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SEISMIC RESPONSE CONTROL OF SUPER HIGH-RISE RC BUILDINGS UTILIZING BUCKLING RESTRAINED BRACES

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In this paper, the seismic response control of BRBs in super high-rise RC buildings subjected to earthquake ground motions is investigated by nonlinear time history analysis. The analysis model is a 36 stories super high-rise RC building. A bare frame structure is used as a reference model. The parameter of the analysis was the configuration of the BRBs. Two kinds of seismic response controlled building models were examined. In one model, the RC frame was braced by BRBs in each story (each model) and in the other one, each BRB spanned over two stories (over model). The RC beams in the braced span of the over model were abandoned. By comparing the maximum story drift ratio of the reference model with the braced ones, the seismic response control was confirmed for both the each model and the over model. In addition, the over model exhibited almost the same seismic response control as compared to the each model, although the number of BRBs was significantly reduced and the RC beams in the braced span were abandoned.

Keywords: Newly-built RC moment-resisting frames, Nonlinear time history analysis, Three-dimensional frame model, Story drift ratio, Plasticity ratio, Energy dissipation.

1 INTRODUCTION

Buckling restrained braces (BRBs) have been widely used as energy-dissipating devices to retrofit existing reinforced concrete (RC) frames in Japan. Some effort has also been devoted to applications of BRBs in newly-built RC moment-resisting frames, where efficient and reliable connections between the BRBs and the concrete components become an important issue. Insufficient connection may deform excessively during major earthquakes so as to impair the efficiency of BRBs to dissipate earthquake energy. Poorly-detailed connections may also subject the surrounding concrete components to complicated tensile and shear forces and degrade their seismic performance. Accordingly, the authors suggested a continuously buckling restrained braced frame (CBRBF) system in which the BRBs are arranged in the form of a Warren truss (Qu *et al.* 2013). The BRBs in the adjacent stories share the same gusset plate, which is fastened to the concrete beam-to-column joint by prestressing bolts and is kept by a pair of RC corbels that project from the column surface. In such a manner, the prestressing bolts are mainly responsible to resist the horizontal force while the RC corbels the vertical one. The corresponding BRB connection details in the CBRBF system have been confirmed effective through cyclic loading test and FE analysis of RC subassemblies with BRBs. However, the subassemblage tests and corresponding analysis did not provide insight into the dynamic behavior of the whole building. In this paper, the passive control effect of BRBs in super high-rise RC buildings subjected to earthquake ground motions is investigated by nonlinear time history analysis.

2 NUMERICAL MODEL

2.1 Example Building

Example building is a 36-story, 5-span RC plane frame structure (Figures 1 and 2). Cross sectional properties of the reinforced concrete components of the structure is listed in Table 1. A bare frame structure is used as a reference model.

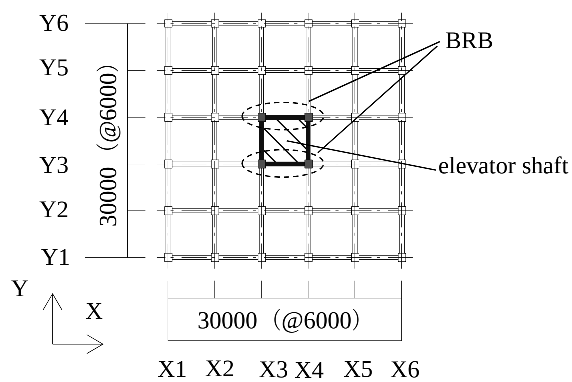

Figure 1. Frame plan.

