# Numerical analysis of beam with sinusoidally corrugated webs

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Abstract

The paper presents numerical tests results of the steel beam with sinusoidally corrugated web, which were performed in the Autodesk Algor Simulation Professional 2010. The analysis was preceded by laboratory tests including the beam's work under the influence of the four point bending as well as the study of material characteristics. Significant web's thickness and use of tools available in the software allowed to analyze the behavior of the plate girder as beam, and also to observe the occurrence of stresses in the characteristic element - the corrugated web. The stress distribution observed on the both web's surfaces was analyzed.

*Keywords: sinusoidally corrugated web girder, steel girder, FEM, stiffener plate*

## 1. Construction analysis

In the Autodesk Algor Simulation Professional 2010 the numerical analysis of a steel beam with sinusoidally corrugated web was carried out. The numerical model was elaborated based on the results of experimental studies of the real models, which were carried out at an earlier stage of work.

## 2. Model description

The girder was described with a shell model. The shells were located at the center of the flanges with widths of 260 mm, thickness of 20 mm, and at the center of the corrugated web of 7 mm thickness. Spacing of the shells of the top and bottom flange was 370 mm.

The Autodesk Algor Simulation software enables direct, combined data exchange with a large group of CAD programs. Thanks to this capability, the curve described by the sinusoid equation (1) was created in the AutoCad 2010 [1].

$$y(x) = A \cdot \sin\left(\frac{\pi \cdot x}{0.5 \cdot (2w)}\right). \tag{1}$$

The analyzed construction was considered as simply supported and loaded with concentrated forces.

The boundary conditions were defined in the bottom flange at a spacing of 2400 mm; at the location of 10 mm ribs. A load was declared as a system of concentrated forces with a $^1/_2P$ of a total load, which was present over the entire width of the flange, at a distance of 800 mm from the support. In order to reflect the high stiffness of the element, which charged the girders during the laboratory tests, the shell elements of the same rigidity were used in the computer model, through which the load was transferred to the flange of the plate girder

The shell of the top flange was divided into smaller segments to precisely position the load. The discretization was made automatically using the Mesh Between Two Sketch Objects method, which is available in the Autodesk Algor Simulation; individually for each part of the model. Manual changes were made by verifying the side ratios at locations with a negligible effect on the accuracy of the results. The four-node shell elements with a linear interpolation were used.

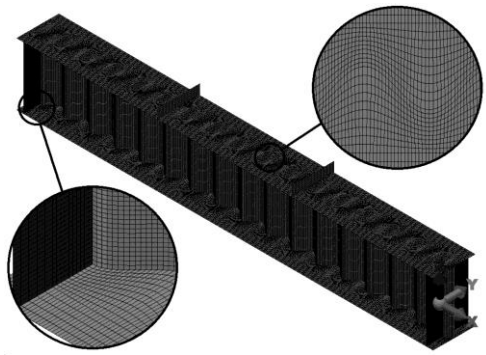

Figure 1: A finite element mesh of the shell model with sinusoidal web

Generation of the model occurred with the separation of zones with different ratio of sides (Fig. 1). In the web's shell elements with a 1:1 side ratio were used. The beam's flanges contained elements with a ratio of the sides' length depending on the location of the elements. In the extremities, at the edge of the flange, the sides' length ratio was about 1:2. In the middle part of the flange, the dimensions of the flange's finite elements were matched to the dimensions of the finite elements of the web. This type of solution was necessary in order to ensure co-operation between the flanges' plates and the web's shell.

An elasto-plastic model of the material has been adopted for the individual components of the plate girder. Based on the plasticity criterion, the material was governed by the law of the plastic flow as well as the law of the kinematic reinforcement. The yield strength and the tensile strength were assumed on the basis of own experimental research. Samples were prepared from the web's sheet. Material properties of ribs and the flanges were

* This work was financially supported by the statutory budget funds of Faculty of Civil Engineering and Architecture in Lublin University of Technology.

adopted on the basis of metallurgical tests of sheets used for laboratory tests of the girders. Reinforcement was determined by the adoption of the tangential deformation modulus Et=0.01E.

A nonlinear static analysis for the prepared models was performed, taking into account a material non-linearity, for which the yield strength was determined by the H-M-H hypothesis.

## 3. Results

During laboratory tests, variations in deformation have been observed, causing the appearance of tensile or compression stresses on the opposite surfaces of the web's sheet. This observation was confirmed in the numerical model. Fig. 2 shows the values of deformations occurring at a measurement point but on different surfaces.

