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The Research of the Influence of Beams and Columns Internal Forces in Bottom Frame Layer of Masonry Building with Bottom Frame on Filler walls

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Abstract: During earthquakes, the beams and columns internal forces in bottom frame layer of masonry building could be influenced by filler walls, and the failure modes that not meet the expected design might occurred in the structure. Therefore, the research of its influence on filler walls was of great significance to perfect the seismic design method of such buildings and to improve its seismic performance. In this paper, ABAQUS finite element procedure was used in modeling, and a six-story masonry building with bottom frame of single span was analyzed, besides, the four typical arrangement forms of no filler walls, complete, half-height and half-span filler walls were considered to study the influence of beams and columns internal forces in bottom frame layer. The results showed that after the filler walls were arranged completely, the moment and shear of all positions were decreased except that the shear of right columns in bottom frame layer was increased 1.5 times; After the half-height filler walls were arranged, the shear mutation was appeared in middle of bottom frame layer columns, and the mutation amplitude was 24%~36% of the original columns shear, and it was easy to occur short column failure; After the half-span filler walls were arranged, the bottom frame layer beams control sections positions were moved to no filler walls side, and the middle of beams shear were increased 6 times to the situation of no filler walls, and it was easy to occur shear failure in the positions of middle spans. Therefore, it was necessary to implement strengthening design in above positions.

Keywords: *masonry buildings with bottom frames; beams and columns internal forces; finite element analysis; filler*

1. Introduction

For masonry building with frame-shear wall at the bottom (short for masonry building with bottom frame), the one or two-stories in bottom were frame shear-wall structure, and the upper was masonry structure, it was a kind of composite structure building. In the bottom frame layers of such buildings, according to the use function requirements, the filler walls were often arranged. As kinds of nonstructural components, in the structure design, the filler walls were usually simplified as the load on structures, and consider it had no effect on the beams and columns internal forces in bottom frame layer. However, all of the earthquake damage experience showed that the beams and columns internal forces in bottom frame layer could be affected by filler walls in earthquake process, and then the failure modes that not meet the expected design were appeared in structures. Thus, the research of the influence of beams and columns internal forces in bottom frame layer of masonry building with bottom frame on filler walls was of great significance to perfect the seismic design theory of such buildings and to improve its seismic performance.

At present, the research of masonry building with bottom frame was mainly incarnated in the influence of its natural period global deformation bottom frame layer injury and lateral stiffness [1] on filler walls, besides, the interaction between filler walls and bottom frame layer [2] was studied. But the influence of beams and columns internal forces in bottom frame layer on filler walls was still unclear, considering the influence of internal forces and seismic performance of the frame structure were indispensable[3~7], therefore, it was necessary to study its influence on beams and columns internal forces in bottom frame layer of masonry building with bottom frames.

In this paper, ABAQUS finite element analysis was used in modeling, and a six-story masonry building with bottom frame of single span that extracted from practical projects was analyzed, according to the specific conditions, four typical arrangement forms of no filler walls, complete, half-height and half-span filler walls were considered, then the changes of beams and columns internal forces in bottom frame layer were compared and analyzed, and the influence law was obtained, then the design suggestion was given.

2. Structure General Situation and Finite Element Modeling

2.1. Structure General Situation

In this paper, a single span structure that extracted from a practical project of 7 degree was analyzed; there was one frame layer with 3.3m high in bottom, and five masonry layers with 3m high in upper part. The span was 6m, and the plate thickness was 120mm. For upper masonry structure, the fired common brick was used, and its strength grade was MU10, the mortar was M5, and the wall thickness was 370mm. For bottom frame, the concrete used in beams and columns was C40, its density was 25kN/m^3, and its elastic modulus was 3.25×10^{4}MPa. The section sizes and reinforcements of beams and columns in bottom frame layer were shown in fig.1.

