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THE BUCKLING BEHAVIOR OF DOUBLE T STEEL SECTIONS ACCORDING THE INFLUENCE OF WELDING TECHNOLOGY

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Abstract: *In the Civil Engineering domain, an important role is paid by the weight reduction of steel structures, mostly because of the high cost of material. In order to be able to do that, the steel structures are designed in the elastic - plastic domain which makes the local and global instabilities have an overwhelming importance. Currently highly topical, but especially for the future structures, the welding technology with its great flexibility is one of the most attractive options for making the geometry of metallic elements. In this paper the authors want to find a closer connection between the welding technology and the requirements concerning the buckling behavior of the pillars, requirements imposed by the various standards of design. In this paper we obtained a method of verification of the influence that the welding technology has on the instability of metallic elements and the critical loads are much more simple to estimate.*

Key words: *buckling, residual stress, welding technology.*

1. Introduction

The estimation of the buckling load and deflection in engineering was made for the first time by Euler. He used the equilibrium between the internal and external moment and the general differential ordinary equation which bears his name. The approximation based on Euler's equation represents an ideal buckling behavior and in practice the influence of the yield stress, cross section and residual stresses plays a crucial role and in general they influence the reduction factor value (c) [1], [2], [6].

The relative slenderness:

$$\lambda_{rel} = \frac{L_{cr}}{\pi \cdot \sqrt{\dfrac{E \cdot I}{f_y \cdot A}}} \tag{1}$$

L_{cr} - the buckling length
f_y - the yield stress
I - the inertia momentum
A - Section area
E - Elasticity modulus

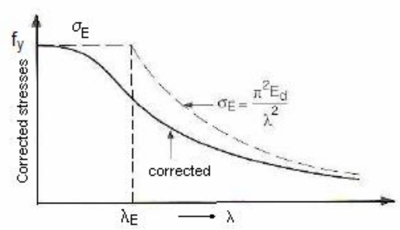

Fig. 1. *Reduction factor function of slenderness*

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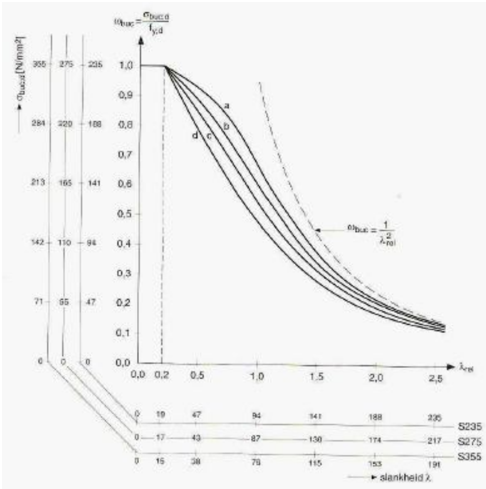


Fig. 2. *Sectional shapes and yield material diagram for the reduction factor*

The real ultimate stress is lower that Euler's buckling stress and the equation (1) was obtained without considering the shape and dimensions of the section and the method of construction.

Based on the buckling analysis obtained through the well known Euler equation, the practical experiences made for different sectional shapes groups and different steel properties, four slenderness graphics result and they are used in all the standards of Civil Engineering (Fig. 1a). The ultimate load [8] is calculated with the equation:

$$F_{cap} = \cdot \frac{\chi A f_y}{\gamma_{M0}} \qquad (2)$$

2. Analytical Model for Residual Stresses Consideration

2.1. General considerations:

– The load is not in the geometrical center of the section and has a variation function of initial deflection and compressed load value.

– The maximum loads are in the middle section of the girder and are applied over the whole girder.

– For low value loads the materials are in elastic state on the entire section and the classical equations can be used.

– When the loads increase and a part of the section starts to yield the deflection increases nonlinearly and we must get a new approximation for the phenomenon.

– The compression stress in the area which becomes plastic will not increase over the compression yield stress.