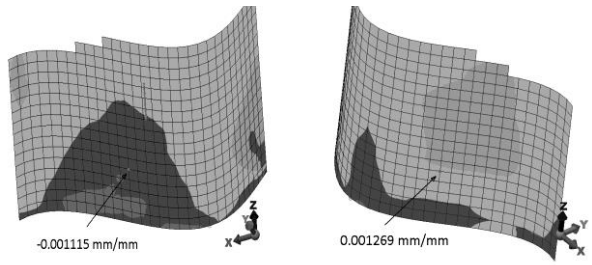


Figure 2: Deformation value at the 1-1 direction of a measurement point on the opposite surfaces

The computer simulation of behavior of the beam with corrugated web under load, showed the highest normal stresses $\sigma_{1\text{-}1}$ in the flange of the plate girder. The remaining part of the cross-section has much smaller values of normal stresses.

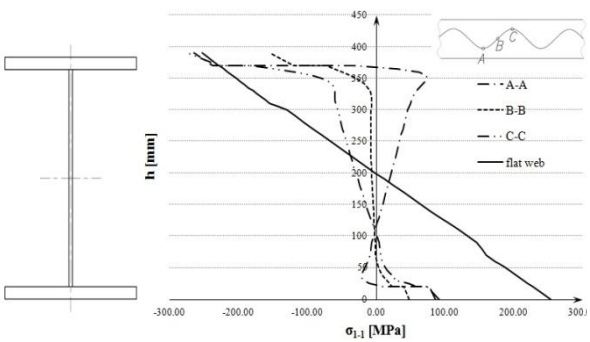


Figure 3: Deformation value at the 1-1 direction of a measurement point on the opposite surfaces

As a result of the bending moment, the normal stresses $\sigma_{1\text{-}1}$ present in the B-B cross-section take values at a low level. In the remaining sections considered, the range of the normal stresses depends on the location of the cross-section; the stresses are completely different in comparison to the girder with the flat web.

From the chart showed in Fig. 3, it can be concluded that, as expected, the bending moment is transmitted to a much greater extent by the flanges.

The numerical calculations have shown that in case of the beams with the corrugated web, the shear is transmitted mainly through the web.

Fig. 4 shows the τ1-2 tangential stress diagrams, which compares the distribution of tangential stresses occurring in the beam with the corrugated web, with the distribution of tangential stresses occurring in the beam with the flat web. For the beam with sinusoidal web, tangential stresses were defined in three cross-sections of the girder: D-D, E-E and F-F.

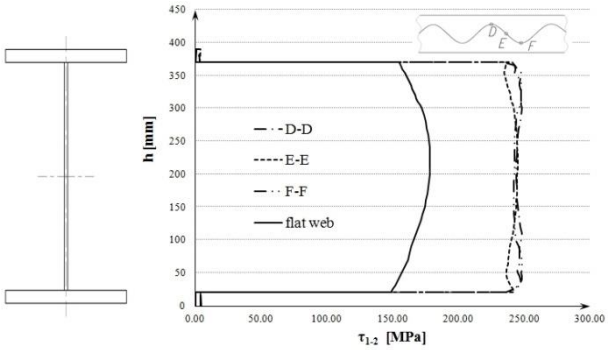


Figure 4: The $\tau_{1\text{-}2}$ stress distribution at section height for force about 1250 kN

It can be seen that in the E-E section (the section overlapping with the axis of symmetry of the cross-section), at the height of the web, the tangential stresses have a similar distribution in terms of shape to the stress distribution in the web of the girder with the flat web. At mid-height of the web, the shear stresses take on the greatest values. In the D-D and F-F sections, the distribution of tangential stresses is almost constant over the entire height of the web.

## 4. Conclusions

Based on the results of the numerical analysis, the following conclusions can be drawn:

- the construction analyzed can be effectively modeled using the SHELL type finite elements;
- there are places, where on one side of the web deformations show stretch, and compression on the opposite side;
- the bending moment is mainly transmitted through the flanges, which depends on the small stiffness of the corrugated web itself, and the normal stresses do not distribute symmetrically at the height of the beam's cross-section;
- in the section overlapping with the axis of symmetry of the cross-section, at the height of the corrugated web, the tangential stresses have a similar distribution, in terms of shape, to the distribution of stresses in the web of the beam with the flat web; in sections approaching the crest of the wave the distribution of the tangential stresses is almost constant over the entire height of the web.

Obtained results may and should also constitute a basis for the verification of analytical methods for calculating the elastic critical moment of beams with sinusoidally corrugated webs. An overview of such analytical approaches was presented in [2].

## References

[1] Program manual of Autodesk Algor Simulation 2010, Autodesk Inc., 2010.

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