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DUCTILITY OF IPE AND HEA BEAMS AND BEAM-COLUMNS

A.Anastasiadis[1], V.Gioncu[1]

[1] Politehnica University Timisoara, 1900 Timisoara,
str. Traian Lalescu 2, Romania

ABSTRACT

The paper deals with the determining of available local ductility of steel beams and beam-columns made by hot-rolled IPE and HEA profiles. Using the local plastic mechanism the influence of junction between flange and web was investigated. Based on the analysis of a great number of numerical tests, using DUCTROT'96 computer program, simplified design relationships are proposed for direct checking of rotational capacity of beams and beam-columns. A member behavioral classes for IPE and HEA also are presented.

KEYWORDS

Local ductility, Local plastic mechanism, Available ductility, Hot-rolled sections, DUCTROT computer program, simplified design relationships.

INTRODUCTION

An efficient seismic design requires to use the method of capacity design, which is based on the principle to obtain a global plastic mechanism, ensuring the formation of sufficient number of plastic hinges only in the beam ends and not in the columns. But assure of a good structural behaviour requires also the verification of rotation capacity of these plastic hinges, which must be greater than the necessary rotational demands (Gioncu & Petcu, 1997). So, the ductility capacity of a structure strongly depends on available ductility of individual structural members that constitute the structure, and first of all, these ductility capacities should be quantified. Current steel and aseismic codes as EC3, EC8, includes only qualitative specifications without a clear definition of 'sufficient ductility' and how these ductility must be assured, not only by constructional details but with a direct checking provided from a practical method. The classification of cross section ductility classes, as given in EC3, contains many shortcomings presented by Gioncu and Mazzolani (1995) and must be reconsidered in order to evaluate the real inelastic deformation capacity of structural members, taking into account the member span.

The present study deals with the assessment of available ductility of IPE and HEA sections, widely used in practice as beams and beam-columns. In the first part of the paper the rotation capacity, based on the local plastic mechanism and the influence of junction on double T sections is presented and investigated. In the second part, using a great number of numerical tests, simplified design relationships for available rotation capacity of beams and beam-columns is proposed.

AVAILABLE ROTATION CAPACITY

An adequate measure for determining local ductility of steel members is the rotation capacity of plastic hinges which can be calculated by different ways: (i) using FEM methods, (ii) integration of the moment-curvature relationship, (iii) using a collapse mechanism coming from experimental evidence, (iv) determining the effective width, (v) approximate formulae, (vi) simple formulae obtained from statistical analysis of experimental results. Among these methods, the use of plastic collapse mechanism method seems to be the most efficiently for design purposes (Gioncu & Petcu 1997, Gioncu & Mazzolani, 1998).

The formula to calculate this rotation capacity, R, determined in the lowering postbuckling curve at the intersection with the theoretical full plastic moment, taking into account both stable and unstable part of curve, is given by (Fig.1):

$$R_{av.p} = \frac{\theta_{pu}}{\theta_p} - 1 = \frac{\theta_u}{\theta_p} - 1 \qquad (1)$$

where:

θ_u- ultimate rotation obtained with the intersection of theoretical full plastic moment

θ_p- elastic rotation at the level of full plastic moment

However, for a complete definition of available local ductility, it is essential to be defined also the fracture rotation capacity, R_f , for which the first crack occurs in the buckled flange. This fracture could be developed in the stable or unstable part of curve, depending on geometrical conformation of member, given by (Fig.1):

$$R_f = \frac{\theta_f}{\theta_p} - 1 \qquad (2)$$

where:

θ_f- fracture rotation of a buckled flange

θ_p- elastic rotation at the level of full plastic moment

This fracture ductility, strongly depends on the yield ratio, buckled length and ultimate strain of the used steel (Gioncu & Mazzolani, 1999, Anastasiadis, 1999). It is clearly that for a good behaviour of plastic hinges must be assured that:

$$R_{av.p} \geq R_f \qquad (3)$$

where:

$R_{av.p}$- plastic available rotation capacity of a member

R_f- fracture rotation capacity

The available rotation capacity of a plastic hinge must be determined taking into account that the member belongs to a structure with a complex behaviour. This complex behaviour is studied using of a simple substitute member with very similar behaviour (Gioncu & Petcu, 1997). In Fig. 2 is presented the determination manner of 'standard beam' span for beams and beam-columns, for seismic loads,

Fig. 2a, and both for gravitational and seismic loads, Fig.2b. For columns, the influencing factors is the ratio between upper and lower column bending moment.