– In the parts of section where the stresses are small the compression yields will be considered reduced, cross-section or effective cross-section.

– The effective cross-section is asymmetric and the gravity center shifts with every load value.

– If we consider that the stress at mid-section is extended over the whole girder, the gravity center changes the position in all the sections.

– For calculation, the force is located in the gravity center and the shift of the gravity center is approximate using an added bending moment. That bending moment generates an extra deflection and the shift against the gravity center of the section.

– The initial deflection is considered.

If the partial yielding load on the structure is named F_1, then the total deflection of the middle section of a column will be:

$$e_1 = \frac{F_E \cdot d_0}{F_E - F_1} \qquad (3)$$

where, the Euler buckling load:

$$F_E = \frac{\pi^2 \cdot E \cdot I}{L_{cr}^2} \qquad (4)$$

d_1 - the total deflection at force F_1
d_0 - the initial deflection (when F = 0 N)
F_1 - the partial yielding load.

Because the sine shapes of the deflection, the most critical cross-section is the middle section of the beam and the stress shape in that part is considered to be the seam in all the beam cross sections. In reality the end part of the beam starts to yield at larger loads than the middle part of the beam. That assumption is made for mathematical modeling simplification. Schematically, the iterative modification of the loads and stresses in the middle section of the beam used in mathematical method is presented in Figures 3, 4, 5 and 6.

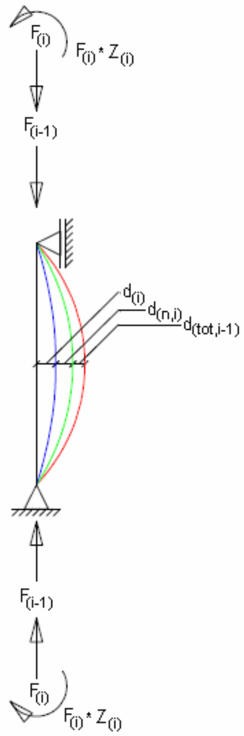


Fig. 3. *The calculation scheme of the deflection of the compressed beam*

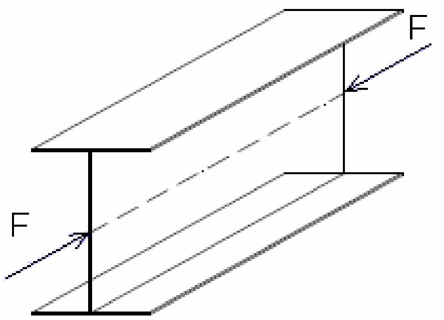


Fig. 4. *Force in the gravity sectional point*

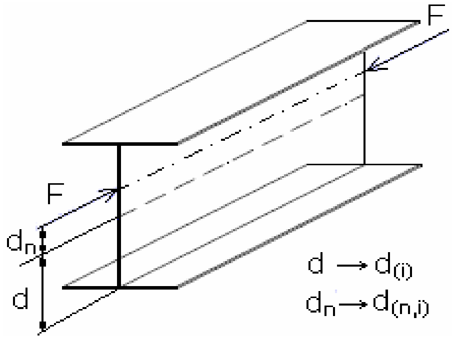


Fig. 5. *Stiffness d_n of point application*

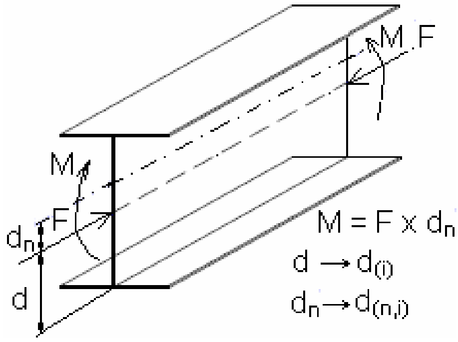


Fig. 6. *Loading force system for deflection calculation*

The current analysis of the load case *"i"* dates, are the forces of the previous load case and the deflection calculated in this previous load case, *"i - 1"*. The original deflection, d_0 appears in the first load case $i = 1$. The residual stress is considered using the simplified shape repartitions, presented in Figures 7, 8, 9, 10 and 11.

