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An experimental study on influence of shear failure type partial wall on reinforced concrete frame

Hisato Hotta *, Takeshi Nakajima

Department of Architecture and Building Engineering, Tokyo Institute of Technology, 152-8550 Tokyo, Japan

A B S T R A C T

Partial walls separated from columns are generally treated as nonstructural elements because their behavior aren't analyzed much. Partial walls jointed rigidly to RC frames raise horizontal load-carrying capacity, however they may give an influence on RC frames when they fall in brittle failure. Objective of this paper is to clarify the influence of partial walls falling in shear failure on RC frames through a static loading test and a shaking table test. The experiment shows that, after one of the partial walls fails, story drift rapidly increases. It shows progress of flexural deformation at one end of columns, and it may cause story collapse. The result is obtained from both loading tests.

A R T I C L E I N F O

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1. Introduction

Walls connected to the upper and the lower beams, however, apart from the both side columns, briefly called "partial walls" in this paper, are very popular as exterior walls in a large number of buildings, especially in apartment houses in Japan. In many cases, they had not been regarded as structural elements, because they did not satisfy the requirements for bearing walls, and their presence had been ignored in structural calculation until about decades ago for a long time. However, if slightly, they have a certain lateral stiffness and strength, therefore they have some influence on the structure, and it is necessary to grasp it adequately. In the previous paper, we reported the influence of the flexural yield type walls and concluded that elongation of the walls due to flexural yielding sometimes influenced much to the strength themselves and the behaviors of the beams connected to them. This paper deals with a case that the walls expected to fail due to shear prior to yield due to bending. In this case, it is considered that there is some fear that brittle failure of a wall at a certain story may cause the story collapse. The objective of this paper is to clarify influence of partial walls on reinforced concrete (RC) frames through a static loading test and a shaking table test.

2. Specimens

Two types of specimens, one of which is MW12 with 12 cm wide partial walls and the other is MW15 with 15 cm wide ones, were provided. The specimens for static loading test are named MW12-S and MW15-S by adding "S", and the specimens for shaking table test are named MW12-D and MW15-D by adding "D". The size and the reinforcement of the specimens for the both loading tests are the same as each other. A typical specimen (MW12-S) is shown in Fig. 1. The specimens are 1/8 scale models of one span and two story frames with a partial wall at mid-span at every story. The members have the dimensions as described in Table 1 and as detailed in Fig. 2. The walls are designed to fail due to shear before flexural yielding. By contrast, the beams and the columns are sufficiently strengthened against shear. Mechanical properties of the concrete and the reinforcement are indicated in Table 2.

3. Static Loading Test

The outline of the loading is illustrated in Fig. 1 above mentioned. In order to restrict the wall's axial elongation

* *Corresponding author*. Tel.: +81-3-5734-3108 ; E-mail address: hotta@arch.titech.ac.jp (H. Hotta)

caused by their bending yield, a steel tube with sufficient stiffness is attached to the top of the specimens with pin support. Due to this treatment, the specimens show almost the same behavior as that on the lower part of middle-rise buildings. A constant axial force equivalent to 0.15 bDFc (25.1 kN) was loaded by vertically pulling PC bars running through the center of the columns. The both ends of the second story beam of the specimen was horizontally pulled and pushed with the same force.

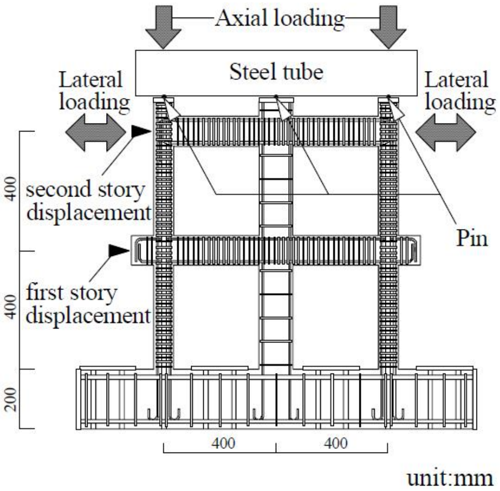

Fig. 1. Specimen (MW12-S) and outline of static loading.

