Assumption tests regarding the 'narrow' rectangles dimensions of the open thin wall sections

E Oanta[1,2], C Panait[1], A Sabau[1], M Barhalescu[1] and A E Dascalescu[2]
[1]Constanta Maritime University, Faculty of Naval Electro-Mechanics, 104 Mircea cel Batran Street, 900663, Constanta, Romania
[2]'Politechnica' University of Bucharest, Faculty of Power Engineering, 313 Splaiul Independentei, Sector 6, 060042, Bucharest, Romania

E-mail: eoanta@yahoo.com

Abstract. Computer based analytic models that use the strength of materials theory are inheriting the accuracy given by the basic simplifying hypotheses. The according assumptions were rationally conceived hundreds of years ago in an age when there was no computing instrument, therefore the minimization of the necessary volume of calculi was an important requirement. An initial study was an attempt to evaluate how 'thin' may be the walls of an open section in order to have accurate results using the analytic calculus method. In this initial study there was compared the calculus of the rectangular sections loaded by twisting moments vs. a narrow section under the same load. Being compared analytic methods applied for a simple shape section, a more thorough study was required. In this way, we consider a thin wall open section loaded by a twisting moment, section which is discretized in 'narrow' rectangles. The ratio of the sides of the 'narrow' rectangles is the variable of the study. We compare the results of the finite element analysis to the results of the analytic method. The conclusions are important for the development of computer based analytic models which use parametrized sections for which different sets of calculus relations may be used.

1. Introduction

Testing the limits of the 'classic' theory and development of new analytic calculus approaches, which are most of the time computer based methods, are some long run concerns of the authors. Until now there were studied the extents of the small displacement hypothesis [1], the influence of the elastic supports [2, 3] and the appropriateness to consider a rectangular section loaded by a twisting moment as a 'narrow' rectangle, [4]. These aspects are important in the development of the computer analytic models which may be used for various purposes: development of solvers for parametrized complex problems, development of the analytic models within hybrid models, which also require numerical and experimental studies. However, the results of an analytic model may be considered the reference from which other optimization studies may be considered. Because the analytic studies have an inherent lack of accuracy due to the basic simplifying assumptions, there must be used alternate methods to evaluate the extents of the hypotheses. In this way there may be used experimental studies, which is an expensive and particular solution. The use of the finite element method for a wide range of case studies may offer a vision regarding the accuracy of the results offered by the analytic relations. In the paper we use the finite element method for a parameterized section in order to compute the stresses and the displacements of a beam having an open 'thin' wall section.

2. Problem formulation

In a previous study we evaluated the stresses and the displacements of a rectangular section loaded by a twisting moment for several ratios of its sides. There were used two approaches: the first one used the calculus relations for a rectangular section, figure 1, and the second one used the relations for an open thin wall section, figure 2.

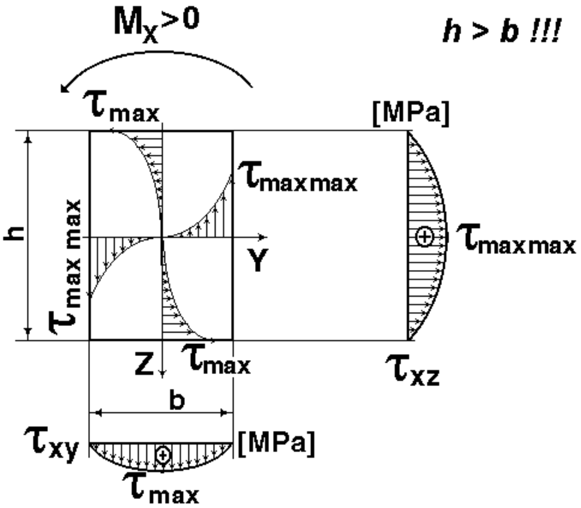

Figure 1. Stresses in a rectangular cross section.

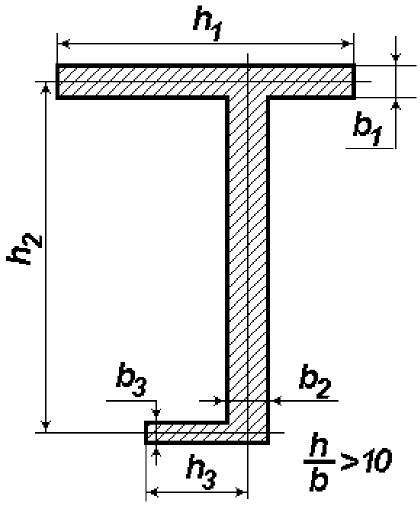

Figure 2. Open thin wall section.

