An Evaluation of Shear Strength of RC Frame with Old Masonry Wall

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SUMMARY:

Earthquakes have frequently occurred all over the world recently. It is thus necessary to verify the seismic performance evaluation of school buildings which are a quasi-public structure to reduce damages. School buildings are composed of RC structure with columns and beams. Partition walls and waist-high walls of the buildings are composed of masonry walls. It is difficult to find definite data about the characteristic behavior of deteriorating hysteresis and masonry walls of school buildings older than over 30 to 40 years. Therefore, in this paper, in order to evaluate the seismic performance of deteriorated RC and masonry walls, the samples (specimens for test) and core test pieces from existing buildings in Korea for material and shear test were collected. This research aims to determine the performance of the masonry walls to measure the pure shear strength by loading the masonry wall inside of the RC Frame. In addition, the test result is compared with theoretical value of shear strength of AIJ, KBC Codes.

Keywords: deteriorated RC frame, old masonry wall, shear test, seismic performance

1. Introduction

While large-scale earthquakes are recently reported all over the world, huge loss of lives and property damages occur in buildings for which seismic design was not applied. In Korea, people are now more interested in and pay attention to earthquakes. In particular, more than 80% of the deaths due to collapsed buildings were the result of collapse of masonry buildings in the magnitude 8.0 Sichuan Earthquake, China, in May, 2008, and the magnitude 7.0 Port-au-Prince Earthquake, Haiti, in January, 2010. As a result, there is an urgent need for ensuring earthquake-resistance of masonry buildings. Meanwhile, since 1970s, the number of masonry buildings constructed has sharply increased to account for approximately 50% of the entire buildings in Korea, because of short construction periods and low construction costs, but the masonry buildings have not been designed for the earthquake-resistant and are vulnerable to earthquakes. In particular, it is necessary to examine the very old existing masonry walls for earthquake resistance.

The first earthquake damage prevention measures in Korea is the addition of the regulation related to earthquake resistance design to the relevant legislation in 1988, and school buildings higher than 3 stories are categorized as Seismic Category I since 2005 to extend the scope of earthquake resistance design.[5] School buildings have columns and beams made of RC, partition and waist walls are composed of masonry. Thirty to forty years-old school buildings are low in strength and there are almost no data that definitely describe behaviors of old masonry walls. Studies on unreinforced masonry structures are divided into masonry material test, member test for masonry walls, shaking table test and analytic research for each structure. Many researches are underway in other countries, but the studies are still at its beginning stage.

In this study, we will take masonry wall samples from existing old school building composed of RC frame and masonry walls in Korea to verify seismic performance through the shear test. In this test, the shear strength of the masonry walls provided in the RC frame was measured to identify the performance of the masonry walls. The theoretical values of the shear strength according to Japan (AIJ) and (KBC2009) standard were compared with the test result.

2. Loading test of aging masonry wall

2.1 Sampling aging masonry wall

Usually, school buildings in Korea are low story and a floor plan of one-sided corridor type. In most cases, columns, beams and slabs of the buildings are reinforced concrete structures. Partition walls between classrooms and waist walls are masonry. As shown in Figure 1, the S Elementary School constructed in 1969 is a 3-story reinforced concrete structure, and has a waist wall in the long span direction. For this test, a specimen was taken from a partition wall between classrooms on the ground floor in the S Elementary School of which dismantlement was underway. (Figure 2)

(a) Photo before dismantlement **(b) Photo showing dismantlement (Feb. 2011)**

Figure 1. S Elementary School to be dismantled (Gwangju, Korea, 1969)

