An Experimental Study on Influence of Mullion-type Wall of Predominant Bending Failure in Reinforced Concrete Frame

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Abstract: Mullion-type walls, which are not regarded as structural elements in general, joined to RC frames may raise horizontal load-carrying capacity of the structure. However there is some probability that the axial elongation of them after their yielding due to bending moment has a bad influence on a behavior of RC frames. In this paper, one eighth scale two story and three story specimens were made and tested. Those consist of 1 span RC frame and the mullion-type walls at every story. The conclusions are as follows. The mullion-type wall elongates axially in each story after it yields due to bending moment, and the beams connected with the walls at the upper story are forcibly and more conspicuously deformed by the elongation of the walls. Consequently the rotation angle of the upper beams is about one and a half times as large as the drift angle. Experimental horizontal load-carrying capacity corresponds to the value calculated as the elongation produces plastic hinge in beams. These verification indicates that the mullion-type wall joined to RC frame raises horizontal load-carrying capacity unless the elongation causes brittle failure of beams.

1. INTRODUCTION

Continuous mullion-type walls are very popular as exterior walls of structures for condominiums in Japan. In general, they are not regarded as structural elements, because they do not satisfy the requirements for bearing walls, and their existence are ignored in structural calculation. However, if slightly, they have a certain lateral stiffness and strength, therefore, they have some influence on the behavior of the structure in which they are installed. They may raise the ultimate lateral strength of the structure. On the other hand, they will yield due to bending moment at both the ends and will axially extend after yielding. The end moment and the elongation of them may have bad influence on the behavior of main structure. Nowadays, under performance-based design, it becomes more important to fully grasp load-displacement curves of the structure including inelastic region. The purpose of this paper is to show the influences above mentioned through an empirical examination.

2. OUTLINE OF THE EXIPERIMENT

2.1 Specimens

Two specimens, one of which was 1 span-2 story plain frame(MW2) and the other was 1 span-3 story one(MW3), were made and tested. As shown in Fig.1, both of them were about 1/8 scale models of actual structures. They had the story height of 40cm and the span of 80cm, and a continuous mullion-type wall was installed at the center of the span. The dimensions of the columns, the beams and the wall are indicated in Fig.2. Their reinforcements are indicated in Table 1. Longitudinal reinforcements were deformed bars with the nominal diameter of 6mm and shear reinforcements were round bars with the diameter of 3mm. The beams and the walls were strengthened laterally almost until the limit of strengthening as shown in Table 1. The center hole of the column is for PC bar provided to induce axial force. Mechanical characteristics of the reinforcements and the concrete are indicated in Tables 2 and 3.

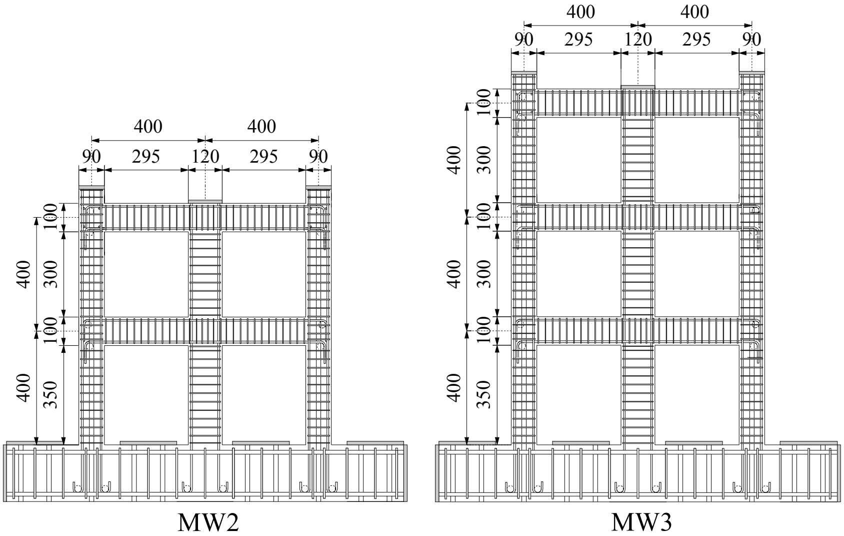


Figure1　Specimens(unit:mm)

