Effects of Brick Masonry Infill on Seismic Performance of R/C Building

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Abstract
This paper presents the brick infill effects on seismic performance of R/C building. Brick masonry infill in R/C frame structure was evaluated by applying an equivalent diagonal strut model that representing elements of a brick infill. In this model, distributed compression transferred diagonally between infill/frame interfaces where the frame-infill contact length can be evaluated by static equilibriums related to compression balance and lateral displacement compatibility. The seismic performances of existing R/C building were evaluated considering infill effects by applying the diagonal strut model. Two calculations of seismic performance of R/C building: without and with considering brick infill, were conducted. Consequently, the brick masonry infill significantly increases the lateral strength and lateral stiffness of the R/C building.

Keywords: brick masonry infill; RC existing building; seismic performance

INTRODUCTION
Reinforced concrete (R/C) buildings with brick infill are widely used in building. In last decade, a lot of R/C buildings were damaged and collapsed by the earthquakes in West Sumatra, Indonesia [1,2]. However, some of R/C buildings that had a lot number of a brick masonry infill in the frame structure survived during the earthquakes [1]. It seemed that the brick infill contributed to resist the seismic load.

In seismic design calculation of R/C building, contribution of the brick masonry infill in R/C frame buildings is always ignored assuming it as nonstructural element. Some previous studies by numerous researchers found that brick infill in the frame structure can increase the lateral strength of the overall structure which is about four times larger than frame structure without brick infill, but the ductility is reduced by about half than the bare frame [3]. Therefore, seismic performance of existing buildings by considering the effects of brick infills can be evaluated by analytical model.

A number of analytical models have been proposed by researchers one of them is a strut diagonal model reported by Maidiawati et al in Reference [4], where the model has been verified through test results of bare frame and infilled frame structure [3]. Therefore, in study seismic performance of an existing R/C building in Padang, West Sumatra was evaluated by applying such analytical model to nonstructural brick infill.

MODELING OF MASONRY INFILL
Modeling of brick masonry infill and the frame structure developed by Maidiawati et al as reported in References [4] was applied to nonstructural wall to evaluate the seismic performance of a frame structure with brick infill effect. In this model, a brick infill in the frame structure is replaced by an equivalent diagonal strut thickness and material that has the same brick panel...
In this model, a compression stress distribution at the infill/frame interface is replaced by an equivalent rectangular block, as shown in Figure 1(b), where the averaged compressive strength, $f_{m}'$, is evaluated by multiplying the uniaxial compressive strength of infill, $f_m$, by a reduction factor, $\alpha = 0.65$. The diagonal compression, $C_s'$, which acts on the bottom/top of the compressive/tensile column as shown in Figure 1(c), so the total diagonal force, $C_s'$, as shown in Figure 1 (d) given in equation (1). $C_s$ is resolved into the horizontal and vertical components, which are represented by the distributed forces along column height, as shown in Figure 1 (e), as given by equation (2) and (3), respectively [4].

\[
C_s = W t f_m'
\]

\[
c_h = t f_m' \cos^2 \theta
\]

\[
c_v = t f_m' \sin \theta \cos \theta
\]

Fig. 1: Modeling of masonry-infilled frame

Assuming that the compressive column yields in flexure at the bottom, the moment distribution along column height, $M(y)$, is obtained with Eq. (4). Yield moment, however, is calculated with Eq. (5) based on the Japanese standard [5].

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

\[
M(y) = y_o M_o - Q_s y + 1/2 C_y \dot{y}^2
\]  

(4a)

In the case of $h_s \leq y \leq L$

\[
M(y) = y_o M_o - Q_s y + C_y h_s y - 1/2 C_y h_s^2
\]

(4b)

\[
M_y = 0.8 \sigma f D + 0.5 N D \left[1 - \frac{N}{b D F_t}\right]
\]

(5)
where, \( h_s \): infill/column contact height, as shown in Fig. 1(b), \( L \): clear column height, as shown in Fig. 1(e), \( M_c \): flexural strength of column, \( Q_u \): shear force at column bottom, which is determined with Eq. (7), as derived later, \( a_t \): total cross-sectional area of tensile reinforcing bars, \( \sigma_y \): yield stress of longitudinal reinforcement, \( D \): column depth, \( N \): axial force, \( b \): column width, \( F_c \): compressive strength of concrete. However, the axial force at the bottom of column is calculated as a summation of building weight, axial force due to shearing force in the beam, and vertical component of the strut force, \( C, h_c \).

Lateral displacement along column height, \( \delta(y) \), is obtained with Eq. (6) is derived based on the method of double integrals of Eq. (4)/EI.

