

Tests on Seismic Behavior of Pre-cast Shear Walls with Vertical Reinforcements Spliced by Two Different Grout Ways

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Abstract: To evaluate the seismic performance of pre-cast concrete shear wall with vertical reinforcements spliced by two different grout ways, quasi-static tests of two concrete shear walls holed by prefabricated corrugated pipe and one concrete shear wall holed by drawing out the pipe were tested. The test results showed that the wall holed by prefabricated corrugated pipe was basically the same as the wall holed by drawing out the pipe in failure modes. The hysteretic curves of the specimens are full, the trend of the skeleton curve is basically the same and the capacity of the energy dissipation is close. The displacement ductility factors are more than 4. For the two walls holed by prefabricated corrugated pipe, when the lap length is reduced, the seismic performance decline as well, but the wall still meets the current seismic code requirements.

Keywords: Pre-cast shear wall, restraint anchor, the way of hole, seismic behavior, quasi-static test.

1. INTRODUCTION

Pre-cast concrete shear wall structure is suitable for residence industrialization, which has the advantages of convenience in construction, easy-to-control quality, reducing energy and water usage, producing less construction trash and lower cost. In addition, Chinese government is promoting green building technology and application, and the construction process of pre-cast concrete shear wall structure has the characteristic of green construction, therefore it is the development tendency of the future construction (Zhu 2003, Guo 2011) [1, 2]. Many studies have investigated the performance of pre-cast concrete shear wall. Qian *et al.* (2011a, 2011b) [3, 4] study seismic behavior of pre-cast reinforced concrete (RC) shear walls with vertical reinforcements spliced by grout sleeves, test results showed that the integrity behavior of the rough interface of the side face of the pre-cast wall is better than that of the shear keys. Jiang *et al.* (2011) [5] studied the connection method between reinforced bars of the pre-cast concrete structure, and the basic anchoring length of plug-in filling hole for lap-joint of steel bar was given. Zhu *et al.* (2012) [1] studied the seismic performance of joints of new pre-cast concrete shear wall structures. Some foreign researchers had done a lot of experiments and researches on the seismic performance of pre-cast concrete wall (Pekau 1988, Mochizuki 1981, Harry 1982, Oliva 1982, Nazza 2005) [6-10].

At present, grout sleeve splicing and restraint grout splicing are the main connections for vertical reinforcements in the construction process of pre-cast concrete wall. In order to reduce the overlap length of grout splicing, Jiang *et al.* (2011, Liu 1981) [11, 12] developed the restraint grout splicing, as shown in Fig. (1). The technology reduced the overlap length by increasing stirrup bars within the range of lapped segments, and the hole was formed by drawing out the screwed steel pipes, which is complicated and difficult to control. In order to simplify the process, the wall holed by prefabricated corrugated pipe was used. The main objective of this research is to evaluate the feasibility of restraint grout splicing.

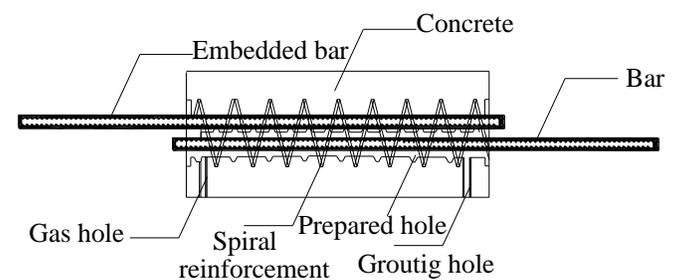


Fig. (1). The overlap method.

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2. EXPERIMENTAL PROGRAM

2.1. Specimen Preparation

Three full-scale pre-cast concrete walls were tested to evaluate their seismic performance, which were designed with the specification of Technical specification for concrete structures of tall building and Specification of testing methods for earthquake resistant building JGJ101-1996. Structure of restraint grout splicing is shown in Fig. (2a), where 1 is the longitudinal bar in the shear walls, 2 is spiral stirrups, 3 is the horizontal bar in the shear walls, 4 is corrugated pipe, 5 is mortar layer, 6 is the bar embedded in the strip foundation. The details of the specimens are shown in Table 1 and Fig. (2b). The pre-cast concrete walls were 2000mm in width, 3000mm in height and 200mm in thickness. The concrete compressive strength of the wall after 28 days was 37MPa, and the compressive strength of grouting material after 28 days was 37MPa. The yield strength (f_y), tensile strength (f_u) and elongation of different steel is listed in Table 2.