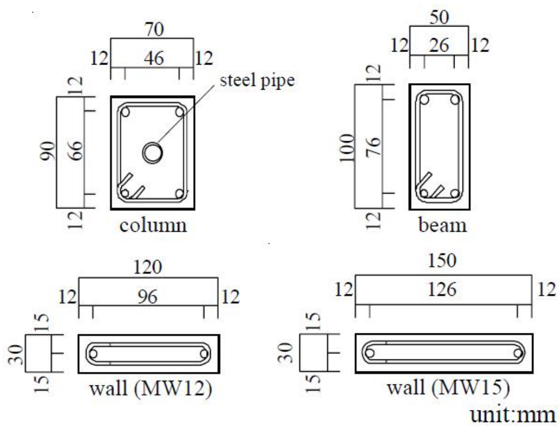

Fig. 2. Section of members.

Table 1. Section detail of members.

column	b D (mm)	90×70
	Main reinforcement	4-D6 pg=2.01%
	Hoop reinforcement	2-3φ @15 pw=1.05%
beam	b D (mm)	50×100
	Main reinforcement	4-D6 pg=2.53%
	Hoop reinforcement	2-3φ @18 pw=1.57%
wall (MW12)	b D (mm)	30×120
	Main reinforcement	2-D6 pg=1.76%
	Hoop reinforcement	2-3φ @79 pw=0.6%
wall (MW15)	b D (mm)	30×150
	Main reinforcement	2-D6 pg=1.41%
	Hoop reinforcement	2-3φ @79 pw=0.6%

Relationships between the lateral load and the displacement of the second story are indicated in Fig. 3. MW12-S recorded the maximum lateral load (27.2 kN) in the third loading loop, and the second story wall and the first story wall fell in shear failure in turn in the fourth loading loop. MW15-S recorded the maximum lateral load (32.0 kN) in the third loading loop, and soon, the wall of the second story fell in shear failure. And the wall of the first story fell in bond failure in the fourth loading loop.

Table 2. Mechanical properties of the materials.

For static loading test (MW12-S,MW15-S)			
Concrete			
Age	Compressive strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa·10³)
28	26.6	3.05	27.0
35	28.4	3.26	25.9
Reinforcing bars			
Size	Compressive strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa·10³)
D6	347	506	187
3φ	630	680	213
For shaking table test (MW12-D,MW15-D)			
Concrete			
Age	Compressive strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa·10³)
29	30.0	2.96	27.2
Reinforcing bars			
Size	Compressive strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa·10³)
D6	334	495	197
3φ	493	663	201

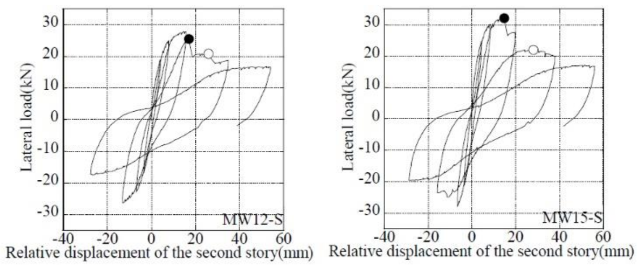

Fig. 3. The relationships between the lateral force and the displacement.

Relationships between the story drift angle of the first story and that of the second story are shown in Fig. 4. Dots ∘ and • indicate the point the first and the second story walls failed. It is recognized the story drift of the second story increased compared with that of the first story after the second story wall failed. It shows progress of flexural deformation at the second story column-base. This tendency is outstanding in MW15-S. That means, the walls of MW15-S are stiffer than those of MW12-S, therefore the difference of story stiffness between the first story and the second story appears more clearly after one of the partial walls fails.

