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ANALYTICAL STUDY ON EFFECT OF CENTRAL OPENING OF MASONRY INFILL TO THE LATERAL STRENGTH OF RC FRAME STRUCTURE

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In order to get accuration analytical model for describing the lateral strength of brick masonry with openings, a newly simple method was introduced. Comparison of reinforced concrete frame structures with openings and the experimental results of brick masonry with openings (holes) of 25% and 40% was used in this analytical model. In the high-risk seismic areas many reinforced concrete buildings with infill frame with openings. Where the presence of openings will reduce the strength of the wall. In addition, the influence of the area and location openings in the walls are strongly needed to obtain a more realistic method for designing reinforced concrete structures.The brick mansory was assumed as the non-structural component. However, based on the observations after the earthquake, the presence of brick masonry has a significant contribution to the seismic capacity of reinforced concrete structures. The diagonal strut method was used, where the elastic and plastic behavior of the fill-portal by considering the limited ductility of the infill frame material. The comparison of the new analytical model and the experimental brick masonry with opening 25% and brick masonry with opening 40% shows a good agreement. Finally, it can be said that the new analytical model can be used.

Keywords: analytical study, central opening, masonry infill, lateral strength, RC Frame

1 INTRODUCTION

The presence of walls as filling materials in reinforced concrete structures, specifically, increases the strength and lateral stiffness of the structure; but the existance of this infill wall reduces the overall structure ductility [1-5]. The increase in lateral strength and stiff-ness of the structure only works if the reinforced concrete structure is completely filled with brick walls. When walls have openings (holes), the behavior and seismic capacity of rein-forced concrete structures will be unpredictable. Regardless, these openings in the walls are used for certain functions and purposes, such as doors, windows and others. Analytical studies for evaluation of full-wall lateral strength of frame structures have been done [6,7]. Meanwhile, an analytical model for the evaluation of the lateral strength of walls with openings was developed using the diagonal strut method [2,8]. In this model, it is stated that the frame structure with brick walls with openings has an effect on the lateral strength, the value of the lateral strength depends on the ratio of the area and location of the opening to the wall area. In this study, an analytical model is developed for walls with openings with the concept of a diagonal strut based on the contact height between the wall elements and the column structure. The results of the analytical model are then verified with the results of experimental testing.

2 ANALYTICAL MODEL OF MASONRY INFILL

The masonry wall analytic model was developed based on the diagonal strut that occurs in the infill wall when the wall meets lateral deformation [6]. The diagonal strut width W represents the existence of a wall with the same thickness and material as the wall. The diagonal strut will provide a diagonal compressive force working on the lower end of the compression column and the top end of the tension column along the contact area between the wall and the column. The width of the diagonal strut W is obtained based on the function of the contact height.

In this study, an analytical model for walls with openings in the middle (Figure 1a) is developed based on the diagonal strut model [6, 7]. In this model, diagonal struts occur on the wall elements on the left and right sides of the wall opening, while the wall elements above and below are assumed to have no struts as shown in (Figure 1b). Diagonal compression forces Cs1 and Cs2 occur in each strut as shown in Figure 1c. The diagonal force Cs1 working on the top of the tension column and on the wall below the opening is determined by equation 1(a). The diagonal force Cs2 working on the bottom of the compression column and on the wall above the opening is determined by equation (1b). The diagonal compressive force is determined by the width of the strut W with the thickness t and the compressive strength of the masonry wall fm' which is obtained by multiplying the compressive strength of the masonry wall with the reduction factor. The forces Cs1 and Cs2 are decomposed into horizontal (Ch) and vertical (Cv) distribution forces as shown in Figure 1d given by equations 2a and 2b.

