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THE METHODOLOGY OF DETERMINING THE LOAD-BEARING CAPACITY OF HIGH PROFILE SHEETS USING THE EXPERIMENTAL METHOD

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Abstract

In civil engineering, high-profile sheets (HPS) are widely used. They are used as load-bearing elements in a system of stacked roofs, for covering large-span structures or as permanent formwork when casting concrete slabs. Determining the load-bearing capacity of these elements is a complex task, and designers take this data from the manufacturer's catalog. Data on the load-bearing capacity are usually given depending on the serviceability limit state (SLS), without special consideration of the support conditions. For these reasons, this paper presents an in detail methodology for determining the load-bearing capacity of a standard type of HPS, using an experimental method. The research was carried out on a sheet panel with a span of 6000 mm of a simple beam static system. The length of the support on the purlin was 200 mm and it was secured with eight bolts. The load to failure test was conducted according to the SRPS U.M1.047 standard using the method of applying an equally distributed gravitational load. The experimentally obtained results were compared with the catalog values provided by the manufacturers. The test showed that the applied support conditions (length of contact with the purlin, number and arrangement of connecting means in the connection) have a positive effect on increasing the load-bearing capacity and cost-effectiveness of the HPS.

Key words: *High profile sheet, Experimental test, Load-bearing capacity*

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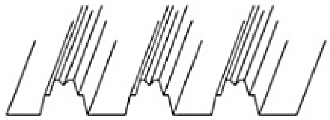
1. INTRODUCTION

Modern trends in civil engineering necessitate an increasingly frequent use of prefabricated elements, which are an imperative for rapid construction. For this reason, the use of second-generation high-profile steel sheets [1] has facilitated completely new architectural solutions in the design of structures. The main reason for this is that these elements provide, above all, an economically advantageous solution for cladding and covering large industrial, sports and agricultural facilities. Thanks to the specific shape of the cross-section (Figure 1), as well as their light weight, they are most often used for medium and large spans. They are laid over the purlin, connected with appropriate fasteners, so in addition to their basic role, they can often interact with the main structure, contributing simultaneously to its spatial stability (stressed skin concept) [2].



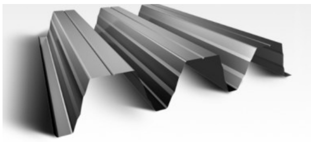


Figure 0. High profile sheets of second generation [1,3]

Data on the load-bearing capacity of HPS are regularly provided in manufacturers' catalogues. The load-bearing capacity is most often given as a function of the allowable deflection (serviceability limit state – SLS), and much less often as the strength at failure (ultimate limit state – ULS). Since in practice HPSs are most often laid on the main supporting steel structure with different support lengths, and the connection is achieved with bolts, data on these support conditions are usually omitted from manufacturers' catalogues.

This paper presents a methodology for determining the ultimate strength of capacity of a standard type of HPS experimentally. A special attention is paid to the support conditions, because in addition to the height of the profile, span and static system, the load-bearing capacity of HPS may also depend on the contact length of the support and the number of fasteners in the connection.

2. EXPERIMENTAL SETUP

2.1. Objectives and the subject of the experimental research

Determining the load-bearing capacity of HPS using analytical methods is a complex task, considering the geometry and complex behavior of the structure in the post-elastic zone. Therefore, in this paper, an experimental analysis was implemented to determine the limit states of the type TR 153 HPS. It will provide recommendations to future designers and manufacturers for designing and conducting their own research when using this type of structure. The analysis will also show to what extent the applied parameters affect the ultimate strength of the HPS.

2.2. Structural static system and support conditions

The determination of the load-bearing capacity of the HPS TR 153 was performed on a sheet metal specimen of a manufactured width of 870 mm, thickness of 0.73 mm and a spacing between supports (clear opening) of 6000 mm. The specimen was made of steel of strength class S320G. The static system was assumed to be a simple beam, which is the most common case when designing and constructing this type of roof covering. The selected type of HPS has a significant load-bearing capacity, and therefore a contact length of with the purlin of 200 mm was adopted. Supports (purlins) consist of two hot-rolled ⊏160 profiles. For the purpose of achieving the desired contact length of 200 mm, additional 10 mm steel plates were welded onto the profiles. Bolts M6x20...8.8 were used as fasteners of the sheet and the purlin, with a wide flat washer between the bolt and the sheet. Purlins are rested over the auxiliary supports anchored into the concrete floor slab. Figure 2 shows the specimen setup with the support structure.

