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NUMERICAL ANALYSIS OF CASTELLATED BEAM

Abstract

This paper deals with modeling of the behavior of castellated beam. The calculations also take into account the imperfections. The solution incorporates finite element models and standardized calculation. The main contribution is to undertake case studies to determine the coefficients of lateral-torsional buckling and description of the stress state of the profile.

Keywords

Castellated beam, lateral-torsional buckling, finite element analysis, computational model.

1 INTRODUCTION

The current technologies make possible to manufacture very different shapes of steel beams. For example, various castellated beams can be produced. Many of these shapes are not covered by current design standards. Their design and assessment can be done in various ways. Structural behavior of these beams is often studied with use of the finite element method [12, 13, 14].

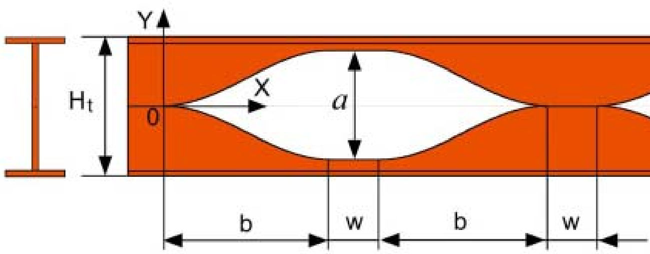

Fig. 1: Angelina castellated beam shape [1]

An application of the finite element method to numerical modelling of steel castellated beams is discussed in [15]. Similar approaches can be used for castellated timber beams [6]. An elastic-plastic analysis of these types of beams is proposed in [10]. Neural networks can be used to advance the analysis [5].

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The article discusses a determination of buckling coefficients for the selected Angelina castellated beam [8]. An approach to numerical modelling of uncommon castellated beams is also studied in order to find a more general way for analysis of such types of beams. The discussed numerical models are compared with standard-based calculations [2, 3, 4] and they are also verified by comparison with basic approaches of structural analysis.

2 DESCRIPTION OF CASTELLATED BEAM

The studied castellated beam is shown in Fig. 1. There are two studied alternatives: simply supported beam and a cantilever beam. The second case is used only for study of interaction between bending moments and shear forces. This particular type of beam is produced by the ArcelorMittal. The beam has large openings which can be used for various installations under the roof of building. Only one alternative of the beam is studied in this paper. The basic cross-section type is the IPE 270. The S235 steel is used.

3 NUMERICAL ANALYSIS

The ANSYS [7] finite element analysis system is used for numerical modelling. The 3D model uses the SOLID45 eight-node isoparametric brick finite elements. The model consists of 21 907 finite elements and 34 319 nodes (the cantilever beam model) or of 18 027 finite elements and of 37 432 nodes (the simply supported beam model). The computations respect structural, geometric and constitutive non-linearities. There are used the CONTA174 and TARGE170 contact finite elements [7] for modelling of structural non-linearities. Steel behavior is modelled with use of the elastic-plastic material model with linear hardening.

The finite element model of the cantilever beam is shown in Fig. 2 and Fig. 3. The SCIA [11] finite element analysis software is used for shells-based numerical modelling of the beam. The results obtained by SCIA are used for verification of the computations.

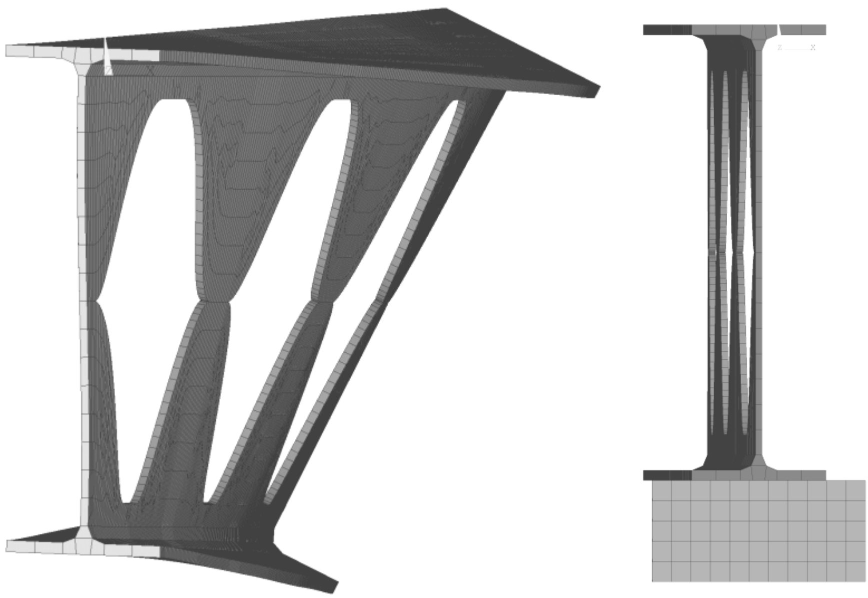

Fig. 2: Numerical models with embedded geometric imperfections

The Fig. 2 illustrates the embedded geometric imperfections of the beam model. These imperfections are based on a pre-buckling deformation caused by continuous load on the top flange of the beam.

