DUAL SYSTEM DESIGN OF STEEL FRAMES INCORPORATING BUCKLING-RESTRAINED BRACES

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ABSTRACT:
Buckling-restrained braced frames have been shown to exhibit stable energy dissipation behavior under cyclic loading. However, after the buckling-restrained braces yield, the system have a trend of very large story drift and drift concentration. This paper presents an analysis on the seismic behavior of dual system incorporating buckling-restrained braces. Moment resistant frame are considered as backup frame in this paper. The study focuses on the stiffness requirements of backup frame on seismic responses of two different models (4-, and 12-stories) located in general site of Japan and subjected to three sets ground motions with two different seismic levels. Structural behavior is evaluated from story drift angles obtained through nonlinear time history analyses. Performance of the models shows that in order to minimize the story drift angles of the dual system, less then 10% of backup frame stiffness ratio is needed to ensure uniformity of story drifts.

KEYWORDS:
Dual System, Steel Frame, Buckling-restrained Brace, Seismic Design, Stiffness Ratio, Story Drift Angle

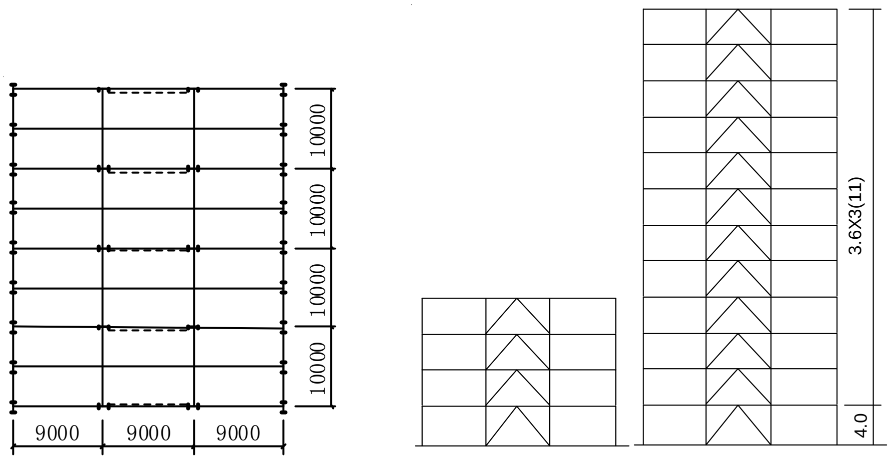
INTRODUCTION

Lateral displacements on structural buildings have been of great concerns for engineers. In order to minimize the effect of earthquake and wind forces, special diagonal members, called braces, have been used successfully. However, these members when subjected to compressive forces exhibit buckling deformation and show unsymmetrical hysteretic behavior in tension and compression. If buckling of a steel brace is restrained and the same strength is ensured both in tension and compression, the energy absorption of the brace will be markedly increased and the hysteretic property will be simplified. These requirements motivate researchers and engineers to develop a new type of brace, the buckling-restrained brace (BRB). The concept of the BRB is simple: restraining the buckling of the brace so that the brace exhibits the same behavior in both tension and compression.

Although BRBF system exhibits very good and stable hysteretic behavior in both tension and compression, it may undertake very large story drift after the BRBs yield. Sabelli (2003) has reported that the seismic performance of BRBFs is comparable if not better than their conventionally braced counterpart. Uang et al. (2003) studied a dual system incorporating BRBs. Their results from nonlinear time-history analyses demonstrated significant improvement in maximum and residual drifts using the dual system. Inoue et al. (1996, 1998) analyzed behavior of steel moment frames combined with hysteretic dampers and examined the strength required for the main frame not to go beyond yielding under earthquake loading.