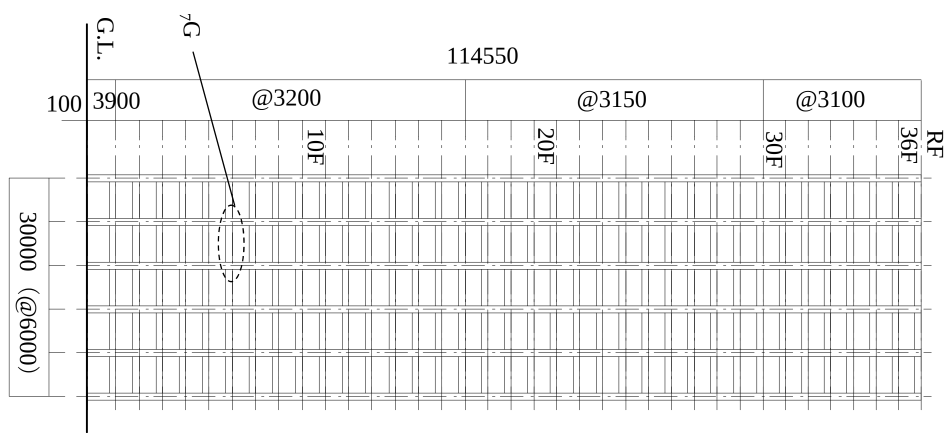

Figure 2. Frame elevation.

Table 1. Cross sectional properties of the reinforced concrete components.

Beam				Column			
Story	b[mm]	D[mm]	p_t[%]	Story	b[mm]	D[mm]	p_g[%]
31～R	550	800	0.88	33～36	800	800	1.61
25～30	550	850	1.02	30～32	800	800	1.99
22～24	550	850	1.23	21～29	800	800	2.39
18～21	550	850	1.38	11～20	900	900	1.89
1～17	550	900	1.38	1～10	1000	1000	1.82

(b: breadth, D:depth, p_t: ratio of tension reinforcement, p_g: ratio of reinforcement)

2.2 Analysis Model

The analysis is conducted on MIDAS Gen Ver. 830 (MIDAS Information Technology Co., LTD., 2012). The analysis model was three dimensional frame model with the first story base column fixed. The restoring force characteristics of the column and beam members follow the modified Takeda model. Tangent stiffness-proportional damping model is adopted and the damping ratio h = 0.03. BRB is modeled by truss elements with bilinear restoring force characteristics.

2.3 Parameters and Structural Plan

The analysis parameter is shown in Table 2. The parameter of the analysis was the configuration of the BRBs. Two kinds of passive controlled building models were examined. In one model, the RC frame was braced by a diagonal BRB in each story (‘each model’) (Figure 3(a)) and in the other one, each BRB spans over two stories (‘over model’) (Figure 3(b)). Described below in the plan of the over model. In the BRB connection proposed by the authors the beams around central core can be changed to minor steel beams. BRBs of the same yield strength can be installed in the upper and lower stories. The beams become zero force members of the truss and carry only the vertical load. In this analysis, the beam around the central core was modeled by H-section steel with pins at both ends. The deformation of individual BRBs in the ‘over model’ is approximately twice that of the BRBs in the ‘each model’ because they span over two stories. Further by modeling the beams around the central core as minor steel members, the deformation of the BRB can be increased. In order to accommodate the varying axial force of column due to installation of the BRBs, around the core was constituted by strong RC frame (about 1.2 times the cross-sectional area and reinforcement of the column). The BRB yield strength in each floor is shown in Figure 3. In both models, the connection of the RC frame and BRB was assumed to be rigid.

2.4 Input Ground Motion

A total of six ground motion waveforms were normalized to PGV = 50, and 75 cm/s as the input ground motions for the analysis. They are three standard records (EL Centro

NS, Taft EW, and Hachinohe NS) and the three simulated ground motion (Hachinohe, Kobe, and Random) which are stipulated by the Building Standard Law.

Table 2. Analysis parameters.

