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Research Article

Modelling of Mortarless Masonry As an Equivalent Strut Inside Reinforced Concrete Frames

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ABSTRACT

This study aimed to model mortarless masonry as an equivalent masonry strut inside RC frames. For this, determining the axial rigidity, width and thickness of equivalent strut is necessary. Many studies exist for determining these properties in literature and in seismic codes and by using the formulas proposed before, these properties of equivalent strut was obtained with the help of a detailed FEM analysis peroformed in a past study. Modelling of equivalent strut can be completed by using the maximum axial load capacity of the strut as proposed in a previous study. As a result for ¼ scaled frame the axial rigidity of equivalent strut was found as 11224,68N/mm.

KEYWORDS: *- Masonry, Flexible Joint, Stiff Joint, Damping.*

1. INTRODUCTION

Strong ground motions affect cities and cause catastrophic damage to buildings and people around the globe. To decrease the undesired harmful affects of strong earthquakes, finding economically feasible solutions for seismic retrofit of existing buildings and for designing new buildings is urgently necessary. In recent years mortarless masonry was proposed to act as a frictional damper inside RC (reinforced concrete) frames [1,2]. These mortarless blocks don't increase the stiffness of the frame at all when compared with traditional masonry infill walls, however in a previous study it's emphasized that during lateral loading of frames , mortarless blocks do act as an equivalent compressive strut during some stages of loading and this increases the frictional energy dissipation between blocks [2]. So modelling mortarless blocks as a weak diagonal strut and an increased equivalent viscous damping in a structure can be a simple and reasonable approximation to the natural situation of loading stages during earthquake loading.

Mortarless blocks can carry vertical loads after columns fail due to shear forces, and this must be taken into account for a detailed analysis as indicated in a previous study [3]. However mortarless walls can not be trusted always because their out of plane failure is expected under large lateral displacement of structures during earthquakes, so this affect was not taken into account in the scope of this study.

Traditionally , infill walls in RC frames has been modelled as an equivalent compressive strut and in some major seismic codes , this approach was adopted [4]. In a previous study a formula was proposed to obtain the axial rigidity of equivalent masonry strut inside a RC frame by using the initial stiffness of infilled frame , taken from a

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detailed FEM (finite element) analysis [4]. In this study same approach was adopted and FEM analysis results from a previous study of the author of this study was used [5].

2. METHOD

According to a previous study if the initial latearal stiffness of an infilled frame is known from a detailed FEM analysis, by equating the initial stiffness to the initial stiffness of a model with an equivalent masonry strut, many properties of the equivalent compressive strut can be obtained and for this a formula was proposed (equation 1) and in Figure 1, this situation can be observed [4].

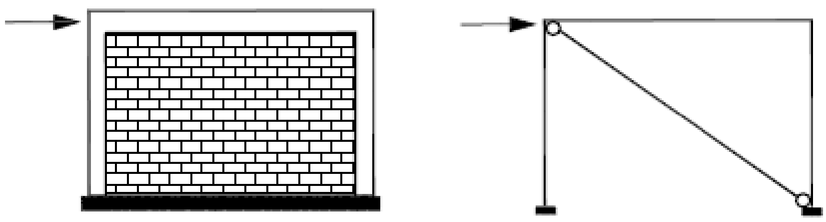

Figure 1: Actual frame under lateral loading and modelling as an equivalent masonry strut [4].

$$Di= \frac{k_d cos^2\theta}{1+\frac{k_d}{k_c}+sin^2\theta+0.25\frac{k_d}{k_b}cos^2\theta} + 24\frac{E_f\, I_c}{h'^3}(1-1{,}5(3\frac{I_b}{I_c}\frac{h\prime}{l\prime}+2)^{-1})\ [4] \qquad (1)$$

