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CONSIDERATIONS ON LOCAL DUCTILITY OF STEEL FRAMED STRUCTURES UNDER SEISMIC ACTIONS

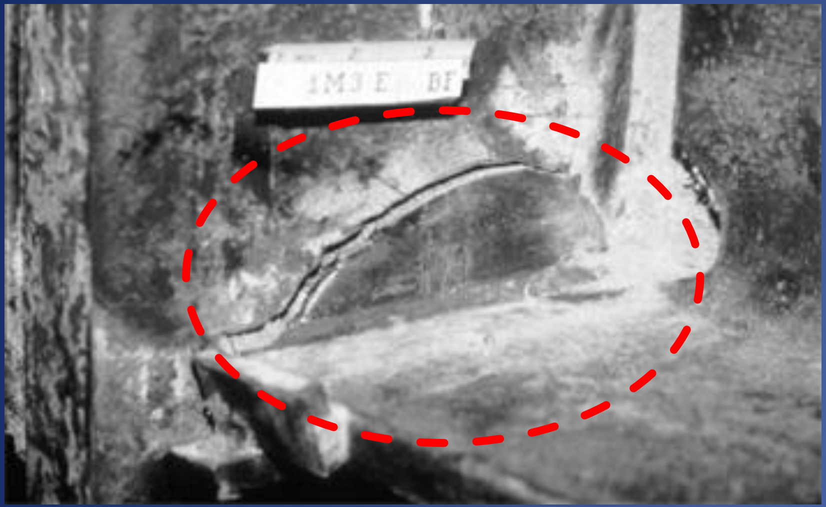
Anthimos ANASTASIADIS

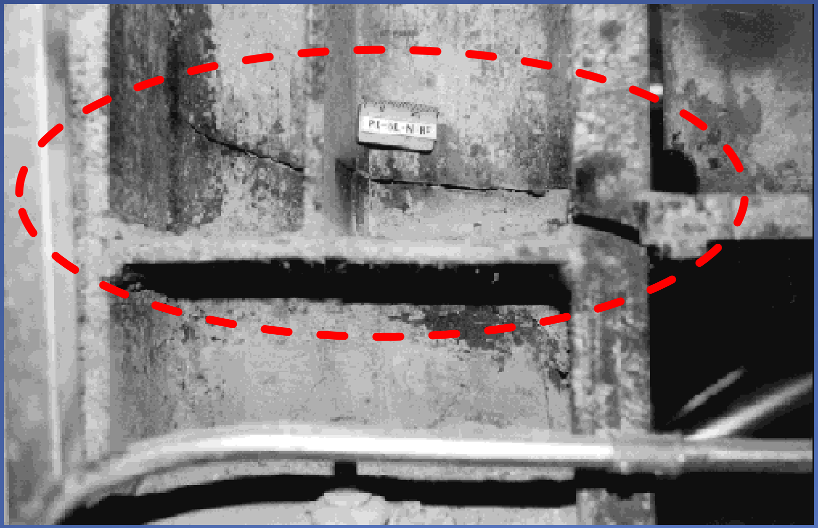
ASA
Structural Consultants
Thessaloniki, Greece

Marius MOSOARCA

´´Politehnica´´University of
Timisoara, Romania
Faculty of Architecture

The severe Northridge, USA, 1994, and Kobe, Japan, 1995, earthquakes unveil the deficiencies in the design of steel framed structures that was considered, until then, as invulnerable. Fractures at the joint region without any sign of ductile behavior were observed.





As a consequence the issue of ductility and particularly the local ductility regained a leading role in the seismic design, not only based on the material ductility but also to the section, joint and member level of inelastic deformation.

With regard to local ductility specified to current Eurocode 8 (2004). Chapter 6 (*Specific rules for steel buildings)*

- It prescribes width-to-thickness ratios corraleted to q factor, although **does not specify a clear methodology.**

- The width-to-thickness ratios are taken from the Eurocode 3, **which is mainly used for static loading.**

- The local ductility classification **does not consider the span of the member.**

- Some limits for the plastic rotation of beam to column connections are provided, although does not specify a clear methodology.