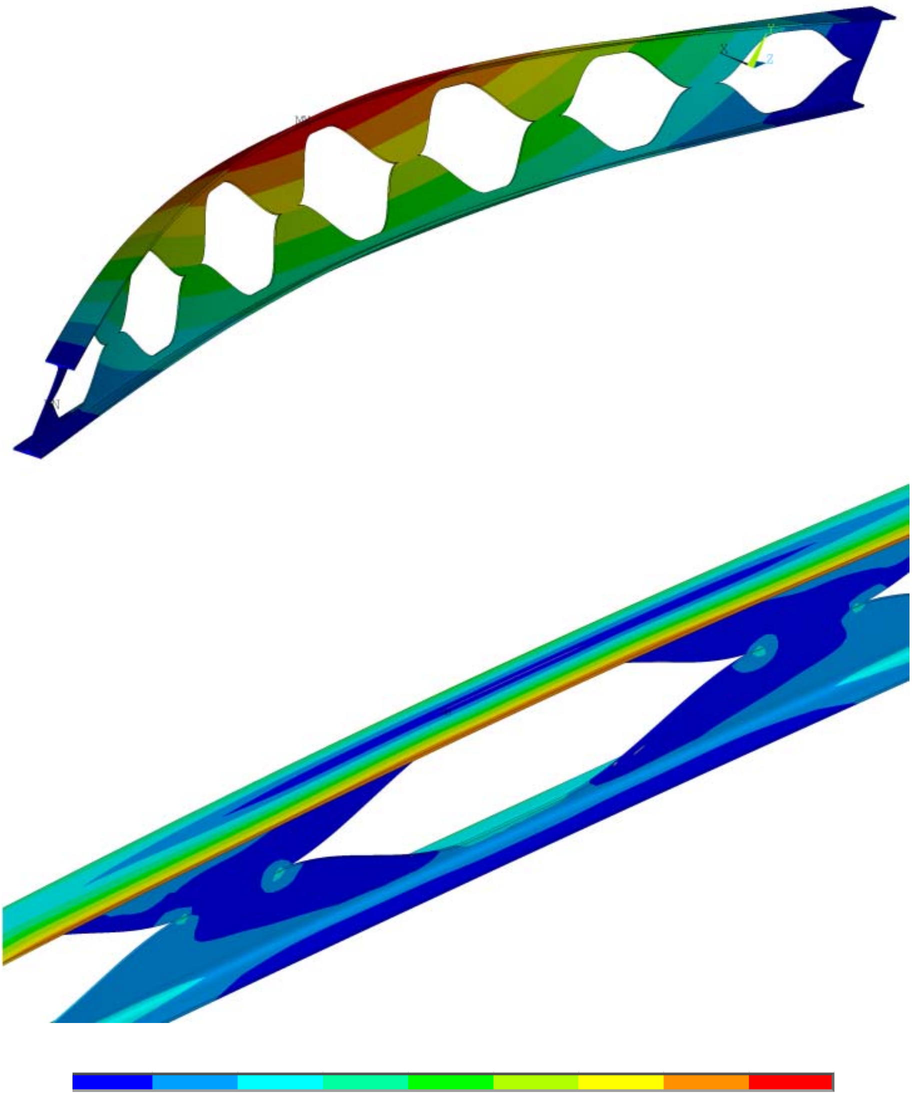

Fig. 3: Von Misses stress [MPa]

The results of non-linear computations which incorporate the 2nd order theory are shown in Fig 3. Von Mises stresses are shown. The upper part of the Fig. 3 shows the deformations.

The final values of the torsional-lateral buckling coefficients e_0/L are shown in the Fig. 4. These results have been obtained for various initial imperfections. The Fig. 4 compares numerical results with result obtained by standard-based computations (according to the ČSN and the EC technical standards). The differences between the solutions are small. It is obvious that standard-based computations are slightly more conservative than the numerical analysis.