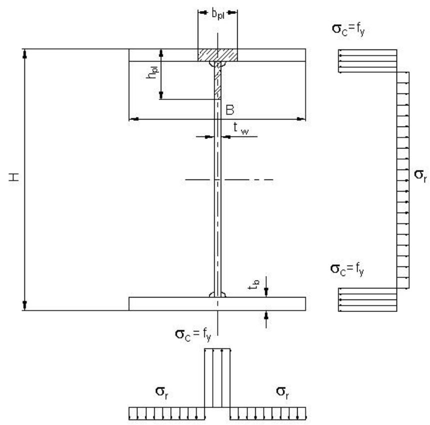


Fig. 7. *Reduced residual stress diagram*

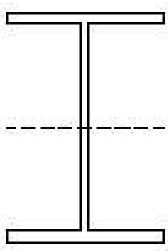


Fig. 8. *Profile without reductions (I_1,A_1)*

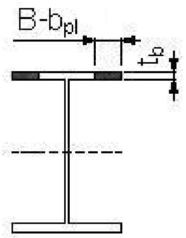


Fig. 9. *Profile with reduction on left flange (I_2,A_2)*

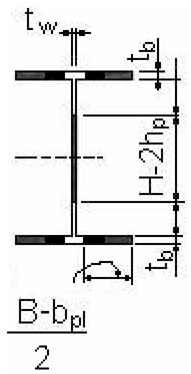


Fig. 10. *Profile with reduction on web and flanges (I_3,A_3)*

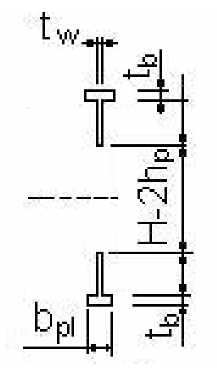


Fig. 11. *Profile with reduction on web and flange (I_4, A_4)*

2.2. Analysis model

The equilibrium between the internal and external bending moments represents the condition of mathematical expression of ultimate load and deflection.

The external load bending moments are the loads multiplied by the deflection. The internal moment is the curvature multiplied by stiffness. The curvature represents the second derivative of the deflection. Solving this condition we have an iterative expression for the current deflection, $d_{(tot,i)}$ [9]:

$$d_{tot,i} = d_{tot,i-1} + d_{n,i} + d_i = \frac{\frac{F_i \cdot z_i \cdot L^2}{8 \cdot E \cdot I_i}(F_{i-1} + F_i) + F_{E,i}\left(d_{tot,i-1} + \frac{F_i \cdot z_i}{8 \cdot E \cdot I_i}\right) - F_{i-1} \cdot d_{tot,i-1}}{F_{E,i} - F_{i-1} - F_i} \quad (5)$$

$$d_i = d_{tot,i} - d_{tot,i-1}$$

$$M_i = F_{i-1} \cdot d_i + F \cdot d_{tot,i}$$

$$\sigma_{st,i} = \sigma_{st,i-1} + \frac{M_i}{h_i} - \frac{F_i}{A_i} \quad (6)$$

$$\sigma_{dr,i} = \sigma_{dr,i-1} - \frac{M_i}{h_i} - \frac{F_i}{A_i}$$

where:

$d_{tot,i}$ - the total deflection at load case *i* (mm)

$d_{tot,i-1}$ - the total deflection at load F_{i-1} (mm)

$d_{m,i}$ the deflection due to the bending moment in the load case *i* (mm)

d_i - the extra deflection due to the difference in normal force (mm)

F_i - the value of load in case *i* (N)

F_{i-1} - the load in the in the case *i-1* (N)

I_i - the moment of inertia in case *i* (mm^4)

A_i - the area of section in the case *i* (mm^2)

$F_{E,i}$ - the Euler buckling load in case *i* (N)

h_i - the difference between the original gravity point and the effective point of gravity in case *i*.

