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The effects of opening on the strength of shear walls under multi-axis loading

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1. Introduction

Shear walls are one of the critical structural elements in buildings, designed to prevent the release of radioactive materials in case of an accident. The instability of reinforced concrete (RC) walls is commonly associated with out-of-plane unsteadiness, which can lead to various failure modes of the walls. However, the impact of multi-axis loading was not fully considered in most of the experimental studies because it was assumed that these walls mainly act as in-plane structural elements and has many constraints such as problems with axial load control under cyclic tests [1]. Not only there are a few numbers of experimental studies on the effects of multi-axis loading on RC shear wall, but also there is a lack of a numerical model of simulating shear wall [2-4].

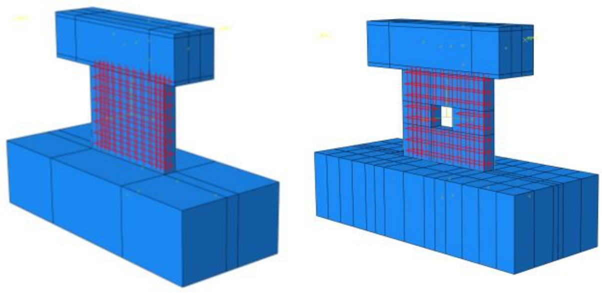
In addition, to fulfill the functional requirement, openings must be included in the design of shear walls. But it is important to note that these openings can reduce the strength of the wall and create stress concentration around the opening, leading to the formation of cracks during the early stages of the loading process. In this study, an analytical study was carried out to evaluate the shear strength of shear walls based on the presence or absence of opening under the multi-axial loading.

2. Finite element model of shear wall

In this section, a finite element analysis model was developed to simulate the behavior of a reinforcement concrete shear wall previously tested in an experimental study. The target specimen was created as a part of the the auxiliary buildings details for the nuclear power plant[5].

2.1 Finite element geometry

Figure 1 shows the finite element model of shear wall specimen. The model consists of loading beam, shear wall, and foundation beam. The thickness of the wall was 180mm, the span length was 1,500mm and the height was 1,200mm. The concrete material was depicted by 8 nodes solid elements(C3D8R), and reinforcement material was depicted by 2 nodes truss elements(T3D2). The axial force was applied to 1,100kN and the in/out-of-plane load were applied to the loading beam as displacement control method as shown in Figure 2.



(a) w/o opening (b) w/ opening

Fig. 1. Finite element model of shear wall

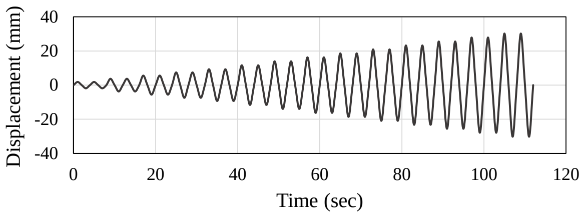


Fig. 2. Time-history of cyclic loading

2.2 Material models

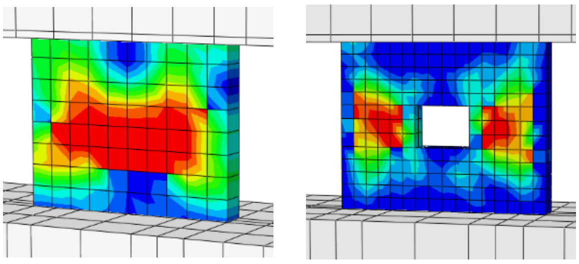
The concrete damage plasticity (CDP) model provided by ABAQUS was used as the material model of concrete. The stress-strain relationship of the concrete used in this study follows the constitutive equation proposed by Mander *et al.* [6]. The plasticity values of CDP material using this study presented in Table 1. The reinforcements were modeled using perfect plasticity model, Poisson's ratio and Young's modulus were 0.3 and 205GPa respectively.

Table 1. Plasticity of Concrete

Dilation Angle	Eccentricity	f_{bo}/f_{co}	K	Viscosity Parameter
45	0.1	1.16	0.667	0.0001

3. Analysis results

Figure 3 show compressive damage pattern of both models in uni-directional loading condition. The damage is concentrated in the middle of the wall and around the opening. The hysteretic behavior of the shear wall model is shown in Figure 4. In the analysis of bi-directional loading, the shear strength decreased by approximately 9.75% compared to that in uni-directional loading.