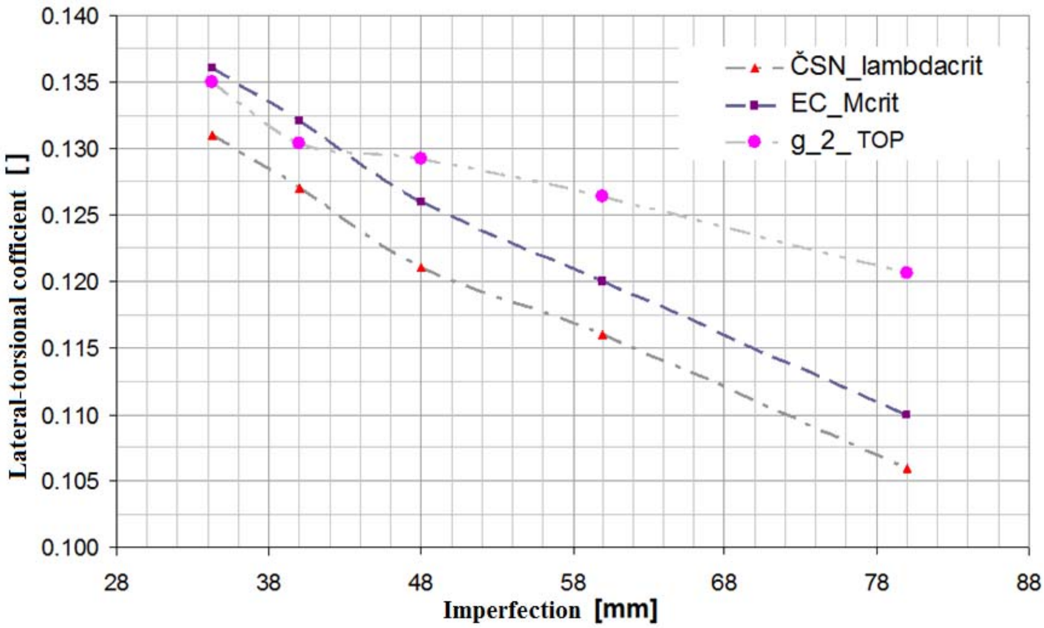

Fig. 4: Coefficient of lateral-torsional buckling for span 12 m ($\gamma_{M1} = 1$)

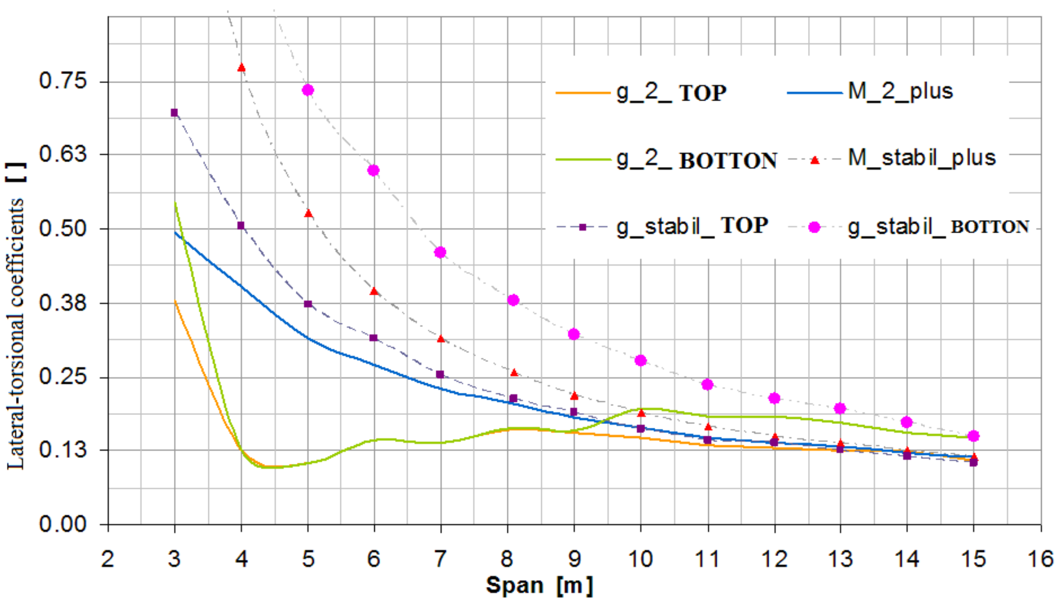

Fig. 5: Coefficient of lateral-torsional buckling in dependence on free span

The obtained values of the lateral-torsional buckling coefficients are listed in the Tab. 1. These values are valid for 12 m span. The Fig. 5 shows dependence between lateral-torsional buckling coefficient size and the beam span. These results have been obtained by numerical simulation with use of the software [11]. It the beam span is short then there is no buckling of the flange but there occur limit stresses in around the cuts which are near the supports. These stresses are caused by large shear forces near the supports.

