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Effects of rigid zone determination in beam-column connections on the inelastic behaviour of BRB frames

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Abstract— **Past studies show that gusset plates, which connect braces to beams and columns in braced frame structures, affect the inelastic behaviour of the structures. Meanwhile, the gusset plates are often not considered in the numerical models. In an attempt to solve that issue, this study evaluates the rigid zone determination effects on the inelastic behaviour of the beam-column connections by considering the presence of gusset plates. Structural steel frames with concentric bracing systems using buckling-restrained braces (BRB) were modeled in this study considering different rigid zone modelling methods (Model A and Model B) and with beam stubs welded to the columns and simple beam splice connections (Model C). Static pushover analyses were performed on all models. Inelastic behaviour of each frame was quantified in terms of base shear versus roof story drift, ductility ratio, and the distribution of the plastic hinges.**

I. Introduction

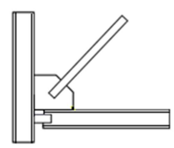
Concentric braced frames are considered as excellent options for seismic-resisting steel structural system because they provide good lateral strength, stiffness, and ductility to resist seismic loads acting on the structure. However, the energy dissipation might be restricted by the possibility of brace buckling. Thus, buckling-restrained braces (BRBs) were developed to replace conventional braces in order to eliminate this issue [1]. Similar with other braces, BRBs are connected to the primary members of the frame using gusset plates.

In current practices, although the beam and column members are modelled as deformable components, the connection regions are generally modelled as rigid zones and the inelastic mechanisms in the joint are not well represented, especially where gusset plates exists. Different considerations of rigid zones will result in different values of story drift and may lead to different predictions of the seismic performance of the structures [2].

Lateral loads acting on braced frames will cause the structure to deform which induces relative rotation between the beams and the columns. The relative rotation gives additional force thus additional in-plane stress occurs in the gusset plate.

Commonly, braces are modeled to have pinned ends which represent their connections to gusset plates. In some cases, the beam-to-column connections are designed as simple connections in order to shift the lateral load resisting mechanisms to the braces axial forces. The gusset plates provide additional stiffness to the beam-column joint and may extend the rigid zones toward the edges of the gusset plates.

This study observes the effects of these two methods of rigid zone analytical modelling on the inelastic behaviour of BRB frame structures with simply connected beams between columns as shown in Fig. 1. Moreover, in order to allow beams' end rotation without neglecting the presence of gusset plates, simple bolted beam splices as shown in Fig. 2 was also evaluated. The inelastic behaviour of all models were studied by conducting static pushover analyses.



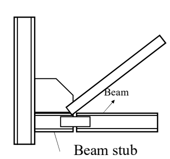


Fig. 1 Connection with simply connected beams (left)
Fig. 2 Connection with beam stubs and splices (right)

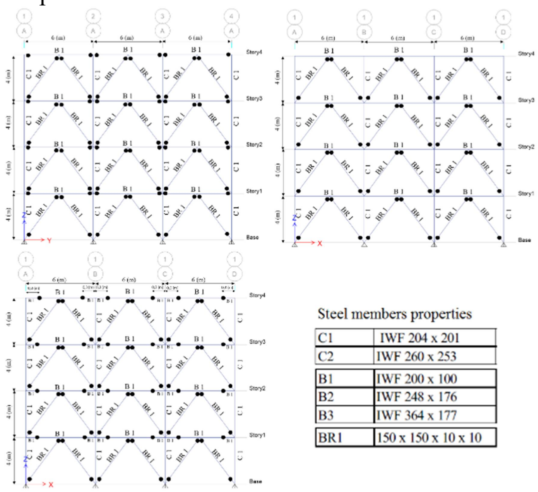
II. Modeling and Analysis

A. Numerical Models

The structural models represent a four-story office building frames with three spans of 6 meter length beams in each direction. BRBs are installed on all exterior frames as shown in Fig. 3. Wide-flange steel sections are used for beams and columns, while BRB sections are used for the braces. Gusset plates are designed conservatively relative to the brace resistance [3]. Loads and load combinations are applied on the models according to ASCE 7 [4]. Capacity design check was conducted to check the adequacy of structural members based on the loading combinations mentioned above [5],[6].

