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Local Ductility and Global Behavior Factor of Steel Frame Structures Braced by Centered Bars System

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Abstract. When an earthquake occurs, civil engineering structures are subjected to forces that lead to a non linear behavior. This is often the case for designed steel structures. So, they absorb a larger part of the seismic energy transmitted to its resistant elements (columns and diagonals). This ability to dissipate energy through plastic deformation is expressed by the q behavior factor, used in the seismic design codes. In this paper a distribution of the local required ductility as a function of the behavior factor is given for steel structures braced by the stability bents of X shape.

Keywords: behavior factor, local ductility, steel structures, stability bents, non linear analysis, centered bars.

1. Introduction

The observation of the damage of the structures in an earthquake shows that they resume a much higher energy than that considered for their design.

The explanation of this situation lies largely in the mechanism of dissipation of the energy transmitted by the earthquake through the inelastic deformation in the structural resisting elements. Specifically, the q global behavior factor of the structure justifies this phenomenon.

Experimental developments due to Ballio [1], focused on the evaluation of the earthquake resistance of structural elements in steel. An investigation conducted by Boushaba [2] concerned the relationship between local ductility factor requirements and behavior of steel structures in seismic context.

Many researches related to other analyses who do not fit with the context treated here, led to the development on solutions and approaches for solving difficulties posed certain aspects of seismic codes in general and particularly in the Eurocode 3 [3] and the Eurocode 8 [4] (Unified Rules for construction in seismic zones).

In addition, further investigations using numerical approaches led to the development of many numerical based programs as it is the case for the Drain 2D which is a general purpose program for the inelastic analysis of plane structures. It was developed by Kanaan and Powell[5]. It has been used by Mechiche[6] to study the behavior factor of structures braced by steel stability bents. The latter is based the book written by Plumier[7] the calculation and design of structures subjected to seismic forces. Also, other references exist which include a nonlinear dynamic analysis of X-steel braces carried out by Hirotani *& al* [8], the effect of using different kind of bracing system reported by Behruz Bagheri Azar, *& al.* [9] and Seismic Demands with Buckling-Restrained Braces. Rafael Sabelli *& al.* [10]. Adding to this, numerical models for simulating the cyclic behavior and the seismic response of steel structures were treated by Giulio Ballio *& al.* [11]. In this research field a work on the Performance-based plastic design is cited by Dipti R. & *al.* [12].

The purpose of this work is to provide a method for evaluating this factor and give a relationship between the μ_i local and the behavior factor of a given structure.

1.1. Definition of the global seismic q behavior factor

Under the seismic action of an earthquake, a structure absorbs some energy. The latter is composed of several terms whose namely are E_e elastic strain energy, E_{cin} kinetic energy, E_v damping energy of structure visco-elastic behavior and E_{ep} strain energy of hysteresis. Thus, the total energy spent in the structure by the earthquake, will be :

$$E_t=E_e+E_{cin}+E_v+E_{ep} \qquad (1)$$

The last term, which implies the work of materials in the non linear domain, leads to mathematical approach difficulties.

We no longer have the linear correspondence between force and displacement and there is no direct solution to this problem.

As this last term may be very important towards the others in a well built structure, it is economically interesting to take it into account, first in defining the conditions in which stable elasto-plastic behavior may be reached with safety, then in suggesting a reliable calculation method.

Concerning the required conditions to reach a stable elastic behavior, we will refer to Euro code 8 chapter 3-3 [4]. For the adopted assessment methodology to evaluate this factor, the most complete one is chosen.

It consists to use a non linear dynamic program without any hypothesis.
The input seismic signal used corresponds to the significant area's considered characteristics. The study is summarized in the following steps:
Let a seismic signal a(t) and a number of structures designed in a same type. A number of response calculus of a given structure is performed by a non linear analysis program, by the application of an input seismic signal resulting from the product of a(t) by a coefficient λ.
By varying the λ coefficient values, we get successively :

1. A coefficient λ_e, so the elastic limit f_y of the material is reached at a point of the structure.
2. A coefficient λ_{max}, such as the D_{max} displacement obtained by the non linear dynamic calculation performed on the structure with a f_y elastic limit of the material, is equal to the one given by an application of a linear dynamic evaluation process with the same signal λ_{max} .a(t) in the case of an elastic limit of $q.f_y$.

