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Design concept for multistage buckling-restrained braces

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Abstract— **A new multistage buckling-restrained brace (MS-BRB) is introduced, consisting of two short LYP225 low yield point cores (LYP) and a longer SA440B high yield point (HYP) core. The cores are axially decoupled, enabling the LYP cores to yield earlier while the HYP core remains elastic, providing a restoring force. This paper presents a numerical archetype frame study, comparing the peak floor acceleration, interstory drift, residual drift and core strain under three different seismic intensities. It is demonstrated that an MS-BRB with equal initial stiffness and gross yield strength as a conventional BRB will produce slightly lower peak interstory drifts, suggesting that the same basic design procedure as used for conventional BRBs is appropriate.**

I. Introduction

Buckling-restrained braces (BRB) are often used in conjunction with a simply supported frame, but the low post-yield stiffness of this system tends to produce large residual drifts, which may control the post-earthquake repair/replace decision. To address this issue, a new multistage buckling-restrained brace (MS-BRB) is introduced (FIGURE 1).

The proposed MS-BRB consists of two short LY225 low yield point (LYP) cores, and a long SA440B high yield point (HYP) core. The LYP cores yield at small drifts, dissipating energy, while the HYP core provides an elastic restoring force. At large drifts, where non-structural damage supersedes the rational for controlling residual drifts, both cores yield, acting similar to a conventional BRB.

This paper presents key results from an archetype frame study [1] investigating the residual drift, peak interstory drift, peak floor acceleration and core strain of MS-BRBs. A simple and rational design procedure is proposed.

II. Archetype Frame

A. Frame Design

Three and six story archetype frames (FIGURE 2) were adapted from [2]. These feature two perimeter braced bays on each side, and simply supported gravity framing. All columns are modelled as elastic continuous columns with pinned bases, except for those at BRB gussets, which have fixed bases with fibre hinges. The interior gravity columns are represented by a stiff leaning column. Beam and column sizes are described in FIGURE 2. The 4x6 bay three story structure has 4m floor heights and 9m bays, while the 5x5 bay six story structure features a 5.5m ground story and 9m bays. The seismic mass (DL+0.3LL) includes 4.7kPa on typical stories, and 4.2kPa at the roof.

B. BRB Design

The BRBs were designed using the equivalent static force procedure of ASCE 7-16 [3], assuming a redundancy factor of 1.0, an importance factor of 1.25 and force reduction "R factor" of 8. The benchmark BRB adopted an elastic-to-yield area ratio of $A_e / A_y = 3.0$, a yield-to-workpoint length ratio of $L_y / L_{wp} = 0.7$ and yield strength of $f_y = 295$MPa (SN400B). Refer to [4] for a discussion of how to calculate the stiffness.

The MS-BRBs were then designed with the same initial stiffness and gross yield strength. This was achieved using cores with $f_{y,L} = 225$MPa (LY225), $f_{y,H} = 490$MPa (SA440B), $A_e / (A_{y,L} + A_{y,H}) = 2.5$, $A_{y,H} / A_{y,L} = 0.5$, $L_{y,L} / L_{wp} = 0.47$ and $L_{y,H} / L_{wp} = 0.85$, where the subscripts L and H represent the LYP and HYP cores, respectively.

C. Ground motions

Each 2D frame was subjected to the suites of 10 scaled ground motions developed by SAC study to represent the Los Angeles 50% (SLE), 10% (DBE) and 2% (MCE) in 50 year hazards. The original amplitude scaling factors were applied, targeting an elastic design spectrum defined by short and 1sec spectral accelerations of $S_{DS} = 1.4$g and $S_{DS} = 0.91$g.

