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Efficiency of Eurocode 8 design rules for steel and steel-concrete composite structures

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ABSTRACT

Seismic design codes allow the realization of structures able to dissipate energy through cyclic plastic deformations located in specific regions, selected to involve the largest number of structural elements. The capacity design approach requires an opportune selection of the design forces and an accurate definition of structural details in the plastic hinges. The structural elements in which plastic hinges are located are over-sized with respect to the seismic actions obtained by the use of the design spectrum, while the elements that shall remain elastic are over-sized with respect to dissipative elements. The capacity design methodology requires an accurate control of the localization of plastic hinges, strongly influenced by the actual mechanical properties of materials. In the present work, developed within the European research project OPUS, different case studies were designed according to Eurocodes and subjected to a deep structural analysis, aiming to evaluate the effective allowable ductility (behaviour factor) with respect to what imposed during the design phase and taking into account the effective mechanical behavior of materials.

1. Introduction

Seismic design codes [1–4] allow the exploitation of plastic resources realizing ductile structures able to dissipate the seismic energy stored during the earthquake through cyclic plastic deformations located in the suitably chosen “dissipative zones”. Plastic deformations shall be located within the structures in order to guarantee the involvement of the largest number of structural elements. The larger is the number of the plastic hinges, the larger is the attainable global structural ductility and the smaller is the deformation demand at local level (Fig. 1).

The design of dissipative zones (i.e. plastic hinges) in correspondence of the selected elements and the development of an efficient energetic dissipation, without significant decreases of strength and stiffness, are obtained through a proper methodology called *capacity design* and an accurate definition of structural details of elements, joints and connections. Obviously, the choice of dissipative elements depends on the structural typology: different dissipative elements/mechanisms are foreseen for Moment Resisting Frames (MRF), Concentrically Braced Frames (CBF) and Eccentrically Braced Frames (EBF).

For example, in multi-storeyMRF buildings, the condition $\sum M_{Rc} \geq 1.3 \times \sum M_{Rb}$[1] shall be checked in correspondence of each beam-to-column joint of the structure, being ΣM_{Rc} and ΣM_{Rb} the sums of the design values of the bending resistance of respectively columns and beams framing at a joint (Fig. 2), in order to allow the development of the largest number of plastic hinges and to dissipate the highest quantity of seismic energy. The above presented condition aims at avoiding the development of poor dissipative mechanisms such as soft-storey, providing columns with sufficient overstrength with respect to the beams. The 1.3 factor takes into account possible overstrength phenomena of materials used in beams with respect to the ones adopted for columns. Moreover, other specific criteria are adopted for the design of CFB and EBF structures, in which the dissipative elements are respectively the bracing system (X, inverted V and others) and link elements, opportunely designed in order to guarantee a uniform distribution of energy dissipation.

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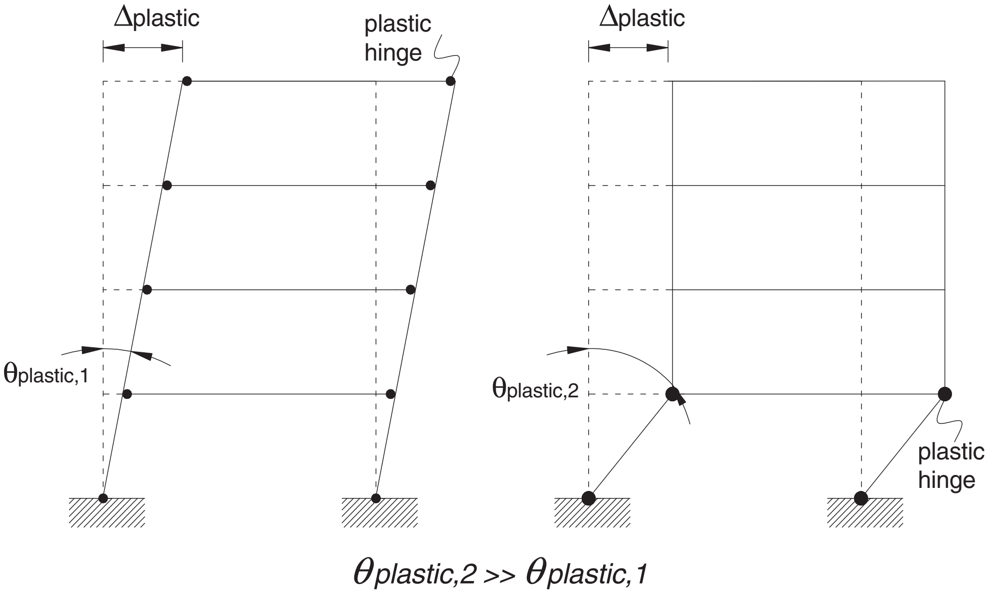

Fig. 1. Global ductility vs. local rotation demand for moment resisting frames.

