several important points of the structure (vertical cross-section shift and displacement above the support support) were recorded during the experiment.

The chosen method of testing and configuration of the experiment corresponded to the gravitational load (own design load, constant roof load, snow, etc.). This type of stress is called "download". This type of load is the most common and it is on every roof structure.

The combination of stresses at support point under load was observed. Specifically, it is bending stress and failure from pressure of beam on Z-purlins. The reinforcement of the overlap was modeled by a series of bolts. The M12 bolts without pads were used. During the load procedure, the Z-purlins were stabilized by crossbars, due avoid collapse of the beams before filling of maximum bearing capacity. The distance of supports for testing was 3.0 m.

## RESEARCH OBJECTIVES

The main aim of the article is demonstration of parametric studies of a comprehensive series of experiments. The details specifications and numbering of test is shown in Table-1. For comparison with the results of test the M/N diagrams were chosen. Individual sets were also compared to each other.

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**Table-1.** The schedule of inputs of physical tests.

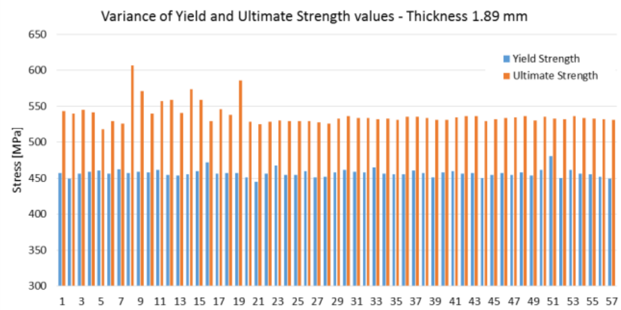
| No. | Thickness | Download | | | | | |
|---|---|---|---|---|---|---|---|
| | | Clip | Bracing width (mm) | | | | SUM |
| | | | 180 | 200 | 250 | 300 | |
| Z300 | 1.95 | WITH | 3 | 3 | 3 | 3 | 12 |
| | | NO | 2 | 2 | 2 | 2 | 8 |
| | 2.95 | WITH | 2 | 2 | 2 | - | 6 |
| | | NO | 2 | 2 | 2 | - | 6 |
| Z350 | 1.95 | WITH | 2 | 2 | - | - | 4 |
| | | NO | 1 | 1 | - | - | 2 |

The extensively measurement of the actual material thicknesses and real mechanical properties (yield strength, load limit, elongation) were necessarily parts of experimental assessment. The obtained data will be used in the future for validation of advanced numerical models.

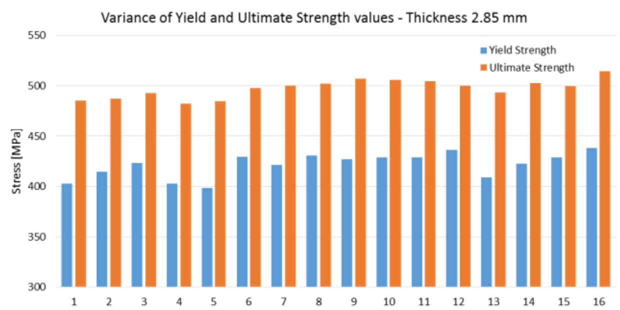
## MATERIAL PROPERTIES

The first and important part of the research was the determination of the actual properties of steel. The yield strength and the load bearing capacity of material are differ from the production information often. For thin-walled Z-purlins profile the S390 GD was chosen with declared yield strength 390 MPa. Whole set of results of the material properties from the tear tests were subsequently used in the analytical assessment of the test load bearing capacity and the compilation of the M/N diagrams.

However, he actual yield strength and working diagram of the material is necessary to know with regard to further advanced analysis and numerical modeling actual behavior of the elements during load process. Correct determination of material properties has a significant effect on the numerical model, especially in the area of the maximum load bearing capacity and in the critical phase when the thin-walled parts are crippling. For this reason, 57 tensile tests were performed on 1.95 mm thickness plates and 16 tensile tests were performed on 2.85 mm thickness plates. These plates were removed from the undamaged parts of the tested Z-purlins. Samples were cut from different test beams and their various parts. Figure-7 shown graphical results of whole test set of material properties.




