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CONSTRUCŢII. ARHITECTURĂ

CROSS-SECTIONS CLASSES OF STRUCTURAL STEEL MEMBERS

BY

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Cross-sectional classification, introduced in EUROCODE 3, is destined to comply with any type of cross-section, disregarding the slenderness of cross-sectional wall plates. From practical reasons, this classification refers to cross-sections considered as a general matter. But in the same cross-section, the plates loaded with compression stresses, thus exposed to local buckling can belong to different classes of sections depending upon the loads acting on that cross-section. Furthermore, the stress diagrams corresponding to these cross-sectional plates are themselves closely related to applied loads and they influence directly the degrees of sensitivity to local buckling. On the other hand, the different degrees of sensitivity to local buckling depend on the slenderness of cross-sectional plates. A cross-section is normally classified by quoting the highest (least favourable) class of its compression elements. The strength calculation (and general stability) of structural members depends on the cross-section classes.

1. Plate Slenderness

The steel structural members are generally made of thin plane plates (the thickness of the plate is much smaller than its width).

For I cross-section made of welded rolled plates (Fig. 1) the following slenderness are defined:

a) slenderness of the web (two-side supported plate)

$$s_i = \frac{h_i}{t_i};$$

b) slenderness of the flange (one-side supported plate)

$$s_t = \frac{b'}{t}; \qquad b' = \frac{b - t_i}{2}.$$

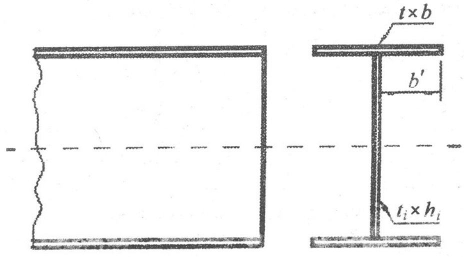


Fig. 1.– Built-up I section.

where: $t_i \times h_i$ are the sizes of the web section, t – thickness of the flange.

2. Classification of Cross-Sections

The classification of cross-sections depends on the proportions of each of its compression elements, as follows:

a) C l a s s 1: cross-section which allows formation of the plastic hinge, with the rotation capacity required for the plastic analysis.

b) C l a s s 2: cross-section which allows formation of the plastic hinge, with a limit rotation capacity.

c) C l a s s 3: cross-section in which the calculated stress in the extreme compression fiber of the member can reach the steel yield strength.

d) C l a s s 4: cross-section, partially active, in which it is necessary to take into account the effects of local buckling when determining their bending moment resistance.

3. Reference Slenderness Levels

The reference slenderness levels (noted as s_0) are those delimiting upper the cross-section class of the structural member. The reference slenderness level allows compressive stresses equal to the steel yield strength

$$\sigma_1 = R_c, \tag{1}$$

where: σ_1 is the maximum compression stress; R_c – the steel yield strength.

The stress distribution depends on the cross-section class namely

a) For Classes 1 and 2 cross-sections the plastic distribution along the whole section is allowed (Fig. 2 a, b).

b) For Class 3 cross-sections the elastic distribution along the whole section is allowed (Fig. 2 a, c).

c) For Class 4 cross-sections the elastic distribution along the active zone of the section is allowed (Fig. 2 d, e).

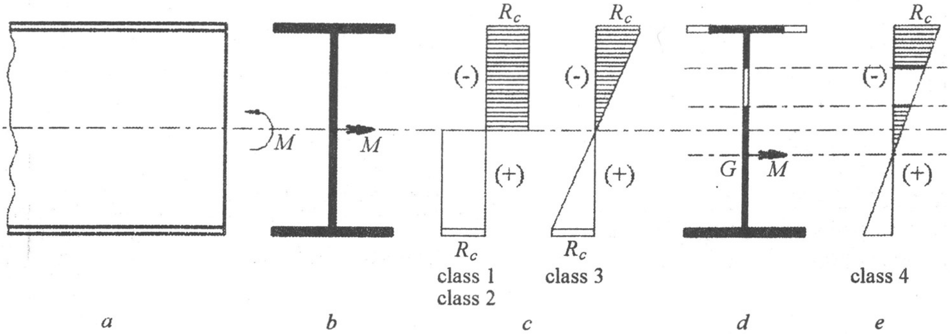


Fig. 2.– Distribution of the stresses according to the class cross-sections.

The reference slenderness levels, s_0, refer to every element of a cross-section which is either totally or partially in compression; the slenderness values, s_0, depend on the plate type namely

a) two-side supported plate (web of the section);

b) one-side supported plate (flange of the section).

