

## Effective Length of RC Column with Spandrel Wall

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### ABSTRACT

In this study, the nonlinear dynamic analysis of a reinforced concrete frame specimen with a spandrel wall was carried out to evaluate the effective length of a column. The column that confined with the spandrel wall was assumed as a rigid zone. The analysis results were compared with the shaking table test results. At initial steps of excitation, dynamic response and frequency results were similar with the test results. However, the analysis and test results showed difference after the specimen damaged severely. It was considered that a constant rigid zone in the analysis could not reflect actual effective length of a column depending on the damage.

### 1. INTRODUCTION

One of the characteristics of a reinforced concrete(RC)school building is having a spandrel wall. The waist-high spandrel wall(below spandrel wall) in the RC frame confines deformation of the lower part of a column when the frame is subjected to lateral force. For that reason, the effective length of a column becomes shorter than the column which was not confined by a spandrel wall. For considering this short column effect to the structural design or analysis, generally, the spandrel wall is considered as a rigid zone. A research that how much rigid zone is valid has studied since 1960s. The rigid zone has evaluated by means of the experiment and analysis in previous study, however, the rigid zone has assumed to match test results and still has not generalized. In this study, the nonlinear dynamic analysis was performed to evaluate the effective length and rigid zone of the column that confined by the spandrel wall. And the analysis results were compared with the shaking table test results.

### 2. EFFECTIVE LENGTH AND RIGID ZONE OF COLUMN

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The effective length of the RC column that confined by spandrel wall can be calculated by subtracting from the total length to the rigid zone. According to the (AIJ standard 2010), the rigid zone at a joint can be considered as shown in Fig. 1. Generally, a length of the rigid zone of the member is considered as the remains of the column excepting the 1/4 of the width of the connected member.

(Arima et al. 2008) derived the vertical distance  $S$ , to the hinge position of the column from the top of the spandrel wall. They modeled the resistance of the spandrel wall as a compression strut and calculated the distance based on the upper bound theorem as shown in Fig. 2. The distance  $S$ , can be calculated by Eq. (1). Although the lower part than hinge position of the column is subject to bending moment, it can be considered as rigid zone.

$$S = -h_0 + \sqrt{(h_0^2 - (b \cdot h_0 - D)D) / a}, \quad (1)$$

Here,  $a = (0.5n + 0.21) / m$ ,  $b = 0.11 / m$ ,  $m = (M_{yt} + M_{yb}) / (c \sigma_b \cdot t_w \cdot D^2)$

$$n = \kappa \cdot \rho_{sh} \cdot \sigma_y / c \sigma_B$$

$c \sigma_B$ : compressive strength of concrete,  $\sigma_y$ : yield strength of wall main bar,

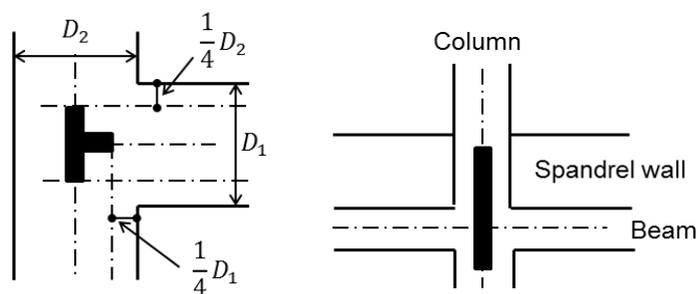
$\rho_{sh}$ : reinforcement ratio of wall,  $t_w$ : thickness of wall,  $D$ : width of column

$h_0$ : height of column,  $M_{yb}, M_{yt}$ : yield moment on top and bottom of column,

$\kappa$ : 2 .... case that wall was attached to both sides of column

1 .... case that wall was attached to one side of column

For the analysis of the specimen, the rigid zone was calculated as 470mm and 427mm by Arima's hinge position and the AIJ standard, respectively. For reference, the height of the spandrel wall was 480mm. In this study, the rigid zone was applied to the analysis by the AIJ standard for assuming more ultimate state.



(a) Column-beam joint (b) Column with spandrel wall

Fig. 1 Rigid zones at joint by AIJ

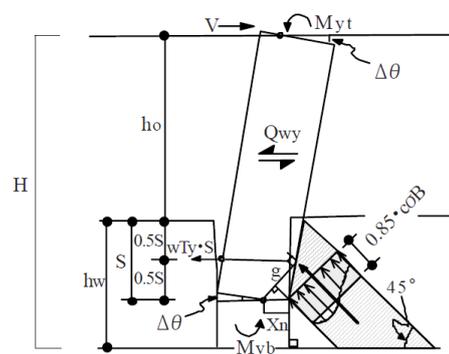


Fig. 2 Mechanical model of the column with spandrel wall

### 3. ANALYSIS MODEL AND METHOD

The reinforced concrete frame with the spandrel wall and detail of the sections are shown in Fig. 3. The 3D nonlinear analysis program (CANNY 2009) was used for the analysis. And the analysis model is shown in Fig. 4. Each member of the specimen was idealized by a linear element having springs. The spring behaves according to the hysteresis curve. The beam was modeled using only flexural rotational springs at the both sides. The column was modeled using two flexural springs, a shear spring and an axial spring. The tri-linear model which represents the stiffness degradation, pinching behavior was applied to the flexural spring. For the shear spring, the model adding strength deterioration to flexural behavior was used. And axial stiffness model, which has stiffness degrading and yielding in tension and elastic curve in compression, was applied to the axial spring. The spandrel wall was neglected and the confine effect of the column was considered as the rigid zone.