In the case of \( 0 \leq y \leq h_s \)
\[
\delta(y) = \frac{1}{EI} \left( \frac{1}{24} C_s y^4 - \frac{1}{6} Q_u y^3 + \frac{1}{2} M_c y^2 \right)
\]  
(6a)

In the case of \( h_s \leq y \leq L \)
\[
\delta(y) = \frac{1}{EI} \left( \frac{1}{6} C_s h_s - \frac{1}{6} Q_u \right) y^3 + \left( \frac{1}{12} M_c - \frac{1}{4} C_s h_s^3 \right) y^2 + \frac{1}{6} C_s h_s^3 y - \frac{1}{24} C_s h_s^4 \}
\]  
(6b)

where, \( EI \) are bending stiffness column. For Eq. (4) and (6), \( Q_u \) is obtained by Eq. (7) by assuming no rotation occurs at the column top.

\[
Q_u = \frac{2M_c}{L} + C_s h_c^3 - \frac{C_s h_c^3}{L} + \frac{C_s h_c^3}{3L^2}
\]  
(7)

Lateral deformation along infill height, \( \delta'(y) \), is defined by Eq. (8) by assuming a uniform shear strain, \( \theta \). Therefore, intersection height between column and infill deformation can be evaluated by solving Eq. (9).

\[
\delta'(y) = \theta y = \frac{\delta(y = L)}{L} y
\]  
(8)

\[
\delta(y) = \frac{\delta'(y)}{L} y
\]  
(9)

According to the above procedure, the contact length between infill/column, \( h_s \), is obtained for tension and compressive columns. Consequently, the width of compression strut, \( W \), is determined as a function of the smallest contact lengths between infill/column given by Eq. (10).

\[
W = 2h_c \cos \theta
\]  
(10)

SEISMIC PERFORMANCE OF R/C BUILDING

Description of Building
In this study, an existing three-story R/C building in Padang, Indonesia, was evaluated by applying the analytical model to non-structural brick walls. The building is an electrical laboratory of Electrical Engineering Department of Padang Institute of Technology where is located in Gajah Mada street, Nangglao Padang. The investigated building was constructed before the September 2009, Sumatra-Indonesia earthquake, however, the building survived during the earthquake, as shown in Photo 1. The building representing the typical Indonesian building with the first story plan illustrated in Figure 2. Data of building such as cross-sectional dimensions of columns, rebars of column and material of concrete were obtained by site inspection as shown in Photo 2: measurement of columns, rebars scan and hummer test. Consequently, the cross-sectional dimension of column, \( C \), were 400x400 mm with 12D22 of longitudinal rebars and 2Ø12-150 of...
transverse hoops. Many brick walls with and without openings were used as infill in R/C frames as shown in Figure 3. Compressive strengths of concrete of 41.2 MPa and brick wall of 12.00 MPa were obtained through hummer tests. The yield strengths of longitudinal and transverse rebars were 343MPa and 294 MPa, respectively.

![Photo 1: The Investigated Building](image)

(a) Measurement of  
(b) Rebars scan  
(c) Hummer test

**Photo 2: Site Inspection of Investigated building**

![Fig. 2: First Floor Plan and Cross Section Column of Investigated Building](image)

![Fig. 3: Brick Infill Plan of First Floor of Investigated Building](image)
Seismic Performance of R/C Building

Seismic performance of existing R/C building was evaluated only for the first story on the basis of the Japanese standard [6] along West-East and North-South directions. The seismic performance of investigated building was presented in relationship between strength index and ductility index. The cumulative strength index, $C$, at a certain ductility index, $F$, was calculated by Eq. 11.

\[ C = C_i + \sum \alpha_j C_j \]  

where, $C_i$ was strength index of the $i$-th group of vertical members having the same ductility index, given by Eq. 12, $\alpha_j$ was an effective strength factor of the $j$-th group, $C_j$ is strength index of the $j$-th group having the same ductility index larger than that of $i$-th group, $Q_u$ was ultimate lateral load-carrying capacity of the $i$-th group of columns which was evaluated as the smaller value between the shear force at flexural yielding. The ductility index, $F$, represents deformability of certain vertical members, was calculated according to structural specifications based on the reference [5].

The analytical model was applied to evaluate the full brick infill effects. In the case of multi-span infilled frames, as illustrated in Figure 4(a), however, each column was categorized into an exterior tensile column, interior column and exterior compressive column, as shown in Figures 4(b), 4(c) and 4(d), respectively [4]. As report by Maidiawati et al in Reference [4], In particular, distributed forces due to the struts were unsymmetrically applied to the bottom and top of interior column, as shown in Figure 4(b). Consequently, shear force at the interior column end was determined by Eq. (13)

\[ Q_u = \frac{2M_s}{L} + C_i h_i - \frac{C_i h_i^2}{L} \]  

Calculated seismic performance of R/C building was compared between with and without infill effects in both directions, as shown in Figure 5. The figure exhibits that the strength of R/C building by considering brick infill is higher than those of without infill. The strength of R/C building by considering brick infill in North-South direction is much higher than those of in West-East direction, as shown in Figure 5(a), because there are no full brick infills in R/C frame in West-East direction, as illustrated in Figure 4. The figures show that the brick infill significantly increase the lateral strength of investigated building. The performance of such building by considering infill is almost reach 0.8 of strength index in which it is relative high performance to save building during the September 30, 2009, West Sumatra earthquake.
CONCLUSIONS

Based on evaluation of seismic performance of existing building, the major results summarizes as follows.

1. Brick infill in R/C frame structure increases the lateral strength and stiffness of R/C building.
2. The contributions of brick infill on seismic performance of R/C building can be evaluated by applying the analytical strut model.
3. It is assumed that the presence of brick infills in R/C frame structure can save the investigated building during the September 30, 2009, Sumatra Earthquake.

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