In the modal analysis procedure, commonly used in the engineering practice, the possibility to exploit plastic resources is translated in lower values of design seismic action. To obtain the design spectrum, the elastic response one is divided by a reduction factor, summarizing the parameters governing the structural response, the available inelastic resources and the sensitivity to the second-order effects.

The aforementioned reduction factor is already introduced by several modern standards such as Eurocode 8 [1], in which it is identified as the *behavior factor* "*q*", or the US standards, Uniform Building Code UBC[3], NEHRP provisions [2], American Seismic Provisions for Structural Steel Buildings [4], in which the *reduction factor* "*R*" is defined. The larger the reduction factor is, the larger shall be the structural ductility and the lower can be the seismic design actions used for ultimate limit states (Life Safety – LS or Collapse Prevention – CP). In such a way it seems possible to obtain systematically structural solutions characterized by a reduced overall weight.

However, the exploitation of the plastic capacity can be limited by other criteria adopted in the design process: for example, in the assessment at serviceability limit state, the limitation of second order effects as well as the assessments of limit states associated to static load combinations shall be considered. The fulfilment of such conditions can limit the benefits of ductile design, leading to a structure whose seismic response can be quite far from the one supposed at design stage. Moreover, the elements in correspondence of dissipative zones of the structure often result over-sized with respect to the seismic actions obtained by the design spectrum, so that, in practice, only a small percentage of ductile resources can be effectively exploited. At the same time, as the capacity design rules are applied, the protected elastic elements are further over-dimensioned with respect to dissipative ones [5,6].

According to previous concepts, the seismic ductile design foresees an accurate control of plastic hinges' development that strictly depends on the distribution of plastic resistances of the structural elements: as a consequence, the *capacity design* methodology strongly depends on the actual mechanical properties of materials.

Despite what already presented, actual European production standards [7] do not provide adequate limitations for the mechanical properties of the steel products, evidencing the lack of agreement among provisions coming from different standards. As a consequence, the adoption of the aforementioned design approach is allowed by Eurocode 8 [1] for steel and composite steel-concrete structures only with the introduction of adequate safety factors and controlling that actual values of the mechanical properties do not modify the location of plastic hinges.

These conditions limit the adoption in the design practice of the steel and steel-concrete composite structures, potentially a very interesting option in seismic zone because of the intrinsic ductility and dissipative

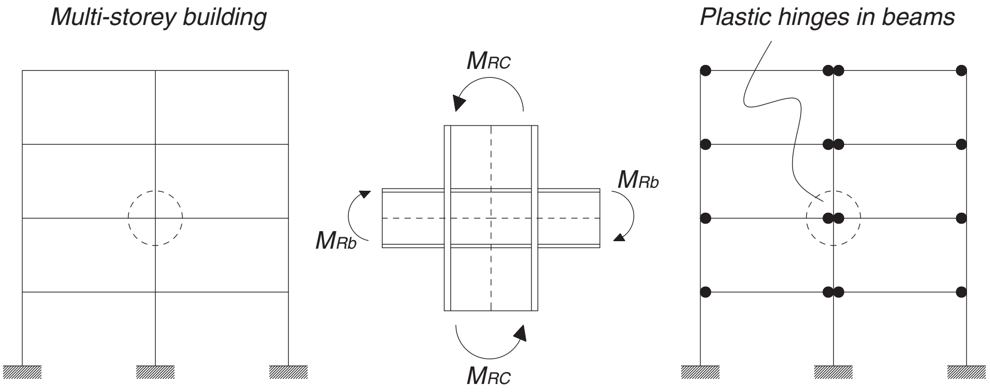

Fig. 2. Distribution of plastic hinges to allow the maximum dissipation of seismic energy in MRF structures.