CYCLIC AND STRAIN RATE LOCAL DUCTILITY OF STEEL BEAMS

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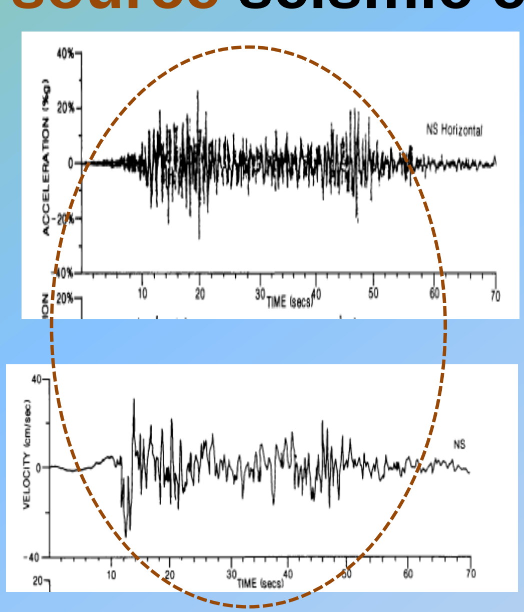
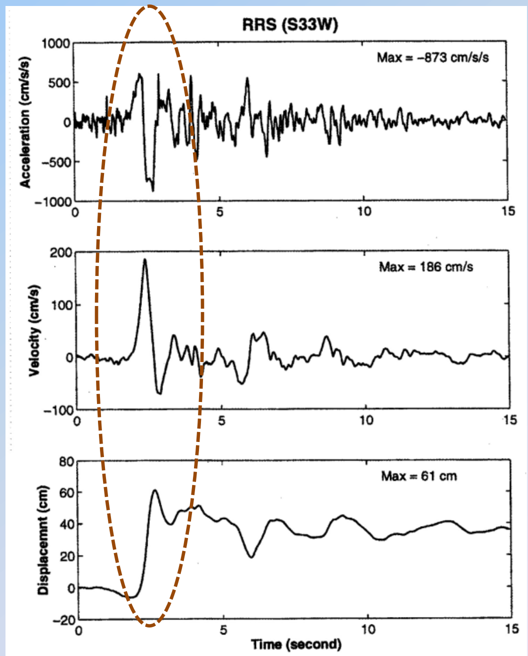
The inelastic behaviour of structures strongly depends on the type of earthquake excitation.

The engineering community, starting from the San Fernando earthquake, USA, 1971, and further on after the Northridge, USA, 1994, and Kobe, 1995, Japan, earthquakes, well recognized and classified the differences between the far source and near source seismic excitations.



Far Source. Michoacan earthquake, Mexico City.



Near Source. Rinaldi Station, Northridge earthquake, S33W.

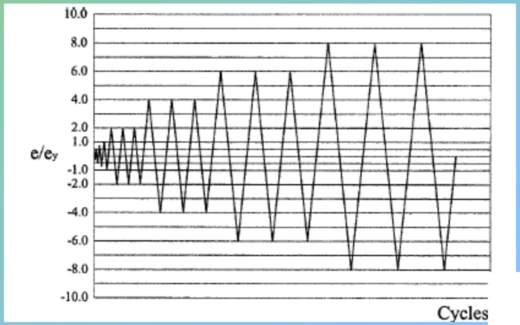
Generally, it was demonstrated that the far source earthquakes were related to a cyclic action and low rate of loading, while in case of near source earthquakes, the load rating is high, developing brittle failures to the base material.
Furthermore, the vertical action is another important factor contributing to failures by fracture.

Signs of plastic deformation in the web, flange and panel zone

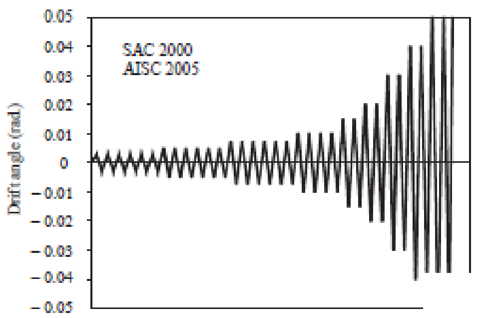
Far source Tohoku earthquake, 2011

Near source Kobe earthquake, 1995

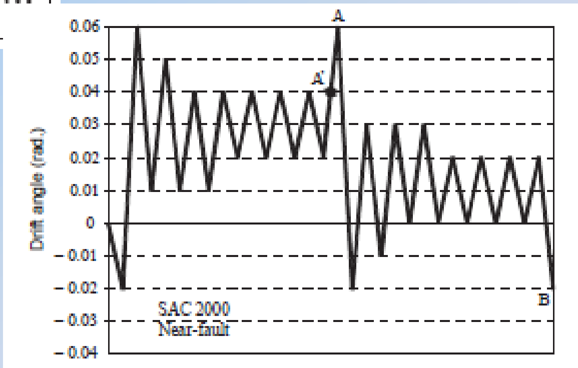
Considering the ductility, both the local and global one, as well as the associated strength both of them are depending on the loading history and the rate of loading.



ECCS recommendation, 1986



SAC 2000, AISC 2005



Krawinkler 's proposal for near source earthquakes

Nowadays, the majority of seismic design studies are focused on the force excitation differences, and how they affect the inelastic response of a structural element or a system, mainly investigating the input action defined by the required ductility.

Due to the fact that the same structural element disposes a different inelastic capacity under the different types of excitation, it is of paramount importance to study the available capacity of a system or a member to different actions.

So, in order to capture the aforementioned behaviour there is a need to define an available local ductility that takes into account the characteristics of each type of excitation (far vs. near source actions).