In this paper, backup frame is used to supply additional stiffness to the system after BRBs yield. Backup frames are considered as some rigid or semirigid connections in spite of the all pinned BRBFs. With the property of exhibiting very large deformation capacity in the elastic range, backup frame can serve as a restoring force to bring the drift back to its center under earthquakes. This paper focuses on the stiffness demands of the backup frame in BRBFs to minimize the story drift angles. Two BRBFs have been chosen as typical models for the study. Only 2D representations of the models are utilized in this study.

SYSTEM STUDIED



(a) Plan view (b) Lateral view

Fig.1 Plan and lateral views of the models

Profile of the Models

The building models here are two chevrons-braced frames, a 4-story and a 12-story, with buckling-restrained braces. Plan and lateral views of the models are shown in Fig. 1. The story height at the first floor is 4.0 m and 3.6m for the rest floors. The buildings are assumed to be in a normal position, Japan. JBL (Japan Building Standard Law) was used in the design. A total load of 7.5kN/m2 was used for all the floors. All the connections in the buildings are pinned.

Seismic Load

According to JBL, seismic shear Q_i in the i^{th} story is $Qi = Z \cdot Rt \cdot Ai \cdot Co \cdot W$, where Z is the seismic hazard zoning coefficient, Rt is the design spectral coefficient which is determined by the type of soil profile and fundamental natural period of the buildings, Ai is the lateral shear distribution factor which is determined by the fundamental natural period and the weight distribution of the buildings, Co is the standard shear coefficient which is given 0.2 in this study, W is the weight of the building above the i-th story. The fundamental natural periods of the buildings are calculated from the formula T=0.03*H for steel structures, where H is the height of the buildings.

All the shears are firstly designed to be carried by buckling-restrained braces only. Beams and columns are considered as rigid. The stiffness of the entire system of the i^{th} story is determined so that the ith story drift angle will be 1/200 under the specific earthquake design force with corresponding base shear coefficient equals 0.2. In order to satisfy stiffness requirement, which is 1/200 story drift under Level 1 defined as maximum 0.25m/s for velocity, cross section areas of the BRBs are determined. However, the braces are expected to yield under Level 2, with maximum 0.5m/s for velocity, ultimate lateral shear strength was calculated with the structural coefficient Ds equals 0.25. In that way, yielding strength of braces was increased to an artificial value. Thus, cross section areas and yield strength are given for the bare braced frames. For the purpose of compare seismic behavior of bare braced frame to that of braced frame with backup frame, total stiffness of the models remains constant.

Analytical Model

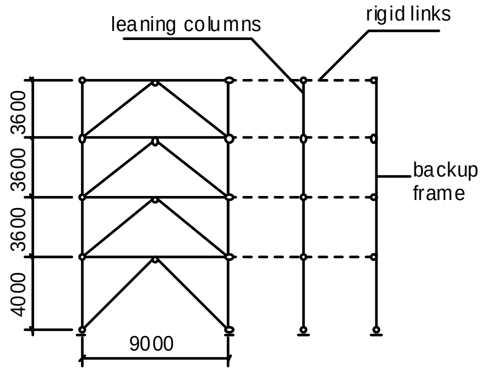


Fig.2 Analytical model of 4-story frame

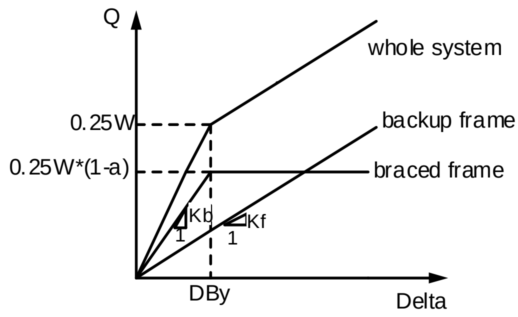


Fig.3 Bilinear model of the dual system

As shown in Fig. 2, analytical model includes three parts: brace-column-beam part in which beams and columns are considered as rigid, leaning columns which are used to carry gravity, and backup frame. For the study of totally pinned frame, backup frame does not exist. The backup frame is used to compensate for the P-Δ effects and provide the system with additional lateral stiffness. Only bending deformation of the backup frame was taken into account. Stiffness ratio between backup frame and the whole system was used as the most important parameter in this paper. In order to keep the total stiffness to be constant, braced frame stiffness decreases while the backup frame stiffness increases in the same value. For example, if backup frame has a stiffness ratio of 10%, the rest 90% stiffness ratio was carried by braced frame. Bilinear hysteretic model was used in the analyses in which the backup frame was considered as elastic. Fig. 3 shows the bilinear model used in the analyses.

