The utilization of brick walls for resisting earthquake in building technology

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Abstract. Many structures in Indonesia use reinforced concrete frames with brick walls as their infill. Commonly, the engineers consider brick walls as the partitions and count them as the non-structural elements in the structure design. However, brick walls are capable of resisting earthquake by yielding high stiffness to the structure in case the brick walls are integrated well with the frames. It will reduce the non-structural destructions that happen to structures which is one of the most frequently impacts in the earthquake. This paper will take the effects of applying brick walls as the structural elements up by comparing it with the structure using brick walls as the partitions. The modeling of the brick walls uses the equivalent spectrum method meanwhile the seismic analysis uses the reson spectrum method. The utilization of brick walls can cause the decrement of the natural period to 42%. It also reduces the structure displacements to 53% in X-direction and 67% in Y-direction and the story drifts to 57% in X-direction and 71% in Y-direction. Otherwise, it causes the increment of the base shear only up to 3% in X-direction and 7% in Y-direction.

1. Introduction
Brick walls are used widely as infill for reinforced concrete frames system due to its economic and availability. Infilled frame is a combination system of reinforced concrete frame or steel frame and panels (such as masonry and concrete) that fills the vertical space of the frame [1]. In the structure design, the engineers generally count brick walls as the additional dead loads on beams and assume the structure as the open frame because it is too complex to analyze the brick walls. These practices make us not put attention to the wall mounting on the frame. We often waive the use of rigid joint between the wall and the frame. However, we cannot neglect the fact that brick walls will always interact with the frames under lateral loading.

Earlier studies revealed that brick walls can give great effects to the structure. Tanjung and Maidiawati [2] carried out an experimental study on a single infilled frame and a single open frame. Both types of structures accepted the lateral load in X-direction that increased continuously until collapse occurred. The observation during the experiment showed that the lateral load transfer mechanism was changed from frame to truss mechanism. The tension axial force increased at the left column and the compression axial force also increased at the right column. At that time, the bending moment and shear force decreased at both columns. The results of that experiment depicted that the brick wall affected the lateral resistance of the structure. From the experiment, they found that the open frame displacement was 52,5% higher than the infilled frame displacement.

Paudel and Adhikari [3] carried out an analysis study on the open frame and the infilled frame structures to discover the effect of brick walls by observing their displacement. The structure is (G+6)
story with 20m×16m plan area. The height of the ground to the (G+1) story is 3.2 m and the other story is 3.0 m. They used the equivalent diagonal strut method to model the brick walls. In the equivalent diagonal strut, brick wall is modeled as single strut. From the study, they found that the presence of brick walls could decrease the structure displacement up to 68% in X-direction and 61% in Y-direction. Both previous studies denote that brick walls contribute in diminishing the structure displacement significantly. It means that the infilled frame can resist earthquake better than the open frame where the brick walls act as the partitions.

There are several modeling method proposed by researchers in order to fully understand infill wall behavior. The modeling method are classified in two types, they are micro model and macro model [4]. Micro model is a modeling using Finite Element Method (FEM) which is able to perform the condition of brick wall and its failure in detail. Since this method needs complex calculation and longer time to do the analysis, the researchers simplify the modeling into diagonal strut element which is called as macro model. In this method, the brick wall will be replaced by pin jointed diagonal strut. In other words, the infilled frame will act as braced frame. The thickness of the strut is equal to the the thickness of the wall and its length is equal to the diagonal length between its both compression corners [5]. To obtain the effective width of the equivalent diagonal strut, there are three necessary parameters. They are relative stiffness of the frame and infill, contact length, and the aspect ratio.

Based on those studies, this paper will analyze an infilled frame structure and an open frame structure under seismic loading. The objective is to discover the effect of brick wall utilization in increasing the stiffness of the structure. This paper uses the equivalent diagonal strut method to model the infill wall and response spectrum method to analyze the seismic loading. The outcome of this study is to compare the natural period, displacement, and story drift of each structure.

2. Method
This study designs three stories building of reinforced concrete structure system located in Medan, Sumatera Utara. The total height of the building is 10.5 m, and the height of each story is 3.5 m. The building area is 80 m² with its length is 16 m, and its width is 3 m. This building uses 25 cm × 50 cm beams, 20 cm × 30 cm secondary beams, 25 cm × 40 cm tie beams, and 40 cm × 40 cm columns. There are two building models here, the first is open frame and the second is infilled frame as shown in figure 1(b) and 1(c).

