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Research on the Influence of Infill Walls on Seismic Performance of Masonry Buildings with Bottom Frame-Shear Walls

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Abstract

In order to discuss the influence of filler wall on the seismic performance of masonry buildings with bottom frame -shear walls,3D solid element modelings was presented to analyse the structure characteristics and seismic response characteristics of various layout forms of bottom frame -shear walls, such as non-filler walls ,a few filler walls and complete filler walls. Analyse stiffness characteristics, deformation characteristics, energy dissipations and damage laws of building structure with different numbers of filler walls under different ground motions. The results show that the contributions of lateral stiffness of filler wall bottom frame layer mainly depends on tensile strength of filler walls. Setting the filler wall will greatly improve the lateral stiffness of the bottom frame layer. The lateral stiffness of bottom-frame complete filler walls is 9.3 times than that of non-filler walls. Under strong ground motion, the storey drift of bottom frame layer can be reduced by 40%-50% setting filler walls. Due to the filler wall, the weak layer of the building structure moves from the bottom frame layer to the transition layer. The probability of failure of the transition layer increases during the earthquake.

Key words

Masonry buildings with frame wall at the bottom, Seismic behavior, Finite element analysis, Infilled walls.

1. Introduction

The masonry buildings with frame wall at the bottom was a kind of hybrid structure which is supported by frame-shear wall structure at the bottom one or two stories. The structure had advantages of flexible arrangement, easy application from the frame at bottom and convenience of drawing materials, low cost from the masonry structure. However, due to the low lateral stiffness of the bottom of the structure, the earthquake action on the bottom layer was relatively stronger. The deformation was concentrated on the bottom frame, which was too large to lose the bearing capacity. As a result, buildings damaged badly during the earthquake.

At present, many scholars have carried out series of studies on the seismic performance of masonry buildings with bottom frame. However, research on the influence of the filler wall on the seismic performance of the frame structure, structural lateral displacement and story drift angle, hysteretic behavior and damage was insufficient.

The influence of the material, position and quantity of filler walls on the internal force of the bottom frame beams and columns, the influence rules of stiffness of bottom frame and upper structure and the influence of filler walls on seismic response characteristics of bottom frame masonry buildings had no definite conclusions. As a result, it is hard to give suggestions of how to set bottom frame shear walls in masonry buildings.

Aiming at the above problems, this paper combined a finite element model of a bottom frame building by means of numerical analysis and contrasted differences in the response of a building to a selected ground motion in a bottom frame building setting different numbers of filler walls. After all, the paper explored the influence of filler walls on seismic performance of bottom frame brick buildings.

2. Structure General Situation

The chosen masonry residential building with bottom frame had 6-storey in Sichuan, China, of which the first floor was frame structure with the height of 3.3m. While the rest 5-storey were masonry structure with single height of 2.9m. The foundation form was shallow foundation under columns. As shown in x was the plan layout. The bottom frame beam section size was 400mm *850mm and the column section size was 500mm*500mm. The thickness of the top layer and the sixth layer was 120mm and that of the standard layer was 100mm. The upper masonry structure was made of fired common bricks with the wall thickness of 370mm and density of 18 kN/m^3. The roof load was 0.5 kN/m^3 and the floor live load was 2 kN/m^3.In the upper beam arranged full-length reinforcing bar of 6Ø25 and full-length reinforcing bar of 5Ø25 for the bottom beam. While the column arranged reinforcing bar of 20Ø25.The concrete grade of both beams and columns were C40, with bulk density of 25kN/m^3 and elastic modulus of 3.25×10^4MPa.The model showed as Fig. 2.The beam column section reinforcement diagram showed as Fig.1. All the wall junctions were equipped with 240mm*240mm columns.