Model	reference	each	over
BRB	No	each story	over two stories
Slab of core part	Yes	No	
Column around core part	normal frame		strong frame
Beam around core part	normal frame		steel beam
natural period [s]	2.92	2.77	2.77

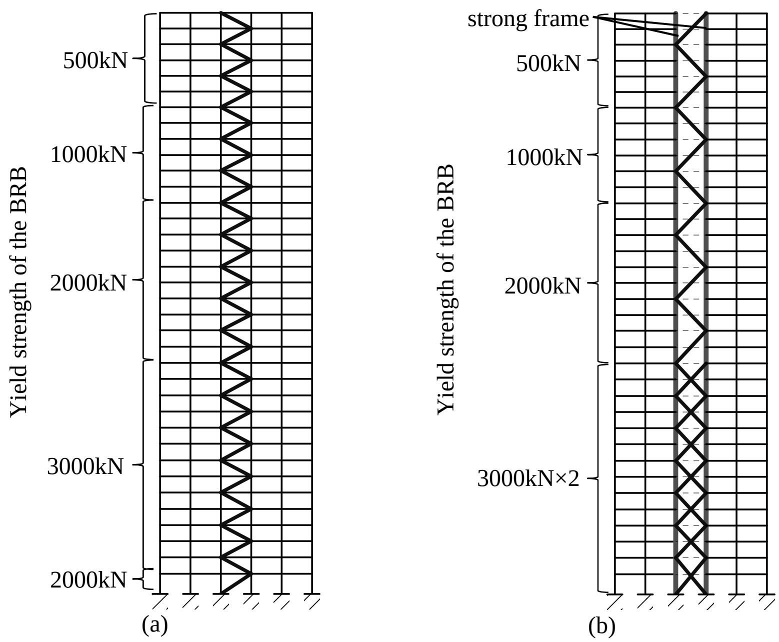

Figure 3. Analysis model: (a) each model; (b) over model.

3 ANALYSIS RESULTSAND DISCUSSIONS

3.1 Maximum Response Story Drift Ratio

The maximum response story drift ratio distributions in all models obtained from the analysis are shown in Figure 4. By comparing the maximum story drift ratio of the reference model with the braced ones, the effect of passive control was confirmed for both the 'each model' and the 'over model'. In addition, the 'over model' exhibited almost the same passive control effect as compared to the 'each model', although the number of BRBs was significantly reduced and the RC beams in the braced span were abandoned.

3.2 Behavior of Beam

The plasticity ratio of the beam ($_7$G in Figure 2), μ_r, in all models to the simulated Hachinohe record (PGV = 75 cm/s) is shown in Table 3. It can be see that the beam rebar yielded in the bare frame and 'each model'. According to the results of μ_r, deformation could be decreased by 42% in the 'over model' than that in the reference model. BRBs start to dissipate energy at an early stage with story drift ratios much smaller than those at beam yielding. Therefore, the damage of the RC frame could be decreased. In addition, 'over model' has a greater deformation reduction effect than 'each model'.

