# FINITE ELEMENT ANALYSIS OF TORSIONAL-FLEXURAL BEHAVIOUR OF THIN-WALLED FRAME CONSIDERING JOINT WARPING CONDITIONS

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***Abstract:*** *Frames composed of thin-walled beam elements are frequently used as load-carrying systems in engineering practice. In this work the influence of different structural joint types on torsional moment transmission from column to beam is analysed. Two types of beam cross sections are considered, the I-beam cross section and the channel one. Four different structural joints are examined for both cross sectional types. Numerical simulations are undertaken using MSC. Nastran's shell model consisting of eight-nodded flat elements. The results obtained are discussed through the test problems.*

**Keywords**: FRAMES, THIN-WALLED BEAM, JOINTS, TORSION, WARPING

## *1. Introduction*

Frames composed of thin-walled beam elements are frequently used as load-carrying systems in engineering practice. They are appealing because of their high stiffness-to-mass ratio, but such weight-optimised structures display a very complex structural behavior [1-2]. Load-carrying evaluations of such structures are usually carried out under the assumption of a simplified torsional-flexural behaviour of structural joints, completely ignoring the torsional-warping characteristics. Although such an approach simplified the analysis significantly, it fails to represent the real frame behaviour, because the joints of actual frames could exhibit a flexible warping behaviour falling in between the two extreme warping boundary condition cases: fully restrained and free warping conditions [3-4].

Analysis of thin-walled frames have shown that torsion applied to one member can be transmitted to unloaded one generating at the same time flexure in that member. In the case of solid frames and structures it is only the flexure that is produced in the second member. Relating to Morell [5] and Sharman [6], joint structure at the connecting point of two members affect magnitude and orientation of torsion transferred from column to beam. There are two components of deformation in function of imposed torque: one due to St. Venant's torsion and another one due to the warping torsion.

The steel frame examined in this paper is composed of two thin-walled elements joined by the joint. Two types of beam cross-sections are considered: I-section and channel one. Dimensions of the frame and cross-section geometries are given in Fig. 1. The structure is clamped at both ends and loaded by a torque approximately at the middle point of a column. Joint types studied in this work are: unstiffened mitre joint, box joint, stiffened mitre joint and a combination of stiffened mitre and box joint, Fig 2.

The purpose of this work is to determine how the warping is transmitted due to joint type and to obtain the real frame behavior. In Morell's work [5] the influence of joint type on an unloaded member deformation due to three different joint types: box joint, mitre joint and stiffened mitre joint, respectively, was presented. It was shown that in the case of box joint the deformation of the unloaded member is mainly influenced by the warping, while in the case of stiffened mitre joint St. Venant's torsion was more dominant.