Consequently, associated with the seismic characteristics, two types of available capacity could be described, namely:

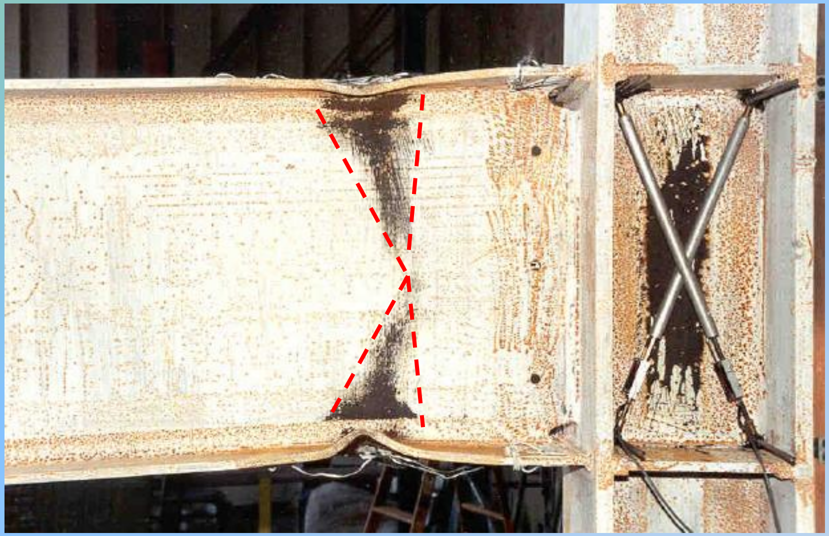
- **the cyclic local ductility,** **which is related to the far-source earthquakes, where the cyclic action is predominant,**

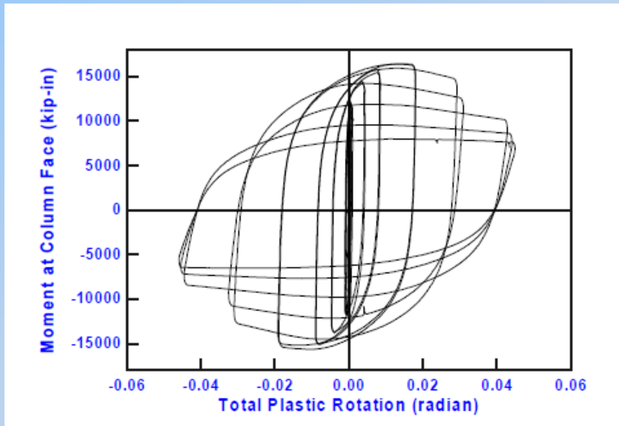
and

- **the strain rate local ductility,** **where the loading rate is more important.**

From experimental evidence and also from real earthquake failures, it was observed that :

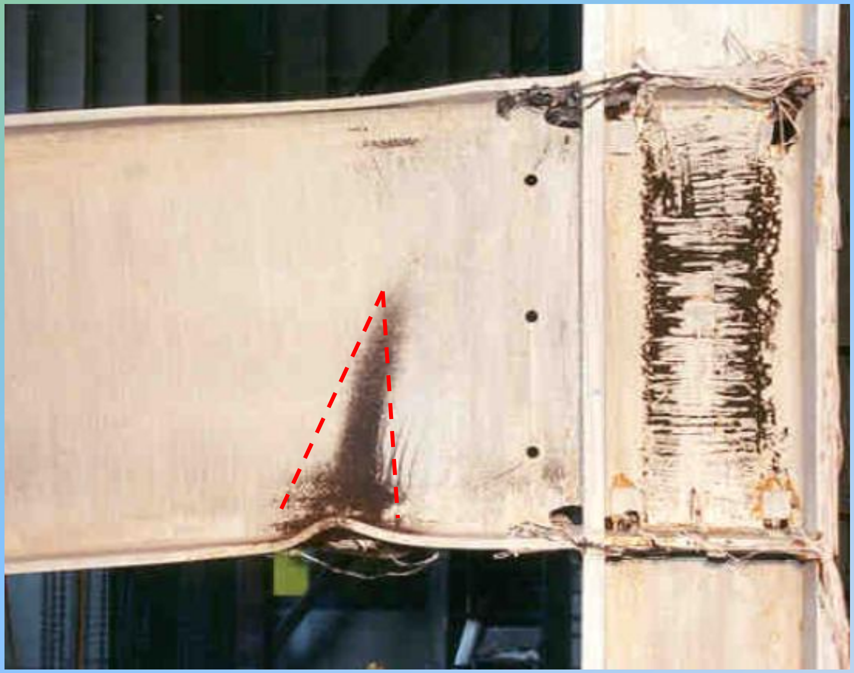
for the far-field seismic action due to its cyclic nature, a complete plastic hinge could be developed with a high dissipative capacity and large amplitude of local flange buckling.

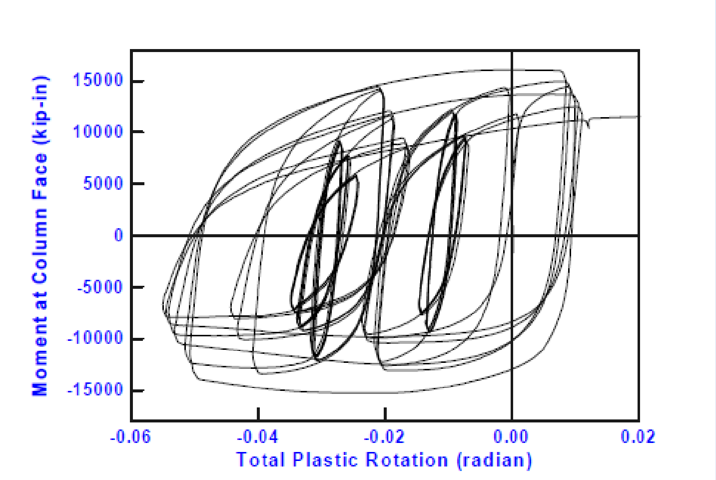




Taken from: Uang C.M., Yu Q.S., Gilton C.S , 2000. "Effects on loading history on cyclic performance of steel RBS moment connections", *Proc. 12th World Conference on Eartquake Engineering (12 WCEE 2000)*, cd paper 1234

for the near field earthquakes **due to its impulsive character, an incomplete plastic hinge is possible to be developed and further due to strain-rate an early fracture or a reduced plastic rotation could be experienced because of the highly increased yielding ratio.**