The calculus relations for a rectangle section are:

$$\begin{cases} \tau_{\max\,\max} = \dfrac{M_X}{\alpha \cdot h \cdot b^2} \\ \tau_{\max} = \dfrac{M_X}{\alpha' \cdot h \cdot b^2} \end{cases}, \ \Delta\varphi = \frac{M_X \cdot \ell}{\beta \cdot h \cdot b^3 \cdot G}. \tag{1}$$

Coefficients α, α' and β are depending on the $\dfrac{h}{b} > 1$ ratio and their values are listed in tables.

The calculus relations for a 'narrow' rectangle section are:

$$\tau_i = \frac{M_X}{I_t} \cdot b_i, \ \Delta\varphi = \frac{M_X \cdot \ell}{G \cdot I_t}, \tag{2}$$

where I_t may be computed using the relation

$$I_t = \frac{1}{3} \cdot \sum_{j=1}^{N} \left(h_j \cdot b_j^3 \right) \tag{3}$$

and it is designated torsion second moment of area [5], or torsional moment of inertia, [6].

The comparison of the results led to the conclusion that for the $\dfrac{h}{b} = 10$, the values of the stresses and of the angle of twist between two sections located at distance ℓ have an error of 6% and the error is under 5% for a ratio of the sides larger than 13.

In order to have an overview regarding the domain where the analytic calculus method may be applied for complex shapes, we considered the finite element method as a main instrument of investigation.

IOP Conf. Series: Materials Science and Engineering **145** (2016) 082010 doi:10.1088/1757-899X/145/8/082010

3. Method of analysis

A model of a beam having an open thin wall section (OTWS), figure 3, was developed in NX. The dimensions of the cross section are assigned to some parameters, therefore by changing the value of the parameters we have a new version of an open thin wall section. Parameter p_0 controls the thickness of the wall.

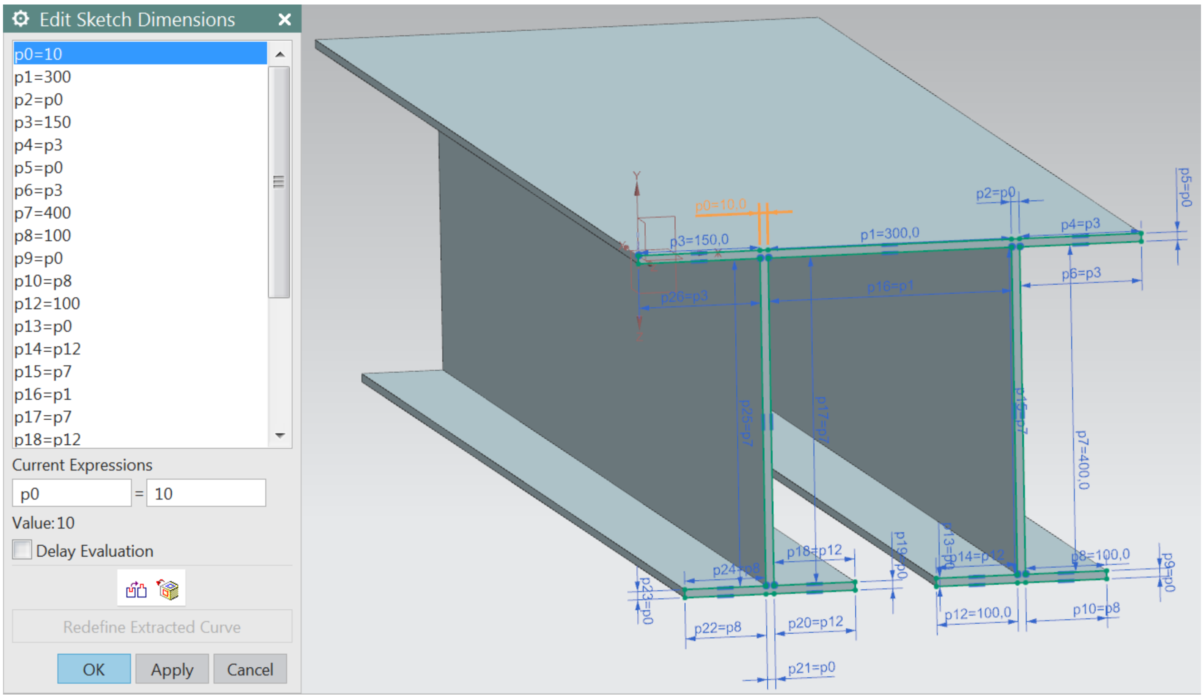

Figure 3. Definition of a parameterized cross section in NX.