Figure 1. Modeling of (a) floor plan, (b) 3D open frame, and (c) 3D infilled frame.

This paper assumes that the soil profile in the location is medium soil. According to SNI 03-1726-2012 [6], for Medan, the value of the acceleration response, \( S_S = 0.526 \) g and \( S_1 = 0.332 \) g. The spectral response curve as shown in figure 2.
The structure description is shown table 1.

| Particular                  | Structure   |
|-----------------------------|-------------|
| Grade of Concrete           | M20         |
| Grade of Steel              | Fe 400      |
| Seismic Design Category     | D (as per SNI 1726-2012) |
| Importance Factor, $I_c$    | 1.0         |
| Response Reduction Factor, $R_c$ | 8          |
| Deflection Amplification Factor, $C_d$ | 5.5 |

Both buildings use infill wall. However the infill walls in the first model become the additional dead load on beams. In the second model, the infill walls become the diagonal compression members or struts. The wall thickness becomes the strut thickness. The equivalent width of the diagonal strut is given by expressions [7]:

\[ a = 0.175(\lambda_1 \times h_c)^{-0.4} \times r_{inf} \]  
\[ \lambda_1 = \left[ \frac{E_{me} \times t_{inf} \times \sin 2\theta}{4E_{fe} \times I_c \times h_{inf}} \right]^{1/4} \]  
\[ \theta = \tan^{-1} \frac{h_{inf}}{L_{inf}} \]

where:
- $\lambda_1$ = coefficient which is used to determine the effective width of the bracing
- $h_c$ = column height between centre lines of beam (m)
- $r_{inf}$ = diagonal length of infill wall (m)
- $E_{me}$ = modulus of elasticity of infill material (kN/m²)
- $t_{inf}$ = thickness of the infill wall (m)
- $\theta$ = slope of infill diagonal to the horizontal (°)
- $E_{fe}$ = modulus of elasticity of frame material (kN/ m²)
- $I_c$ = moment of inertia of column (m⁴)
- $h_{inf}$ = height of the infill (m)
- $L_{inf}$ = length of the infill (m)
3. Results and Discussions

3.1. Natural period
There are nine mode shapes with nine natural periods. The natural periods of infilled frame is 45% lower than those in open frame as shown in figure 3.

![Figure 3. Equivalent diagonal strut illustration.](image)

The compressive strength of brick wall that is used in this study is 3.54 MPa and its modulus of elasticity is 2478 MPa [8]. For analyzing seismic load, this paper performs response spectrum analysis using ETABS software.

3.2. Lateral displacement and story drift
ETABS software results in the elastic lateral displacement of the structure. Nevertheless, we must enhance that value by multiplying it with $C_d/I_e$. Brick walls reduce the lateral displacement of structure up to 53% in X-direction and 67% in Y-direction. Figure 4 and 5 show the lateral displacement of both structures.

![Figure 4. The natural periods of open frame and infilled frame.](image)
The story drift of infilled frame is also lower than the open frame. Brick walls reduce the story drift of structure up to 57% in X-direction and 71% in Y-direction. Figure 5 and 6 show the story drift of both structures.

Figure 5. Lateral displacement in X-direction.

Figure 6. Lateral displacement in Y-direction.

Figure 7. Story Drift of Structures in X-direction.
4. Conclusions

Based on the study, the natural periods, displacements, and story drifts of the infilled frame are lower than the open frame. The natural period of the infilled frame is 45% lower than the open frame. The displacement and the story drift of the infilled frame in X-direction are 53% and 57% lower than the open frame. Meanwhile, in Y-direction, its displacement and its story drift are 67% and 71% lower than the open frame. These results are consistent with the previous studies by Paudel and Adhikari that the brick walls can reduce the displacement of the structure significantly. This happens because the stiffness of the infilled frame comes not only from its beams and columns but also its brick walls which act like struts. Hence, the structure that uses brick walls will have high stiffness and because of it, the natural period, displacement, and story drift of the infilled frame will decrease. The lower the natural period, the smaller the sway takes place when the earthquake occurs. The lower the displacement and the story drift, the smaller the damage that the structure may experience. Therefore, the utilization of brick walls is very important in resisting earthquake and the structure engineer must keep in mind that to acquire the function of brick walls as structural element, the walls have to be rigid with the frames.

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