$$C_{s1} = W_1.t.f_m' \quad (1a)$$

$$C_{s2} = W_2.t.f_m' \quad (1b)$$

$$C_h = t.f_m'\cos^2\theta \quad (2a)$$

$$C_v = t.f_m'.\sin\theta.\cos\theta \quad (2b)$$

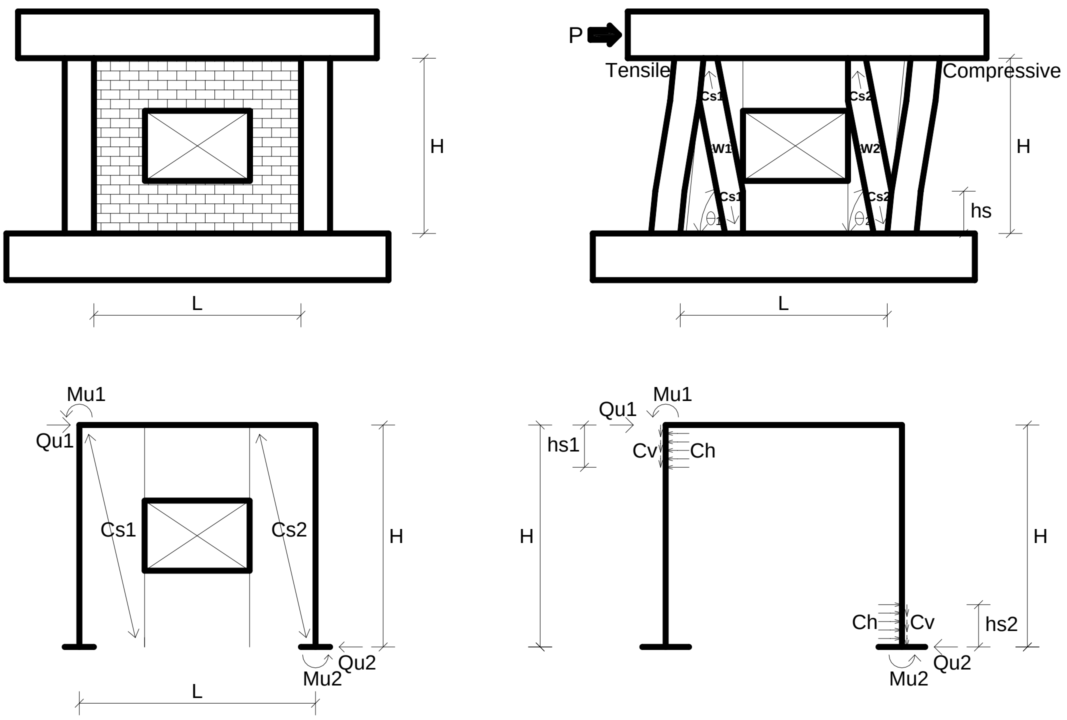


Fig. 1.Modeling of reinforced concrete portal structure with opening wall 25% (a). Masonry wall with opening 25%, (b) Lateral deformation due to load (P). (c) Diagonal compression force creates ultimate moment and ultimate shear force (d) Diagonal compression force distribution

The width of the diagonal struts W1 and W2 is derived by assuming the yield column is in a flexural condition, so the column displacement can be derived from the moment distribution equation. To determine the width of W2, the equation for the moment distribution from the end of the compression column is given by equation 3.

In the case of $0 \le y \le h_{s2}$

$$\mathbf{M}(y)=M_{u2}-Q_{u2}.y+\frac{1}{2}C_h.y^2 \quad (3a)$$

In the case of $h_{s2} \le y \le H$

$$\mathbf{M}(y)= M_{u2} - Q_{u2}.y+C_h.h_{s2}.y-\frac{1}{2}C_h.h_{s2}^2 \quad (3b)$$

where H is the column clear height, as shown in Figure 1a, Mu is the flexural strength at the column end; and Qu is the shear force at the column end, which is obtained by Equation (5).