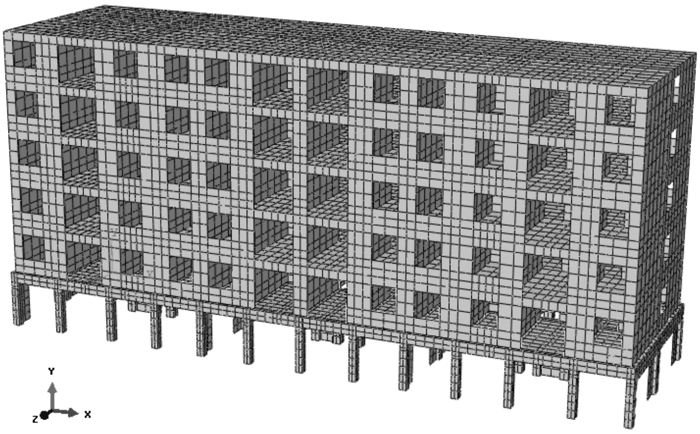


Fig.1. The 3D solid finite element model of 6-story masonry buildings

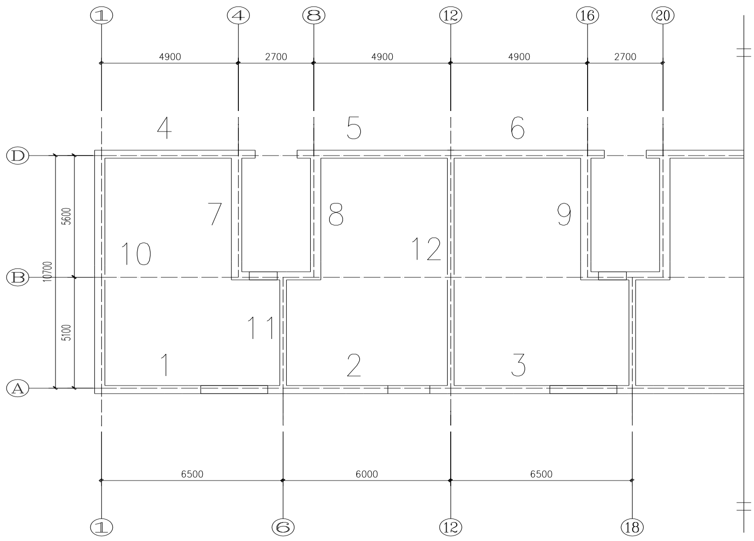


Fig.2. Building layout and filler wall arrangement diagram

3. Finite Element Modeling

The ABAQUS finite element program was used in masonry buildings 3D solid modeling. The bottom frame beams and the columns were restrained by tying, so were the floors and walls. In order to ensure that the two contact surfaces did not move relatively to each other. The framework of steel reinforcements was embedded into concrete by using embedded method. And then, optimize the division of the grid to analyses. Fig.2 showed the meshed cube.

During the structural seismic analysis, the representative value of gravity load concentrated on each particle was presented as the representative value of gravity load of each floor and gravity load of walls and columns from upper half floor and lower half floor. When calculating the representative value of gravity load, the combined value of variable load was 0.5 and the roof live load is not included. The calculation results were described in table 1. The gravity of the vertical load of the model was reflected by the material density. The floor live load was applied to each floor by surface load.

The influence of arrangement of the filler walls on masonry buildings with bottom frame was considered 12 filler walls in total. The layout of the location is shown in Fig.2. Filler walls numbered 1-6 were longitudinal filler walls. Filler walls numbered 7-12 were lateral filler walls.

4. Stiffness and self-vibration characteristics

Force loading on the model, the storey drift and the storey shear force under different filler walls were obtained. And then, the lateral stiffness ratio of the bottom frame layer and the transition layer were calculated. Main calculation results are shown in table 1.

Table 1**.** Layout of filler walls and stiffness calculation

Conditions	**Layout of filler walls**	**Storey**	**Lateral stiffness /N/m**	**Stiffness ratio d2/d1**
1	Non-filler wall	2	5.34×10^9	1.089
		1	4.90×10^9	
2	1～6, 10	2	5.11×10^9	0.970
		1	5.26×10^9	
3	12	2	5.31×10^9	0.838
		1	6.33×10^9	
4	7, 8, 9	2	4.93×10^9	0.550
		1	8.98×10^9	
5	11	2	5.02×10^9	0.539
		1	9.32×10^9	

Note: Number of filler walls corresponding to working condition 1 to 5 accumulates successively

According to the data in table 3, with the increase of the number of filler walls, the lateral stiffness of the bottom frame layer increased. When the structure is fully arranged with filler walls, the stiffness of the bottom frame layer was nearly doubled. At the same time, as the number of filler walls increasing, the lateral stiffness ratio of transition layer and the bottom frame layer decreased constantly, which indicated that the effect of filler walls should be fully considered in structural design. Control the lateral stiffness ratio of the bottom frame layer and the transition layer within a reasonable range so as to ensure the safety of the structure. When filler wall materials were aggregate concrete hollow blocks and autoclave fly ash hollow blocks, the stiffness of the bottom frame layer increases by 7.8 times. The contribution of different materials to the stiffness of the bottom frame depended on the tensile strength of the material.

