Numerical analysis of an innovative box section

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Abstract

The following paper is concerned with numerical determination of load capacity of an innovative box section. Results of the numerical analysis were verified by a physical experiment. Due to an unprecedented idea of applying longitudinal grooves on the lateral sheets, issues of local buckling and global stability are addressed. Numerical analysis was performed for beams of different lengths and subjected to various loading conditions. The results show that for some of the analysed cases the longitudinal grooves deteriorate performance of the beams and considerably decrease their load capacity whereas in other cases improve it. Hence, due to the section's susceptibility to local buckling under certain loads, identifying real loading conditions is crucial for proper design of the structures that employ the innovative box section.

Keywords: box section, buckling, longitudinal grooves, load capacity, numerical analysis

1. Introduction

Along with accession to the EU, Poland became a meaningful member of EU Structural Founds. Our country is profiting particularly in the development of innovative solutions which entrepreneurs try to apply also in building market. The present paper is concerned with an innovative box section which is designed to constitute a main structural element of steel halls. Author of this project* has turned to the Institute of Structural Engineering PUT with a request of complex research of this section including theoretical and physical analysis. The examined box section (as shown in Fig.1) consists of two distanced channels C160 and two lateral sheets of 2.5mm thickness. The innovation is that the lateral sheets have two longitudinal grooves. The aim of the investor* is to develop production of modular steel halls made from the discussed section. At present a prototype hall with overhead crane was erected at company's area (see Fig.1).

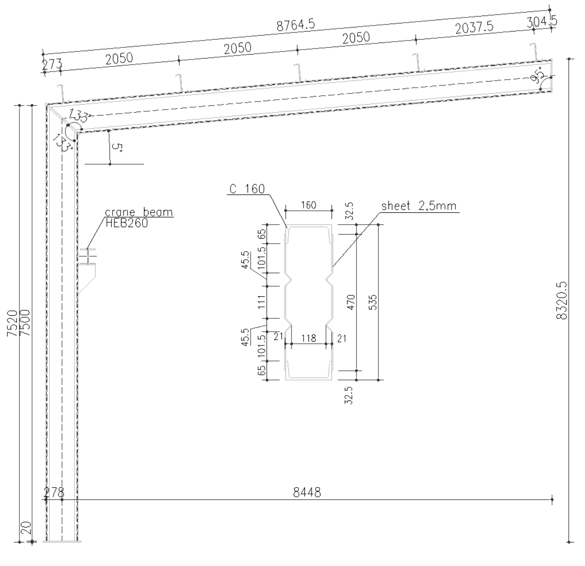

Figure 1: The innovative box section and half of steel frame

2. Problem formulation and numerical models description

The aim of the research was the evaluation of section's load capacity and analysis of its stability. Because of an unusual shape of the section, bar model was irrelevant. Thus 3D model was created. The analysis was performed for several beam lengths and different loading conditions. Among others the following cases were examined:

- free-ends beam subjected to a load uniformly distributed over the web of the top channel,
- free-ends beam under 4 point bending,
- eccentrically compressed beams.

In all numerical models four-node general purpose shell elements with reduced integration were employed (S4R elements) along with elasto-plastic definition of the material. All calculations were performed using Riks procedure. Results of the numerical analysis were compared with experimental results.

In preliminary numerical analysis free-ends beams of three different spans were considered: 4m, 5m and 6m. Loads applied to numerical models were uniformly distributed over the top surface of the cross-section, i.e. over the web of the top channel. Magnitudes of loads were set to a value causing equal bending moment in the midspan of every model. Value of the bending moment in turn, was calculated in such a way so as to cause yield stresses in outermost fibres of the cross-section when load proportionality factor (LPF) employed in Riks procedure attains value equal one.

3. Results

According to the expectations, preliminary numerical analysis showed that for the analyzed span range the box section is susceptible to instability of lateral sheets with longitudinal grooves. When the load is applied perpendicular to the web of either of the two channel sections, sheets are not only subjected to in-plane bending but also to compression. They tend to deform inwards due to the fact that the longitudinal grooves act as imperfections under such load, i.e.

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when the load is applied in the direction perpendicular to the axes of the grooves. Phenomenon of buckling of the sheets was observed for all three analyzed beam spans and was identified as a critical failure mechanism for beams of 4 and 5m span. In Fig. 2 one can observe that only the beam of 6m span was capable of bearing a full value of load (LPF ≈ 1) that causes yielding of outermost fibers of the cross-section in the midspan. However, it is worth noting that buckling of sheets and yielding of outermost fibers took place almost simultaneously which would suggest that such sheets are well suited for this beam length. For the other two beams instability of lateral sheets took place for the values of loads much smaller than the load causing yield moment in the midspan. For the 4m-beam value of the critical load due to buckling of sheets constitutes only about half of the load causing yield moment in the midspan.