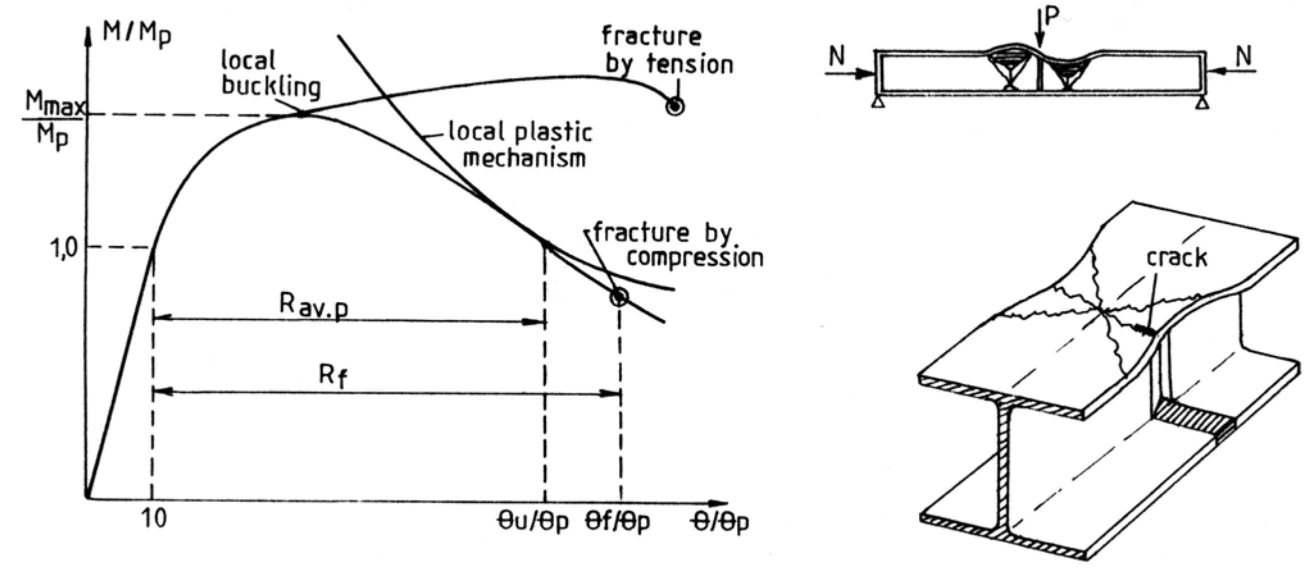


Figure 1: Definition of rotation capacity

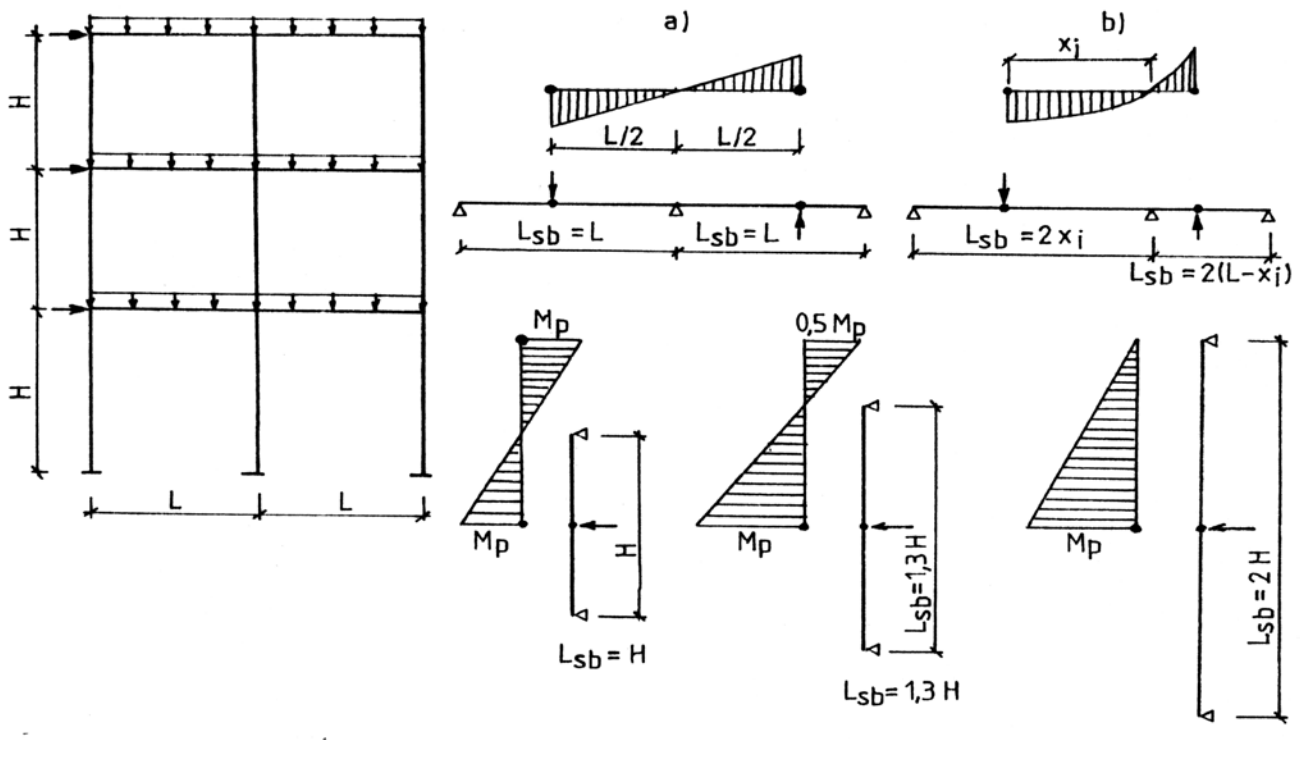


Figure 2: Determination of ‘standard beam’ for beams and beam-columns

A computer program DUCTROT’96 for welded sections was elaborated at INCERC Timisoara on the basis of the local mechanism of the above mentioned standard beam (Gioncu & Petcu, 1996). The values obtained using this computer program, relies a good correspondence with experimental data, giving confidence in the theoretical results (Gioncu & Petcu, 1997, Gioncu & Mazzolani, 1998, Anastasiadis, 1999). A problem which appears in design practice is relies to the hot-rolled profiles, namely if the results obtained with DUCTROT can be used for these sections, when the presence of junction reduces the flange slenderness.

INFLUENCE OF JUNCTION ON PLASTIC ROTATION CAPACITY

One of the main factors influencing section ductility, clearly affecting the superior level, member available ductility, is the mode of fabrication. Hot-rolled profiles widely used in structural design provide different ductility capacity than welded sections (Gioncu & Mazzolani, 1999, Anastasiadis, 1999). In the plastic mechanism method for hot-rolled sections, the ultimate plastic rotation, θ_u, of plastic hinge is determined, in the same way as for welded sections, using a local plastic quasi-mechanism composed by plastic zones and yield lines, taking into account the influence of rigid zone created by the junction of flange and web, Fig.3 (Anastasiadis, 1999, Piluso, 1995). The comparison between theoretical and experimental values, for improved proposed new shape mechanism is presented in Fig.4 showing a good correspondence.