After setting the filler walls, the period of the structure became shorter and the lateral stiffness increased, but only the first 4 order cycles changed, with no obvious changes. Compared the data in table 2. Although the bottom frame layer stiffness increased significantly by setting filler walls, the effect of stiffness of the whole structure was not obvious. From the aspect of the form of vibration, by setting filler walls the number of torsional vibration mode decreased and the number of Translation mode increased, which means filler walls can improve the torsion resistance of the structure. The torsion-translation period ratio means the ratio of first natural period dominated by torsion and first natural period dominated by translation. The larger the torsion-translation ratio was, the smaller the torsional stiffness of the structure was and more obvious the torsional effect was. From table 2, the torsion-translation period ratio was 0.64 with non-filler walls, which decreased to 0.62 after arranging filler walls. It showed that the torsional stiffness of the structure became larger so the torsional effect of the structure was reduced by filler walls.

Table 2**.** Self-vibration period of structure

Modal NO.	**Non-filler walls**		**Filler walls**	
	period /s	**Vibration type**	**period /s**	**Vibration type**
1	0.39	Translation mode	0.37	Translation mode
2	0.28	Translation mode	0.25	Translation mode
3	0.25	Torsional mode	0.23	Torsional mode
4	0.13	Translation mode	0.12	Translation mode
5	0.10	Plate mode	0.10	Plate mode
6	0.10	Torsional mode	0.10	Torsional mode
7	0.09	Plate mode	0.09	Plate mode
8	0.09	Plate mode	0.09	Plate mode
9	0.09	Plate mode	0.09	Plate mode

5. Structure response of each loading stage

6 seismic loads were chosen for time history analysis based on properties of soil. The seismic behavior of the structure was analyzed by 5 ground motions and 1 generated seismic wave, which are Taft wave, sun wave, smg wave, cpc wave and pic wave. Use data in table 3 to describe the PGA of seismic oscillation to the frequent earthquakes and rare earthquakes. Fig.3 shows the acceleration time history curve and response spectrum of Taft wave. Fig.4 shows the results of the value of the building's vertex displacement of the three models under Taft wave.

Under different ground motion, the lateral displacement of the structure showed the same rule: With the increase of the number of filler walls, the lateral displacement and the vibration amplitude of structure apex decreased. However, the structural base shear force increased with the increase of the numbers of filler walls, so was the seismic effect of the bottom frame.

Under the action of seismic wave, the total input energy and the transformation and dissipation of the non-filler walls and the filler walls were shown in Fig.5.

Table 3. Maximum value of seismic acceleration for time history analysis (cm/s^2)

Fortification intensity	**Degree**			
	6	**7**	**8**	**9**
Frequent earthquake	18	35(55)	70(110)	140
Rare earthquake	125	220(310)	400(510)	620

