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Study on seismic absorption schemes of reinforced concrete frame bent-buckling restrained brace structure

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Abstract. The reinforced concrete main building structure of a 600 MW thermal power plant is taken as the background project. The buckling restrained brace (BRB) is used as the energy dissipation element to optimize the seismic design of the original frame bent-brace structure. Through time history analysis of the original structure and three kinds of shock absorption structures, their seismic performance under rare earthquakes is compared. The results show that the BRB can effectively control the displacement response at the weak layer, improve the internal force distribution of the structure, and make the structure meet the requirements of 8 degree fortification. In the high intensity area, the reinforced concrete frame bent-BRB (RCFB-BRB) structure is worth popularizing.

1. Introduction

Reinforced concrete frame-bent structure (RCFBS) is a common structural form in industrial buildings in China, which occupies a large proportion in lifeline engineering. In order to meet the technological requirements, the structure is very complex, and its mass and stiffness are unevenly distributed in space, which leads to more weak positions and poor seismic performance. Especially in high earthquake intensity areas, it is not recommended to adopt [1-3].

In order to improve the seismic performance of RCFBS, the conventional method is to add shear walls or steel braces, but the shear walls may affect the use of space in the building. Although steel braces can provide greater lateral stiffness for the structure in the elastic stage, they are easily buckling and instability or even withdraw from work under strong earthquakes, which has a negative impact on the structural stress. Based on this, the BRB can yield under tension and compression and provide greater damping [4-5] under strong earthquakes, so it becomes the preferred hardware facility to improve the seismic performance of such structures. In the industry code [6], it is clearly pointed out that "the design of energy dissipation and seismic reduction can be adopted for main factory buildings in 8-degree and 9-degree areas". Therefore, adding BRB to RCFBS to improve its seismic performance has become a new technology encouraged and promoted by the state.

At present, BRB is mostly used for new steel structures and seismic strengthening of existing concrete structures. The BRB is widely used in civil buildings, but seldom used in industrial buildings. Therefore, it is necessary to deeply study the RCFB-BRB structure, in order to provide technical support for the popularization and application of this structure system. Taking the reinforced concrete main building structure of a 600 MW thermal power plant as the background project, the BRB is used as the energy dissipation element to optimize the seismic design of the original frame bent-brace



structure. Three kinds of seismic reduction schemes are put forward. Through time history analysis, the seismic performance and the effect of seismic reduction are tested.

2. The seismic reduction schemes

2.1. Project overview

The main structure of a 600 MW thermal power plant is selected, with longitudinal frame brace structures and transversal frame bent-brace. Seismic fortification intensity is 8 degree; site classification is II categories; earthquakes are grouped into the first group and the characteristic period is 0.35s. Fig. 1 shows the plane layout of prototype structure, and typical profile is shown in Fig.2. The main workshop is arranged in four columns: steam engine room, deaeration room and coal bunker room. The total length, width and height of the structure are 90m, 54.1m and 60.1m, respectively; the concrete is C40 and the longitudinal bearing force rebar is HRB400; stirrup is HPB235 and steel brace is Q235B.

