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Cyclic lateral loading test of cylindrical wall for seismic evaluation of containment building

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1. Introduction

Nuclear power plant (NPP) buildings require a high level of seismic safety. In particular, the shape of containment buildings of NPP is cylindrical to withstands the increased internal pressure due to the vapor pressure or explosion. In addition, the post-tensioning force is applied to resist membrane tensile stresses caused by internal pressure.

Due to the high strength demand, the concrete shear walls in NPPs were designed with high reinforcing bar ratio. In this case, the walls are susceptible to diagonal concrete web-crushing. To investigate the behavior of web-crushing failure, concrete walls were tested. However, the most specimens were planar shape.

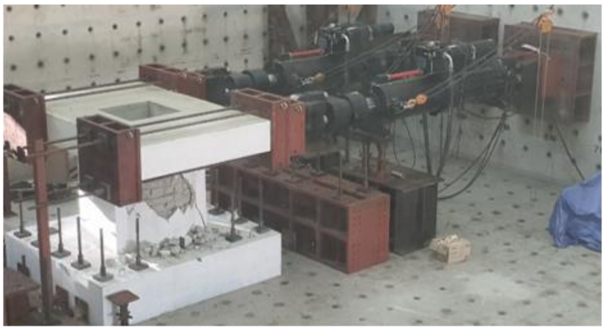
In the present study, the cylindrical walls were investigated focusing some considerations. 1) effects of horizontal post-tensioning on concrete delamination in cylindrical wall. 2) the effect of delamination on the shear strength of cylindrical walls.

2. Test plan

In the case of NPP containment walls, the shear reinforcing bar and post-tensioning bar ratios are close to 1%. Thus, the majority of the specimens were designed with high reinforcing bar ratios.

Total four cylindrical walls were prepared (One for RC, and three for PSC). Table 1 shows the test parameters and information of test specimen. To verify the effect of horizontal post-tensioning effect on cylindrical wall, the horizontal post-tensioning ratio of 0 %, 50 %, and 100 % of design stress (1300 MPa) were applied. The dimensions of a cylindrical wall specimen were 1400 x 1300 x 90 mm (external diameter x height x thickness). The aspect ratio of specimens was determined based on the moment/shear (M/V) ratio of the prototype containment building.

To simulate the seismic loading condition, the loading rate was 100 mm/s. The loading rate was calculated based on elastic time history analysis of containment building (PGA of 0.3 g). Due to the large scale of test specimen, two actuators were used. **Figure 1** shows the test set-up. The lateral loading protocol followed ACI 374.2: Three repeated cyclic loads were applied at each load step, as the drift ratio was increased to 1.25 – 1.5 times the previous drift ratio.



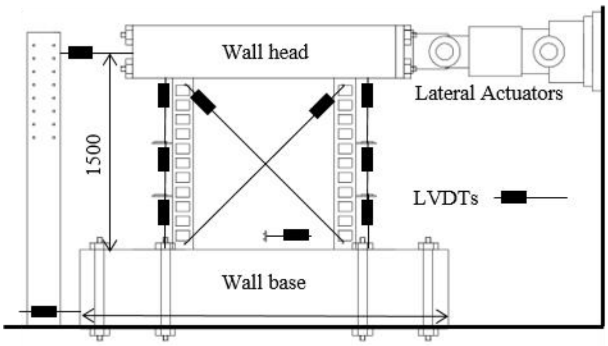


Figure. 1. Test set up

To measure the applied post-tensioning force, load cells were installed at the both ends. To apply the planned force, a greater jacking force was applied

Table 1: Major parameters

Specimens	Compressive strength of concrete: f_c', MPa	Post-tensioning bar (Tendon ratio (%)/ applied post-tensioning stress)		Reinforcing bar ratio (%)	
		Vertical	Horizontal	Vertical	Horizontal
RC	38	-	-	1.86	0.72
PSC-V	38	0.64 / 1300 MPa	1.00 / 0 MPa	1.86	0.72
PSC-Vh	38	0.64 / 1300 MPa	1.00 / 650 MPa	1.86	0.72
PSC-VH	43	0.64 / 1300 MPa	1.00 / 1300 MPa	1.86	0.72

considering the loss of post-tensioning force (i.e. seating of the wedges). The measurements were continued during jacking and until the wedge was settled.