The record of El-Centro NS ground motion(1940,  $PGA=351\text{cm/sec}^2$ ) was used for the earthquake simulation as shown in Fig.5 and Table 1.

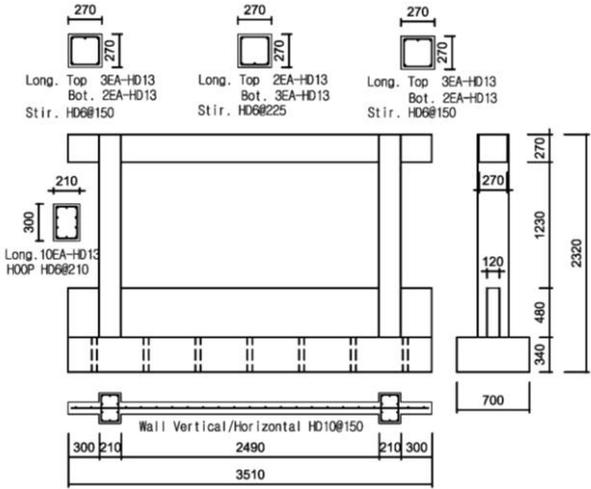


Fig. 3 Specimen(unit:mm)

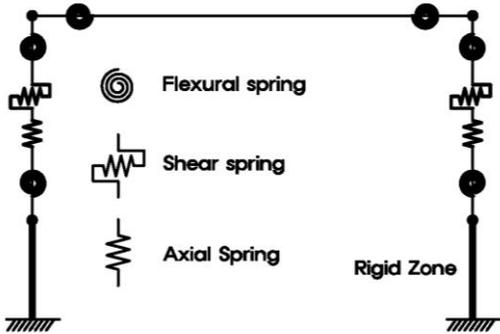


Fig. 4 Analysis model

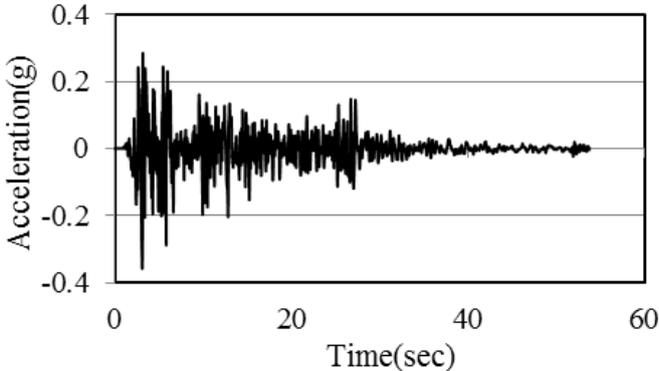


Fig. 5 El-Centro NS earthquake ground motion

Table 1. Intensity of the excitation

Test step	Scale (%)	PGA (cm/sec <sup>2</sup> )
1	33	117
2	67	234
3	100	351
4	133	468
5	167	585

**4. ANALYSIS RESULTS**

Fig. 6 shows the result of periods at each excitation step. The analytical periods to 100% scale of excitation were similar with the test results, though at the 33% scale of excitation, the period by analysis was a little smaller than the test result. A theoretical period is about 0.11 sec assuming that the beam is rigid. For that reason, the analytical result at 33% excitation was considered as reasonable. However, the analytical periods did not increase after 133% excitation unlike the test results. On the test, the column was damaged severely. The joint between the column and spandrel wall was cracked and it was considered that the effective length of the column was longer. On the other hand, because the rigid zone was constant in the analytical process, the change of the effective length of the column was not considered. It was considered as the reason that the analysis results under high ground acceleration were different with the test results. For this reason, the analysis was carried out again only at 167% excitation considering varying the length of the rigid zone. The applied lengths of the rigid zone were 320mm, 240mm, 160mm and these were about 2/3, 1/2, 1/3 of height of the spandrel wall, respectively. Fig. 7 shows the analytical periods considering the length of rigid zone. It was considered that effective rigid zone was until somewhere between 1/2 and 1/3 of the spandrel wall.

Fig. 8 and Fig. 9 show the time history of the dynamic responses at 100% and 167% excitation, respectively. At 100% excitation, 427mm of the rigid zone by AIJ standard was applied. On the other hand, at 167% excitation, 200mm of the rigid zone was applied according to above mentioned analysis results. The dynamic responses by the analysis were nearly matched to the test results in tendency and amplitude.