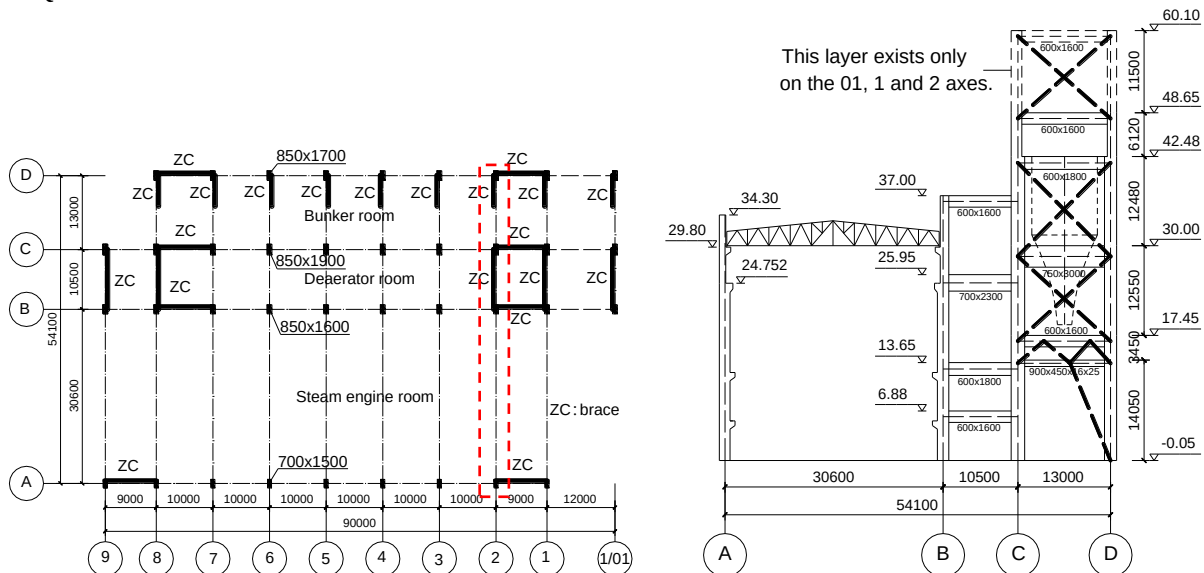


Figure 1. Plane layout of prototype structure. Figure 2. Typical profile of prototype structure.

2.2. Finite element analysis of seismic performance of original structure

Nonlinear 3D model of main powerhouse structure is established by finite element analysis software SAP2000 (Figure 3). Beams, columns and steel braces are modeled by three-dimensional spatial frame elements, and floors are modeled by shell elements. Moment hinges (M3) are set in frame beams, coupling hinges (PMM) are set in columns, and revised axis hinges [9] are set in steel braces to simulate the performance of members after yielding. Through spectrum analysis, Northridge wave, Elcentro wave and Taft wave meet the requirements of seismic wave in the Code for Seismic Design. Figure 4 shows the envelope diagram of the lateral displacement angle of each layer of the original structure under rare earthquakes. The figure shows that the second floor of the structure is a weak layer, and the maximum inter-story displacement angles under the action of Northridge wave and Elcentro wave are 1/49 and 1/46 respectively, which do not meet the elastic-plastic limit requirements of the code. Measures should be taken to reduce the displacement response of the structure.

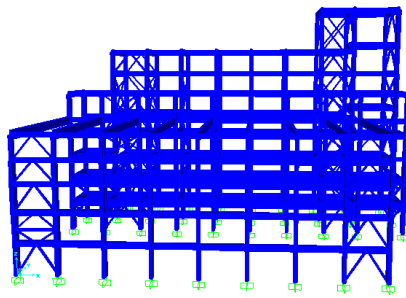


Figure 3. FEM structural model.

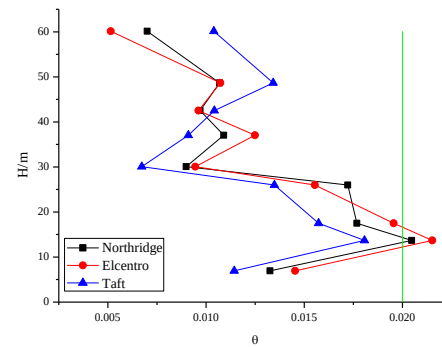


Figure 4. Story drift envelopes.

2.3. The seismic reduction schemes

In this paper, the seismic reduction design of the original structure is carried out by replacing the steel braces with BRB. Considering the complexity of frame-bent structure, three seismic reduction schemes are proposed, namely, scheme 1—original brace stiffness scheme, scheme 2—inter-story shear adjustment stiffness scheme, and scheme 3—main structure stiffness reduction scheme. In scheme 1, the stiffness parameters of BRB are set by using the stiffness of original braces and considering the stiffness of their compressive stability; in scheme 2, the stiffness of each layer is optimized on the basis of scheme 1, and the stiffness of each layer is adjusted by interlayer shear force, so that the displacement angle between layers is more uniform and the torsional response of the structure is more reasonable; in scheme 3, the size of beam and column of the main structure is reduced by 10% on the basis of scheme 2, in order to give full play to the advantages of energy dissipation of BRB and reduce engineering costs.

3. Results and Discussions

LINK element is used to simulate BRB in finite element model, Wen model is used in mechanical constitutive relation, and the stiffness ratio after yield is 0.05.

