Fracture Mechanics of Concrete and Concrete Structures -
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Study on seismic behavior of concrete composite bearing wall

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ABSTRACT: Two concrete composite bearing walls were tested under low cyclic reversed lateral loading. The behavior such as deformation process, failure mechanism, hysteretic characteristic, ductility, energy-dissipation capacity and curve of stiffness degradation was studied. In the mean time, working performance of the prefabricated slabs and frame were investigated. The test results revealed that the prefabricated slabs and frame could work in coordination very well, they could form two seismic fortifications. The wall has good load-carrying capacity, seismic behavior and ductility. Besides, the load-carrying capacity and ductility of the wall connected with horizontal muscle is better than the other group.

1 FOREWORD

Energy saving of the residence and replacement of the bricks are hot issues of the construction industry. A new type of wallboard is designed in this paper, which is called the concrete composite bearing wall. The wall mainly composed of prefabricated slabs with polystyrene inside and contact framework is the main strength component of the concrete composite bearing wall housing. The prefabricated slabs and the contact framework were joined by reinforcing steel bar. The stealthy frame composed of columns and rib-beam could work in coordination with the prefabricated slabs to resist loading.The prefabricated slabs array in alternating can cut off the energy transmission. The building structure and the heat preservation could undergo integration and improve traditional measure to prolong the life of heat preservation material. The conformation of wall is displayed in Figure 1. [1] [2]

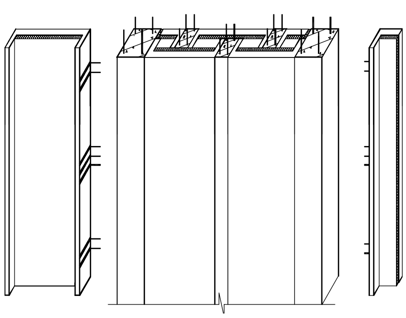

Figure 1. concrete composite bearing wall.

The concrete composite bearing wall is different from brick wall and common concrete wall, this paper mainly introduce about loading process, craze instance, failure process, the hysteretic characteristic, ductility, energy-dissipation capacity, curve of stiffness degradation and research harmony work of the prefabricated slabs and frame by experiment and analysis of finite element.

2 EXPERIMENTAL SCHEME

Two experimental walls (DW-01 and DW-02) were designed to simulate the bearing wall of twelve floors building, the size of the wall are 2330mm width, 270mm thickness and 2800mm high. The dimension of the components is showed in Figure 2.

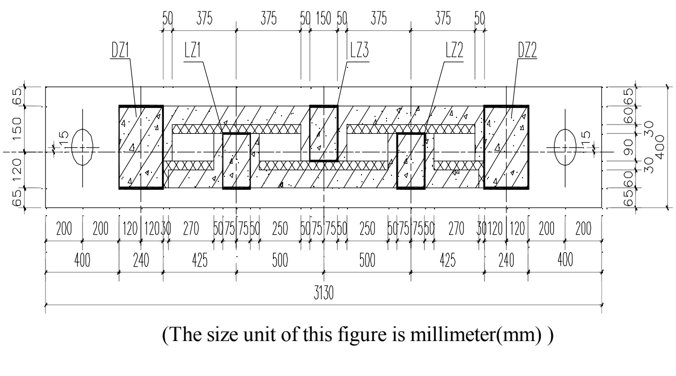

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Figure 2-a. ichnography of wall.

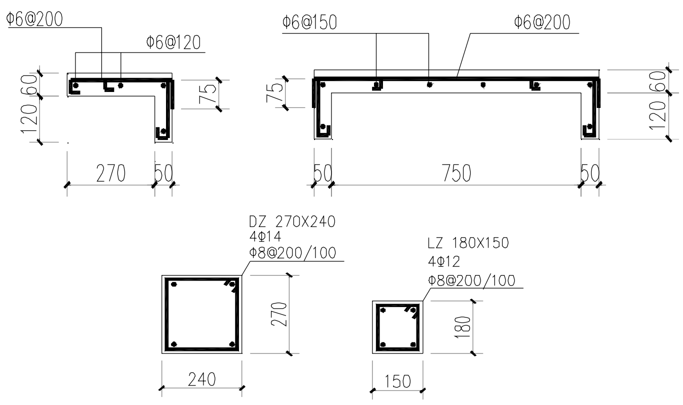

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Figure 2-b. component dimension.