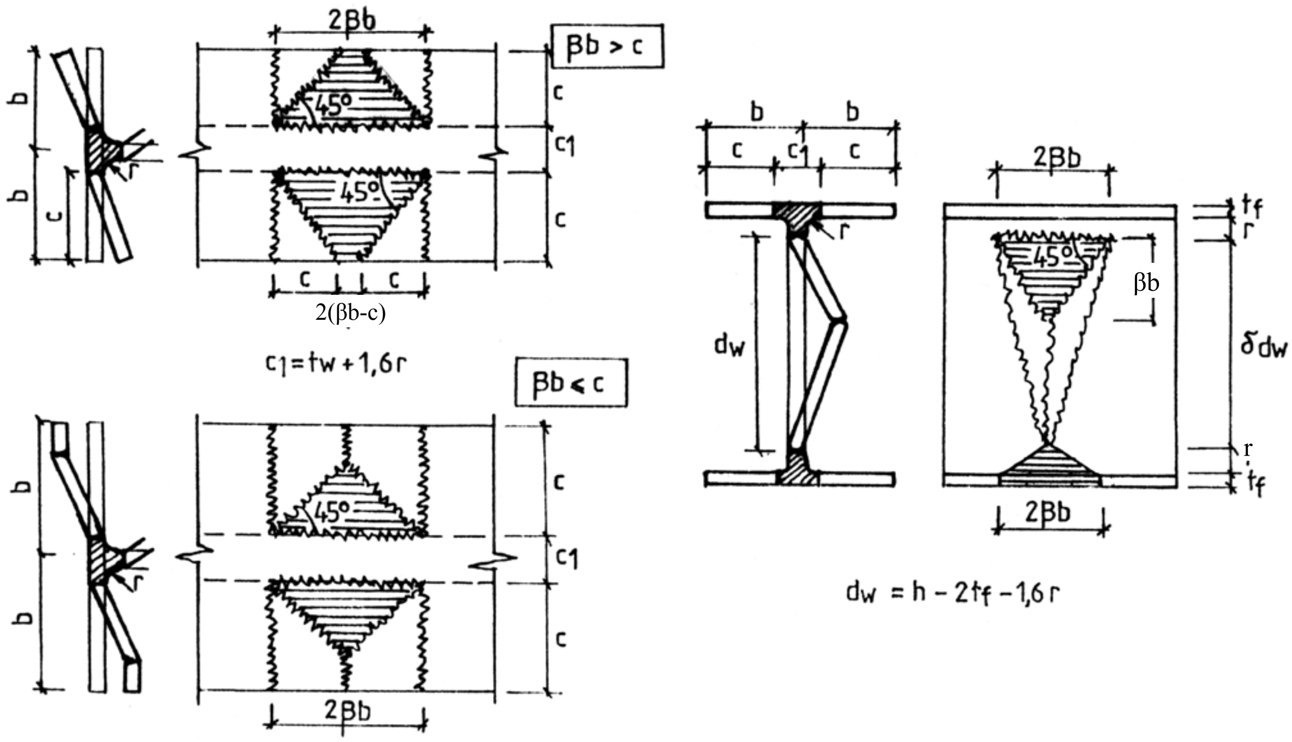


Figure 3: Local plastic mechanism

In Figs.5 and 6 the influence of junction for different IPE and HEA beams is plotted. One can see the important increasing of plastic rotation capacity of hot-rolled sections as compared with the same sections in which the influence of a rigid zone is neglected. For IPE beams the increasing is about 64%, while for HEA beams it is about 38-48%. In the aim to use the results obtained using the DUCTROT'96 computer program a simplified coefficient of correction, c_r, is proposed:

$$c_r = \left(\frac{b}{c}\right)^2 = \left(\frac{b}{b - 0.5t_w - 0.8r}\right)^2 \qquad (4)$$

where:

b- half width flange
c- width between half width flange and junction
r- junction of section between web and flange