In the preparation process of the specimen, it was intended that the wall panel reinforcing cage could be manufactured as two independent units (an upper pre-cast wall and lower strip foundation), required only to be brought

together at the commencement of casting. The steel corrugated pipes were reserved in the upper wall, and grouting material was filled in the hole when the installation of upper and lower portion was complete. The mortar layer and filling hole for steel bar should be filled with grouting material at the same time to make sure the integrity.

2.2. Experimental Infrastructure

Fig. (3) depicts the loading frame used for conducting the experiments. Lateral loading was applied to each unit through the use of a 5000 kN servo-controlled hydraulic actuator. This actuator was bolted to the reaction wall. To provide axial stress similitude between specimen and prototype, a 5000kN hydraulic jack was used. Two steel supports were used to provide lateral stability to the wall. Four displacement sensors with a range of 100 mm were placed on one side of the wall to monitor the lateral displacements.

2.3. Loading Program

To check the alignment, the axial load was applied with an interval of 500 kN, and the strain and displacement sensors were monitored regularly. After the final positioning,

Table 1. Details of the specimen.

Specimen	Axial compression ratio	overlapped length	Method to form hole
BW9	0.2	0.9lae	Prefabricated corrugated pipe
GJ9	0.2	0.9lae	Drawing out the pipe
BW7	0.2	0.7lae	Prefabricated corrugated pipe

Table 2. Material properties of steel.

Reinforcement	Diameter (mm)	f_y (MPa)	f_u MPa	Elongation %
HRB400	6	472	635	29
HRB400	8	430	685	27
HRB400	10	545	655	27
HRB400	12	495	655	27

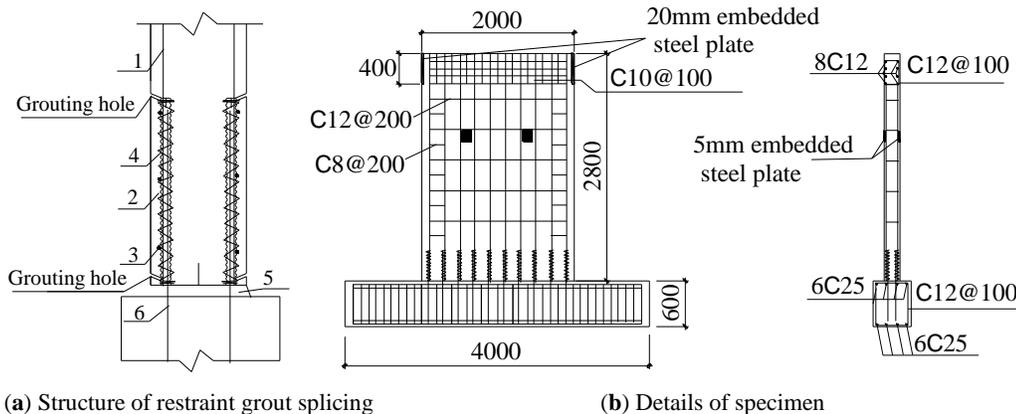


Fig. (2). The structure and details of specimen.

the alignment was checked up to the maximum predetermined axial load. Then, the lateral load actuator was connected to the specimen after the application of full axial load. A reverse cyclic lateral load was applied in terms of load and displacement control as shown in Fig. (4). Before the specimen yielded, one cycle was applied at each of the elastic lateral load. At each level of ductility displacement (Δy), three full cycles of reverse lateral load were applied. Test was conducted until either the specimen failed due to large deformation or the lateral load resistance of the specimen had deteriorated to 85% of the lateral bearing capacity.

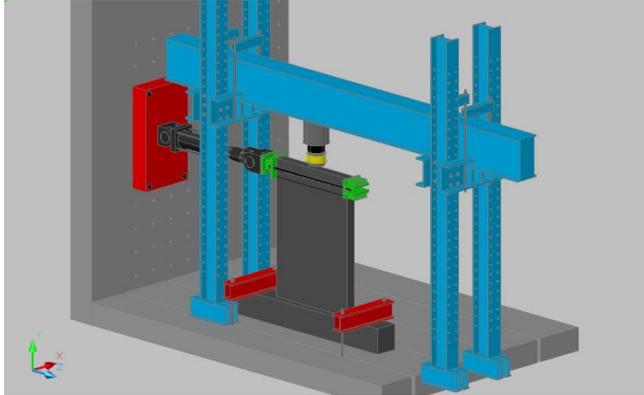


Fig. (3). Schematic representation of loading frame.

