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Research on seismic strengthening technology of a single span structure

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ABSTRACT. *The seismic reinforcement design of existing buildings has a wide range of application prospects, and the selection of reasonable structural system reinforcement scheme is the focus of seismic reinforcement design.The research direction of this paper is to obtain a better seismic strengthening method of single span frame structure with overhanging veranda in primary and secondary schools, and to provide a better seismic reinforcement design scheme for this kind of existing buildings.The main conclusions of this paper are as follows: the three strengthening schemes can reduce the seismic response of the structure, reduce the deformation of the structure under the earthquake action, and improve the seismic performance of the structure.Among them, the shear wall (SW) scheme can significantly reduce the deformation of the ground floor structure, and the isolation bearing (ISO) scheme has the best effect on reducing the overall deformation.But in the specific project operation, we should consider the project budget and time cost and other factors, and use the reinforcement scheme reasonably.*

KEYWORDS: *Single span frame structure, seismic reinforcement, elastic response spectrum analysis, static elastic-plastic analysis*

1. Seismic damage characteristics of single span frame type primary and secondary school buildings

Frame structure has a good seismic performance, but in the Wenchuan earthquake, Yushu earthquake and other major earthquakes, frame structure buildings have also suffered serious collapse damage, of which the single span frame structure damage and collapse phenomenon is very serious, the following will be the single span frame type of primary and secondary school building damage characteristics are briefly introduced.

(1) Plastic hinge appears at the top and bottom of frame column

Under the action of earthquake, the damage of frame structure can be divided into beam hinge mechanism and column hinge mechanism. Under beam hinge mechanism, the relative stiffness of frame beam is low. When subjected to

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earthquake, due to large bending moment, the beam end begins to yield, forming plastic hinge, which makes the frame have greater internal force redistribution capacity and energy dissipation capacity, and the ultimate story displacement of the structure is large, which can achieve the "anti-seismic" anti-seismic Design principles. In the column hinge mechanism, because of the plastic hinge at the end of the column, the story displacement is too large, which leads to the collapse of the building. In the earthquake stricken area, many frame structures appear column hinge mechanism without damage to frame beams, which leads to house collapse and serious damage, as shown in Figure 1.

Figure. 1 Collapse caused by column hinge mechanism

(2) Failure of frame joint area

When there are cross diagonal cracks or diagonal diagonal cracks in the core area of frame joints, when there are few or no stirrups in the joints, the longitudinal load-bearing reinforcement of the frame column will be bent and bulged outward, as shown in Fig. 2. The failure of the frame joint makes the beam column lose the connection with each other. The failure of the joint is caused by the insufficient shear bearing capacity, the insufficient stirrup configuration and the insufficient anchorage length of the reinforcement at the beam end.

Figure. 2 Frame node failure

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(3) The corner pillar is seriously damaged

Usually, under the action of earthquake, the unsymmetrical building structure will produce torsion deformation. The corner column of frame structure plays a very important role in the anti torsion of the building. It is subjected to large shear force, and at the same time, the corner column is subjected to bidirectional bending moment. Moreover, the corner column is usually less restrained than other columns, so its seismic damage is more serious than that of the inner column. As shown in Figure 3, the upper end of corner column of a frame structure is sheared, the concrete is crushed, and the longitudinal reinforcement is extruded and bulged.

Figure. 3 Shear failure of corner column of frame structure

(4) Short column failure

The short column can be approximately regarded as a column whose ratio of column height to side length of column section is less than 4. When there are staggered layers, interlayer or half story high infilled wall, or the connection beam is set above the foundation, it is easy to form frame short column. The shear span ratio of short column is small, the stiffness is large, and the seismic force is large in the earthquake, which often leads to brittle shear failure, cross cracks and even brittle fracture. As shown in Figure 4, a short column was formed at the landing of the stairs, which caused serious damage. Therefore, the formation of short columns should be avoided in structural design.

