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Experimental study on the influence of openings on strength and stiffness of RC walls
Part 3: Overview of 2nd test series

Keyword:
RC shear wall　　Opening in wall
Strength reduction　　Stiffness reduction

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1. Introduction

The presence of opening alters the seismic structural behavior of the RC walls. Even though the influence of opening on the behavior of structural RC walls was recognized by past research studies, the influence of parameters such as additional reinforcement around opening, location, size of opening, etc. is still poorly understood. In Part 1 and Part 2 (previously presented in the year 2021), two parameters were investigated, which are the influence of the size of opening and the influence of additional reinforcement of opening. In this study, (Part 3 and Part 4), presenting the 2nd series of the experiment, another three parameters have been investigated: the influence of opening shape, opening location, and the effect of steel bracing around the opening on the seismic performance. This paper (Part 3) presents details of investigated parameters and an overview of tests results. Discussion of results is presented in Part 4.

2. Experimental program

2.1 Loading setup

Four hydraulic jacks were used, and each jack was attached to a loading plate that is attached to the surface of the specimen from each side which is presented in Part 1. Here loading is applied to walls with openings maintaining a pure shear state and is capable of applying cyclic loading to resemble the seismic loading influence. The lateral loading program consisted of 2 cycles for each shear strain of 0.0125%, 0.025%, 0.05%, 0.1%, 0.2%, 0.4%, 0.6%, 0.8% and 1.5%. Specimens that did not significantly degrade in strength after the 1.5 %, were then pushed monotonically.

2.2 Test parameters

This study presents an experimental study of five small-scaled RC panels with openings investigating three main parameters: influence of aspect ratio of opening, the influence of eccentricity of opening from the center, and influence of retrofitting opening by steel bracing. All specimens have a length and height of 600mm×600mm and thickness of 60mm provided with a single layer of reinforcement. The reinforcement ratio used for all specimens is the same as 1st Series with a steel ratio (ρ_w) 1.3% placed in a single layer of D6 with a spacing of about 40mm. D10 were used for additional reinforecement around the opening. Reinforcement properties are identical to the previous 1st series experiment (Part1), and the average concrete compressive strength of the 2nd series test is 25.9 MPa. The following section describes the details of each parameter.

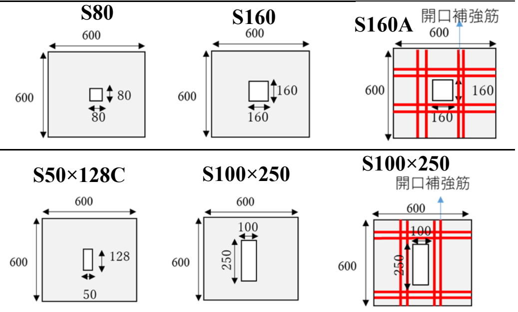
2.2.1 Opening aspect ratio

In a previous study [1], the influence of several parameters based on tests in literature was investigated. There was a large variation in reduction of strength even for the same area opening size, and the aspect ratio is thought to be one of the reasons causing such difference. Thus, three specimens S50×128C, S100×250, S100×250A, were designed (as shown in Table 1), to have the same opening area ratio (OAR) of ($\sqrt{\frac{\sum h_0 l_o}{h l}}$)as specimens S80, S160, that were tested in Part 1&2 but with a different opening aspect ratio of about 2.5. Specimens S160A and S100×250A, had additional reinforcement around the opening that is required by AIJ code [2], as discussed previously in Part 1.

2.2.2 Opening eccentricity

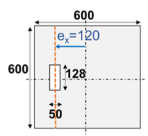
Table 1. Specimens with different aspect ratio (units: mm)

Opening area ratio	$\sqrt{\frac{\sum h_0 l_o}{h l}}$ =0.13	$\sqrt{\frac{\sum h_0 l_o}{h l}}$ =0.27	$\sqrt{\frac{\sum h_0 l_o}{h l}}$ =0.27
Previous study (part 1&2) Aspect ratio h_o/l_o= 1	S80	S160	S160A 開口補強筋
Present study (part 3&4) Aspect ratio $h_o/l_o \approx$ 2.5	S50×128C	S100×250	S100×250 開口補強筋



Another parameter such as location of opening was thought to have some impact on the performance of walls as per a study [3]. However, the influence of opening location is still not clear and poorly understood, thus one specimen S50×128EC was designed with a horizontal eccentricity of 20% from the center as shown in Table 2.

Table 2. Specimen with horizonal eccentric opening

Opening eccentricity	Opening area ratio, $\sqrt{\frac{\sum h_0 l_o}{h l}}$ = 0.13
Eccentricity of *20%* from center in one direction (horizontal)	

2.2.3 Retrofitting by steel bracing

Opening in walls are thought in disrupting the continuity of flow of forces by intersecting the diagonal compression strut forces in the wall. Thus, a specimen S160Br was designed with steel braces inside the openingas shown in Fig. 1e-f to examine the influence of steel bracing on the diagonal compression strut. Details of test specimens are shown in Table 3 and Figure 1.