Tab. 1: Lateral-torsional buckling coefficients for the 12 m span

Angelina_12 m	*M_stabil_ plus*	*g_stab top*	*g_stab bottom*	*M_2_plus*	*g_2_top*	*g_2_bott*
scia_angelina	0.149	0.138	0.213	0.138	0.129	0.184
ansys_angelina	0.180	0.162	0.241	0.168	0.126	0.213
scia_full	0.161	0.138	0.230	0.160	0.149	0.201
ansys_full	0.190	0.179	0.260	0.177	0.175	0.236

suction, flange in tension TS_wind		*g_stab top*	*g_stab bottom*		*g_2_top*	*g_2_bott*
scia_angelina		0.362	0.144		0.246	0.141
ansys_angelina		0.439	0.181		0.305	0.162
scia_celý		0.414	0.176		0.299	0.171

real supports					*g_2_top*	*g_2_bott*
ansys_real					0.136	0.220

An interaction between bending moments and shear forces is shown in the Fig. 6. These results were obtained with use of the ANSYS software [7] for the case of the cantilever beam. This type of the Angelina beam is sensitive to the shear force because of relatively small effective height of the web.

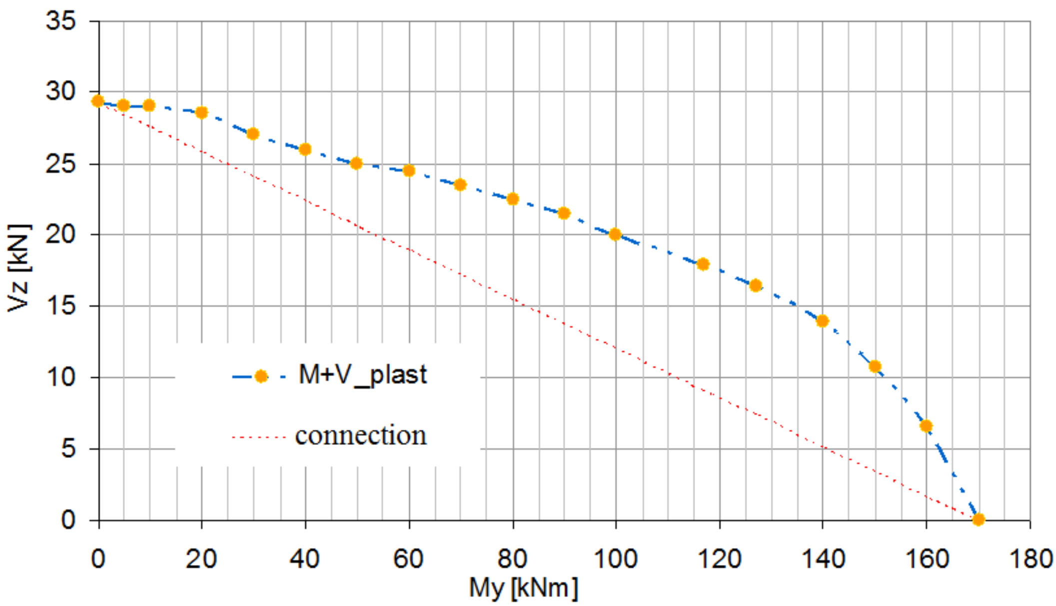

Fig. 6: Interaction between bending moments and shear forces

4 CONCLUSION

The article discusses computation of lateral-torsional buckling coefficients of the Angelina castellated beam. The results of the numerical computations in the ANSYS [7] and the SCIA [11] finite element analysis packages are compared with result obtained by the standards-based computations. There is a very good agreement between the results for the studied beam. There are studied stress concentrations around the openings of the beam. The correctness of the numerical analysis depends on correct initial imperfections, on finite elements mesh properties and on modelling of the supports. Initial imperfections can be determined by using standards-based procedures. The numerical analysis is very similar for both used types of software and the results are also very similar. It is recommended to use shell or spatial finite elements for modelling of castellated beams because models based on beam elements cannot simulate local buckling effects.

The further works will be focused on other sizes of the Angelina beams. It is planned to study their behavior in an interaction with timber or reinforced concrete root structures. A reliability approach is also planned to be utilized for the planed works [9].

It can be stated that used of the mentioned commercially available software is a feasible tool for preliminary determination of static behavior and stability properties of non-standard castellated steel beams. These types of beams are not fully covered by the technical standards. For example, lateral-torsional buckling coefficients for these beams are not always available.

These data can be obtained by numerical simulations based on the finite element method. A non-linear behavior of the structure has to be considered. It is important to include an elastic-plastic behavior of steel. A geometrically non-linear behavior (at least the 2nd order theory) has to be considered, too. However, numerical simulations have to be completed and verified by laboratory testing of the studied structural elements.

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