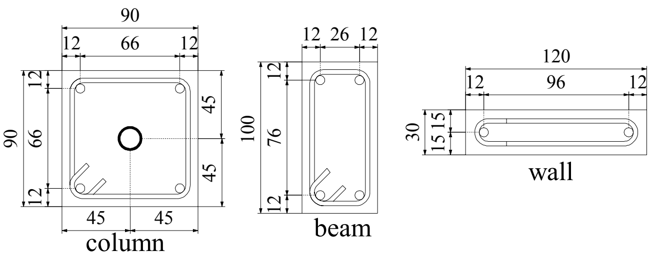


Figure2　Sections of members(unit:mm)

Table1　Reinforcement

	Longitudinal Reinforcing Bars	Hoop Reinforcing Bars
beam	D6(2.6%)	3φ @25(1.1%)
column	D6(1.6%)	3φ @30(0.53%)
wall	D6(1.8%)	3φ @30(1.5%)

Table2　Mechanical Characteristics of the Reinforcements

	Yield Strength(MPa)	Tensile strength(MPa)	Young's modulus(MPa $\times 10^4$)
D6	374	486	18.2
3ϕ	500	616	18.7

Table3　Mechanical Characteristics of the Concrete

age	Compressive Strength(MPa)	Tensile strength(MPa)	Young's modulus(MPa$\times 10^4$)
28	29.1	2.81	2.67
45	30.7	2.86	2.60

2.2 Loading setup and method of loading

The specimens were fastened to the basement by 16 PC bars at the center of the loading frame, as shown in Fig.3. A constant axial force equivalent to $0.2bD\sigma_B$ was loaded to both the columns by two center-hole jacks set under the specimen and PC bars piercing the columns vertically. The top of the specimen was horizontally pulled and pushed with the same forces by the upper two oil jacks, and the lower ones were to load reacting forces. By means of them, the PC bars to fasten the specimen did not share the lateral reacting force at all.

Cyclic loading test was carried out under controlling the story drift angle of the first story. The controlled drift angles were positive and negative 0.005rad, 0.01rad, 0.02rad, 0.04rad 0.06rad and positive 0.08rad.

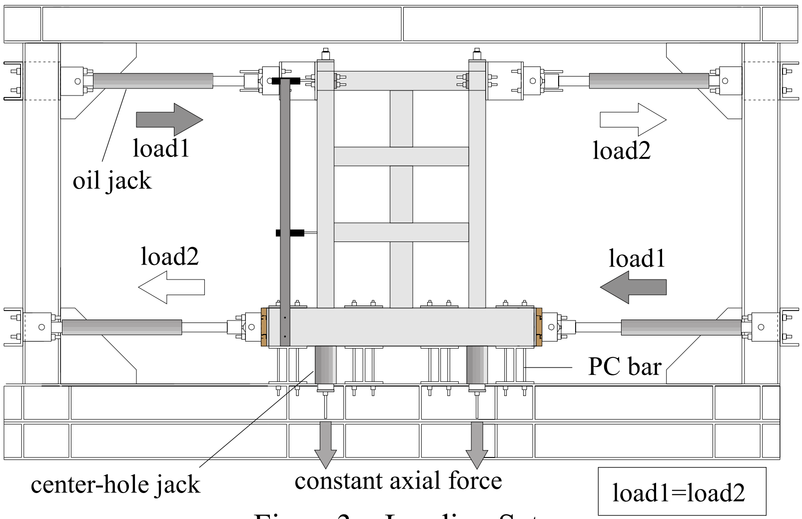


Figure3 Loading Setup

3. TESTING RESULTS

3.1 Load-displacement curves and development of cracking and destruction

Relationships between the lateral load and the story drift angle of the first story are indicated in Fig.4. In the figure, broken lines stand for the strength calculated neglecting the existence of the walls. The maximum strength of the specimen MW2 was 31.1kN at the drift angle of 0.02rad, and that of the specimen MW3 was 28.1kN at the drift angle of 0.018rad. They significantly exceeded the calculated ones. Until the drift angle when the specimens showed the maximum strength, all the ends of the beams and the walls were yielded due to bending. As for the columns, the yielding was recognized at only bottom ends of the first story columns. Crack distributions of both the specimens at the drift angle of 0.02rad are illustrated in Fig.5. At that time, many flexural cracks were observed in the beams and the walls, and many shear cracks were observed in the beam-column joint and the beam-wall joint, however, there were no cracks inducing brittle failure in the members. After they showed the maximum strength, both ends of the walls were crushed, and the strength degraded gradually. However, the strength exceeded the ultimate lateral strength calculated neglecting the existence of the walls until the drift angle of 0.04rad. Crack distributions at the drift angle of 0.06rad are shown in Fig.6. As for the specimen MW3, the top end of the top wall was fatally crushed and deformed to out-of-plain at 0.04rad, and the plastic hinge was observed at the bottom ends of the second story columns.

