Numerical study on masonry infill wall by using in-plane element and joint interface with RC frame

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Abstract. Commonly house’s damage under earthquake is because their capacity inadequate to prevent from collapse, and the masonry wall system is not designed to resist the earthquake force. However, masonry infill wall is commonly used as partition and to separate large area with a purposed. Interaction between frame and masonry infill wall are not good connected to prevent building damage from earthquake. To understand the interaction between frames and infill wall can be simulated by numerical method or by Macro-modelling approach. The purpose of this numerical study is modelled a frame as a single element, a masonry infill wall as a plate element, and an interface between frame and masonry infill wall as an elastic spring. The concept of modelling depends on material parametric provided and the number of elements. Modelling with computational software facilitate to create material element and model and this modelling is conducted by Tohoku-coast NS time history seismic. The result shows the frequency parameter expressively increase from frequency on frame model to frame with infill wall model, or the time period parameter significantly reduce with the addition of infill wall. By the addition of mortar thickness which increased the stiffness also affect the frequency parameter and maximum displacement. The thickness of mortar brought the optimal value to good response is recommended with thickness of 0.5 cm to 1.5 cm. The finding is that infill wall gives significant influence on frame response if the interface of frame and infill wall designed with good material characters.

1. Introduction
Indonesia is on of areas with the potential of annual earthquakes quite often and quite large. Indonesia has two old tectonic plates and it has a lot active mountain. Because of the condition, Indonesia have been considered as vulnerable from earthquake and its impact. Most of house and building in Indonesia use masonry as infill wall. Because of that, the research proposes to investigate the effect of masonry infill wall into RC frame on simple house or building.
Masonry infill walls are frequently used among houses and buildings construction in Indonesia. The function of interior masonry infill walls is commonly used as partitions and to divided large area on building to be separation room by any required purposed. In the other sides, masonry exterior infill walls are used to protect the inside building. They are built on large-scale manufacturing, commercial, institutional and residential structures throughout the Indonesia. They generally neglect the stiffness contribution and are regarded to be non-structural components [1][2]. In fact, masonry infill walls increase the frame stiffness, the frame strength, and reduce displacement on frame system. However, by using the masonry infill wall on buildings are also increasing undesirable mass. Under seismic loading, the behaviour of masonry infill frame increase energy dissipation capacity on the regular building, although increasing stiffness are also shown by increasing base shear force [3][13]. Moreover, experimental investigation on the masonry infill walls by seismic behaviour and analytical
methods have improved its effect, the relationship between infills and frames have been observed the complexity computational. Many of possible failures mode unpredictable occur if masonry infill walls considered in the analysis and design method, because the interacting parameters have been clearly identified [4].

Masonry infill wall are nonlinear material and inelastic response, it is not simple modelling on the computational methods. The nonlinear materials are most important factor and considered accurately in analytical modelling and that requires complex computational methods. The researchers usually used diagonal strut as an element structural to interpret these or the other types of infill wall. Diagonal strut was connected by the two loaded corners on infill panel without openings. Other alternative approximately method to define the masonry infill wall use the macro- and micro-modelling. Those method are frequently investigated to find the effect of these element on frame analysis structure [7-12]. Several behaviour impact of frame structure with infill wall under seismic loading inspect the lateral displacement, storey drift ratio, base shear forces, and the other parameter output which has been defined [8][15]. The other contradiction of the infill wall brought the asymmetric building plan, short column or soft-storey phenomenon [9].

The mechanic of masonry infill wall material on the numerical simulation was defined as the standard material properties. However, the interface material and the bed joint and head joint material on masonry infill wall was difficult to identify and to model on numerical simulation. Then its contribution or its failure as connection was neglected on simulation, because the interface material and bed-head joint are also conduct as element non-structural [6][20].

2. Numerical Study
Masonry infill wall had been investigated by used macro-modelling as the basic parameter of this strut its equivalent width. In the first stage, by comparing of the parameter of struts are taken from literature with determining the width of compression diagonal strut. Second stage, application on the sensitive analysis which it performed by considering 2-, 4-, 6-, and 8-storey RC with bare frame and infill wall. Single strut and three-strut model for simulation of wall panel were used in all infilled frames. Pushover analysis were used to assess 36 model with different RC Frame and infill wall effect. The result shown the effect of infill panels over the elevation influence into structure performance. The infill panels discontinued at the ground level was reduced the capacity [1].