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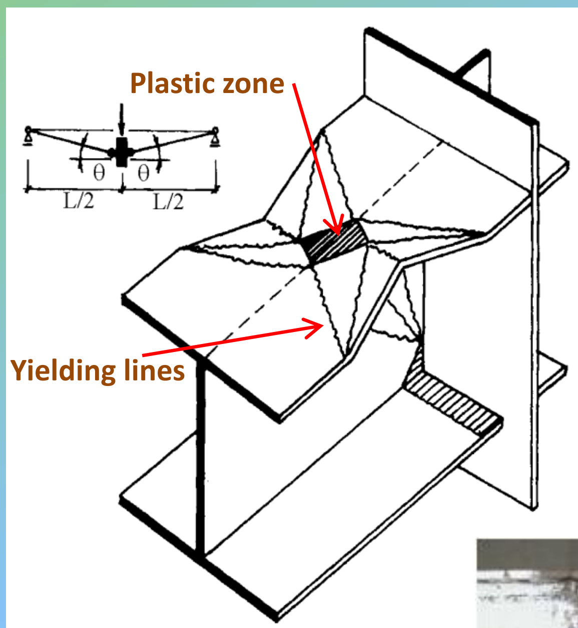
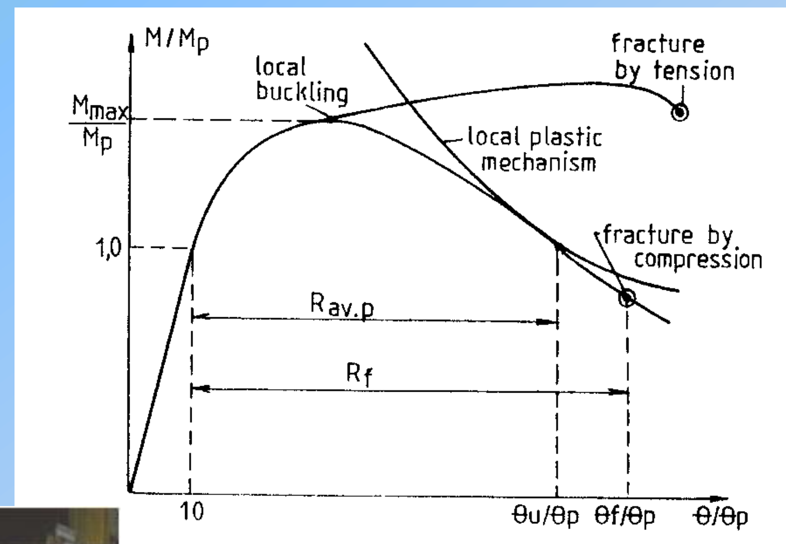
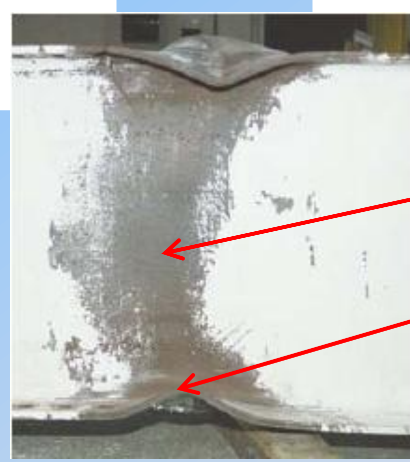
For the prediction of the inelastic capacity, the local plastic collapse mechanism was used. The plastic mechanism is composed of yielding lines and plastic zones, which primarily dissipate the input energy.



Plastic Collapse Mechanism Modeling



Moment-Rotation definition

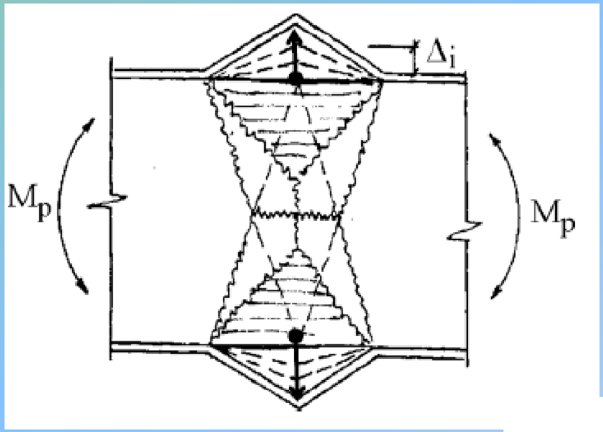


Web deformation

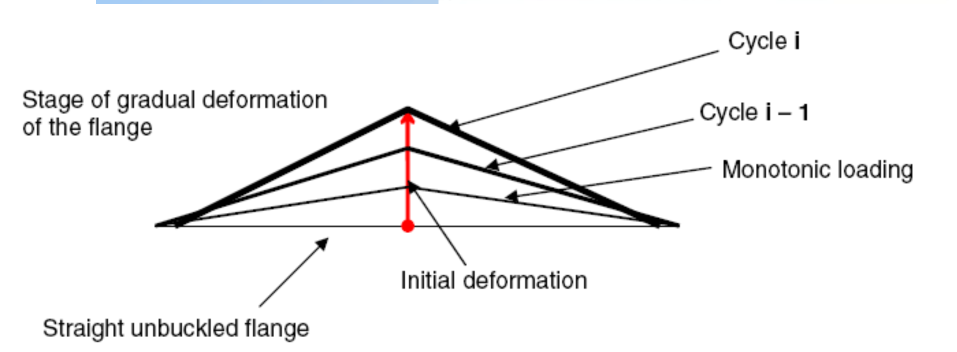
Flange deformation

Plastic Collapse Mechanism Experimental Plastic hinge

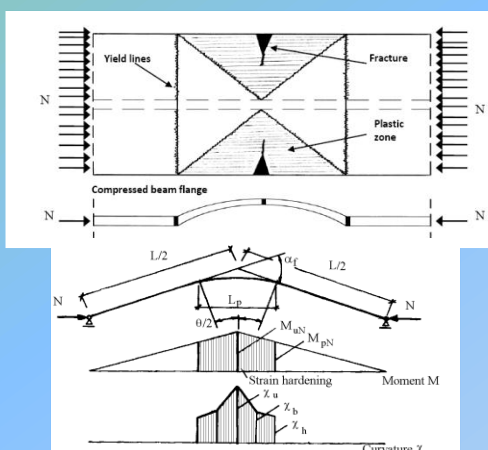
The model for cyclic loadings is based on the concept of accumulated initial deformations, described by the shape of the local plastic mechanism, in the same manner as the initial geometrical imperfections act in the elastic field for stability problems. So, the effect of the cyclic bending is implemented (as being the gradual strength and deformation deterioration).



