MS Excel Toolkit:
Design of steel-concrete composite columns in accordance with EN 1994-1-1

Guilherme de Azevedo Guedes Lebre

Dissertation in Civil Engineering, Master Degree

Instituto Superior Técnico, University of Lisbon

EXTENDED ABSTRACT

This dissertation aims to develop a reliable and user-friendly MS Excel toolkit with the capability to check steel-concrete composite columns at ultimate limit states of axial compression, combined compression and uniaxial bending, combined compression and biaxial bending in accordance to EN 1994-1-1. Generally, the cross-section of composite columns is designed doubly symmetrical and uniform over the member length. In addition with the remaining clauses and construction details, this type of columns are within the scope of the simplified method of design. Therefore, a plastic analysis of the cross-section is conducted.

The expressions in *EN 1994, Annex A1* define a set of five points forming a polygon for M-N interaction. The toolkit calculate a high number of (M;N) points sufficient to define an interaction curve, taking advantage of total bending resistance of the cross-section, which represent an increase up to 7%.

Due its geometry, rectangular cross-sections are analyzed by rectangular stress blocks and the circular cross-sections by expressions that geometrically decompose the steel section and the concrete into regions above or below neutral axis.

The computing capability of MS Excel, allied to Visual Basic programmed Macros, make it possible to produce and compile several results. Therefore parametric studies were conducted to determine the influence of structural steel strength, concrete strength, longitudinal reinforcement area, tube thickness, and tube diameter, on the cross-section resistance. In general, the resistance provided by the variation of one parameter, increase with the decrease of the remaining parameters contribution.

Keywords: Steel-concrete composite column; toolkit; plastic analysis; safety check; EN1994-1-1;

1 INTRODUCTION

The steel-concrete composite columns are within the definition of composite structural elements, which includes structural elements as columns, beams and slabs, composed by various structural materials «interconnected to limit its longitudinal sliding and separation». (1)

Specifically, steel-concrete columns are subjected during its life span to axial compression or combined compression and bending. Commonly, columns are designed to support the gravity loads applied on buildings slabs and beams, leading them to the foundations and also to resist to horizontal loads, such as seismic and wind.

A comparative analysis between steel-concrete composite columns, reinforced concrete columns and steel columns, shows that composite columns has higher axial compression and bending resistance, and also flexural stiffness (Table 1). The cross-sections analyzed are illustrated in Figure 1.

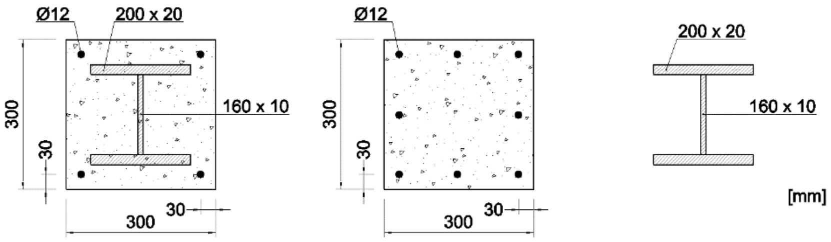


FIGURE 1 – (FROM LEFT TO RIGHT) CROSS-SECTION OF A COMPOSITE COLUMN, REINFORCED CONCRETE COLUMN AND STEEL COLUMN

In order to compare the decrease of resistance and stiffness between the major axis of bending (y-y) and the minor axis (z-z), a relative value for both axis is shown for each type of cross-section.

TABLE 1 – COMPARATIVE ANALYSIS OF AXIAL COMPRESSION AND BENDING RESISTANCE, AND FLEXURAL STIFFNESS FOR COMPOSITE COLUMN, REINFORCED CONCRETE COLUMN AND STEEL COLUMN

Cross-section	Axial compression resistance	Bending Resistance			Flexural stiffness		
		y-y axis	z-z axis		y-y axis	z-z axis	
Steel-concrete	100%	100%	64% y-y	100%	100%	70% y-y	100%
Reinforce concrete	42%	30%	100% y-y	46%	49%	100% y-y	72%
Steel	66%	77%	52% y-y	62%	65%	39% y-y	38%

2 TYPICAL CROSS-SECTIONS

The types of cross-sections to be analyzed by the *toolkit* (Figure 2 – a, b, d, e) are within the scope of simplified method of design (EN1994-1-1, clause 6.7.3). The characteristics and advantages of each type are presented in the dissertation.

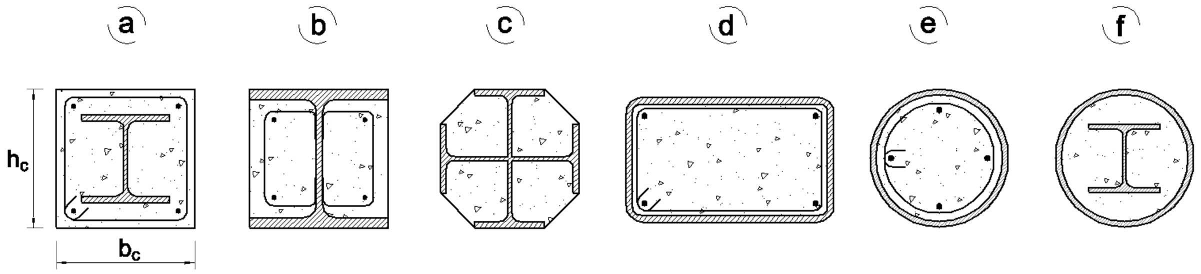


FIGURE 2 – TYPICAL CROSS-SECTIONS

3 RESISTANCE OF THE CROSS-SECTION

The resistance of cross-section is obtained from a plastic[1] analysis considering: total interaction[2] between concrete and steel reinforcements, and between concrete and structural steel; tensile strength of the concrete should be neglected; steel (structural and longitudinal reinforcement) has equal compression and tensile strength.