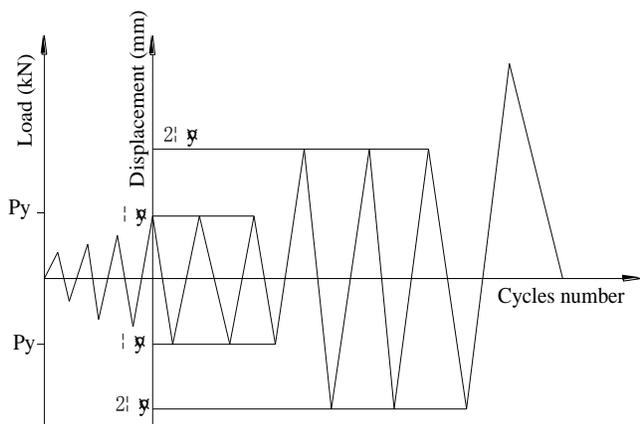


Fig. (4). Load program.

3. TEST OBSERVATIONS

During the initiation of loading, specimen BW9 was in elastic stage, the lateral load-displacement of loading process was coincide with unloading process. When the lateral load was 462kN, horizontal cracks were appeared at the bottom of the tension side. As the load increasing, the horizontal bending crack become the flexure-shear crack, and extended along the diagonal direction. When the lateral load was 853kN, the tensile reinforcement yielded. When the displacement was 60mm, the reinforcement at the bottom of the wall was exposed and the concrete was crushed, which the specimen failed.

During the initiation of loading, specimen GJ9 was in elastic stage, the lateral load-displacement of loading process was coincide with unloading process. When the lateral load was 550kN, horizontal cracks were appeared at the bottom of the tension side. As the load increasing, the horizontal bending crack become the flexure-shear crack, and extended along the diagonal direction. When the lateral load was 830kN, the tensile reinforcement yielded. When the displacement was 70mm, the reinforcement at the bottom of the wall was exposed and the concrete was crushed, which the specimen failed.

During the initiation of loading, specimen BW7 was in elastic stage, the lateral load-displacement of loading process was coincide with unloading process. When the lateral load was 300kN, horizontal cracks were appeared at the bottom of the tension side. As the load increasing, the horizontal bending crack become the flexure-shear crack, and extended along the diagonal direction. When the lateral load was 778kN, the tensile reinforcement yielded. When the displacement was 55mm, the reinforcement at the bottom of the wall was exposed and the concrete was crushed, which the specimen failed.

4. TEST RESULT AND DISCUSSION

4.1. Hysteretic Response

The measured load-displacement hysteretic hoops are shown in Fig. (5). For all of the three specimens, the load-displacement hysteretic hoops have the similarity: Before the specimen yielded, the area of hysteretic hoops increased with the increasing of the load, and the area was small because of the small residual deformation. After the specimen yielded, the area of hysteretic hoops increased. When the displacement was same, the loading stiffness and strength of next cycle degraded obviously compared with last cycle, but the degradation of unloading stiffness was not obvious. The hysteretic hoops looks like reverse S shape, which means the specimen had good energy-absorbing capacity. After the specimen reached the ultimate load, the load capacity declined slowly, which means the specimen had good ductility. Hysteretic performance of BW9 and GJ9 was close, and hysteretic performance of BW7 was poor.

4.2. Displacement Ductility

The measured load-displacement skeleton curves are shown in Fig. (6). It can be seen that the shapes of the three specimens are similarity, the bearing capacity of BW9 and GJ9 is close, which is larger than BW7.