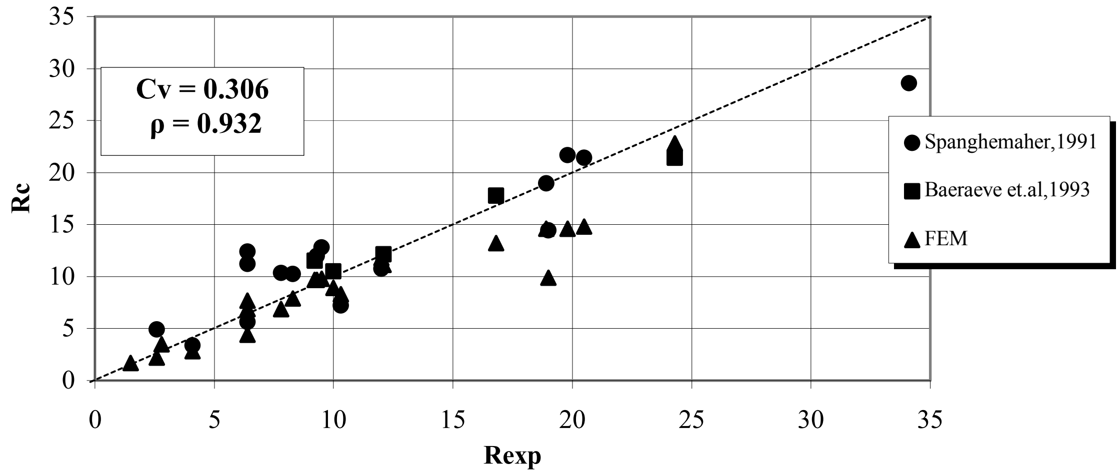


Figure 4: Correlation between theoretical and experimental data

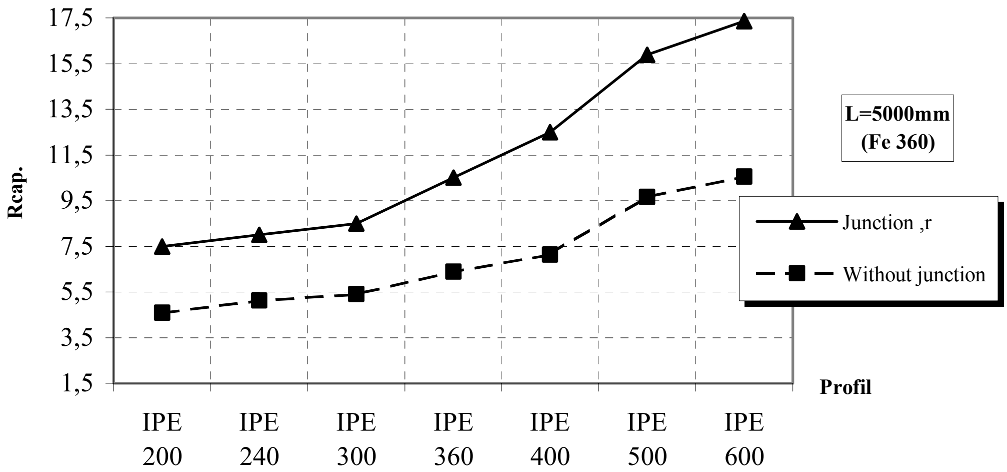


Figure 5: Influence of junction on IPE profiles

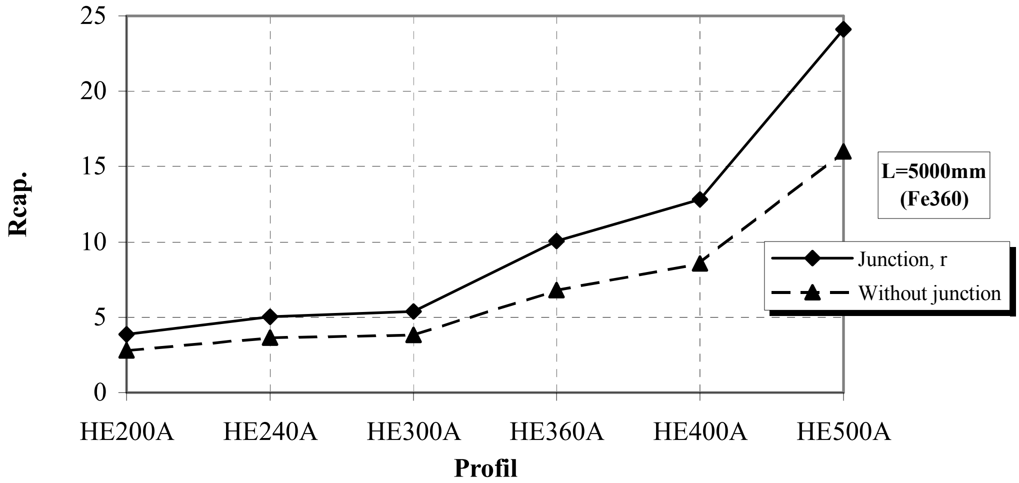


Figure 6: Influence of junction on HEA profiles

The correlation between the exact values and the corrected values obtained using DUCTROT '96 and relation (4) is presented in Fig.7, showing that the simple methodology allows to determine the improved values for rotation capacity of hot rolled sections.

