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Seismic performance of high-rise buildings with energy-dissipation outriggers

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ABSTRACT

To improve the seismic performance of high-rise building structures with outriggers, a new structure with energy-dissipation outriggers installed using buckling restrained braces (BRBs), which replace the ordinary diagonal bracing, is proposed in this study. To verify the seismic performance of the new structure, a case study was carried out. Two high-rise structures, one with conventional outriggers, the other with energy-dissipation outriggers, were designed. The numerical models for the two structures were established with the aid of a commercial software, Perform-3D. The responses of the two structures under frequent earthquakes, basic earthquakes, and rare earthquakes were analyzed and compared. The results show that compared to the ordinary structure, the seismic performance of the new structure is improved significantly. Under frequent earthquakes, both structures remain basically elastic, and the responses of the two structures are almost identical. Under basic earthquakes and rare earthquakes, the BRBs in the new structure yield initially and dissipate a large amount of the input energy to provide adequate protection to the main structural members. Furthermore, the influences of the strength and layout of BRBs on the seismic performance of the new structure were investigated, providing reference for engineering applications.

1. Introduction

With the socio-economic development and rapid urbanization in mainland China, many supertall buildings have been constructed or are under construction. A large proportion of these tall buildings apply steel-concrete hybrid structure systems such as steel frame-reinforced concrete (RC) core tubes owing to their unique advantage of reducing construction cost and saving construction time. To effectively reduce the interstory drift of high-rise buildings under earthquakes and winds, outriggers connecting the outer frame and core tube are usually adopted to form a strengthened story. However, because of the effect of the outriggers, the lateral stiffness of the strengthened story is much larger than that of the adjacent stories, resulting in the abrupt change of internal forces in the structural members of such stories and the possible formation of weak stories under strong earthquakes [1].

To improve the performance of the structure with outriggers under earthquakes and winds, Smith and Willford [2] developed a new structure with energy-dissipation outriggers, in which viscous dampers are installed between peripheral frame columns and outriggers, as the relative vertical deformation between the core tube and column is large. The new energy-dissipating outrigger system was successfully applied to the Saint Francis Shangri-la Place in Manila. Zhou and Li [3] analyzed the earthquake responses of two high-rise steel structures, one with conventional outriggers and the other with similar viscous damped outriggers. It was found that under severe earthquakes, the responses of the structure with viscous damped outriggers, which contributes an additional damping ratio of 4%, are much lesser than those of conventional structures. However, compared to the conventional structure with a rigid connection between the outrigger and the peripheral column, the lateral stiffness of the structure with a viscous damped outrigger is significantly reduced owing to the weakened damping connection between the outrigger and the peripheral column. Thus, under frequent earthquakes, the lateral displacement and interstory drifts of the structure with damped outriggers are larger than those of the conventional structure. The function of the outriggers in reducing the lateral displacement and interstory drifts of a structure under frequent earthquakes could not be performed effectively.

To further improve the seismic performance of tall building structures with outriggers, a new structure with energy-dissipation outriggers installed with buckling restrained braces (BRBs), replacing the ordinary diagonal bracing, is proposed in this study. Compared with the temperature-sensitive viscous dampers, BRBs are usually cheaper

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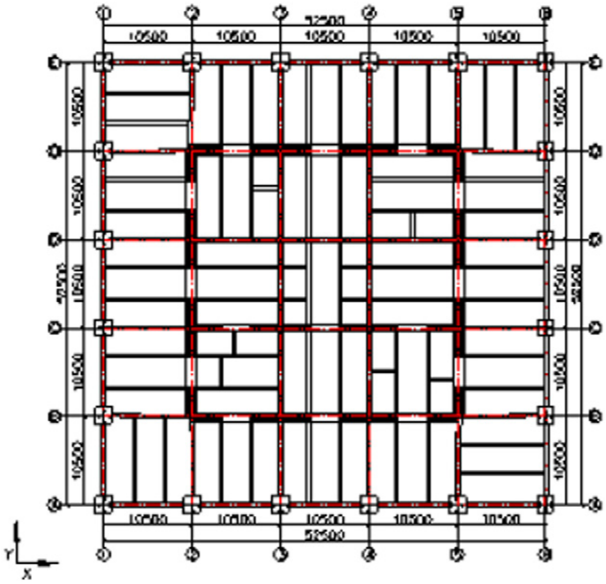

Fig. 1. Structural plan layout of typical floor.

