Displacement based design of BRB for the seismic protection of R.C. frames

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ABSTRACT: Different rehabilitation systems have been developed to upgrade the seismic performance of existing reinforced concrete frame buildings with non-ductile detailing: in particular, buckling restrained dissipative steel braces (BRB) offer many advantages. In this paper a displacement-based procedure to design dissipative BRB for the seismic protection of masonry-infilled frames is proposed. A two-fold performance objective is considered to protect the structure against the collapse and the non-structural damage by limiting global displacements and interstorey drifts so that structural and infill integrity is granted under a given seismic event. Positioning these devices in a structure to maximize their effectiveness at minimum cost is a very important issue which is considered too. As an example, an infilled-frame building, designed according to the non-seismic Italian Code and thus only for vertical loads, is analyzed. Non linear static analyses to assess the effectiveness of the proposed rehabilitation design procedure are performed.

1 INTRODUCTION

In the last decade a very diffuse retrofitting system uses BRB that offer some unquestionable advantages: openings adaptive, irrelevant weight increase, easy installation and minimum interference to buildings use, strength increase controlled, relevant dissipation increase. BRB differs from a conventional brace in that it is capable of yielding both in tension and compression instead of buckling thus exhibiting a stable hysteretic energy dissipation with a cyclic response practically coincident with the steel constitutive law. In this work, a design procedure to determine the characteristics of dissipative steel braces \( B \) to retrofit an existing building \( S \) is discussed. The procedure is based on displacement response control and the use of well known non linear static analysis.

2 DESIGN CRITERIA

In BRB design it is useful to be aware of BRB effects on structural behavior: 1) initial stiffness increasing, 2) strength increasing, 3) modal shapes changing, 4) energy dissipation increasing. Effects 1, 2 and 3 influence the structural capacity curve while effect 4 influences the demand curve.

A reasonable force-displacement model to describe BRB behavior is the bilinear law. In design it is reasonable to set the following elements: 1) material properties that are limited to commercial products; 2) plano-altimetric configuration of braces that is determined by architectural constraints; 3) yielding displacement that depends on expected displacements of braced structure. Finally BRB design reduces to determine their stiffness \( K_b \).

In order to develop their beneficial effect, BRB should yield when the structure is still elastic. Considering an equivalent substitutive structure, the system \( S + B \) can be schematized with a trilinear capacity curve, sum of those ones of the two systems \( S \) and \( B \).

Placement in plant and elevation as well as installation modality is a relevant matter in BRB design. Geometric restraints usually influences braces positioning which should be analyzed case by case even if some general considerations can be drawn. Braces positioning influences both structural deformation, since it modifies modal shapes, and damping devices effectiveness. The addition of braces should reduce or eliminate translation-rotation coupling effects, induce constant or linearly increasing interstory drifts, maximize damping, and minimize costs. Different criteria to optimize BRB stiffness distribution are given in scientific literature: brace stiffness proportional to interstory drifts is assumed here as a simple criteria to make braced frame deformation linear.

3 DESIGN PROCEDURE

The proposed design procedure for BRB generalizes Kim & Choi's approach (2004). In the latter the required energy dissipation is provided by the hysteretic deformations of the BRB only while the structure is assumed to remain elastic. This assumption makes the method not always applicable. Generally, in case of strong seismic events, the structure could undergo plastic deformations that should be take into...
account in BRB design procedure. The procedure is iterative because the addition of BRB modifies the structural response and in particular the capacity curve that has to be updated as long as BRB characteristics are being defined. The proposed design procedure is based on the well known Capacity Spectrum Method (ATC40 1996) where the total effective damping of a braced structure is expressed in terms of equivalent viscous damping as a linear combination of the equivalent damping of the structure only, the equivalent damping of BRB and the inherent damping. In a displacement based design perspective, the performance objective is selected at first as the target displacement to meet a selected limit state at a given seismic action. The required total effective damping to make the maximum displacement less than the target one is then determined and the BRB additional damping estimated as the difference between the total damping and the hysteretic damping of the structure only. BRB characteristics are finally determined to guarantee the required additional damping. Since it usually happens that the performance point of the braced structure is different from the target one, iterations are needed until convergence. The main steps of the procedure are described in details in Albanesi et al. (2007).

4 CASE STUDY

The proposed design procedure is applied for the retrofitting of a 2D r.c. regular frame structure with 3 bays (3 m long) and 5 stories (5 m high). Beams and columns have $300 \times 500 \text{ mm}^2$ and $400 \times 400 \text{ mm}^2$ rectangular sections respectively. The structure is designed to resist vertical loads only and is subject to a strong earthquake defined by a soil B EC8 elastic response spectrum with $\text{pga} = 0.40 \text{ g}$.

Pushover analyses of the existing and braced structure are performed by applying a load profile proportional to the first mode. The performance point of the existing structure in terms of base shear and top displacement is $V_b = 984 \text{ kN}$ and $D_t = 76 \text{ mm}$ with a shear type deformation and damage spreading mainly at lower columns ends (Figure 1(a)). The performance objective is to reduce maximum displacements so as to avoid structural damage. Pushover analysis of the existing frame shows the first damage occurs at the end of a beam at the first story when $D_t = 50 \text{ mm}$. BRB addition modifies the capacity curve of the existing frame (Figure 2(a)) and thus its performance point. The iterative procedure converges quickly to the target displacement (Figure 2(b)). The performance point of the frame with BRB designed at step 6 is $V_b = 1336 \text{ kN}$ and $D_t = 48 \text{ mm}$. As shown in Figure 1(b) the braced structure still has a shear type deformation but no damage results.

5 CONCLUSIONS

A displacement based procedure to design BRB for the seismic rehabilitation of existing r.c. frames is presented. The procedure is applied to a case study 2D r.c. frame and is proved to be effective and promising even if further analyses are needed for a complete validation.

REFERENCES

