Romanian application of cold-formed steel beams with screwed corrugated webs

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EXPERIMENTAL INVESTIGATIONS OF COLD-FORMED STEEL TRAPEZOIDAL BEAMS OF SCREWED CORRUGATED WEBS

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Abstract: The paper presents the results of a new experimental investigation on steel trapezoidal beams made by cold-formed steel profiles for flanges (i.e. back-to-back lipped-channel sections) and corrugated sheets for web. The tests were carried out at the Technical University of Cluj-Napoca in co-operation with Politehnica University of Timisoara. Self-drilling screws have been used both for connecting the flanges to the web and as seam fasteners to ensure the continuity of the web. Monotonic tests were performed on two beams of 12 meter span, having different connecting arrangements between the flanges and web.

1. Introduction

The use of corrugated webs instead of plain ones brings many advantages but also several disadvantages. One major disadvantage derived from the production cost of the corrugated sheets and their connection with the flanges. Keeping the web of the beam, the reduction of self-weight is possible by the reduction of the thickness, resulting high slenderness and higher risk of web buckling. The use of corrugated web for the beam increases the shear buckling stability. As a result of its profiling, the web does not participate in the longitudinal transfer of bending stresses. Therefore, in static terms, the corrugated web beam behaves similar to a lattice girder, in which the bending moments and applied forces are transferred only via the flanges, while the transverse forces are only transferred through the diagonals and verticals of the lattice girder, in this case the corrugated web. So, the girder's flanges provide the flexural strength of the girder with no contribution from the corrugated web which provides the girder's shear capacity. The failure of the corrugated web occurs by steel yielding, web buckling (local or distortional or their interaction). Lateral-torsional buckling of the girder and local flange buckling of corrugated web, separately or in interaction, represent other possible failure modes. The Austrian company Zeman supply single story steel structures with large spans, using welded thin corrugated web to thick flanges [1].

Research related to bending moment capacity of corrugated web beams was done by Lindner and Aschinger [2,3]. They demonstrated that web shear flux produces weak axis bending moments, which reduce the overall bending moment capacity of the structural element. Sherman and Fisher [4] were studied the corrugated web and flange connection of such beams. They concluded that is enough to weld only the longitudinal edge of trapezoidal sheeting, to carry the longitudinal slippage between web and flange.

Lindner [5] studied by experimental tests the lateral-torsional behaviour of steel girders with corrugated webs and found that the torsional section constant I_T for a beam with corrugated web doesn't differ from that of a beam with flat web, but the warping section constant I_w is different.

The dimensioning of corrugated web beams is ruled by Annex D of the EN 1993-1-5:2006 [6], together with specific aspects of EN 1993-1-1:2006 [7] and EN 1993-1-3:2006 [8].

A new technological solution of such a system, composed by webs made of trapezoidal cold-formed steel sheets and flanges of built-up cold-formed steel members (back-to-back lipped channels) has been developed at the CEMSIG Research Centre (http://www.ct.upt.ro/en/centre/cemsig) of the Politehnica University of Timisoara [9-10]. The connections between flanges and web were made with self-drilling screws. Five beams with different arrangements for self-drilling screws and shear panels have been experimentally tested. It should be emphasize the new solution, as a whole, is 100% composed by cold-formed steel elements, avoiding the combination of two types of products, i.e. cold-formed for webs and hot-rolled for flanges.

A similar solution has been proposed and analysed in the frame of PRECASTEEL project [11], but using blind rivets as seam fasteners for the corrugated web and bolts for web-to-flange connections. For flanges, back-to-back lipped channel or two types of hat-sections have been used. Deep corrugation web sheeting of longitudinal intermediate stiffeners have been applied in this solution. However, looking to the test results, one observes the sensitivity to distortion of corrugation still remain high.

A structural steel solution used for portal frame configuration has been investigated at the Technical University of Cluj-Napoca [12]. The frame is made ~~from~~ by cold-formed steel beams with screwed corrugated web and SHS columns, ~~presenting~~ showing very good structural performance.

By extending the application of the technical solution described in [9-10] for parallel flanges girders, promising experimental results have been obtained on trapezoidal beams made of cold-formed steel profiles and corrugated web [13]. Monotonic test were performed on two beams of 12 meter span, having different connections between the flanges and web. The paper presents the experimental program and the obtained results.