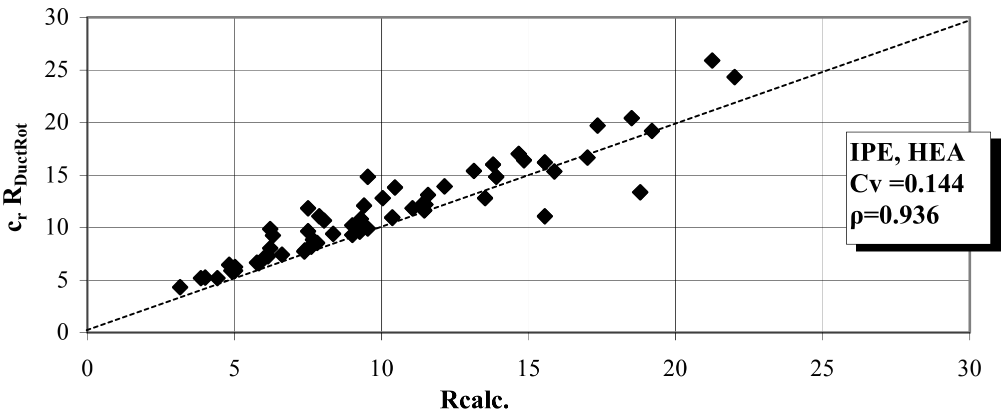


Figure 7: Correlation between exact and corrected values

SIMPLIFIED DESIGN RELATIONSHIPS FOR ROTATION CAPACITY

Rotation capacity of beams

Design relationship, based on the very high number of numerical tests using DUCTROT computer program is proposed for beams under monotonic loads (Gioncu & Mazzolani, 1998):

$$R_{av.mon} = 3x10^4 c_r \frac{t_f}{bL_{sb}} \varepsilon \left(0.8 + 0.2 \frac{f_{yw}}{f_{yf}} \right) \ ; \varepsilon = 235 / f_{yf} \qquad (5)$$

where:

c_r-coefficient taking into account the influence of junction

t_f- thickness of flange

b- half width of flange

L_{sb}- span of standard beam

f_{yw}, f_{yf}- yield tensile strength for web and flange

In relationship (5), in comparison with the original equation, a new coefficient, c_r, is introduced for considering the effect of flange and web junction.

Rotation capacity of beam-columns

In the same manner as for beam, an approximate relationship for beam-column rotation capacity considering the effect of axial force and moment diagrams is proposed (Anastasiadis, 1999):

$$R_{av.mon} = 1481.3 c_r \left(\bar{\lambda}\, {}^{b}\!/_{t_f} \sqrt{f_y} \right)^{-1.33} \qquad np=0.10 \qquad (6a)$$

$$R_{av.mon} = 5099.9 c_r \left(\bar{\lambda}\, {}^{b}\!/_{t_f} \sqrt{f_y} \right)^{-1.61} \qquad np= 0.40 \qquad (6b)$$

where:

b/t_f- flange slenderness

$\bar{\lambda}$ - non dimensional slenderness

$$\bar{\lambda} = \left(\frac{N_P}{N_{cr}}\right)^{1/2} = \frac{f_{yf} W_{pf} + f_{yw} W_{pw}}{\pi^2 E I_e / \mu L_{sb}}$$

f_y- yield tensile strength of section
L_{sb}- span of standard beam

Over 160 numerical tests were performed to obtain an adequate statistical parameters, Fig.8. The results from the relationships (6a,b) cover the practical domain for HE 100A-HE600A considering the ratio of moments, M_{sup} / M_{inf} =1...0 as well as the influence of axial force, n_P.