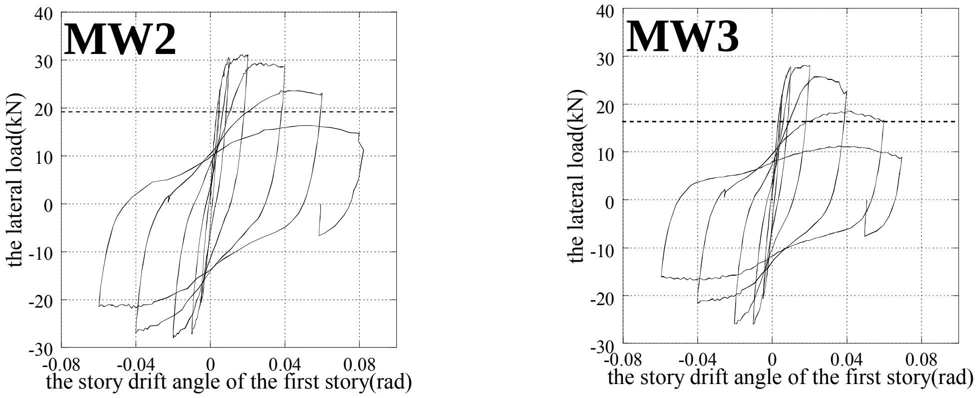


Figure4 Relationships Between the Lateral Load and the Story Drift Angle of the First Story

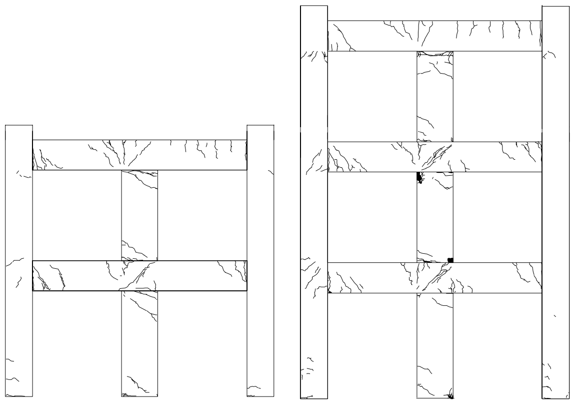


Figure5 Crack Distribution(0.02rad)

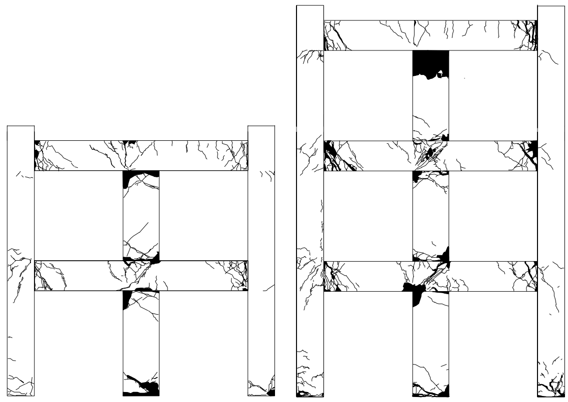
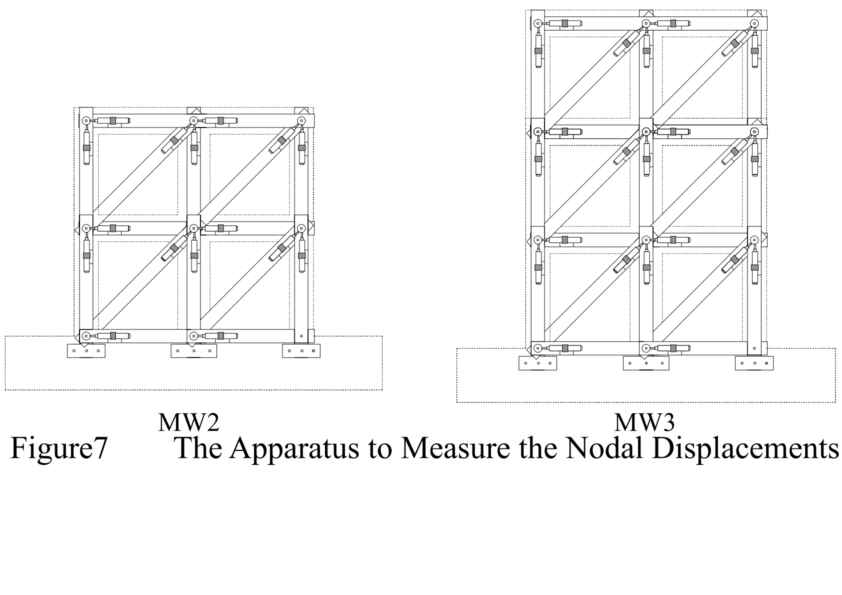