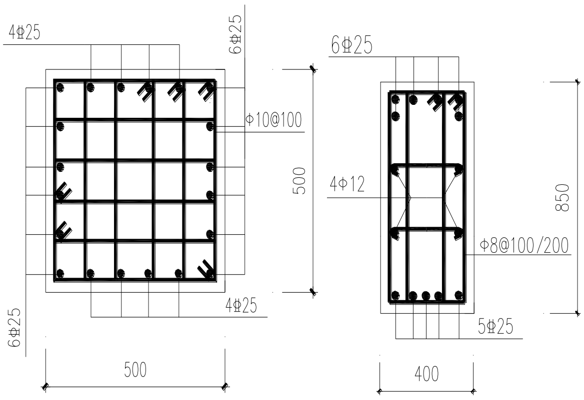


Figure 1: *Section reinforcements of beams and columns*

2.2. Unit type and Connection Mode

The ABAQUS finite element program was used in modeling of masonry building with bottom frame, the secondary spatial truss unit T3D3 was used in steel bar, and the linear reduction integral unit C3D8R was used in concrete.

In analysis, the relative slip between steel bar and concrete was not considered, and the steel bars were embedded into the concrete of beams and columns in bottom frame layer, directly. Meanwhile, consider there were no relative slip between beams and columns, plates and walls, beams and walls, which means that the binding constraint connection was used.

2.3. Constitutive relations of Materials

(1) Constitutive relation of concrete

The uniaxial stress-strain constitutive relation of concrete was two-parameter model that proposed by Guo zhen-hai, considering the characteristics of concrete plastic damage model in ABAQUS, the concrete stress-strain relation was simplified, that was to say, the tensile stress-strain relation curve was linear before the tensile strain reached to the strain that corresponded to tensile strength[8].

The compressive stress-strain relation curve of concrete was expressed as:

$$y=ax+(3-2a)x^2+(a-2)x^3 \quad x\le 1$$

$$y=x/[\alpha(x-1)^2+x] \qquad x\ge 1 \tag{1}$$

The tensile stress-strain relation curve of concrete was expressed as:

$$y=\varepsilon_{tp}E_0 x/f_t \qquad x\le 1$$

$$y=x/[\alpha(x-1)^{1.7}+x] \qquad x\ge 1 \tag{2}$$

(2) Constitutive relation of masonry

In this paper, the materials of filler walls were MU10,M5[9~10],the uniaxial compressive constitutive relation of masonry structure was used, and its formula was:

$$\varepsilon=-\frac{1}{\xi}\ln\left(1-\frac{\sigma}{f_m}\right) \tag{3}$$

2.4. Model Load

In the model analyzed, the vertical load and horizontal seismic action were considered simultaneously. For vertical load, the dead and live load of plate in the range of load areas were considered, which was shown in fig.2, and simplified as a surface load in the range of model thickness, then applied it to the floors of each layer. For horizontal seismic action, it was calculated by base shear methods, and applied it to the floors of each layer in the form of concentrated force, the horizontal seismic action calculation results of each layer were shown in tab.1.

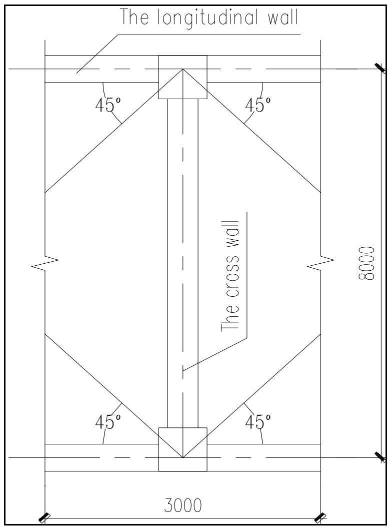


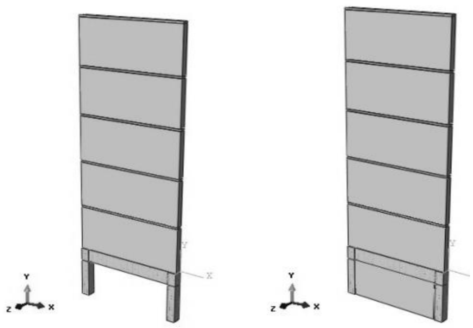
Figure 2: *Calculation diagram of load areas*