(a)




(b)

**Figure-7.** The variation of material properties of the steel from tensile test. The 1.89 mm thickness [nominal value 1.95 mm] (a) and 2.85 mm thickness [nominal value 2.95 mm] (b).

Next, the procedure of calculation the actual work diagrams by numerical model the sample in ANSYS 16 program was chosen. The exact geometry was determined (see Figure-8a) and the finite element model was prepared (see Figure-8d). For compare of a precision the sample before test (see Figure-8b) and after tensile test (see Figure-8c) are shown.

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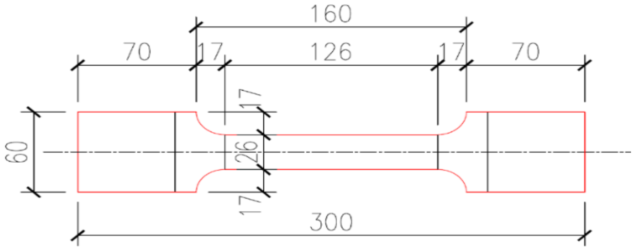
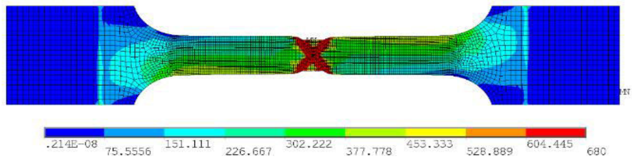



(a)

(b)

(c)




(d)

**Figure-8.** The exact geometry of sample for tensile test (a), sample before (b) and after test (c), and the finite element model, von Mises stress (d).

The tensile tests provided data in the form of a working diagram of the displacement of the press head and the applied load applied (see Figure 9).

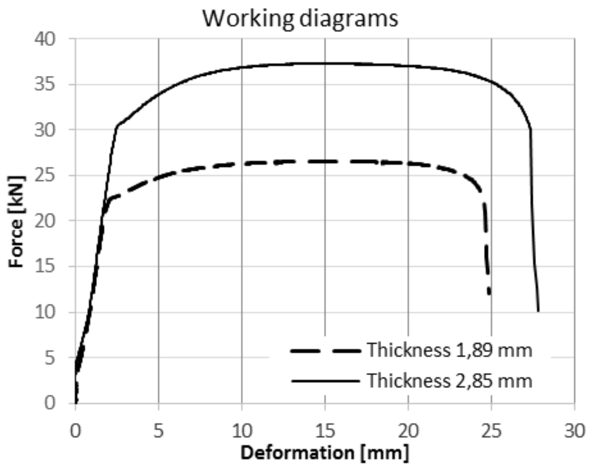



**Figure-9.** The working diagram for two tested samples.

The same data could be obtained from the numerical model. The multilinear material model was gradually modified by iteration to obtain working diagram corresponding to tensile test data.

The procedure from material model to working diagram for example is shown in Figure-10.

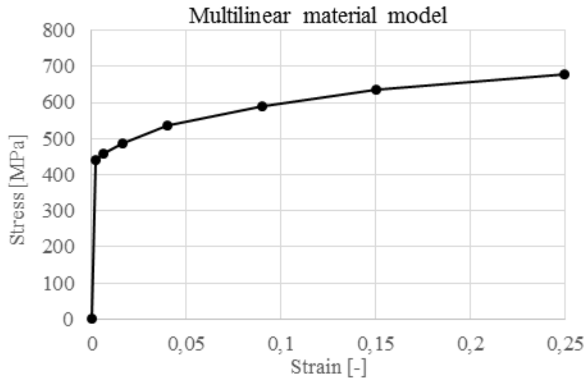



**Figure-10.** Possibilities of material models.

## RESULTS FROM EXPERIMENTS

The results of the laboratory tests included a several parts. Very important one was the maximum bending moment. This moment was calculated from the maximum force.

