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Experimental study on the influence of openings on strength and stiffness of RC walls
Part 4: Discussion of experimental results

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

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1. Introduction

Part 3 of the study showed the test parameters detail, experimental results, and Part 4 (this part) shows and discusses the experimental results and comparison with tests of the 1st series.

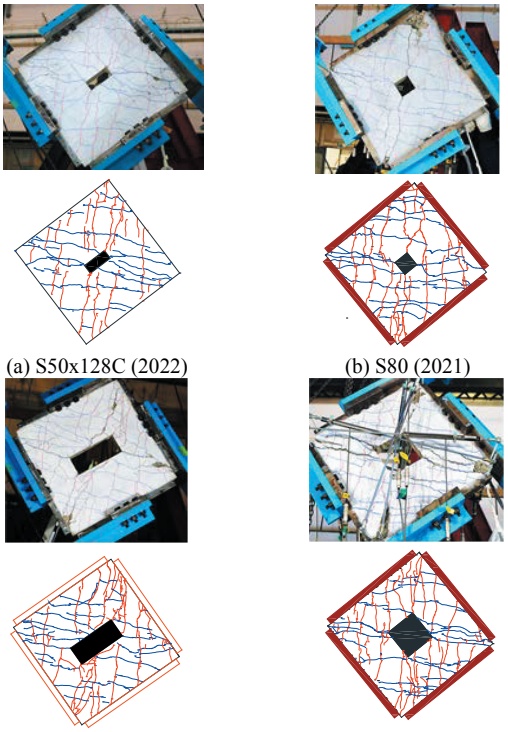
2. Discussion on test results

2.1 Comparison of crack pattern and failure mode

The developed cracks at maximum strength, are shown in Figure 1 to Figure 3 with comparison of Series 1 (2020) and Series 2 (2021).

2.1.1 Effect of opening aspect ratio

Figure 1 show the crack pattern of wall with rectangular and square opening of same opening area ratio (OAR) of 0.13. Fig. 1c,1d show the cracks of walls with large OAR of 0.27 having different opening shape. The direction of crack for all specimens are almost diagonal as expected due to pure shear loading. However, the crack direction is thought to start at the corner of the openings, and it continues till the edge of the wall. Thus, the cracks angles for square opening were at angle of 45º, on the other hand the rectangular openings were between 30º~40º.

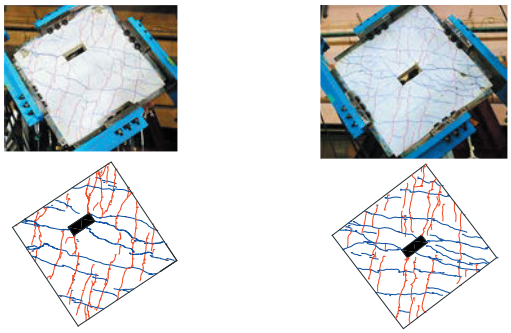


(a) S50x128C (2022)　(b) S80 (2021)
(c) S100x250 (2022)　(d) S160 (2021)

Fig. 1. Comparing cracks (Specimens h_o/l_o= 2.5 & h_o/l_o= 1)

2.1.2 Effect of opening eccentricity

Fig. 2a,2b show the crack pattern of wall with eccentric and center opening of same OAR of 0.13 and opening aspect ratio of 2.5. From Fig. 2, it has been observed that less cracks developed in the center of wall in the case of eccentric opening case.

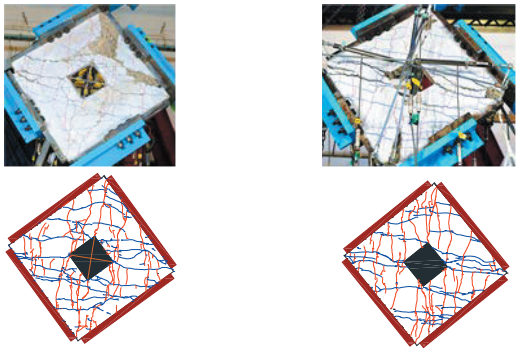


(a) S50x128EC (2022)　(b) S50x128C (2022)

Fig. 2. Comparing cracks (center vs. eccentric)

2.1.3 Effect of retrofitting with steel bracing

Figure 3, show the crack pattern of wall with and without steel bracing of same opening 160mm×160mm. It is found that crack are relatively less for S160Br at the edge of opening (around the diagonal)(wall with retrofitting) compared to S160 (without retrofitting). Cracks are wide in the central diagonal location for S160 but for retrofitted wall, the cracks seemed narrow there due to the transfer of load through steel bracing.



(a) S160Br (2022-with bracing)　(b) S160 (2021-without bracing)

Fig.3. Comparing cracks for openings with and without bracing

2.2 Comparison of hysteresis curves

A comparison of hysteresis curves of specimens for different opening shape, location, and retrofitting is shown in Figure 4 to 6.

2.2.1 Effect of aspect ratio

From Fig.4, slight reduction in strength (12%) is found for wall with rectangular opening having aspect ratio (AR) of 2.5 compared to that of square opening (AR of 1) with same opening area ratio of 0.13.