Cyclic local ductility



Moreover, in case of near-field actions / strain-rate ductility, cracks may appear to the flange (fracturing the flange by compression or tension) as well as a limited plastic collapse mechanism may be developed in the web due to the impulsive shape of the action. The model takes into account the aforementioned mechanism as well as the increasing of the yielding ratio due to the velocity.

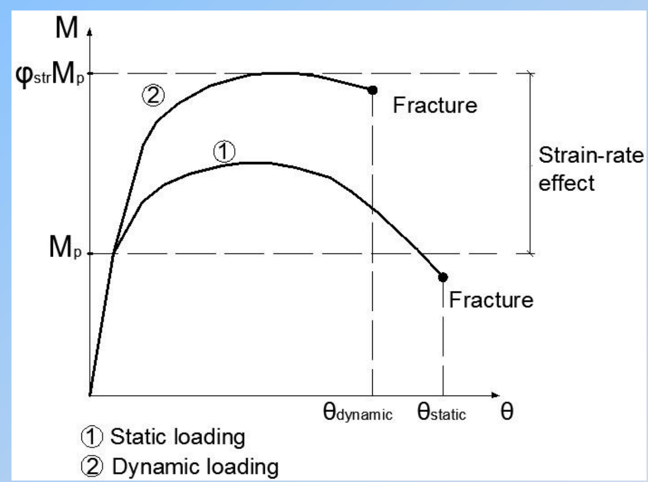


Fracture of compressed flange

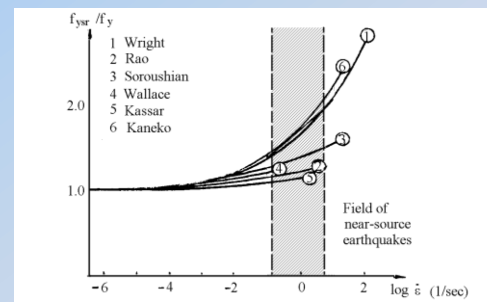
$$\theta_{uf} = 2\,\varepsilon_{uf}$$

$$\varepsilon_{uf} = 1.5\,\varepsilon_u$$

Fracture of tensioned flange



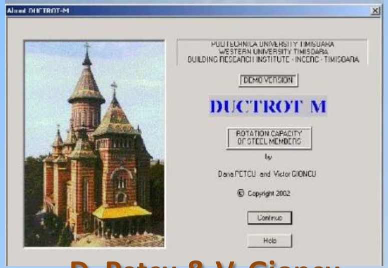
M-θ influenced by strain-rate



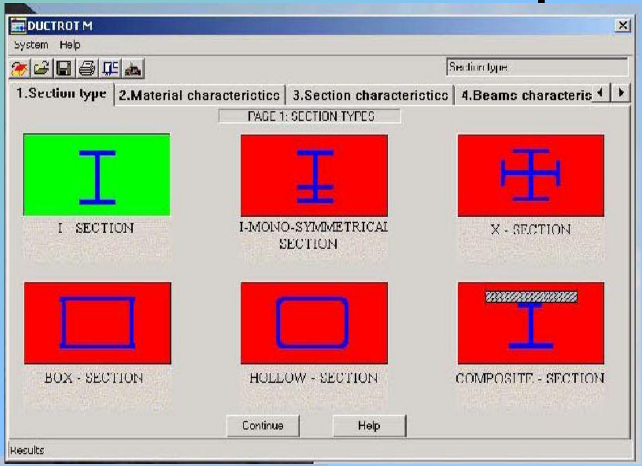
Increasing of yielding ratio due to the increasing of strain-rate

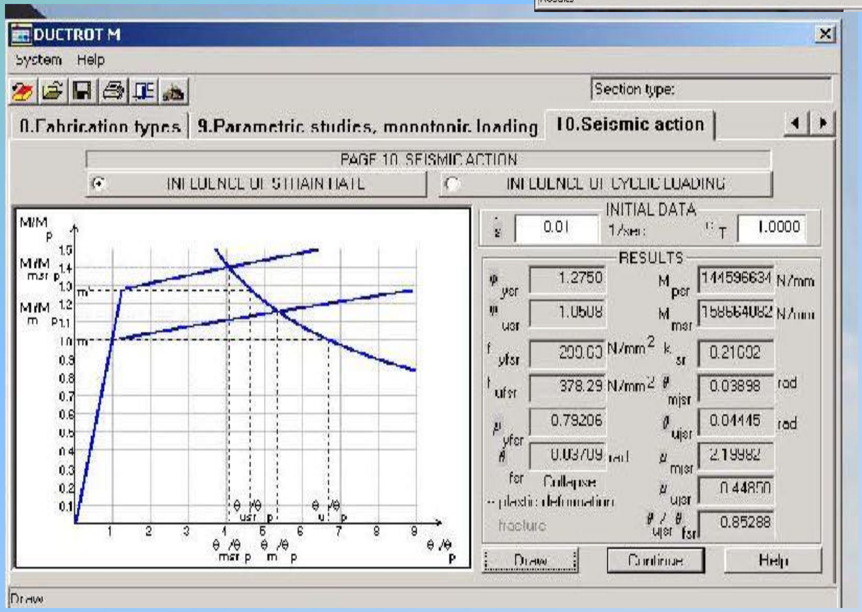
Strain-rate local ductility

In order to study the two different types of local inelastic capacity a parametric study was performed, by using the DuctRot-M computer software incorporates all the aforementioned parameters.

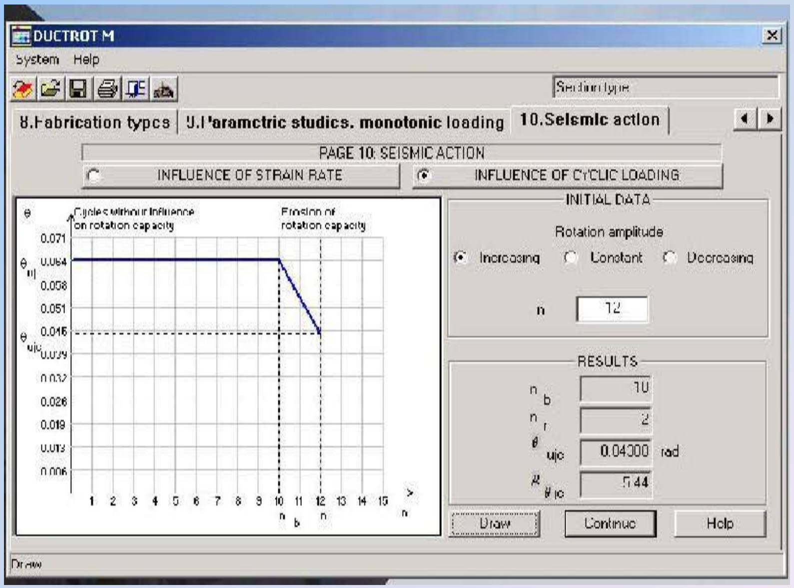


D. Petcu & V. Gioncu





Prediction of Strain-rate ductility



Prediction of Cyclic ductility

CYCLIC AVAILABLE DUCTILITY OF STEEL I-BEAMS

In order to study the local ductility, a parametric analysis was carried out by investigating the main parameters affecting the inelastic capacity of I-section, such as:

(a) the cross section conformation and section slenderness,

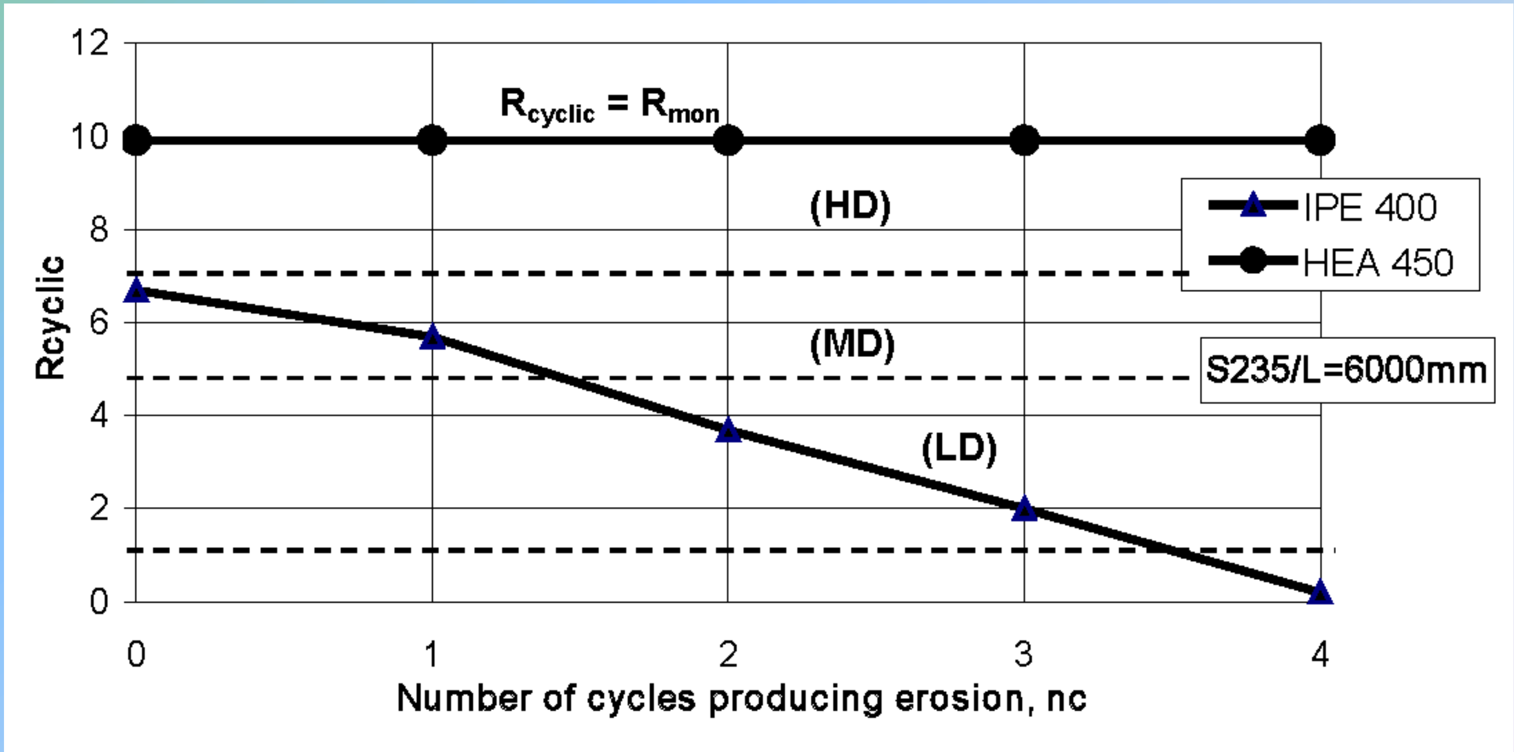
(b) the effect of the yield limit strength.

Important parameters are:

- **n_b, the number of cycles produced in stable elasto-plastic field, before the reduction of the moment capacity due to local buckling.**

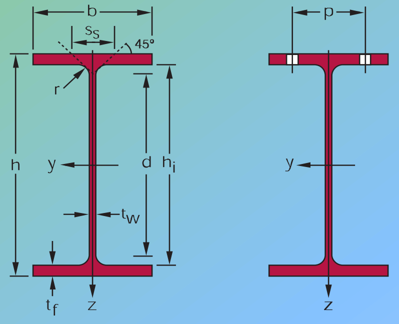
- **n_c, the number of decisive strong cycles producing the degradation of rotation capacity.**

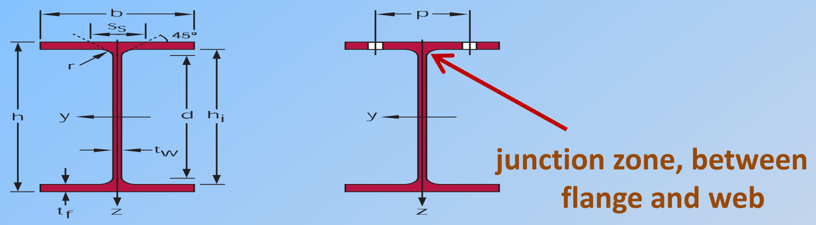
By comparing two different types of hot-rolled sections, with approximately the same flange slenderness ratios (i.e. for IPE400, $c/t_f = 5.11$, for HEA450, $c/t_f = 5.85$) and different web slenderness (i.e. for IPE, $d/t_w = 38.48$, for HEA450, $d/t_w = 29.91$), as well as with different load carrying capacity, one can observe that HEA450 keeps the cyclic rotation capacity constant, which is the same with monotonic one. For the IPE a gradual degradation of the cyclic rotation capacity is finally noticed.