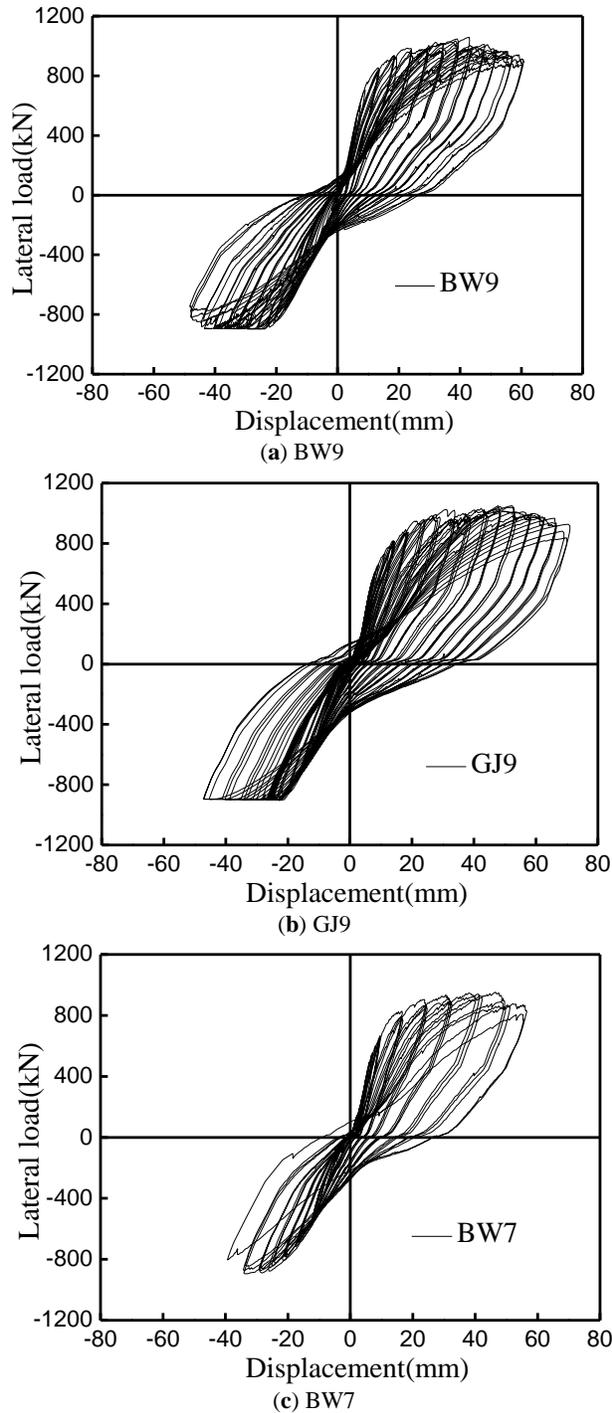


Fig. (5). Load-displacement hysteretic loops of specimens.

Table 3. Test results.

NO	N_{cr} (kN)	Δ_{cr} (mm)	N_y (kN)	Δ_y (mm)	N_u (kN)	Δ_u (mm)	μ
BW9	462	5.9	853	13.2	1034	60.4	4.7
GJ9	550	7.2	830	15.4	1023	71.4	4.6
BW7	300	4.3	778	13.7	910	55.3	4.0

Note: where N_{cr} is crack load, Δ_{cr} is crack displacement N_y is yield load, Δ_y is yield displacement, N_u is ultimate load, Δ_u is ultimate displacement, μ is displacement ductility.

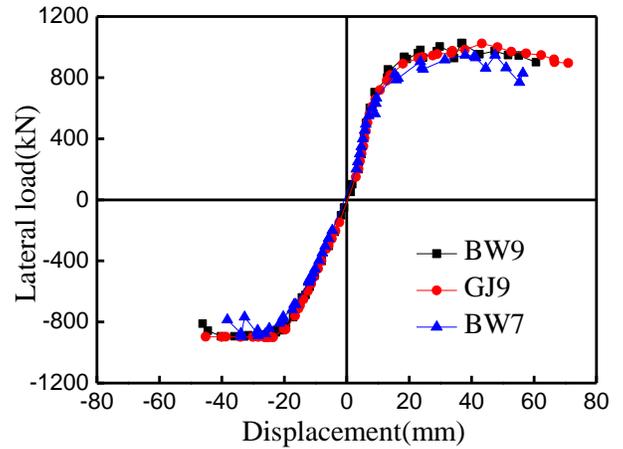


Fig. (6). Load-displacement skeleton curves.

Table 3 compares performance measures of the specimens in bearing capacity and ductility. The data represent the averages of the push and pull direction. Fig. (7) describes the definition of yield displacement and displacement ductility. Where Δ_y is the yield displacement that is determined according to energy method, Δ_u is the displacement when the lateral load attains ultimate bearing capacity.