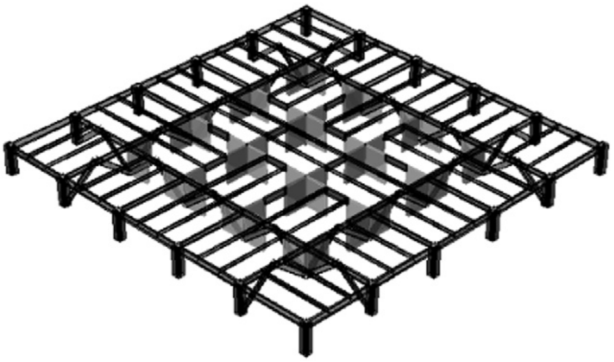

Fig. 2. Schematic diagram of floor with outrigger trusses.

Table 1
Strength grade of structural material.

	Column	Beam	Shear wall	Slab	Outrigger truss
Concrete	C50	–	C50	C35	–
Steel	Q345	Q345	–	–	Q460
Steel bar	HRB400	–	HRB400	HRB400	–

Table 2
Dimensions of components in outrigger truss (unit:mm).

Member number	Width	Height	Web thickness	Flange thickness	Component length
OTB-1	350	700	16	36	10,500
OTB-2	350	700	12	20	10,500
OTX-1	350	700	40	60	6723
OTX-2	350	700	12	20	10,500

and more reliable in terms of durability [4]. Previous studies have shown that BRBs have a large energy-dissipating ability, and can be used not only as ordinary bearing bracings, but also as displacement dampers [5,6]. To limit the lateral displacement of a new structure under frequent earthquakes, the axial stiffness of the BRBs is determined using the principle of equal-rigidity substitution. This ensures that the new structure has the same lateral stiffness as the structure with conventional outriggers. In addition, the strength of BRBs is selected so that under frequent earthquakes, the BRBs as well as the main structure remain in the elastic stage. Furthermore, under basic earthquakes and rare earthquakes, the BRBs yield initially and dissipate most of the input energy so that the main structural members can be adequately protected. To verify the seismic performance of the new structure, a case study was carried out in this research.

2. Project profile

A typical high-rise steel and concrete composite frame-RC core tube structure with 55 stories and a total height of 229.8 m was designed for the case study. The seismic intensity is 7. The peak ground acceleration (PGA) values of the three earthquake levels are 55, 150, and 310 gal, respectively. The site soil class is III, the design group is 2, and the characteristic period of the ground motion is 0.55 s. The height of each story is 4.2 m excluding the bottom floor (4.8 m) and mechanical floor (3.6 m). The structural plan layout of the typical floor is shown in Fig. 1. The peripheral frame consists of steel-reinforced concrete (SRC) columns and steel beams. The outrigger trusses are arranged at the 32nd floor in two directions, as shown in Fig. 2. The strength grade of the structural material is given in Table 1. The outrigger truss consists of the top chord members, bottom chord members, and diagonal bracings, as shown in Fig. 3. All of them are steel I-section members. The dimensions of the components in the outrigger truss are listed in Table 2. Accordingly, another structure with the previously mentioned energy-dissipation outriggers was designed. In this new type of structure, the diagonal braces (named OTX-1) in the side span located outside the core tube in the conventional structure are replaced by BRBs. The dimensions of the BRBs are determined by the equal-rigidity principle. All structural details except for the outrigger trusses are identical for the two structures.

3. Numerical models

3.1. Finite element models

The finite element models of the two structures were established with the aid of a commercial program, Perform-3D [7]. Beams were simulated using a plastic hinge model, assuming that flexural plastic hinges occurred only at the two ends of the members. For beams with a relatively large span-to-depth ratio, flexural deformation is the controlling factor, and the shearing behavior is regarded as elastic. With the same forming mechanism involving plastic hinges for beams, columns were simulated using the plastic hinge model as well. The force–displacement relationship of the cross-section was derived from the fiber model. The truss members were simulated by inelastic axial bars, in

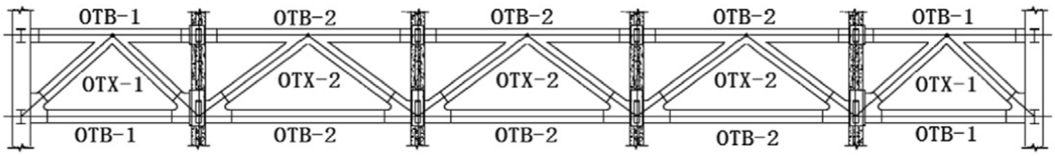

Fig. 3. Schematic diagram of outrigger truss.