3.1 AXIAL COMPRESSION

3.1.1 PLASTIC RESISTANCE TO COMPRESSION

Considering that all components resist to compression, the design value of the plastic resistance to compression, $N_{pl,Rd}$, is determined adding the plastic resistance of each component, which depends on its area and stress design value, 6.7.3.2(1):

$$N_{pl,Rd} = A_a f_{yd} + 0{,}85\, A_c f_{cd} + A_s f_{sd} \qquad [6.30]$$

The factor 0,85 for concrete take into account the influence of long time acting loads, excluding creep and shrinkage (3), which are considered in the determination of effective flexural stiffness, $\mathrm{E_{c,eff}}$,. Moreover, the 0.85 factor may be replaced by 1.0 for concrete filled tubular hollow sections due to more favorable development of concrete strength and confinement. (1)

3.1.2 EFFECT OF CONFINEMENT ON CROSS-SECTION RESISTANCE

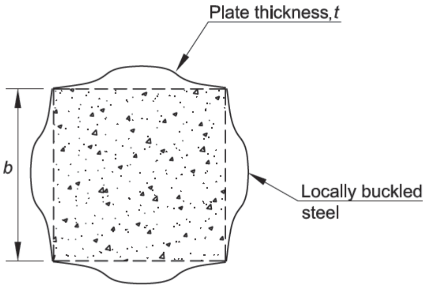


FIGURE 3 – LOCAL BUCKLING DUE TO TRANSVERSE STRAIN, ON A CONCRETE FILLED RECTANGULAR TUBE

For, concrete filled circular tubes, account may be taken of increase in strength of concrete, higher than the design value, f_{cd}. This effects only occurs in circular tubular sections, due to the impeded transverse strain provided by the steel tube. Transverse compression of the concrete leads to three-dimensional effects, which increase the resistance for normal stresses. At the same time, circular tensile stresses result in the round section reducing its normal stress capacity. This effect does not occur in concrete filled rectangular tubes, since the transverse strain acts perpendicularly on the plate which cause local buckling, as shown in Figure 3. Additionally, bending moment decrease the compressed area, consequently diminish the effect of confinement.

---

[1] – A plastic resistance is obtained from a vertical diagram of tension/compression for each structural material.
[2] – Interaction is related with the sliding between two components and depends on the stiffness of the connection, its number and position (1).

3.2 COMBINED COMPRESSION AND UNIAXIAL BENDING

For each plastic neutral axis, LN_p, a static equilibrium of axial forces may be conducted to determine an exceeding force, i.e., the design normal force, N_{Ed} (Figure 4). The associated bending moment is obtained from the product of each component force, in tension and compression, with the respective distance between force application point and section centroid (half of the height). As the neutral axis varies, each point (M; N) of the interaction curve is determined by the methods presented in chapter 4. A set of four points (Figure 5, points A to D) along the interaction curve may be defined for the various composite symmetrical cross-sections.

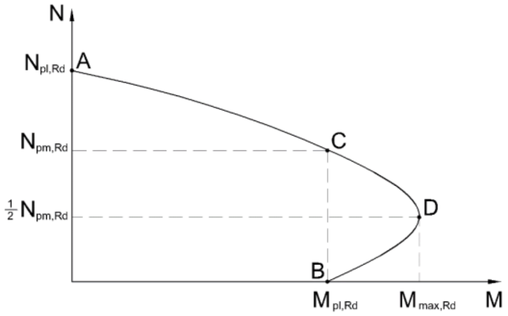


FIGURE 5 – M-N INTERACTION CURVE

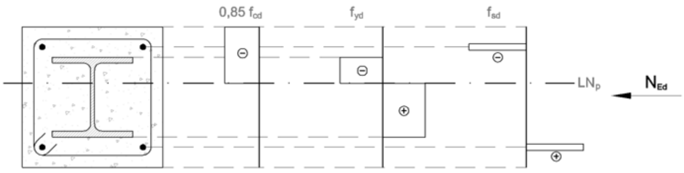


FIGURE 4 – STRESS DIAGRAM OF CONCRETE, STRUCTURAL STEEL AND REINFORCE STEEL

Where:

$N_{pm,Rd}$ – Plastic resistance of concrete to compression

$$N_{pm,Rd} = \alpha_{cc}\,A_c f_{cd} \qquad (3.1)$$

$$\alpha_{cc} = \begin{cases} 1{,}00 & \text{(concrete filled tubular sections)} \\ 0{,}85 & \text{(remaining composite sections)} \end{cases}$$

$M_{pl,Rd}$ – Plastic resistance bending moment

$M_{max,Rd}$ – Maximum plastic resistance bending moment

3.3 COMBINED COMPRESSION AND BIAXIAL BENDING

When subjected to biaxial bending, composite columns shall be analyzed separately for each axis (major axis of inertia, y–y; minor axis of inertia, z–z). Therefore, two interaction curves, M_Y-N and M_Z-N (Figure 6), are defined.