The experiment was done in Key Laboratory of Concrete and Prestressed Concrete Structure, Ministry of Education, PRC. The reversed lateral load is forced by servo system and axial load is kept at 1000kN invariable, the designed axial compression ratio is 0.16. The reversed lateral load is controlled by load before the steel is yield and then controlled by displacement until failure. The experiment set-up is showed in Figure 3. [3] [4]

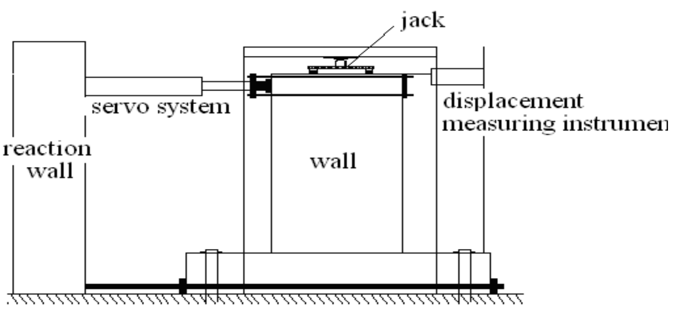

Figure 3. experiment set-up.

3 TEST RESULTS

3.1 *Test phenomenon*

The failure process of the two specimens is consistent, and generally could be divided into elastic stage, elastic-plastic stage and failure stage. The cracks of wall are drawn in Figure 4.

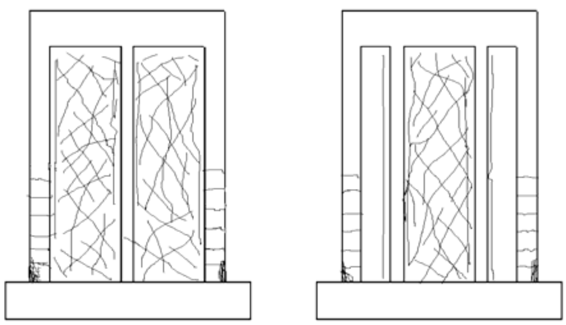

Figure 4. distribution of wall cracks.

Before lateral load achieved 60 percent of the limit load, the residual deformation of the specimen is small, the strain of steel and prefabricated slabs concrete is small too, and minor cracks appeared in surface of the prefabricated slabs only. The stealth frame and prefabricated slabs could resist external load together, the wall is in elastic stage.

While the lateral load achieved 60~75 percent of the limit load, the crack extended, the width of the main crack constantly increased, the number of cracks increased gradually, and the stiffness of the wall fell with the increasing load. When lateral load approached the limit load, the prefabricated slabs concrete broke off, the concrete crushed in the corner of prefabricated slab and bending cracks appeared in the pulled column.

The prefabricated slabs withdrew from work gradually with the number of cracks increased; the number of the bending cracks of the stealthy frame increased rapidly, and the concrete crushed in the compressed column of the stealthy frame while the lateral load achieved the limit load, the capacity of loading started declined. Because the interaction of the stealthy frame and the prefabricated slabs, and the wall cracked but didn’t collapsed and could bear any load. It indicated that the wall has good capacity anti-collapse. That the inside edge rib of the prefabricated slab cracked revealed that the prefabricated slab and the rib columns could made up of concrete composite columns. [5]

3.2 *Steel strain*

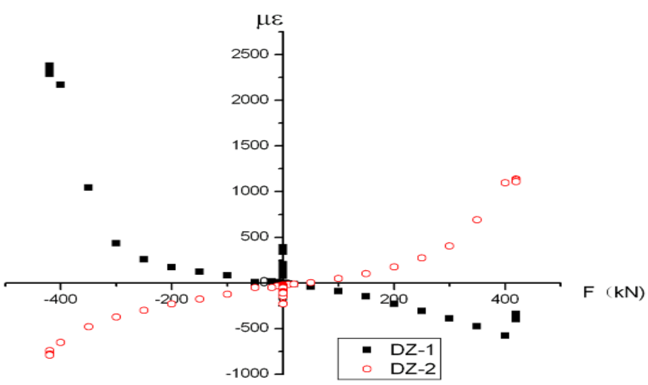

Figure 5-a. side column steel strain.