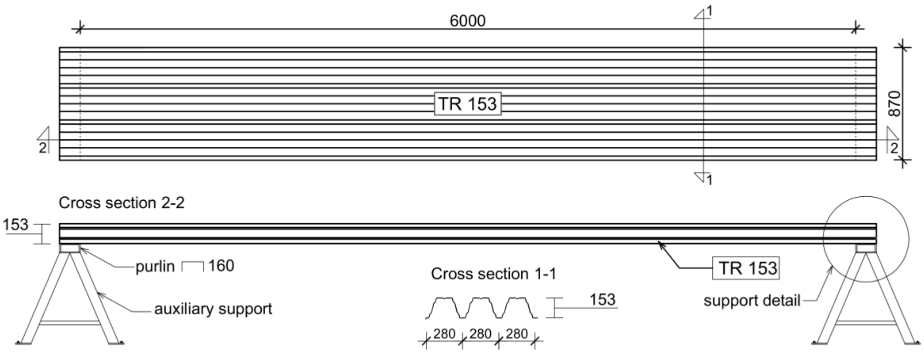
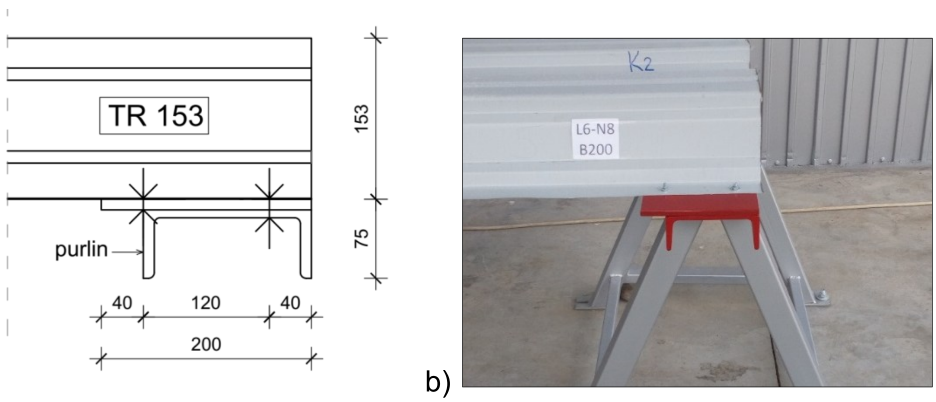


Figure 2. Setup, longitudinal and transversal cross-section of the test specimen, source: Authors

The connection between the sheet and the purlin is achieved with eight bolts, which are placed in two parallel rows at a distance of 40 mm from the longitudinal edges of the purlin. By placing the bolts in two parallel rows, a force coupling is formed in the connection, which brings about a certain degree of restraint (Figure 3).



a) b)

Figure 3. Case N8 B200 support details: a) workshop drawing; b) experiment, source: Authors

2.3 Test load application methodology

The procedure for applying a test load is defined in a large number of world standards [4, 5, 6]. In this study, the bending test of the specimen was performed under an equally distributed - gravitational load until failure, by applying bags weighing 0.25 kN, and according to the adopted loading pattern (Figure). This method of applying the load has been changed by a large number of researchers [7, 8, 9]. Testing under gravitational load is simple and economically advantageous, especially from the point of view of the availability of the test load, as well as the potential of field application. One of the disadvantages of this method is the need to add bags according to a certain scheme, in order to simulate a load equally distributed on the specimen.

Based on the data on the load-bearing capacity of the tested samples provided by the catalogs, and the standard recommendation that a single load step should not exceed 1/6 of the maximum load, it was adopted that the gravity load be applied in steps of 0.2 kN/m^2. Considering that the surface area of the tested specimen was 5 m^2, in each step (stage) 4 bags corresponding to the force of 1 kN were added, which corresponds to the surface load of 0.2 kN/m^2 (Figure). The dead weight of the sample was 0.1 kN/m^2 and it was taken into account when calculating the equivalent surface load in all load stages.