Figure. 4 Short column formed at the landing

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2. Seismic response analysis of single span frame structure

At present, China's seismic design code mainly adopts the basic aseismic design criteria of "no damage in small earthquakes, repairable in moderate earthquakes, and no collapse in large earthquakes", that is, buildings are generally not damaged or need no repair in case of frequent earthquakes lower than the seismic fortification intensity in this region, and the buildings may be damaged but repaired after repair Can continue to use: when suffering from a rare earthquake higher than the seismic fortification intensity of the region, the building will not collapse or cause serious damage to life safety. In the seismic design of buildings, the simplified two-stage design method is adopted, that is, in stage one, the bearing capacity and elastic deformation of structural members are checked according to the combination of seismic action effect corresponding to frequent earthquake intensity and other load effects; in stage 2, the elastic-plastic deformation of structure is checked according to the seismic action effect corresponding to rare earthquake intensity. At present, the commonly used structural analysis methods mainly include: elastic response spectrum method, static elastic-plastic analysis method, elastic-plastic dynamic time history analysis method.

2.1 ABAQUS added plastic damage model (CDP)

ABAQUS is a finite element method software, which is used for structural and field analysis in mechanical, civil and electronic industries. ABAQUS was originally a product of HK Company in the United States. It was sold to Dassault in the mid-2000s. The software is also known as Dassault simula. ABAQUS is well suited for scientific research. Its specification is professional and detailed, and the examples of checking calculation in the manual are mostly from published scientific research papers. The main modules of ABAQUS include three parts: visual graphic interface CAE, implicit solver sandard, explicit solver explicit, and other special function modules.

2.2 Basic theory of response spectrum method

The theory of response spectrum is mainly used to determine the earthquake action by response spectrum. In a certain time period of earthquake acceleration, the maximum displacement, velocity and acceleration response of a particle in a single degree of freedom system are curves that change according to the natural vibration period of the particle; the spectrum used to analyze the internal force and deformation response spectrum of structural system under earthquake action is the spectrum curve obtained by analysis and calculation under the earthquake action of single degree of freedom elastic system. In the seismic design codes of China and other countries, the response spectrum theory is widely used to determine the earthquake action. The acceleration response spectrum is the most common response spectrum analysis. The acceleration response spectrum refers to the curve between the maximum response acceleration and the natural vibration period of a single

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particle elastic system under earthquake action. Different damping ratio of structure leads to different response spectrum.

2.3 Elastoplastic dynamic time history analysis method

Dynamic elastoplastic analysis, also known as time history analysis method, also known as direct dynamic method, refers to the process of calculating dynamic balance equation when the structure is subjected to dynamic load. Based on the dynamic characteristics of the structure and the applied dynamic load, the response (displacement and internal force) of the structure at any time is calculated. Compared with the mode decomposition response spectrum method and Pushover Method, the elasto-plastic dynamic time history analysis method has the following advantages:

(1) The input of seismic wave is a complete process, which truly reflects the structural response caused by earthquake action at various times, including stress, strain, damage morphology, etc

(2) At present, many programs can consider the structure performance by defining the material constitutive relation when doing the elasto-plastic dynamic time history analysis. It can simulate any structure more accurately and make the calculation model closer to the actual situation.

(3) Compared with Pushover Method Based on plastic hinge, this method is based on the concept of plastic zone

The structural analysis results of shear wall are more accurate and reliable.

The elastoplastic dynamic time history analysis method also has some disadvantages

(1) Because the finite element software which can be used in this method is not design oriented, so it is more complex to use, the workload of modeling is heavy, the data processing is cumbersome, and the amount of calculation is large and the calculation time is long.

(2) Due to the use of finite element analysis, damage model, constitutive relation of reinforced concrete and other theoretical knowledge are required.

With the continuous improvement of computer hardware level and the continuous development of analysis theory, elastic-plastic dynamic time history analysis is gradually applied to the structural analysis of complex high-rise and super-high-rise buildings, which will become the development trend of structural analysis in the future.

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3. Seismic performance analysis of single span frame structure

3.1 Project overview

Taking a typical single span frame teaching building as an example, based on ABAQUS response spectrum analysis and dynamic elastic-plastic analysis, the influence of three common reinforcement methods on seismic performance is compared, which provides reference for the reinforcement design of this kind of structure.