Table-2 shows a summary of the results for the six test type. There are combinations of two different heights of Z-purlins, two thickness value and also variation without clip and with clip.

**Table-2.** Summary of the average bending moment results.

| **Height of Z-purlins** | **Thickness** (mm) | **CLIP** | **Bending moment** (kNm) |
|---|---|---|---|
| 300 | 1.95 | NO | 32.2 |
| 300 | 1.95 | CLIP | 52.1 |
| 300 | 2.95 | NO | 65.7 |
| 300 | 2.95 | CLIP | 96.8 |
| 350 | 1.95 | NO | 34.5 |
| 350 | 1.95 | CLIP | 60.5 |

Very interesting were variations of mechanical failure of joints. As mentioned above, for example it is bending stress and failure from pressure of beam on Z-purlins (see Figure-11). Exhaustion of load bearing capacity occurs locally by loss of stability and plasticization of the cross-section.

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**Figure-11.** Detail of Z-purlins damage.

**COMPARE WITH CURRENT DESIGN CODE**

At present, the procedures and equations from design codes are used for assessment. Combined bending moment and local load or support reaction is calculated from equation (1) [1] (EN 1993-1-3, 6.28c):

$$\frac{M_{Ed}}{N_{c,Rd}} + \frac{F_{gd}}{R_{w,Rd}} \leq 1.25 \qquad (1)$$

In equation (1):

- $M_{Ed}$ is bending moment,
- $N_{c,Rd}$ is shear force,
- $M_{c,Rd}$ is moment resistance of the cross-section,
- $R_{w,Rd}$ is local transverse resistance of the web.

Equation (1) is possible to use to express the interaction diagrams. This corresponds to the load bearing capacity of the thin-walled profile in maximal combination of bending moment and shear force. The position of the points on the diagram can be expressed using the so-called M / N ratio.

Figure-12 shows interaction (M / N) diagrams by design code for Z300 purlin of 1.89 mm thickness with clip and without clip. Also includes results from tests number 1 to 12 with clip and 13 to 20 without clip. Figure-14 shows interaction diagrams for Z300 purlin of 2.85 mm thickness with clip and without clip. Also includes results from tests number 21 to 26 with clip and 27 to 32 without clip. Finally, figure-15 shows M / N diagrams by design code for Z350 purlin of 1.89 mm thickness with clip and without clip. Also includes results from tests number 34, 35, 37 and 38 with clip and from 33 and 36 without clip. Since the moment is dependent on the span of purlins, there is only one match between test result and each diagram (for 3 m span).