The initial assumptions of the analysis are:

– There is an initial deflection
– There is a force in the section which generates partial yielding
– A deflection due to the original load exists
– There is an additional force
– There is a difference between the original center of gravity and the effective center of gravity.

3. The Determination of Plastic Areas Induced By Welding Process

For joining [3], [4], [7] by welding beams we realize the process was studied using a different technology variant. The function of welding technology, the b_{pl}, h_{pl}, A_{pl} and the stress shape change. The technological analyzed calculation variant is given by Figures 12-17.

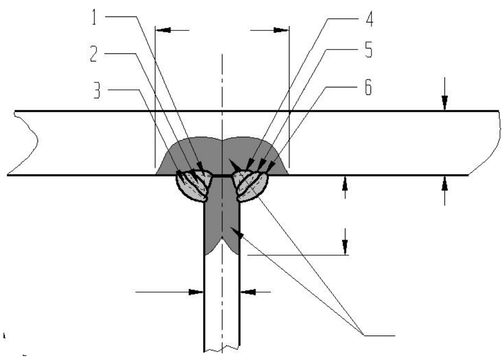


Fig. 12. *Asymmetrical V1 weld variant*

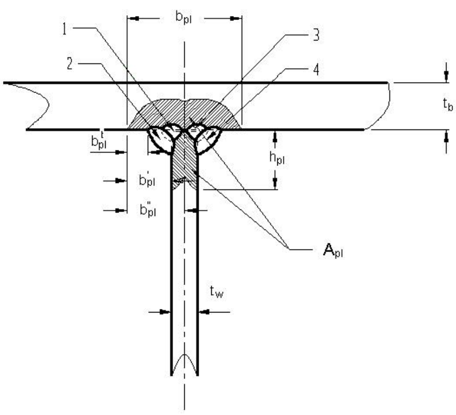


Fig. 13. *Asymmetrical V2 weld variant*

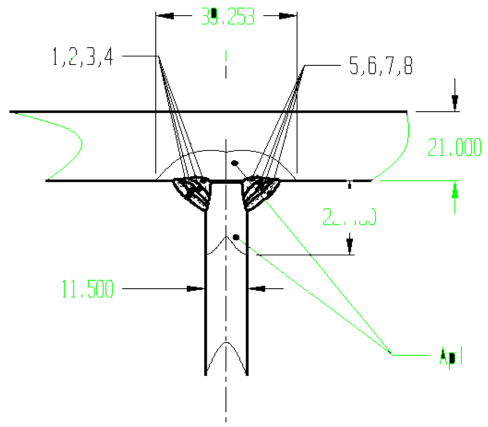


Fig. 14. *Asymmetrical V3 weld variant*

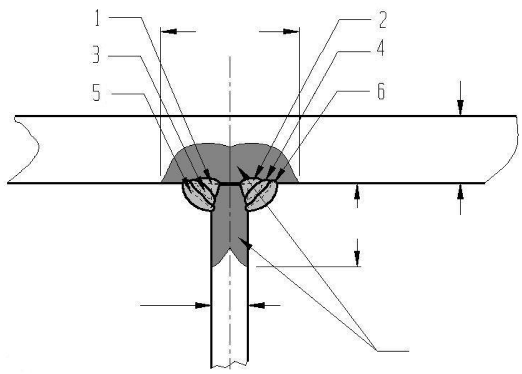


Fig. 15. *Symmetrical V1 weld variant*

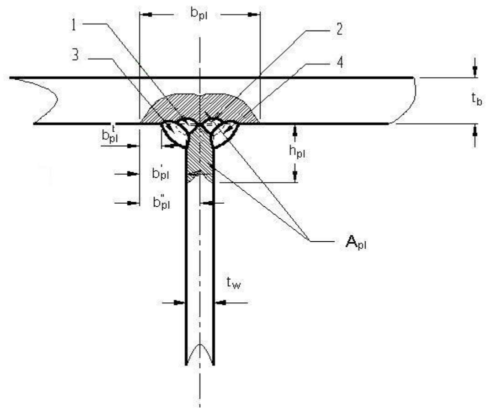


Fig. 16. *Symmetrical V2 weld variant*

The plastic areas induced by welding process are presented in Table 1 [9].