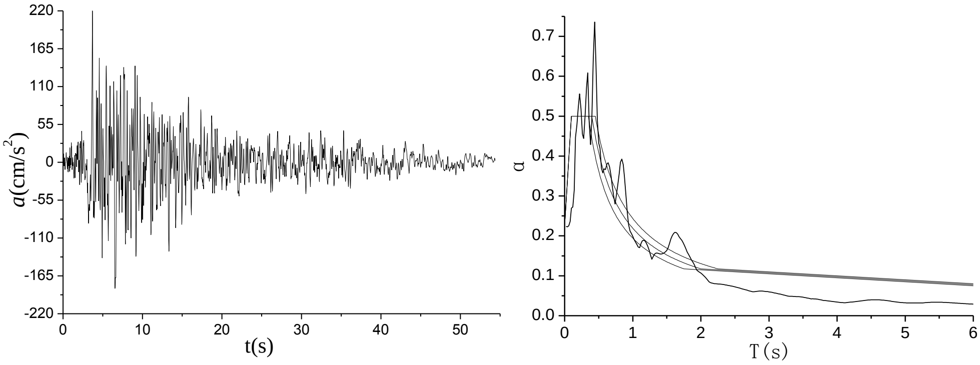
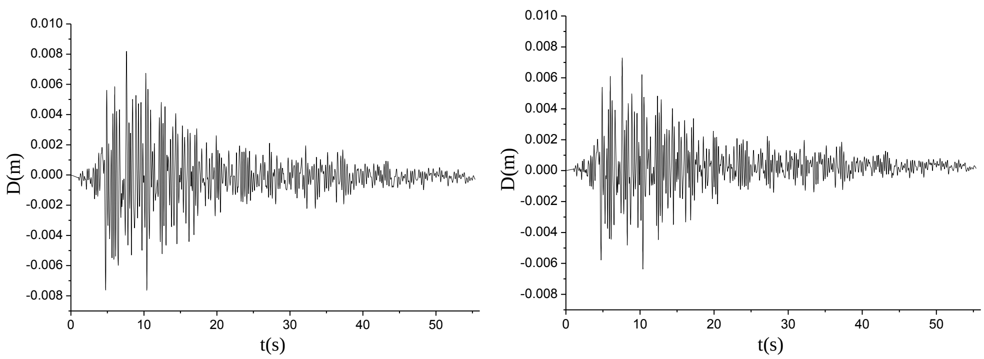
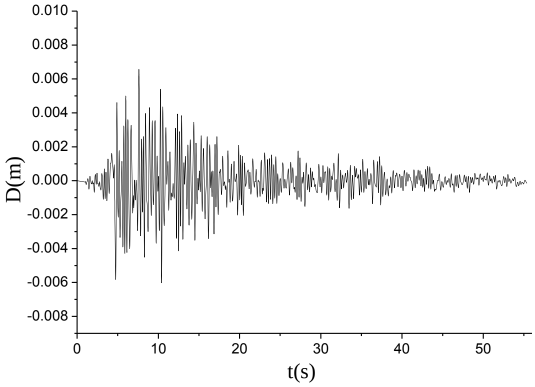


Fig 3: Time history and Response Spectrum of the Taft wave

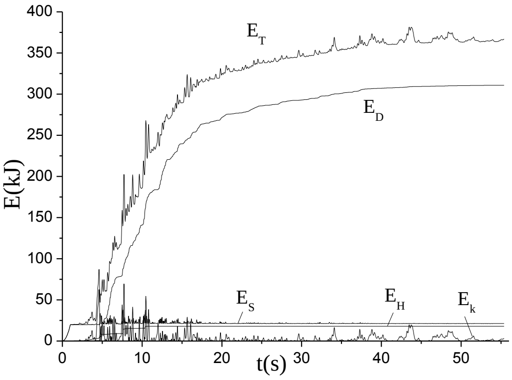


(a) Non-filler walls (b) partially filled walls

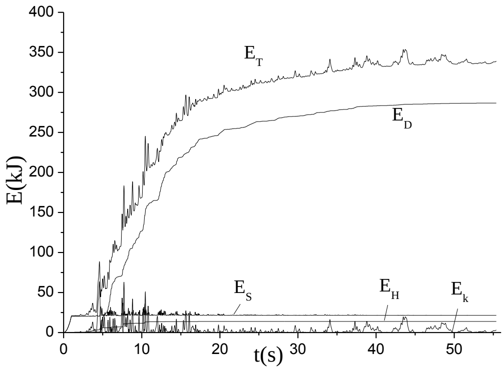


(c) Complete infilled walls

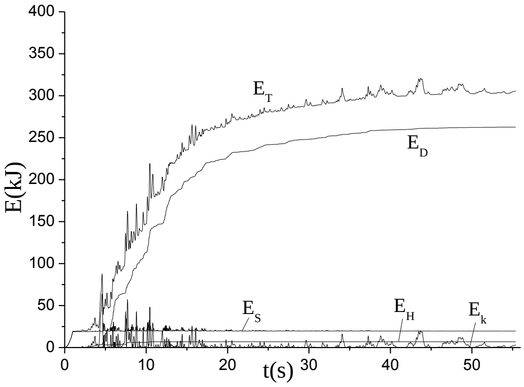
Fig.4. The maximum displacement value of sixth floor under Taft wave