For each determined axial force, bending moments of each axis may be related in accordance with M_y–M_z curve (Figure 6) defined by the following expression:

$$\left(\frac{M_{y,Ed}}{M_{pl,y,N,Rd}}\right)^{\alpha} + \left(\frac{M_{z,Ed}}{M_{pl,z,N,Rd}}\right)^{\beta} \leq 1 \qquad (3.2)$$

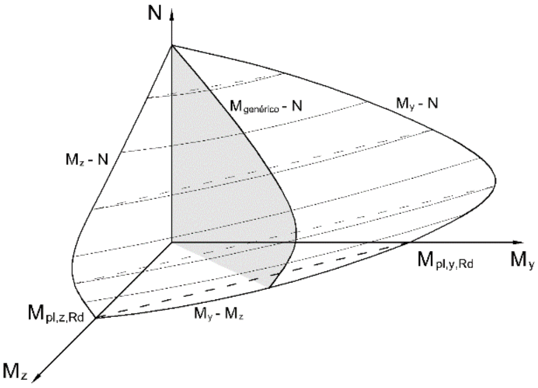


FIGURE 6 – INTERACTION SURFACE M_Y–M_Z–N

When $\alpha = 1$ and $\beta = 1$, M_y–M_z curve becomes a straight line (Figure 6 – dashed line):

$$\frac{M_{y,Ed}}{M_{pl,y,N,Rd}} + \frac{M_{z,Ed}}{M_{pl,z,N,Rd}} \leq 1 \qquad [6.47]$$

3.4 INFLUENCE OF TRANSVERSE SHEAR

Commonly, composite columns are subjected to transverse shear on both directions. A study of the influence of transverse shear, V_{Ed}, on cross-section strength was conducted separately for each axis, in accordance to EN1994-1-1, 6.7.3.2(2) to (4).

The reduction of design steel strength usually occurs, for each axis, in different steel elements: $V_{z,Ed}$ affects flanges and $V_{y,Ed}$ affects webs.

The analysis of the results (Figures 8 to 10) shows that the influence of transverse shear is more relevant for the resistance to bending along the minor axis of inertia (z-z), as a result of flange reduced design steel strength, which have a greater area than the web.

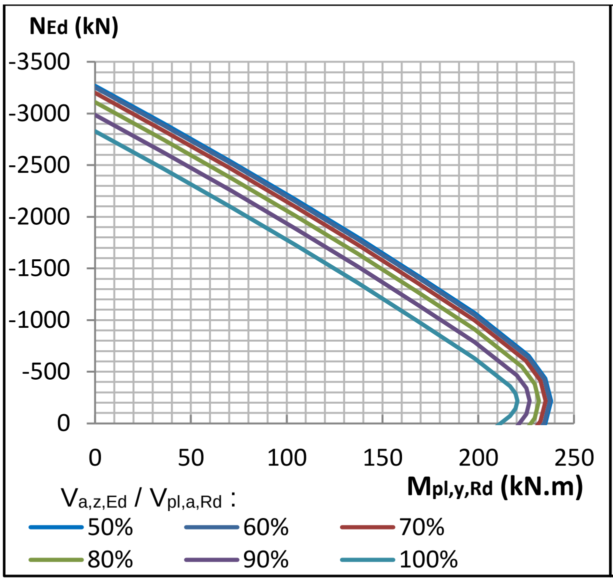


Figure 8 – Influence of transverse shear on interaction curve (M_Y - N) for the cross-section presented in Figure 9

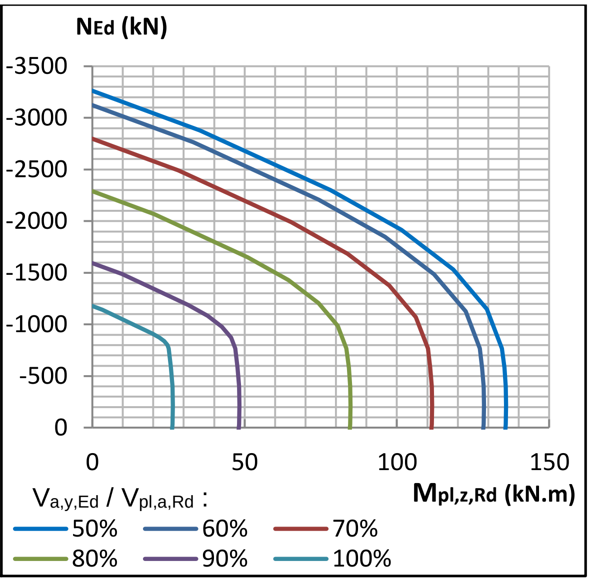


Figure 7 - Influence of transverse shear on interaction curve (M_Z - N) for the cross-section presented in Figure 9