The effect of the slenderness (cross-section conformation) on the local inelastic capacity

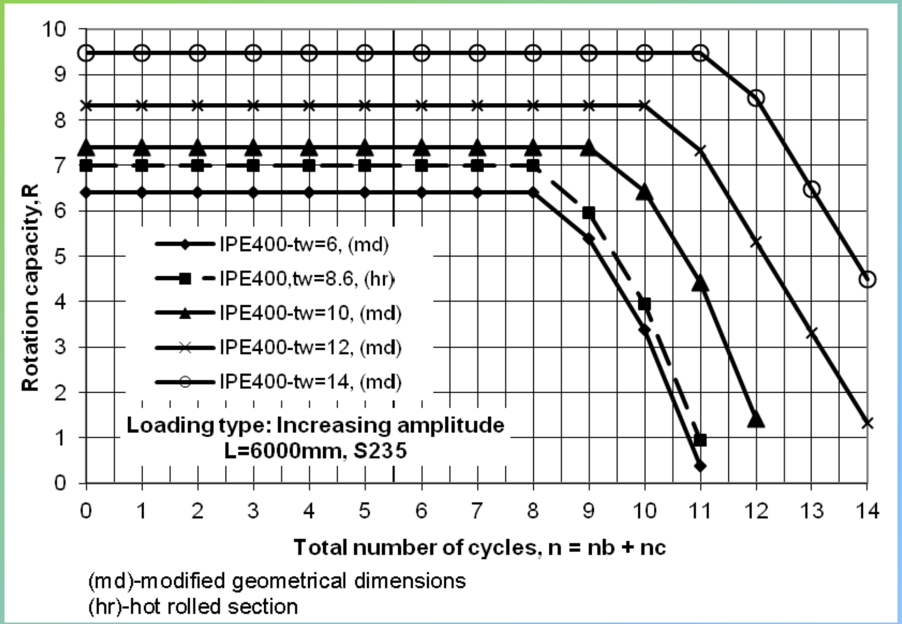
HEA sections have a superior behaviour, due to greater web thickness and to lower web height, and greater intersection zone, between flange and web.



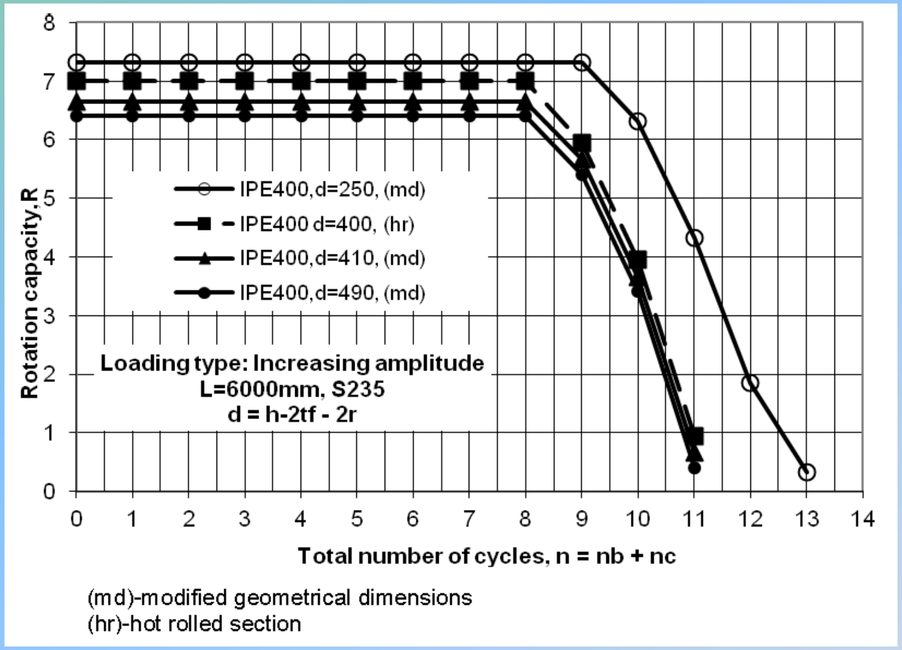


In order to demonstrate the effect of the two aforementioned critical parameters, a sensitivity analysis was carried out.

By using an IPE section, the web thickness and height was varied, while keeping the flange width and thickness constant.



The effect of the web thickness on the local inelastic capacity



The effect of the web height on the local inelastic capacity

It can be observed that the increase of the web thickness leads to the increase of the rotation capacity, while the reduction of web height also leads to the increase of the rotation capacity.

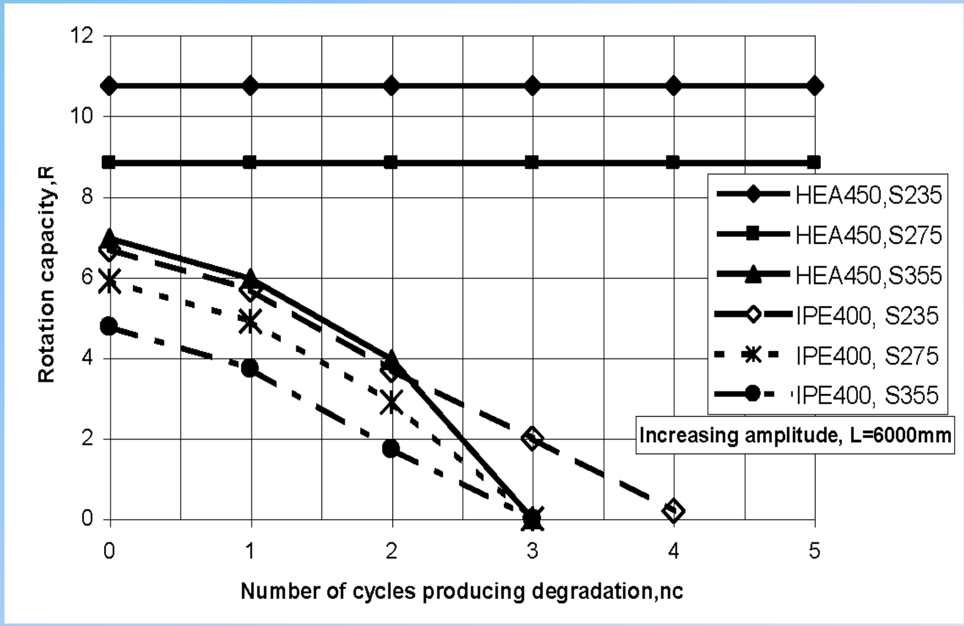
However, the effect of the web thickness is more pronounced than that of the web height; thicker web plates increases the number of cycles until buckling, n_b.