The dynamic analysis results of the RC frame with the spandrel wall can be different depending on the effective length of the column. It is difficult to reflect the effective length of column to analysis with a constant rigid zone. Thus it is necessary to study with respect to the analysis method and model that can represent the change of the effective length of the column depending on the damage.

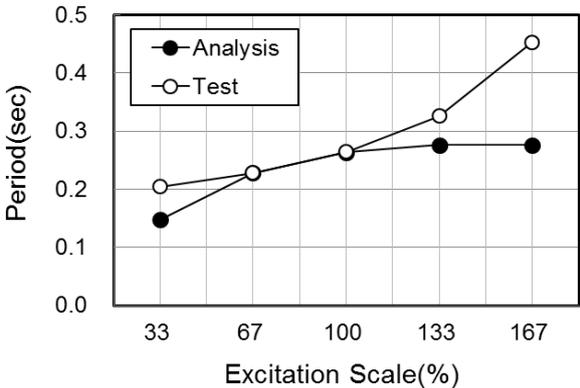


Fig. 6 Periods at each step

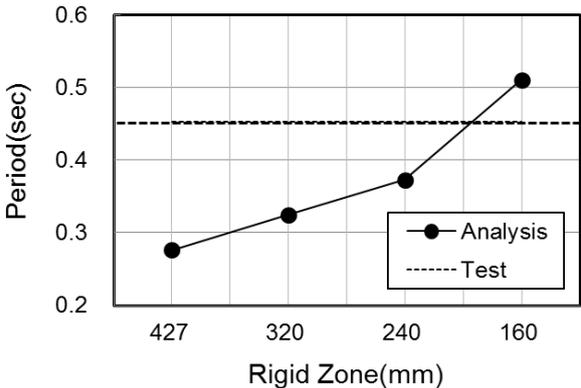
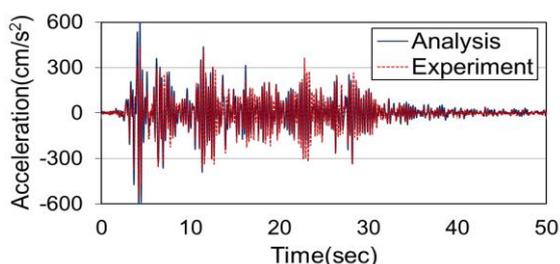
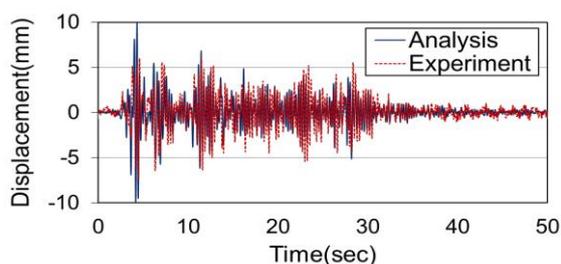


Fig. 7 Periods according to rigid zone at 167% scale of the excitation

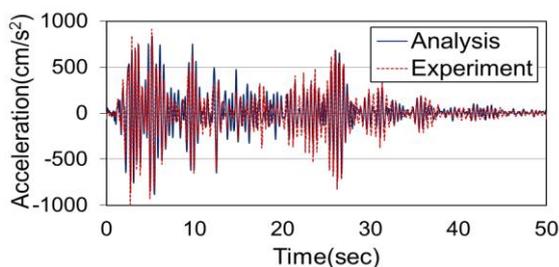


(a) Acceleration response

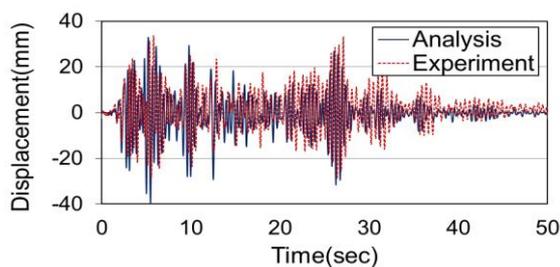


(b) Displacement response

Fig. 8 At 100% scale of the excitation - rigid zone length : 427mm



(a) Acceleration response



(b) Displacement response

Fig. 9 At 167% scale of the excitation - rigid zone length : 200mm

## 5. CONCLUSIONS

In this study, the nonlinear dynamic analysis of the frame with waist-high spandrel wall was carried out to evaluate the effect of rigid zone of the column. The analysis was considered varying the length of rigid zone. The analysis results applying the rigid zone by AIJ standard (about 1/10 of the height of the spandrel wall) were similar with the test results at initial steps. However, when the frame was damaged severely at the final step, the rigid zone was lower to about 2/5 of the height of the spandrel wall. Because it is difficult to consider the effective length of the column depending on damage, it is necessary to study with respect to the analysis method of model that can represent the change of the effective length of the column depending on the damage.

## ACKNOWLEDGEMENT

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