(a) Non-filler walls



(b) partially filled walls

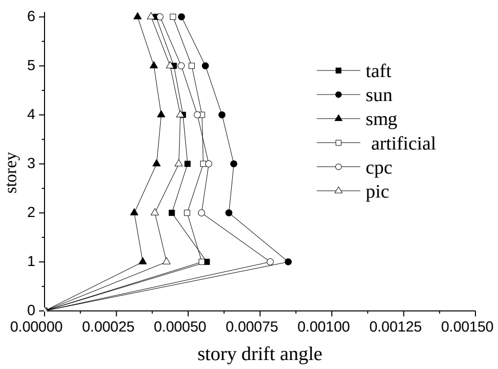


(c) Complete infilled walls

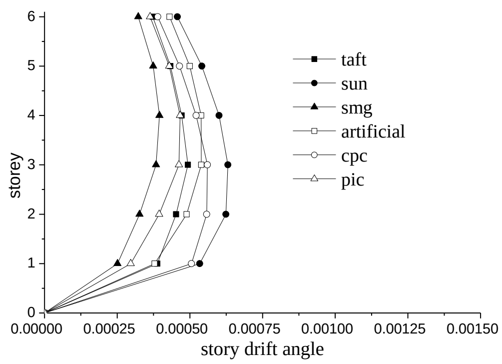
Fig.5. The energy dissipation under Taft wave

In the initial stage of seismic action, the acceleration of seismic action was small and the structure stayed in the elastic stage. The hysteretic energy and damping energy of the structure were small, and the total input energy was composed of kinetic energy and elastic strain energy. With the increase of seismic action, the damping energy dissipation of the structure increased.

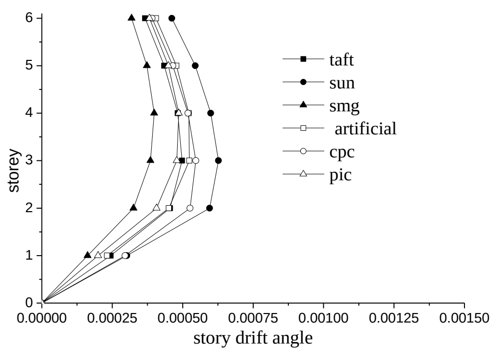
The structure gradually entered the plastic stage from the elastic stage and the hysteretic energy increased obviously. When the earthquake intensity became smaller, plasticity ended developing. However, the damping energy and hysteretic energy of the structure were slowly increasing. As can be seen from Fig.5, the difference of the kinetic energy and the elastic strain energy of the masonry structure with bottom frame filler walls was small. The damping energy dissipation and hysteretic energy dissipation of the structure showed great differences, which decreased with the increase of the number of filler walls. The damping was proportional to the stiffness of the structure. The stiffness and damping of the bottom frame were both increased after setting the filler walls, which reduced the speed of the whole structure in the process of vibration. Therefore, the damping energy dissipation reduced. The magnitude of hysteretic energy was related to material yield and stiffness degradation. After setting the fill walls, the hysteretic energy of the bottom frame layer increased. As a result, the damage of the superstructure reduced so did the hysteretic energy of the whole structure.