3.1. Interlayer displacement angle

Fig. 4 shows the envelope diagram of the inter-story displacement angle of the original structure and three kinds of shock absorption structures under three seismic waves when rare earthquakes occur. It can be seen from the figure that the inter-story displacement angle of the second floor of the original structure is largest, which is due to the unequal height of the column, staggered layers, and easy to occur translation-torsion coupling vibration, and become the weak layer of the structure. The inter-story displacement angles of the weak layers can be effectively controlled by the three shock absorption structures. Compared with the original structure, the maximum inter-story displacement angles of the weak layers are reduced by more than 20%. Among the three schemes, the inter-story displacement angles of the scheme 2 are more evenly distributed, and the effect of vibration reduction is the best. Because of reducing the size of beam and column, the inter-story displacement angle is slightly larger, but it can meet the norm limits and has surplus, so the scheme 3 has better economy.

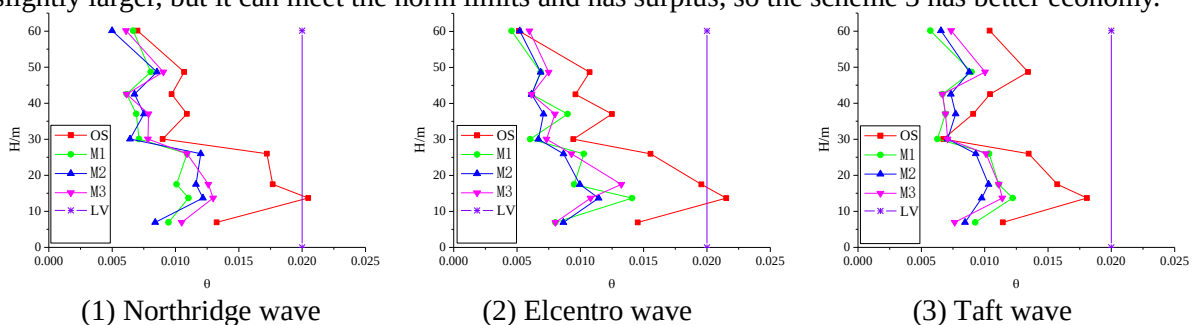


Figure 5. Loading device and monitor point.

3.2. Base shear force

Table 1 shows the comparison of maximum values of base shear and vertex displacement between the original structure and three kinds of shock absorption structures. It can be seen from the table that the base shear force of each shock absorption scheme is reduced by more than 17% and the vertex displacement is reduced by more than 27%. It is because that the BRB can provide damping by hysteretic energy dissipation then reduce seismic response. Among the three schemes, the vertex displacement of the scheme 2 decreases the most, while the base shear force is well controlled.

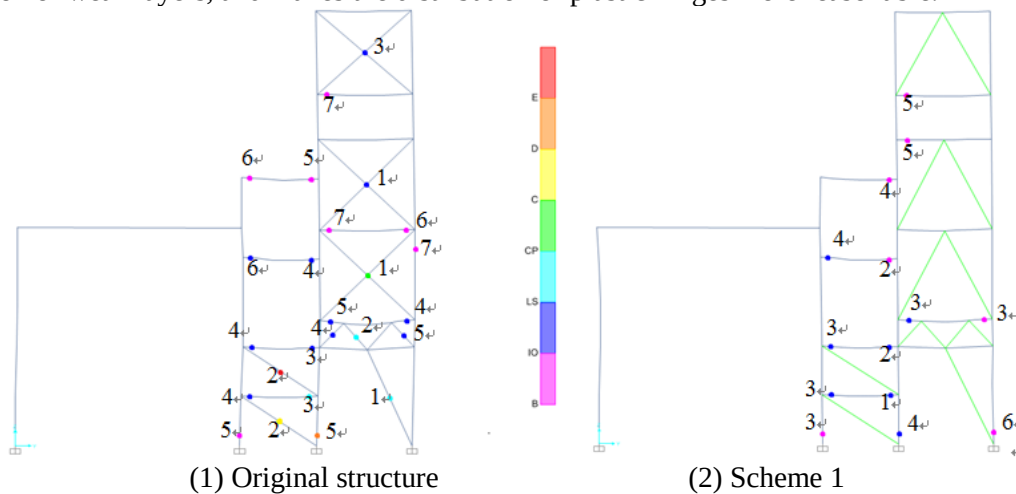
Table 1 Comparison of base shear and vertex displacement peak value of structures

seismic wave	Original structure		Scheme 1		Scheme 2		Scheme 3	
	BS	VD	BS	VD	BS	VD	BS	VD
Northridge	119650	756	94505	508	96318	512	85745	547
		-	21%	32.80%	19.5%	32.30%	28.3%	27.60%
Elcentro	96601	749	74516	490	77395	462	70305	492
		-	22.9%	34.60%	19.9%	38.40%	27.2%	34.30%
Taft	97567	726	75261	508	78169	495	71008	518
		-	19.4%	30.00%	17.3%	31.80%	29.2%	28.60%

BS denotes base shear, its unit is kN. VD represents vertex displacement, its unit is mm.