This geometrical model was exported as a Parasolid text file (*.x_t) and then imported in Femap/Nastran, figure 4.

The geometrical model was discretized using solid linear elements. At one end of the structure all the degrees of freedom were locked, in this way being modelled the fixed end of a bar. At the other end of the structure was applied the load. It was considered a twisting moment created by a couple of equally distributed forces along two symmetric line segments (in Femap 'curves') of the cross section.

4. Discussion

Using the finite element model previously created there were followed two directions of investigation.

The first study is focused on the number of layers of elements along the width of the 'thin' wall, for a given geometric model. In order to have accurate results there were tested 1..6 layers of elements and the results of the FEM model were analysed in order to remark: the trend of the output values when the number of layers is increasing and the corresponding quantitative variation of the results; the best ratio 'refinement of the mesh' vs. 'volume of calculi'. Because we don't have an 'exact' solution, we compare the results from each study to the following one, in this way being evaluated a relative error. Following this idea we used several discretizations up to the maximum size of the database the program can handle. As a general trend, we remarked that the more layers we used the larger values of the stresses we reached. Figure 5 presents the level of detail of a model, level which uses 5 layers of elements along the thickness of the wall. Finally, we came to the conclusion that 5 layers of elements lead to the best precision the program can offer.

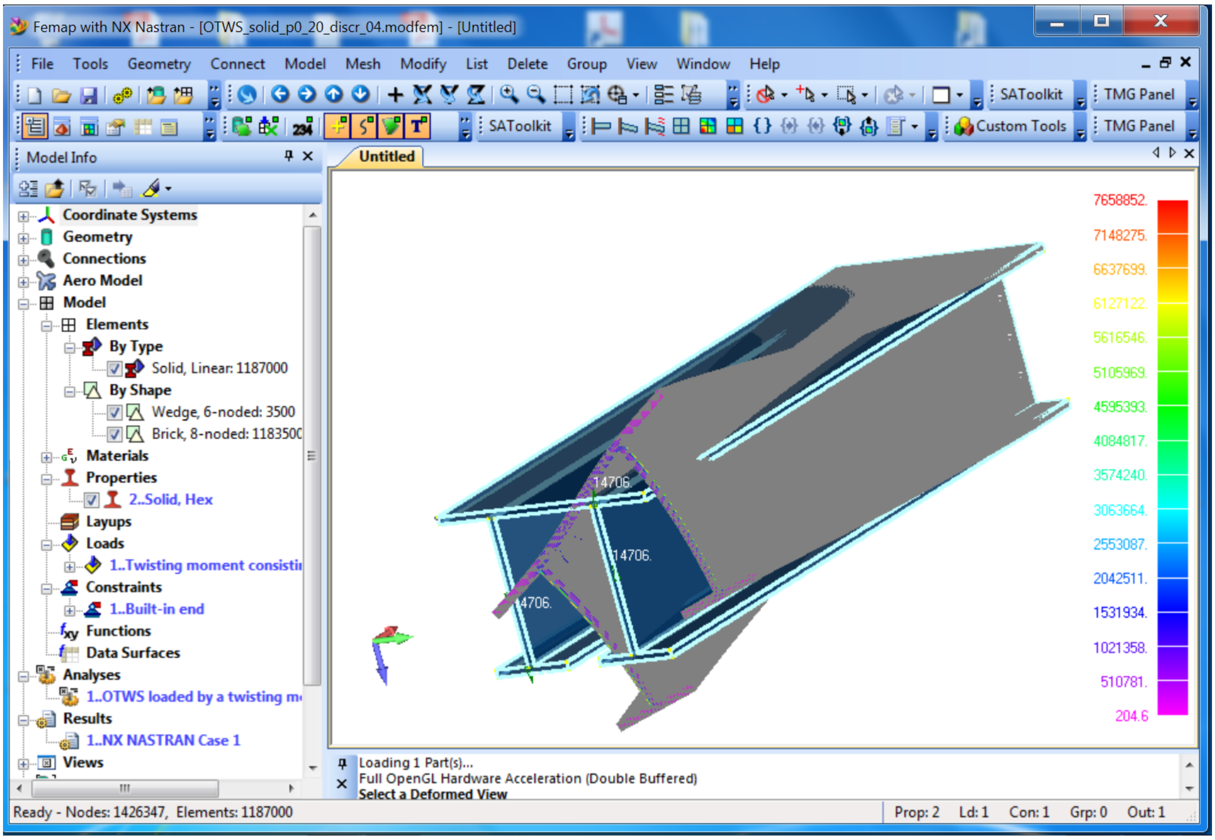

Figure 4. The finite element model in Femap.