Assuming that the curvature profile along the column height was similar to the moment profile, a lateral flexural drift profile along the column height (y) was produced by the double integrals of Equation (3)/EI (= elastic flexural rigidity of the column) as follows:

In the case of $0 \le y \le h_s$

$$\delta_c(y)=\frac{1}{EI}\left(\frac{1}{24}C_h y^4-\frac{1}{6}Q_{u2}y^3+\frac{1}{2}M_{u2}y^2\right) \quad (4a)$$

In the case of $h_s \le y \le H$

$$\delta_c(y) =\frac{1}{EI}\left(\left(\frac{1}{4}C_h h_{s2}-\frac{1}{6}Q_{u2}\right)y^3+\left(\frac{1}{2}M_{u2} -\frac{1}{4}C_h.h_{s2}^2\right)y^2\right)+\frac{1}{6}C_h.h_{s2}^3.y-\frac{1}{24}C_h.h_{s2}^4 \quad (4b)$$

$$Q_u = \frac{2.M_{u2}}{H} + C_h.h_{s2} - \frac{C_h.h_{s2}^{\ 2}}{H} + \frac{C_h.h_{s2}^{\ 3}}{3H^2} \tag{5}$$

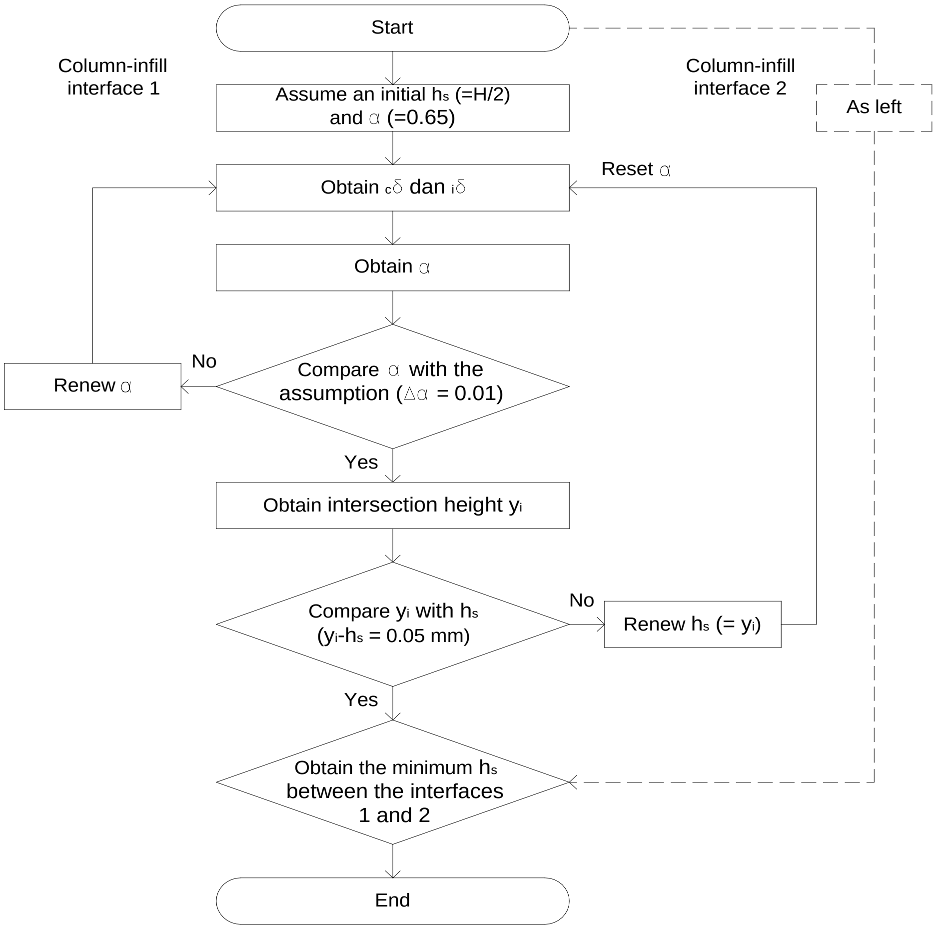


Fig. 2. Flow Chart to determine contact height (hs)

