STUDY ON SEISMIC EFFECT OF BLOCKS FILLED IN MULTI-RIBBED COMPOSITE WALL

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ABSTRACT :

Earthquake, which breaks out abruptly and unpredictably, is seriously threatening the safety of people's life and possessions. As China is an earthquake-prone country, it is of great importance for us to exploring new damage-reduction methods. Multi-ribbed composite wall structure (MRCWS) is a new type of structure which has certain advantages in light weight and seismic performance, and multi-ribbed composite wall (MRCW) is the main bearing component of MRCWS. In this paper, first of all, the constitution and characteristics of MRCWS is simply introduced. And then based on the former experiment, comparisons are made between the wall filled and unfilled with blocks. After that, with FEM analysis applied, the FEM model of MRCW is proposed and the energy-dissipation rate of each part is calculated. It draws the conclusion that the blocks play an important role in strengthening the bearing capacity, stiffness and dissipating the input energy, which indicates that they are beneficial to the seismic performance of MRCW.

KEYWORDS: Multi-ribbed composite wall, seismic performance, energy dissipation, blocks

1 INTRODUCTION

1.1 Background

Earthquake, which breaks out abruptly and unpredictably, is seriously threatening the safety of people's life and possessions. China is an earthquake-prone country with widely-spreading earthquake regions and strong earthquake intensity, and almost all the provinces, autonomous regions and municipalities in China used to suffer attacks caused by over 6.0 magnitude earthquake in the history. According to the statistics, during the 20th century, the devastating earthquakes happened in China accounted for 1/3 of the world, and as high as 60 million people were killed in the earthquakes which occupied about 1/2 of the world. Not long ago, a powerful earthquake of 8.0 magnitude struck China's Sichuan province, which killed tens of thousands of people, toppled nearly 5,461,900 buildings and caused millions of people homeless.
For earthquake disasters, the damage and collapses of engineering structures are the mainly direct factors which induce the loss of life and economic assets. Therefore, it is an effective way to reduce earthquake disasters by strengthening the seismic fortification and seismic performance of the engineering structures. Recently, with the vocation of national government, some new building structures having certain advantages in light weight and seism resistance are put forward, such as small concrete hollow block structure, CL structure, ZW structure and multi-ribbed composite wall structure etc. (Zhu 2004)

1.2 Multi-ribbed Composite Wall Structure

Multi-ribbed composite wall structure (MRCWS) is a new kind of building structure which has good performance in seism resistance and energy dissipation. It is composed of multi-ribbed composite wallboard (MRCWB), concealed outer frame (COF) and floor. MRCWB, a new pre-cast board component, is made up of low-ratio-of-reinforcement RC frame filled with light-weight blocks, and the blocks are made of industrial waste such as slag, fly ash etc. COF is composed of end frame column, concealed column and concealed beam. MRCW is connected with COF by U-shape steel bars which extend from the wallboard, and then they are cast together to make a unity called multi-ribbed composite wall (MRCW). When horizontal loads applied, MRCWB could be strongly constrained by COF, and COF could also be effectively supported by MRCWB at the same time, which indicates that they can bear the loads together and deform coordinately (Yao 2003). The constitutions of MRCWS and MRCW are shown respectively in Figure 1 and Figure 2.