Thus, the q behavior factor of the structure is definite as follows:

$q=\lambda_{max} /\lambda_e$ [2] and [8]. (2)

3. The figure 1., synthesizes the adopted assessment approach.

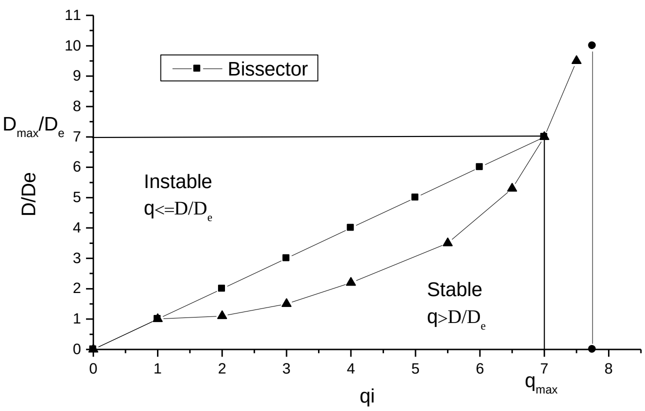
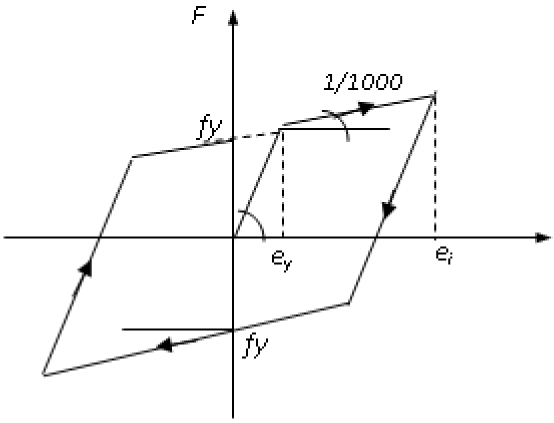


Fig. 1. Determination of the q behavior factor**.**

1.2. Behavior factor and ductility definitions

The ductility defines the ability of a material or a resistant structure's element to elongate in the plastic field, without collapse or losing resistance.

If necessary, a complete explanation and commentary of the relationship «load – displacement » is given in [1] and [8].
In this study, only structural resistant elements of which characteristics, when they are subjected to a cyclic action, are of the type elastic perfectly plastic, as shown in figure 2., are used.
A non null value is affected to the hardening modulus due to the numerical treatment in the convergence process.



Ductility $\mu=e_i/e_y$

Fig. 2. Behavior of an ideally elasto-plastic connection.

It is obvious that some ductility must necessarily exist in the various elements of a structure.

Thus, the factor D/D_e of figure 1., is finally and simply the global ductility factor. However, the distribution of the local required ductility is not uniform.

The aim of this study is to give an approach of the relationship between the q global behavior factor of the structure and the local required ductility for steel structures braced by centered bars.

2. Study assumptions hypothesis

For these structural applications, the Drain2D structural design program was used. It was developed by A. Kanaan and G.H Powell in the University of California at Berkeley [5].
A linear element of its library which plasticizes in tension and has an elastic buckling in compression, was considered in this research.

2.1. Used structural design program features

The used program performs dynamic analysis with the introduction of a seismic signal giving the soil accelerations in function of the time. Also, it can support other dynamic loadings.

In the non linear dynamic analysis, a step by step integration scheme is chosen to reflect the changes in term of time intervals.

It has a library of linear and plane finite elements.

2.2. Seismic action

The seismic action is defined by the Boumerdes earthquake of (21-05-2003) and El Centro signal records, California (18-05-1940). The El Centro signal, has been fully used.

After some analysis, the strain maxima are reached during the period 0 to 5. 10 seconds, which corresponds to the strongest accelerations.