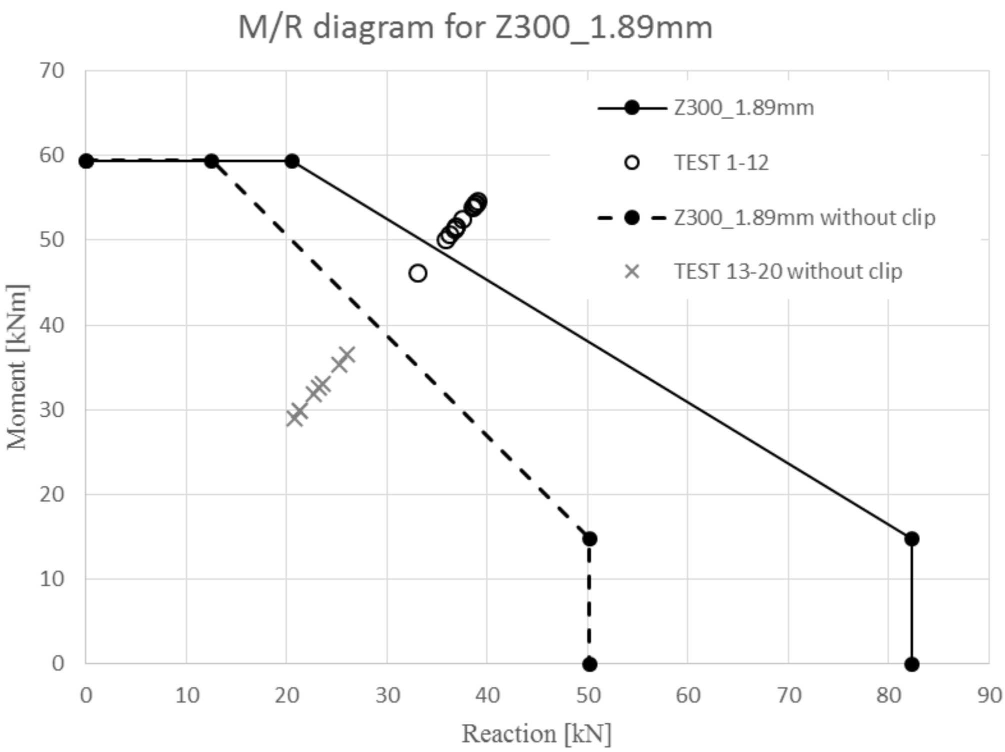


**Figure-12.** Interaction (M / N) diagrams by design code for Z300 purlin of 1.89 mm thickness with clip and without clip, and results from tests.

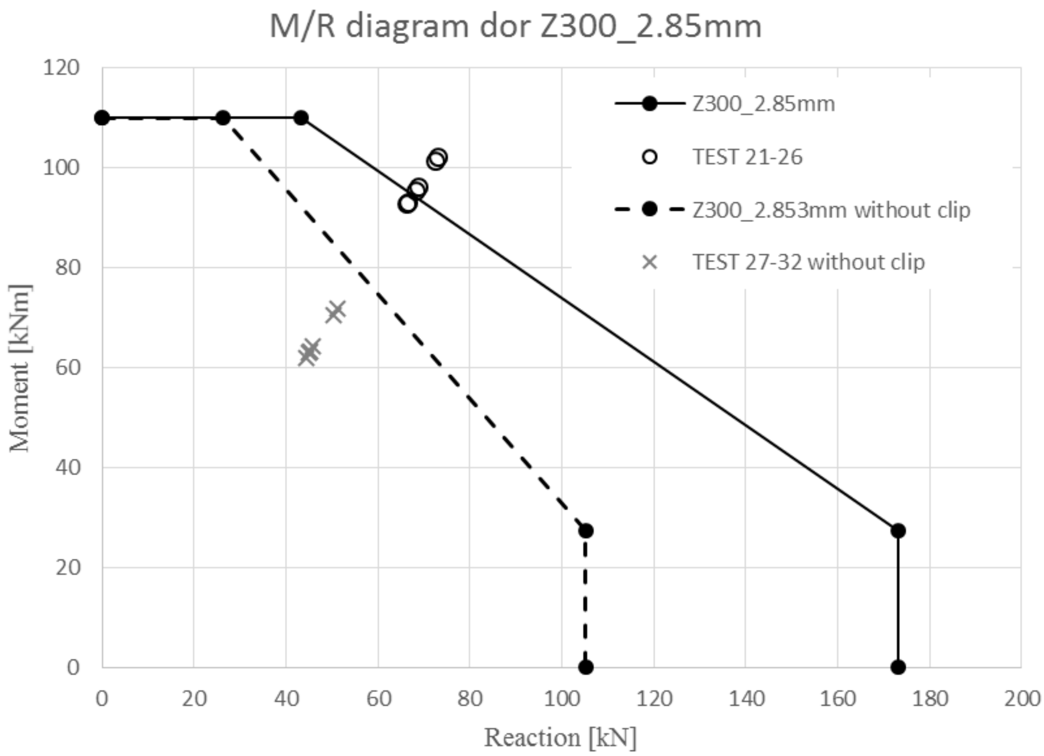


**Figure-13.** Interaction (M / N) diagrams by design code for Z300 purlin of 2.85 mm thickness with clip and without clip, and results from tests.