Table 1: *Calculation of horizontal seismic action*

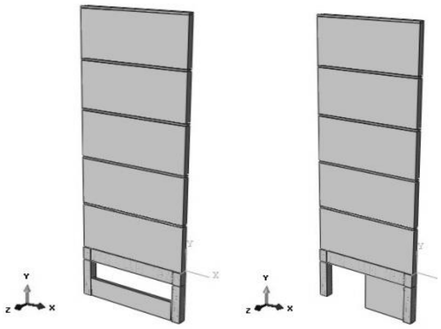
Layer	H_i/m	G_i/kN	G_iH_i /kN·m	$\frac{G_iH_i}{\sum_{j=1}^{n}G_jH_j}$	F_i/kN
6	18	144.54	2645.08	0.197	17.70
5	15	230.58	3527.87	0.262	23.61
4	12	230.58	2836.13	0.211	18.98
3	9	230.58	2144.40	0.160	14.35
2	6	230.58	1452.65	0.108	9.72
1	3	257.39	849.400	0.063	5.69

3. The Influence of Beams Internal Forces in Bottom Frame Layer on Filler Walls

According to the specific circumstances in practical projects, four typical arrangement forms of no filler walls, complete, half-height and half-span filler walls were considered, as shown in fig.3. Through comparative analysis, the influence of beam internal force in bottom frame layer on filler walls was studied.



(a) no filler wall *(b) complete filler wall*



(c) half-height filler wall *(d) half-span filler wall*

Figure 3: *Four arrangement forms of filler walls*

Under the combined action of the vertical load and horizontal seismic, the moment and shear calculation results of structure model bottom frame beams corresponded to the four above arrangement forms of filler walls were shown in tab.2. Among them, ML represents the left support moment of beam, and other variables were similar to it.

Table 2: *Main calculation results of beams internal forces*

Arrangement Forms	(a)	(b)	(c)	(d)
M_M(kN·m)	133.0	62.4	133.3	128.5
M_L(kN·m)	59.7	11.3	58.8	45.6
M_R(kN·m)	24.4	14.0	33.8	6.9
V_L(kN)	449.1	236.7	447.2	411.0
V_R(kN)	254.6	101.2	261.1	112.5
V_M(kN)	15.6	9.5	16.9	93.2

According to the calculation results in tab.2, the beams internal force diagram under different filler walls arrangement forms were drew, and compared it to the internal force that corresponded to no filler walls, and then the influence of bottom frame beams internal forces on filler walls could be obtained.

The comparison of moment and shear of bottom frame beams between the arrangement of complete and no filler wall was shown in fig.4, among which, the dash line represents the internal forces of bottom frame beams under the arrangement of no filler walls.

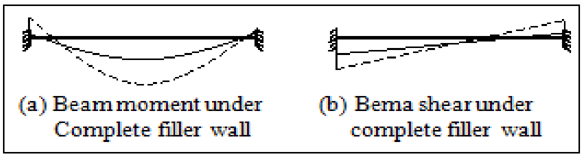


Figure 4: *The comparison of moment and shear of bottom frame beams under complete filler walls*

The tab.2 and fig.4 showed that after the complete filler wall was arranged in masonry building with bottom frame, compared to the arrangement of no filler walls, the middle span and right support moment of bottom frame beam were decreased about 50%, and the left support moment decrease amplitude was bigger, which was about 20%; and the beam end shear was also decreased, which was about 50%. The bottom frame arranged of filler walls was a shear-wall with side frame to resist the external load together, because of the existence of filler walls, the deformation of bottom frame beam was decreased, and then its internal force was decreased, too. Above all, this was the reason for why the moment and shear was decreased.

The comparison of moment and shear of bottom frame beams between the arrangement of half-height filler walls and no filler walls were shown in fig.5.

From tab.2 and fig.5 we could know, after the half-height filler walls were arranged in masonry building with bottom frame, compared to the arrangement of no filler walls, both the right support moment and right beam end shear were increased, but the increase amplitude was smaller, this was because the half-height filler wall was lied in the lower half part of the bottom frame layer, and disconnect with bottom beam, thus, its effect on beam internal forces was small.

The comparison of moment and shear of bottom frame beams between the arrangement of half-span and no filler walls were shown in fig.6.