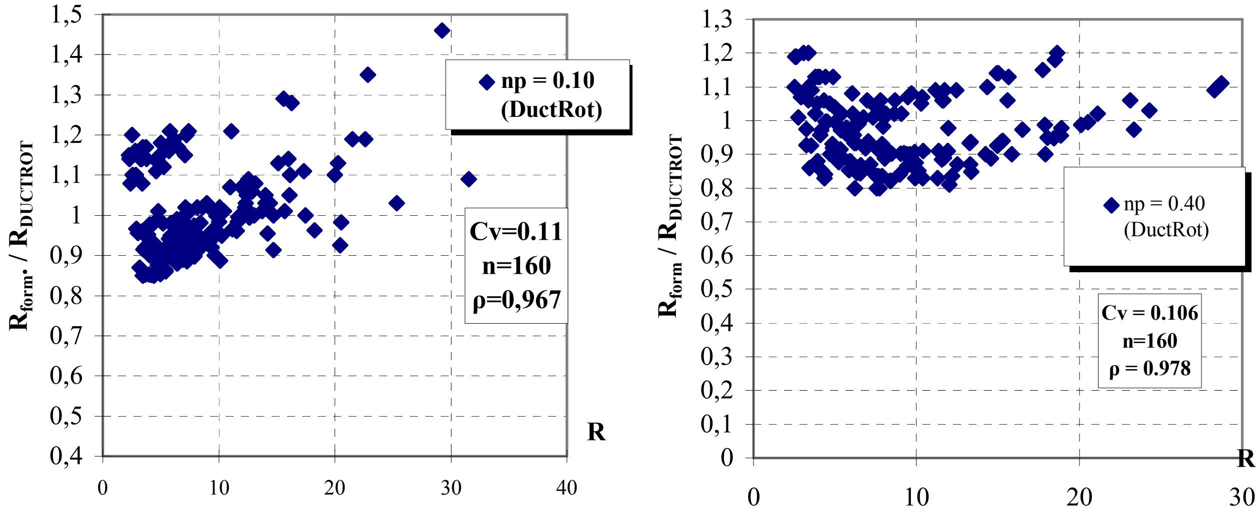


Figure 8: Correlation between the relation 6a,b and DUCTROT

The above relationships take into account only the basic factors affecting the monotonic rotation capacity, R_{mon}. However, other factors influencing local ductility is given elsewhere (Gioncu &Mazzolani, 1999, Anastasiadis, 1999). For seismic available ductility, R_{seism}, a simple design formulae was proposed by Gioncu & Petcu (1997) :

$$R_{seism} = r_s\,(b/t_f\,,\, n_P)\, R_{mon} \qquad (7)$$

MEMBER BEHAVIOURAL CLASSES FOR IPE AND HEA PROFILES

It was demonstrated that the concept of cross-section behavioural classes does not correspond with the real inelastic deformation capacity. As a consequence this concept should be substituted by the member behavioural classes approach (Gioncu & Petcu, 1997, Mazzolani &Piluso, 1995). A new classification according to the member concept is proposed for hot-rolled sections, based on the classification criteria (High ductility, H, R ≥7.5, Medium ductility, M, 4.5<R<7.5, Low ductility, L, 1.5<R ≤ 4.5), Table 1, 2. Analyzing these tables it is very clearly that the length of member and the member type, as well as the steel quality, have a great influence on the local available ductility. Using the values from these Tables the designer can choose the profile with, for a given data, assures a good inelastic global behaviour of a structure.

TABLE 1

MEMBER CLASSIFICATION FOR BENDING BEAMS

Profil	L=3000			L=4000			L=5000			L=6000			L=7000		
	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510
IPE 140	H	H	H	H	H	M	M	M	M	L	L	L	L	L	L
IPE 160	H	H	H	H	H	M	M	M	M	L	L	L	L	L	L
IPE 180	H	H	H	H	H	M	H	M	M	M	M	M	L	L	L
IPE 200	H	H	H	H	H	M	H	H	M	H	M	M	M	M	M
IPE 220	H	H	H	H	H	H	H	H	M	H	H	M	M	M	M
IPE 240	H	H	H	H	H	H	H	H	M	H	H	M	H	M	M
IPE 270	H	H	H	H	H	H	H	H	M	H	H	M	H	M	M
IPE 300	H	H	H	H	H	H	H	H	M	H	H	M	H	M	M
IPE 330	H	H	H	H	H	H	H	H	M	H	H	M	H	M	M
IPE 360	H	H	H	H	H	H	H	H	H	H	H	M	H	M	M
IPE 400	H	H	H	H	H	H	H	H	H	H	H	M	H	H	M
IPE 450	H	H	H	H	H	H	H	H	H	H	H	M	H	H	M
IPE 500	H	H	H	H	H	H	H	H	H	H	H	H	H	H	M
IPE 550	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
IPE 600	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H