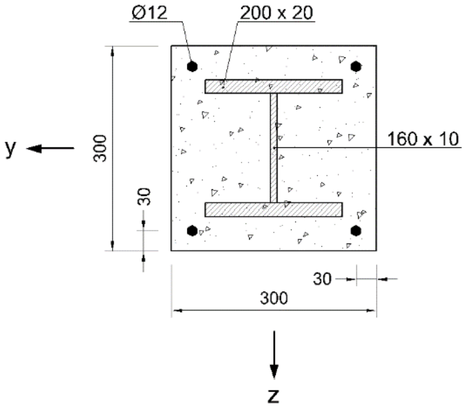


Figure 9 – Cross-section analyzed

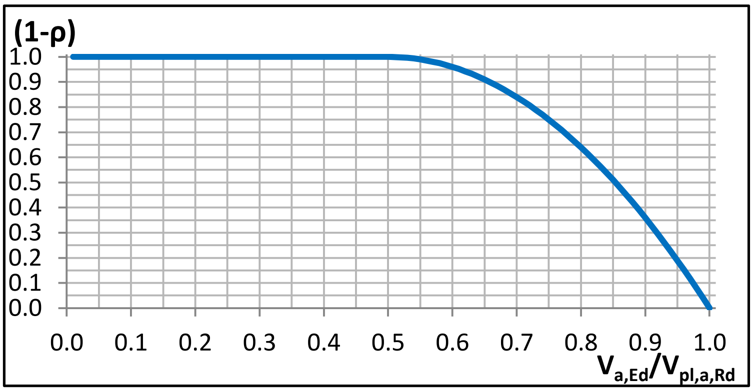


Figure 10 - Design steel strength reduction due to transverse shear

4 METHODS TO DEFINE M-N INTERACTION CURVE

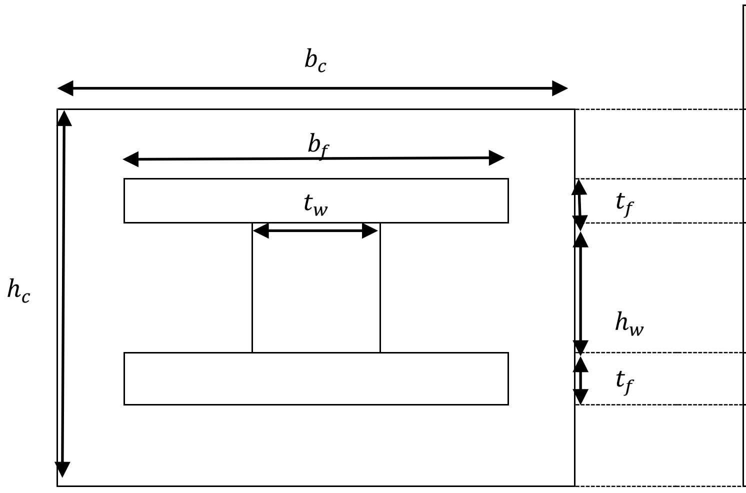
The expressions in *EN 1994, Annex A1* aims to define a set of five points forming a polygon. However, to take advantage of the total resistance of the cross-section the toolkit determine a much higher number points thus defining an interaction curve.

In order to determine with precision the bending moment associated to the axial force introduced by the user, the methods here presented shall analyze a higher number of neutral axis to define the points (M; N) along the interaction curve, since the value of the bending moment is obtained from an interpolation based on the previously calculated points. The interpolation produces a value that is inside the interaction curve, thus favoring the security. The calculation of a high number of forces (for each neutral axis) is possible taking advantage of MS Excel computing efficiency to geometrically decompose the steel section and the concrete. Briefly, the methodology developed to define the interaction curve and the bending moment associated to the introduced axial force, is listed below:

- Definition of the neutral axis position to calculate, along the cross-section;
- Calculation of axial force value for each neutral axis;
- Define the positions of the two neutral axis that has an associated axial force lesser and greater than the introduced axial force;
- Calculation of the bending moment associated to the neutral axis positions defined initially;
- Calculation of the bending moment associated to the introduced axial force by interpolation, based on the two previously calculated axial forces and bending moments;
- Calculation of the position of the neutral axis by interpolation, based on the same values;

4.1 RECTANGULAR CROSS-SECTIONS

Due to its geometry, rectangular cross-sections maybe decomposed to rectangular stress blocks. As an example, in Figure 11 a concrete encased section is decomposed for the analysis along the major axis of inertia (y-y). The definition of rectangular stress-blocks for the remaining types of cross-sections are presented in the dissertation.



Steel Base	Height	Concrete Base
0	$\frac{h_c - 2t_f - h_w}{2}$	b_c
b_f	t_f	$b_c - b_f$
t_w	h_w	$b_c - t_w$
b_f	t_f	$b_c - b_f$
0	$\frac{h_c - 2t_f - h_w}{2}$	b_c

FIGURE 11 – DEFINITION OF RECTANGULAR STRESS BLOCKS FOR A CONCRETE ENCASED SECTION ALONG MAJOR AXIS OF INERTIA

The positions of neutral axis to be analyzed are, in a first stage, set on the beginning and end of each rectangular block. This allows to calculate which block correspond to the introduced axial force, without using too much computing capacity.

In a second stage, only the block where the neutral axis lays is divided into a high number of equal height blocks. The position of neutral axis are now set on the start/end of the divided blocks. The axial force and bending moment are calculated for each new position of the neutral axis (each column), in accordance with Table 2.

TABLE 2 – CALCULATION SCHEME OF AXIAL FORCE AND BENDING MOMENT, FOR EACH NEUTRAL AXIS, USING RECTANGULAR STRESS BLOCKS

					Plastic Neutral Axis $(z_{LNp,k})$ $\quad k = \{1, 2, \dots, n+1\}$				
Rect-angular Block (i)	**Steel base** $(b_{a,i})$	**Concrete Base** $(b_{c,i})$	**Height** (h_i)	**Block Centroid** $(z_{CM,i})$	$z_{LNp,1} = 0$	$z_{LNp,2} = h_1$	$z_{LNp,3} = h_1 + h_2$	...	$z_{LNp,k} = \sum_{i=1}^{k-1} h_i$
1	$b_{a,1}$	$b_{c,1}$	h_1	$z_{CM,1} = h_1/2$	N_1	N_1	…	…	…
2 (…)	$b_{a,2}$	$b_{c,2}$	h_2	$h_1 + h_2/2$	N_2	N_2	…	…	…
n	$b_{a,n}$	$b_{c,n}$	h_n	$z_{CM,n} = \left(\sum_{i=1}^{n-1} h_i\right) + \frac{h_n}{2}$	N_n	N_n	…	…	…
			$h = \sum_{i=1}^{n} h_i$	**Axial Force** $N_{Ed,k}{}' =$	$\sum_{i=1}^{n} N_i$	...	…	…	...
				Bending Moment $M_{Rd,k}{}' =$	$\sum_{i=1}^{n} (z_{CM,i} - \frac{h}{2}) \times N_i$	...	…	…	...

The concrete tensile strength should be neglected. Therefore, the normal force for each block (i) is calculated by the following expression:

$$N_i = h_i \left(b_{a,i}\, f_{yd} + b_{c,i}\, \alpha_{cc}\, f_{cd}\right) \qquad (4.1)$$

$$\alpha_{cc} = 0 \quad \Leftarrow \quad z_{CM,i} > z_{LNp,k}$$

The transverse shear influence, is taken into account in the design value of steel strength, f_{yd}, for the appropriate rectangular block. The final value of axial force is obtained adding the resultant force of the reinforcement steel calculated in accordance to the relative position of the neutral axis in analysis. The bending moment final value is obtained, as well, adding the bending moment of reinforce steel, which is given by the product of each force and the distance between its centroid and the composite cross-section centroid $(h/2)$.