Table 3. Summary of test specimens with details

Specimen name	S50×128C	S50×128EC	S100×250	S100×250A	S160Br
Panel dimensions (mm), $h \times l \times t$	600 × 600 × 60				
opening size (mm × mm), $h_o \times l_o$	50×128		100×250		160×160
opening area ratio $\sqrt{(\sum h_o l_o)/(h\,l)}$	0.13	0.13	0.27	0.27	0.27
opening aspect ratio, h_o / l_o	2.56	2.56	2.50	2.50	1.00
opening eccentricity, e_x / l (%)	0	20	0	0	0
Main reinforcement	D6@40mm (SD295)				
Main reinforcement ratio, ρ_w (%)	1.33				
Additional steel at each opening side, A_v or A_h	-	-	-	2D10*	-
Additional steel provided (A_v+A_h) at each corner of opening (mm^2)	-	-	-	156*	-
Minimum additional steel area (A_v+A_h) calculated by AIJ (mm^2)	-		-	91	-
Concrete compressive strength (MPa)	25.9				

* To avoid congestion of reinforcement, two additional rebars D10 replaced two D6 rebars around each side of opening

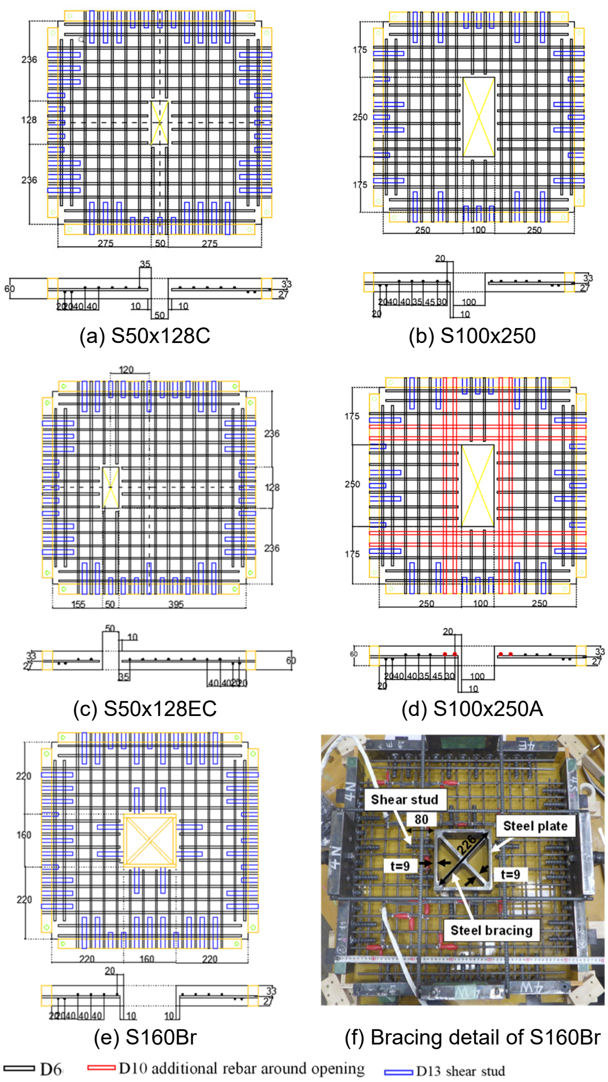


Figure 1. Dimensions and reinforcement of specimens; units in mm

3. Experimental results

The lateral load versus shear strain of all specimens is shown in Figure 2. The summary of maximum strength, as well as initial stiffness, is shown in Table 4. The first cracks appeared at a shear strain of 0.0125~0.025% accompanied by gradual degradation of stiffness. The first yield of reinforcement observed by strain gauges attached to steel rebars was at story shear strain of 0.08%~0.15% of shear strain. Maximum strength occurred at a shear strain of 0.4%~0.6%, where almost all reinforcing bars yielded.

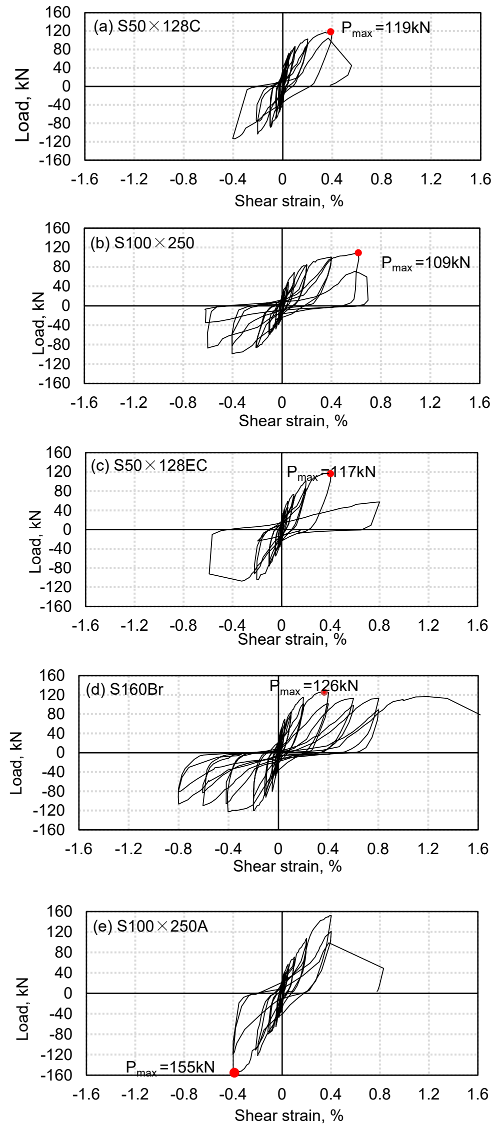


Figure 2. Applied load vs. shear strain graphs of the test specimens

Table 4. Maximum shear strength and initial stiffness

Sp. ID	Qmax (+) (kN)	Qmax (-) (kN)	$K_{initial}$ (@0.0125%) (kN/mm)
S50x128C	119	113	426
S50x128EC	117	107	378
S100x250	109	97	309
S100x250A	152	155	348
S160Br	126	122	520

Conclusion and References

The conclusion and references are shown in Part 4 of this study.

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