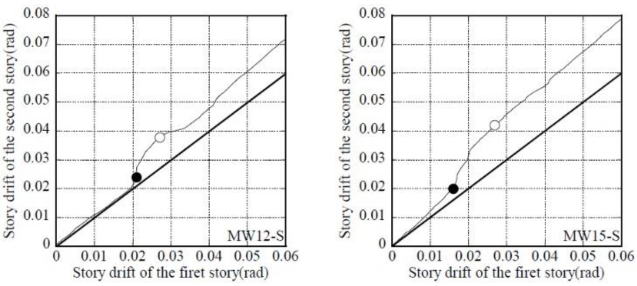

Fig. 4. Relationship between story drift of the second story and the first story.

4. Shaking Table Test

The outline of the setup is illustrated in Fig. 5. How the mass is connected to the specimen is detailed in Fig. 6. A H-shaped steel is connected at the top of the column of the specimen by pin connections. The total mass of the additional mass is 1.97 tons. Its center of gravity is almost coincident with the central point of the second story beam, therefore it can be said that the loading is similar to that of the static loading test. The H-shaped steel also plays the role of restricting the walls' axial elongation. As the axial force of the columns due to the mass is shorter than design axial compression of 0.15 bDFc (28.4 kN), the lack is filled up by pulling PC bars running through the columns. Input ground motion is NS component of JMA KOBE wave. As the size of the specimen is 1/8 times as large as a practical frame, amplitude of the wave is reduced to 1/8. The compression ratio of time axis is 3/10. The wave is named briefly "Kobe" in this paper. The natural period of the specimen including the additional mass is about 0.10 sec., therefore the specimen corresponds to a building with natural period of 0.33 sec., namely, a 5-6 story middle-rise building in actual size. A typical input ground motion is shown in Fig. 7. Run table is shown in Table 3.

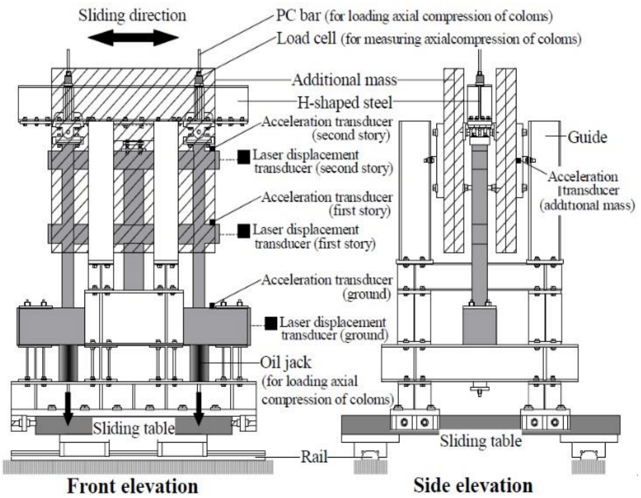

Fig. 5. Outline of loading setup and measuring.

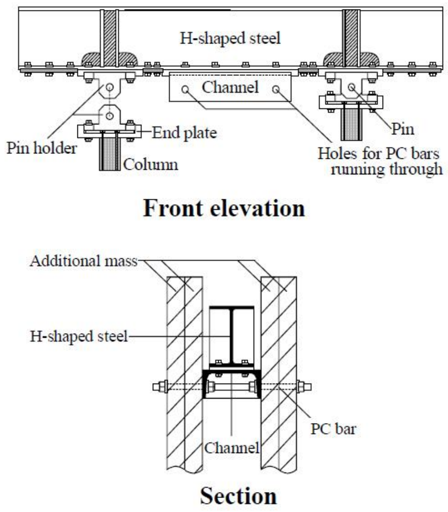

Fig. 6. Detailed drawing of connection to specimens of additional mass.