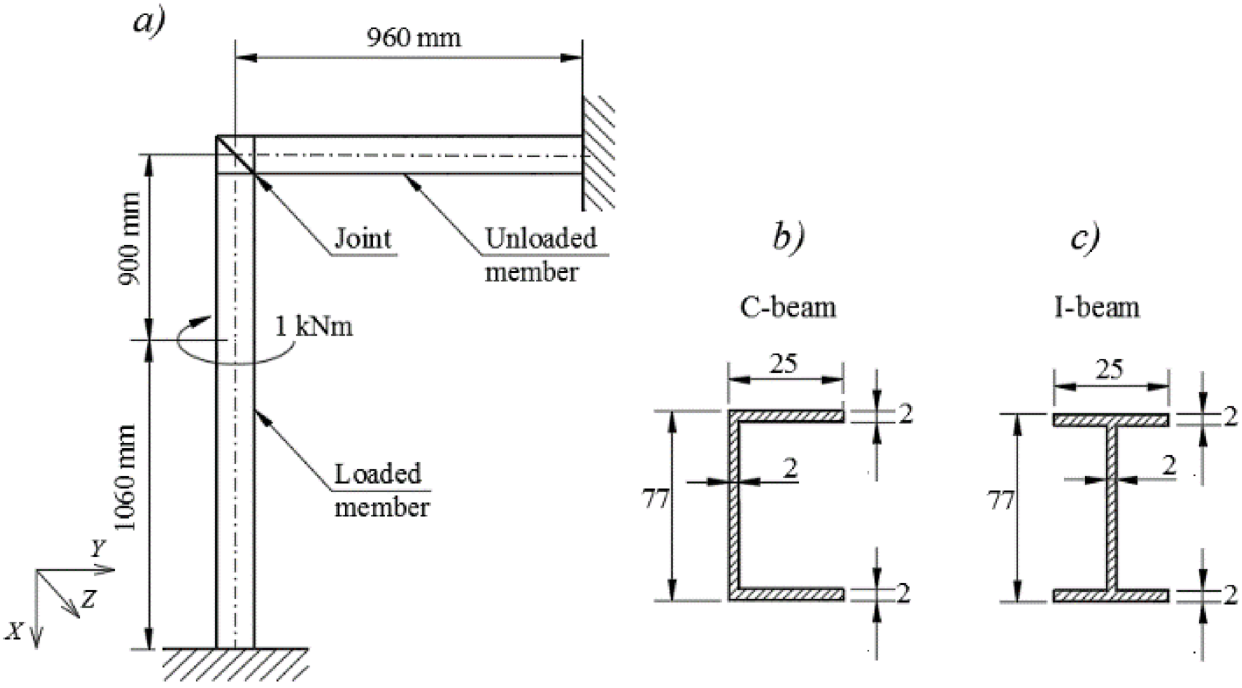


***Fig. 1*** *Structure analyzed: a) L-frame; b) geometry of C-beam; c) geometry of I-beam*

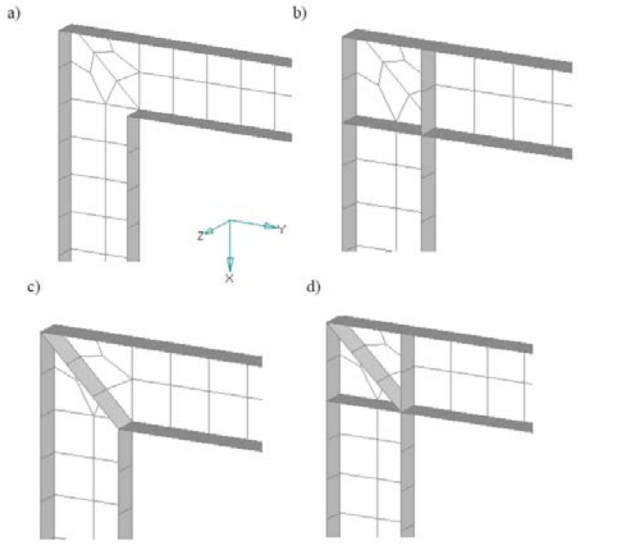


***Fig. 2*** *Joint types: a) unstiffened mitre joint; b) box joint; c) stiffened mitre joint; d) box/stiffened mitre joint*

## *2. Numerical analysis*

Numerical simulations are undertaken using MSC. Nastran's shell model consisting of eight-nodded flat elements. The results obtained in the finite element study are presented using diagram-forms: two for each joint type showing both cross-sections. As well, the results obtained for the channel-section are compared with those given by Morell [5]. As one can see, a good agreement has been established. Thereby, mesh quality is proved.

As announced, there are two diagrams for each case analyzed: first one representing the rotation about the *Y*-direction along the unloaded member, and the second one representing the rotation about the *X*-direction along the loaded member, always generating the similar curve trend.

### *2.1 Unstiffened mitre joint*

Fig. 3 shows the rotation of the unloaded member about the *Y*-direction. As one can see, the rotation of the channel beam is mainly positive, while for the I-beam it is negative and reaches higher absolute values.

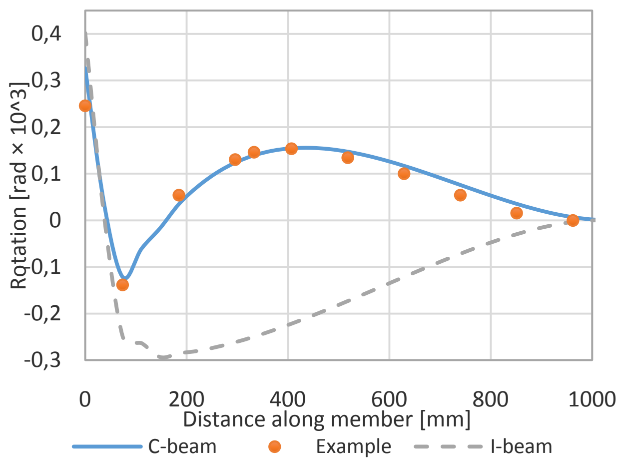


***Fig. 3*** *Unstiffened mitre joint – rotation of the unloaded member*

On the other hand, the rotation of the loaded member is positive with the highest value at the point where the torque is applied, Fig. 4. The results obtained for the channel-section are very close to those reported by Morell and of lower values than those obtained for the I-beam.