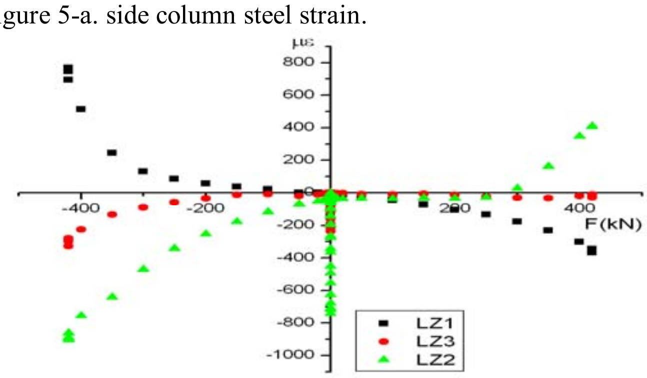

Figure 5-b. rib column steel strain.
Figure 5. steel strain changes line.

The steel strain of side column and rib are shown in Figure 5. In elastic stage, the steel strain is little and changes in linearity. The framework is in state of tension and compression from beginning to end, and resists external moment. After the wall crack, the steel strain increases rapidly and the concrete crushed when the load reached the limit load, then the wall's capacity of loading started decline. It could be known that the frame moment could constrain the prefabricated slabs, could restrict the extension and development of prefabricated slab's crack, the prefabricated slabs could give a good support to the frame, increase the lateral rigidity of wall and share part of the level load. In a conclusion, the frame and the prefabricated slabs could work in coordination well to resist loading. [6]

3.3 *Hysteretic curve and F- Δ curve*

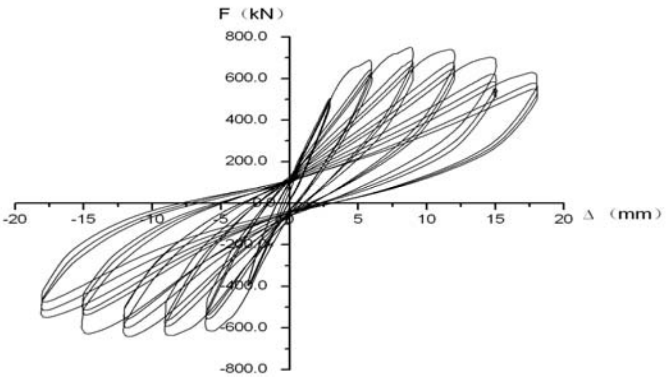

Figure 6-a. hysteretic curve.

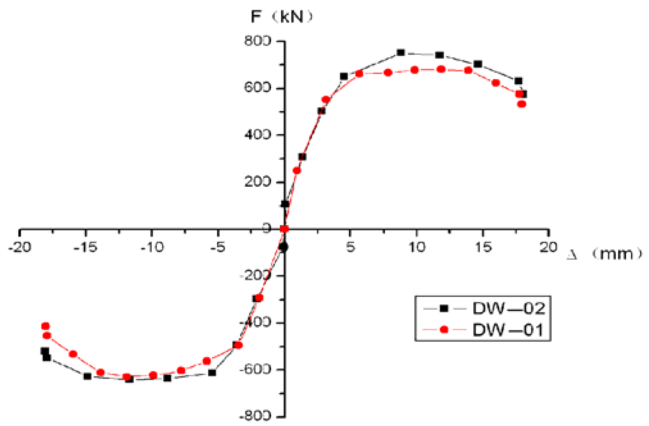

Figure 6-b. F- Δ curve.
Figure 6. hysteretic curve and F- Δ curve.