There are three configurations of structural models analysed in this study, which have identical dimensions and members' sections. Variations are made on the modelling of the beam-column joints where the BRBs are connected.

The rigid zone models in each configurations are shown in Fig. 4. Beams in Model A and B are simply connected to the columns. The difference between Model A and Model B is in the rigid zone consideration. In Model A the rigid zones extend to half-width of the columns, assuming there is no gusset plates contribution to the joint rigidity. In this case the braces and the beams have moment-released ends. In Model B, the gusset plates are assumed to significantly increase the joint rigidity. Therefore, the rigid zones extend to the edge of the gusset plates. In this case, only braces have moment-released end, while the beam ends are restrained from rotation by the presence of the gusset plates. Model Cmodifies Model B with simple bolted beam splices, which are modelled as rotational hinges. The beam stub length was taken to be the same as the width of the gusset plates.



Steel members properties

C1	IWF 204 x 201
C2	IWF 260 x 253
B1	IWF 200 x 100
B2	IWF 248 x 176
B3	IWF 364 x 177
BR1	150 x 150 x 10 x 10

Fig. 3 Modeling of exterior BRB frames for Model A, B, and C and the steel members size

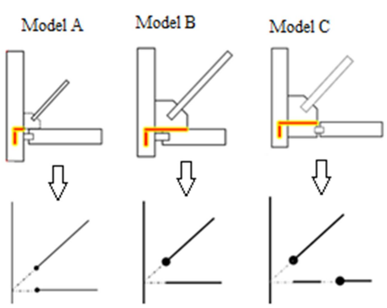


Fig. 4 Rigid zone (top) and beam-column connection model (bottom) for Model A, B, and C

B. Non-linear static/ Pushover analysis

Static pushover analyses for all models were conducted by applying lateral loads on each story which increase monotonically. The roof displacement was taken as a parameter of interest with the other parameters such as base shear, and story shear recorded for each step of analysis. The analyses were terminated when the resulted nonlinear mechanisms create instability or at least one of the plastic hinges reached its ultimate deformation [7].

III. Behaviour

A. Base shear vs Roof story displacement

The global inelastic behaviour in terms of base shear versus roof displacement was plotted as shown in Fig. 5. It was found that the base shear for Model B was higher than the other models for the same roof displacement.

B. Ductility

The ductility ratio is calculated as the ratio of the ultimate deformation to the deformation when plasticity started to occur. The plastic deformation in this study was taken at step 2 of the pushover analysis where permanent deformation was identified. Model C is found to have the highest ductility ratio at 16.539 as compared to Model A at 15.844 and Model B at 15.716.

C. Distribution of plastic hinges

At the end of the pushover analysis, Model B experienced plastic hinges formed at beams of Story 1, while the other models only experienced plastic hinges formed on BRB elements.

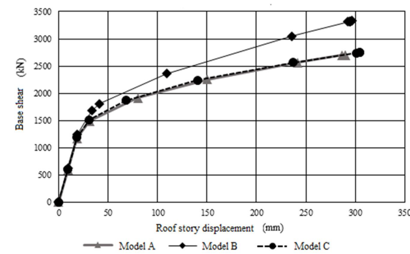


Fig. 5 Base shear vs roof story displacement for all models

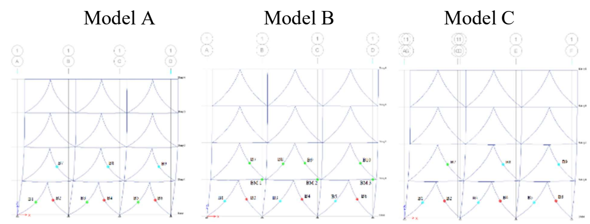


Fig. 6 Plastic hinges formation for all models

IV. Conclusion

From the analyses, it was found that different rigid zone considerations affect the nonlinear behaviour of BRB frames. In Model A, where the contribution of gusset plates to the joint rigidity is neglected, the base shear might be underestimated compared to Model B. It makes the rigid zone modelling method less conservative for design. Model A also neglect that plastic hinges may occur in the beams, as demonstrated in Model B.

Alternatively, splicing the beams, as represented in Model C, can perform similarly to the expected inelastic behaviour of BRB frames, where the energy dissipation occurs through axial yielding of the braces.

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