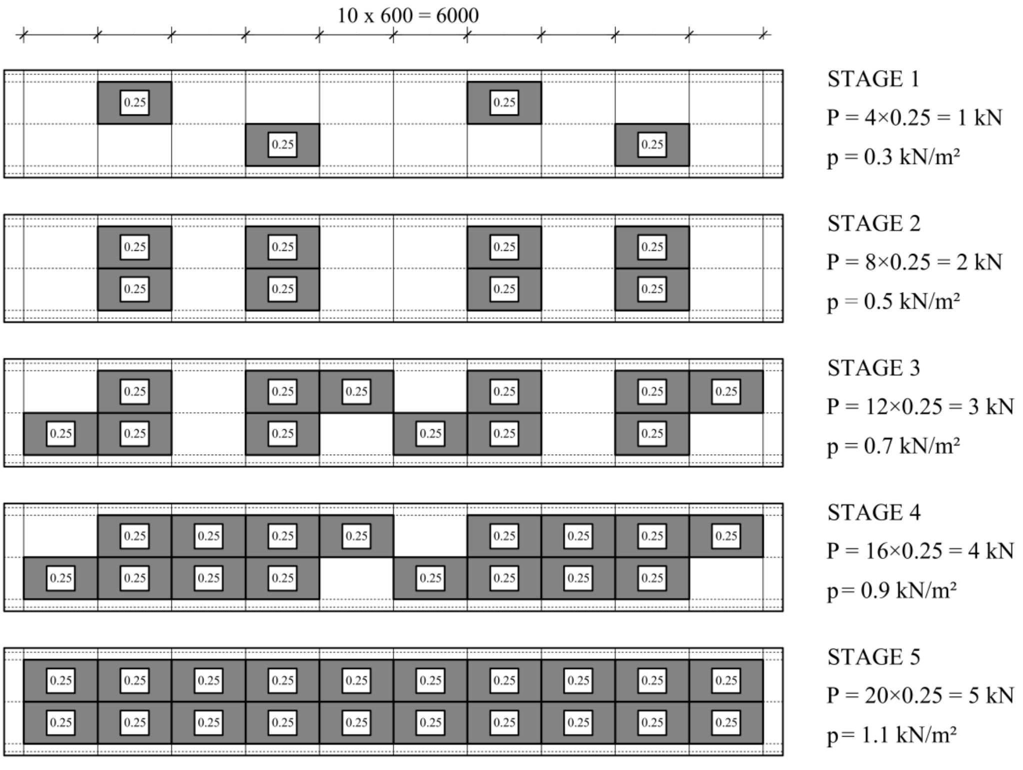


Figure 4. Loading the sample in stages; legend: P – applied force [kN], p – equivalent surface load [kN/m^2], source: Authors

After stage 5, bags were applied in the second layer according to the same load pattern (stages 1-5). The procedure was repeated until the sample failure.

2.4 Measuring points setup and load process

During testing of specimens with equivalent uniformly distributed load, deflection measurements were performed at half and quarter spans. The arrangement of measurement points is shown in Figure 5.