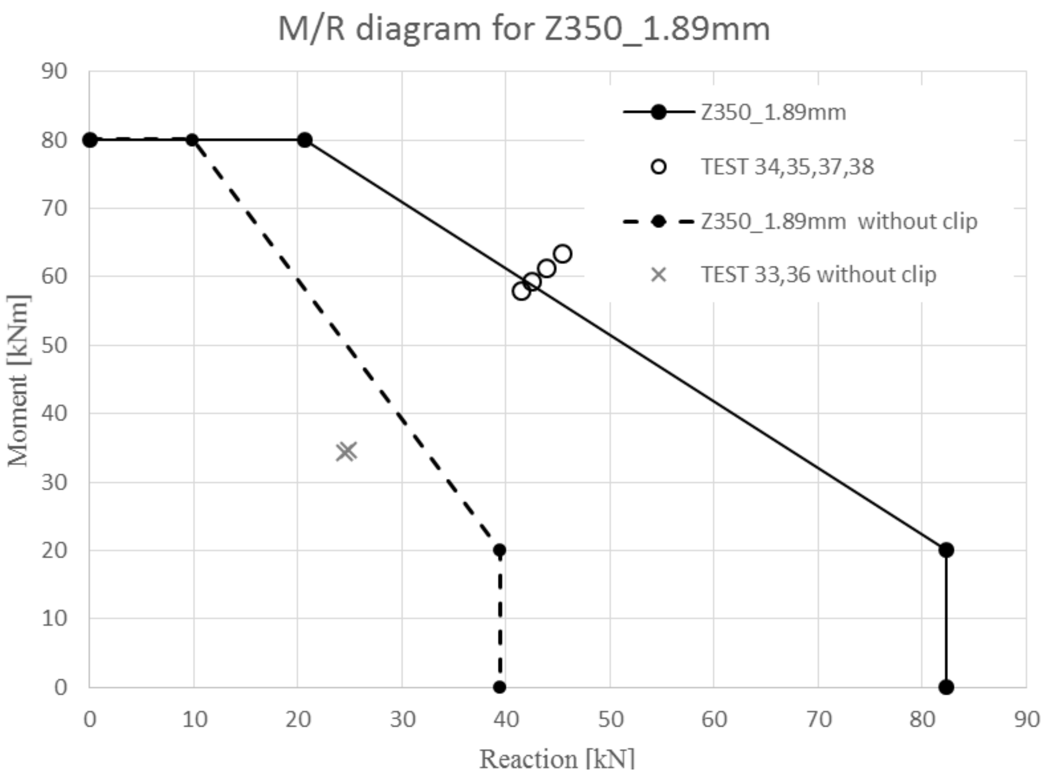


**Figure-14.** Interaction (M / N) diagrams by design code for Z350 purlin of 1.89 mm thickness with clip and without clip, and results from tests.

## CONCLUSIONS AND DISCUSSIONS

The paper presented a parametric study of the experimental testing of the connection of thin-walled Z-purlins and roof structure frames. The Z300 and Z350 purlins were chosen. These are can be used on designing of large-scale production halls. However, it is not common in practice yet. The main reason is complicated design and unpredictable construction behavior. Detailed numerical analyzes combined with detail testing can bring usable suggestions.

This parametric study presents extensive testing of thin-walled structures. The results are evaluated against the interaction diagrams from the design code. It is considered with several thicknesses and with different reinforcement of connection - with clip and without clip.

Results graphs show that the clip increases the stability of the connection. Values of load bearing capacity correspond to the results of the analytical solution. On the other hand, in the case without a clip it is not true. Results from the analytic solution are higher than tests results.

Further research in this area is required. It is necessary to test different purlins support span for comparison with the interaction diagrams.

## ACKNOWLEDGEMENTS

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