The hysteretic curve and F- Δ curve are shown in Figure 6. From the hysteretic curve of the wall can be seen, Before lateral load achieved 60 percent of the limit load, the hysteretic curve is a straight-line, and hysteretic loop surrounded by the small size; the rigidity of wall remain basically unchanged and the wall is in elastic stage. With the increased load, the hysteretic curve started to tilt axis displacement and hysteretic loop increased. After some circulation, the hysteretic curve transformed from shuttle type to into anti-S-type, and residual displacement was large. The wall was in elastic-plastic stage. When lateral load achieved the limit load, the capacity of lateral loading and rigidity of the wall began to decline, but the wall could resist loading and have steady hysteretic loop still because of the mutual restraint of the stealth frame and the prefabricated slabs.

From the F- Δ curve of the wall can be seen, the F- Δ curve is a straight-line at begin and began to bent with the load increased. When the lateral load achieved the limit load, the F- Δ curve began to decline, the rigidity and capacity of loading declined but slowly. As we could find, the wall have good hysteretic characteristic, ductility, energy-dissipation capacity and the energy mainly dissipated at cracks in the the prefabricated slabs and framework.

3.4 *Stiffness degradation*

Stiffness degradation is a full expression of the wall cracks and plastic deformation. Before the cracks in the surface were seen with the eyes, the walls had been cracked and the stiffness had been degraded. Cracking stiffness is defined at the point when the steel's strain changed obviously. The remaining load use the secant stiffness, and use the power function for the stiffness degradation curve fitting. The secant stiffness is defined as follow[5]:

$$K_i = \frac{|+F_i| + |-F_i|}{|+\Delta_i| + |-\Delta_i|} \tag{1}$$

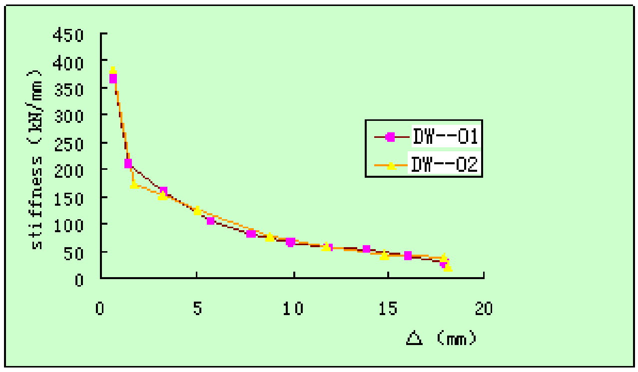

Figure 7. curve of stiffness degradation.

From the stiffness degradation Figure 7 can be seen :in the initial stage, when the wall approached the limit state, stiffness degradation's curve started to bent and the wall transformed from elastic stage to elastic-plastic stage; and the stiffness decreased gradually. The power function for the stiffness degradation curve is showed in the Table 1.

Table 1. Stiffness And Power Function For The Stiffness Degradation.

NO.	Initial Stiffness (kN/mm)	Crack stiffness (kN/mm)	Power function for the stiffness degradation	Correlation coefficient
DW-01	367.6	220.0	$K=315.73\Delta^{-0.7353}$	0.9424
DW-02	383.4	257.7	$K=314.74\Delta^{-0.7362}$	0.9153

4 FINITE ELEMENT ANALYSES

4.1 *Analysis mode*

In order to understand and have a better study on the wall, finite element analysis had been done after experimental study. Now, reinforced concrete finite element model can be divided into three modes: separate, integral and modular model. In the integral model, the steel were set in equality and had a good bond with the concrete, the unit is considered homogeneous materials, steel's contribution to the overall wall is simulated by parameter and the integrated unit of concrete and steel stiffness matrix could be answered.