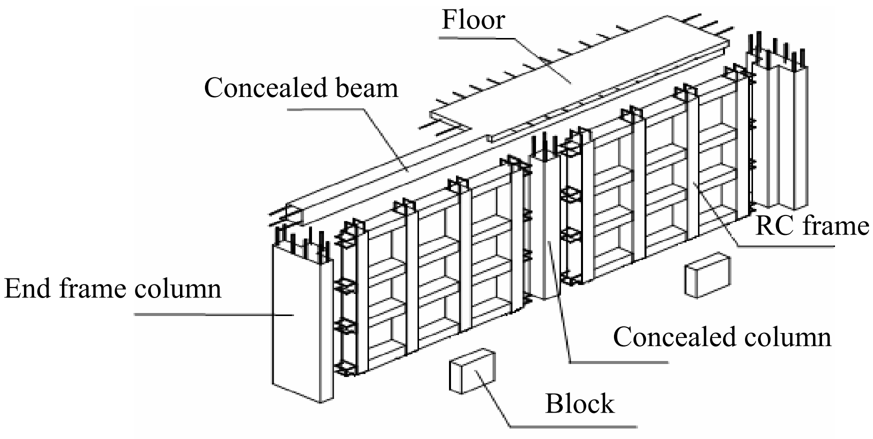


Figure 1 Multi-ribbed composite wall structure

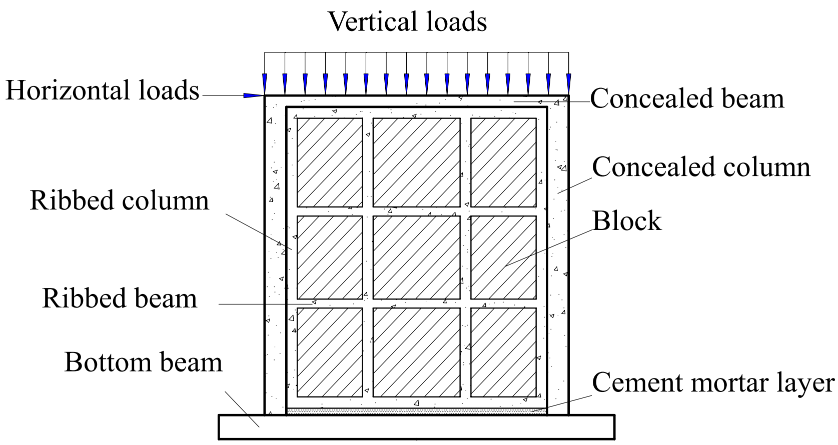


Figure 2 Multi-ribbed composite wall

The research of MRCWS started in 1990, and some phased results have been gained through a number of experiments and theoretical analyses. It was shown in the former experiments that with the blocks constrained by the RC frame, the cracks in the blocks are limited to a certain degree, and when low-cyclic reversed loads applied, the cracks produced by the loads of one direction could get closed under the loads of the other direction, so that the stiffness and bearing capacity of MRCW will not reduce dramatically. Meanwhile, with the blocks' cracking, restituting and frictionizing repeatedly, an amount of energy is dissipated, making it possible to protect the main bearing component of MRCW. When earthquake happens, MRCW appears to get damaged step by step from the blocks to RC frame and then to COF, which indicates a damage-reduced failure mode (Yao 2008). From these phenomena it can be clearly seen that the blocks play an important role in strengthening the seismic performance of MRCW, and this paper is aiming to discuss the blocks' seismic effect on MRCW.

2 EXPERIMENTAL STUDY

With 3 batches of specimens tested, about 36 MRCW models have been studied on the bearing mechanism, failure mode, seismic performance etc. In order to discuss the seismic effect of the blocks, the specimen MLB1 filled with blocks and MLB5 unfilled with blocks (Zhang 2004) are used to be compared in detail as follows.

2.1 Summary of Experiment

The dimensions of the specimens adopted 1/2 scale are shown in Figure 3. The reinforcements in RC frame adopted 4Φ4, and the stirrups adopted Φ2@100; the reinforcements in COF adopted 4Φ6, and the stirrups adopted Φ4@100.

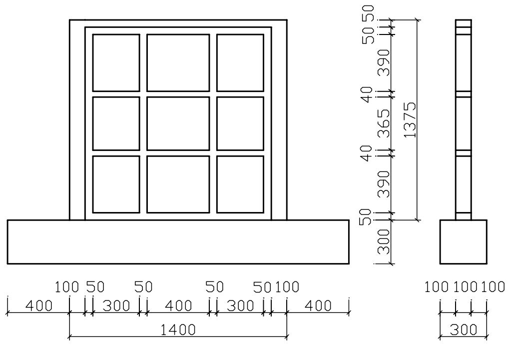
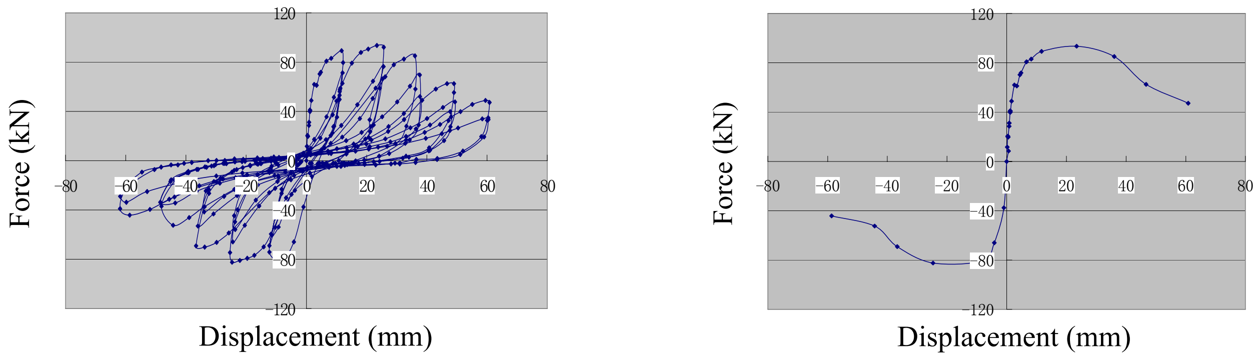