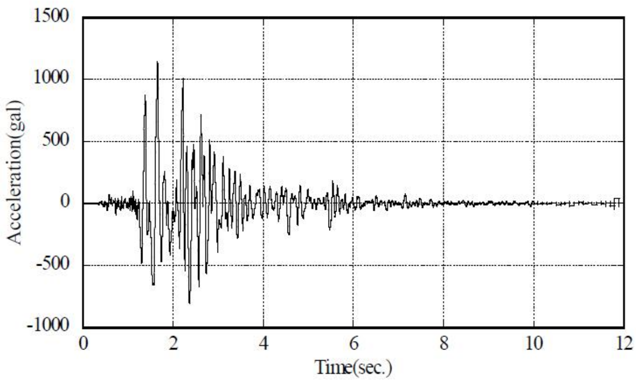

Fig. 7. Input ground motion (Kobe·1.0).

Table 3. Run table of shaking table test.

Run	MW12-D		MW15-D	
1	Kobe	0.1	Kobe	0.1
2	Kobe	0.3	Kobe	0.3
3	Kobe	0.5	Kobe	0.5
4	Kobe	0.7	Kobe	0.7
5	Kobe	1.0	Kobe	1.0
6	Kobe	1.2	Kobe	1.2
7	Kobe	0.5	Kobe	0.5
8	Kobe	0.7	Kobe	0.7
9	-	-	Kobe	1.0
10	-	-	Kobe	1.2

The relationships between the lateral force and the displacement are shown in Fig. 8 for several input level, Run-4, -5, -6 and -8. In the figure, the lateral force means the one obtained by multiplying the recorded absolute acceleration of the additional mass by the mass of 1.97 tons, which is equivalent to the sum of restoring force and damping force, and the displacement is the relative displacement between the stub and the second floor. Until Run-3, both specimens showed almost elastic behavior. During Run-4, the both specimens went into inelastic region and hysteresis loop gradually shifted to slip type. As for Run-5, a number of shear cracks are observed in the walls after shaking for both the specimens, however, they had not yet experienced the strength degradation due to shear failure of the walls. During Run-6, the walls at both the stories were failed due to shear in both the specimens. As shown in Fig. 9, it can be recognized that the elongation of the walls rapidly decreased after the time indicated by dots ∘ and •, and it is considered that the walls were failed at the time indicated by the dots, respectively. According to the above consideration, as for the specimen MW12-D, the wall at the lower story failed at first (1.53 sec) and then the upper story wall failed (1.61 sec), and as for MW15-D, the upper wall failed at first (1.53 sec) and then the lower one (1.63 sec.) As for Run-8, both specimens exhibited considerable slip behavior, and the restoring force did not reach the residual lateral strength of the specimens.

Story drift angle of the first story is compared with that of the second story in Fig. 10. It is recognized that the story-drift at the story where the wall failed former rapidly increased compared with the other during two times of the shear failure of the walls. It is the same results as provided in the static loading test, though the wall failed earlier was different according to the specimens. In the specimens for the shaking table test, two failure occurred in a very short period of 0.1 sec and the columns were designed still little stronger than the beams, therefore, the influence of the brittle behavior of the wall is limited small. The reason they occurs in a short period can be considered that shear failing of one wall releases the restriction of the elongation for the other wall, and that weaken the shear strength of the wall, however, if less stronger columns are used, the attention should be continuously paid on this problem, because there is still some fears the brittle failure of the wall eventually cause story collapse.

Equivalent damping ratio evaluated each half loop as shown in Fig. 11 is plotted in Fig. 12 for both the specimens. This includes the ordinary viscous damping ratio because the lateral force is the sum of restoring force and damping force in the hysteresis previously described. The horizontal axis of Fig. 12, x_{max} corresponds to that in Fig. 11 and it is almost equivalent to the lateral displacement of the story when x_{max} is smaller than about 10mm, therefore the plots in Fig. 12 are the equivalent damping ratios before the wall fails. In spite that the walls do not fail, they exhibited 0.1 and more. The damping ratios for MW12-D are totally higher than those for MW15-D.