The masonry infill wall had been simulated by macro-modelling under Seismic Design Codes (EC8-Part 1, ASCE 41-60). From these Seismic Design Codes contain provision that to determine the stiffness of solid infilled frames which modelling as a diagonal strut, however several provisions are not provided for infill wall with opening. Their research was to study analytical equation of reduction factor, which these functions express as the ratio of the effective width of diagonal strut of an infill wall with openings. In order to be able to calculate the initial lateral stiffness of RC frames with opening infill wall. The result that the difficulties to introduce infill wall by using macro-modelling, and its shown significant impact into the response of frame in the modelling structure. Reduction factor is used to propose as a multiplication factor in order to calculate the reduced equivalent width of compression struts. Regarding the inter-storey drift, the results show that the weakness of a floor level at the larger openings in the infill wall and the inter-storey drift ratio at the first storey has increased dramatically [21].

The behaviour of masonry infill wall on single frame is analysed according numerical simulation with macro-modelling approaches. These approaching method is proposed by previous research which has been executed by an application software both for research and engineering practice. Macro-modelling method is continuous model with homogeneous materials where the brick, mortar, and interface masonry and mortar are presented with equivalent continuum. Homogeneous masonry materials have been conducted which the component of masonry have been taken from RVE [22]. The components are head joint, cross joint, bed joint, and brick unit. The homogeneous material showed the matrix material properties (1) to consider plane element material [23]:

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\[ [S] = \begin{bmatrix} S_1 & S_1 & 0 \\ S_2 & S_2 & 0 \\ 0 & 0 & S_1 \end{bmatrix} \text{ with } x = 1, y = 2 \] (1)

Each element on matrix had been obtained by approximately function (2) and (3), which each symbol on the function interpret the material properties each interface element and bed-head joint on masonry infill wall:

\[ S_1 = S_2 = \frac{h_i \cdot h_i \cdot E_i \cdot h_i \cdot \varepsilon_1 - E_i \cdot h_i \cdot \varepsilon_2 - E_i \cdot h_i \cdot \varepsilon_3 - E_i \cdot h_i \cdot \varepsilon_4}{2(h \cdot t_i) (t+ t_i)} \] (2)

\[ S_1 = S_1 = \frac{h_i \cdot \varepsilon_1 - E_i \cdot h_i \cdot \varepsilon_2 - E_i \cdot h_i \cdot \varepsilon_3 - E_i \cdot h_i \cdot \varepsilon_4}{2(h \cdot t_i) (t+ t_i)} \] (3)

\[ S_1 = \frac{1}{2G \varepsilon} = \frac{\frac{G_\varepsilon G_\hbar h_i(h \cdot t_i) + E \cdot (h \cdot t_i) (G \hbar G \varepsilon) + E}{2G(h \cdot t_i) (E \cdot l^3 + G(E \cdot h_i t_i))} + \frac{G_\varepsilon G_\hbar h_i(h \cdot t_i) + E \cdot (h \cdot t_i) (G \hbar G \varepsilon) + E}{2G(h \cdot t_i) (E \cdot l^3 + G(E \cdot h_i t_i))}} \] (4)

Modulus of shear on material properties have relation between modulus of young and poisson’s of ratio, are shown below:

\[ G = \frac{E \cdot \varepsilon}{(1 + \theta) (1-2\varepsilon)} \] (5)

In this numerical study, the frame is modelled using single element, the masonry infill wall is modelled using a plate, and the interface between frame and masonry infill wall is simulated by elastic spring [17-18]. All the beam-column element is clarified by discrete element to support a reliable simulation of masonry infill wall. The macro-modelling approaches used constructed the computational simulation to investigate the behaviour of frame concrete with masonry infill wall.[19]

### 3. Method

Masonry infill wall dimension on this study have 400 cm length, 350 cm height, and 15 cm of thickness of masonry infill wall. The frame concrete has column section, 15 x 15 cm, and beam section, 15 x 20 cm. The masonry material has been designed with data as follows 1) modulus elasticity of brick is 386.3 MPa, Poisson’s ratio is 0.2, 2) Modulus elasticity of mortar is 879.3 MPa, Poisson’s ratio is 0.2. The concrete material has been designed with modulus elasticity is 17912.49 MPa, compression strength is 14.525 MPa, Poisson’s ratio is 0.16. Interface between frame concrete and masonry infill wall as known with mortar connection will be investigated with variation of thickness.