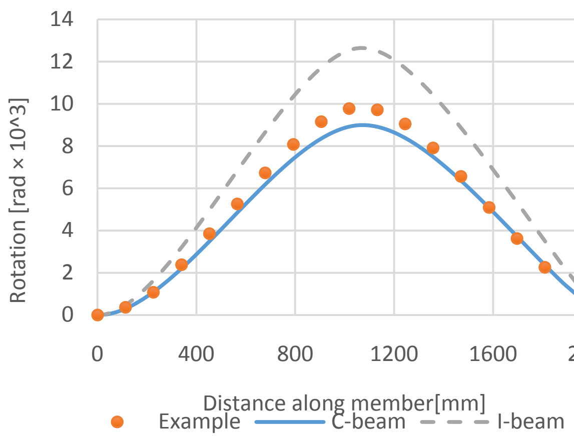


***Fig. 4*** *Unstiffened mitre joint – rotation of the loaded member*

### *2.2 Box joint*

The box joint is a stiffer joint type then the mitre joint therefore causing different response of the unloaded member. In contrast to the unstiffened mitre joint, in this case the negative rotation about the *Y*-direction occurs, Fig. 5. The rotation of the loaded member is drawn in Fig. 6. As expected, the loaded member rotates in a positive direction of the *X*-axis, reaching lower values than those obtained for the mitre joint.

Again, higher deformation values are obtained in the case of I-beam for both loaded and unloaded members.

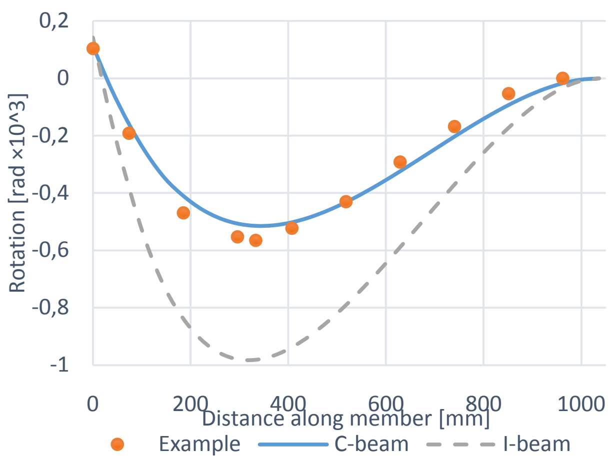


***Fig. 5*** *Box joint – rotation of the unloaded member*

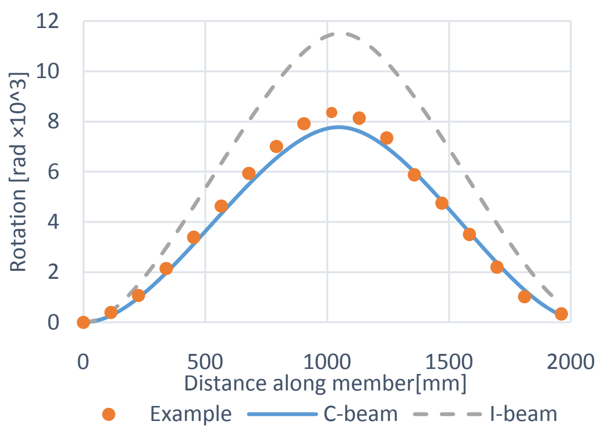

***Fig. 6** Box joint – rotation of the loaded member*

### *2.3 Stiffened mitre joint*

Fig. 7 shows the rotation of the unloaded member at the frame with the stiffened mitre joint. In contrast to the preceding cases, the rotation of the unloaded I-member achieves lower values comparing to the channel section. The rotation of the loaded members is shown in Fig. 8.