Input Ground motions

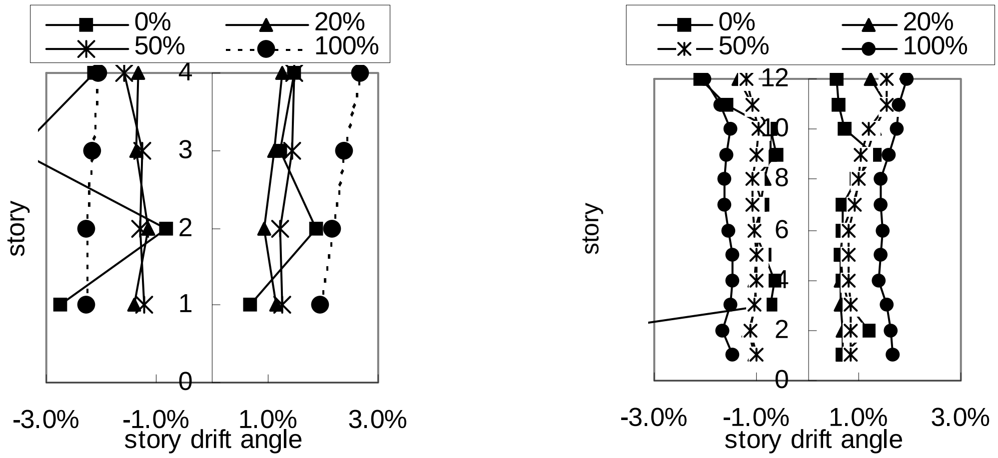
Three earthquake records, 1940 El-Centro, 1968 Hachinohe and 1952 Taft in two horizontal directions are scaled to different levels defined as Levels 1 and 2 with PGVs corresponding to 0.25, 0.5 m/s respectively. Take the Level 2 as an example, in which PGV was specified as 0.5m/s, one of the horizontal PGV components in the three sets were amplified to 0.5m/s and the other orthogonal components in the sets were amplified by keeping the original PGA ratios in both orthogonal directions. The PGVs and PGAs of the three sets in Level 2 are shown in Table 1.

TABLE 1 PGVS AND PGAS IN LEVEL 2 INPUT GROUND MOTIONS

Earthquakes	EW-Elce	NS-Elce	EW-Hach	NS-Hach	EW-Taft	NS-Taft	Median
PGV (m/s)	0.55	0.50	0.53	0.50	0.50	0.44	0.50
PGA (m/s2)	3.14	5.11	2.68	3.30	4.97	4.71	3.81

EATHQUAKE REPONSES OF DUAL SYSTEMS INCORPORATING BRBS

Fig. 4 shows the maximum story drift angles in each story under ground motion NS-Elcetro with PGV 0.50m/s. From the figure we can see that for a bare pinned frame (0% case), after yielding of some braces, the story drifts concentrate on some certain stories, such as the third story for 4-story model. Giving some additional elastic backup frame stiffness to compensate for P-Δ effects, story drift concentration decrease significantly and maximum story drift becomes more uniform. The more the backup frame stiffness, the more uniform of story drift distribution. For the case of 100% backup frame stiffness ratio, which means only elastic backup frame without BRBs, the story drift angle distribution is the most uniform among all the four cases shown in the figure. However, in terms of maximum story drift angles, 100% case does not show the smallest SDAs among the four cases. In the middle of the two extreme cases, which are bare BRB frame (0% case) and elastic backup frame (100% case), the two cases with ratio 20% and 50% show smaller SDAs.

