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A STUDY FOR SEISMIC IMPROVEMENT OF CONCRETE FRAME WITH PERFORATED WALLS

Ryota Ishii[1], Tetsuya Ohmura[1]

[1]Graduate School of Engineering, Tokyo City University, Japan

ABSTRACT: The Japanese building standard act was revised in 1981 considered non-linearity. However, a number of buildings built before 1981 are existing, seismic evaluations for those building have actively been assessed based on the seismic evaluation standard published by The Japan Building Disaster Prevention Association after especially 1995 Kobe Earthquake. In practical seismic evaluation works, it is relatively simple and easy to make models of general buildings, but unconventional frames are complex such as a staircase or a frame with different level girders. A perforated concrete wall is modeled as a shear wall, if the opening ratio is 0.4 and less. On the other hand, one with more than the opening ratio of 0.4 is modeled as a column with a wing wall. The modeling concept is simplified to smoothly assess the seismic performance of a building even though it is not confirmed that the models is suited to their actual behavior. In this paper, FE analyses were performed, and their results were examined. Finally, partially closing the openings down to an opening ratio of at least 0.4 is recommended because seismic slits could fail to work well.

Keywords: Perforated walls, Lateral force resist mechanism, Ratio of openings, Compressive strut

1. INTRODUCTION

The Japanese building standard act was revised in 1981 considered non-linearity. However, a number of buildings built before 1981 are existing, seismic evaluations for those buildings have actively been assessed based on the Seismic Evaluation Standard [1] published by The Japan Building Disaster Prevention Association after especially 1995 Kobe Earthquake. This standard takes the strength and ductility into account and defines three grades of seismic assessments to evaluate the seismic index. The modeling for columns and walls is extremely important in particularly the second grade of the seismic evaluation often taken, because the girders are assumed as rigid, and the strength and ductility of columns and walls directly influence on the seismic index.

This standard also corresponds to diversified buildings. However, for a frame of such as a staircase with beams located mid-story, the modeling concept depends on a judgment by an engineer.

In practical seismic evaluation works, it is relatively simple and easy to make models of general buildings, but when dealing with unconventional frames such as staircases or a frame with different level girders as mentioned above, it is much more complex.

First of all, the ratio of opening for a perforated wall should be calculated based on the standard. The ration of openings is defined as the square root of the openings area divided by the wall area as follows

$$r_0 = \sqrt{\frac{\sum h_i \cdot l_i}{h \cdot l_w}} \qquad (1)$$

where r_o *is* the ratio of opening; h_i and l_i are the height and width of the opening; h is the height of the story; l_w is the bay.

A perforated concrete wall is modeled as a shear wall, if the opening ratio is 0.4 and less. On the other hand, one with more than the opening ratio of 0.4 is modeled as a column with a wing wall. The modeling concept is simplified to smoothly assess the seismic performance of a building even though it is not confirmed to be suited to their actual behavior. However, in order to secure the flexible length for seismic improvement, a seismic slit is often located at the edge of a column or a window in a practical seismic improvement work.

In this paper, an actual frame with a perforated wall was modeled and FE analyses were performed. To be compared with the original model, also three models with seismic slits mentioned above were analyzed.

2. FRAME PROPERTIES

Fig.1, 2 and 3 show the focused frame in a three-story concrete school building built in 1973. The seismic index of 1st , 2nd and 3rd story was respectively 0.53 , 0.40 , 0.84 in the longitudinal direction, and more than 1.0 in every story in the span direction. Some mullion walls and spandrel walls located between the columns 1 to 2 in Fig.1 were ignored when the frame was modeled, because only the behavior of the perforated wall located between columns 3 to 4 in Fig.1 should be focused.

The building was damaged by the 3.11 earthquake. The cracking condition is shown in Fig.1. The crack width without any note was 0.3mm. Diagonal cracks were observed at around the edge of openings. 20.7 N/mm^2 of the concrete strength was assumed in the models, because the effect of the concrete strength difference in each story should be eliminated at first in this paper.

The wall had 120mm of thickness and 9mm of longitudinal and transverse rebar with 200mm space. The orthogonal frame were ignored.

3. MATERIAL PROPERTIES IN THE ANALYSIS

Material properties in the analysis is shown in Fig.4. Parabolic model for a compressive concrete, the Hordiji's model for a tensile concrete and Von Mises criterion were adopted. Rebars were modeled as a bi-liner model with perfect bond.

4. ANALYSIS

The model is shown in Fig.5. A four nodes and quadrilateral isoparametric plane stress element was applied to concrete meshed about 100mm square. Longitudinal rebar in columns and girders was embedded and only axial stress was considered. All rebar in wall and the transverse rebar in columns and girders was smeared and layered.