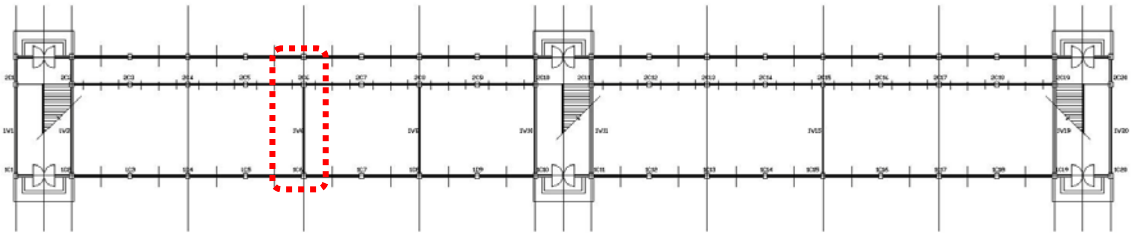


Figure 2. Floor plan of first floor of S Elementary School

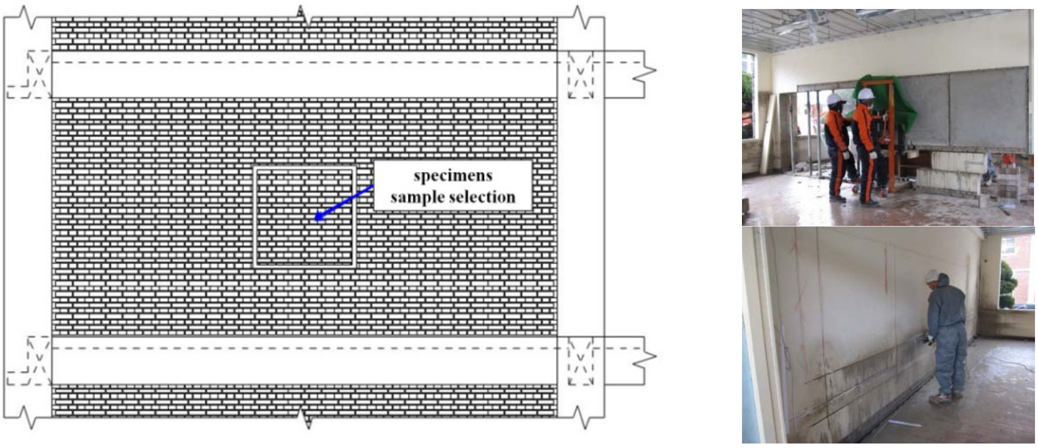


Figure 3. Point of sampling and cutting masonry wall

As shown in Figure 3, the specimen of 1000mm x 1200mm was cut from the masonry partition wall 60cm above the floor, using a concrete cutter. The masonry wall was made in the British 0.5B bricklaying type, and the finishing mortar was in very good condition.

2.2 Static load test

2.2.1 Masonry wall specimen

The RC frame specimen for test was produced by using the masonry wall of approximately 1200mm×1000mm×200mm sampled from the S Elementary School. The masonry wall sampled from the wall is shown in Table 5. The No. 1 specimen in the Figure is an RC frame without masonry infill walls. The No.2 specimen is plastered with mortar on the masonry wall, and the No.3 is a specimen in which the finishing mortar was removed from the surface of masonry wall.

Table 5. Masonry wall test samples

Specimen	Masonry wall (㎜)			Variable	Laying
	Width	Length	Wall thickness		
No.1	-	-	-	RC frame	0.5B
No.2	1000	1200	206	With surface mortar	0.5B
No.3			184	Without surface mortar	0.5B