Figure 3 Dimensions of specimens

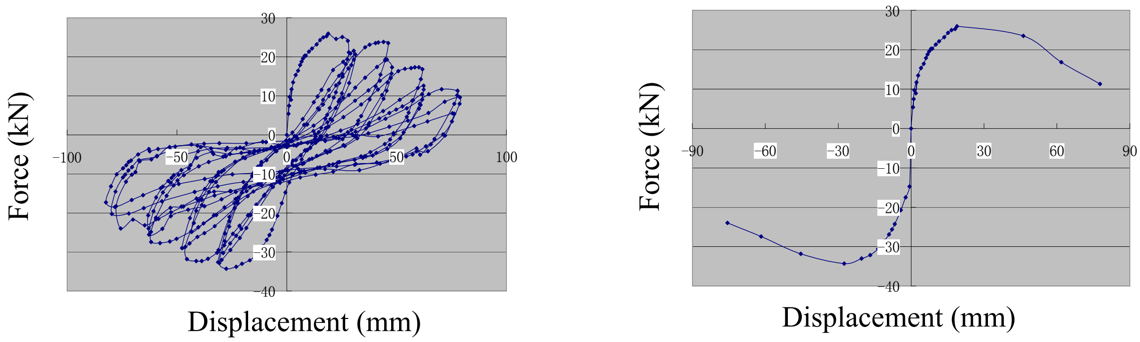
In the experiment, the vertical loads stayed constant with an axial compressive ratio of 0.2. The horizontal loads adopted mix-loaded method, and before the specimens yielded, the experiment was controlled by monotonic loading; while after the specimens yielded, it was controlled by displacement with 3 times repeated for each stage.
The experimental results are shown in Table 2, and the hysteresis curves and skeleton curves are shown in Figure 4.

Table 2 Experimental results (kN)

Specimen	Cracked load				Broken load			Ultimate load
	Block	Ribbed beam	Ribbed column	Concealed column	Ribbed beam	Ribbed column	Concealed column	
MLB1	30	50	70	88	60	88	93	93
MLB5	—	15	15	20	25	25	25	26



(a) Specimen MLB1



(b) Specimen MLB5

Figure 4 Hysteresis curves and skeleton curves

2.2 Experimental Analysis

2.2.1 Failure process

According to the experimental phenomena and results, both the failure process of MLB1 and MLB5 could be approximately divided into three stages: elastic stage, elastic-plastic stage and failure stage. In the first stage, the horizontal loads were less than 40% of the ultimate value, and there were no cracks in the ribbed beams and columns, only a few exiguous cracks developed in the blocks filled in MLB1, and the skeleton curve remained approximately linear; in the second stage, the cracks emerged in the ribbed beams and columns, and the skeleton curve became non-linear as the stiffness started to decrease with the increasing of displacement; in the last stage, after the horizontal loads reached the ultimate value, some cracks cut through the ribbed beams and columns, even extended to the concealed column, and the reinforcements in the concealed columns had been yielded as well.

When the experiment finished, the reinforcements in ribbed beams of MLB5 got exposed and twisted, the bottom beam and RC frame got separated and the concrete of concealed columns got crushed at the bottom; while for MLB1, only the blocks got broken and dropped, but RC frame and concealed outer frame did not appear to be seriously broken, which could still bear the vertical loads effectively and keep the wall standing.

Based on this observation, it can be concluded that both MLB1 and MLB5 present shear failure type, and the blocks have no effect on changing the failure type of MRCW. However, with the blocks filled in MRCW, the destructive degree of RC frame and COF of MLB1 is reduced much more evidently than MLB5, which indicates that the blocks act as a kind of damage-reduced component.

2.2.2 Bearing capacity

Compared the results shown in Table 1, it is clearly seen that the bearing capacity of MLB1 is improved more dramatically than that of MLB5, and the cracking load, yield load and ultimate load of MLB1 are enhanced by 3.19, 2.80 and 2.58 times than MLB5, which shows that the blocks have a dramatic effect on improving the horizontal bearing capacity of MRCW.

2.2.3 Stiffness

Seen from Figure 4, the shape and changing law of skeleton curve for MLB1 and MLB5 are mostly the same. Before the wall cracked, the curve generally keeps linear and stiffness holds constant ; with the wall cracked, the stiffness gradually gets reduced, and it falls to zero when the horizontal loads reach ultimate; after that, the stiffness becomes negative, and the value becomes increased till the curve inflexion.

However, as a result of the blocks' supporting effect, the initial stiffness is over 4 times larger than MLB5, which implies that the blocks dramatically increase the initial stiffness of MRCW.