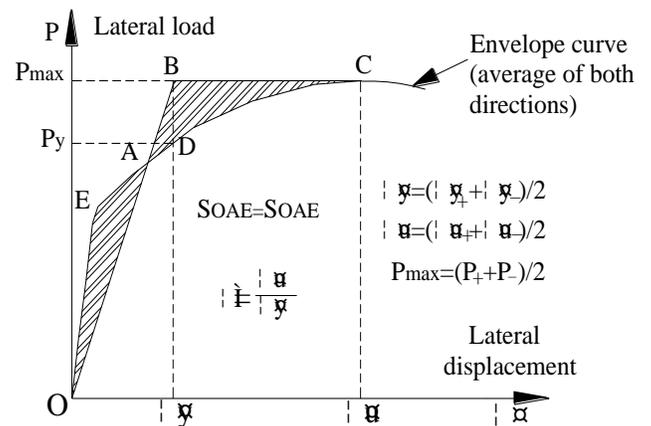


Fig. (7). Displacement ductility parameters.

It can be seen from the table that the yield displacements of the specimens are close, which means that the behaviour of hole formed by drawing out the screwed steel pipes and prefabricated corrugated pipe basically the same before yielding. The ultimate displacement and ductility of BW9 is smaller than GJ9, which means the deformation capacity of hole formed by drawing out the screwed steel pipes better

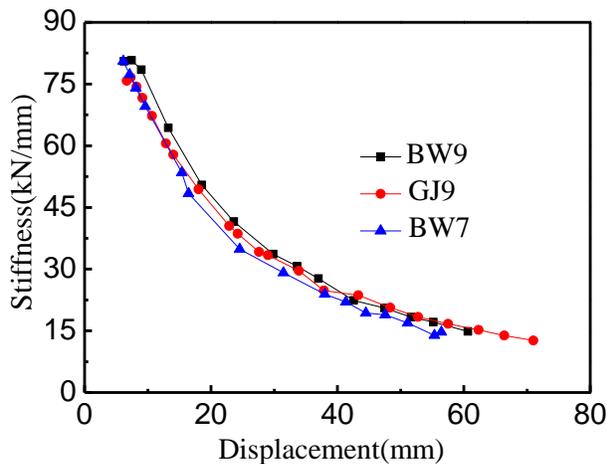
Table 4. Equivalent viscous damping coefficient.

Specimen	BW9	GJ9	BW7
Crack stage	0.3918	0.3788	0.3933
Yielding stage	0.3533	0.3997	0.4045
Ultimate stage	0.4145	0.3979	0.3779

than prefabricated corrugated pipe. The ultimate displacement and ductility of BW9 is smaller than BW7, which means that the reducing of splicing length declines the deformation capacity.

4.3. Stiffness Degradation

The stiffness degradation curves are shown in Fig. (8). Stiffness degradation is an important behavior for seismic performance of structure. The cumulative damage in the structure would cause stiffness degradation, which can be expressed with equivalent stiffness $K=F/\Delta$, where K is the equivalent stiffness, F is the load, Δ is the displacement.

**Fig. (8).** Stiffness degradation.

It can be seen from Fig. (8) that the stiffness decreases with the increasing of displacement. At initial stage, the stiffness decreases quickly, and then the tendency slows down with the increasing of displacement. As the displacement is same, the stiffness of BW7 is the smaller than others. As the displacement is small, the stiffness of BW9 is smaller than GJ9, and the stiffness of BW9 begins to be larger than GJ9 with the increasing of displacement.

The above analysis shows that the stiffness of hole formed by drawing out the screwed steel pipes and prefabricated corrugated pipe is basically the same. The reducing of splicing length would bring down the stiffness of specimen.

4.4. Energy Dissipation Capacity

The equivalent viscous damping coefficient (h_e) is commonly used to determine the energy dissipation capacity of the structures and members in the earthquake. The equivalent viscous damping coefficient of different stage is

listed in Table 4. It can be seen that the equivalent viscous damping coefficients of specimens are close, which means that the energy dissipation capacity basically the same.

CONCLUSION

Three full-scale pre-cast concrete walls were tested under low cycle loading. The following conclusions can be drawn from the work reported above.

1. As the axial compression ratio and splicing length is same, the hysteretic curve, ductility, stiffness degradation and energy dissipation capacity are similarity, which means that the two kinds of splicing method have equal seismic performance.
2. As the splicing length reducing, the behavior of the specimen is influenced, and the splicing length meets the requirements of seismic code.
3. The hysteretic curves of the specimens are full, the energy dissipation capacities good. The displacement ductility coefficients are greater than 4, which meet the requirements of ductility.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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