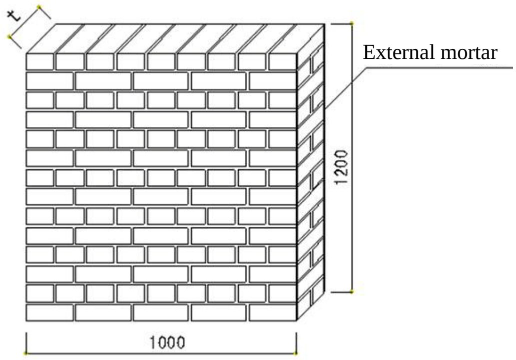


Figure 4. Sampled masonry wall

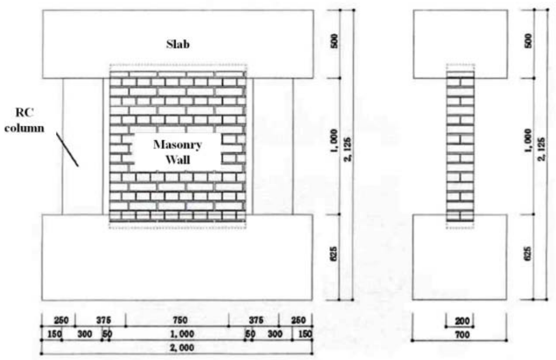


Figure 5. Specimen

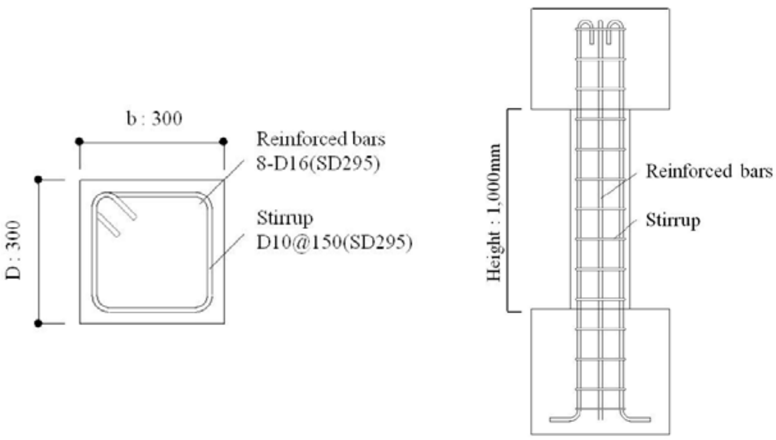
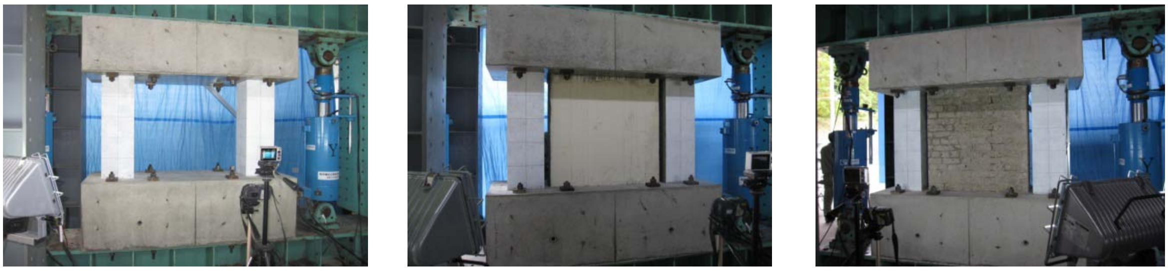


Figure 6. Reinforcement bar arrangement of RC frame column

In precedent studies[3][4], researchers proposed their own method of test to verify the shear capacity of masonry walls. In this test, the sample is taken directly from existing building, in order to produce the original masonry wall conditions as possible with less damage to the specimen as shown in Figure 5. As shown in Figure 7, a clearance of (=50mm) between the masonry wall and the RC column was ensured, and the RC column was made not to restrict the masonry wall in loading. The RC column section and the arrangement of reinforcement bars are shown in figure 6.

2.2.2 Loading

Figure 8 shows the test set up and loading condition. The reverse symmetry loading device was constituted to carry out unidirectional static loading test. A vertical constant load of 36kN was given in a controlled manner with vertically installed actuator which is equivalent to 0.1bDFc of the RC column. The actuator having a capacity of 500kN was used to apply the lateral load to the specimen in the controlling the displacement. A Pantograph was installed to avoid deformation in the out-of-plane direction of the wall. The loading rate was set up not faster than 1mm/sec for quasi-static test.



a) No.1 specimen **b) No.2 specimen** **c) No.3 specimen**

Figure 7. Masonry wall test specimens

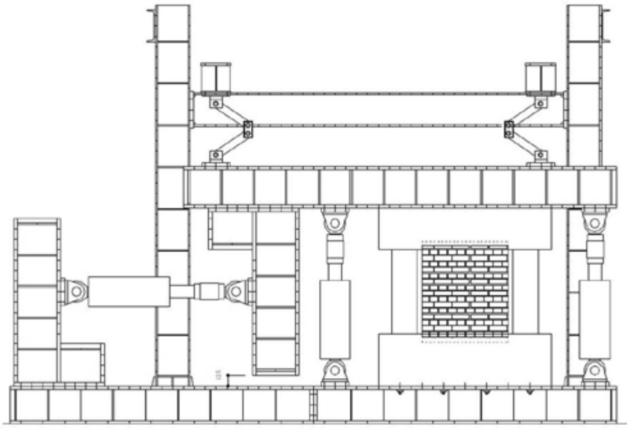


Figure 8. Configuration of actuator

2.2.3 Measurement detail

Figure 9 shows the points for measuring displacement. Two actuators were installed on the upper part of concrete beams to measure displacement of the specimen. Four measuring device are installed diagonally and vertically to measure bending and shear deformation respectively as shown in figure 9. Load was measured at 3 points arranged at the end of the actuator installed laterally and at the upper end of vertically installed actuators.