Figure6 Crack Distribution(0.06rad)

3.2 Two dimensional deformation of the specimens

An apparatus to measure the nodal displacements as illustrated in Fig.7 was set at one side of the specimens, and two dimensional shape of the grids consisted of the horizontal members and the vertical ones was calculated by means of the least squares method. The results are illustrated in Fig.8. In the figure, the displacement is enlarged 10 times as large as the actual one.

The story drift angles of every story was almost same as each other until the drift angle was 0.02rad, however, after that, the angle at the upper story became larger than that at the lowest story. Some elongation of the mullion-type walls began to be observed at about 0.02rad, and it became significant gradually. The beams were enforced to deform upward at the beam-wall joint due to the elongation of the walls.



MW2 MW3

Figure7 The Apparatus to Measure the Nodal Displacements

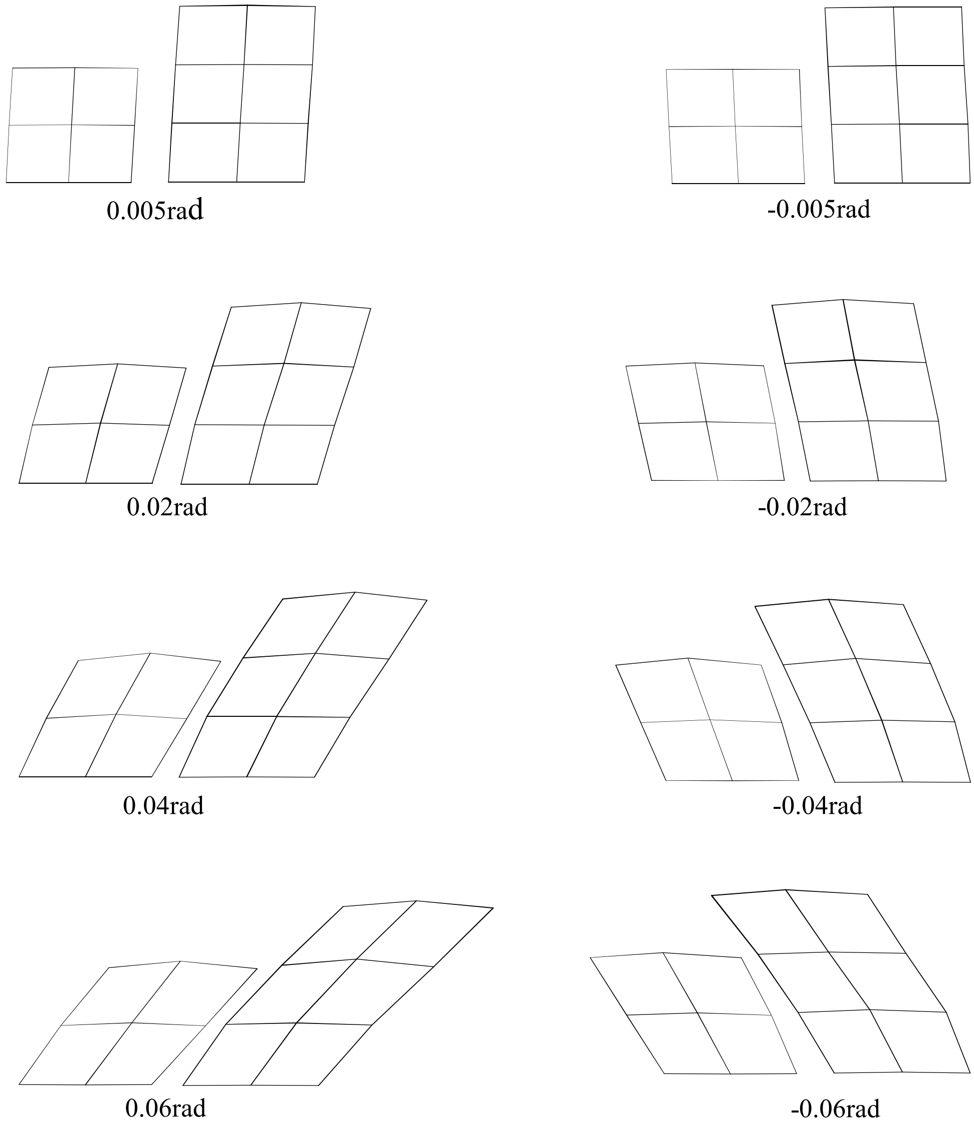


Figure8　　Two Demensional Diformation

3.3　Elongation of mullion-type walls and its influence on beams

