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# An evaluation of the critical section on beam-column joint of reinforced concrete frame with non-structural walls

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### Abstract

The purpose of this study is to establish the evaluation method for the critical section of beam-column joint of reinforced concrete frame with non-structural walls. The experiment of column with wing walls and spandrel walls were conducted. The failure mode of the column was designed to be bending failure. The spandrel wall was install at only bottom of column. The wing wall of compressive side was damaged widely, and the damaged area were spread to the crossing section of wing wall and spandrel wall. The experimental results shows that the position of the critical section of the column with non-structural walls, considering the effect of compressive stress of spandrel wall, was proposed to evaluate the critical section of the column. The calculation results were agreed with the experimental results. The calculation results also shows that the position of the critical section would be changed due to the thickness of wall and compressive strength of concrete.

Keywords: Reinforced Concrete, Non-structural Wall, Critical Section

#### 1. Introduction

Not only life safety against an extremely large earthquake, but also the business continuous planning (BCP) after the earthquake are important for the seismic design of buildings. In recent years, the design method of the reinforced concrete frame with non-structural walls to control damage of the buildings were discussed [1]. The reinforced concrete frame with non-structural walls could easily have high rigidity and strength than that without non-structural walls. And, forces acting on beam-column joint would be decreased.

To evaluate the ultimate shear force of reinforced concrete frame with non-structural wall governed by the bending failure at the bottom of 1-story column with wing wall and beam with spandrel and hanging wall, the position of critical section of beam and column with non-structural wall would be important.

Shioya [2] was proposed the evaluation method of maximum shear force for column confined by spandrel and hanging walls. The proposed method based on the upper bound theorem of the ultimate analysis could evaluate the maximum shear force. Shioya et. al. [3] also proposed the evaluation method of the maximum shear force for the steel reinforced beam with wing walls. The calculate results of the proposed method based on the principle of virtual work was agreed with experimental result. Kabeyasawa et. al. [4] was conducted static test of column with wing wall and spandrel wall. The experimental results showed that the rigid zone to evaluate initial stiffness of column is not effected the wall width. On the other hand, the width of walls were effective on the maximum shear force. These research showed that to evaluate the maximum shear force confined with nonstructural wall, the wall width and strength of materials and the height of the corresponding point.

The purpose of this study is to establish the simple evaluation method for the critical section of beamcolumn joint of reinforced concrete frame with non-structural walls. In this study, static test of the column with wing wall and with spandrel wall are conducted. Due to the experimental result, we proposed the evaluation method based on the free-body model of column with spandrel walls.



## 2. Experimental Program

### 2.1 Specimens

The experiment of column with wing walls and spandrel walls were conducted. The bar arrangement of the specimens are shown in Fig. 1. There are 2 specimens, column with wing wall (M-C) and column with wing wall and spandrel wall (M-C-Sp). A failure mode of the column is designed to be bending failure. The scale of specimen has 1/2. The section of column is 400\*400mm, longitudinal reinforcement is 16-D19, and shear reinforcement is 4-D10 @ 100mm. The section of wing wall and spandrel wall is 100\*400mm, vertical and horizontal reinforcement is 2-D6 @ 100mm, and edge reinforcement is 2-D10. The spandrel wall was install at only bottom of column. The stabs was set on the top and bottom of the column for loading.



## 2.2 Material Property

The material characteristics of concrete and steel are shown in Table 1 and 2. The specified compressive strength of concrete is 30N/mm<sup>2</sup>, and yield strength of reinforcement is 397 N/mm<sup>2</sup> for vertical and horizontal reinforcement of wall, 375 N/mm<sup>2</sup> for shear reinforcement of column and beam and 393 N/mm<sup>2</sup> for longitudinal reinforcement.

Slump	Air	Temp.	Young Modulus	Comp. Strength
[cm]	[%]	[°C]	[N/mm <sup>2</sup> ]	$[N/mm^2]$
18.0	4.0	15.0	2.69×10 <sup>4</sup>	38.3

Table 1 - Material characteristics of concrete

Table 2 – Material characteristics of steel



Size	Quality	Young Modulus	Yield strength	Yield strain	Tensile strength
		$[N/mm^2]$	[N/mm <sup>2</sup> ]	[µ]	$[N/mm^2]$
D6	SD295A	1.94×10 <sup>5</sup>	397	2046	533
D10	SD345	1.91×10 <sup>5</sup>	375	1959	511
D19	SD345	1.95×10 <sup>5</sup>	393	2021	584

#### 2.3 Loading Program

A static cyclic loading test with constant axial force is conducted. The loading instrument is shown in Fig.2. Constant axial force is 346kN, as the axial force ratio for column is about 0.07. The loading cycle is controlled based on rotational angle of column, relative displacement of top of the column divided by the height. The loading cycle is R=1/3200, 1/1600, 1/400, 1/200, 1/100, 1/30, 1/25, 1/20, 1/120, 1/15.



## 3. Experimental results

#### 3.1 Specimen M-C

The relationship between the lateral force and drift angle is shown in Fig. 3. In this figure, yield point of edge reinforcement of wing-wall is shown as square shape point, yield point of axial reinforcement of column is shown as diamond shape point, and maximum strength is shown as circle shape point. The crack patter that was observed in the experiment is shown in Fig. 4.

In R=1/800 cycle, bending crack of wing-wall and column was observed In R=1/400 cycle, the edge reinforcement of wall was yielded. In R=1/200 cycle, compressive failure at wall edge was caused. In R=1/100 cycle, the axial reinforcement of column was yielded and reached maximum strength. The maximum shear force for positive direction was 334.7kN, and for negative direction was 292.6kN. In R=1/50 cycle, buckling of the edge reinforcement of wall was occurred, and resistant force was decreased. After that, the reinforcement was fractured.