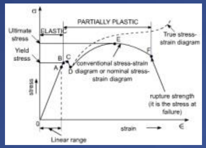
- It prescribes dissipative and not dissipative mechanisms (globally), although does not consider the formation of a plastic hinge as a function of detailing (strengthening, weakening solutions).

- The seismic action is taken from the spectra, although the above one does not considers the type of action, for instance the far and near field earthquakes.

It is important to remark that the ductility, both the local and global one, as well as the associated strength, depends on the loading rate and the history of loading.

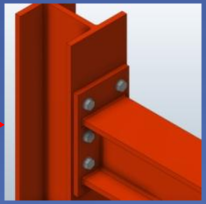
In order to develop a ductile design for steel structures a discrete process, considering all the levels of influence, should be defined namely:

(1) material,



(2) cross-section,

(3) connection,



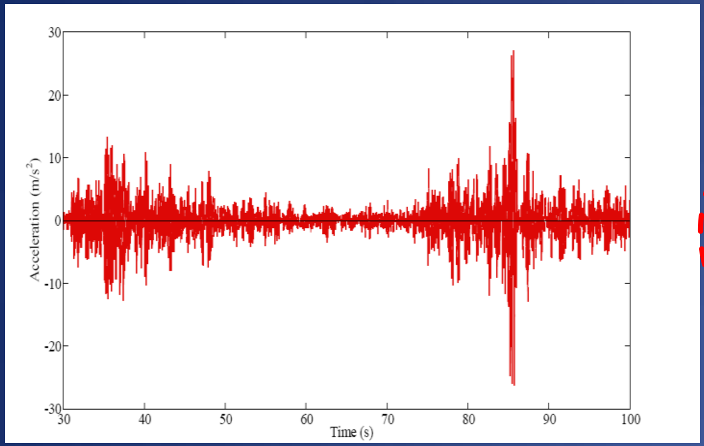
(4) joint,

(5) member.

The paper emphasizes the framework for the definition of the local ductility considering all the aformentioned parameters