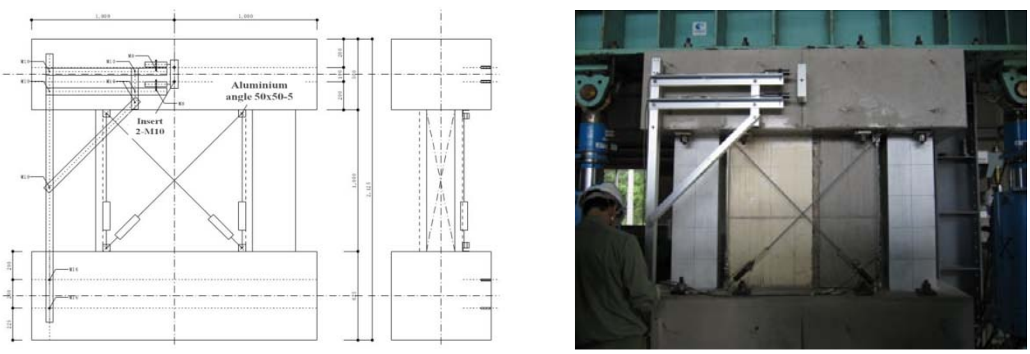


Figure 9. Measurement method

2.3 Calculated strength values of RC Frame & masonry wall

Table 6 shows shear strength of the RC column and the masonry wall suggested in KBC2009 and AIJ for each specimen. It is shown that bending strength (approximately 110kN) is smaller than shear strength (approximately 167~170kN) to imply that rupture in bending occurs first.

Table 6. Calculated strength of RC frame and masonry wall

Specimen		Axial force (kN)	KBC2009 (kN)	AIJ (kN)	
				Q_{mu}	Q_{su}
RC	No.1	35.1	172.1*2	111.4*2	167.6*2
	No.2	19.1	171.1*2	110.5*2	167.3*2
	No.3	23.3	171.3*2	111.3*2	167.6*2
Masonry wall	No.1	-	-	-	
	No.2	16	17.9	29.9	
	No.3	11.8	15.9	28.8	

Q_{mu}: Plastic Bending Ultimate Strength, Q_{su}: Plastic Shear Strength

3. Result of masonry wall loading test

3.1 Result of masonry wall shearing test

Figures 10-13 show the relationships of load obtained from unidirectional lateral load under a constant axial force and displacement of each specimen under consideration. As shown in Figure 10, the initial stiffness and initial strength of No.2 (RC column + masonry wall with finishing mortar) > No.3 (RC column + masonry wall without finishing mortar) > No.1 (RC column). Final shear strength of all three specimens was approximately 315kN which is the maximum shear strength. It is considered that the masonry wall lost its capacity from the inter-story drift angle of approximately 1/200(5mm) so that it behaves only with the strength of the RC column. Figure 11 shows theoretical and test shear strength with respect to load-displacement of No.1 specimen (RC column). The No.1 specimen showed the calculated shear strength (Q_{su}) of the reinforced concrete column on the basis of KBC2009 and AIJ standard, which is approximately the same as the test result. However, the calculated bending strength (Q_{mu}) of the reinforced concrete column on the basis of AIJ standard showed a significant difference. The result calculated in 2.3 showed precedent rupture in bending, but the No. 1 specimen exhibited shear rupture (Figure 15.(a)). The result revealed that the calculated shear strength was even closer to the calculated strength of the column. ★ in Figure 11 is a normal indicator in which cracks occur in a masonry wall to represent RC column strength where inter-story drift angle is 1/500 so as to examine the strength of a masonry structure.[3]

Table 7 Calculated strength and test value of specimens

Specimen	Test value		KBC 2009 (kN)				AIJ (kN)			
	1/500 (2mm)	1/12.5 (8mm)	A*	B*	C*	D*	A*	B*	C*	D*
No.1	176.3	309.2	344.2	-	-	344.2	222.8	-	-	222.8
No.2	251.5	310.7	342.2	176.3	17.8	194.1	221.0	176.3	29.9	206.2
No.3	202.5	309.5	342.6	176.3	15.9	192. 2	222.6	176.3	28.8	205.1

A*: RC column strength, B*: Test strength of RC column at inter-story drift angle 1/500, C*: Masonry wall strength, D*: Specimen strength