A lateral shear drift profile along the infill height δi(y) was obtained by Equation (6), considering the infill shear deformation assumed above and the compatibility between the column and infill drifts at the ends. Ultimately, an intersection height y_i between the column and the infill can be evaluated by solving Equation (7). The unknown h_s is obtained by iteration until $y_i = h_s$is satisfied. The overall procedure is presented in the flowchart in Figure 2. Consequently, the width of the compression strut W was determined by the minimum frame-infill contact length between both ends of the strut, as shown in Equation (8).

$$\delta_i(y) = \frac{\delta_c(y{=}H)}{H} y \tag{6}$$

$$\delta_c(y_i) = \delta_i(y_i) \tag{7}$$

$$W_2 = 2.h_{s2} \cos\theta_2 \tag{8}$$

With the same procedure carried out on strut 1 in the tensile column, W_1 obtained is given in equation (8).

$$W_1 = 2.h_{s1} \cos\theta_1 \tag{9}$$

The maximum lateral strength of the wall with the opening in the middle is obtained by Eq. (9).

$$Q_{ui} = C_{s1} \cos\theta_1 + C_{s2} \cos\theta_2 \tag{10}$$

3 EXPERIMENTAL FOR VERIFICATION

3.1 Structure Modeling

Reinforced concrete frame structure with holes in the middle of the brick walls are 25% (IFO-1), and 40% (IFO-2). The planned frame structure has a beam cross-sectional dimension of 200 mm × 200 mm with a span length of 1750 cm, using 4D13 mm longitudinal steel and Ø6-50 mm transverse reinforcing steel. The cross-sectional dimensions of the column in this study were planned to be 125 mm × 125 mm with a net column height calculated from the upper beam and lower beam 750 cm, using 4D10 mm longitudinal steel and Ø4-50 mm transverse reinforcing steel as shown in Figure 3.

The brick wall with opening in the middle 40% as shown in figure 4 and 25% as in picture 5 were made of bricks with a scale of 1:4, so the size is 55 mm x 28 mm x 13 mm. The brick walls were plastered with 5 mm thick mortar on both sides of the wall surface.

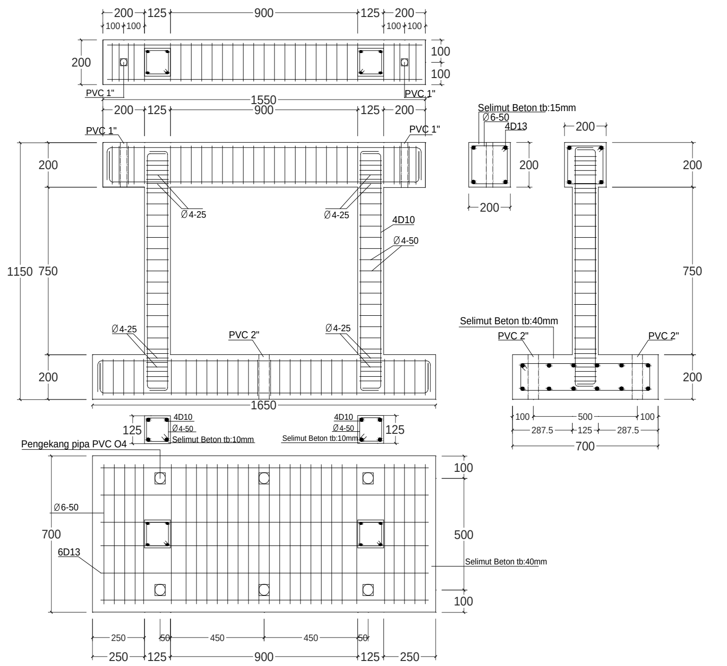


Fig. 3. Frame structure without brick walls

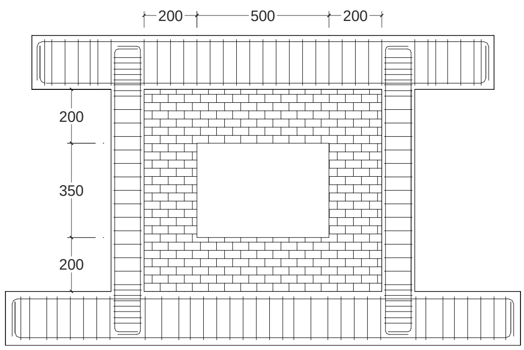


Fig. 4. Frame structure with opening in the middle of the wall 25% ($IF_{O\text{-}1}$)