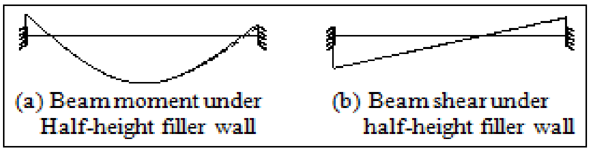


Figure 5: *The comparison of moment and shear of bottom frame beams under half-height filler walls*

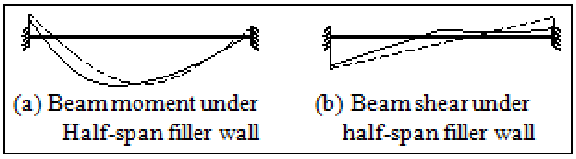


Figure 6: *The comparison of moment and shear of bottom frame beams under half-span filler walls*

The tab.2 and fig.6 showed that after the half-span filler wall was arranged in masonry building with bottom frame, compared to the arrangement of no filler walls, the middle span moment of beam had no obvious change, but the central position of maximum moment section was moved from the middle of beam to the middle of half-span on the arrangement of no filler walls; The left and right supports moment were decreased, but the decrease amplitude of right support was bigger, which was about 30%; All the beam ends shear were decreased, for the end of no filler walls, the shear decreased about 90%, and for the end of filler walls was about 50%.

The beam mid-span shear was increased suddenly in the edge of half-span filler walls, and the increase amplitude was 6 times as large as the arrangement of no filler walls, this was because the setting of half-span filler walls was equal to add an concentrated force in the middle span of beam, which lead to the increase of beam middle span shear, and the stress mutation was appeared, thus, in designs, there should be proper strengthen in those positions.

4. The Influence of Columns Internal Forces in Bottom Frame Layer on Filler Walls

Under the combined action of the vertical load and horizontal seismic, the moment and shear calculation results of structure model bottom frame columns corresponded to four above arrangement forms of fill walls were shown in tab.3.

Table 3: *Main calculation results of columns internal forces*

Arrangement	(a)	(b)	(c)	(d)
N_L(kN)	963.8	800.9	998.1	904.6
N_R(kN)	549.0	366.6	537.0	387.7
M_{LT}(kN·m)(kN·m)(kN·m)(kN·m)	111.7	39.9	106.0	95.7
M_{LB}(kN·m)	140.6	57.9	100.7	121.7
M_{RT}(kN·m)	39.9	18.2	46.0	19.9
M_{RB}(kN·m)	7.9	7.9	7.7	17.6
V_{LT}(kN)	145.4	96.5	153.5	125.2
V_{LB}(kN)	145.4	96.5	117.9	125.2
V_{RT}(kN)	21.2	31.0	29.2	-1.5
V_{RB}(kN)	21.2	31.0	36.9	12.3

According to the calculation results in tab.3, the columns internal force diagrams under different filler walls arrangement forms were drew, then compared it to the internal forces that corresponded to no filler walls, and then the influence of bottom frame columns internal forces on filler walls was obtained.

The comparison of moment and shear of bottom frame columns between arrangement of complete and no filler walls was shown in fig.7, among which, the dash line represents the internal forces of bottom frame columns under the arrangement of no filler walls.

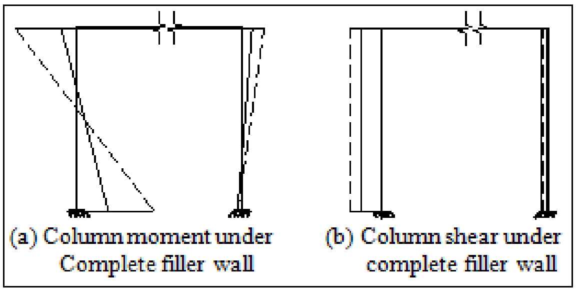


Figure 7: *The comparison of moment and shear of bottom frame columns under complete filler walls*

The tab.3 and fig.7 showed that after the complete filler wall was arranged in masonry building with bottom frame, compared to the setting of no filler walls, the column axial force decreased about 66%~80%, the column end moment decreased about 35%~45%, the left column shear decreased about 66%, but the right column shear increased 1.46 times. After the filler wall was arranged completely, the column internal forces decreased in total, the right column shear increased slightly, and should be paid attention in design.