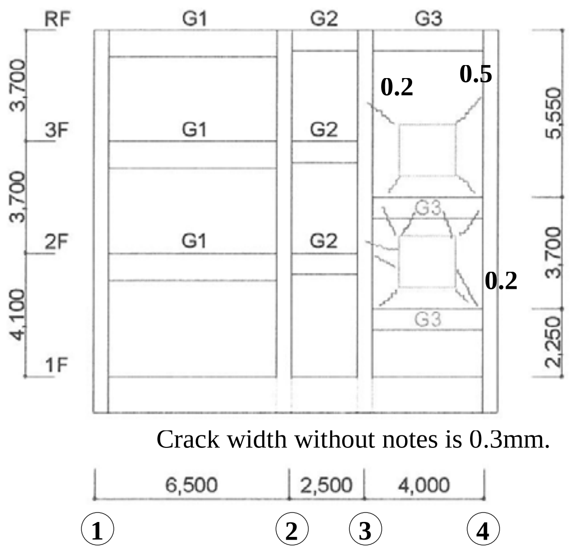


Fig.1 Elevation and crack patern damaged by 3.11 EQ

Section	500 × 500
Rebar	10-D22
Hoop	□-9ϕ @100

	$_2G_1$	$_2G_2$	$_2G_3$
Section	900 × 300	700 × 300	700 × 300
Upper	4-D19	5-D19	4-D22
Lower	4-D19	3-D19	2-D22
STP	□ -9ϕ @200		

Fig.2 Column and girder

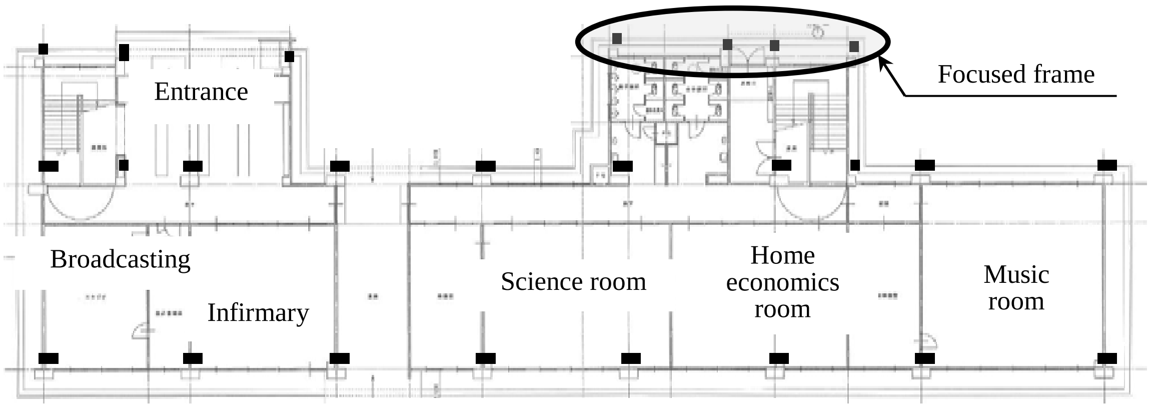
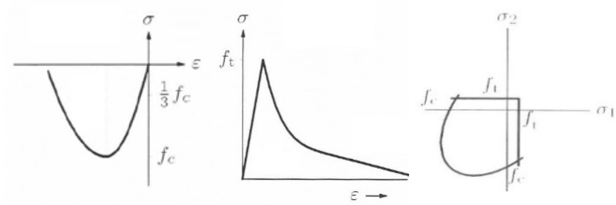


Fig.3 Plan

Table 1 shows analysis models and Fig 6 shows slits location. Model #1 has no slit. Model #2 has *1 of the slits at the edges of the windows as shown Fig.6. Model #3 has *2 of slits at the edges of the columns as shown Fig 6. Model #4 has *2 and *3 of slits. The lateral force from the left to the right was applied for Model #1 to #4 and that from the right to left for Model #1(−) to #4(−).



(a) Compression (b) Tension [3] (c) Criterion

Fig.4 Concrete model [2]

Table 1 Models

No.	Slit	Loading direction
#1	N/A	Left to right
#2	At windows (*1)	
#3	At left columns (*2)	
#4	At both columns (*2 and 3)	
#1 (−)	N/A	Right to left
#2 (−)	At windows (*1)	
#3 (−)	At left columns (*2)	
#4 (−)	At both columns (*2 and 3)	

*1 , *2 and *3 are indicated in Fig.7

The lateral forces was applied to the each slab. The amount of the lateral force depend on their rule floor area and the lateral force distribution factor was 3, 2 and 1 respectively. In addition, 12kN/m2 of the gravity load was applied at first. The foundation girders were supported by pin supports and the uplifting of the foundation girders wasn't taken into account.