2.3. Studied structures

The studied structures are braced by centered bars spans (in shape cross) with multiple stories (Figure 3.).

In this study, the all degrees of freedom for each node are selected, that is to say that each node is free to move horizontally, vertically and rotate around a perpendicular axis to the plane of the structure.

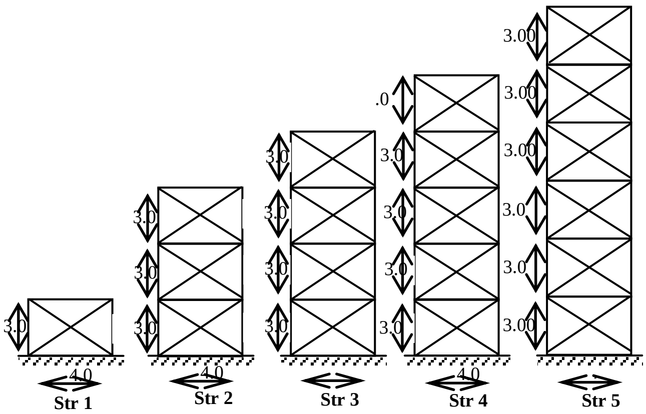


Fig. 3. Definition of the 1 to 5 studied structures.

2.4. Preliminary static design

The preliminary sizing is done by an application of vertical loads and introduction of a digressive relation.

This must be done by according a particular attention to a verification of buckling in the columns.

The following sections were selected for all the structures to perform an accurate analysis.

The Columns, beams and diagonals elements are respectively of HEA 240, IPE 240 and L80x80x8 profiles.

2.5. Hypothesis on the dissipative zones

As it is recommended in Euro code 8[4], the design of structures is made to make the tensioned diagonals plasticizing before the columns.

This choice is done for preliminary collapse considerations.

This criterion is quietly stable if we compare this q behavior factor issued from two similar structures analysis in conformity or not to this prescription (see figure 4).

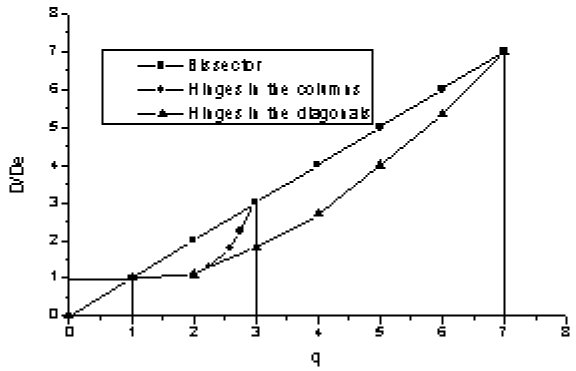


Fig. 4. Criterion of plasticization.

2.6. Ductility evaluation

The results in terms of ductility are presented, which are common in the seismic context where the μ values are:

$\mu_c=(e_{ec}+e_{pc})/e_{ec}$ (in the columns) (3)

$\mu_d=(e_{ed}+ep_d)/e_{ed}$ (for the diagonals) (4)

with e_{ec}, e_{pc}, e_{ed}, e_{pd} elastic and plastic elongations, respectively for the columns and the diagonals [3].

3. Presentation of the results

The study has concerned the following points:

- The q behavior factor values are evaluated for each structure.
- After this step, the e displacements values of the columns and diagonals are investigated.

  There are used, to evaluate the local ductility $\mu_i=e_i/e_y$ in function of the height. These calculations concern each structure. Finally, the distribution of the local ductility in function of the height H is given.