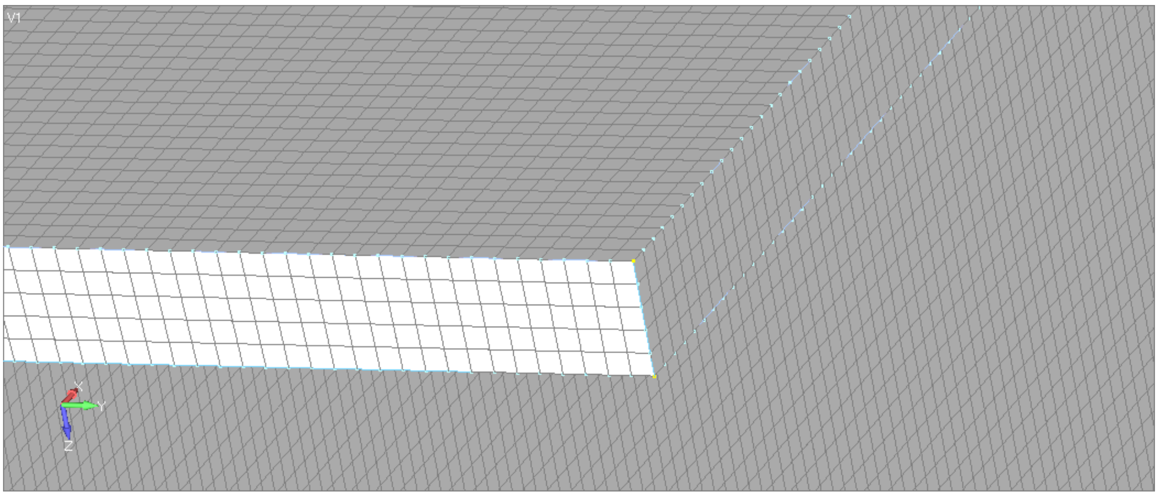

Figure 5. Details regarding the number of layers of elements along the thickness of the section.

The second study regards several variants of OTWS having different thicknesses of the wall, for which parameter p_0, previously mentioned, has distinct values. To have reliable results, there were created several models for many values of the p_0 parameter. Figure 6 presents the results, where along the horizontal axis we have the minimum ratio $\frac{h}{b}$ and along the vertical axis we have the stresses. Thus, the solid thin line represents the variation of the shear stress using the analytical calculus. The other lines show the variation of the stresses resulted from the Femap models: the solid thick line represents the maximum shear stress, the dashed line represents the solid mean stress and the dotted line represents the von Mises stress. These two last stresses were considered in order to remark the trend of the stresses' variation at several $\frac{h}{b}$ ratios.