2. Design of beam specimens for testing

In order to obtain realistic specimens for testing the selected geometry of the corrugated web beam was considered similar with the cold-formed steel truss solution tested by Jakab et al. [14]. Fig. 1(a) presents the structural solution [12] based on a pilot project, while Fig. 1(b) shows the geometry for the beam considered for testing and the main dimensions. The loadings considered for the predesign phase of the beam with corrugated web have been selected according to specific loading conditions for Cluj-Napoca / Romania, i.e.: (1) dead load from cladding: 0.20 kN/m^2 (γ_G=1.35); (2) technological loading: 0.15 kN/m^2 (γ_G=1.35); (3) snow loading: 1.5 kN/m^2 (γ_S=1.5).

Fig. 1: (a) Structural solution; (b) Geometry of the proposed specimen for testing

In case of 4 m bay, a total load of 10.89 kN/m for ULS stage has been obtained. Purlins at a distance of 1.5 m, equally distributed, have been used, considering the slope of the roof of 10%. For the beam test setup, a similar load distribution was used applying concentrated loads into 8 points, i.e. the geometrical location corresponding to the purlin location (see Fig. 2).

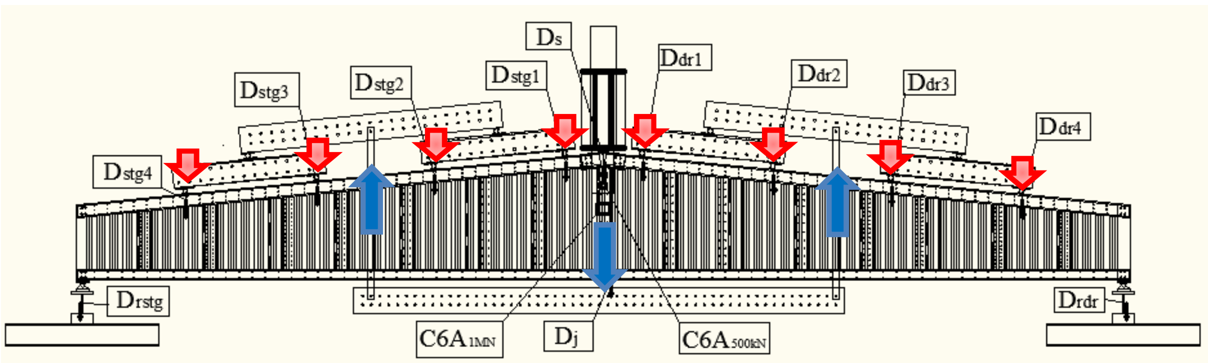


Fig. 2: Load/measuring device distribution for the experimental test

Two beams with corrugated webs with a span of 12 m have been selected for testing, considering different arrangements for self-drilling screws, denoted as Beam-1 and Beam-2. Fig. 2 presents the components of the beams with corrugated web, i.e.

- back-to-back lipped channel sections for upper flanges – 2×C150/2.0 (grade S350GD+Z);
- back-to-back lipped channel sections for upper flanges – 2×C120/2.0 (grade S350GD+Z);
- corrugated web with the corrugation depth of 43 mm and the thickness of 0.5 mm – LTP45/0.5 (grade S250GD+Z);
- reinforcing shear panels – supplementary plates of 0.5 mm thickness and 830 mm length, at the beam ends where the shear force is maximum (doubling the corrugated web on both faces) (grade S250GD+Z);

- self-drilling screws of 4.8 mm diameter with EPDM washers for both flange-to-web connection and seam fasteners for corrugated webs;
- bolts M12 class 8.8 for upper flanges to the end support connection.

Due to constructive reasons, the beam assembly includes 3 welded pieces: two identical one over the supports, to be able to distribute the support reaction at the full height of the beam and one central piece for the upper flange joining (see Fig. 3).

Fig. 2 presents the experimental arrangement. Ten points bending tests, monotonically conducted, were applied for each specimen with a loading velocity of 2 mm/min.

The full-scale testing program was completed with tensile tests to determine both the material properties for beam components and the behaviour of connections.

Fig. 3: Support and ridge detail of the tested beam

The flat sheet disposed in the support area is fixed to the support element and to the flanges. Supplementary, uniformly distributed local fixing to the web trapezoidal sheeting was applied. The continuity of the web was realized by overlaps and 2 rows of seam fasteners, following the principle of stressed skin action. The number of the seam fasteners was determined by the level of shear forces, increasing in the area of the supports and reducing the number in the span.

In Fig. 4 are presented the details of the seam fasteners distribution of the corrugated webs, i.e. 16 pcs. uniformly distributed in the support area and 11 pcs. in the span. The difference between Beam-1 and Beam-2 specimens was the number and the distribution of the flange-to-web fasteners (see Fig. 5) and the thickness of the web in the support area, i.e. Beam-2 specimen had a double web (2×0.5 mm thickness of corrugated sheet) on ¼ of the span. The specimens Beam-1 and Beam-2 had totally 300 kg and 320 kg respectively.