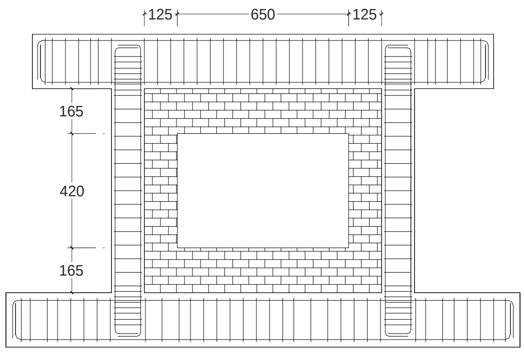


Fig. 5. Frame structure with opening in the middle of the wall 40% (IFO-2)

3.2 Test Method

The test object which had been made was mounted on the testing equipment (loading frame), where the lower beam of the test object was clamped on a rigid floor with a thickness of 100 cm. The rigid floor was perforated as deep as 120 cm from the top surface of the beam to the bottom of the floor. The beams and rigid floor were connected using PVC pipe clamping Ø4 inserted in the hole and fastened at the top of the beam to the bottom of the rigid floor with bolts and nuts until it could be assumed that the frame structure on the test object was perfectly clamped.

After the frame structure was attached to the test equipment, the LVDT (Lateral Vertical Displacement Transducer) was installed horizontally on the upper beam and left and right of the column. LVDT was also installed vertically on the left and right sides of the column. So, in this test, 5 LVDT were installed. The function of the LVDT is to measure the displacement that occurs both in the column and in the beam when the load is applied. The LVDT which were installed on the column both vertically and horizontally were placed on a simple steel holder which aim to ensure that the lateral displacement measured by the LVDT is lateral displacement of the upper beam relative to the lower beam. The lateral displacement of the test object would be read through a data logger connected to the LVDT.

The test equipment was installed a data logger as briefly introduced above. A data logger is an electronic device that records data from time to time connected via cables to the LVDT and load cells. The benefit of installing this data logger is its ability to automatically record data within 24 hours. A load cell is a transducer that is used to generate an electrical signal whose magnitude is directly proportional to the force being measured. Different types of load cells include hydraulic load cells, pneumatic load cells and strain load cells. The load cell records the capacity of a given alternating lateral load. The given load was pumped using a Hydraulic Jack, pumping was done manually using human power. The Hydraulic Jack rod would press the test object in accordance with the desired displacement control and be pulled back, so it forms an alternating lateral load. To make it easier to be understood, the schematic of the testing equipment is shown in Figures 6(a) and (b) below:

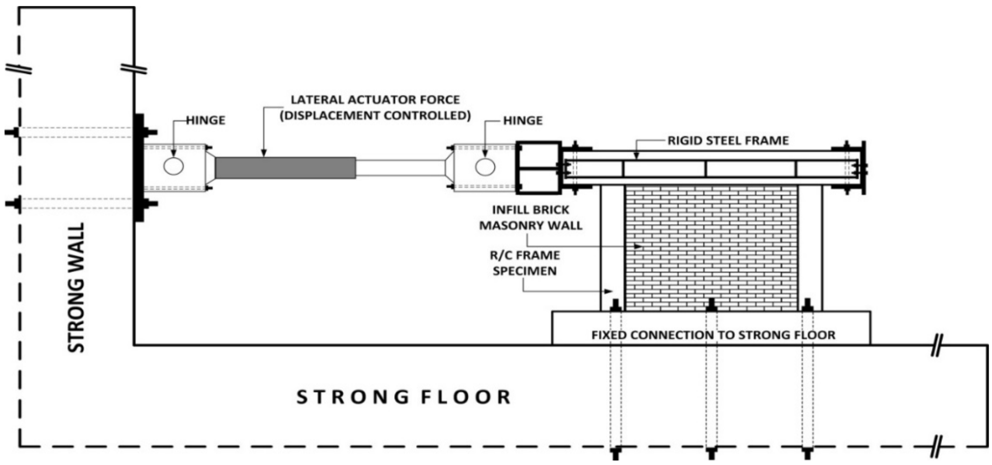


Fig. 6 (a). Front look

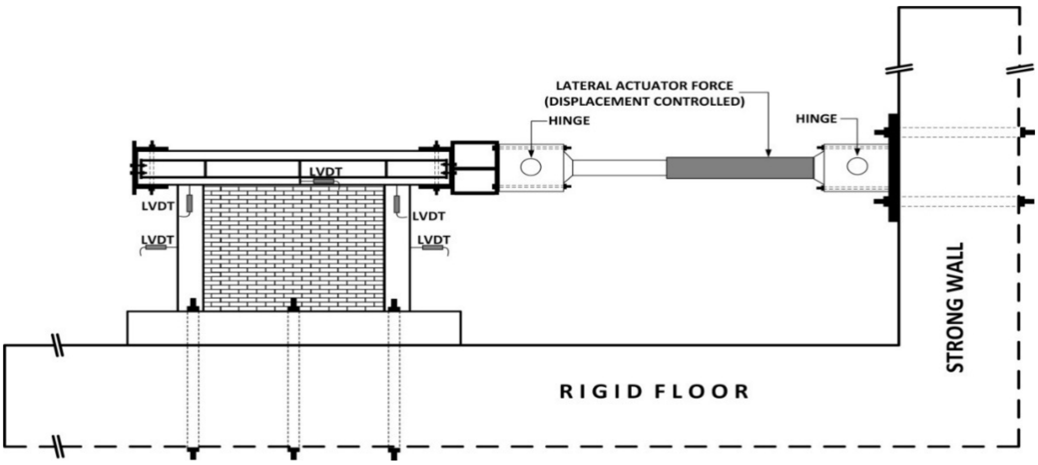


Fig. 6 (b).Back View

Material testing was carried out on each component of the material used, especially concrete, reinforcing steel, and bricks. The purpose of this material data collection is to determine the ability and strength of the material to withstand the tensile and compressive forces given. Based on the results of testing in the laboratory, the compressive strength values of concrete, brick, and brick walls are presented in table 1, while the results for the tensile strength of steel are shown in table 2.

Table 1. Quality of concrete, brick, and brick walls

The structure model	Fc Concrete (MPa)	Fc Brick (MPa)	Fc Brick Walls (MPa)
Frame	49,9	-	-
Frame + full brick walls	49,9	10,9	13,0
Frame + opening 40% (IF_{O-1})	49,9	10,9	13,0
Frame + opening 25% (IF_{O-2})	49,9	10,9	13,0

Table 2. Quality of reinforcement

Reinforced Diameter (mm)	Yield strength (Fy) (MPa)	Tensile strength (Fu) (MPa)	Young modulus (MPa)
Ø 4	390.200	597.000	2.700
Ø 6	345.800	444.000	2.055
D10	449.500	623.100	1.815
D13	399.000	570.400	2.010

3.3 Experimental Results

The lateral strength of masonry walls with openings in the middle was verified with the results of experimental studies on reinforced concrete portal structures with brick walls openings in the middle with alternating lateral static loads with test results described in the reference [9]. Figure 7 shows the relationship of lateral force and displacement for 4 structural test objects, namely a reinforced concrete portal structure without walls, a portal structure with brick walls, a portal structure with a wall having an opening of 25% in the middle of the wall and a portal structure with an opening of 40% in the middle of the wall [9]. The maximum lateral strength of portal structures without walls, structures with full walls, structures with walls having 25% opening and walls with 40% openings are 51.2 kN, 127.7 kN, 74.7 kN and 61.5 kN, respectively. The results of this experiment show that the lateral strength of the portal structure with full brick walls is more than twice the lateral strength of the structure without walls and the opening in the middle of the wall reduces the lateral strength of the structure based on the area of the opening.