To calculate the bending moment and neutral axis position associated to the introduced axial force value, an interpolation is made using the values previously calculated that are inferior (-1) and superior (+1) to the introduced axial force value:

$$\mathrm{M_{pl,N,Rd}} = \mathrm{M_{pl,N,Rd-1}} + \frac{\left(\mathrm{M_{pl,N,Rd+1}} - \mathrm{M_{pl,N,Rd-1}}\right)}{\left(\mathrm{N_{Ed+1}} - \mathrm{N_{Ed-1}}\right)}\left(\mathrm{N_{Ed}} - \mathrm{N_{Ed-1}}\right) \tag{4.2}$$

$$\mathrm{LN_p} = \mathrm{LN_{p-1}} + \frac{\left(\mathrm{LN_{p+1}} - \mathrm{LN_{p-1}}\right)}{\left(\mathrm{N_{Ed+1}} - \mathrm{N_{Ed-1}}\right)}\left(\mathrm{N_{Ed}} - \mathrm{N_{Ed-1}}\right) \tag{4.3}$$

Naturally, for rectangular cross-sections, this procedure shall be applied for both axis of inertia.

4.2 CIRCULAR CROSS-SECTIONS

For circular cross-section the interaction curve is determine by expressions that geometrically decompose the steel section and the concrete.

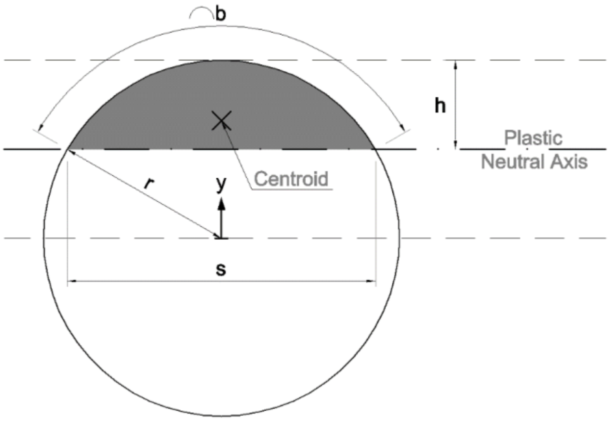


FIGURE 12 – DECOMPOSE OF A CIRCUMFERENCE INTO THE AREA OF CONCRETE ABOVE AND BELOW THE PLASTIC NEUTRAL AXIS

$$h = r - y_{LN_p} \tag{4.4}$$

$$r = \frac{4 \cdot h^2 + s^2}{8 \cdot h} \tag{4.5}$$

$$s = \sqrt{8 \cdot r \cdot h - 4 \cdot h^2} \tag{4.6}$$

$$b = 2 \cdot r \cdot \arcsin\left(\frac{s}{2 \cdot r}\right) \tag{4.7}$$

$$A = \frac{r \cdot b}{2} - \frac{s \cdot (r - h)}{2} \tag{4.8}$$

$$y_{CM} = \frac{s^3}{12 \cdot A} \tag{4.9}$$

The expressions (4.4) to (4.9) determine the area of concrete above the neutral axis. The area below, may be easily calculated subtracting above area from the total area of concrete.

The area of the steel section above the neutral axis, is obtain by the subtraction of two areas, as shown in Figure 13, considering the exterior and interior radius, R_{EXT} and R_{INT}, respectively.

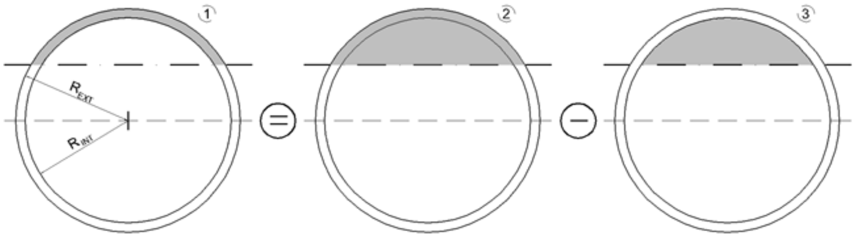


FIGURE 13 - DECOMPOSE OF A CIRCUMFERENCE INTO THE AREA OF STEEL ABOVE AND BELOW THE PLASTIC NEUTRAL AXIS

The determination of the centroids (application points of the forces used to determine the bending moment) are calculated for region 1 (Figure 13), for example, by the following expression:

$$y_{CM,2} = \frac{y_{CM,1} \cdot A_1 + y_{CM,3} \cdot A_3}{A_1 + A_3} \Leftrightarrow$$

$$\Leftrightarrow y_{CM,1} = \frac{y_{CM,2} \cdot (A_1 + A_3) - y_{CM,3} \cdot A_3}{A_1} \tag{4.10}$$

Where:

$y_{CM,2}$ e $y_{CM,3}$ – Centroids of regions 2 and 3 (Figure 13) obtained from expression (4.10), considering the radius R_{EXT} e R_{INT}, respectively.

For the positions of the neutral axis below the cross-section centroid ($y = 0$), the values of the area and centroid position of concrete and steel below the neutral axis are equal to values of symmetrical (along $y = 0$) neutral axis.

The axial force and bending moment is calculated for each position of the neutral axis along all the height of the cross-section. In order to obtain an interaction curve defined with precision, the cross-section is divided into 10 equal height parts on zone A, and 100 parts on zone B, shown in Figure 14.