The values of the reference slenderness levels are defined in the Tables 1,...,4, for effective slenderness, $s \leq s_0$, the cross-section belongs to one of the four section classes. For the tubular sections (Fig. 3 *a*) bent or/and compressed, the reference slenderness levels will be determined as follows:

(2) $$s_0 = \begin{cases} 50\varepsilon^2, & \text{for class 1 cross–sections,} \\ 70\varepsilon^2, & \text{for class 2 cross–sections,} \\ 90\varepsilon^2, & \text{for class 3 cross–sections,} \end{cases}$$

$$s = \frac{d}{t},$$

where:

$$\varepsilon = \left(\frac{240}{R_c}\right)^{0.5},$$

with R_c – the steel yield strength, [N/mm^2], s – effective slenderness level, d – the outside diameter of the tubular section.

In the case of angle-type sections (Fig. 3 *b*), the effective slenderness will be determined using the relation

(3) $$s = \frac{b_1}{t} \leq s_0; \qquad b_1 \geq b_2,$$

where: s_0 is the reference slenderness level determined using the relations in Tables 1 and 2, corresponding to the one-side supported plate; the mean slenderness level of the unequal angle must also satisfy the condition (only for Class 3 cross-sections)

(4) $$s = \frac{(b_1 + b_2)/2}{t} \leq 11.5\,\varepsilon.$$

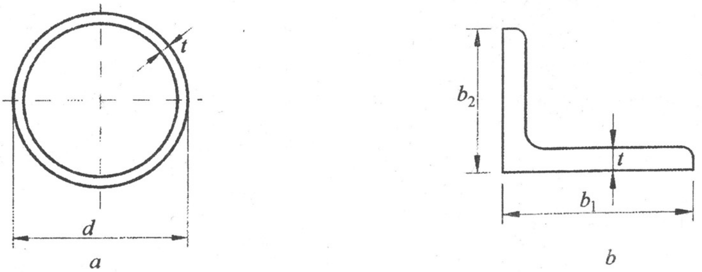
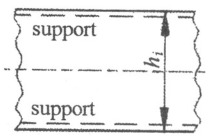
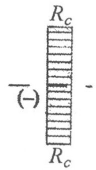
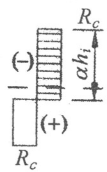
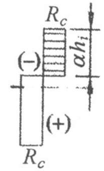
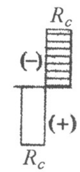


Fig. 3.- Tubular section and angle section.

Table 1

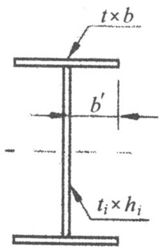
Reference Slenderness Levels, s_0, for Class 1 and Class 2 Cross-Sections

Reference slenderness levels for two-side-supported plates (web plates)				
				
	$\alpha = 1.0$	$\alpha > 0.5$	$\alpha < 0.5$	$\alpha = 1$
s_0 (class 1)	33ε	$\frac{396\varepsilon}{13\alpha - 1}$	$\frac{36\varepsilon}{\alpha}$	33ε
s_0 (class 2)	38ε	$\frac{456\varepsilon}{13\alpha - 1}$	$\frac{41.5\varepsilon}{\alpha}$	83ε

$s_i = \frac{h_i}{t_i}$; $s_t = \frac{b'}{t}$; $b' = \frac{b - t_i}{2}$;

$s_i \le s_0$; $s_t \le s_0$;

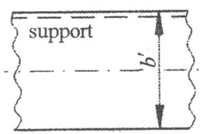
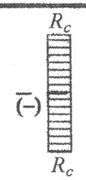
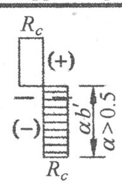
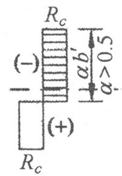
$\varepsilon = \left(\frac{240}{R_c}\right)^{0.5}$; R_c, [N/mm^2].



α is to be determined from the equivalence relations between the strains and tensions within the section.