Fig. 3 – Relationship between lateral force and angle (M-C)



Fig. 4 – Crack pattern

## 3.2 Specimen M-C-Sp

The relationship between the lateral force and drift angle is shown in Fig. 5. The crack patter that was observed in the experiment is shown in Fig. 6.

In R=1/800 cycle, bending crack of wing-wall and column was observed. And also the cracks at the crossing area of wing-wall and spandrel wall was observed. In R=1/200 cycle, the edge reinforcement of wing wall was yielded at the face of spandrel wall. In R=1/100 cycle, the axial reinforcement of column was yielded at the face of spandrel wall and reached maximum strength. The maximum shear force for positive direction was 372.9kN, and for negative direction was 339.0kN. In R=1/50 cycle, buckling of the edge reinforcement of wing wall was caused, and resistant force was decreased. The compressive failure area were moved inside of the crossing area of wing wall and spandrel wall.





Fig. 5 – Relationship between lateral force and angle (M-C-Sp)



Fig. 6 –Crack pattern (after R=1/20 cycle)

The strain distribution of vertical reinforcement on tensile side, the edge reinforcement of wing wall and axial reinforcement of column, at R=1/800, 1/400, 1/200 is shown in Fig. 7. The highest strain point of the wall edge reinforcement is almost at the face of spandrel wall, and that of the axial reinforcement of column is under the face of spandrel wall. It means that the critical section of the column with wing wall is under the face of spandrel wall. To evaluate seismic performance of the frame with non-structural wall, evaluation method of the position of critical section is needed.



Fig. 7 -Strain Distribution of vertical reinforcement of wall and column at each cycle peaks

## 4. Evaluation of critical section

In this section, we propose an evaluation method for a position of the critical section. The evaluation model is shown in Fig. 8. The position of the critical section would be represented as a highest moment point of the moment distribution of member, and shear force at that point equal to zero. To evaluate the position of the critical section, we considered the equilibrium of bending moment and shear force of the column. In this model, the resistant force by the compressive stress of concrete and tensile stress of horizontal reinforcement of spandrel wall are considered, and shear stress on the side of wing wall is not considered. We assumed that the compressive stress of horizontal reinforcement of spandrel wall is compressive strength of concrete Fc for any position, and the tensile stress of horizontal reinforcement of spandrel wall is yield strength. We also assumed that maximum bending moment of the column is reached the bending strength of the column with wing wall.

Based on some assumptions, the position of the critical section from the face of the spandrel wall L could represent as equation (1).



Fig. 8 - Evaluation model of critical section

$$L = -h_0 + \sqrt{h_0^2 + \frac{2M_y}{(F_c + p_w \sigma_{wy})t}}$$
(1)

Where, h0: shear span of the column, My: bending strength of column with wing wall, t: wall thickness.

We adapted the proposed equation (1) to the specimen M-C-Sp. The calculated position of the critical section is L=93mm. It is good agreed with the crack patern and damage region of that specimen, see Fig. 6. The comparison of the moment – angle relationship of the specimens is shown in Fig.9. In this figure, moment of



specimen M-C is at bottom of the column, and momento of specimen M-C-Sp is at the critical section. This figure show that the moment – angle relationship of these specimen is almost same. It means the propsoed equation (1) could evaluate the position of critical section properly.



Fig. 9 - Comparison of moment-angle relationship

## **5.** Conclusions

In this study, static test of the column with wing wall and with spandrel wall were conducted. Due to the experimental result, we proposed the evaluation method based on the free-body model of column with spandrel walls. The conclusions are as followings;

- 1) The experimental results showed that the column with wing wall designed as bending failure column was reached maximum shear force at about R=1/100, and after that buckling of the edge reinforcement of wing wall was caused, and resistant force was decreased.
- 2) The experimental results also showed that the position of critical section of the column with wing wall confined by spandrel walls would be under the face of spandrel wall.
- 3) The proposed method to evaluate the position of critical section of the column with wing wall and spandrel walls based on a free-body model considering the resistant force by the compressive stress of concrete and tensile stress of horizontal reinforcement of spandrel wall was proposed. The calculated position of the critical section was agreed with the observed result in the experiment.

#### References

- [1] T. Kabeyasawa, T. Mukai, H. Fukuyama, H. Kato, H. Suwada, M. Teshigawara and K. Kusunoki (2016): A Full Scale Static Loading Test on Five Story Reinforced Concrete Building utilizing Columns with Wing Walls [in Japanese], *Journal of Structural and Construction Engineering (Transactions of AIJ)*, 81(720), 313-322
- [2] S. Shioya (1997): Maximum Lateral Shear Force of R/C Columns with Spandrel Wall [in Japanese], Journal of Structural Engineering, 43B, 199-210
- [3] S. Shinya, K. Yoshimatsu, K. Ohtonari (2004): Elasto-plastic Behavior of Wing Wall Beams Steel Reinfroced Concrete Frame with Beam Sideway Mechanism and The Maximum Shear Force [in Japanese], *Journal of Structural and Construction Engineering (Transactions of AIJ)*, **576**, 157-164
- [4] T. Kabeyasawa, S. Kato, T. Kabeyasawa, Y. Hosokawa (2013): Effect of Spandrel and Hanging Walls on Flexural Capacity of Reinforced Concrete Columns with Wing Walls [in Japanese], *Journal of Structural Engineering*, **59B**, 15-20