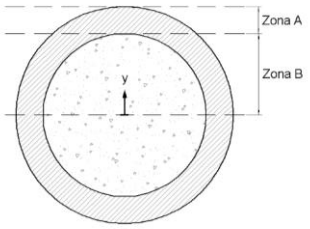


FIGURE 14 – ZONE A & ZONE B

The bending moment is determine by the following expression:

$$M_{pl,Rd} = \sum_i d_i F_{x,i} \tag{4.11}$$

Where,

$F_{x,i}$ – Axial force of component i (steel / concrete)

d_i – Distance between the component centroid and the centroid of the cross-section ($y = 0$)

The contribution of the reinforce steel is calculated also by the expression (4.11). To calculate the bending moment and neutral axis position associated to the introduced axial force value, an interpolation is made as shown in expression (4.2) and (4.3), respectively.

5 MS EXCEL TOOLKIT

The toolkit was developed on MS Excel due to its computing capability and user-friendly frontend. Favoring an easy interpretation of the results, the following features were set up:

- Minimization of input data and summarization of results in the first sheet of the workbook;
- Reports separated in different sheets accordingly to each design check;
- Alerts the user when the admissible limits are not respected and the additional verifications to perform;
- Scheme of the cross-section designed by the user and the respective M-N interaction curve;
- Ability to choose between welded steel sections with user defined dimensions and commercial steel sections;

Due to the different geometries, two toolkits were designed for rectangular or circular columns. Although, the structure and organization of the front-end is very similar, and may be briefly organized into: Materials, Geometry, Actions and Results. Examples of toolkit application are presented in the dissertation, and the respective safety checks reports as well.

6 PARAMETRIC STUDIES

Parametric studies were conducted to determine the influence of structural steel strength, concrete strength, density of reinforcement steel, thickness of steel plates, and tube diameter variation on cross-section resistance. A resume of analysis and results are presented as follows. Although the similar results, each parameter was analyzed for the various types of cross-sections.

6.1 STRUCTURAL STEEL STRENGTH

The variation of axial compression plastic resistance depends, for this case, only on the variation of steel yield strength, f_{yd}. Therefore the highest variation is registered between steel classes S275 and S355 ($\Delta f_{yd} = 355 - 275 = 80$).

$$\Delta N_{pl,Rd} = A_a \times \Delta f_{yd}$$

The normal force value for the point of maximum bending moment, is constant, as shown in the following expression:

$$\frac{1}{2} N_{pm,Rd} = \frac{1}{2} \alpha_{cc}\, A_c f_{cd} = constant$$

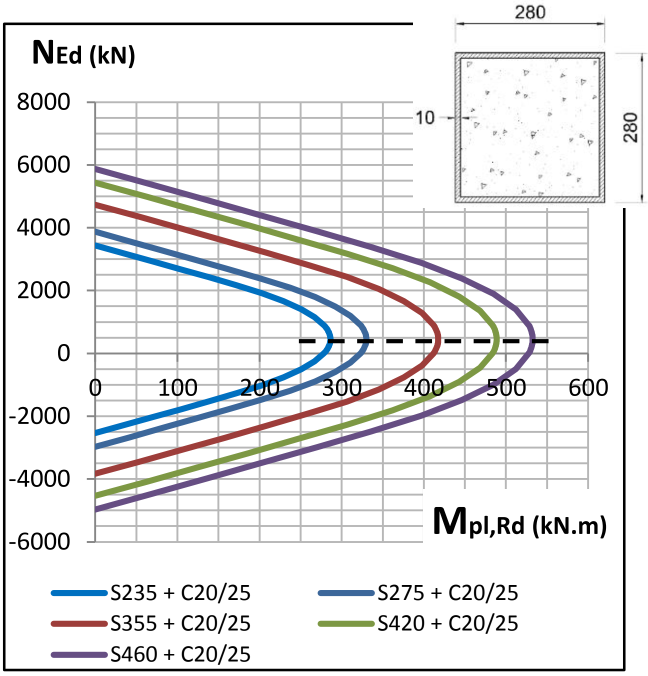


FIGURE 15 – M-N INTERACTION CURVES FOR DIFFERENT STRUCTURAL STEEL STRENGTHS

6.2 CONCRETE STRENGTH

The increase of concrete resistance lead to a higher normal force value of the point of maximum bending resistance, allowing to increase the favorable compression zone of the interaction curve. In this case the variation of axial compression plastic resistance, is given by:

$$\Delta N_{pl,Rd} = \alpha_{cc}\, A_c\, \Delta f_{cd}$$

And also,

$$\frac{1}{2} \Delta N_{pm,Rd} = \frac{1}{2} \alpha_{cc}\, A_c\, \Delta f_{cd}$$

In other hand, the tensile cross-section strength is not affected by concrete:

$$N_{pl,Rd,tension} = A_a f_{yd} + 0{,}0 \times A_c f_{cd} + A_s f_{sd}$$

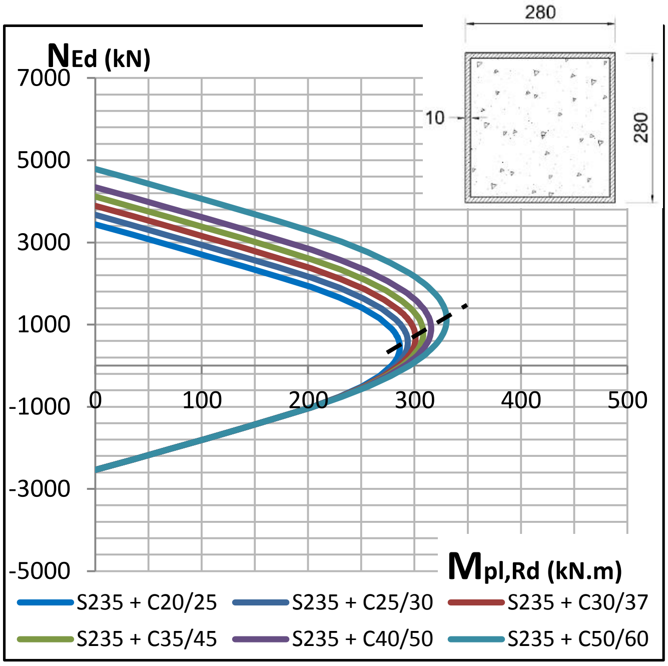


FIGURE 16 – M-N INTERACTION CURVES FOR DIFFERENT CONCRETE STRENGTHS

6.3 LONGITUDINAL REINFORCEMENT AREA

The percentage of longitudinal reinforcement was analyzed by constant increments ($\Delta\rho = 1\%$). Therefore, Figure 17 shows a linear variation of the resistance to compression and to bending.