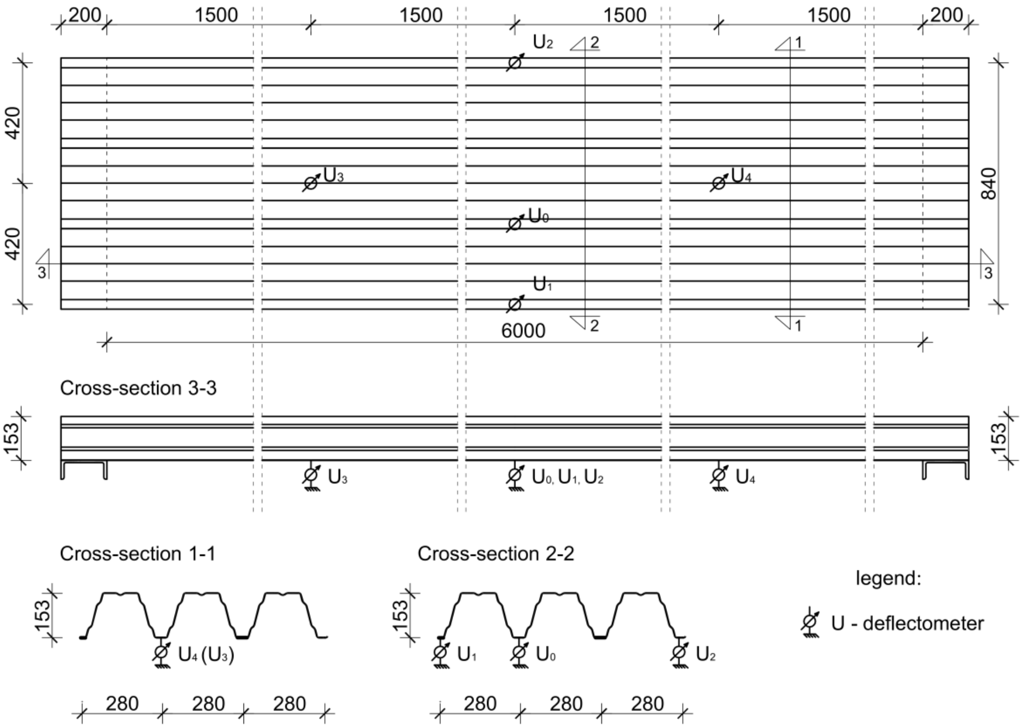


Figure 5. Graphic display of measuring points arrangement, source: Authors

The deflection was measured using linear variable differential transformers (*LVDT*), and mechanical deflectometers and the obtained signals were processed using the measuring-acquisition system *MGCplus* and software package *CATMAN.*

The sample testing process was performed according to the current national standard SRPS U.M1.047 [10] with certain adjustments to the test subject. The sample was first loaded to an operational load of 1.6 kN/m^2, which approximately corresponds to 65% of the assumed load capacity of the sample (p_u). The load was maintained at that value for 5 minutes, after which it was reduced in equal steps to 0.1 kN/m^2. This load was maintained constant for 5 min, and then increased until the specimen failed. The highest load applied during the test was taken as the specimen's load capacity (p_u).

3. RESULTS OF THE EXPERIMENTAL ANALYSIS

Based on the previously described experimental setup, this chapter presents the obtained results of the measured deflection for all measurement POINTS, as well as deflection diagrams in two orthogonal directions (gravity axes). FigureFigure 6 shows sample arrangement and support conditions under load p = 2.5 kN/m^2, where the emergence of a certain degree of restraint in the connection between the sample and the support can be observed. Bolts, set in two rows, reduced lifting of the edges of HPS and rotation of the support cross-section. The lower flange of the specimen, which is in contact with the inner edge of the support is crushed. This is a consequence of the small thickness and rigidity of the base material (Figure 6-б).

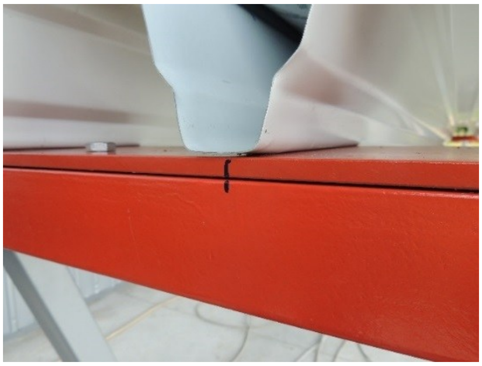
a)  b) 

Figure 6. Specimen N8 B200: a) Arrangement of HPS under load p=2.5 kN/m^2 b) support detail under p=2.5 kN/m^2, source: Authors

The obtained results are presented in the following diagrams (Figure 7, Figure 8, Figure 9, Figure 10).