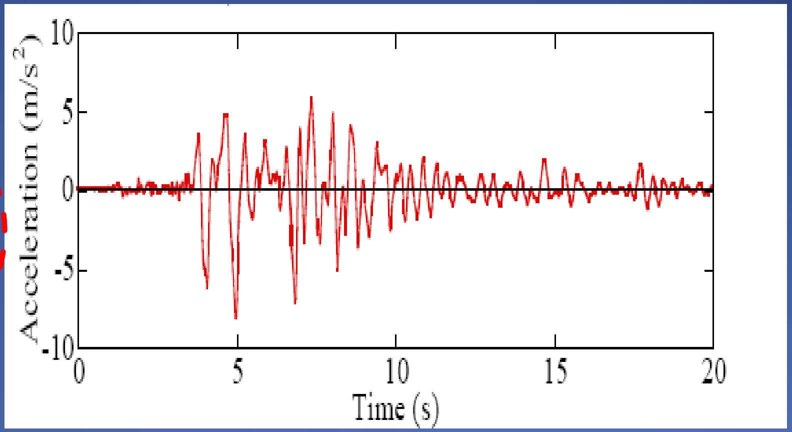
THE FRAMEWORK FOR THE DEFINITION OF THE LOCAL DUCTILITY

1. Local ductility as a function of the loading condition



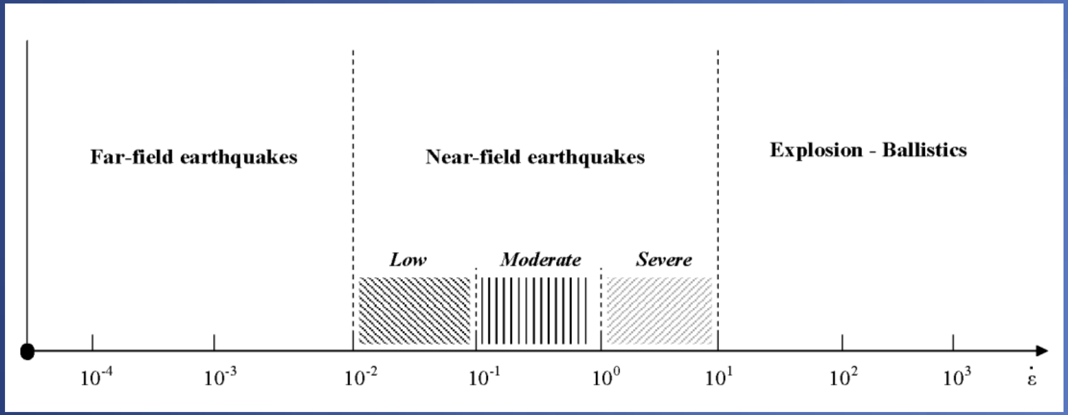
Far -field action

Loading History



Near -field action

Loading Rate

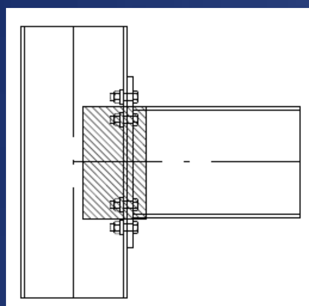


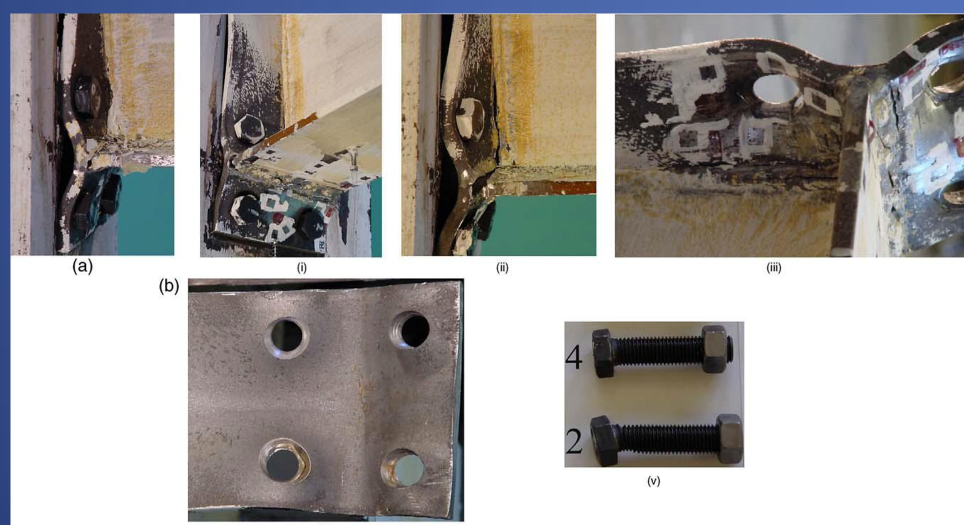
Strain-rate

Table 1. Basic influences of the local ductility under different seismic loading conditions

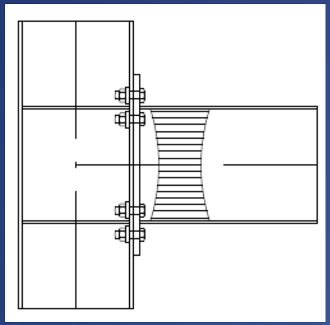
Local Ductility Levels	Far-field earthquakes	Near-field earthquakes
Material ductility (ε_y, ε_u, f_y, f_u, ρ_y)	- Low loading velocity - Bauschinger effect - Random material variability	- High loading velocity, strain-rate - Rapid increasing of yielding strength as compared with the ultimate one, material embrittlement
Cross-section ductility (b_f, t_f, d_w, t_w)	- Flange / web local buckling - Gradual cross-section stiffness and strength degradation	- Fracture of flanges, no time for local buckling
Joint ductility (panel zone and the connection components) $\mu_{\theta,joint,av.}$	- Gradual stiffness, strength and ductility degradation of the component elements - Alteration of the SC-WB mechanism due to the additional strength of the slab	- Fracture of weldments and / or bolts - Alteration of the SC-WB mechanism due to the uncontrolled yield strength increasing
Member ductility (b_f, t_f, d_w, t_w, L) $R_{av.}$, $\mu_{\theta,member,av.}$	- The slab effect not permitting the buckling of the upper flange under the alternation of the moment action - Low cycle fatigue behavior (10-20 cycles)	- The slab effect develops stress concentration at the lower flange - Ultra low cycle fatigue behavior (3-6 cycles).