Table 2

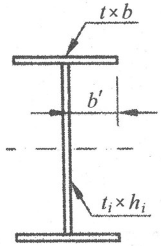
Reference Slenderness Levels, s_0, for Class 1 and Class 2 Cross-Sections

Reference slenderness levels for one-side-supported plates (flanges)						
						
Product type	Rolled plate	Welded plate	Rolled plate	Welded plate	Rolled plate	Welded plate
s_0 (class 1)	10ε	9ε	$\frac{10\varepsilon}{\alpha}$	$\frac{9\varepsilon}{\alpha}$	$\frac{10\varepsilon}{\alpha\sqrt{\alpha}}$	$\frac{9\varepsilon}{\alpha\sqrt{\alpha}}$
s_0 (class 2)	11ε	10ε	$\frac{11\varepsilon}{\alpha}$	$\frac{10\varepsilon}{\alpha}$	$\frac{11\varepsilon}{\alpha\sqrt{\alpha}}$	$\frac{10\varepsilon}{\alpha\sqrt{\alpha}}$

$s_i = \frac{h_i}{t_i}$; $s_t = \frac{b'}{t}$; $b' = \frac{b - t_i}{2}$;

$s_i \leq s_0$; $s_t \leq s_0$;

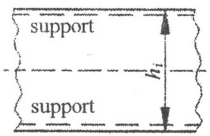
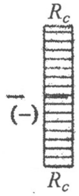
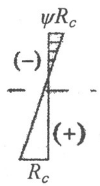
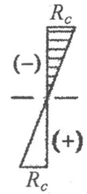
$\varepsilon = \left(\frac{240}{R_c}\right)^{0.5}$; R_c , [N/mm^2].



α is to be determined from the equivalence relations between the strains and tensions within the section.

Table 3

Reference Slenderness Levels, s_0, for Class 3 Cross-Sections

Reference slenderness levels for two-side supported plates (web plates)				
				
	$\psi = +1$	$\psi > -1$	$\psi < -1$	$\psi = -1$
s_0	42ε	$\dfrac{42\varepsilon}{0.67+0.33\psi}$	$62\varepsilon(1-\psi)\sqrt{(-\psi)}$	124ε

$s_i = \dfrac{h_i}{t_i}$; $s_t = \dfrac{b'}{t}$; $b' = \dfrac{b - t_i}{2}$;

$s_i \le s_0$; $s_t \le s_0$;

$\psi = \dfrac{\sigma_2}{\sigma_1}$;

σ_1 – the maximum compression stress;

σ_2 – opposite fiber stress;

$\varepsilon = \left(\dfrac{240}{R_c}\right)^{0.5}$; R_c , [N/mm^2].

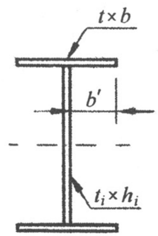
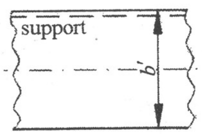
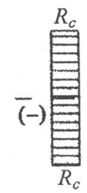
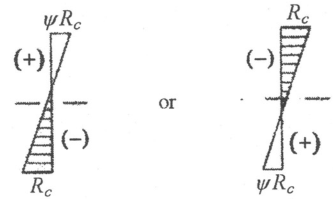


Table 4

Reference Slenderness Levels, s_0, for Class 3 Cross-Sections

Reference slenderness levels for one-side supported plates (flanges)				
				
Product type	Rolled plate	Welded plate	Rolled plate	Welded plate
s_0	15ε	14ε	$23\varepsilon\sqrt{k_\sigma}$	$21\varepsilon\sqrt{k_\sigma}$

$s_i = \frac{h_i}{t_i}$; $s_t = \frac{b'}{t}$; $b' = \frac{b - t_i}{2}$;

$s_i \le s_0$; $s_t \le s_0$;

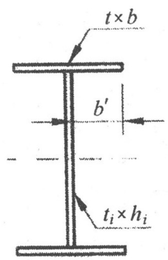
$\psi = \frac{\sigma_2}{\sigma_1}$;

σ_1 – the maximum compression stress;

σ_2 – opposite fiber stress;

$\varepsilon = \left(\frac{240}{R_c}\right)^{0.5}$; R_c , [N/mm^2] ;

k_σ – local buckling coefficient.



4. Structural Analysis Models

By structural analysis we mean the computation model used in computing the stresses inside the structure associated with the resistance computation model of the cross-section.

The structural analysis model is exemplified for a constant, section beam twice-embedded (Figs. 4 and 5).

