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Experimental study on the influence of openings on strength and stiffness of RC walls
Part 1: Outline of experiment plan

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

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1. Introduction

The presence of openings 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. Therefore, the objective of this study is to investigate two influencing parameters: the effect of opening size and the effect of additional reinforcement around the opening on seismic performance. This study presents an experimental study of six small-scaled RC panels with openings tested under pure shear static cyclic loading applied by a novel experimental setup as shown in Figure 1. Part 1 of this study presents the experimental plan and Part 2 describes the test results.

2. Experimental program

2.1 Loading setup

In order to understand the behavior of reinforced walls with openings with complex forces, it is needed first to understand its behavior under pure shear loads, thus a setup applying a pure shear is proposed as shown in Figure 1 and Figure 2 where 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. The loading setup is inspired by experiments of pure shear by F. Vecchio and M.P. Collins [1]. The new point here is that the idea of pure shear is further applied to panels with openings. In addition, the loading setup here is capable of applying cyclic loading to resemble the seismic load and cyclic loading influence. All jacks together applying an incremental cyclic loading and were controlled by a shear strain %, defined as the shear deformation divided by the height of the specimen (h= 600mm). The lateral loading program consisted of 2 cycles for each peak drift angle 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 specimens:

This study presents an experimental study of six small panels of length and height of 600mm×600mm and thickness of 60mm provided with a single layer of reinforcement. One solid specimen without opening and the other five specimens focus on two parameters: size of opening and additional reinforcement around the opening. The details of the specimens are shown in Table 1 and the properties of reinforcement are shown in Table 2.

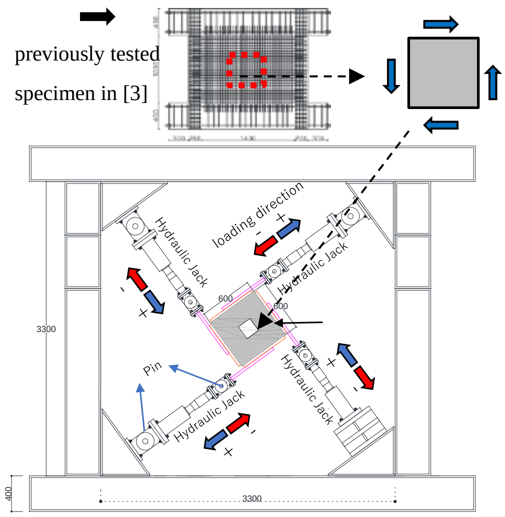

Figure 1. Schematic diagram of test setup

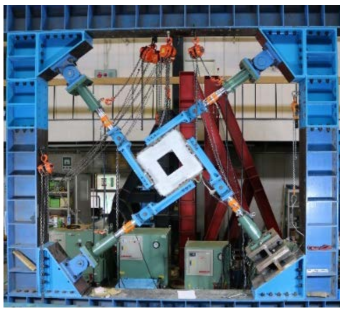
Figure 2. Photo of experimental loading setup

Table 1. Summary of specimen details and parameters

Specimen name	S80	S80A	S160	S160A	S240	SS
Panel dimensions (mm) $h \times l \times t$	600 × 600 × 60					
opening size (mm × mm) $h_o \times l_o$	80×80		160×160		240×240	-
opening ratio $\sqrt{(\sum h_o l_o)/(h l)}$	0.13	0.13	0.27	0.27	0.40	-
Main reinforcement	D6@40mm (SD295)					
Main reinforcement ratio, ρ_w (%)	1.33					
Additional steel at each opening side A_v or A_h	-	1D10*	-	2D10*	-	-
Additional steel provided (A_v+A_h) at each corner of opening (mm^2)	-	78*	-	156*	-	-
Minimum additional steel area (A_v+A_h) calculated based on AIJ [2] (mm^2)	46	55	76	91	-	-
Concrete compressive strength (MPa)	32.2					

* To avoid congestion of reinforcement, the additional reinforcement D10 replaced another D6

Table 2. Reinforcement mechanical properties

Bar	Nominal strength	Yield strength (MPa)	Ultimate tensile strength (MPa)
D6	SD295	315	525
D10	SD295	353	515

開口部が鉄筋コンクリート造壁の耐力及び剛性に及ぼす影響の検討　その１　実験計画の概要

The size of openings was designed to reflect three different sizes of openings as illustrated in Figure 3, where the specimen with the largest opening (S240) represents the case of opening larger than the limits (opening area ratio > 0.4) proposed in AIJ standard [2] and shown in Eq.1. According to AIJ [2], if the equivalent opening area ratio is greater than 0.4, the wall should be modeled as a frame instead without the need for considering reduction factors in Eq.1.

r = minimum of $\{r_1, r_2, r_3\}$ (1)

$$r_1 = 1 - 1.1\left(\frac{\sum l_o}{l}\right);$$

$$r_2 = 1 - 1.1\sqrt{\frac{\sum h_o l_o}{hl}};$$

$$r_3 = 1 - 0.5\left(1 + \frac{\sum l_o}{l}\right)\frac{\sum h_o}{h};$$

where r: reduction factor for lateral strength; l_0: horizontal length of opening; h_0: vertical length of opening; h: height of the wall; and l: length of the wall.