Profil	L=3000			L=4000			L=5000			L=6000			L=7000		
	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510	Fe 360	Fe 430	Fe 510
HE 160A	H	H	H	M	M	L	M	L	L	L	L	L	L	L	L
HE 180A	H	H	H	M	M	L	M	L	L	L	L	L	L	L	L
HE 200A	H	H	H	M	M	L	M	L	L	L	L	L	L	L	L
HE 220A	H	H	H	M	M	M	M	M	L	L	L	L	L	L	L
HE 240A	H	H	H	H	M	M	M	M	L	M	L	L	M	L	L
HE 260A	H	H	H	H	M	M	M	M	L	M	M	L	M	L	L
HE 280A	H	H	H	H	M	M	M	M	M	M	M	L	M	L	L
HE 300A	H	H	H	H	H	M	M	M	M	M	M	L	M	L	L
HE 320A	H	H	H	H	H	M	H	H	M	H	M	M	M	M	L
HE 340A	H	H	H	H	H	H	H	H	M	H	H	M	H	M	L
HE 360A	H	H	H	H	H	H	H	H	H	H	H	M	H	M	M
HE 400A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	M
HE 450A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
HE 500A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
HE 550A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
HE 600A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H

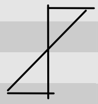
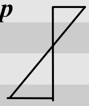
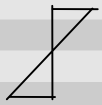
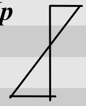
CONCLUSIONS

Available local ductility of hot-rolled beam and beam column was investigated by approximate methods using local plastic mechanism and DUCTROT computer program. It was found that the influence of flange and web junction is very high, the rotation capacity showing an important increasing for hot-rolled sections. Simplified relationships for beams and columns are proposed for design purposes. For IPE and HEA members, a classification in function of member classes also was proposed.

It must be underlined that due to the results obtained in the last decade on the field of local and global ductility it is the time to introduce in EC8 an annex containing proposals for directly checking of structure ductility, as the same level as for strength and rigidity.

TABEL 2

MEMBER CLASSIFICATION FOR ELEMENTS UNDER COMBINED COMPRESSING AND BENDING

Profile	M-N		Fe 360			Fe 430		
	np	**Msup /Minf**	**H=3000**	**H=4000**	**H=5000**	**H=3000**	**H=4000**	**H=5000**
HE 240A	0.10	***Mp***	H	M	L	M	L	L
	0.20		H	M	L	M	M	L
	0.30		H	M	L	M	M	L
	0.40	***Mp***	H	M	L	M	M	L
	0.10	***0.5Mp***	L	L	L	L	L	L
	0.20		M	L	L	L	L	L
	0.30		M	L	L	L	L	L
	0.40	***Mp***	M	L	L	L	L	L
	0.10		L	L	L	L	L	L
	0.20		L	L	L	L	L	L
	0.30		L	L	L	L	L	L
	0.40	***Mp***	L	L	L	L	L	L
HE 340A	0.10	***Mp***	H	H	M	H	M	M
	0.20		H	H	M	H	H	M
	0.30		H	H	M	H	H	M
	0.40	***Mp***	H	H	M	H	H	M
	0.10	***0.5Mp***	H	M	M	H	M	M
	0.20		H	M	M	H	M	M
	0.30		H	M	M	H	M	M
	0.40	***Mp***	H	M	M	H	M	M
	0.10		M	L	L	M	L	L
	0.20		M	L	L	M	L	L
	0.30		M	L	L	M	L	L
	0.40	***Mp***	M	L	L	M	L	L

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