So, a certain web thickness provides the possibility for a stable deformation of the flange supported by the web.

Related to the second parameter of study, namely, the yield strength:

At a first look, it appears to be decisive regarding the rotation capacity under cyclic action.

Nevertheless, the severe ductility reduction is associated with the number of the cycles as compared to the influence of the increasing yielding strength, especially for IPE sections.



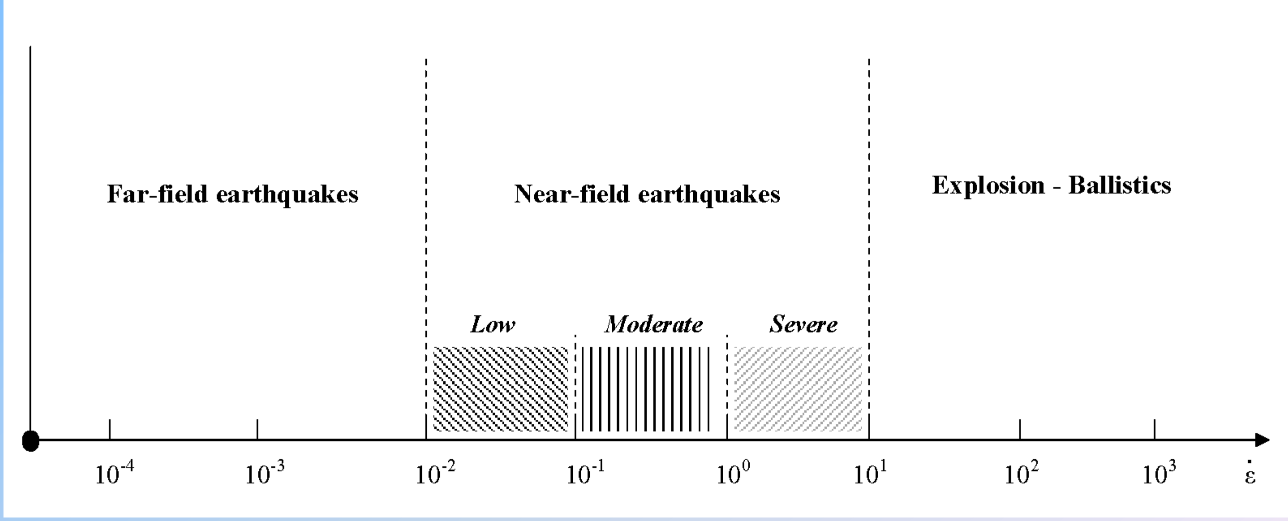
The same is true for the HEA sections made by S355 steel quality.

However, for lower qualities of HEA sections the effect of the cycles seems to be ineffective. In fact, the stable behaviour of this type of cross-section derives from the cross-section conformation.

STRAIN-RATE AVAILABLE DUCTILITY OF STEEL I-BEAMS

It is well recognized that the increase of the yield ratio due to a high strain-rate has a detrimental effect on the inelastic capacity leading to brittle failures.

So, It significantly reduces the capacity of the seismic energy dissipation, especially in the field of 10^{-1} to 10^{1} sec^{-1} where there is the range of the velocities of near-field earthquakes.



The parameters under consideration are:

- **the steel quality**

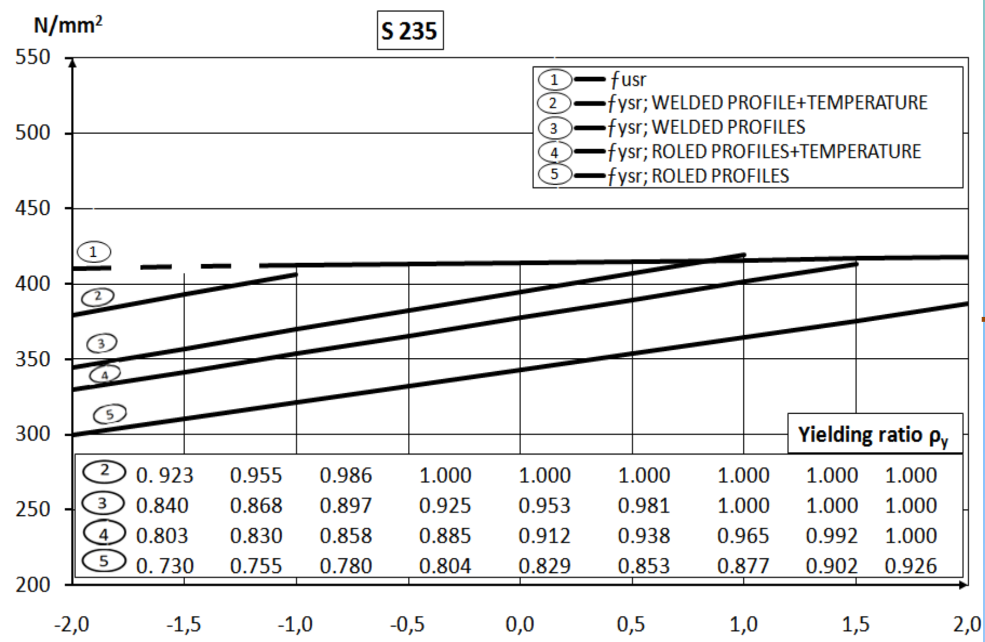
(S235 and S275, mainly used in beams due to capacity design reasons),