5. BASE SHEAR FORCE AND WHOLE DRIFT

Fig.7 shows the base shear force and whole drift of Model #1 to 4. The whole drift was calculated by the lateral displacement divided by the height of the center of the roof girder. The maximum base shear force of Model #1 which had no slit was the largest and the others showed approximately the same base shear force. About 20% of the maximum base shear force reduction was shown because of the effect of their slits. On the other hand, the difference of the maximum base shear force between #2 to 4 which had slits was extremely small value. Therefore, it could be considered there is only a slight effect of the slit pattern difference.

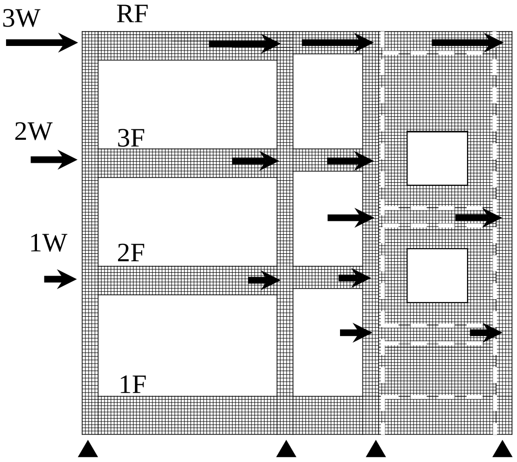


Fig.5 Mesh and lateral load

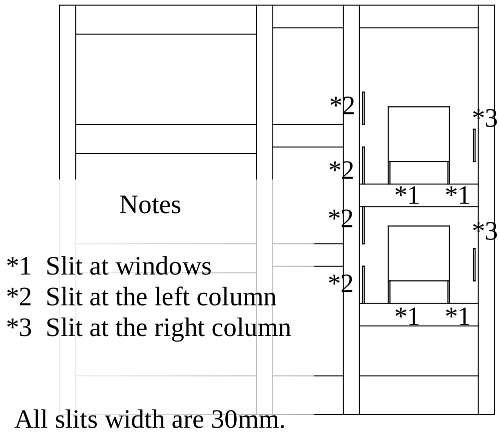


Fig.6 Slit plan

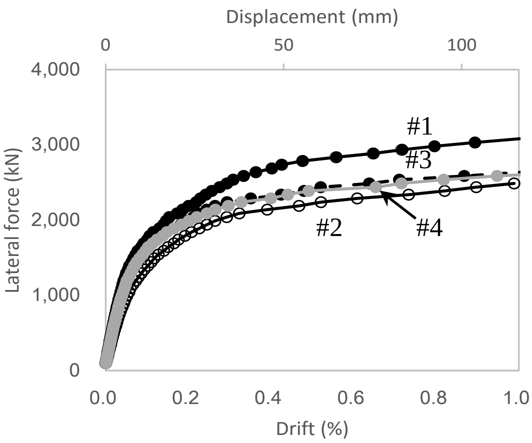


Fig.7 Lateral force and drift (L to R)

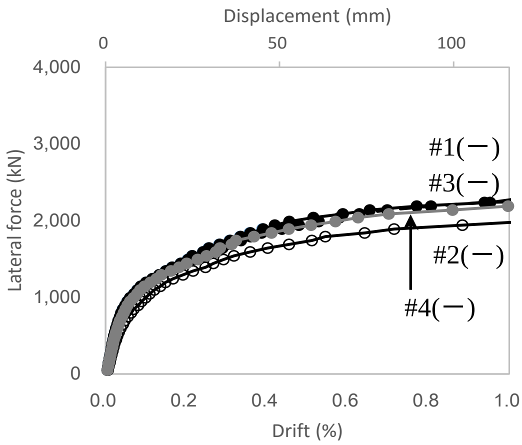
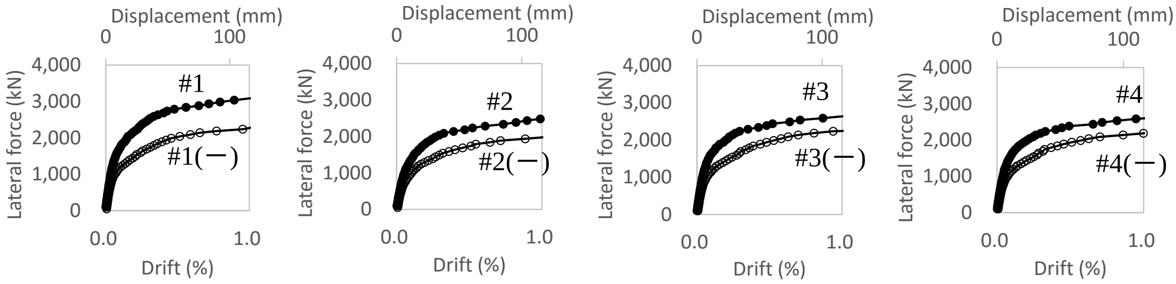