(a) Non-filler walls



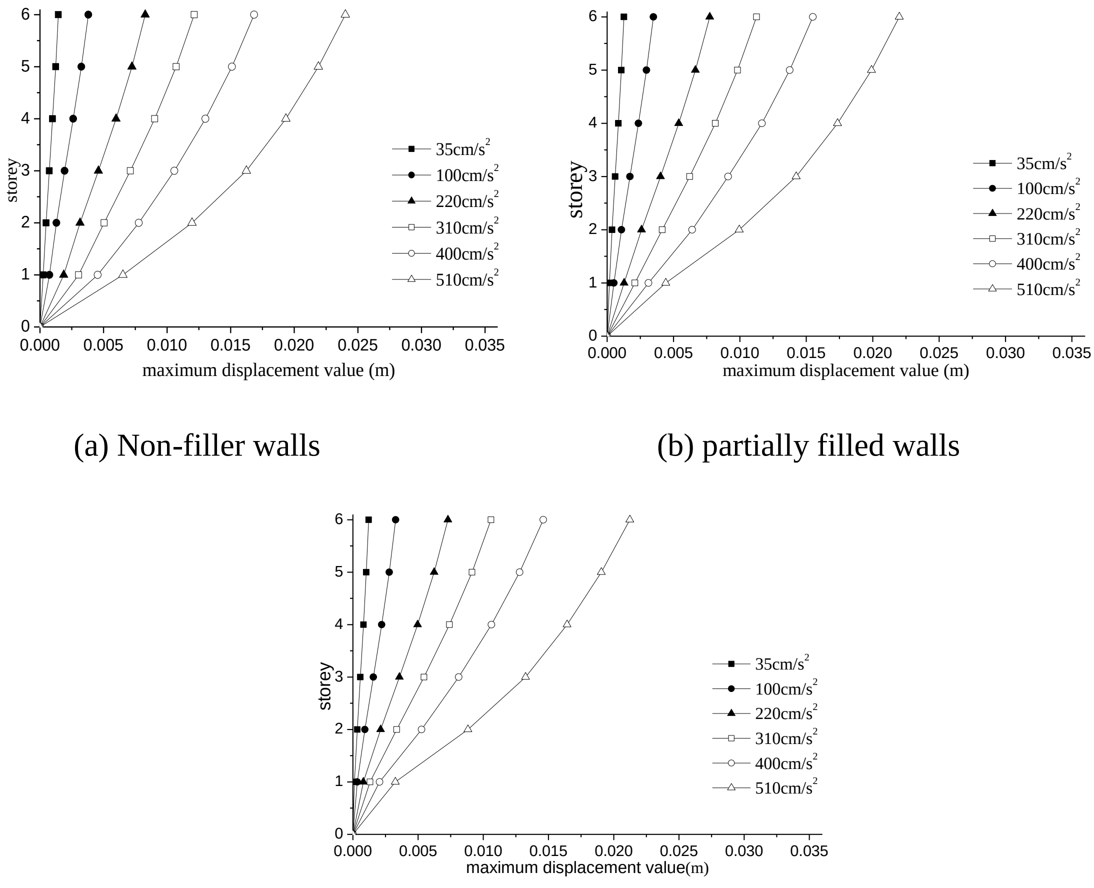
(b) partially filled walls



(c) Complete infilled walls

Fig.6. Story drift angle under Taft wave

Fig.6 showed the response of the story drift angle of the structure under different seismic waves. The response of the displacement angle and the maximum lateral displacement of the structure under different seismic actions showed the same trend. With no filler wall, the displacement angle of the bottom frame layer was bigger than that of the upper masonry. The storey drift angle of upper masonry floor uniformed distribution. With the increasing number of filler walls, the bottom frame drift angle decreased and the maximum lateral shift structure reduced in turn. The results showed that filler walls made the weak layer of the structure change from the original frame layer to the transition layer. Therefore, in engineering practice, it is necessary to consider the strengthening of the transition layer by filler walls. In order to obtain the seismic response of the structure from elastic stage, cracking stage, elastic-plastic stage to failure stage, elastic plastic time history reaction of structure with no filler walls and filler walls was studied under corresponding wave around the minor earthquake, moderate earthquake and major earthquake.



(a) Non-filler walls

(b) partially filled walls

(c) Complete infilled walls

Fig.7. The maximum displacement value of the point

In order to obtain the seismic response of the structure from elastic stage, cracking stage, elastic-plastic stage to failure stage, elastic plastic time history reaction of structure with no filler walls and filler walls was studied under corresponding wave around the minor earthquake, moderate earthquake and major earthquake. It can be seen from Fig.7, when the value of acceleration of seismic wave was small, the displacement of each layer of the structure was small and uniformed distribution. The inter storey drift angle increased with the increase of PGA. The displacement angle of each layer was different due to the different degree of yielding. With no filler walls, the bottom frame layer was the weak layer and the inter layer displacement angle was relatively large. After setting filler walls, transition layer gradually became the weak layer and the transition layer displacement increased with the increase of seismic wave acceleration. The set of the filler walls changed the yield mechanism of the structure.

6. Conclusion

(1) The lateral stiffness of the bottom frame is directly affected by the filler walls and the contribution of the filler walls to the stiffness of the bottom frame depends on the tensile strength of the material.

(2) The value of bottom layer lateral stiffness is related to the number of filler walls. With full filler walls, the stiffness of filler walls increased to 9.3 times of that without filler walls. The correlation between the lateral stiffness of the transition layer and the number of the bottom frame filler walls was small. However, with the increase of seismic intensity, the stiffness ratio of the transition layer and the bottom frame layer decreased gradually.

(3) Setting filler walls in bottom frame can reduce the translation period and reversal period, which improved the torsion resistance obviously.

(4) Under strong earthquake, arrangement of more filler walls reduced the inter layer displacement by40%~50%. Because of the set of the filler walls, the weak layer of the building structure moved from the bottom frame layer to the transition layer.

(5) The research on the Seismic performance of bottom frame masonry building with two story frame at the bottom setting filler walls was unsure. The related experimental research will be the focus of the follow-up study.

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