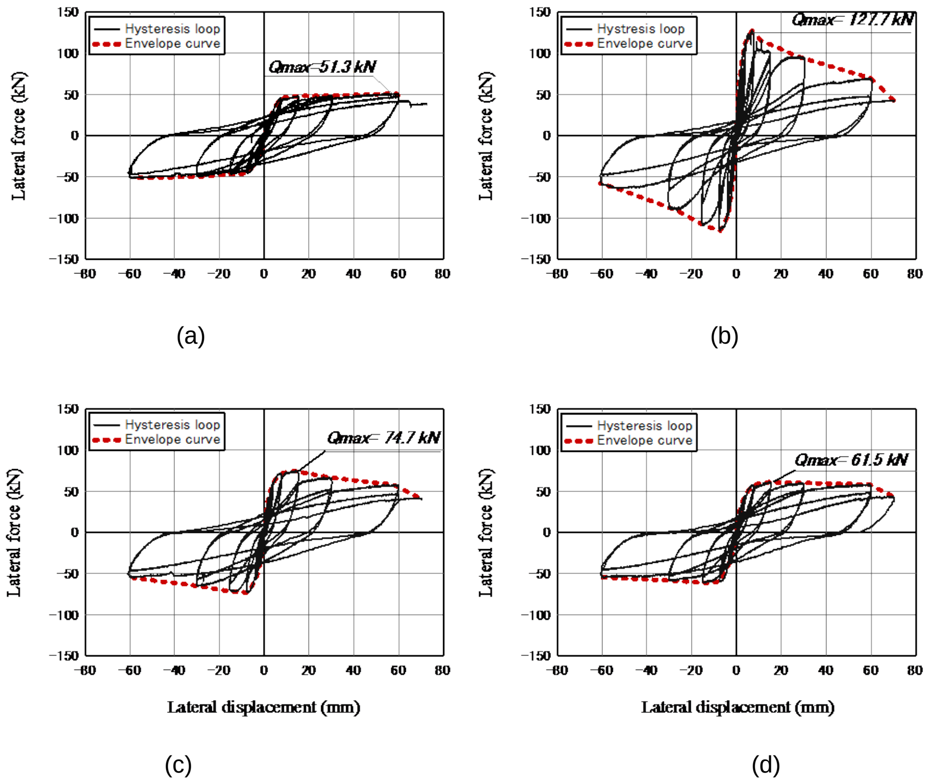


Fig. 7. Correlation between lateral forces and displacement

(a). Without Brick Wall (b). Full brick wall (c). Brick wall with opening 25% (d). Brick wall with opening 40%, Maidiawati et al [2018]

The lateral strength of a brick wall based on experimental results can be determined by extracting the value of the lateral strength of a portal structure with full walls and walls with openings against the lateral strength of a portal structure without walls at the same displacement. As a result, Figure 8 shows the lateral strength of brick walls with openings based on experimental results.