4.1. Structural Members with Class 1 Cross-Sections

The structural members with Class 1 cross-sections allow the "plastic–plastic" computation model (Fig. 4) that is

a) The stress determination is done on a plastic mechanism

$$M_1 = M_2 = M, \qquad M_1 + M_2 = \frac{pl^2}{8}, \qquad 2M = \frac{pl^2}{8},$$

resulting

$$M = \frac{pl^2}{16}. \tag{5}$$

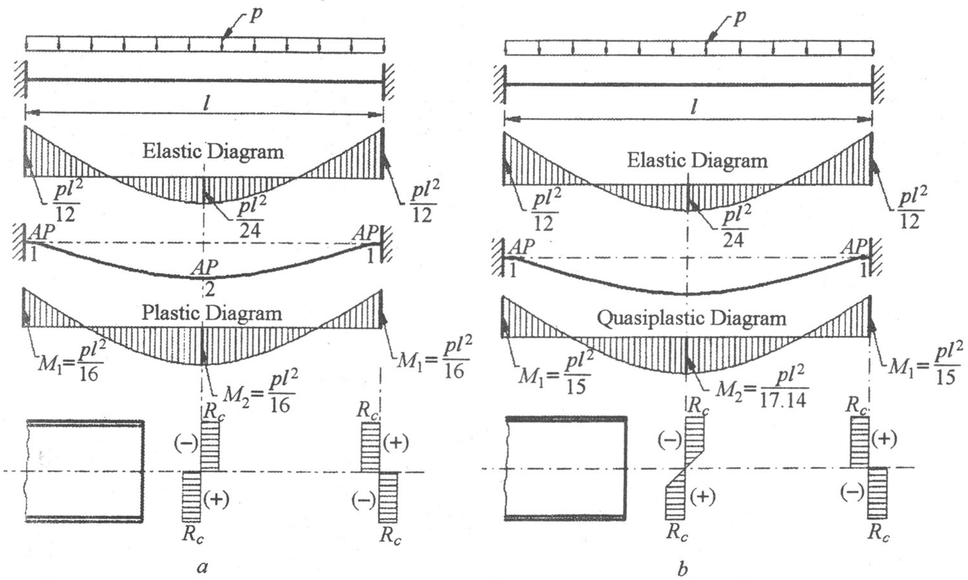


Fig. 4.– *a* – Structural member with Class 1 cross-sections; *b* – structural member with Class 2 cross-sections.

b) The cross-sections verification (if the action of the shearing force on the supports is neglected) is done using the relation

$$\frac{M}{M_p} \leq 1. \tag{6}$$

It can be noticed that the cross-sections subsumed in Class 1 allow the complete utilization of the plastic reserve of the structure and the plastic reserve of the cross-section namely

a) The plastic reserve of the structure (as compared to the elastic diagram)

$$r_s,\ [\%] = \frac{pl^2/12 - pl^2/16}{pl^2/16} \cdot 100 = 33.3\%.$$

b) The plastic reserve of the cross-section (for the plan area of the web equal to the plan area of the flanges)

$$r_2,\ [\%] = \frac{W_p - W_e}{W_e} \cdot 100 = \left(\frac{W_p}{W_e} - 1\right) = 13\%.$$

4.2. Structural Members with Class 2 Cross-Sections

The structural members with Class 2 cross-sections allow the “elastic–plastic” analysis model (Fig. 4) that is

a) the stress determination is performed on the elastic structure;

b) 20% of the “peaks” of the moments of flexure are redistributed, and consequently

$$M_1 = 0.8\frac{pl^2}{12} = \frac{pl^2}{15},$$
$$M_2 = \frac{pl^2}{8} - \frac{pl^2}{15} = \frac{pl^2}{17.14}; \qquad (7)$$

c) the cross-section verification (if the action of the shearing force on the supports is neglected) is done using the relation

$$\frac{M}{M_p} \leq 1,$$

where: $M = M_1 = pl^2/15$; M_p – the plastic-resisting bending moment of the cross-section.

It can be noticed that Class 2 cross-sections allow the partial utilization of the plastic reserve of the structure and the total utilization of the plastic reserve of the section *i.e.*

a) The partial plastic reserve of the structure

$$r_1,\ [\%] = \frac{\dfrac{pl^2}{12} - \dfrac{pl^2}{15}}{\dfrac{pl^2}{15}} \cdot 100 = 25\%.$$

b) The plastic reserve of the section (for the plan area of the web equal to the plan area of the flanges)

$$r_2,[\%] = \frac{W_p - W_e}{W_e} \cdot 100 = \left(\frac{W_p}{W_e} - 1\right) \cdot 100 = 13\%.$$

4.3. Structural Members with Class 3 Cross-Sections

The structural members with Class 3 cross-sections allow the "elastic–elastic" analysis model (Fig. 5), that is

a) The stress determination is performed on the structure displaying elastic behavior