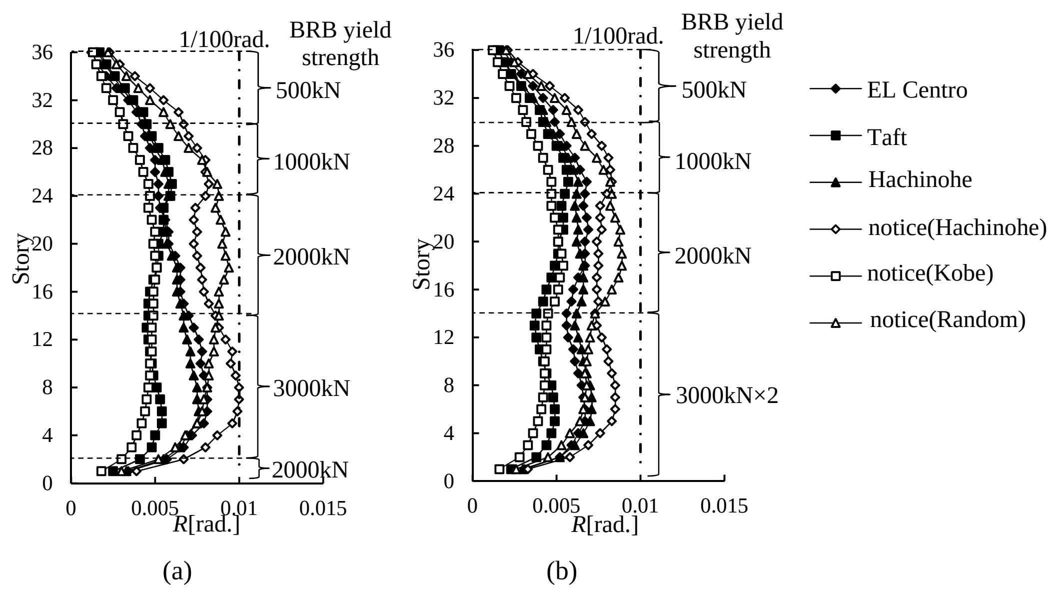

Figure 4. Maximum response story drift ratio distributions (PGV = 75cm/s): (a) each model; (b) over model.

Table 3. Plasticity ratio of the beam μ_r.

	reference	each	over
notice wave (Hachinohe PGV=75cm/s)	1.34	1.09	0.92

3.3 Behavior of BRB

The axial force N_{BRB} - axial displacement δ_{BRB} relationship of the BRB in the 23rd story - is shown in Figure 5. Plasticity ratio of the BRB, μ_{BRB}, is shown in Table 4. Energy dissipation in the BRBs is shown in Figure 5. The BRBs of 'each model' have not yielded against the simulated Hachinohe record (PGV = 50cm/s). The 'over model' has shown greater hysteresis loop than the 'each model'. Focusing on the energy dissipation, the 'each model's energy dissipation is 49 kNm, the 'over model' model is

481 kNm. The 'over model' represents the energy dissipation of the two stories, it is 240 kNm and considered as a half to contribute to one story, and has five times the energy dissipation of the 'each model'. BRB is deformed twice in the 'over model', compared to the 'each model' by the story drift of the two stories. Thus, in the 'over model', it is possible to increase the deformation of the BRB and is considered to function more effectively.

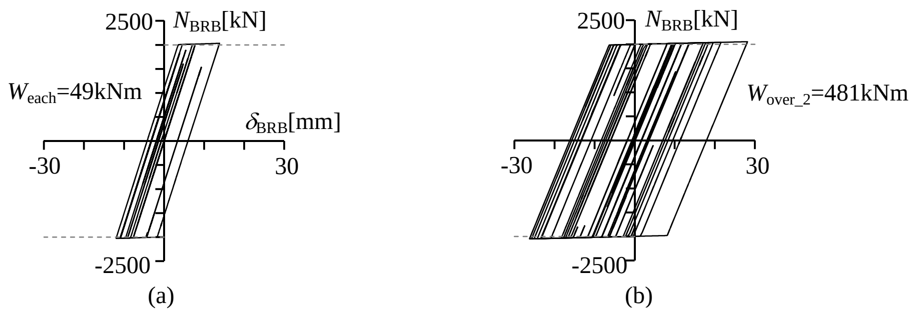

Figure 5. Response axial force - axial displacement relationship of BRB (notice wave (Random PGV = 75cm/s)): (a) each model; (b) over model.

Table 4. Plasticity ratio of the BRB $\mu_{BRB.}$

	Each	Over
notice wave (Hachinohe PGV=50cm/s)	0.92	1.72
notice wave (Random PGV=75cm/s)	1.77	2.81

4 CONCLUSIONS

The summarized conclusions obtained in this paper are as follows.

(1) The 'over model' that was planned in this paper exhibited almost the same passive control effect as compared to the 'each model', although the number of BRBs was significantly reduced and the RC beams in the braced span were abandoned.

(2) The results of the plasticity ratio of the beam μ_r, show that deformation could be decreased by 42% in the 'over model' than in the reference model. Therefore, the damage of the RC frame could be decreased and the 'over model' has a greater deformation reduction effect than the 'each model'.

(3) The results of the deformation of the BRB and plasticity ratio of BRB μ_{BRB} show it is possible to increase the deformation of the BRB in the 'over model' compared to the 'each model', 'over model' is considered to be able to function effectively.

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