Figure 4 shows the reinforcement dimension and details of the specimens in which the main reinforcement was placed in a single layer of D6 with a spacing of 40mm having a reinforcement ratio of, ρ_w =1.3%. The reinforcement is decided to represent a full-scale solid specimen that was tested by the authors in a previous study [3].

As for the parameter of additional reinforcement, two specimens S80A and S160A had additional reinforcement around the opening calculated based on AIJ [2] using Eq.2.

$$A_d f_t + \frac{A_v f_t + A_h f_t}{\sqrt{2}} \geq \frac{ho + lo}{2\sqrt{2}l} Q_D \quad (2)$$

A_d : cross-sectional area of diagonal reinforcement at a corner of the opening. A_v and A_h are: cross-sectional area of additional bars for peripheral reinforcement in vertical and horizontal directions, respectively. f_t: allowable tensile stress of reinforcement.

To avoid congestion of reinforcement in the specimen due to its small size, the additional reinforcement D10 replaced another D6, taken into consideration the necessary steel area to be added by AIJ [2]. The summary of additional reinforcement provided and minimum required steel area are shown in Table 1.

A steel plate was attached to each of the four sides of the specimens for connecting the specimen with hydraulic jacks. Shear studs of D13 were provided along with the steel plate and specimen for connection as shown in Figure 4.

2.3 Test instrumentation

Four LVDTs were attached diagonally along with the specimen on both front and backside (total of 8 LVDTs) to calculate the total shear deformation of the specimens as shown in Figure 5. In addition, strain gauges were attached to reinforcement bars around the openings.

Conclusion and References

The conclusion and references are shown in Part 2 of this study.

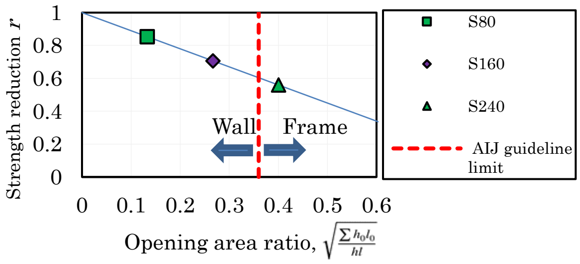

Figure 3. Relation of opening size and reduction factor by AIJ [2]

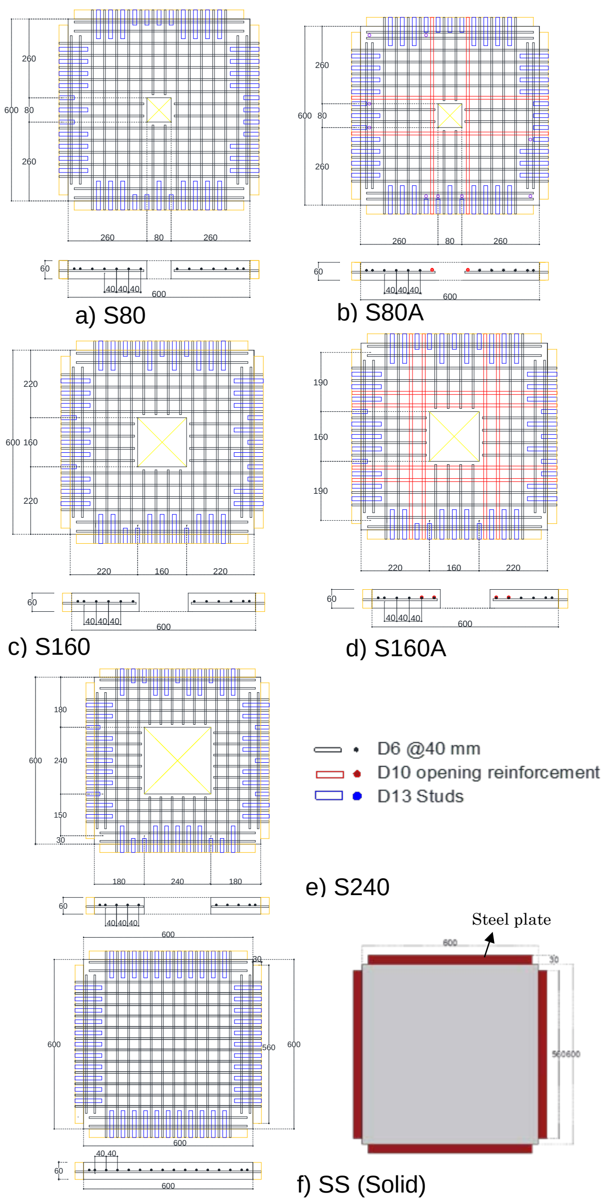

Figure 4. Dimensions and reinforcement of specimens; units in mm

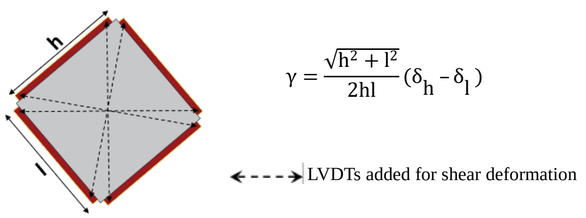

Figure 5. LVDTs added for shear deformation of the specimens

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