A review study on the effect of openings on the seismic performance of RC wall panels

Keywords

Seismic response
Strength reduction factor
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RC walls with openings
RC wall database

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1. Introduction

RC walls often contain various types of openings for functional requirements of buildings. The openings are usually in the form of a doors, windows, or utility ducts. The seismic response of a perforated wall panel is influenced by different parameters of the opening such as opening area, opening aspect ratio and opening location. Several experiments were conducted to investigate the effect of openings on RC wall performance in past studies; however, each of the past studies were conducted separately so an overall summary of the influence of different opening parameters on seismic capacity is still unclear. Therefore, the main objective of this study is to investigate the effect of different opening parameters on the lateral behaviour of RC walls based on available past experimental data. The experimental results of these studies are then compared to the lateral strength reduction factor due to openings obtained from existing analytical methods.

2. Summary of opening parameters

Geometric parameters of walls with openings are illustrated in Fig.1. Notations in h and l refer to the overall height and length of the wall panel, respectively; h_o and l_0 are the height and length of the wall opening, respectively; x_{ecc} and y_{ecc} are the horizontal and vertical distance from the opening center to the wall center, respectively.

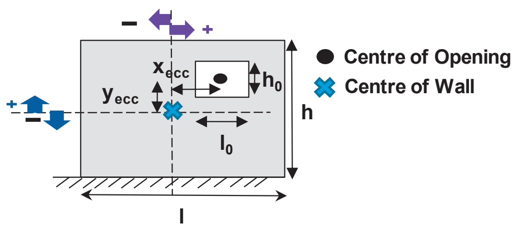

Fig.1 Key opening parameters

3. Effect of different parameters of opening

All test specimens of past studies analyzed in this study represent single-storied RC walls with a maximum of three openings tested under static lateral cyclic loading.

3.1 Effect of opening height ratio and opening length ratio

From Ono and Tokuhiro's study [1], the effect of opening size on the lateral strength of RC walls is shown in Fig. 2. In Fig.2, the square opening (left) had an 11% area ratio and the rectangular opening (middle and right) had a 21% opening area ratio ($\sum h_o l_o/hl$). In case of rectangular openings, the long opening (Fig.2, middle) had an opening aspect ratio (h_o/l_o) of 0.55 and the tall opening (Fig.2, right) had 1.81. $Q_{max,s}$, $Q_{max,o}$ indicate lateral strength of the solid wall and the wall with an opening respectively. $Q_{max,0}/Q_{max,s}$ denotes the lateral strength reduction factor due to opening. It is noticed from Fig.2 that the lateral strength decreased as opening area ratio increased, whereas a change in aspect ratio for the same opening area ratio did not have much influence on the lateral strength based on their study. From available past experiments [1-5], the effect of the maximum value between opening height ratio ($\sum h_o/h$) and opening length ratio ($\sum l_o/l$) on strength reduction factor is illustrated in Fig.3 for walls with a single opening. A general trend is observed that as the maximum value between $\sum l_o/l$ and $\sum h_o/h$ increased, the lateral strength decreased. However, there is also some strength reduction variation for the same values of $\sum l_o/l$ and $\sum h_o/h$ (such as Ono and Tokuhiro tests at value $\sum l_o/l$ and $\sum h_o/h$ of 0.56), which indicates that other wall openings parameters are also having a large influence.

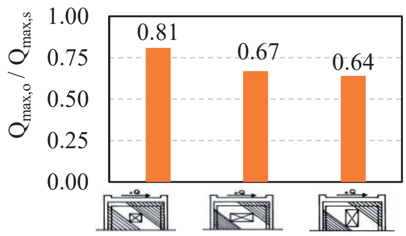

Fig. 2 Effect of size of opening from [1] study

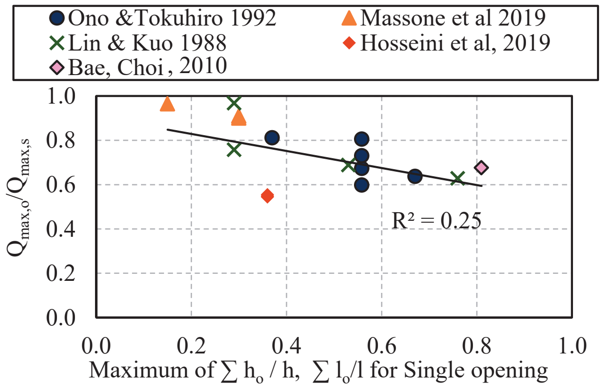

Fig. 3 Effect of opening dimension based on past experiments

3.2 Effect of opening area ratio ($\sum A_o/A_w$)

From available past experiments [1-5], the effect of opening area ratio on the strength reduction factor for walls with a single opening has been illustrated in Fig.4. A_o, A_w correspond to the opening area and wall gross area, respectively. From Fig.4, it is observed that a decreasing trend of lateral capacity was found with the increase in opening area and strength reduction factor was found between 97% - 54% for opening area ratio of 2% -25%. The $R^2 = 0.7$ indicates a stronger correlation of opening area ratio to strength reduction than the maximum single dimension ratio (Fig.3, $R^2 = 0.25$).