The diagrams for Critical Buckling Force and Column Length and the Buckling Curves

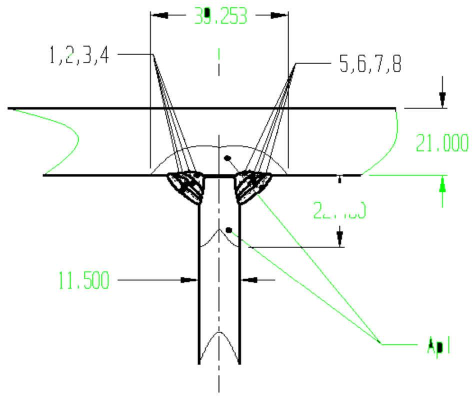


Fig. 17. *Symmetrical V3 weld variant*

for the all the welding technology are presented in Figure 18 and Figure 19, respectively for various column lengths [8].

We try to get good predictions for Columns length between 1 and 50 m and to verify the results using the various usual national and international design standards of curves.

The results were verified using the FEM method too, for diverse Columns length and in von Misses [5], [10] isotropic plastic model using the COSMOS software.

The plastic areas induced by welding process Table 1

Technological variants		A_{pl} [mm2]	b_{pl} [mm]	h_{pl} [mm]	σ_Z^A [daN/cm^2]
Asymmetric	V1	392,646	44,953	27,339	-306,9
	V2	770,425	54,95	26,4	-520,2
	V3	363,94	41,23	26,803	-287,725
Symmetric	V1	392,646	34,953	17,339	-236,3
	V2	770,425	44,95	26,4	-412,2
	V3	363,94	32,3	23,803	-248,23

For the case of a Column with 2 m length and in the hypothesis of 2 mm initial displacement the results are presented in Table 2.

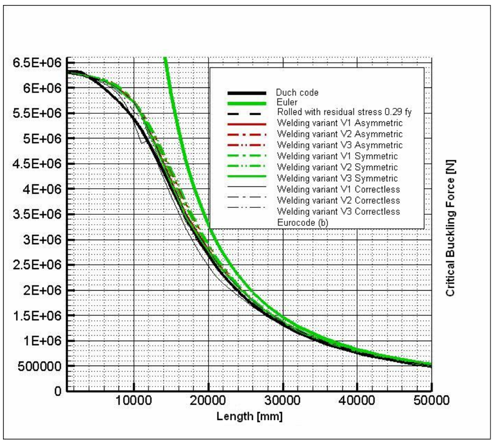


Fig. 18. *Critical Buckling Force resulted for various lengths and welding technologies*

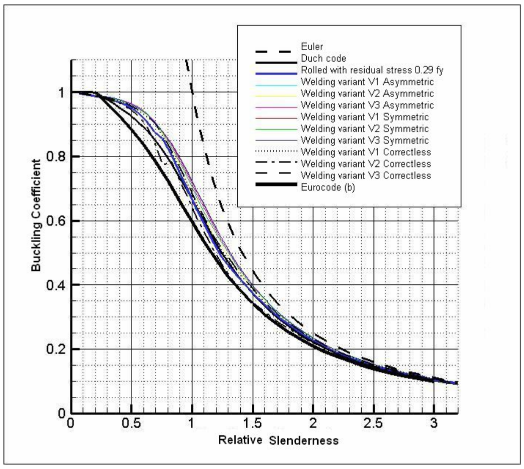


Fig. 19. *The Buckling Curve Factor function of the relative slenderness for various welding technologies*

The distribution of forces and displacements in time are presented in Figures 20 and 21.