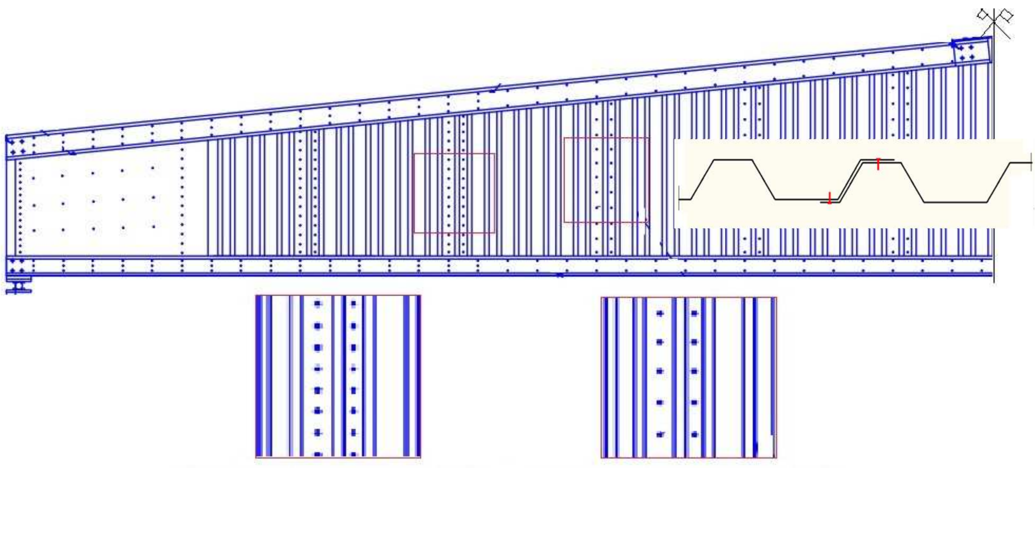


Fig. 4: Seam fasteners used for web sheeting: 16 seam fastener in support area and 11 seam fasteners in span (overlap details)

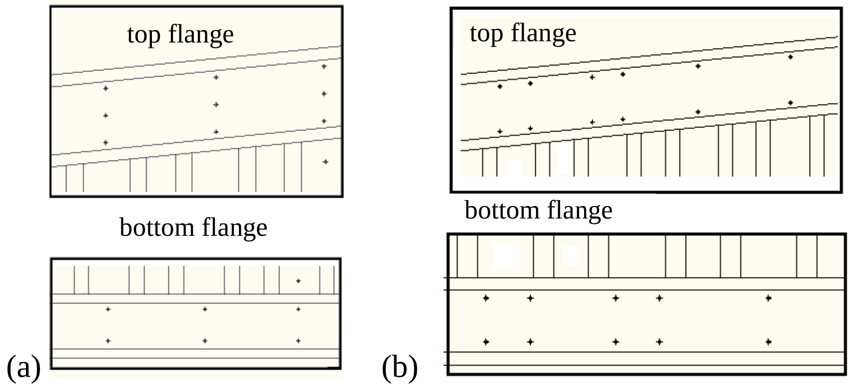


Fig. 5: The distribution of the flange-to-web fasteners for top and bottom flanges. (a) Beam-1; (b) Beam-2

3. Experimental setup

The testing of Beam-1 and Beam-2 specimens was done in the Structural Testing Laboratory of the Technical University of Cluj-Napoca. The main objective of the testing program was to define the load carrying capacity of the specimens and to compare the results with preliminary FEM results, used for the design of the specimens.

The specimens were loaded monotonically, with the load distribution according to Fig. 2. The loading of the specimen was done with 2 parallel devices, as shown in Fig. 6, the distribution of the load was ensured in 8 points as can be seen in Fig. 6. The load distribution devices were stabilized laterally by the vertical guiding elements, braced in 4 points.