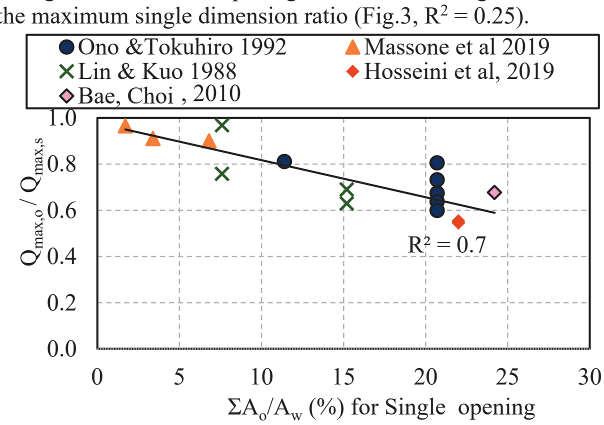

Fig.4 Effect of opening area based on past experiments

3.3 Effect of eccentricity of opening

3.3.1 Horizontal eccentricity (x_{ecc})

The effect of horizontal opening eccentricity on the positive and negative wall strength is shown in Fig.5 for two studies. From Ono and Tokuhiro's study [1] in Fig.5a it is observed that compared to a centrally located opening, a wall with an eccentric opening would have a higher peak strength in the loading direction that puts the opening in tension and a lower peak strength when the opening is in compression. For 22% opening horizontal eccentricity, the specimen yielded 10% decrease in lateral strength for positive loading whereas for negative loading it exhibited a 15% increase in strength compared to a central opening case. Generally, as seismic demands are of cyclic nature, it appears that a centrally located opening would result in the least strength reduction.

In a study by Hosseini et al. [5], the structural performance of RC walls with cut out door openings of different horizontal eccentricity were investigated. For specimens with 6.3% and 12.5% horizontal eccentricity of opening, although the same trend in peak load asymmetry was observed as in Fig 5b, the change in peak lateral strengths for both positive and negative loading varied only by 2% from the central opening case, as shown in Fig.5b. Therefore, based on their study, small opening eccentricity (less than 12%) was found to have an insignificant effect on peak lateral capacity.

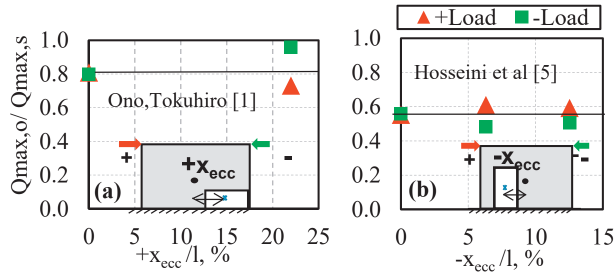

Fig.5 Effect of horizontal eccentricity by Hosseini et al [4]

3.3.2 Vertical eccentricity (y_{ecc})

From Ono and Tokuhiro's study [1], the effect of different vertical position of opening on the lateral strength is shown in Fig.6. It is observed that walls with a 32% vertical opening eccentricity, located at the top edge of wall (Fig.6, right), lateral strength decreased by 10% whereas for an opening at the bottom edge of wall (middle) with the same 32% vertical opening eccentricity, the wall exhibited 21% increase in lateral strength comparing to center opening case (left).

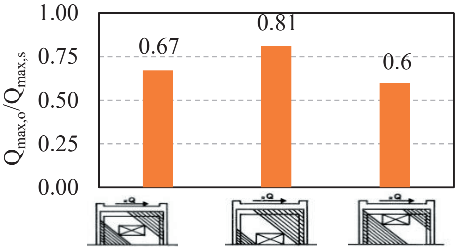

Fig.6 Effect of vertical opening eccentricity from [1] study

4. Validation of existing analytical methods with experiments

From Ono and Tokuhiro's study [1], a lateral strength reduction factor due to opening was calculated analytically considering compression field area (A_e) as shown in Eq. (1) and strength reduction factor in the AIJ guideline [7] is shown in Eq. (2). The comparison of the lateral strength reduction obtained from available past test studies [1-6] (up to three openings considered) with the reduction factor calculated as per AIJ [7] and Ono and Tokuhiro's study [1] are shown in Fig.7a and 7b respectively. It is observed that the Ono and Tokuhiro method resulted in a good match to experimental data, with the exception of walls with three openings. AIJ reduction factors are consistently conservative comparing to Ono and Tokuhiro's as would be expected from a design standard. From Fig.7a-b, it is observed that for walls with three openings [6], the calculated peak strength reduction from both methods (Ono and Tokuhiro and AIJ code) is larger comparing to test results.