3. Test results

3.1 Load-displacement relationship

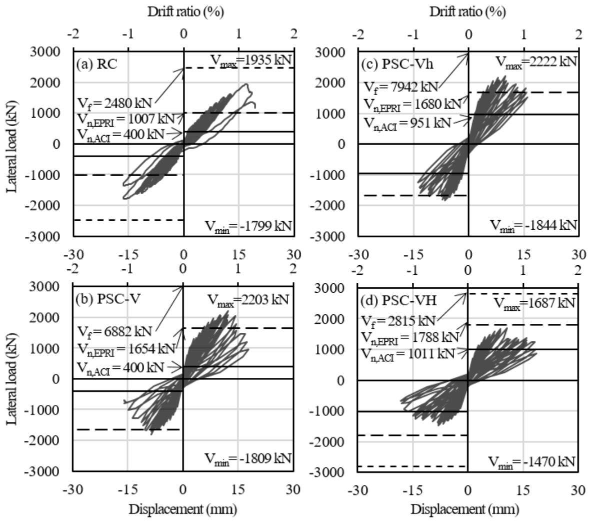


Figure. 2. Lateral load-displacement relationship of specimens.

Table 2: Summary of test results

Specimens	Test results (kN)			V_{test}	V_{test}
	$V_{test,+}$	$V_{test,-}$	$V_{test,a}$	$/V_{ACI}$	$/V_{EPRI}$
RC	1935	1799	1868	4.67	1.86
PSC-V	2203	1809	2005	5.01	1.21
PSC-Vh	2222	1844	2033	2.14	1.21
PSC-VH	1687	1470	1578	1.56	0.88

Figure 2 and Table 2 shows the summary of test results. The V_{max} and $V_{test,+}$ indicate that the maximum strength of specimen in the push direction. On the other hand, The V_{min} and $V_{test,-}$ indicate that the maximum strength of specimen in the pull direction. The $V_{test,a}$ means the average strength of $V_{test,+}$ and $V_{test,-}$. The maximum strength of specimen RC, PSC-V, PSC-Vh and PSC-VH were 1868 kN, 2005 kN, 2033 kN, and 1578 kN, respectively, in average. In the case of RC, the drift ratio at the maximum shear strength was 1.05 %. On the other hand, in the case of specimens with post-tensioning, the drift ratio was 0.7 %. In the **table 2**, the design/evaluation strength based on ACI 359 and EPRI, respectively were compared with the test results. The design strength (ACI 359) was 1.5 – 5.0 times underestimates the actual strength of cylindrical wall. On the other hand, the evaluation strength of EPRI predicted the exact strength in the range of 0.9 – 1.9.

3.2 Failure modes

Figure 3 shows the failure mode of cylindrical wall. The failure mode of RC specimen without post-tensioning, the general concrete web-crushing occurred. On the other hand, in the case of PSC-V with only vertical post tensioning, large area of cover concrete was delaminated under large lateral drift ratio. In the case of PSC-Vh and PSC-VH, the delamination failure occurred when horizontal post-tensioning was applied. The cover concrete failure occurred in the low drift ratio of 0.25 %. Due to the delamination crack, the maximum shear strength was less than that of RC without post-tensioning

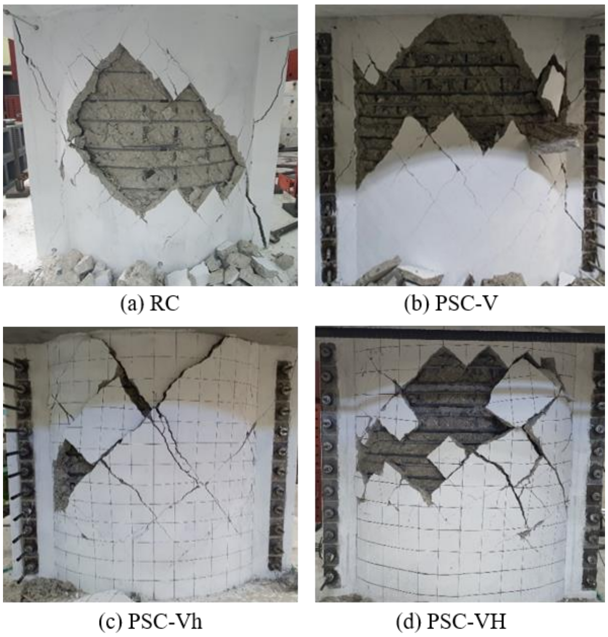


Figure. 3. Failure mode of cylindrical wall

4. Conclusion

To investigate the effect of post-tensioning on shear strength of cylindrical wall, four specimens were tested under cyclic loading. The test parameters were magnitude of horizontal post-tensioning. The major findings of the present study are summarized as follows:

1. In the case of PSC with horizontal post-tensioning, premature shear failure occurred due to delamination of cover concrete.
2. The horizontal reinforcing bars did not resist the shear deformation due to loss of bond strength.
3. The shear strength degradation due to delamination crack was significant. The maximum strengths of PSC specimens with delamination cracks were lower than that of RC specimen.

The present test results should be limited to cylindrical wall with small thickness and a single reinforcement layer. To confirm the effect of delamination, various parameters need to be considered.

ACKNOWLEDGMENTS

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