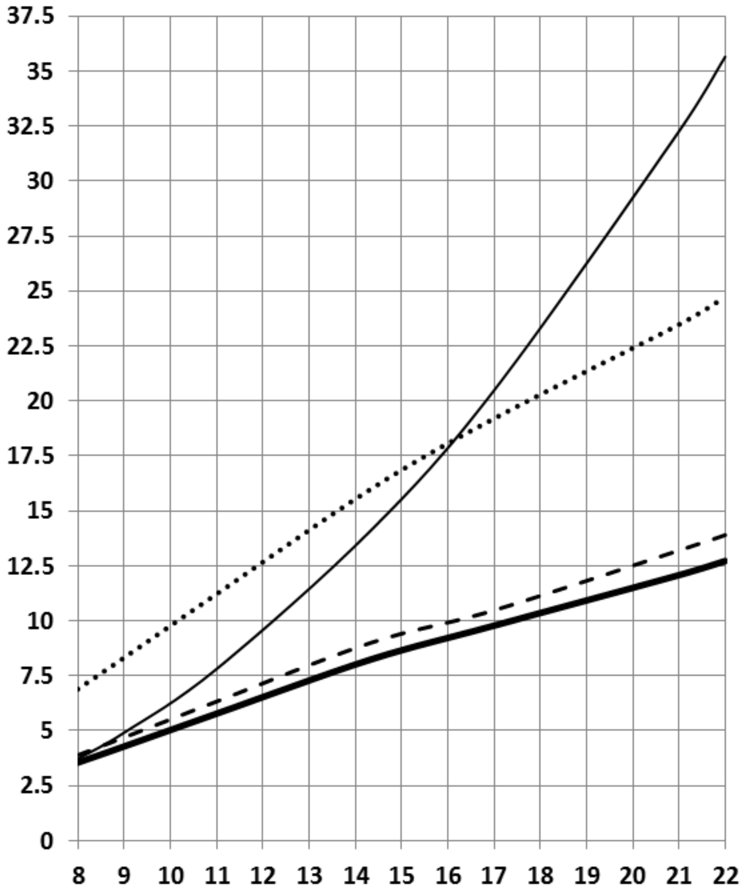

Figure 6. Variation of the stresses with respect to the $\frac{h}{b}$ ratios.

As a general conclusion, all the stresses are increasing for increased values of the $\frac{h}{b}$ ratio. The analytic relations lead to larger values of the shear stresses, in comparison with the maximum shear stresses resulted from the finite element model. However, the must be emphasized the differences between the theoretical backgrounds of these calculus methods, the finite element model taking into account all the strain energy aspects, while the bitorque and the constricted-moment are disregarded in a non-warped section, according to the hypotheses of the analytic model.

For large values of the $\frac{h}{b}$ ratio the wall becomes very thin, the member becomes very slender and unpredictable effects may occur. For these ratios, as it is remarked in the previous figure, the values computed using the analytic method may become at least twice larger than the values resulted from the finite elements model.

5. Conclusions

The paper investigates the domain in which the analytic relations for the calculus of the shear stresses in thin beams loaded by twisting moments may be used. If these relations are used for the predimensioning of a structure, they may lead to oversized dimensions, aspect that may become important because the weight of the structure will also increase. This remark is suggested by the thickness of the hull's plates, for which a small increase of their thickness may lead to an important increase of the overall weight. However, the relations may be used for an initial evaluation of the structural phenomena, emphasizing on the error produced by the non-warped section hypothesis. Another aspect regards the particular shape of the section, for a particular project being necessary studies of the OTW sections used as structural members. However, using the method of analysis presented in the paper there may be created a library of OTW parameterized sections, to be used in the early design of a structure.

Acknowledgement

The paper presents some aspects developed from the ideas studied in the MIEC2010 bilateral Ro-Md research project, E. Oanta, C. Panait, L. Lepadatu, R. Tamas, M. Constantinescu, I. Odagescu, I. Tamas, G. Batrinca, C. Nistor, V. Marina, G. Iliadi, V. Sontea, V. Marina, V. Balan, V. (2010-2012), “Mathematical Models for Inter-Domain Research with Applications in Engineering and Economy”, [8], under the guidance of the National Committee of Scientific Research, Romania, which is a follow-up group of studies of the ID1223 scientific research project: E. Oanta, C. Panait, B. Nicolescu, S. Dinu, A. Pescaru, A. Nita, G. Gavrila, (2007-2010), "Computer Aided Advanced Studies in Applied Elasticity from an Interdisciplinary Overview", [7], under the guidance of the National University Research Council, Romania.

References

[1] Oanta E, Nicolescu B 2003 *Constanta Maritime University Annals* **5** pp 53-58.
[2] Oanta E, Axinte T, Dascalescu A E 2014 *Constanta Maritime University Annals* **22** pp 65-70.
[3] Oanta E, Axinte T, Dascalescu A E 2014 *Constanta Maritime University Annals* **22** pp 71-76.
[4] Oanta E, Axinte T, Dascalescu A E 2015 *Constanta Maritime University Annals* **24** pp 87-92.
[5] Noels L 2013 *Aircraft Structures - Beams & Section Idealization* http://www.ltas-cm3.ulg.ac.be/MECA0028-1/StructAeroBeamsPart2.pdf, accessed on November 29, 2015.
[6] Gitin M M, Prasad L V 1995 *Handbook of mechanical design* (New Delhi: Tata McGraw-Hill).
[7] Oanta E, Panait C, Nicolescu B, Dinu S, Pescaru A, Nita A, Gavrila G 2007 *Computed aided advanced studies in applied elasticity from an interdisciplinary perspective* **ID1223** CNCSIS Romania research project.
[8] Oanta E, Panait C, Lepadatu L, Tamas R, Batrinca G, Nistor C, Marina V, Iliadi G, Sontea V, Marina V, Balan V 2010 *Mathematical models for inter-domain approaches with applications in engineering and economy,* **MIEC2010**, ANCS Ro-Md scientific research project.