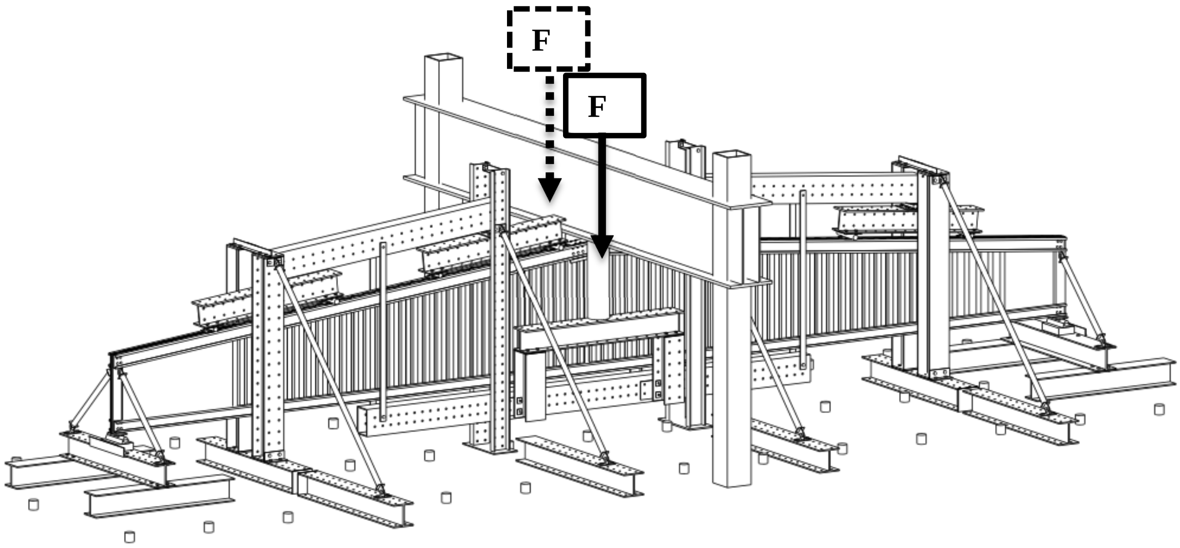


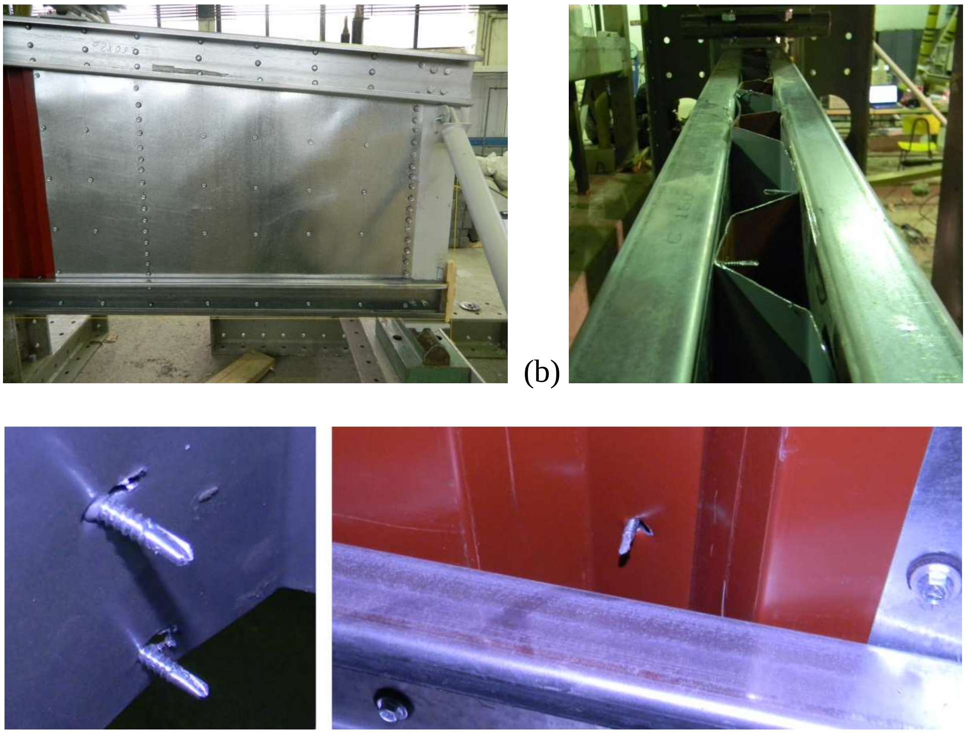
Fig. 6: Experimental arrangement with load application points

To keep the applied load position constant in the mid span, double hinged supports were selected. Because the upper support, point was free to move along the beam line (only the out-of-plane movement was locked by the support brace). Preliminary FEM analyses confirmed that no important differences were recorded between double hinge and simply supported configuration results.

4. Test results

The first tested specimen was Beam-1. In this case the first deformation, which corresponds to the buckling of shear panel, appears for a displacement of 13 mm at 28 kN (see Fig. 7a). At 21 mm small distortions of the corrugated web have been recorded for a load of 55 kN, as shown in Fig. 7b. For a displacement of 40 mm, corresponding to a load of 90 kN, two screws located at the bottom flange near support failed in shear, followed by failure in bearing of web-to-flange connection (see Fig. 7c).