- **the conformation type**
- **(rolled and welded sections),**

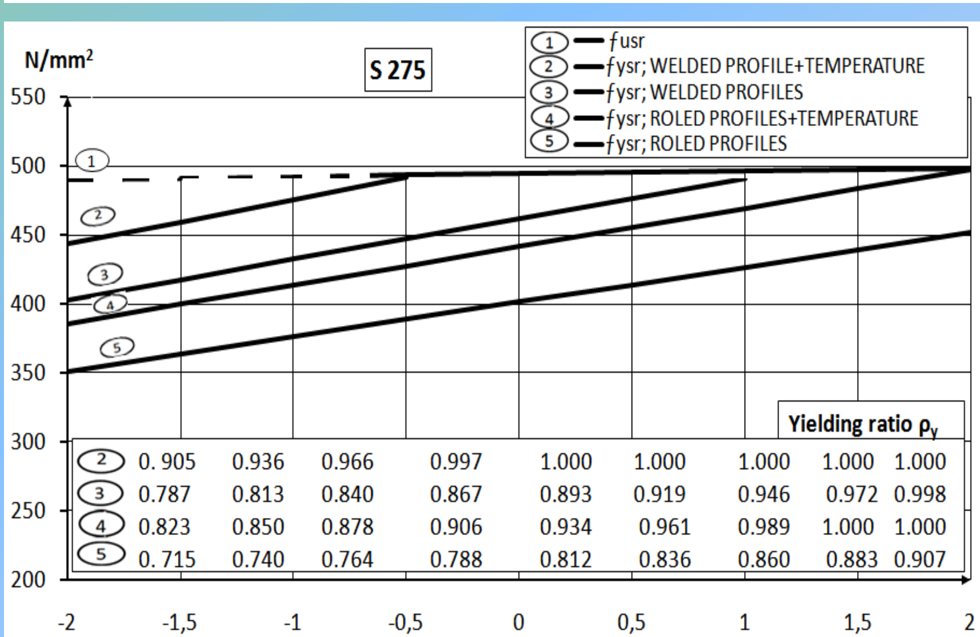
- **the temperature conditions**

(in room conditions and at low temperature),

- **the strain rate level.**



The effects of the strain-rate and of the steel qualities, S235



The effects of the strain-rate and of the steel qualities, S275

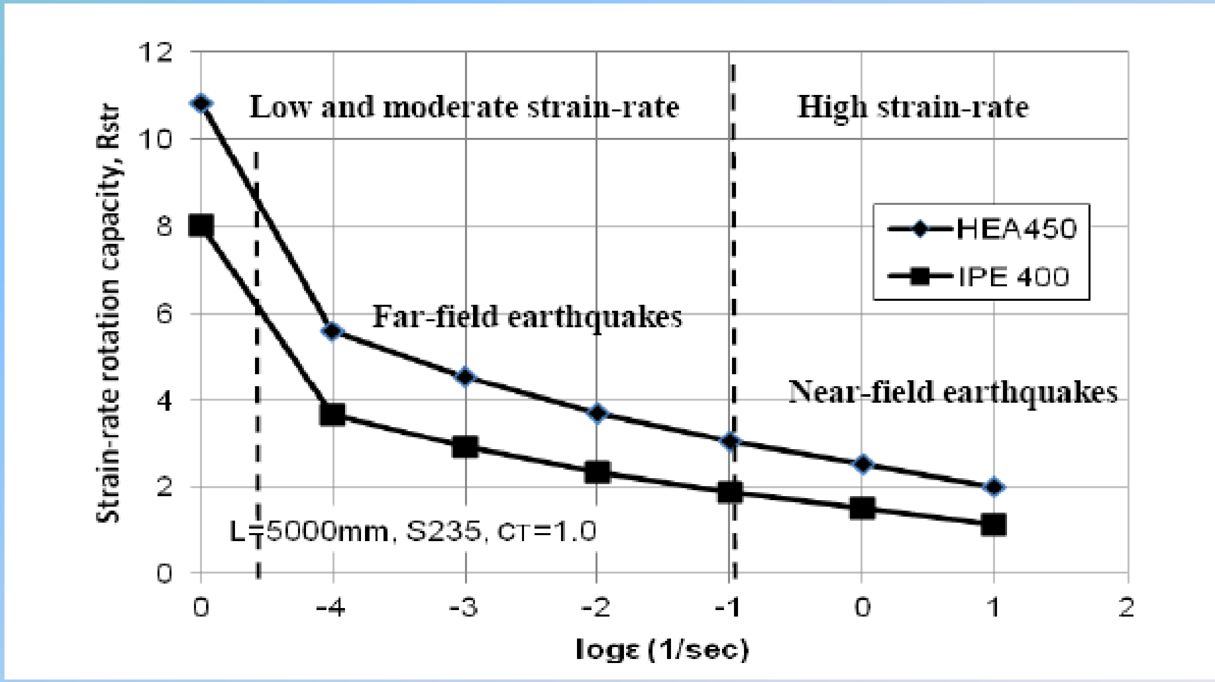
Higher steel quality (S275) has a more favorable behavior in condition of high strain-rate than the steel with lower quality (S235) due to the higher difference between fu and fy.

Rolled sections have a better behavior than the welded ones.

In the case of welded profiles, the poorest behavior during strong earthquakes is reached in low temperature conditions.

Very important reduction of rotation capacities occurs due to strain-rate. So, beyond the loading history type (cyclic or impulsive) it is important also to take into account the effect of the loading rate.

Generally, the thicker the plates the greater the tendency to fracture. HEA sections have a better inelastic capacity than IPE sections; however, suggesting that for the analyzed case the flange slenderness is the same.



The influence of the loading rate on the rotation capacity

CONCLUSIONS

In function of the earthquake type, the paper reveals the differences in the available local ductility, when the cyclic action and the strain-rate are considered.
It is a first step towards the quantification of the inelastic capacity taking into account the real characteristics of the seismic action. Therefore, the loading history and the loading rate are of paramount importance in order to predict the rotation capacity of a steel element.

From the limited parametrical analysis presented herein, it was revealed that HEA sections possess a better inelastic capacity than IPE ones, for both types of action (cyclic and strain-rate).

For cyclic actions the effect of web is more pronounced.

The hot-rolled sections have a superior behaviour, especially in case of strain-rate conditions; with regard to steel quality, the S275 steel seems to be more effective than the S235 one.

As a final remark, one can conclude that the section and member ductility are of primary importance under cyclic actions (i.e. far-field earthquakes); while the material ductility is more important under strain-rate conditions (i.e. near-field earthquakes).
More experimental work should be performed considering different loading histories, not only the traditional one (i.e. ECCS, FEMA, ATC), as well as in combination with different loading rates. In addition, any action of member / connection prequalification would take into account the perspectives provided herein.

Thank you for your kind attention

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