4. Determination of the local ductility μ_i at the Hi level in function of the q value

The distribution of the local required ductility for each structure, in for the columns and the diagonals are :

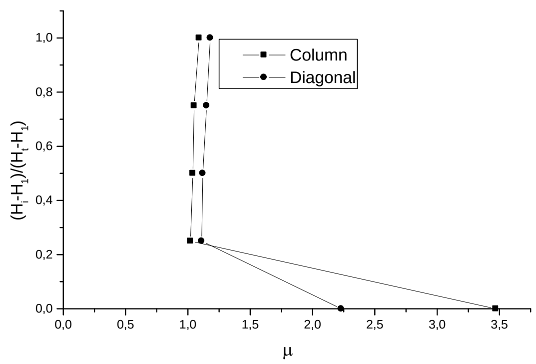
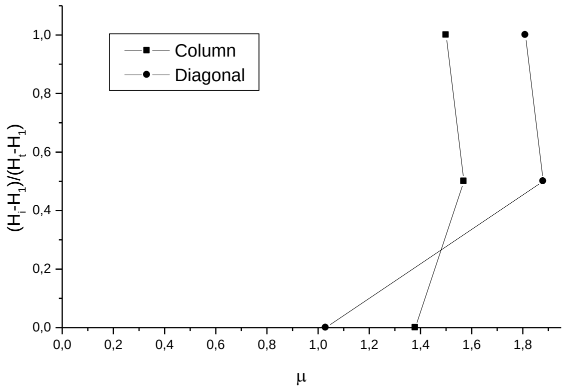
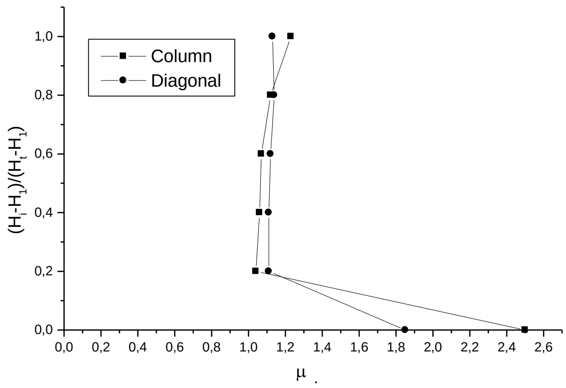


Fig. 5. Distributions of the local ductility for the 2 structure.





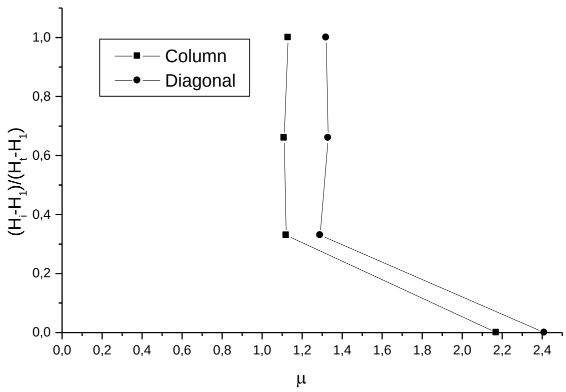


Fig. 6-8. Distributions of the local ductility for the 3 to 5 structures.

5 Proposal of a local required ductility distribution curve

The distributions of the local required ductility to be considered in the structural elements (diagonals and columns) as functions of the height are given in figures 5 to 8 for the 2nd to 5th structures [7].

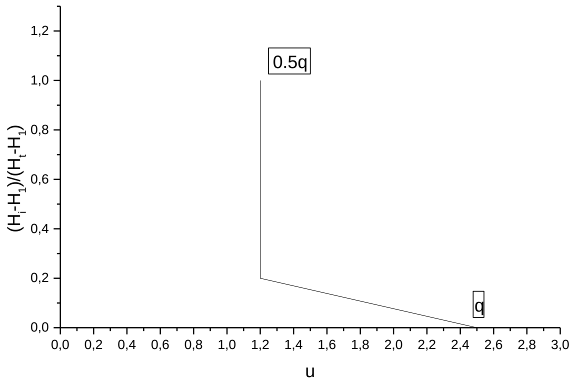


Fig. 9. Proposal of a local ductility distribution for diagonals and columns.

Conclusion

This study has consisted to perform structural analysis calculation based on a non linear dynamic program developed at Berkeley University which constitutes an interesting tool for evaluating the local ductility distribution in function of the q global behavior factor for steel constructions.

In this present work, the studied steel structures are braced by stability bents constituted by centered bars, in X shape.

This study has shown that the required local ductility value at the base of a given structure is in the same order than q for both the columns and the diagonals.

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