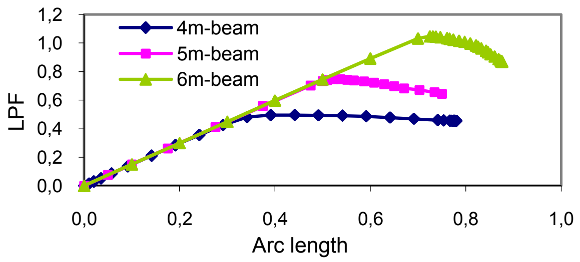

Figure 2: Load proportionality factors for analyzed beam lengths.

Knowing maximum values of load proportionality factors for each beam, critical loads were calculated. Contrary to what one might expect, values of these loads are almost the same regardless of the beam span (see Fig. 3). It confirms the conclusion that the load capacity of the analyzed box section is directly connected with the lateral sheets' resistance to buckling, which in the analyzed span range is almost totally independent of beam length.

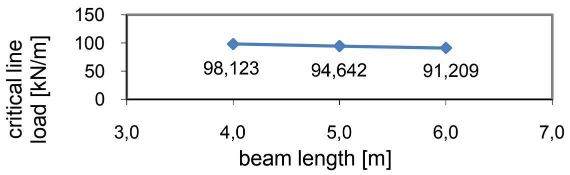

Figure 3: Critical line loads for analyzed beam lengths.

The fact that the buckling of lateral sheets is a critical failure mechanism can be also observed in Fig. 4 that illustrates horizontal displacement of top groove of lateral sheets measured in the midspan. It can be noticed that the LPF for which the buckling takes place overlaps with the maximum LPF form Fig. 2 for 5m-beam.

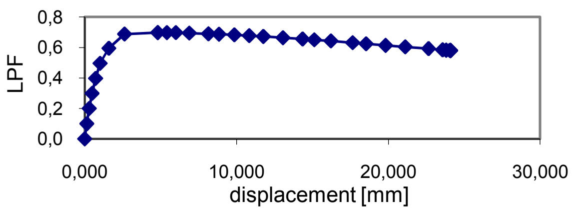

Figure 4: Horizontal displacement of upper fold of lateral sheet measured for the cross-section in the midspan for 5m-beam.

Moreover, on the basis of plots of vertical displacements monitored in the midspan for the top and bottom channels (see Fig. 5) an additional conclusion can be drawn. Namely, due to low stiffness of lateral sheets, top channel bears greater portion of the applied load than the bottom section and hence the vertical displacement of the former is greater than that of the latter. It can be also observed that when the LPF attains its maximum value, i.e. when buckling of sheets takes place, vertical displacement of the bottom channel section decreases, which means that in the post-buckling range the contribution of bottom channel to load bearing capacity is even smaller.

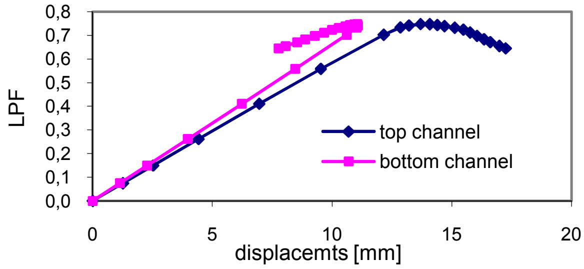

Figure 5: Vertical displacements of top and bottom channel in the midspan of 5m-beam.

Effective stress distribution map of the shortest beam additionally shows that the stresses that arise on the sheets are much greater than the ones that arise on channel sections. On the other hand, for the longest beam these stresses are more or less equal (see Fig. 6).

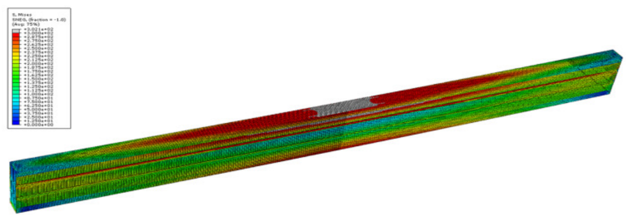

Figure 6: Effective stress distribution map for a 6m-beam. Red and light gray regions represent plastic or near-plastic effective stresses.

4. Concluding remarks

Preliminary analysis of the innovative box section showed that under discussed loading conditions and for the analyzed beam span range, buckling of lateral sheets with longitudinal grooves is a critical failure mechanism. The shorter the beam, the greater is the decrease in the load capacity of beams due to the buckling. Therefore, applying the discussed cross-section according to the investor's intentions in long beams of span greater than 6m seems to be rational.

References

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