(8) $$M_{\max} = \frac{pl^2}{12}.$$

b) The cross-section verification (if the action of the shearing force on the supports is neglected) is done using the relation

(9) $$\frac{M}{M_e} \leq 1,$$

where: $M = M_{\max} = pl^2/12$; M_e – the elastic resisting bending moment of the cross-section

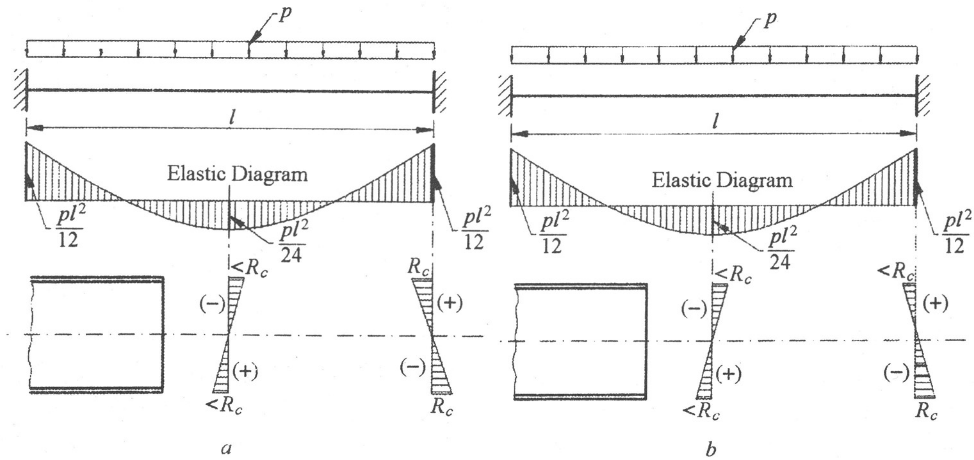


Fig. 5.– *a* – Structural member with Class 3 cross-sections; *b* – structural member with Class 4 cross-sections.

4.4. Structural Members with Class 4 Cross-Sections

In this case, the compression strains may cause the local buckling of the plates composing the structural member, that is the lateral flexure of the plates; consequently, only part of the section is active (Fig. 2 *d*, *e*).

Class 4 structural members allow the "elastic–elastic" analysis model (Fig. 5) that is

a) The stress determination is performed on the elastic structure (in this analysis, it may be presumed that the whole section is active)

$$M_{\max} = \frac{pl^2}{12}.$$

b) The cross-section verification (if the action of the shearing force on the supports is neglected) is performed using the relation

$$\frac{M}{M_{ea}} \leq 1, \tag{10}$$

where: $M = M_{\max} = pl^2/12$; M_{ea} – the elastic-resisting bending moment of the active cross-section.

5. Conclusions

The classification of the cross-sections implies therefore, two conventions:

a) The class of a cross-section is related to a precise type of load applied to this section and generating longitudinal compression stresses: either simple compression or simple bending or compound bending with a proportion settled between bending and compression.

b) The class of a section corresponds to the behaviour of that wall of the section which has the worst behaviour from the viewpoint of the local buckling for the respective type of load.

It has to be added that the class of a section depends to the same extent on the steel of yield stress in the cross section it is made of, by means of the redressing coefficient of wall slenderness $\sqrt{240/R_c}$.

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CLASE DE SECŢIUNI ALE ELEMENTELOR CONSTRUCŢIILOR METALICE

(Rezumat)

Clasificarea secţiunilor, introdusă în EUROCODE 3, este destinată să permită abordarea oricărui tip de secţiune, indiferent de valoarea supleţei pereţilor acestora.

Din motive practice, clasificarea se referă la secţiunile transversale considerate global. În aceeaşi secţiune, însă, pereţii în care se dezvoltă tensiuni de compresiune şi deci expuşi voalării pot fi situaţi în clase diferite, funcţie de solicitările la care este supusă secţiunea. În plus, diagramele de tensiuni care există în aceşti pereţi sunt şi ele strâns legate de solicitările aplicate şi influenţează direct gradul de sensibilitate la voalare. Pe de altă parte, gradul diferit de sensibilitate al pereţilor la voalare depinde şi de supleţea lor.

Clasa secţiunii este determinată de cea a peretelui component, cel mai defavorizat din punct de vedere al stabilităţii locale, pentru un anumit tip de solicitare.

Calculul de rezistenţă (şi calculul de stabilitate generală) al elementelor structurale se efectuează în funcţie de clasa secţiunii.