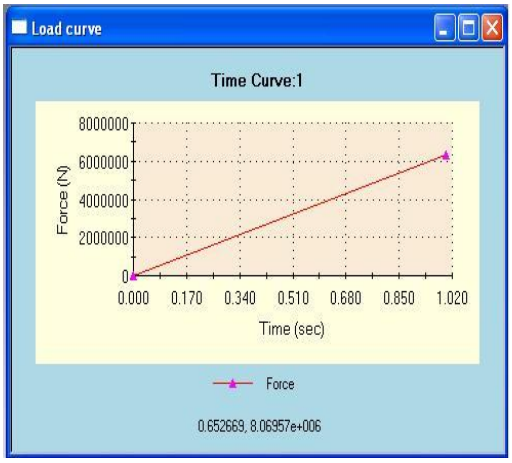


Fig. 20. *Time force analyse modelling*

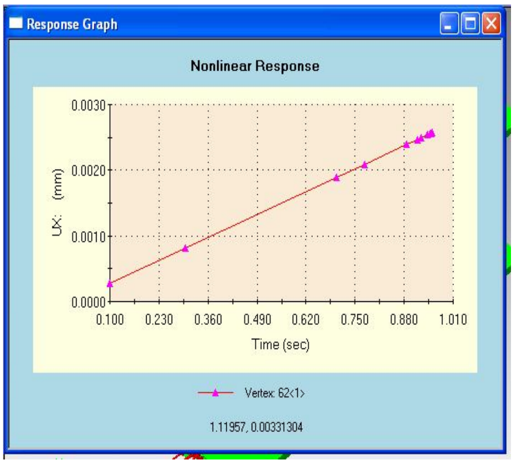
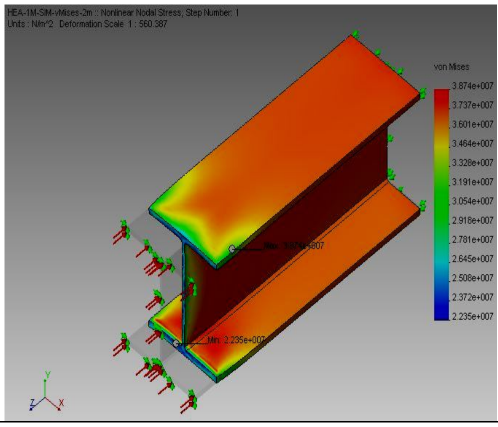
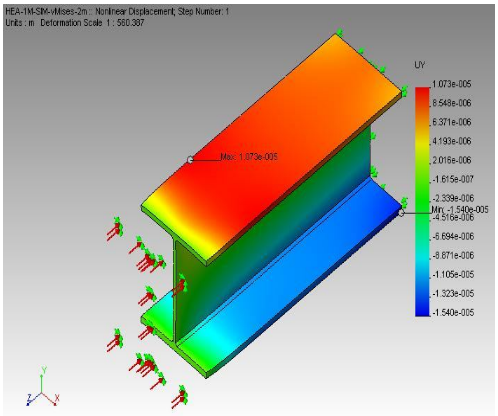