The comparison of moment and shear of bottom frame columns between arrangements of half-height and no filler walls were shown in fig.8.

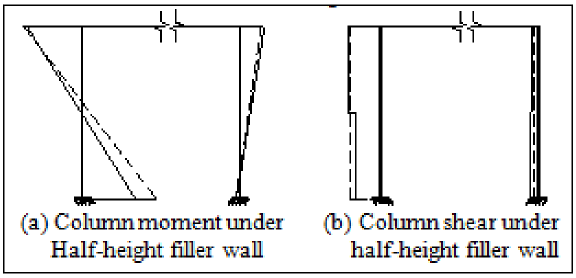


Figure 8: *The comparison of moment and shear of bottom frame columns under half-height filler walls*

From tab.3 and fig.8 we know that after the half-height filler walls were arranged in masonry buildings with bottom frames, compared to the arrangement of no filler walls, the columns axial forces had no obvious change; the top moment of left column decreased about 95%, the decrease amplitude of bottom moment was bigger, which was about 71%; The top moment of right column increased about 1.15 times, the bottom moment was unchanged; The top shear of left column increased, and the bottom shear decreased, the mutation was formed in half-height, and the mutation amplitude was about 24% of the arrangement of no filler walls; Both the top and bottom shear of right columns increased, the increase amplitude was bigger, and the mutation was formed in half-height too, the mutation amplitude was about 36% of the arrangement of no filler walls. The arrangement of filler walls in frame structure increased the column top shear, and the appearance of stress mutation in half-height decreased the slenderness ratio and shear span ratio, then the short column was formed, and then the shear failure was easy to happen. Under the repeated horizontal seismic action, the inclined and cross cracks might be produced, and the crack width was too large to restore, so the steel bars were yield and broke, which belonged to brittle failure, namely, "short destruction", thus, in design, should be paid appropriate attention.

The comparison of moment and shear of bottom frame columns between the arrangements of half-span and no filler walls were shown in fig.9

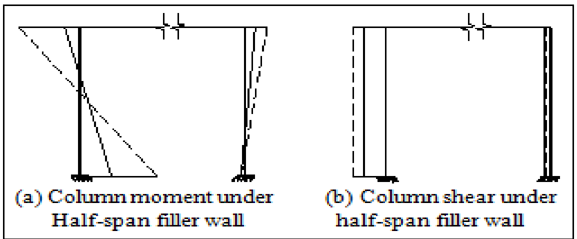


Figure 9: *The comparison of moment and shear of bottom frame columns under half-span filler walls*

The tab.3 and fig.8 showed that after the half-span filler wall was arranged in masonry building with bottom frame, compared to the arrangement of no filler walls, the column axial forces of two sides were all decreased, but the decrease amplitude of the filler wall side was bigger, which was about 70%; The column end moment of left side was decreased, which was about 85%, and the top column moment of right side was decreased about 50%, the bottom was increased about 2.2 times; The column shear of left side was decreased slightly, because the arrangement of half-span filler walls, the top column shear direction was changed, and the bottom moment was decreased about 50%. After the arrangement of half-span filler walls, the column end moment was decreased in total, the increase amplitude of bottom column moment of right side was bigger, but the value was small.

5. Conclusions

(1) After the complete filler wall was arranged, expect the right column shear was increased about 1.5 times, the shear and moment of other positions of frame layer beams and columns were all decreased, and the decrease amplitude was about 50%.

(2) After the half-height filler wall was arranged, the shear mutation would be formed in middle of column, the mutation amplitude was about 24%~36% of original column shear, and the short column destruction was easy to happen.

(3) After the half-span filler wall was arranged, the position of the bema mid-span control section was moved to the side of no filler wall, and the mid-span shear of bottom frame beam was increased about 6 times of the arrangement of no filler wall, besides, the shear failure was easy to happen in the beam mid span.

6. Acknowledgement

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