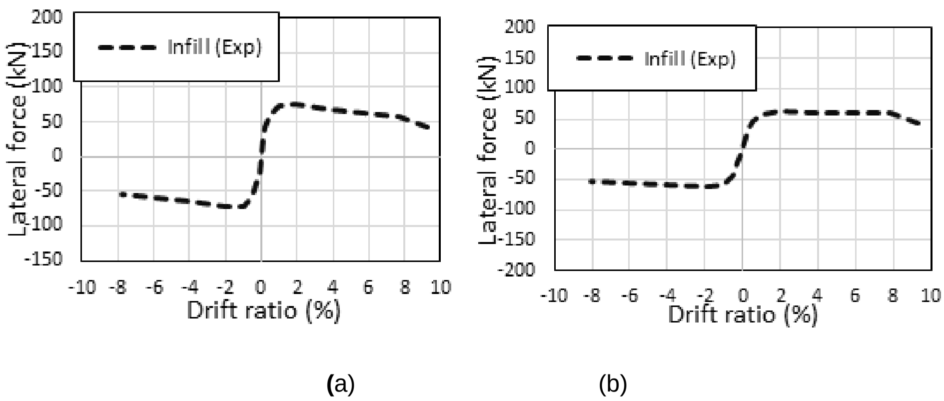


Figure 8. Relationship between lateral strength and drift ratio

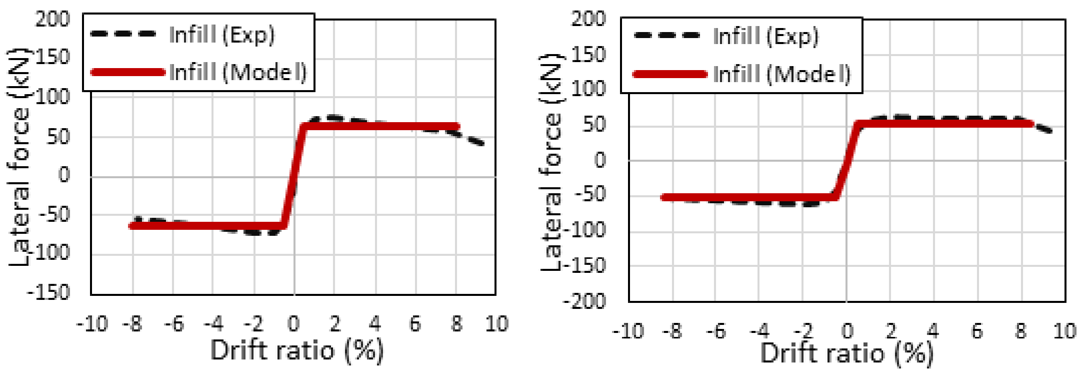
(a)masonry infill with opening 25% (b) masonry infill with opening 40%

4 VERIFICATION OF ANALYTICAL MODEL

Based on the model described above, for a frame structure with a brick wall with opening 25%, the contact height between the wall and column is hs1=hs2=345.9mm, and the diagonal strut width of the wall is W1=W2 = 178.25 mm. So, the diagonal compressive force on the wall CS1=CS2 = 63.2 kN is obtained. With □1 = 0.2 0.97 using equation (9), the maximum value of the brick wall strength is Qui = 32.5kN at a displacement of 5.48 mm. The displacement is obtained from the results of the stiffness of the brick wall divided by the strength of the brick wall.

For a frame structure with 40% opening brick wall, the contact height between the wall and the column is hs1=hs2=365.4 mm, the diagonal strut width of the wall is W1=W2 = 119.85 mm, the diagonal compressive force on the wall is CS1=CS2 = 42.46 kN. With $\square_1 = 0.16$ and $\square_2 = 0.90$, the maximum value of lateral strength of brick wall with 40% opening is Qui = 13.96 kN.

The seismic capacity of a brick wall with openings is expressed in the form of a bilinear relationship between lateral force and displacement as shown in Figure 8. From Figure 5, it can be seen that the ultimate lateral strength value of the simulated wall using the analytic model is quite close to the results of the structural test. The results of this verification indicate that the analytical model developed can be used as a method to evaluate the lateral strength of walls with openings.



(a) (b)

Figure 8. Comparison of the experimental and analytical lateral strength of brick walls (a) 25% opening and (b) 40% opening

5 CONCLUSION

Modeling of reinforced concrete portal structures with opening 25% and 40% was developed based on modeling reinforced concrete portal structures with full walls using the diagonal strut concept.

The comparison of the new analytical model and the experimental brick masonry with opening 25% and brick masonry with opening 40% shows a good agreement. Finally, it can be said that the new analytical model can be used.

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