Here, Di is the initial stiffness, k_d, k_c, k_b are axial stiffness of diagonal, column, and beam respectively. h' and l' are the height and length of frame when the mid points of columns and beams were taken into account in the calculations. Also k_d, k_c, k_b can be considered according to the following approach:

$$k_d = \frac{E_d t w}{d},\ k_c = \frac{E_f A_c}{h\prime},\ k_b = \frac{E_f A_b}{l\prime}\quad [4] \qquad (2)$$

In equation 2, E_f indicates the modulus of elasticity of frame, A_c is the cross sectional area of the column, and A_b is the cross sectional area of beam. As far as it's seen, the ratio between the width and length of the diagonal must be obtained also for the analysis. For this in the same study an approach was proposed for obtaining the ratio between w/d as follows [4]:

$$\frac{w}{d}=k\frac{c}{z}\frac{1}{\Lambda^{ß}} \qquad (3)$$

In equation 3, Λ, k ,c,ß and z are coefficients related with modulus of elasticity of frame members and diagonal, vertical load rate, area of column cross section and height and length of frame and their relationships are written as follows [4]:

$$\Lambda=\frac{E_d t h\prime}{E_f\, A_c}(\frac{h\prime^2}{l\prime^2}+\frac{1}{4}\frac{A_c}{A_b}\frac{l\prime}{h\prime}) \qquad (4)$$

$$\varepsilon_v = \frac{F_v}{2A_c E_f} \qquad (5)$$

$$c= 0.249-0.116v +0.567v^2 \qquad (6)$$

$$ß=0.146+0.0073v+0126v^2 \qquad (7)$$

$$z=1+0.25(l/h-1) \quad (8)$$

$$k=1+(18\ \Lambda+200)\ \varepsilon_v \quad (9)$$

To use the proposed relationships in equations 1-2-3, we obviously need the real or realastic behavior of infilled frame with mortarless masonry. In a previous study of the author of this study , a FEM analysis was performed to the frame under vertical and horizontal loading, by using the Abaqus software. In the analysis, a frame with 40x40 cm sized column-beams was designed according to Turkish earthquake code 2007. It was 3m high and 4m wide. It was designed under lateral and vertical loads to columns. The frame was scaled by ¼ ratio and 12x12cm sized frame with 0,75m height and 1m width was obtained (The RC design was checked again for new size). In the analysis the frame was laterally pushed up to 20 mm displacement (%2 lateral drift). After the analysis, the initial stiffness of the frame with mortarless masonry was determined as 34163,66 N/mm. The details of frame and the obtained lateral load-lateral displacement graph is seen in Figure 2 and Figure 3, and also additional shear reinforcement was added to the frame under the rules of TSC 2007 [5].

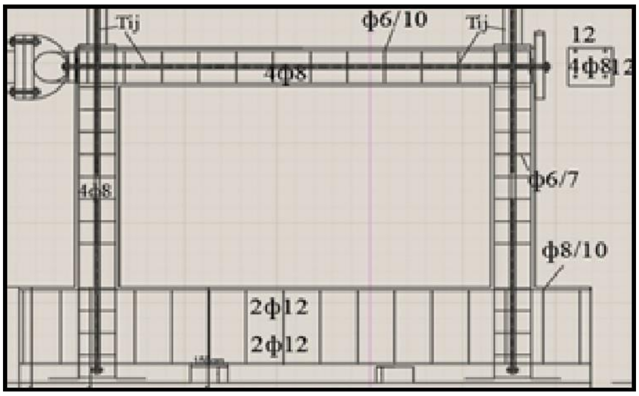

Figure 2. The details of frame used in a past study [5]