2. Local ductility as a function of the conceptual design

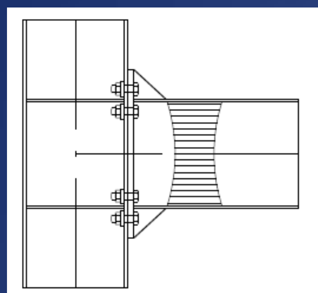
Constructional detailing	Design conformation	Type of the local ductility
	Weak Column – Strong Beam WC-SB The dissipative zone is mainly located at the panel zone as well at the connection and under certain circumstances also in the column	Joint ductility (panel zone + connection deformation) + Member ductility (beam /column deformation)



Experimental assessment of the ductility of extended end plate connections
Ana M. Gira˜o Coelho , Frans S. K. Bijlaard _, Luı´s Simo˜es da Silva

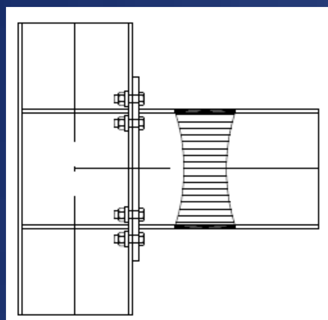
Constructional detailing	Design conformation	Type of the local ductility
	Strong Column – Weak Beam SC-WB The dissipative zone is located in the beam (capacity design)	Member ductility (beam deformation)

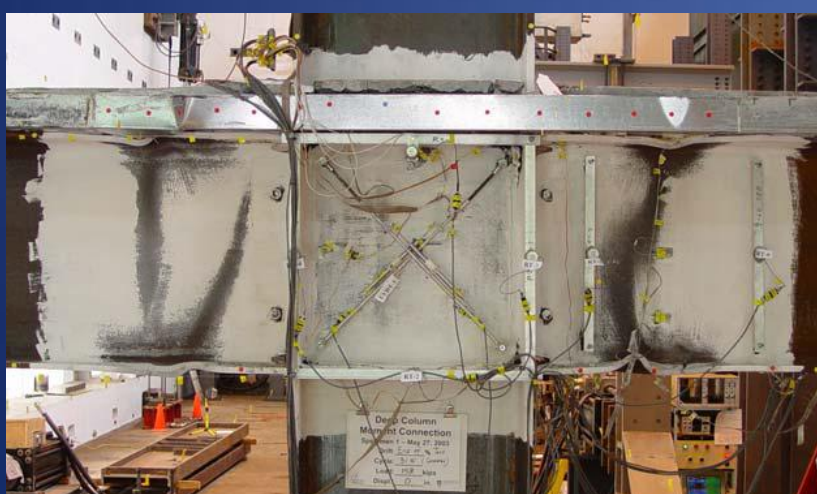
As was demonstrated by the recent earthquakes only the strong column – weak beam concept is difficult to assure a plastic hinge formed away from the column face

Constructional detailing	Design conformation	Type of the local ductility
	Strengthening solution of SC-WB concept by using ribs, haunches, cover plates. The dissipative zone is located in the beam (capacity design)	Member ductility (beam deformation)

Plastic hinge / member ductility

Experiments SAC joint venture, 2000

Constructional detailing	Design conformation	Type of the local ductility
	Weakening solution of SC-WB concept by reducing the beam flanges at some distance from the column face (´´dog-bone´´) connection. The dissipative zone is located in the beam (capacity design)	Member ductility (beam deformation)