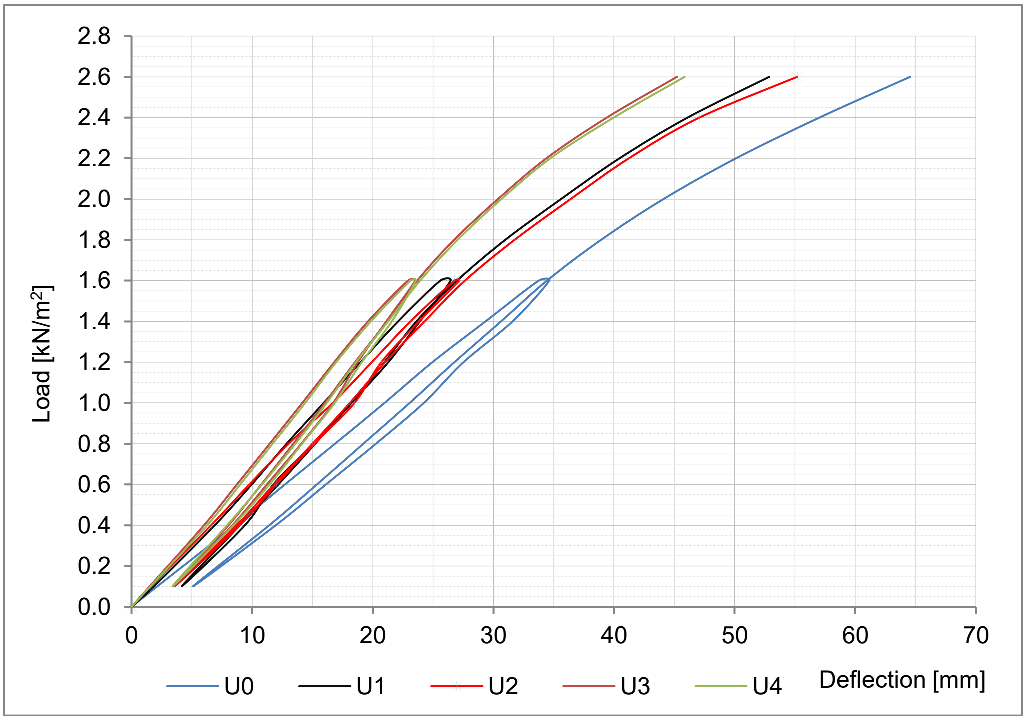


Figure 7. Load-deflection load in the measuring points U_0; U_1; U_2; U_3; U_4

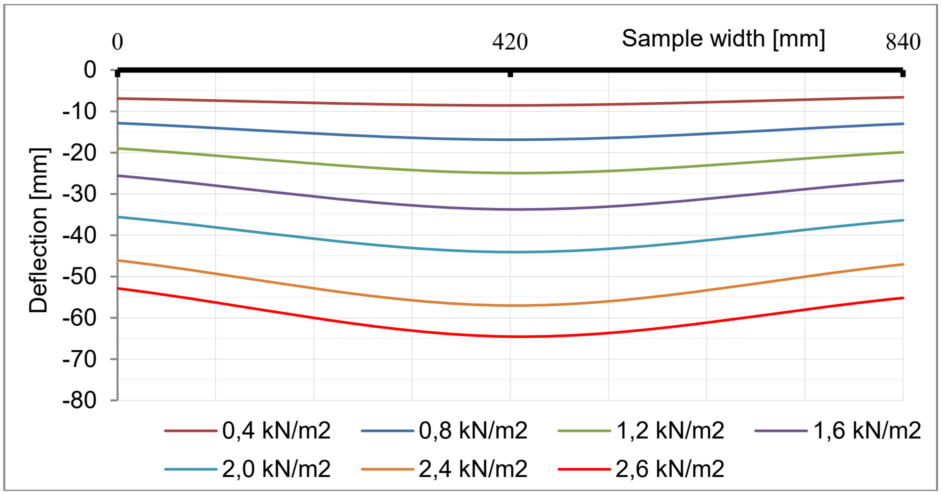


Figure 8. Mid-span cross-section deflection diagram, source: Authors

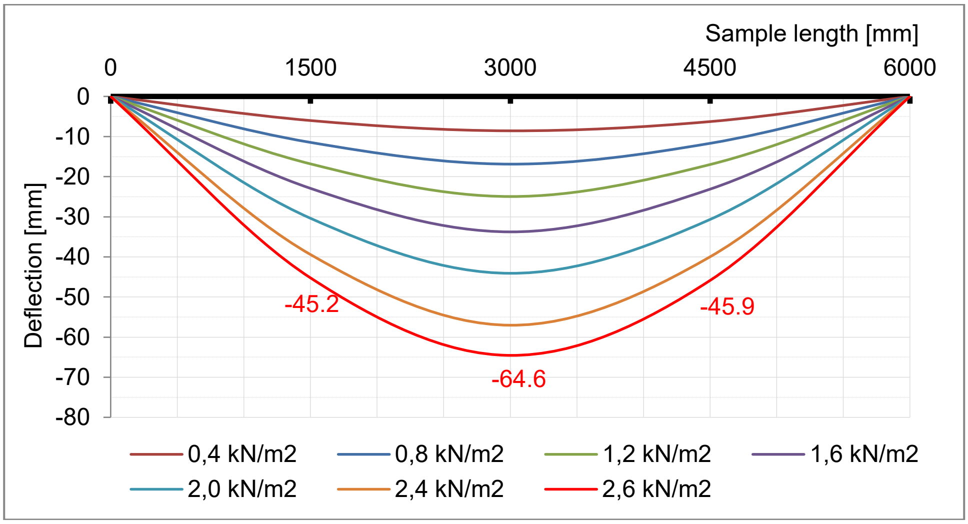


Figure 9. Deflection at the middle of sample width – longitudinal cross-section diagram, source: Authors