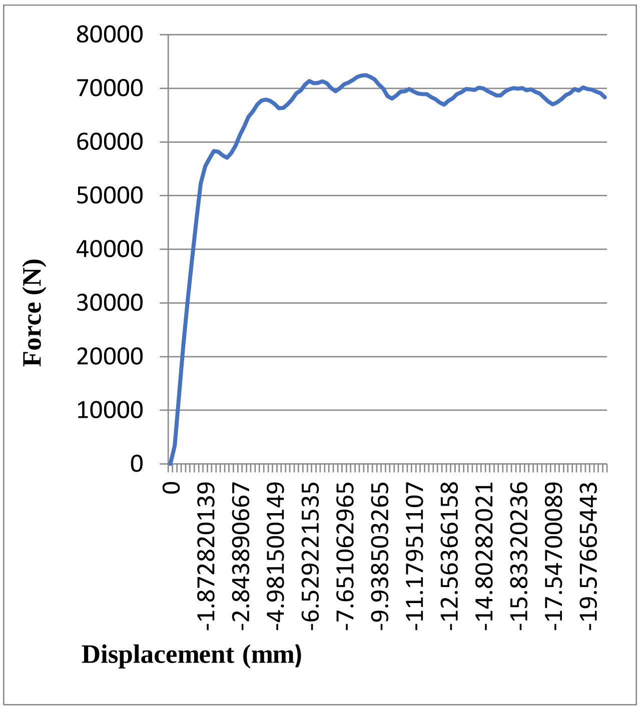

Figure 3. The Lateral load-lateral displacement of RC framewith mortarless masonry infill in a past study [5]

Λ, k ,c and z are coefficients were calculated as: 0.648, 1.03,0.258,1.14 and w/d ratio was calculated as 0.25 by following the method explained in the past paragraphs. In equations 1000mm bay width and 750 mm height (including beam height) of the frame were used. According to equation 1, the k_d parameter was obtained as : 16753,26N/mm. After the algebra performed in equation 1, it derived:

$$\frac{k_d x 0,67}{1+5x10^{-7}k_d+4,20x10^{-7}k_d}=11224,68 \qquad (10)$$

In equation 4 , the k_d parameter is: 16753,26N/mm. By substituting this value in equation 2, w and E_d is founded as: 305,16mm and 558,44N/mm^2. In the Abaqus analysis, the frame was pushed 20 mm laterally so, the equivalent strut must shorten to 1204,32 according to the geometrical relationships of the frame size. In this situation we can calculate the force,N, in the equivalent strut as follows:

$$N= k_d x \Delta L = 16753,26x\ 16,67= 279276.84N=279,27KN \qquad (11)$$

In a previous study, modelling of equivalent infill wall compressive strut was performed, and equivalent compressive strut method was compared with detailed FEM modelling of the infill wall. In the study the force-displacement relationship of the equivalent strut was proposed as Figure 4 and the force value was obtained by using the stress-stress relationships taken from detailed FEM modelling of the infill wall [6].

Figure 4: The mechanical properties of equivalent compressive strut as proposed in a previous study [6]

So here, N value can be used as the Nmax as described in Figure 4. It's clear that Nmax value is higher than this value if the stress analysis of the frame from the previous study [5] was considered, however %2 lateral drift value is an expected limit value in most of vulnerable RC frames with insufficient concrete compressive strength, poor detailing of steel rebars etc..

The compressive strut in structures do change the period and ductility of structures. We can assume mortarless masonry has no detrimental effect to the ductility of RC frames as indicated in a past study [2].

Of course the results calculated in this study must be amplificated, because the values were found by using the frame analysis in the past study in which the frame size was scaled by ¼ ratio.

3. CONCLUSION

In this study an attempt was made to obtain the axial rigidity of the equivalent masonry strut in a RC frame. Because mortarless masonry can be modelled as an equivalent masonry strut and a higher equivalent viscous damping as a simple approach. If the mechanical properties of the equivalent strut is known, later the whole structure's period , frequency can be obtained for the situation with mortarless masonry infill. In a linear analysis , this values can be used. In nonlinear static and nonlinear dynamic analysis of structures, a more detailed masonry strut behaviour must be obtained to reflect the real phenomena to consider damping effects and the effect of wall for helping to carry vertical loads after columns fail in shear. If the out of plane failure of walls are prevented, the loads consume more frictional energy in that situation. In this study, the effect of wall is considered by using %2 lateral load situation in the frame only.

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