Fig.8 Lateral force and drift (R to L)

Fig.8 shows the base shear force and whole drift of Model #1(−) to #4(−) which from the right to the left of lateral force were applied. The maximum base shear force of #1(−), #3(−) and #4(−) were approximately the same. In other words, the effect of the slits at the edges of the columns is extremely small. In addition, about 13% of the maximum base shear force reduction



(a) #1 and #1(−) (b) #2 and #2(−) (c) #3 and #3(−) (d) #4 and #4(−)

Fig.9 Lateral force and drift (L to R)

was shown because of the effect of the slits at the edges of the windows.

Fig.9 shows the comparison of the difference of the lateral force direction. The maximum base shear force in the model which from the left to the right lateral force was applied is larger than that in the model which the backward lateral load was applied in all comparisons.

The maximum difference of the maximum base shear force was 26% between Model #1 and #1(−) as shown Fig.9 (a).

When slits were put into a perforated wall, the stiffness and strength should be appropriately evaluated, because the seismic evaluation of the whole building depends on the stiffness and the lateral strength of the frame with perforated walls. And the maximum lateral strength could be not the same as one under the backward lateral load.

6. CRACK STRAIN VECTOR

Fig.10 shows the crack strain vector at 0.04% of drift of Model #1 and #1(−). The range of dash lines shows the result of Model #1(−). The crack strain vector in our analysis was observed at the edges of the windows and similar to the crack observation damaged by 3.11 as shown Fig. 1. Our analysis result of this showed approximate good agreement with the crack observation.

Generally, in a seismic evaluation based on the Seismic Evaluation Standard, a perforated wall with over 0.4 of opening ratio is modeled as a column with wing wall having a flexible length as shown Fig.11.

The modeling concept is simplified to smoothly assess the seismic performance of a building even though it is not confirmed that the models is suited to their actual behavior, since the ground for the research and test data is insufficient.

Therefore, the flexible length as shown Fig.12 should be improved in a seismic evaluation. We suggest that a perforated wall with over 0.4 of opening ratio should be modeled as not a column with wing walls but a perforated wall with low stiffness and strength.