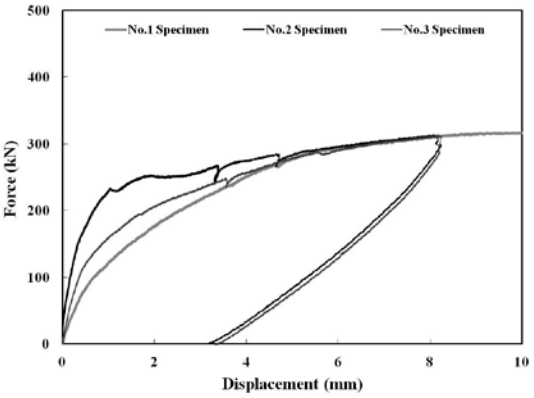


Figure 10 Load-displacement r/n of masonry wall specimen

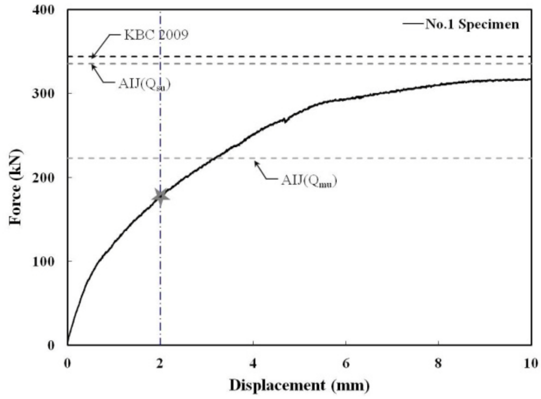
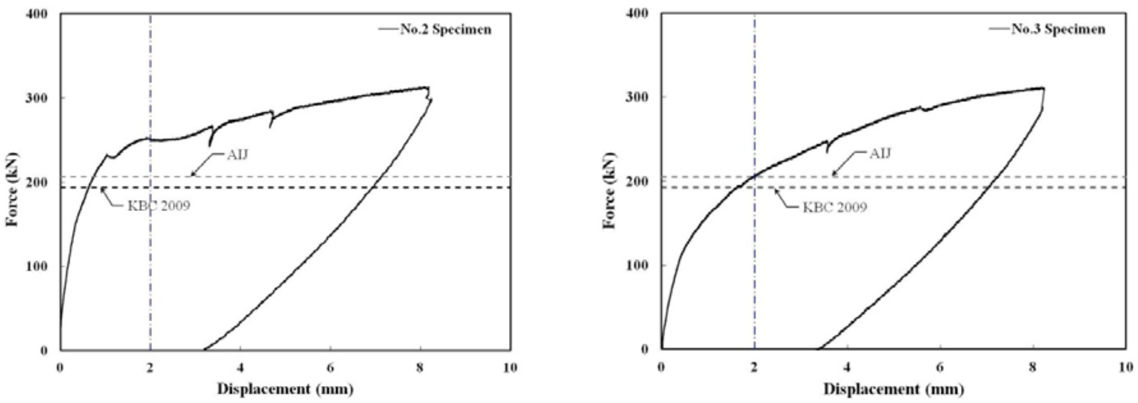


Figure 11 Calculated strength (No.1)



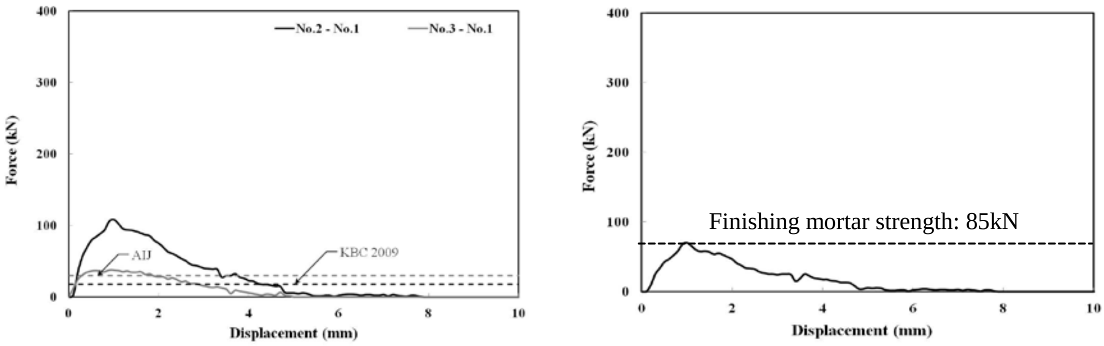
(a) No.2 Specimen **(b) No.3 Specimen**

Figure 12. Load-displacement curves of each specimen

Figure 12 shows the comparison of the test result of load-displacement curves in the case of the masonry wall with and without the finishing mortar as well as with the calculated shear strength based on the inter-story drift angle of 1/500. Here, the test result of RC column shear strength and the calculated masonry wall for both standards at a drift angle of 1/500 was obtained.