Fig. 21. *Time displacement variation*

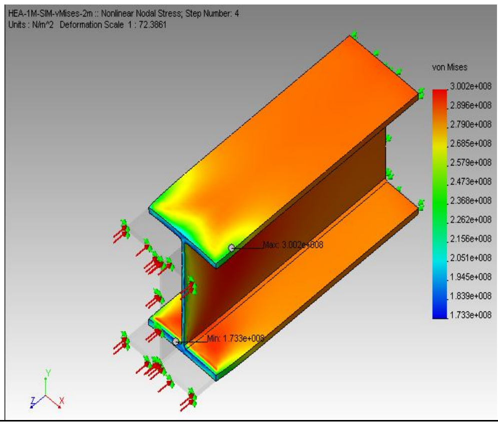
Table 2

$F = 6{,}319\text{x}10^5\ N$





$F = 4{,}8972\text{x}10^6\ N$



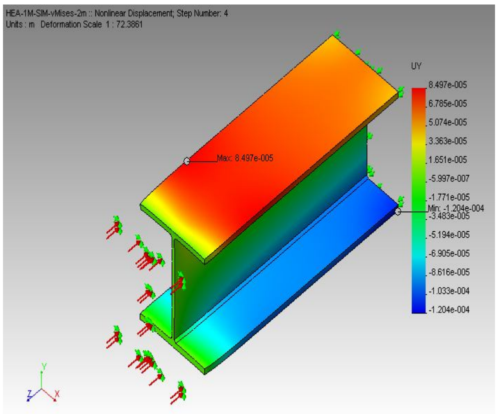


Table 2 (*Continued*)