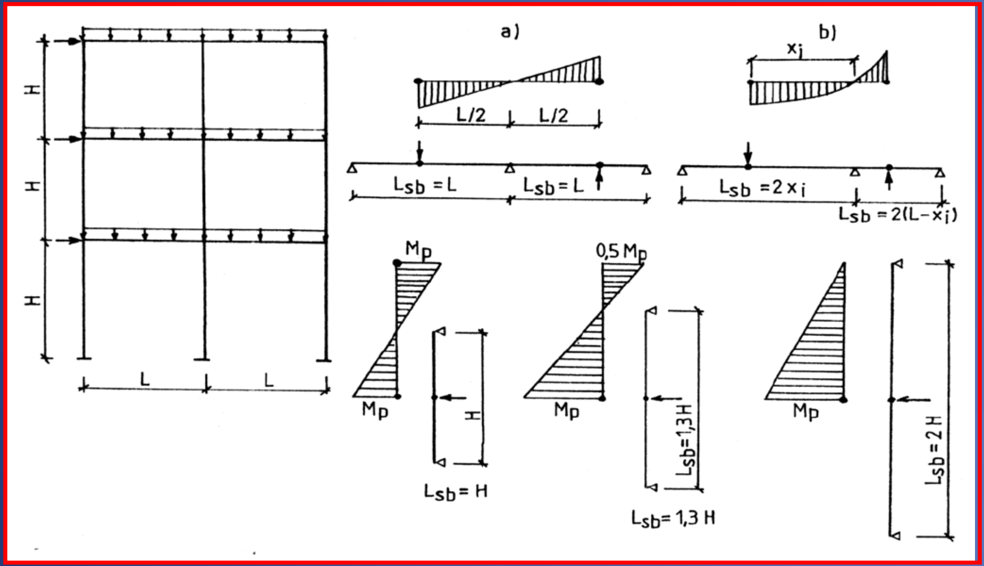


Experiments Lehigh Univ., ATLSS, 2004

3. Local ductility as a function of the structural behavior

The study of the local ductility it is necessary to assume that the element components belong to a frame.

Hence in order to take into account the effect of the frame to the beams and /or columns the ´´standard beam´´ concept was proposed by Prof. Gioncu and further extended assimilating the deformational behavior.



Through the use of ´´standard beam´´ the influence of gravity loads and the level of severity of the horizontal loads were introduced, improving the traditional concept of the three point beam.

For the complete framework definition of the local ductility one can consider the type of deformation and the predominant action.

Thus, the predominant action dictates the type of local ductility that can be calculated (monotonic vs. seismic ductility).

Therefore, in case were the gravity forces are predominant and /or in case of low earthquake action the monotonic plastic ductility could be prevailed.

In case were the effect of earthquake forces are very important the seismic ductility gets the control and in function of the earthquake region could be of the far-source (cyclic) or near-source type (strain-rate).

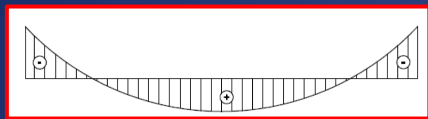
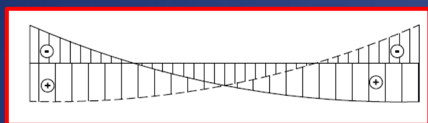
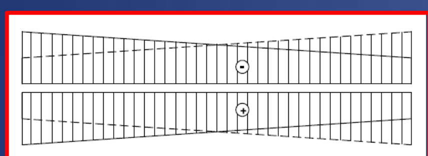
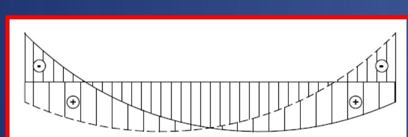
We can distinguish the following types :

Monotonic ductility

Seismic ductility:

- **Cyclic local ductility (far-source actions)**
- **Strain-rate local ductility (near-source actions)**

Local ductility dictated by the structural deformation

Type of deformation	Observations
	Cases were the gravity forces control the behavior. The level of gravity forces are high combined with a long span. The local ductility could be determined by the plastic monotonic one.
	Cases were the earthquake forces control the behavior. The local ductility could be determined by the seismic one. Plastic hinges are formed at both ends.
	Cases with exceptional severity of earthquake forces, also in case with high level of seismic forces and short beam span. There is no point of inflexion. Plastic hinges can be formed initially at one end; during the evolution of the seismic action also it is possible to be formed a plastic hinge at the other end.
	Cases with high level of gravity and earthquake forces, where the potential plastic hinges can be formed at the end as well at the mid-span. During the seismic loading a third plastic hinge it is possible to be formed, at the other end, transforming the beam into a collapse mechanism.

DESIGN FORMAT FOR A DIRECT DUCTILITY BASED DESIGN

Seismic Required Ductility, $D_{req.}$ ≤ Seismic Available Ductility, D_{av}

$$\gamma_{req}\left(\gamma_{fs};\gamma_{ns}\right) D_{req}\left(D_{req.fs};D_{req.ns}\right) \leq \frac{D_{av}\left(D_{av.cyc.};D_{av.str}\right)}{\gamma_{av}\left(\gamma_{cyc.};\gamma_{str.}\right)}$$

The base for the available local ductility of steel beam is the monotonic one, due to the fact that is the most studied and well defined.

By using appropriate factors we could obtain the seismic ductility.

Cyclic ductility, $D_{av.cyc}$

Strain-rate ductility, $D_{av.str}$

$D_{av.cyc}$ = (factors introducing the cyclic effect) x $D_{av.mon}$

$D_{av.str}$ = (factors introducing the strain-rate effect) x $D_{av.mon}$

With respect to safety factors the γ_{av} should be determined taking into account the cyclic and strain-rate effect, while the γ_{req} could be evaluated taking into account the global frame behavior, the local soil conditions and also the characteristics of the action as defined from the far-source, γ_{fs}, and near-source, γ_{ns}, earthquake motion.

Steps for the evaluation of the seismic available local ductility

Determination of the ´´standard beam´´ introducing the frame effect	
Prediction of the local available ductility under monotonic conditions	
Factors influencing the local ductility	
Constructional **Geometrical**	**Loading** **(near, far source earthquakes)**
Prediction of the available local ductility under seismic loading conditions	
Safety Factors	**Correction Factors**
Local Available Seismic Ductility	
Cyclic available ductility **(*cyclic* effect)**	**Strain-rate available ductility** **(*Strain-rate* effect)**

CONCLUSIONS

The prediction of the local ductility is still an open topic, not clearly defined in the current codes of practice.

Actually, the difficulties rise from the inherent variability of the loading, the material and the geometric parameters that can be evaluated in a post-elastic range.

The experimental and theoretical background cumulated, particularly, in the last twenty five years creates the condition for a straightforward verification of the local ductility of steel moment resisting frames.

The paper evidenced the framework under which should be worked in order to obtain a ductile design based on the inelastic capacity of the element components.

Of paramount importance is to recognize the different effect on the available deformational capacity that has an earthquake of near-source with impulsive characteristics and very few inelastic cycles against a far-source earthquake with much more cyclic action, within the inelastic range, and longer duration.

Furthermore, future editions of the codes (e.g. EC 8) must clearly specify, the joint and member available ductility, based on the past and existing experimental and theoretical work.

This paper is dedicated to Professor V. Gioncu who passed away on March 2003. His contributions in the field of stability and ductility were recognized from the international engineering community by numerous publications and honors. We have lost our beloved mentor, and we truly miss his thoughts and suggestions, his passion and enthusiasm for both life and engineering problems. We will always grateful for all that we learned from him.

An action against earthquake effects in highly seismic countries like Greece, Romania and Turkey

Thank you for your attention