Indeed, the position of the material is fixed and the only variable is the force that results from the reinforcement area variation. Although, as the structural steel class of resistance increases, less is the effect of the percentage of longitudinal reinforcement variation on the cross-section resistance.

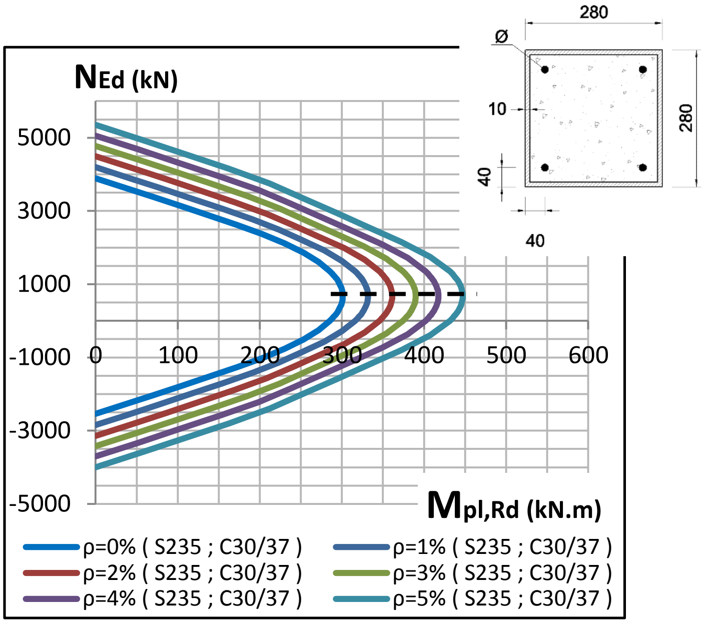


FIGURE 17 – M-N INTERACTION CURVES FOR DIFFERENT PERCENTAGES OF LONGITUDINAL REINFORCEMENT

6.4 TUBE THICKNESS

The variation of tube thickness (Figure 18) has similar influence (to longitudinal reinforcement) on interaction curve. However, in this case, a variation on structural steel strength does not implies a different influence of tube thickness on cross-section resistance.

6.5 TUBE DIAMETER

The variation of the tube diameter (Figure 19) implies that both the area and the force application points varies, so the variation of the cross-section resistance it's not constant for equal increments of the diameter and depends mainly on the initial diameter value.

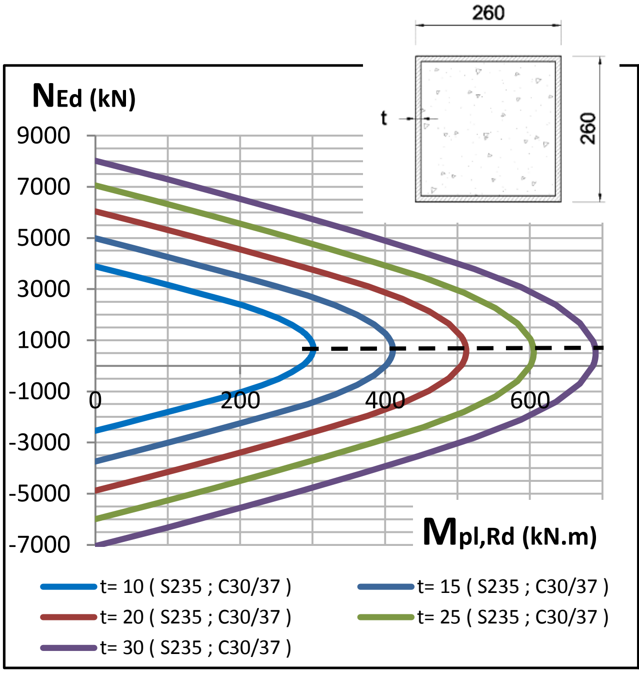


FIGURE 18 – M-N INTERACTION CURVES FOR DIFFERENT TUBE THICKNESSES

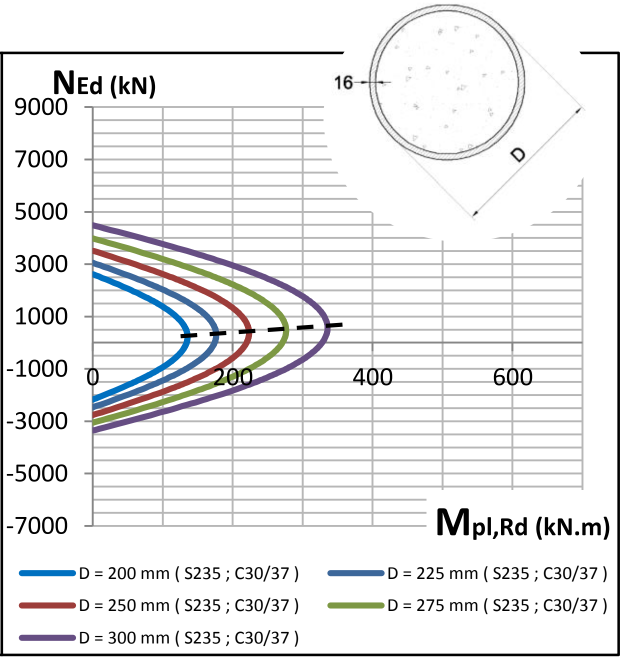


FIGURE 19 – M-N INTERACTION CURVES FOR DIFFERENT TUBE DIAMETERS

7 CONCLUSIONS AND FUTURE WORK

In spite of using the expression defined on EN1994, Annex A1, the toolkit calculates a higher number of points along the M-N interaction curve allowing to consider an increase up to 7% on plastic bending resistance.