2.2.4 Deformation

Ultimate displacement angle, the ratio of the ultimate displacement to the height of specimen, is an important index for estimating the deformation performance of the structures, and the ultimate displacement usually adopts the displacement corresponding to 85% of ultimate load on the descending segment of skeleton curve. As to MLB1 and MLB5, the ultimate displacement angles are respectively 1/36 and 1/27, which suggests that the blocks make the ultimate displacement angles of MRCW decreased a bit, but not too much.

2.2.5 Ductility

Ductility coefficient, the ratio of ultimate displacement to yield displacement, is usually used to evaluate the deformation performance after the structure or component is yielded. The ductility coefficients of MLB1 and MLB5 are respectively 5.1 and 5.8, which are not dramatically different from each other. This indicates that the blocks have little influence on the ductility of MRCW.

2.2.5 Hysteresis and energy dissipation

Before the wall cracked, the hysteresis curve generally kept linear and the stiffness stayed constant. With the loads increasing, the hysteresis loop declined to the displacement axis and the plastic deformation developed obviously. When the displacement used for load controlling, the stiffness was dramatically degenerated, and the area encircled by the hysteresis loop expanded greatly, so that the energy was also consumed enormously. As the displacement increased, the bearing capacity decreased promptly under the condition of large displacement. And as a result of the cracks expending in the blocks and concrete, the strain of steel developing, the residual deformation accumulating, the blocks and concrete smashing and destroying, it was very common for slipping to occur and for the stiffness decreasing rapidly as well, which caused the hysteresis curve to get pinched or even change to anti-S shape. However, there was no breakdown and the specimen still kept standing when the experiment was finished.
During the process of hysteresis loading, an amount of input energy was dissipated with the plastic deformation developed. In order to quantify the energy dissipation, the work index is calculated for MLB1 and MLB5, and the values are respectively 9.2 and 5.2, which indicates that the blocks provide MLB1 with a good energy dissipation performance.

3 FEM ANALYSIS

During the former experiments and studies, it was founded that the blocks filled in MRCW acted as a series of oblique braces, so the frame-brace model was put forward to simulate the mechanical status of MRCW, shown in Figure 5.

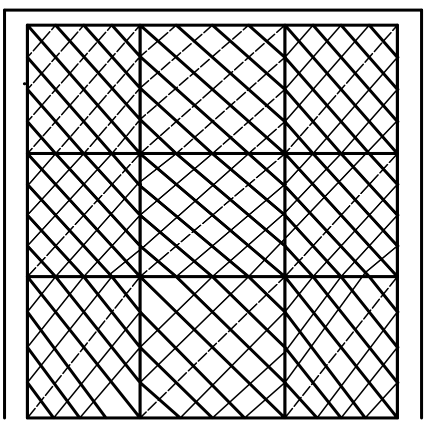


Figure 5 Calculation model of MRCW

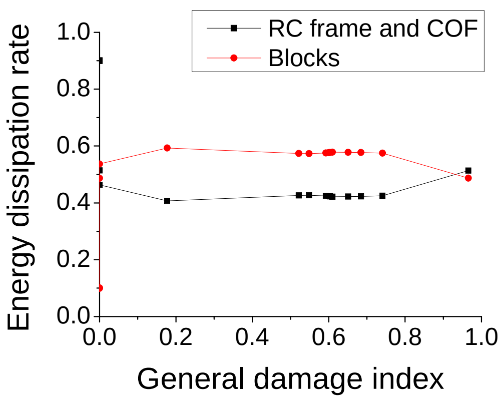


Figure 6 Energy-dissipation rate of MRCW

Based on the FEM program MRCS-D (Xiong 2008), the author calculates the energy-dissipation value of each part in MRCW, and the energy-dissipation rate of each part is shown in Figure 6.

It can be clearly seen from Figure 6 that at the very beginning, the energy-dissipation rate of the blocks occupies about 10%, and the RC frame and COF are the main bearing components. With the stress increasing, the energy-dissipate rate of the blocks enhances dramatically, and it adds up to about 50%~60% in the middle stage, which indicates that the effect of the blocks become greater and greater. And in this stage, the general damage index is primarily caused by the damage of the blocks, while the main component of MRCW is effectively protected to a certain degree. At last, as the blocks being damaged seriously, the energy-dissipation rate gets reduced and the RC frame and COF are used to bear the loads and principally again.

4 CONCLUSION

Multi-ribbed composite wall structure is a new kind of building structure which has good performance in seismic resistant and energy dissipation. As a result of the blocks filled in the wall, the bearing capacity and stiffness of MRCW are dramatically reinforced, while the deformation and ductility performance is not affected very large. What is more, with the blocks' cracking, restituting and fractionating repeatedly, an amount of energy is dissipated, making it possible to protect the main bearing component of MRCW. All of these above show that the blocks play an important role in MRCW, and they have an indispensable effect on improving the seismic performance of MRCW.

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