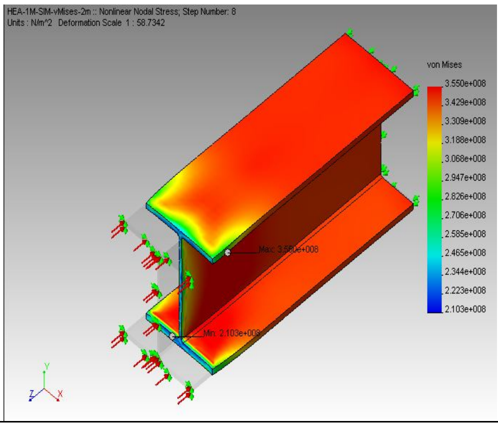
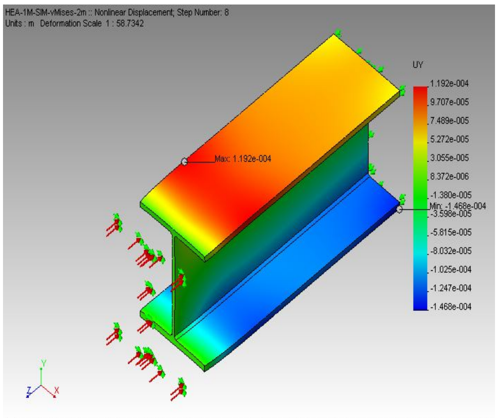
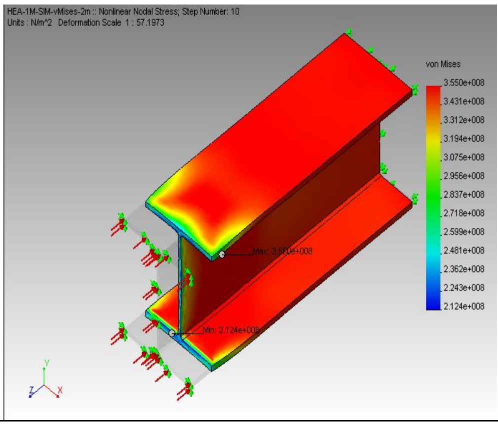
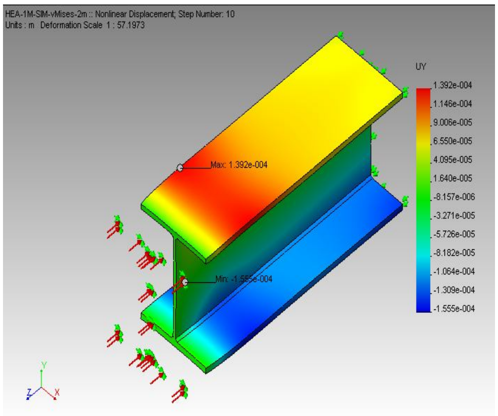
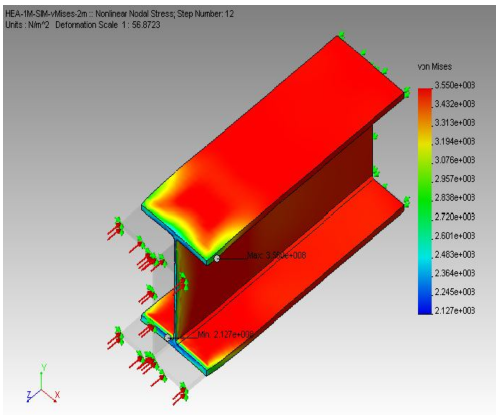
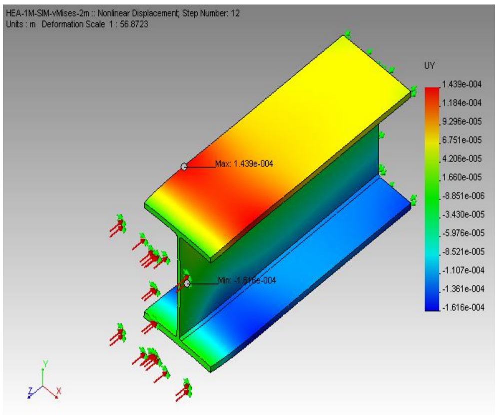
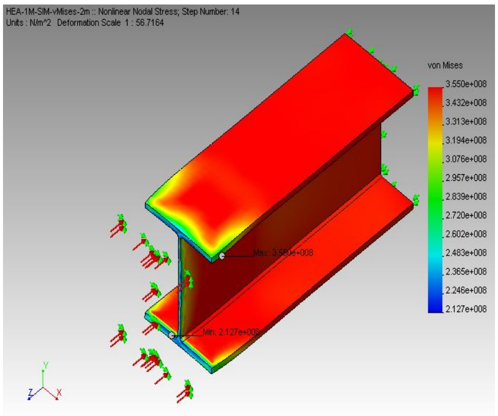
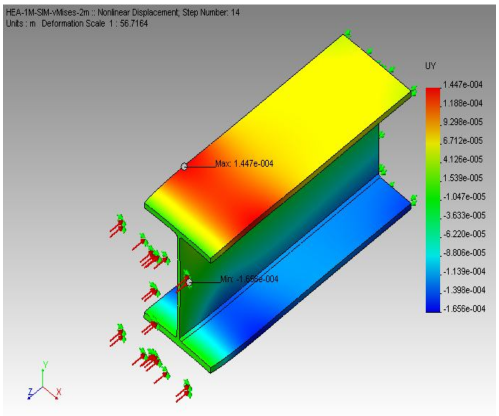
F = 5,9524x10^{6} *N*
 
F = 6,0212x10^{6} *N*
 
F=6,0308x10^{6} *N*
 

Table 2 (*Continued*)

F = 6,033x10^6 N





4. Conclusions

– The own model, based on analytical modeling of Columns instability gives good approximations for critical loads and buckling curves for double T articulated girders.

– The reserves of critical loads in the case of the best welding technology become too large even if the residual deflection (d_0) is L/1000 according to the maximum accepted deflection in the design codes.

– The DIN, Dutch, Romanian and other national Design codes give higher critical loads than the Euro codes and their values are according to the residual stresses and deflections which are obtained when the welding technology is used according to the national welding technological process standards.

– The welding residual stress and distortion estimations establish a technology that can decrease the weight of the structure. In the case of tall buildings, the method can give appreciable economy in steel and welding materials.

– The computing time in the case of the proposed method is less than the FEM method and the program made in Microsoft Visual C/C++ gets output for Tecplot postprocessor product. In this case the graphical possibilities of our program increase and the results can be easily integrated in the design processes of the structure.

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