In general, the resistance provided by the variation of one parameter, increase with the decrease of the remaining parameters contribution for cross-section resistance. For example, the influence of structural steel strength variation diminish with the increase of concrete strength, and vice-versa.

Moreover, due to its high strength, a variation on structural steel strength has a higher influence (on cross section-resistance) when compared with concrete.

Therefore, depending on the contribution of other parameters on cross-section resistance, the maximum increase of axial compression resistance provided by the different variables are: Structural steel strength (46–73%), Concrete strength (21–41%), percentage of longitudinal reinforcement (26–58%), tube thickness (3–7%.mm^{-1}), and tube diameter (0.6–0.7%.mm^{-1}).

The maximum increase of bending resistance provided by the different variables are: Structural steel strength (44–87%), Concrete strength (7–35%), percentage of longitudinal reinforcement (19–168%), tube thickness (3–8%.mm^{-1}), and tube diameter (1.2–1.5%.mm^{-1} for initial diameters of 200–300mm).

Furthermore, the variation of a single parameter implies a linear increase on cross-section resistance. In other hand, if related parameters are variable (i.e. tube thickness and structural steel strength), an exponential increase of resistance is registered.

Additionally, the influence of transverse shear is more relevant for the resistance to bending along the minor axis of inertia, and for hollow sections does not involves generally a decrease of design steel strength, due to an higher transverse shear strength.

For future work, is proposed the development of a toolkit to analyze columns with non-symmetrical or non-uniform cross-sections over its length taken into account the second-order effects in accordance with general method of design. The importance of the analysis of non-linear behavior of structural materials stands out where the steel yield strength is very high when compared to concrete compression strength. The simplified method of design consider that both materials, steel and concrete, have, at ultimate limit state, stresses equal to its design value, thus considering a much higher deformation for steel. Although, plane sections maybe assumed to remain plane implying similar deformation upon failure.

Note also that the methodologies developed in this work have an additional application for plastic analysis of class 1, 2 and 3 composite beams. In fact, their geometry, enable the use of rectangular stress blocks, regarding to the adequate decomposition of the cross-section.

8 REFERENCES

1. **Calado, L e Santos, J.** *Estruturas Mistas de Aço e Betão.* 1ª Edição. Lisboa : IST Press, 2010.

2. **Liu, J.** CE591 Lecture 13. Composite Columns. [Online] [Citação: 5 de Março de 2014.] https://engineering.purdue.edu/~jliu/courses/CE591/PDF/CE591compcol_F13.pdf.

3. **Bergmann, R et al.** *Design Guide For Concrete filled Hollow Section Columns under Static and Siesmic Loading.* 1ª Edição. Germany : CIDECT - Comité Internaional pour le Développement et l'Etude de la Construction Tubulaire, 1995.

4. **EN 1990: 2002.** *Basis of Structural Design.* s.l. : CEN – European Committee for Standardization.

5. **EN 1992-1-1: 2004.** *Design of Concrete Structures – Part 1-1: General Rules and Rules for Buildings.* s.l. : CEN – European Committee for Standardization.

6. **EN 1991-1-1: 2002.** *Actions on Structures – Part 1-1: General Actions: Densities, Self-Weight, Imposed Loads for Buildings.* s.l. : CEN – European Committee for Standardization.

7. **EN 1993-1-1: 2005.** *Design of Steel Structures – Part 1-1: General Rules and Rules for Buildings.* s.l. : CEN – European Committee for Standardization.

8. **EN 1994-1-1: 2005.** *Design of Composite Steel and Concrete Structures – Part 1-1: General Rules and Rules for Buildings.* s.l. : CEN – European Committee for Standardization.

9. **ISO 690: 1987.** *Documentation - Bibliographic references: content, form and structure.* s.l. : ISO – International Organization for Standardization.

10. **Johnson, R P.** *Composite Structures of Steel and Concrete.* 2ª Edição. Oxford : Blackwell Scientific Publications, 2004. Vols. Volume I: Beams, Slabs, Columns and Frames for Buildings.

11. **Reis, A and Camotim, D.** *Estabilidade Estrutural.* 1ª Edição. Portugal : McGraw-Hill, 2001.

12. **Jonhson, R P and Anderson, D.** *Designers' Guide to EN 1994-1-1: Eurocode 4: Design of Composite Steel and Concrete Structures, Part 1-1 : General Rules and Rules for Buildings.* s.l. : Thomas Telford Ltd, 2004.

13. **Hicks, S J. et al.** *Design Guide for Concrete Filled Columns.* Berkshire : Corus Tubes, 2002.

14. **Eggemann, H.** Simplified Design of Composite Columns, Based on a Comparative Study of Building Regulations in Germany and the United States. *Proceedings of the Second International Congress on Construction History.* Queens' College, Cambridge University : Short Run Press, 2006, Vol. I, pp. 1023-1042.

15. **Elremaily, A and Azizinamini, A.** Behavior of Circular Concrete-Filled Steel Tube Columns. [ed.] J F Hajjar, et al. *Proceedings of Composite Construction in Steel and Concrete IV.* Banff, Alberta : American Society of Civil Engineers, 2002, pp. 573-583.