The No. 2 specimen exhibited the calculated strength with the standard of KBC2009 and AIJ, lower than the test result. The reason is because the thickness of finishing motor is considered in calculating the wall area during calculation of masonry wall strength by each standard, but the finishing mortar strength is not considered.

Meanwhile, the No.3 specimen without finishing mortar showed the calculated masonry wall strength with the AIJ standard almost the same as the test value. On the contrary, the theoretical value was slightly smaller than the test value for KBC2009 standard.



(a) Masonry wall strength **(b) Finishing mortar strength**

Figure 13. Load-displacement curves of masonry wall and finishing mortar

The comparison of all test specimens is shown in figure 13. In this figure, the strength measured is only the strength of the masonry wall. Figure 14 shows the difference of strength of finishing mortar the test results of No.2 specimen and No.3 specimen. The finishing mortar strength is maximum at the inter-story drift angle of 1/1000(1mm), after which cracks occurred, and most of shear strength was lost at the inter-story drift angle of 1/200 as shown in Figure 13. (b). Therefore, it is seen that a significant proportion of the shear strength of the masonry wall came from the shear strength of the finishing mortar.

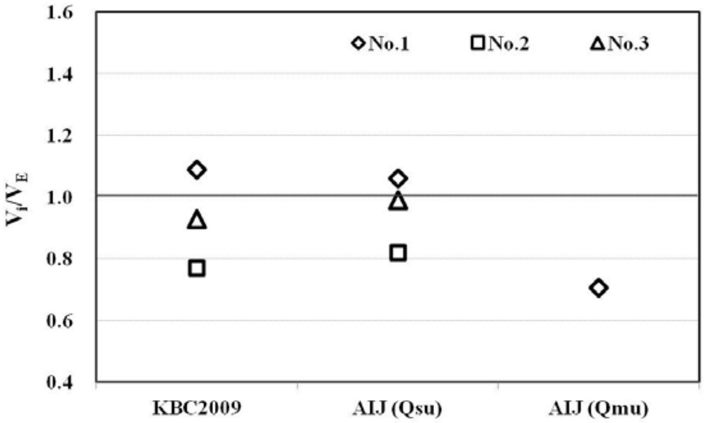


Figure 14. Comparison of test result and calculated strength by each country standard

Figure 14 shows the comparison of the theoretically calculated strength in each country standard and the maximum value from the test result (the inter-story drift angle is 1/500 in No.2 and No.3). In No. 1, it is seen that the RC frame strength is over evaluated in the KBC2009 standard. However, for the masonry wall for No.3, the test result and the calculated value according to AIJ standard was almost the same but for KBC2009 the calculated value was slightly smaller.

3.2 Failure modes

Figure 15 shows final failure mode of each specimen. For No. 1, specimen cracks at the head and the bottom of the RC column as shown in figure 15 a). The masonry wall specimens of No. 2 and No. 3 the cracks starts in the masonry wall right after loading, and the cracks gradually extended to result in shear failure as shown in figure 15 b) and c) respectively.

a) No. 1 specimen b) No. 2 specimen c) No. 3 specimen

Figure 15. Rupture of masonry walls

4. Conclusion

This study is related to the experimental research on structural performance of a masonry wall of a school building older than 40 years. A masonry wall sample was taken from the existing building to identify the shear performance of the masonry wall. The following conclusion was reached by comparing the test result and theoretical values calculated shear strength by Japan and Korea standard.

1) Right after loading, the specimen exhibited shear cracks on the brick wall. The cracks gradually

extended to result in final shear failure.

2) Initial stiffness and initial strength had a difference depending on the type of the masonry wall. The masonry wall lost strength thereof from the inter-story drift angle of approximately 1/200(5mm), to have only the strength of the RC column. With respect to the strength of only the masonry wall, the strength of masonry wall exhibited cracks from the inter-story drift angle of 1/1000 to result in rupture at 1/200.

3) Comparison of the existing theoretical values with the test values revealed that relatively accurate evaluation was made, other than bending strength in RC. For the masonry structure, the AIJ equation made a relatively accurate evaluation, but the theoretical value according to KBC2009 was evaluated slightly lower than the test strength value. In the masonry structure with finishing mortar, it was identified both of the theoretical equations showed lower values than the test strength values. In this regard, further study is required for the effect of finishing mortar.

Generally, the shear performance of masonry wall was investigated in this study, although the numbers of samples taken are not many. It is necessary to further examine in the future on another school building, by taking many samples, in the same manner, and investigate in advance the actual effect of finishing mortar.

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