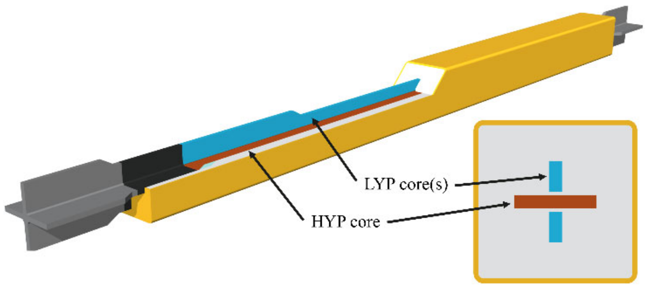

FIGURE 1 Multistage buckling-restrained brace composition

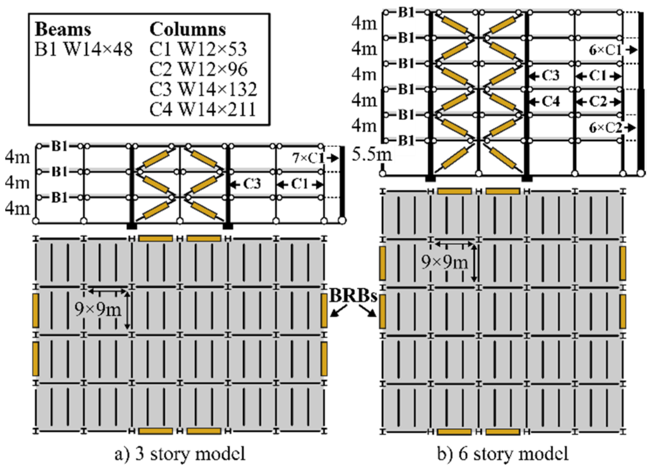

FIGURE 2 Archetype frame models

III. Numerical Results

A. LYP and HYP Core Hysteresis

A representative design level hysteresis is shown in FIGURE 3, comparing the core axial stresses and strains to the benchmark BRBF model. The MS-BRB HYP core develops greater stresses and undergoes limited yielding, while the LYP cores act as the primary energy dissipation component. The MS-BRB hysteresis is more symmetric and reduces the residual drift by about 50%.

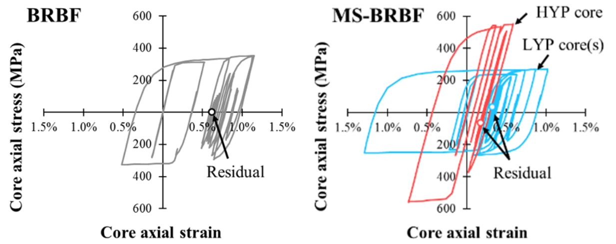

FIGURE 3 Typical hysteresis (3stry, LA13, ground story)

B. Nonlinear Response History Analysis Results

The mean (M) and mean + 1 standard (M+SD) deviation responses at each ground motion intensity are shown in FIGURE 4. Despite having the same initial stiffness and gross yield strength, the MS-BRBF models experience slightly lower peak floor accelerations and peak interstory drifts. A major reduction in residual drift is observed at the SLE hazard level, with a significant, but diminishing reduction at DBE and MCE. This results in a significantly improved performance envelop, controlling residual drifts until the peak transient drifts reach about 2%. At such large transient drifts the non-structural damage is likely to be of greater importance than residual drifts in deciding whether to repair or replace a building.

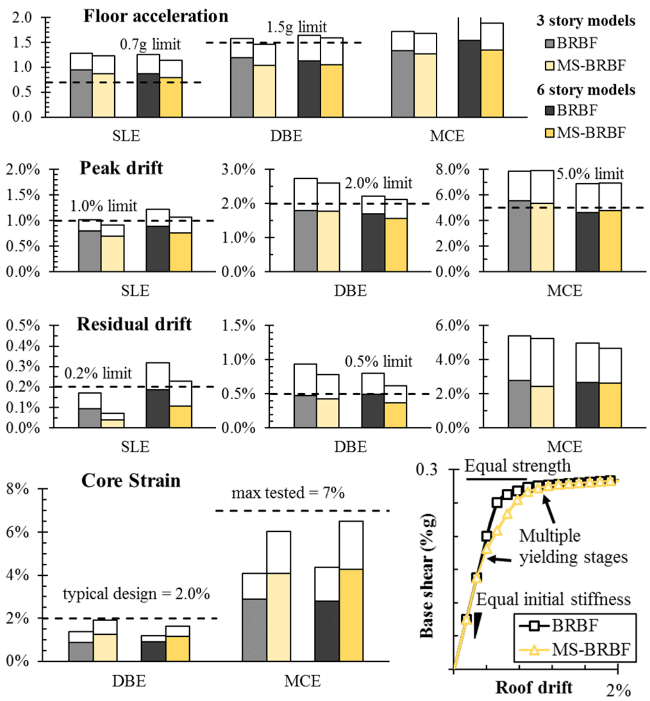

FIGURE 4 Mean and M+SD NLRHA responses, and pushover

The trade-off for this performance gain is an increase in axial strains in the LYP core. However, this increase is less than the reduction in the yield length, as the peak drifts are also reduced. Also, the DBE strains are well within typical practice, while the MCE M+SD demands are within the tested range of some BRB suppliers.

IV. Proposed Design Procedure

The ASCE 7-16 [3] BRBF design provisions are based on the ductility reduction factor approach, where the elastic design spectrum is reduced by a system ductility force reduction "R factor." Inelastic drifts are then estimated as about 2/3 of those predicted by the equal displacement rule, quantified as the "C_d factor". The R and Cd factors are assigned for specific systems based on the MCE collapse probability and expected ductility demand. Well-designed BRBFs are controlled by PDelta-induced collapse, rather than fatigue or fracture of the core.

As MS-BRBs produce slightly lower peak interstory drifts at the DBE and MCE levels, it is suggested to adopt R = 8, the same as conventional BRBFs. This is justified as BRBs are tested to MCE displacements, and only the LYP experiences greater core axial strains.

V. Concluding Remarks

The proposed multistage buckling-restrained brace reduces residual drifts without increasing the peak floor acceleration or required strength. This device offers an attractive solution for engineers designing simply supported frames where residual drifts are expected to control the post-earthquake repair/replace decision.

Acknowledgment

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