The initial stiffness of $K_{0\text{-}Exp}$ = 1998.3 N/mm has been obtained and the maximum load is reached at F_{max} = 101.1 kN. The collapse ~~appears for a~~mechanism produced at displacement of 64 mm. Fig. 8 presents the deformed shape of the beam at collapse.



(a) (b) (c)

Fig. 7: (a) Deformed shape of the beam end shear panel; (b) distortions of the corrugated web; (c) failure in bearing of web-to-flange connection

Fig. 8: Deformed shape of Beam-1 at failure

In the case of second specimen, i.e. Beam-2, the number and distribution of screws for web-to-flange connections have been change (see Fig. 5b), together with the addition of extra corrugated sheet panels (i.e. 3 widths of sheet, resulting in 2×0.5 mm thickness of corrugated sheet, including the shear panels) near each support.

In this case the first deformation, which corresponds to the buckling of shear panel, appears for a displacement of 14 mm at 51 kN (see Fig. 9a). At 35 mm small distortions of the corrugated web have been recorded for a load of 120 kN. For a displacement of 41 mm, corresponding to a load of 128 kN, local buckling of the top flange has been observed (see Fig. 9b). The initial stiffness of $K_{0\text{-}Exp}$ = 3830.0 N/mm has been obtained and the maximum load is reached at F_{max} = 138.6 kN.

(a) (b)

Fig. 9: (a) Deformed shape of the beam end shear panel; (b) local buckling of top flange

Due to the non-uniform loading (loading devices were controlled manually), out-of-plane stability loss of the upper flange between stabilization points was recorded, resulting in a lower load carrying capacity, than the estimated (without considering load introduction imperfections). The collapse appears suddenly after reaching the maximum force, by developing a local failure mechanism on the top flange located in the third part of the span, together with out-of-plane stability loss of the beam. Fig. 10 presents the deformed shape of the beam at collapse. The improvements in the second test showed an increased load-carrying capacity and also a much higher stiffness (beam stiffness was almost double), as shown in Fig. 11.

Fig. 10: Failure mechanism on the top flange of Beam-2

Finally, Fig. 11 shows comparatively, for the two tested specimens, the load-displacement curves and the ultimate (ULS) and serviceability limit state (SLS) levels.

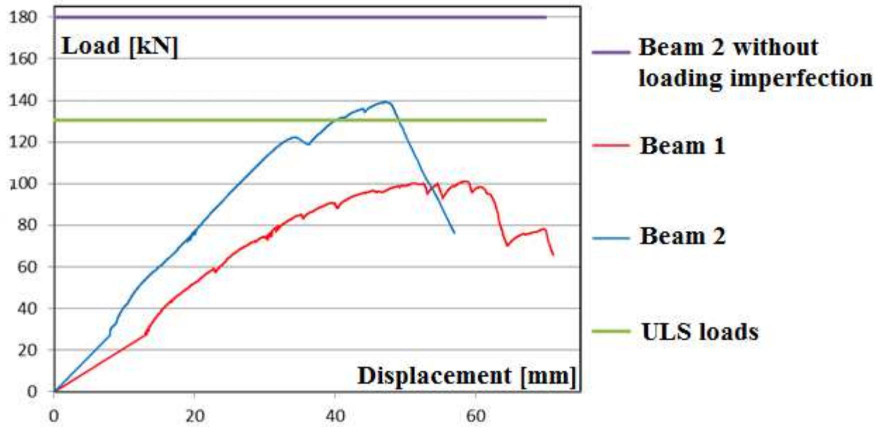


Fig. 11: Load-displacement diagrams for the tested beams

5. Conclusions

The paper presented the results of the experimental program on full scale 12 m span corrugated web beams with trapezoidal shape made by cold-formed steel components. Two specimens, i.e. Beam-1 and Beam-2 were tested monotonically, modelling gravity loading in a simple supported loading configuration. The test results showed the structural performance of the analysed beams, emphasizing the differences in behaviour and collapse mechanism, when the beam configuration is changed.

In case of Beam-1 specimen, where reduced web thickness was applied, the failure was produced under shear, due to the slippage between the web and the flanges, where the connection elements failed. In case of Beam-2 specimen, the web thickness and web-to-flange connections were improved obtaining a much higher load carrying capacity, the failure of the specimen was produced due to stability loss, in which load introduction imperfections took important roles.

It is important to observe the recorded stiffness differences between Beam-1 and Beam-2, the obtained stiffness in the second beam test was almost double, emphasizing the importance or the shear stiffness of the beam web near the support.

The research will continue by numerical models for calibration and validation of experimental models, optimisation of the number of self-drilling screws used for connections and parametric studies.

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