The concrete composite bearing wall is composed of stealthy frame and prefabricated slabs, and the steels are laid in equality. Then the integral model is used to simulate the wall in the paper. In the analysis, solid 65 cell is used to simulate the concrete and the steel is simulated by parameter in the solid 65. [7]

4.2 *Analysis results*

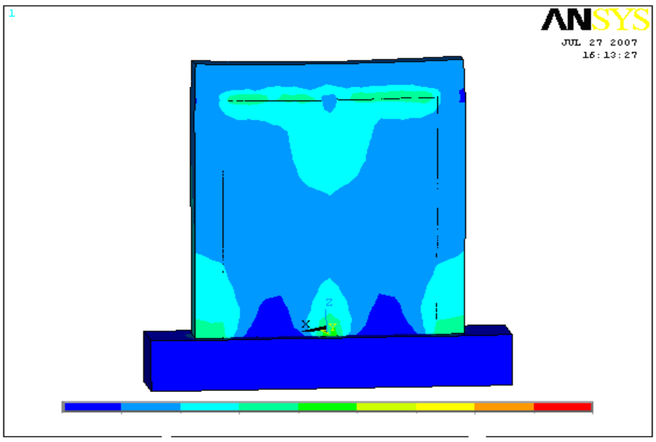

Figure 8-a. axial load.

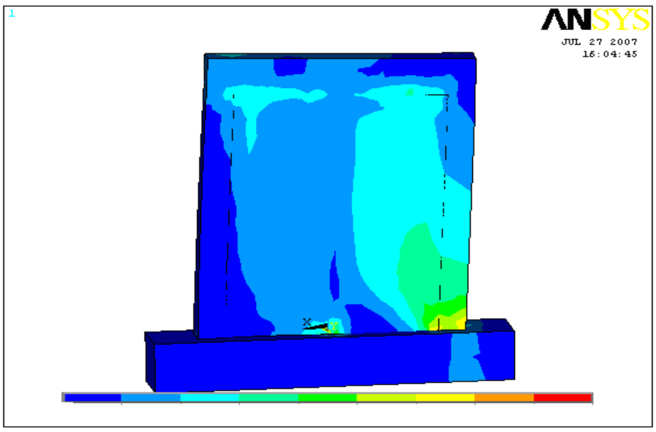

Figure 8-b. level load.
Figure 8. stress distribution.

Form Figure 8-a can be seen, although the prefabricate slabs occupied a large area of the wall, but only bear a smaller proportion of the vertical load, a large proportion of the vertical load is committed by stealth framework. The stress showed arch distribution in the bottom of the trough board and numerical value is small. In the actual works, the prefabricate slabs to resist the vertical load can mot be considered, and the stealth framework composed of block-ribs and rib-columns is considered to resist the vertical load only, but the supporting role to the stealth framework of the prefabricate slabs should not be ignored.

Form Figure 8-b can be seen, the shape of the stress of the wall is bent and the wall's both sides are in a sate of tension and compression, loading performance is the character of a whole wall. The stealth framework and the prefabricate slabs could from a whole wall to resist level load. And the analysis results compared with the test results well.

5 CONCLUSIONS

(1) Concrete composite bearing wall composed of prefabricated slabs with polystyrene inside and contact framework are the main strength components of the concrete composite bearing wall housing. The wall has characters of good integrity, faster construction, good insulation properties, and so on.

(2) Based on the low cyclic reversed lateral loading tests of two concrete composite bearing walls, the behavior such as deformation process, failure mechanism, hysteretic characteristic, ductility, energy-dissipation capacity, seismic behavior and ductility. And the test results reveal that from the beginning to the end, the prefabricated slabs and frame could work in coordination very well; at the end, the prefabricate slabs exit working; they could from two seismic fortifications.

(3) On the basis of the experiment study, we adopted the large-scale finite element software ANSYS to simulate the two experimental wallboards. The force performance of the wallboard processed by vertical load and gradually increased level load. And the result of experiment study and software analysis is compared.

(4) Form the experiment study and corresponding finite element analysis, it is shown that concrete composite bearing wall has good load-carrying capacity, seismic behavior and ductility, and the wall could satisfy seismic design of building, and the wall is could used in building which high does not beyond 30 meters and has value of research.

6 ACKNOWLEDGMENT

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