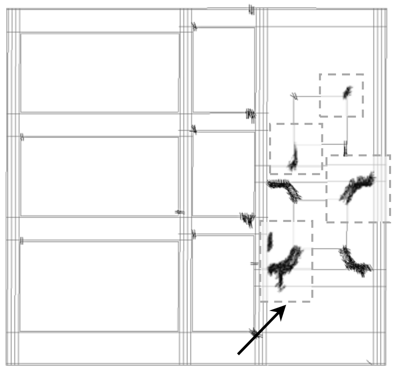

At −0.04%

Fig.10 Crack strain vector at 0.04% drift

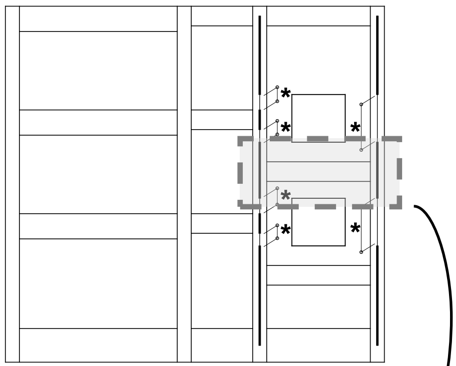


Fig.11 Flexible and rigid length

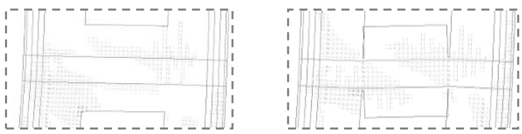
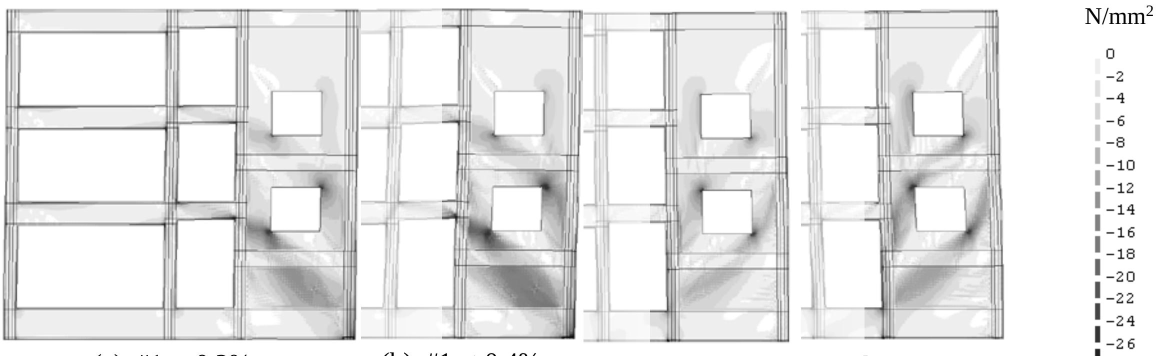

(a) #1 (0.4%) (b) #2 (0.4%)

Fig.12 Deformation

On the other hand, girders are ignored in the second grade of the seismic evaluation based on the Seismic Evaluation Standard. If seismic slits would be located at the edges of columns, the flexible length would be long in the same as Model #2. In addition, also a girder damage evaluation could be ignored even though the girder would be significantly damaged at the edge of seismic slits. It is caused by spandrel and hanging walls with the slits at the edges of openings.



(a) #1 at 0.2% (b) #1 at 0.4% (c) #1(－) at 0.2% (d) #1(－) at 0.4%

Fig.13 Principal stress (σ_2) #1 and #1(－)

7. PRINCIPAL STRESS

Fig.13 shows the compressive principal stress distribution of Model #1 with no slit. The flexible length based on the compressive principal stress distribution shown in Fig.13 is similar to a general perforated wall than the assumed flexible length shown in Fig.11.Although the opening ratio is more than 0.4, the concrete compressive struts were formed. It showed lateral force was transmitted in the diagonal direction.

As mentioned above, the flexible length as shown Fig.11 should be improved in a seismic evaluation, and a perforated wall with over 0.4 of opening ratio should be modeled as not a column with wing walls but a perforated wall with low stiffness and strength in view of the results in this chapter.

In case of a concrete frame with different level girders such as the models in this paper, the stiffness, strength and damage should be properly evaluated, because the compressive principal stress distribution diagram in the positive was different from one in the negative.

Fig.14 shows the compressive principal stress distribution of Model #2, 3 and 4. As shown Fig.13(b), the concrete compressive struts were formed, however, slits prevent from forming a diagonal compressive strut such as Fig.14(b) in Model #1 with no slit, because the slits were located to interrupted the diagonal compressive strut.

In addition, even if slits were located to lengthen the flexible length of the column, only two columns enclosed by the dot line expectedly deformed as shown Fig.14(b) and (c). Therefore, the slits in this models didn’t work not effectively and unexpectedly.

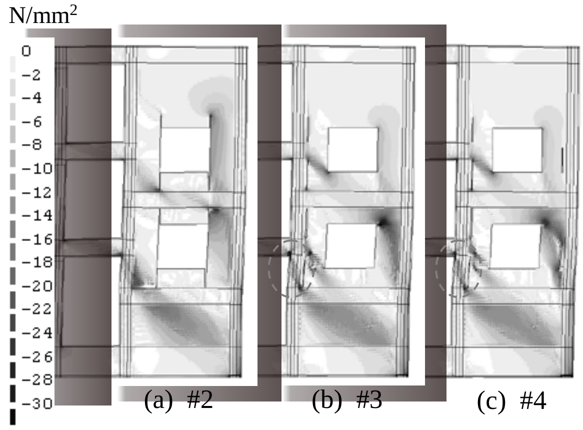


Fig.14 Principal stress (σ_2) at 0.4%

8. CONCLUSION

In case of a concrete frame with different level girders and symmetric openings such as the models in this paper, the stiffness, strength and damage should be properly evaluated, because the hysteresis curve and the compressive principal stress distribution diagram in the positive was different from one in the negative.

In a seismic improvement, not only seismic sits location planning but also the damage of girders at the edges of the slits should be examined when slits would be located at windows, because the damage would be concentrated to the both end of the seismic slits.

Closing the openings down to 0.4 of opening ratio is recommended based on the improving ways in the seismic evaluation standard, because the seismic slits would work unexpectedly and the strut forming was obstructed in the models with seismic slits.

9. REFERENCES

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Corresponding Author: Ryota Ishii