The corridor is a single span, 3.0m high, single span, single storey, 3.0m high, single span, single storey, single span, 3.0m. The structure plan is shown in Figure 5. The size of frame column kzi is 400mm * 400mm, the dimension of transverse frame beam kl2 is 250mm * 350mm, and the dimension of coupling beam ll is 250mm * 250mm. Concrete precast hollow floor slab, beams and columns are made of C30 concrete, and the main stressed reinforcement is HRB400 reinforcement. The site is classified as class II, with fortification intensity of 8 degree and basic acceleration of 0.2g.

In order to study the influence of different reinforcement methods on the seismic performance of the structure, the reinforcement scheme is divided into the following three cases: adding shear wall reinforcement, adding buckling restrained brace reinforcement, adding isolation bearing to form an isolated

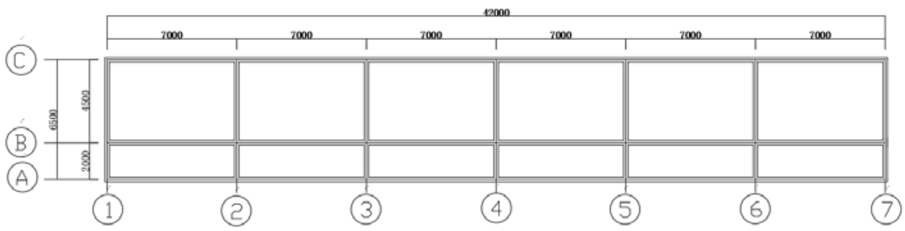

Figure. 5 Layout plan of single span frame structure

In ABAQUS, the plastic damage model (CDP) is used to model the concrete material, the shell element is used to model the floor, and the layered shell element is used to simulate the frame beam and column members (the reinforcement layer is modeled by layer, and the concrete is equivalent to the corresponding layer). The finite element model of frame structure is shown in Figure 6

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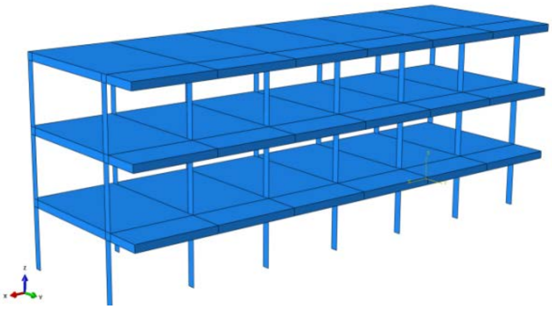

Figure. 6 Three dimensional simulation model of single span frame

The seismic fortification intensity of the structure is 8 degree, the seismic grade of the frame is grade II, the characteristic period is 0.45s, the site category is class II, and the structural period reduction factor is 0.7.

3.2 Modal analysis

The first ten order period and frequency of the structure are shown in Table 1. The natural vibration period of the structure is relatively long and the structure is easy to be damaged.

Table 1 The first ten order period and frequency of the original model structure

modality	Period (s)	frequency
1	0.625	1.600
2	0.580	1.725
3	0.527	1.896
4	0.199	5.021
5	0.189	5.298
6	0.170	5.882
7	0.119	8.400
8	0.117	8.512
9	0.109	9.152
10	0.107	9.341

3.3 Elastic response spectrum analysis

The predominant period of response spectrum analysis is 0.45s, and the fortification intensity is 8 degree 0.2g. According to the seismic code of China, the peak accelerations in X and Y directions are applied at a ratio of 1:0.85. The first ten vibration modes are calculated by response spectrum analysis, as shown in Fig. 7. It