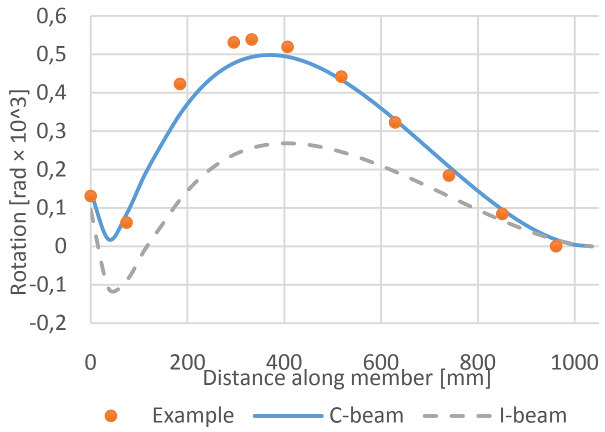


***Fig. 7** Stiffened mitre joint – rotation of the unloaded member*

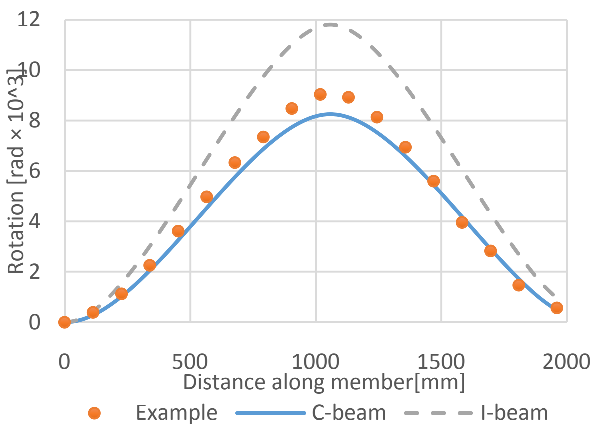


***Fig. 8** Stiffened mitre joint – rotation of the loaded member*

### *2.4 Box/stiffened mitre joint*

Since the box-stiffened mitre joint is a combination of the two joint types gives similar response to that obtained for the box joint frame, Figs. 9 and 10.

However, it should be noticed that intensity of the rotation is smaller due to the stiffer structure.

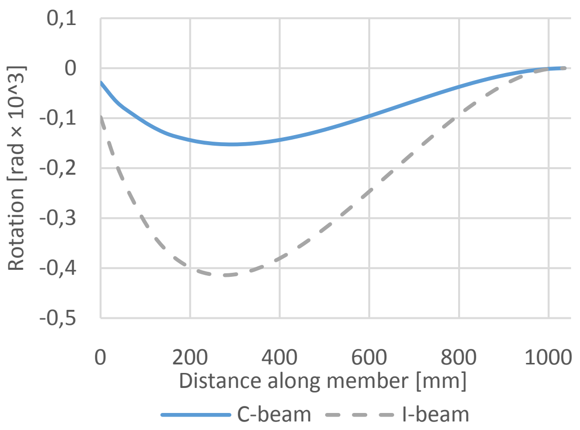


***Fig. 9** Box/stiffened mitre joint – rotation of the unloaded member*

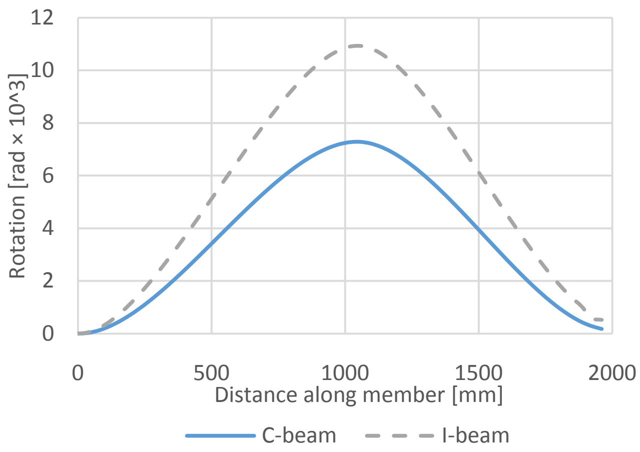


***Fig. 10** Box/stiffened mitre joint – rotation of the loaded member*

## ***3. Conclusion***

A numerical analysis, based on the finite element method, of several beam-to-column joint types has been presented. In this, a plate model consisting of eight-nodded flat elements has been employed.

In all the cases a positive rotation has been obtained at loaded member, as it has been expected. The lowest values of rotation are obtained at the box/stiffened joint type. Analyzing frame composed of channel sections, positive rotations have been obtained at the unloaded member in the cases of mitre and stiffened mitre joints, while negative rotations have occurred at the other two joint types.

The topic of our further research is to examine warping transmission to unloaded member due to the joint type.

## ***Acknowledgment***

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