The relationships between the lateral load and the displacement under the static loading test (solid line) and the relationships between the lateral force and the displacement under the shaking table test (■ and □) are shown in Fig.13. Dot ■ means the time when the specimens recorded the maximum lateral load during each Run from -1 to -6, and dot □ means the time when the specimens recoded the maximum displacement of the second story during Run-6. Though the lateral force is the sum of restoring force and damping force, the velocity of deformation is almost 0 when the dots ■ and □ are recorded, therefore damping force included in the lateral force at the dots ■ and □ is almost 0.

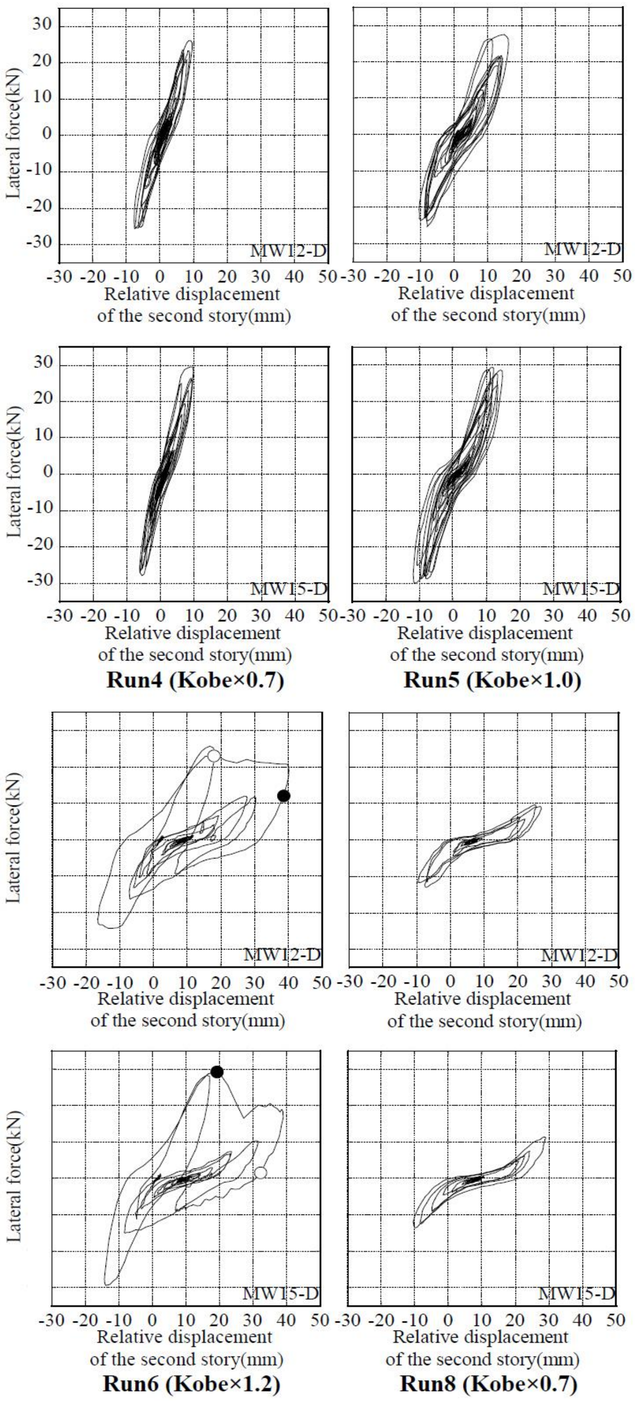

Fig. 8. The relationships between the lateral force and the displacement.