(a) w/o opening w/ opening

Fig. 3. Compressive damage pattern

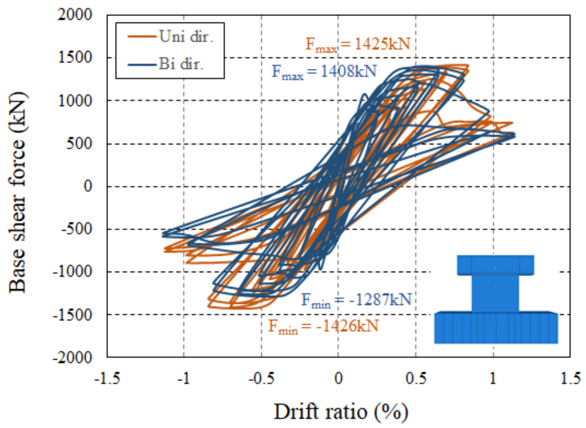


Fig. 4. The hysteresis behavior of shear wall model according to the loading direction

To see the effect of the loading direction in opening wall model, comparing the analysis results in Figure 5. The presence of opening showed about 30% decrease in shear strength. Also, the shear strength in the bi-directional loading on opening model decreased by approximately 7.7%.

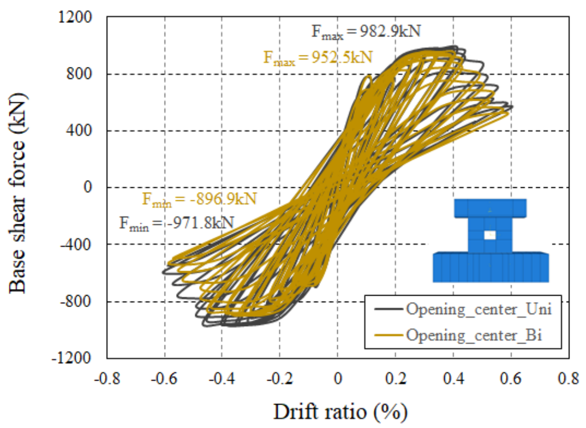


Fig. 5. The hysteresis behavior of opening wall model

Table 2. Shear strength value of FEA result

Shear strength (kN)	w/o opening		w/ opening	
	Uni-dir.	Bi-dir.	Uni-dir.	Bi-dir.
Max.	1425	1408	982.9	952.5
Min.	-1426	-1287	-971.8	-896.9
Uni/Bi	9.75% decrease		7.7% decrease	

4. Conclusions

In conclusion, this study estimated the effects of loading direction and presence of opening on shear strength of RC wall. The current design standards such as ACI 318-08, AIJ and ASCE 4-16 only consider the strength reduction caused by openings as a simple factor and provide only brief guidance on the evaluation of out-of-plane loads. However, further research is necessary to investigate the effects of the size and location of openings and the reduction in strength caused by out-of-plane loads through additional variable analyses. This research is crucial for improving the accuracy and reliability of shear wall design, and for ensuring the safety of structures under various loading conditions.

ACKNOWLEDGEMENT

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REFERENCES

[1] A. Niroomandi, S. Pampanin, R.P. Dhakal, M.S. Ashtiani, and R. Nokes (2021) Experimental study on the effects of bi-directional loadking pattern on rectangular reinforced concrete walls. Earthquake Engng Struct Dyn.

[2] Kabeyasawa, T., Kato, S., Sato, M., Kabeyasawa T., Fukuyama, H., Tani, M., Kim, Y., and Hosokawa, Y. (2014) Effects of bi-directional lateral loading on the strength and deformability of reinforced concrete walls with/without boundary columns, 10th U.S. National conference on Earthquake Engineering.

[3] K.S. Kim, and J.H. Park (2019) Effect of Bi-directional Loading on the Shear Strength of RC Shear Wall: Finite Element Analysis, Transactions of the Korean Nuclear Society Spring Meeting.

[4] A. Niroomandi, S. Pampanin, R.P. Dhakal, M.S. Ashtiani, and R. Nokes (2021) Experimental study on the effects of bi-directional loadking pattern on rectangular reinforced concrete walls. Earthquake Engng Struct Dyn.

[5] J.H. Park, Y.B. Chae, and K.H., Ahn (2021) Seismic Capacity Evaluation of Reinforced Concrete Shear Wall under Multi Axis-Load. KAERI/TR-8426/2020.

[6] J.B. Mander, M.J Priestley, and R. Park. (1988) Theoretical stress-strain model for confined concrete, Journal of Structural Engineering.