Evaluation of Maximum Shear Strength of RC Shear Wall by Multi-Directional Loading Test

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1. Introduction

Prediction methods of earthquake response of RC structures using analytical models still have many inaccuracies and limitations. Actually, various empirical equations to predict shear strength exist, but results obtained from equations are different from experimental results using shear walls of the same specifications [1].

The difficulty in analyzing the behavior of RC shear walls is due to the nonlinearity of the material. Various experiments have been conducted to identify this material nonlinearity. RC shear walls have generally been analyzed by quasi-static testing, considering test cost and specimen size. However, since the boundary conditions of structures have to be satisfied through independent actuators, most RC shear wall experiments have been conducted with in-plane horizontal force loaded, due to the ease of setting the test specimens.

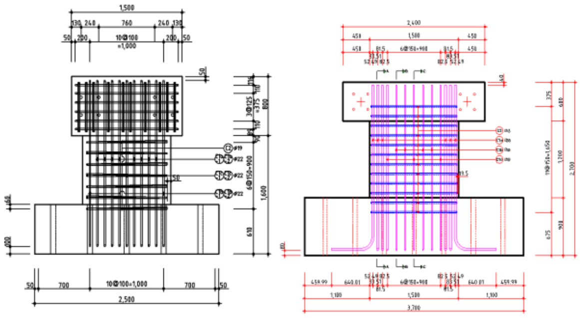
The results of one-way experiments make it simple to analyze the seismic behavior of a shear wall, but it is difficult to analyze the behavior during multi-direction earthquake loads.

An earthquake is a three-dimensional ground motion that causes earthquake load on the RC shear wall structure. In the damage patterns of RC shear walls caused by the recent earthquake in Chile (2010) and New Zealand (2011), bending failure in the out-of-plane direction can be observed. This RC shear wall failure clearly shows that there is a limit to analyzing actual RC shear wall behavior by simple one-way experiments. Recently, two-way quasi-static experiments have been started, but there are still very few experimental studies or data on RC shear walls for multi-directional loads.

2. Test program

2.1 Test specimens

In nuclear power plants, RC shear wall systems are used in the containment and auxiliary buildings to ensure seismic safety. In this study, the auxiliary building of the OPR (Optimized Power Reactor) 1000, developed by KHNP and KEPCO in South Korea, was selected as the target structure. The concrete compressive strength and rebar tensile strength were 6,297 psi and 67,000 psi, respectively. Test specimens were designed using the scale factor "0.3," considering the capacity of the actuators.



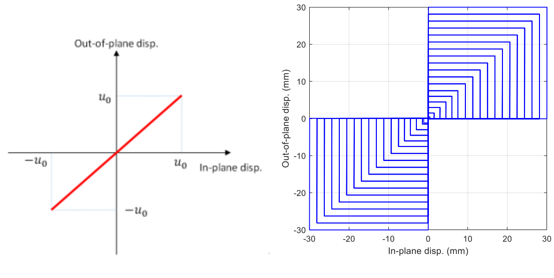
(a) Bending controlled wall (b) shear controlled wall
Fig. 1. Detail of test specimens

In this study, two type of walls were designed. One is a bending controlled wall, and the other is a shear controlled wall.

Figure 1 shows the shape and dimensions of the test specimens. For the bending controlled walls, the thickness and height of the wall were 0.41 m and 0.93 m, respectively. The length of the wall was 1.2 m. For the shear controlled walls, the thickness and height of the wall were 0.18 m and 1.2 m, respectively. The length of the wall was 1.5 m.

2.2 Load pattern

In this study, the synthetic displacement time history was combined with sinusoidal waves, unlike the time history (saw-tooth type) used in previous quasi-static test. Bi-directional loading can be applied in various combinations. Kabeyasawa et al. applied bi-directional loading in an "8" shape [2]. In other words, the out-plane displacement was attained first; then, at each peak, the in-plane displacement was attained while maintaining the out-plane peak displacement. Nirromandi et al. used a loading pattern of clover shape [3]. In this study, the two type of load pattern were applied as shown in Figure 2.



