The comparison analysis of earthquake resistant behavior between frame structure and frame shear wall structure

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Abstract. According to the investigation of earthquake damages in China and abroad, the earthquake resistant behavior of frame shear wall structure is better than that of frame structure. Compared to the reinforced concrete frame shear wall structure, the frame structure is easier to be damaged under the action of earthquakes. In this paper, the five-storey frame structure model is taken as the research object, and a certain number of shear walls are reasonably arranged to form a frame shear wall structure to compare and analyze the earthquake resistant behavior of the two structures. The analysis results show that the frame shear wall structure can achieve good earthquake resistant behavior compared with the frame structure.

1. Introduction

The 2008 Wenchuan earthquake showed that the earthquake resistant behavior of frame shear wall structure was significantly better than that of frame structure [1]. The defect of earthquake resistant behavior of frame structure is pointed out in 2009 Edition of 《National Technical Measures for Design of Civil Construction (Concrete Structure)》 [3]. However, in 《Code for Seismic Design of Buildings》 (GB50011-2010) stipulates that the maximum height of 8 degree (0.2g) cast-in-situ frame structure is 40m, while most designers give preference to frame structure when designing multi-storey buildings [2]. 《Professional technical measures of building structure》 of Beijing Institute of Architectural Design pointed out that the frame structure of the 8 degree zone should not exceed 5 floors and the height should not exceed 20m [4]. In this paper, the 5-storey frame structure is taken as the research object, and the frame shear wall structure is formed by arranging a certain number of shear walls reasonably. The earthquake resistant behavior of the two structures under rare earthquakes is analyzed and compared.

2. Modelling

2.1. Model overview
The layout of the structure is shown in Figure 1.
Figure 1. Frame structure plan.

Floor load value: constant load value is 1.5KN/m², live load value is taken according to load specification, seismic fortification category is key fortification category, design earthquake is divided into third group, seismic fortification intensity is 8 degrees, design earthquake acceleration is 0.15g, building site soil class is III, basic wind pressure is 0.45KN/m², concrete grade of frame columns of each floor is C30, secondary structure ring beam structural column crossbeam is C25, outer wall is made of Mu5 sand aerated insulation block, inner wall is made of aerated concrete block, main reinforcement and stirrup of beam and column are all tertiary steel, and main reinforcement, horizontal and vertical distribution reinforcement of wall are all tertiary steel.

2.2. Arrangement scheme

Scheme 1: Frame structure with second-order seismic grade and standard floor arrangement as shown in Figure 2. The unspecified size of the secondary beam is 200mm×500mm.

Figure 2. Frame structure plan.

Scheme 2: Frame shear wall structure, the seismic grade of the frame is three levels, and the seismic grade of the shear wall is two levels. The standard layer plane is shown in Figure 3. It is not indicated that the size of the secondary beam is 200mm×500mm and the thickness of the shear wall is 300mm.
3. Performance index under frequent earthquakes

The vibration periods of the first three modes with torsional coupling are calculated by PKPM-SATWE software. The details are shown in Table 1.

Table 1. Periods of the first three modes.

| Structural scheme               | Vibration model | Cycle (S) | T3/T1 |
|---------------------------------|-----------------|-----------|-------|
| Frame structure                 | 1               | 0.8328    | 0.82  |
|                                 | 2               | 0.8123    |       |
|                                 | 3               | 0.6817    |       |
| Frame shear wall structure      | 1               | 0.3962    | 0.76  |
|                                 | 2               | 0.3896    |       |
|                                 | 3               | 0.3011    |       |

The calculation results show that the period ratio of frame structure and frame shear wall reaches the limit value 0.9 required by the code. The maximum inter-story displacement angle and the maximum torsion displacement ratio of frame structure and frame shear wall structure under earthquake are shown in Table 2.

Table 2. Maximum inter story displacement angle and maximum inter story displacement ratio under earthquake action.

| Structural scheme               | Floor | Working condition | Maximum inter layer displacement angle | Maximum interlayer displacement ratio |
|---------------------------------|-------|-------------------|----------------------------------------|---------------------------------------|
| Frame structure                 | 1     | X                 | 1/560                                  | 1.14                                  |
|                                 | 1     | Y                 | 1/572                                  | 1.06                                  |
| Frame shear wall structure      | 2     | X                 | 1/860                                  | 1.09                                  |
|                                 | 2     | Y                 | 1/850                                  | 1.12                                  |

It can be seen from table 2 that the inter story displacement angles in X and Y directions of the frame structure reach 1/550 of the seismic code. In order to achieve this value, the column section is 800mm×800mm, the beam section is 400mm×700mm, and the interlayer displacement angle of frame shear wall structure in X and Y directions reaches 1/800 specified in the seismic code, the column section is reduced to 700mm×700mm, and the beam section is reduced to 300mm×650mm. It meets the requirements of interlayer displacement angle. At the same time, the maximum torsion displacement ratios in X and Y directions of the two structures meet the requirements.
4. Elastic-plastic analysis under rare earthquake

4.1. Modelling
Elastic-plastic time history analysis of 5-storey frame and frame-shear wall structure by PKPM software. The models are shown in Figure 4.

![Frame structure](image1)
![Shear wall structure](image2)

Figure 4. PKPM models.

4.2. Seismic wave selection
Two natural waves, TH3TG045 wave and El Center wave, and one artificial wave, RH2TG045, are selected from the seismic wave library in PKPM for elastic-plastic analysis. In the calculation, all seismic records are amplitude-modulated according to the ground peak acceleration of 400cm/s², which is equivalent to the standard 8 degree earthquake level in China. The acceleration time history curves of three seismic waves are selected as shown in Figure 5.

![TH3TG045](image3)
![El Center](image4)
![RH2TG045](image5)

Figure 5. Acceleration time history curves of three kinds of seismic waves.

4.3. Time history analysis
The elastic limit of interlayer displacement angle of frame structure is 1/550, that of frame shear wall structure is 1/800, and the elastic-plastic limit of frame structure is 1/50, the elastic-plastic limit of frame shear wall structure is 1/100. Under frequent earthquake, the structure will not be damaged or can continue to be used. The interlayer displacement angles of frame structure and frame shear wall structure are 1/550 and 1/800, respectively. Under rare earthquake, the structure will not collapse or cause serious damage to life. The limit of interlayer displacement angle of frame structure and frame shear wall structure are 1/50 and 1/100, respectively.

In the nonlinear time history analysis of the three input seismic waves, the maximum displacement envelope diagram of the frame structure and the frame shear wall structure is shown in Figure 6, the
envelope of the maximum interlayer displacement angle is shown in Figure 7, the maximum interlaminar shear distribution is shown in Figure 8.

Figure 6. Maximum displacement envelope diagram of frame structure and frame shear wall structure.

(a) Frame structure.  (b) Shear wall structure.

Figure 7. Envelope of the maximum interlayer displacement angle of frame structure and frame shear wall structure.

(a) Frame structure.  (b) Shear wall structure.
5. Conclusion

A certain number of shear walls are arranged in the frame structure to form the frame shear wall structure. In the large earthquake elastic-plastic analysis, compared with the frame structure, the maximum displacement envelope diagram and envelope of the maximum interlayer displacement angle of the frame shear wall structure are reduced. Compared with the frame shear wall structure, the envelope of the maximum interlayer displacement angle of the frame structure is obviously different, which is far less than the shear capacity of the frame shear wall structure. For buildings in 8-degree zone, it is not recommended to use frame structure, but to form frame shear wall structure through reasonable arrangement of some shear walls, which can achieve good earthquake resistant behavior.

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