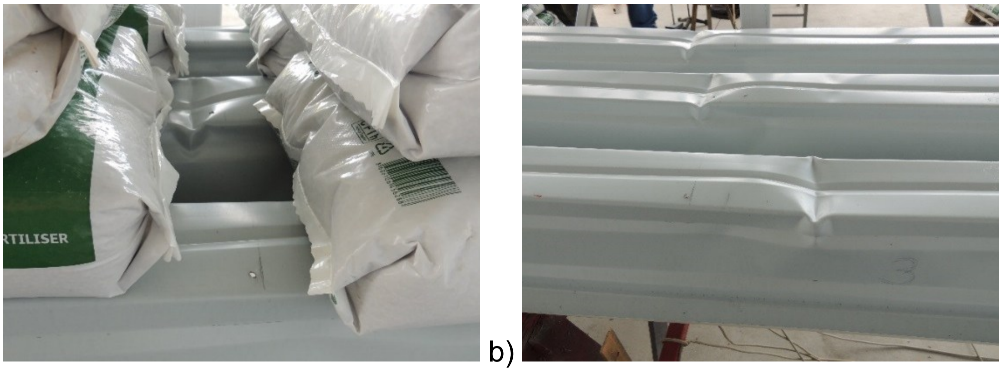
a)  b)

Figure 10. Specimen N8 B200 under the load 2.6 kN/m^2: a) plasticization of the upper flange of the medium crease, b) appearance of the specimen after failure, source: Authors

In the diagram shown (Figure 7) it can be seen that the load-deflection curves are not ideally smooth, due to the interruption in the load application for reading the results from the deflection gauge. The fracture location of the specimen is approximately at mid-span and occurs as a consequence of the local buckling of the upper flange of the specimen (Figure 10), at maximum load p_u=2.6 kN/m^2.

3.1 Discussion and comparative analysis of the results

Since the serviceability limit state is far more important for practical engineering applications, Table 1 provides comparative results of the load-bearing capacity of the analyzed specimen with the available results from the catalog of well-known manufacturers of TR153, for the most commonly specified deflection limits [11, 12, 13, 14].

Table 1. Load bearing capacity TR153 at the given deflection

source	t [mm]	N [n]	B [mm]	p [kN/m2]			
				l/150	l/200	l/300	l/500
Experiment	**0.73**	**8**	**200**	**1.85 (100%)**	**1.43 (100%)**	**0.90 (100%)**	**0.55 (100%)**
Arcelor Mittal	0.75	-	40	0.84 (45%)	0.84 (59%)	0.76 (84%)	-
Balex	0.75	-	60	1.70 (92%)	1.33 (93%)	0.93 (103%)	-
INM Arilje	0.75	-	-	-	1.27 (89%)	0.85 (94%)	0.51 (93%)
Prodanović	0.75	-	90	1.75 (95%)	1.29 (90%)	0.82 (91%)	0.45 (88%)

legend: „-“ data unknown

From the data presented (Table 1), it can be seen that all manufacturers define the load-bearing capacities of their products without a defined number of fasteners in the connection. Also, some manufacturers recommend a very small conteact length, which is unrealistic for practical application for the considered type of HPS.

5. CONCLUSIONS

Based on the conducted research and previous analysis of the results, the following conclusions were drawn:

- The specimen fracture occurs due to local buckling and wrinkling of the upper (pressed) flange at the half the specimen span, which indicates that stress analysis is not of primary importance in determining the load-bearing capacity of the HPS.
- The cross-sectional deflection diagram at mid-span indicates that the deflections are unevenly distributed across the width of the section, i.e. the deflections at the edges of the section are smaller than the deflection at the center of gravity. This phenomenon manifests itself as end-lifting, i.e. the

tendency for the complex geometry of the cross-section to straighten into a flat plate and behave like a tensioned membrane.

- The constructed connection between the specimen and the support using eight bolts significantly reduced the rotation of the support cross-section and the lifting of the specimen ends from the support plate, which indicates the occurrence of a certain degree of restraint in the connection.
- The analyzed length of the contact area and the number of fasteners in relation to the support contributed to the increase in the load-bearing capacity and stiffness of the HPS. The differences in the results were considered in accordance with the available catalog data and ranged from 3% to 55%.

Considering the results of the experimental analysis, it can be concluded that the applied support conditions have a positive effect on the ultimate bearing capacity of the HPS. By varying the length of the support, the number and arrangement of the fasteners, more favorable solutions could be obtained from the aspect of the bearing capacity and serviceability of the structure.

The methodology described in this paper according to which the experimental analysis was carried out represents a quick and simple way to determine the mechanical behavior of HPS beams. A downside of the application of the gravitational load application test method is the insufficient precision in determining the ultimate load capacity, because the load is not applied continuously, but in stages.

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