How the difference between the vertical displacement of the column and that of the wall at the top of the specimens developed are shown in Fig.9. This figure shows that the walls extend before they yield. The difference declined at 0.06rad as for the specimen MW2 and at 0.04rad as for the specimen MW3. The walls in the upper story were crushed at those angles and they finished to play a role of bearing the lateral load.

The member angles of the beams to the connected columns are compared with the drift angle of the first story in Fig.10. If the drift angles of the whole stories are the same and the members do not extend axially, both the angles ought to be equal. However, the member angle of the beam in the top story of the specimen MW2 was 0.031rad and that of the specimen MW3 was 0.035 when the drift angle was 0.02rad. That indicates the beams are required to be more strengthened laterally so as to deform with ductility until larger deformation in the case that the deformation capacity of the structure is expected to be 0.02rad

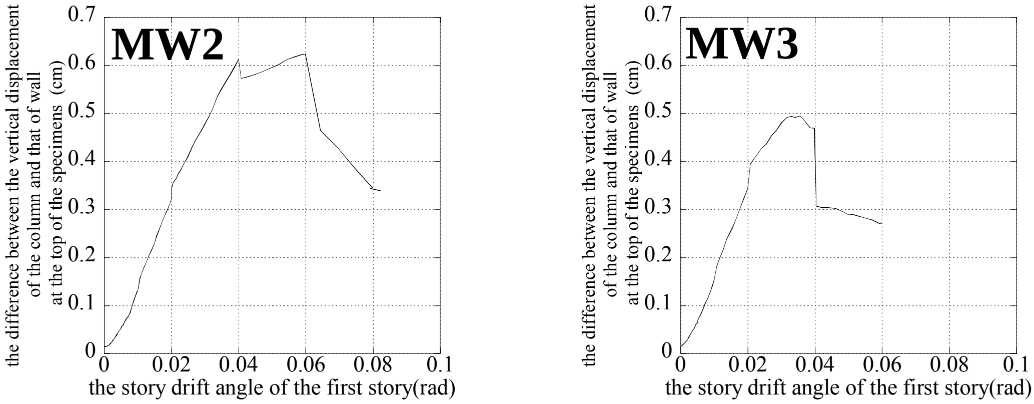


Figure9 The Difference between the Vertical Displacement of the Column and that of the Wall at the Top of the Specimens