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その 4　実験の結果考察

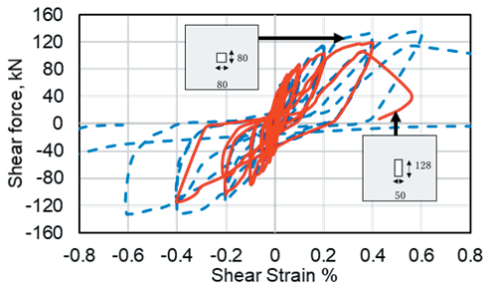

Fig.4 Comparison of hysteresis curves of S80, S50×128

2.2.2 Effect of opening eccentricity

From Fig. 5, it is observed that there no influence in maximum strength for horizontal eccentricity of opening compared to wall with center opening with same opening area ratio of 0.13. However, it should be noted that the eccentricity is only in one direction of only 20%, thus the influence of opening location still needs further investigation.

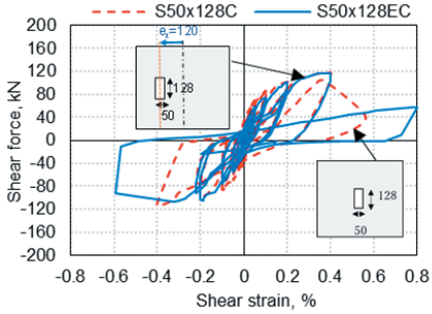

Fig.5 Comparison of hysteresis curves of S50×128C, S50×128EC

2.2.3 Effect of retrofitting with steel bracing

A comparison of Specimen with steel bracing in opening (S160BR) with Solid specimen (SS) and Specimen with opening square opening (S160) is shown in Figure 7.

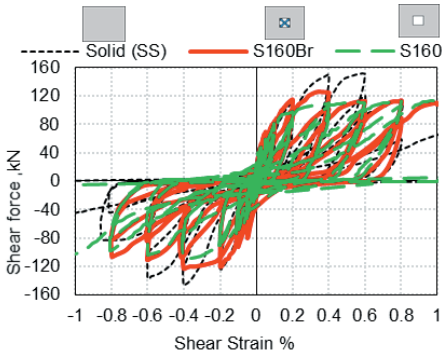

Fig.6 Comparison of hysteresis curves of SS, S160, S160Br

The attachment of steel bracing in opening increased the strength to almost identical to that of solid wall (SS) till 0.2% shear strain. At 0.2%, many steel rebars yielded and gap was observed between the concrete near opening and the attached steel plate. In the region of 0.2~0.4%, the influence of bracing degraded, and response was almost close to S160. At 0.4% shear strain, the strength was slightly larger (13%) than S160 (without retrofitting), and the influence of bracing vanished after 0.4%. It is thought that connection of steel bracing attachment with surrounding wall got weaken at 0.2% which disconnected the bracing from the wall, thus improving connections of bracing with wall after cracking and yielding of specimen is required and needs further investigation for improved resistance.

2.3 Comparison of strength, stiffness reduction factor

A comparison of reduction factor for initial stiffness and strength recommended by the AIJ guideline [2] with the test results is shown in Fig. 7a and 7b respectively. AIJ [2] gave a lower bound of strength even for specimens without additional reinforcement around the opening which is instructed by the AIJ[2].

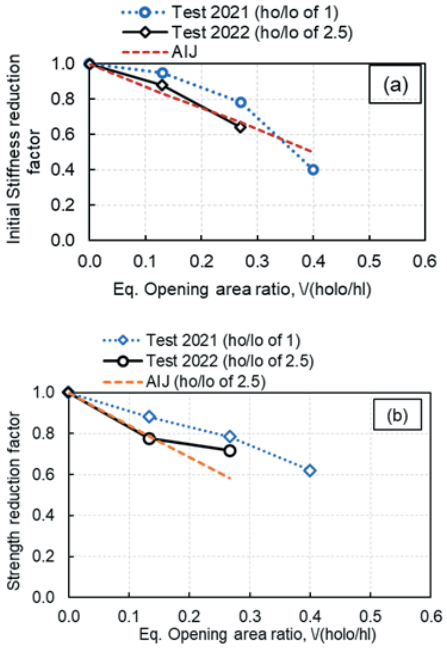

Fig.7 Comparison of (a) initial stiffness (b) strength reduction factor

3. Conclusion

Experimental program of the 2nd series RC walls with openings tested under pure shear loading were presented. Three parameters were investigated: opening shape, opening location, and retrofitting with steel bracing. It was observed that 9-12% strength was reduced for opening aspect ratio changing from 1 to 2.5 (square to rectangular). Tests showed almost no influence of horizontal eccentricity of opening of 20% in one direction. Retrofitting with steel bracing inside the opening increased strength to almost similar of solid wall until shear strain of 0.2%. However, after 0.2%, the strength dropped gradually to that of wall with similar opening size, which is thought to be due of the influence cracking and yielding of reinforcement that affected the attachment of braces with surrounding frame

References

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