$$r = \sqrt{\frac{\Sigma A_e}{hl}} \qquad (1)$$

$$r = minimum\ of\ \{r_1, r_2, r_3\} \qquad (2)$$

$$r_1 = 1\text{-}1.1\left(\frac{\Sigma l_0}{l}\right);\ r_2 = 1\text{-}1.1\sqrt{\frac{\Sigma h_0\, l_0}{h\, l}};\ \ r_3 = 1\text{-}0.5\left(1+\frac{l_0}{l}\right)\frac{h_0}{h}$$

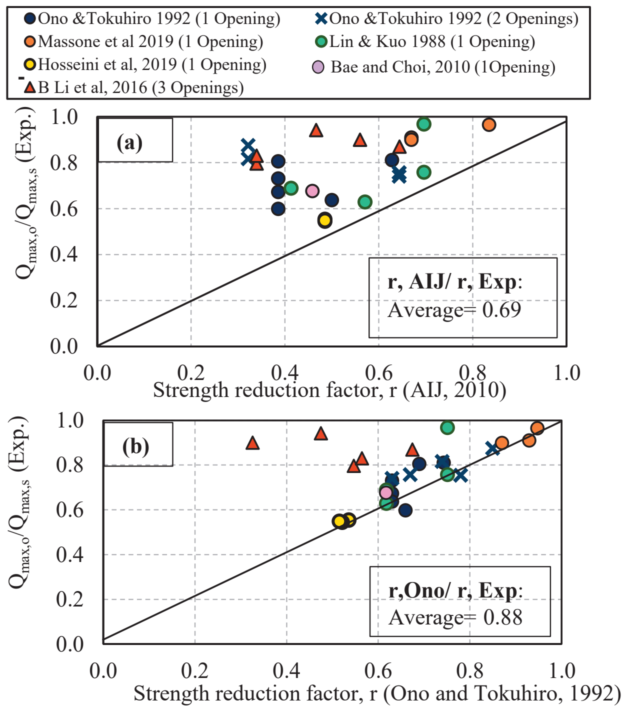

Fig.7 Comparison of strength reduction factor between experiment and analytical methods by (a) AIJ [7] (b) Ono and Tokuhiro [1]

5. Conclusions

The following conclusions have been made from the present study:

- Opening area was found to have a stronger correlation to the lateral strength reduction of RC walls than the opening dimension ratio based on coefficient of determination R^2 values. A lateral strength reduction of 3%~46% was observed for opening area ratios of 2% ~ 25%.
- Horizontal opening eccentricity below 12% had an insignificant influence on peak lateral strength (less than 2%) compared to a central opening. Larger opening eccentricities of 22% reduced the peak lateral strength by 10% compared to a central opening.
- Wall opening vertical eccentricity towards the bottom of the wall showed a smaller strength reduction than the same openings at the center or upper location.
- The strength reduction calculation method by Ono and Tokuhiro exhibits better correlation with experimental results comparing to AIJ guideline. However, AIJ reduction factors are found to be conservative comparing to Ono and Tokuhiro's method. For multiple opening cases, both methods exhibit poor correlation with experimental results.

Therefore, further investigation is required to understand the effect of multiple openings on the seismic performance of RC wall.

Reference:

[1] Ono M, Tokuhiro I (1992): A proposal of reducing rate for strength due to opening effect of RC framed shear walls, Journal of structural & construction engg. AIJ, 4325, 119-129.

[2] Massone LM, Munoz G, Rojas F (2019): Experimental and numerical cyclic response of RC walls with openings, Engineering structures, 178, 318-330.

[3] Lin CY, Kuo CL (1988): Behavior of shear wall with opening, Proceedings of 9th WCEE, Tokyo-Kyoto, Japan.

[4] Bae B, Choi CS (2010): Evaluation of shear strength reduction ratio of RC shear walls with opening, International conference on sustainable building Asia, Seoul, Korea, 311-316.

[5] Hosseini SA, Kheyroddin A, Mastali M (2019): An experimental investigation into the impacts of eccentric openings on the in-plane behavior of squat RC shear wall, Engineering structures,197, 1-13.

[6] Li B, Qian K, Wu H, (2016): Flange effects on seismic performance of reinforced concrete squat walls with irregular or regular openings, *Engineering Structures*, 110, 127-144.

[7] AIJ standard for structural calculation of RC structures, 2010.

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