(a) In phase loading (b) Out-of-phase loading
Fig. 2. Load pattern

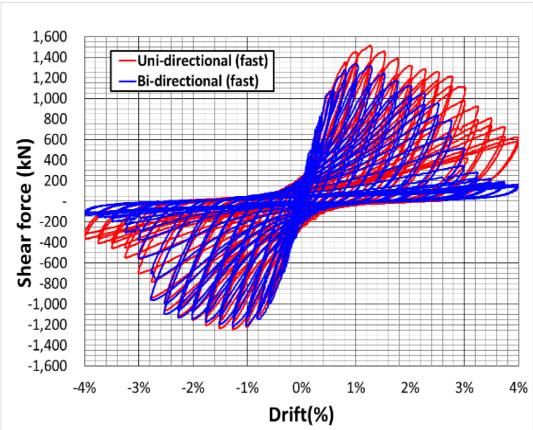
For the shear controlled wall, tests of uni-directional loading and 3 axis loading on RC shear wall were performed. For the bending controlled wall, uni-directional loading and bi-direction loading were applied.

3. Test results

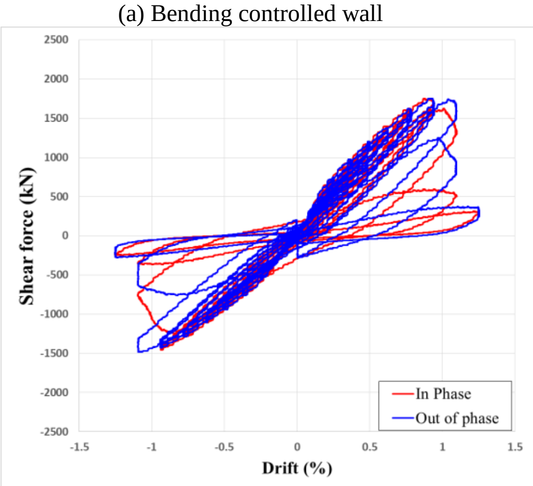
3.1 Load-displacement curves

The shear capacity was calculated from the force-displacement (F-D) curves, as shown in Figure 3. For bending controlled wall, the maximum shear strength in the bi-directional test was lower than that in the uni-directional test. It is judged that the shear strength is different according to the loading direction.

For the multi-directional test, bending moment and shear force were applied to the shear wall. Therefore, the maximum shear strength of the shear wall for the multi-directional test was lower than that for the uni-directional test.



(a) Bending controlled wall



(b) Shear controlled wall

Fig. 3.Force-displacement curves

3.2 Maximum shear strength

Table 1 shows the maximum strengths of specimens in the positive and negative directions. The maximum shear strength obtained from the bi-directional test or 3 axis loading test was lower than that of uni-directional test. In particular, it was found that the maximum strength values decreased by about 11.2% for the bending controlled wall.

From this test, it is necessary to consider the multi-directional loading effect for evaluating the ultimate capacity of an RC shear wall under earthquake load.

Because the shear capacity used in analysis of seismic fragility of a shear wall was based on results of a uni-directional test, it was recommended that the ultimate shear capacity be defined based on the bi-directional test, so as to allow realistic evaluation of the seismic capacity of the RC shear wall structures.

Table I: Comparison of maximum shear strength

Test spec.	Test method	Max. force (+kN)	Max. force (-kN)
Shear controlled wall	Uni-direction	1,863	1,532
	3-Axis loading (In-phase)	1,754	1,454
	3-Axis loading (Out-of-phase)	1,755	1,483
Bending controlled wall	Uni-direction	1,527	1,248
	Bi-direction	1,347	1,193
Shear controlled wall		↓ 5.8%	↓ 5.1%
Bending controlled wall		↓ 11.8 %	↓ 4.4 %

4. Conclusions

In this study, the cyclic loading test was performed to evaluate the seismic capacity of RC shear wall according to the loading direction. From the test results, it can be recommended that the effect of multi-directional loading is considered to evaluate the seismic capacity of RC shear wall..

5. Acknowledgement

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REFERENCES

[1] Gulec, C.K., Whittaker, A.S., Stojadinovic, B. (2008). “Shear Strength of Squat Rectangular Reinforced Concrete Walls.” ACI Structural Journal, 105(4): 488-497.

[2] Kabeyasawa, T., Kato, S., Sato, M., Kabeyasawa, T., Fukuyma, 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, July 21-25, 201, Anchorage, Alaska.

[3] Niroomandi, A., Pampanin, S., Dhakal, R.P., and Ashtiani, S. (2018). “Experimental study on slender rectangular rc walls under bi-directional loading” 11th US National Conference on Earthquake Engineering, June 25-29, 2018, Los Angeles, CA, USA.