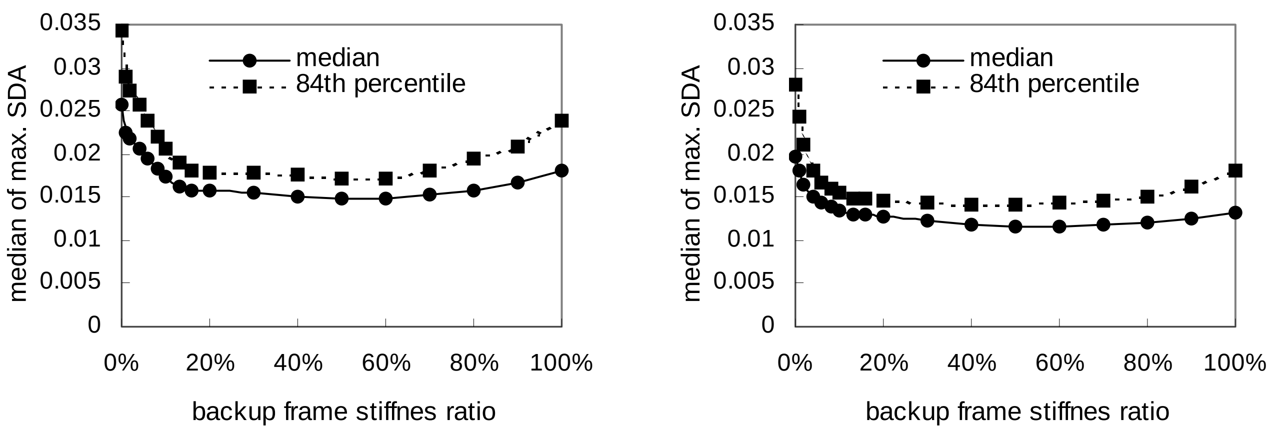


(a) 4-story model (b) 12-story model

Fig. 4 Maximum story drift angle distribution under NS-Elcetro with PGV=0.5m/s

For the purpose of checking the maximum SDAs variation with different backup frame stiffness ratio under the six ground motions, the absolute maximum story drift angles of each ratio under six ground motions were picked out to calculate the median and the 84th percentile of the response distribution. Fig.5 shows the median and 84th percentile of absolute maximum story drift angles of 4- and 12-story models. For bare pinned frames, both median and 84th percentile of maximum story drift angles are much larger than those of the other cases. When the backup frame has a stiffness (about 2%) just to compensate for P-Δ effects, median and 84th percentile decrease abruptly from 0.026 and 0.034 to 0.022 and 0.027 respectively for 4-story model. Then with few percents increase of backup frame stiffness, it benefits the story drift angle of the models a lot. However, although the increase of backup

frame ratio still decrease median and 84th percentile of the models until some ratio points, its effects are not so significant compared with that of few percents cases. The results show that bare pinned frames are not good in terms of maximum story drift angles. Even just provide few percent of backup frame stiffness; such as less then



(a) 4-story model; (b) 12-story model

Fig. 5 Median and 84th percentile of maximum story drift angle

10%, it significantly decreases maximum story drift angles. Before this point, although the median decreases with the stiffness ratio increases, a few percent of the backup frame stiffness ratio decreases the median SDA significantly. If the backup frame stiffness ratio exceeds the point, the median SDA remains almost constant and then increases for large stiffness ratios.

CONCLUSIONS

From the above analytical results, the following conclusions can be obtained:

1. Bare braced frames have the trends of large drift and drift concentration in some stories; however, very few percents of backup frame stiffness can decrease the drift concentration significantly.
2. Even few percents of backup frame stiffness ratios can decrease the maximum story drift of the system abruptly, as well as drift concentration. Less then 10% of backup frame stiffness ratio benefits the system cost-effectively.

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