The frames concrete is drawn with line element with discretization 20 numbers. The masonry infill wall is created as area element with discretization also 20 x 20 numbers. The interface connections are designed with spring as an elastic link. Elastic link is created with 6 degree of freedom which include with tension and compression strength only [19-20]. 6 Degree of freedom consist of 6 stiffness component, 3 stiffness in 3 global coordinates and 3 rotational stiffness of 3 global coordinates. Therefore, the model frames concrete and masonry infill wall are shown a Figure 1 and Figure 2, and stiffness of interface was calculated as table below.

| Thickness of mortar (cm) | 0.5   | 1.0   | 1.5   | 2.0   | 2.5   | 3.0   |
|--------------------------|-------|-------|-------|-------|-------|-------|
| Stiffness of interface   | 4579.69 | 36637.5 | 123651.6 | 293100 | 572460.9 | 989212.5 |

Table 1 Variation of Interface Parameter
According to the preparation model, the total model under investigation with lateral loading are 7 models include frame models. All of model is conducted with seismic force which taken from Tohoku-Coast-NS seismograph at 2011 on Tohoku, Japan. The input time-history data shown in Figure 3. The behaviour investigation will be shown in frequency and period parameter, displacement at beam-column joint.

4. Result
On this numerical analysis with computational software, the behaviour parameter is shown with frequency, periods, and maximum displacement [20]. The time history input was conducted with Tohoku, coast, NS Seismograph, then model can be response the value of parameter, these are shown in table below.

| Table 2 Result Investigation |
|-----------------------------|
| **Model** | **Frequency (rad/sec)** | **Period (sec)** | **Max Disp (mm)** |
| Frame model | 9.109 | 0.6898 | 149.99 |
| F-MIW-t1 | 83.3783 | 0.0754 | 0.9097 |
| F-MIW-t2 | 155.5811 | 0.0404 | 0.2775 |
| F-MIW-t3 | 184.3672 | 0.0341 | 0.1701 |
| F-MIW-t4 | 195.053 | 0.0322 | 0.1474 |
| F-MIW-t5 | 199.634 | 0.0315 | 0.141 |
| F-MIW-t6 | 201.922 | 0.0311 | 0.138 |
From the Table 2 and Figure 4, the result shows that the influence of masonry infill wall affect to frame structures response significantly contribution. These shown the frequency of model from frame model into masonry infill wall model and time period of earthquake response also show significantly decrease from frame without masonry infill wall. The effect of the different thickness gives the different stiffness of interface connection between frame and masonry infill wall, those condition indicates that the huge contribution of the stiffness on frame model and masonry infill wall model. The other indication of the addition thickness of mortar influence number of stiffness of interface, that was shown on the frequency and period of models on the Figure 4. However, the increasing thickness of the mortar interface unable increase frequency or decrease time period because the primarily function of thickness of mortar interface is force distribution and strengthen connection between frames and masonry infill walls.

Based on the Figure 5, on this study is the investigation on displacement of each model shows that masonry infill wall can reduce the displacement on beam-column joint. All the model conditions are also impact of the existing of masonry infill wall stiffness. These results show that masonry infill wall can strengthen the frame response, its contribution indirectly give impact on stiffness and displacement. The addition of thickness on mortar interface also bring influence in displacement value, however increasing thickness unable give more significantly influence. The important point considered on increasing thickness of mortar interface is its function to hold the stiffness between frame and its cost construction. Therefore, from above study results that the optimal thickness be recommended is around 0.5 cm to 1.5 cm thickness of mortar interface.
5. Conclusions
From the numerical study with computational software on the beam-column concrete model and the masonry infill wall gain the optimal conclusion as below:

1. Macro-modelling approach give simple method to simulate the masonry infill wall. The concept of modelling depends on material parametric provided and the number of elements. Macro modelling with computational software facilitate to create material, element and model. Moreover, the interface mortar is created by spring with elastic link.

2. The addition of masonry infill wall on the frame model show evidently previous research that increasing parameter of stiffness on the frame and masonry infill wall model. The contribution of stiffness parameter of mortar interface also gains the frequency response of frame structure. This condition indicates that the thickness of mortar interface able to improve of the structure stiffness between frames and masonry infill wall.

3. The maximum displacement response significantly reduces by addition masonry infill wall and this is also influenced by thickness of mortar interface. The thickness which recommended to use on masonry infill wall is around 0.5 cm to 1.5 cm.

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