3.3. Plastic hinge distribution

Fig. 5 shows the distribution and the appearance sequence of plastic hinges of frame bent structures in axes 2 (Fig. 1) under the action of Northridge wave. The figure shows that the plastic hinges of the original structure first appear at the braces with large slenderness in the middle and lower layers, then the plastic hinges formed at the bottom beam ends and developed upwards. Finally, the plastic hinges of bottom column becomes D-hinge then structure completely destroy due to the bottom braces withdrawal from work. The development trend of plastic hinges of the three seismic reduction structures is very similar. The bottom BRB first yields and dissipate energy, with the increase of seismic energy, the upper BRB of the structure gradually enters the state of energy dissipation, thereafter, the plastic hinges forms at the ends of bottom beam and column and develop gradually to the ends of upper beam. Generally speaking, the plastic hinges of the beam and column are basically in the state of IO hinges (Immediate Occupancy), which shows that the lateral stiffness of the whole structure can be effectively adjusted, and internal forces of the structure can be distributed more reasonable, by layout of the BRB of the three schemes, so three seismic reduction structures avoid the formation of weak layers, and makes the distribution of plastic hinges more reasonable.



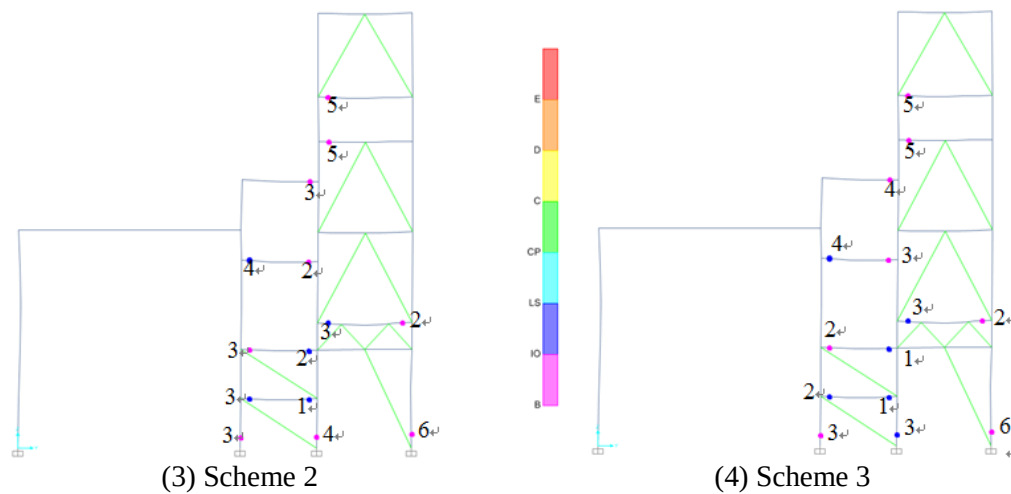


Figure 6. Plastic hinge formations of structures.

4. Conclusions

By comparing the seismic performance of the original structure and three seismic reduction structures under rare earthquakes, the following conclusions can be drawn.

(1) Three seismic reduction schemes (i.e. scheme 1—original brace stiffness scheme, scheme 2—inter-story shear adjustment stiffness scheme, and scheme 3—main structure stiffness reduction scheme) proposed in this paper and they can effectively improve the seismic performance of the original structure. In comparison, the seismic reduction effect of the scheme 2 is the best.

(2) In rare earthquakes, the plastic deformation of the original structure's bottom brace is too large, which leads to the destruction of the column foot then the failure of the structure. Three shock absorber structures can effectively adjust the lateral stiffness of the structure, rationally distribute internal forces, avoid the formation of weak stories, so three shock absorber structures has a larger bearing capacity.

(3) In this paper, the seismic performance of the structure is analyzed in detail from the point of view of numerical calculation, and the best shock absorption scheme is found. However, the effect of shock absorption still needs to be verified by test. Therefore, quasi-static test and shaking table test are needed to test the effect of shock absorption in future.

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