The specimens' mechanical properties for the both loading tests are similar. By the above consideration, the lateral force recorded through the shaking table test can be simply compared with the lateral load recorded through the static loading test. Generally the results under the both loading tests are coincident with each other in MW12 and MW15. The displacement when the specimens show the peak restoring force in the both loading tests are also coincident with each other. In other words, the deformation limit of the walls does not depend on a method of the loading. Under the shaking table test the displacement increases rapidly after the walls failed than under static loading test.

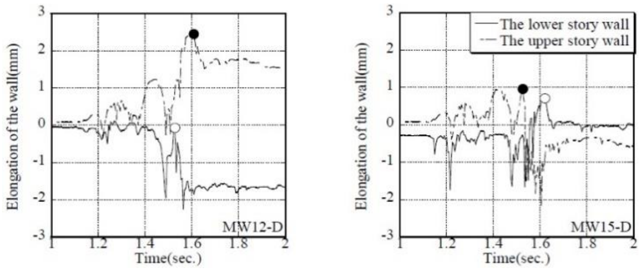

Fig. 9. Time history of the elongation of the walls (Run-6).

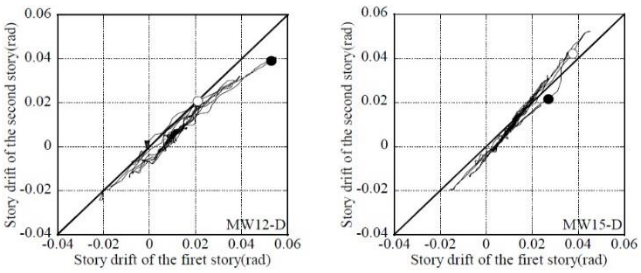

Fig. 10. Relationship between story drift of the second story and the first story (Run-6).

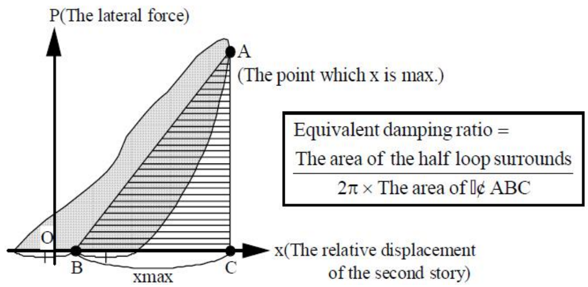

Fig. 11. Evaluation of equivalent damping.

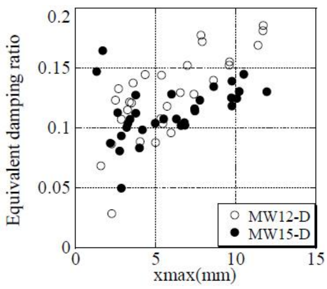

Fig. 12. Relationship between equivalent damping ratio and x_{max} (Run-3, -4, -5).

5. Conclusions

- Shear failure of a wall makes the story drift at the story where the failed wall exists progress more than other story. However whether that cause the story collapse has not clarified yet. It is necessary to do continuous investigation on this issue.
- Equivalent damping ratio more than 0.1 is expected for RC frames with the partial walls before exhibiting the ultimate lateral strength.
- The relationships between the force and the displacement under the static loading test and the shaking table test are coincident with each other. And the deformation limits of the walls under the two loading test are coincident, too.

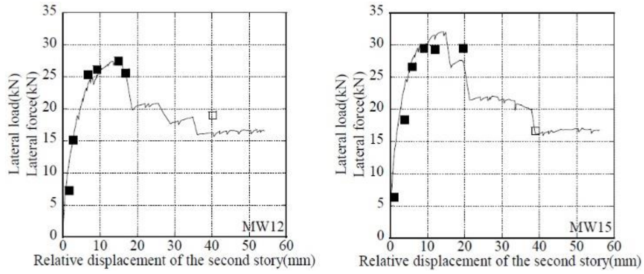

Fig. 13. Outline of loading setup and measuring.

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