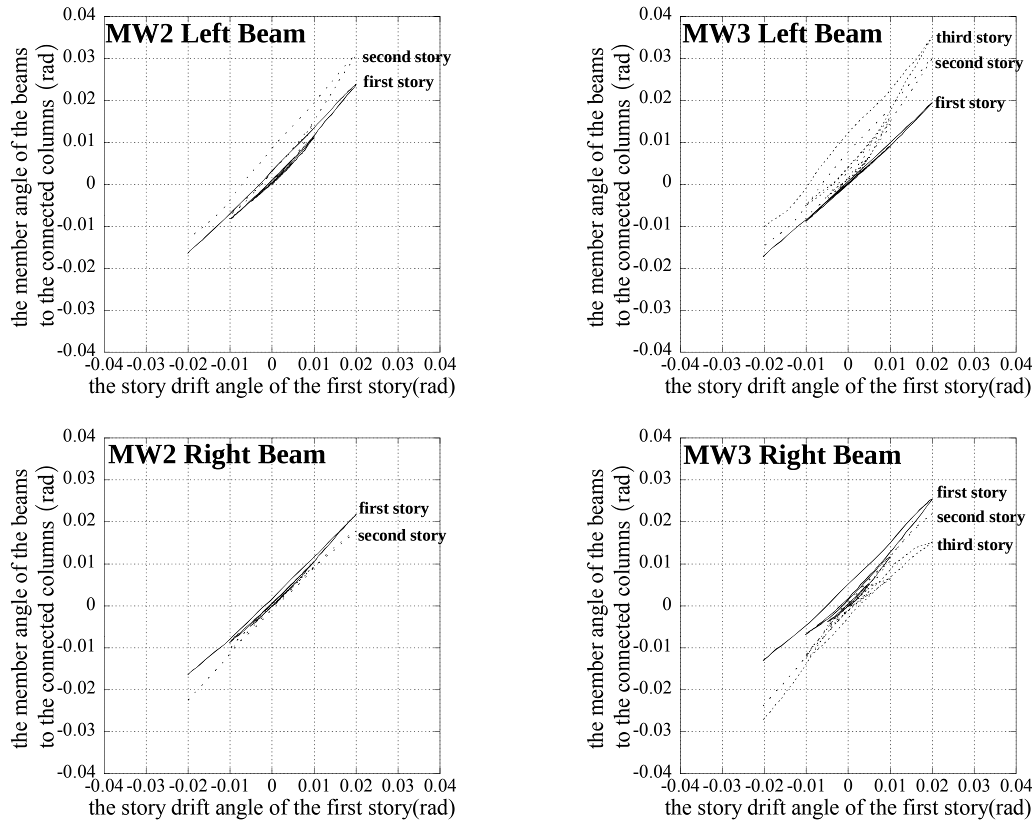


Figure10 Relationship Between the Member Angle of the Beams to the Connected Columns and the Drift Angle of the First Story

4. EVALUATION OF THE ULTIMATE LATERAL STRENGTH

The ultimate lateral strengths of the specimens are calculated under the following 3 cases, and they are compared with the experimental results.

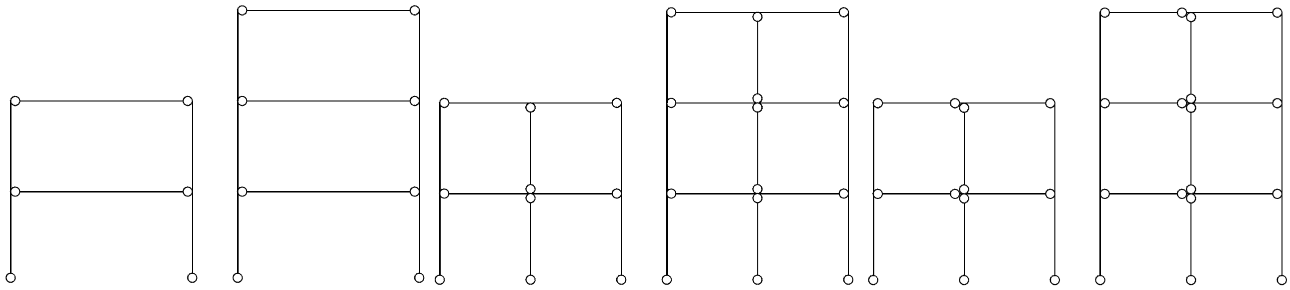
Case 1: in the case of neglecting the existence of the mullion-type walls.

Case 2: in the case of neglecting the elongation of the walls.

Case 3: in the case of considering the elongation of the walls.

As for the above cases, collapse mechanisms are illustrated in Fig.11. In the case of considering the elongation of the walls, the situation of Case 2 is not the ultimate state. In this case, plastic hinges occur at one end of the beams connected to the walls as shown in the figure, because the elongation of the walls forcibly deform the beams.

The calculated ultimate strengths are compared with the experimental one in Table 4. It is confirmed that the ultimate strength of the frame with continuous mullion-type walls can be evaluated to be the calculated one in the case 3 in 2 or 3 story frames, when the members exhibit ductile behaviors.



Case1 Case2 Case3

Figure11 Collapse Mechanisms

Table4 The Calculated Ultimate Strength and the Experimental One

	Exiperimental value	Case1	Case2	Case3
MW2(kN)	31.1	19.2	27.0	30.2
MW3(kN)	28.1	16.3	24.3	28.0

5. CONCLUSIONS

1) In the case beams and walls are sufficiently strengthened against shear force and their ductile behaviors are warranted, the ultimate lateral strength of frames with mullion-type walls are estimated by the calculated one considering elongation of the walls.
2) However, beams are required to be strengthened laterally considering not only the existence of mullion-type walls but also that the beams are more deformed due to the elongation of the walls.

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