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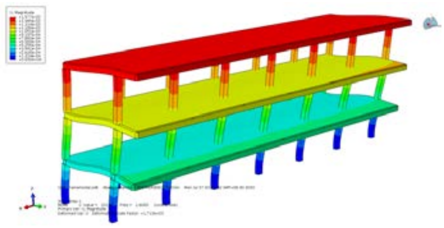
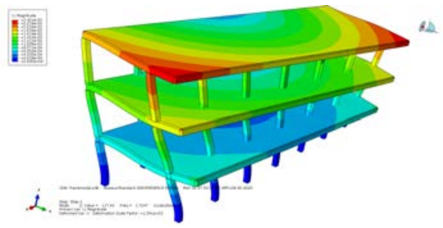
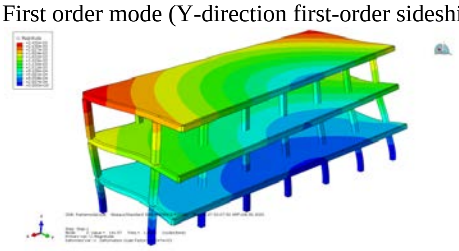
can be seen that the first mode of vibration is Y-direction translation, the second mode is X-direction translation, and the third mode is mainly X-direction translation. It shows that when the y-direction is a single span frame structure, the stiffness in this direction is insufficient and relatively weak. Under the earthquake action, it is easy to damage in this direction.


First order mode (Y-direction first-order sideshift)


Second order mode (first order torsion)


Third order mode (first order sideshift in X direction)

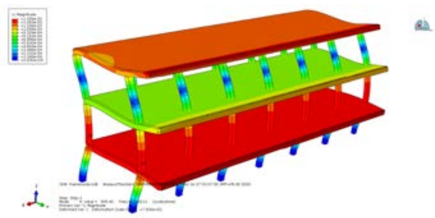

Fourth order mode (second-order sideshift in Y direction)

Figure. 7 The first fourth mode shapes of the original structure

According to the elastic response spectrum analysis by ABAQUS, the floor displacement values of the single span frame are shown in table 2 and the floor displacement diagram is shown in Fig. 8. It can be seen from the table that the shear deformation of the structure is mainly caused by earthquake, and the maximum displacement values in X direction and Y direction are 106mm and 136mm respectively.

Table 2 Displacement table of original structure (frame)

Reinforcement scheme	X direction (mm)			Y direction (mm)		
	F1	F2	F3	F1	F2	F3
Frame(original structure)	0.088	0.094	0.106	0.081	0.136	0.130

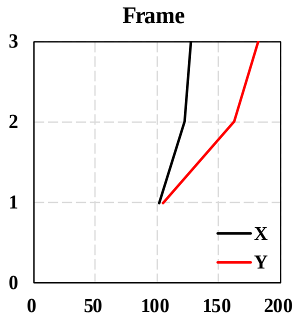


Figure. 8 Floor displacement diagram of original structure (frame)

After the elastic response spectrum analysis, the inter story displacement angles in X and Y directions of the single span frame structure are shown in Fig. 8. It can be seen from the figure that the maximum inter story displacement angle of the structure occurs in the second floor of the structure. The maximum displacement of the single span frame structure in X direction is 0.106 m, and in Y direction is 0.13 M. In the code for seismic design of buildings (50011-2011), the elastic interlayer displacement angle of reinforced concrete frame structure is limited to 1 / 50, the corresponding inter story displacement angle in X direction is 0.088 / 3.6 = 1 / 41, and the corresponding inter story displacement angle in Y direction is 0.081 / 3.6 = 1 / 44. Therefore, it can be seen that it is rare in 8 degrees under earthquake action, the inter story displacement angle of the structure can not meet the requirements of the code, so the structure needs reinforcement.

4. Conclusion

Based on the main forms of existing frame structures, this paper summarizes the characteristics of seismic damage of different forms of frame structures in previous earthquakes, and analyzes the causes of earthquake damage. In this paper, the elastic response spectrum analysis and dynamic elastic-plastic analysis of the single span frame structure with overhanging veranda are carried out, and the weak links of the structure are found out, and its seismic performance is evaluated. In view of the weak seismic links of the single span frame, the structural system seismic strengthening methods of adding frame column at cantilevered end and adding shear wall in Y direction are adopted. The elastic response spectrum analysis and dynamic elastic-plastic analysis are carried out respectively. The seismic performance changes of the structure before and after reinforcement and under different reinforcement methods are compared, and the influence of different reinforcement methods on the seismic performance of the structure is studied. The main conclusions are as follows

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