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PAPER TITLE	**Numerical Model of Reinforced-Concrete Moment Resisting Frames and Effect of Masonry Infill walls in Progressive Deterioration**		
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ABSTRACT:

Structural collapse under the sudden failure of structural member is a curtail issue in concrete structures. However, non-structural members such as masonry infill wall reduces the progressive deterioration caused by column failure. Masonry infill-wall influences the degree of damage due to crack propagation, frame displacement, and adjacent beams rotation in reinforced concrete (RC) structural analysis. The aim of this research is to analyze the effect of masonry infill wall to assess the failure pattern of the adjacent concrete columns in RC moment resisting frames. This numerical analysis measured and compared the behavior of the five RC frame models with masonry infill wall subjected to the progressive failure. The crack propagation behavior, ultimate strength, displacement, failure mechanism, rebar load capacity, beam rotation after collapsing the adjacent column were investigated. The results indicated masonry infill walls transferred the applied load within other structural members. Masonry infill walls played substantial role in decreasing the vertical displacement of RC frames when progressive deterioration occurred. Therefore, RC frames ultimate strength was enhanced and failure mechanism was postponed. However, the RC frames flexibility reduced and brittle failure happened. The findings showed masonry wall location is an important contributor to reduce the displacement and degree of flexibility of the RC structures. Consequently, the impact of masonry infill walls was more effective in the second floor and some of first floor beams.

Modelling Reinforced-Concrete Moment Resisting Frames and Effect of Masonry Infill Walls in Progressive Deterioration

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ABSTRACT

Structural collapse under the sudden failure of structural member is a curtail issue in concrete structures. However, non-structural members such as masonry infill wall reduces the progressive deterioration caused by column failure. Masonry infill-wall influences the degree of damage due to crack propagation, frame displacement, and adjacent beams rotation in reinforced concrete (RC) structural analysis. The aim of this research is to analyze the effect of masonry infill wall to assess the failure pattern of the adjacent concrete columns in RC moment resisting frames. This numerical analysis measured and compared the behavior of the five RC frame models with masonry infill wall subjected to the progressive failure. The crack propagation behavior, ultimate strength, displacement, failure mechanism, rebar load capacity, beam rotation after collapsing the adjacent column were investigated. The results indicated masonry infill walls transferred the applied load within other structural members. Masonry infill walls played substantial role in decreasing the vertical displacement of RC frames when progressive deterioration occurred. Therefore, RC frames ultimate strength was enhanced and failure mechanism was postponed. However, the RC frames flexibility reduced and brittle failure happened. The findings showed masonry wall location is an important contributor to reduce the displacement and degree of flexibility of the RC structures. Consequently, the impact of masonry infill walls was more effective in the second floor and some of first floor beams.

1 INTRODUCTION

Infill masonry walls are considered as non-structural element or partition (M.H. Tsai & T.C. Huang 2010). However, the effectiveness of infill masonry walls in hazardous seismic zones is important when the RC structure is subjected to the lateral loads (Akin LA. 2006). Progressive failure is the main reason of common collapse in reinforced concrete structures. After failure of a structural member such as column, progressive failure begin developing until the collapse of the structure (B.R. Ellingwood & E.V. Leyendecker 1978). The main structural members that play important role in transferring loads are columns. Therefore, the failure of RC columns are crucial issue to be investigated (A. Cachado et al. 2011). Infill masonry walls introduced as an alternative path for crack development and postponement of the RC progressive failure. Furthermore, the infill masonry walls increased the safety with transforming structural member's sudden failure to expected failure mode (S. Farazman, B.A. Izzuddin &D. Cormie 2013). Additionally, Infill masonry walls improved the behavior of RC structures subjected to the lateral loads. The RC structural failure is due to brittleness of cement. However, infill masonry walls mechanism allowed the structure to continue its life service while soft-story mechanism begun. Additionally, it increased the stiffness of the RC structures (G. Mondal, S. & Tesfamariam 2013).

2 ANALYSIS OF MASONRY INFILL WALLS IN RC FRAMES

Three dimensional models are widely used to determine the 3D effect in reinforced concrete structures. When the effect of the 3D models are not taken into account, the results of the two-dimensional models is conservative (Maheri Ṃahmoud R & Pourfallah S. 2012). However, due to the fact that the behaviour of the progressive failures is mainly due to the response of the frame, the 2D dimensional model has satisfactory accuracy. The analysis also reflects the effect of masonry infill walls to postpone the progressive failure and increase the ultimate RC frame capacity. Therefore, the 2D method analysis was applied in this numerical analysis.

3 REINFORCED CONCRETE FRAMES ANALYSIS

The results of numerical analysis for five reinforced-concrete frames with masonry infill walls indicated the variation in strength, displacement, strain, crack development, and rebar failure. The findings demonstrated that the progressive failure for all models were categorized into three main stages including initial stage, compression stage, and chain changes stage. The main contributor in postponing progressive failure is the rebar in the beam compression zone which is related to strain transformation from compression to tension region.

It is important that the beam deformation begun as deflection was increasing during these stages. The displacements of the adjacent columns toward the moving direction (horizontal displacement of 0 mm). In the Figure 1-4, the displacement of all four frames was compared with control frame (Bare Frame). “M” is acronym for each frame model and the number presents 1-4 different frame model (M1-M4). M4 has the greatest resistance force of 140 Kn with the smallest vertical deflection of approximately 20 mm (Figure 1).

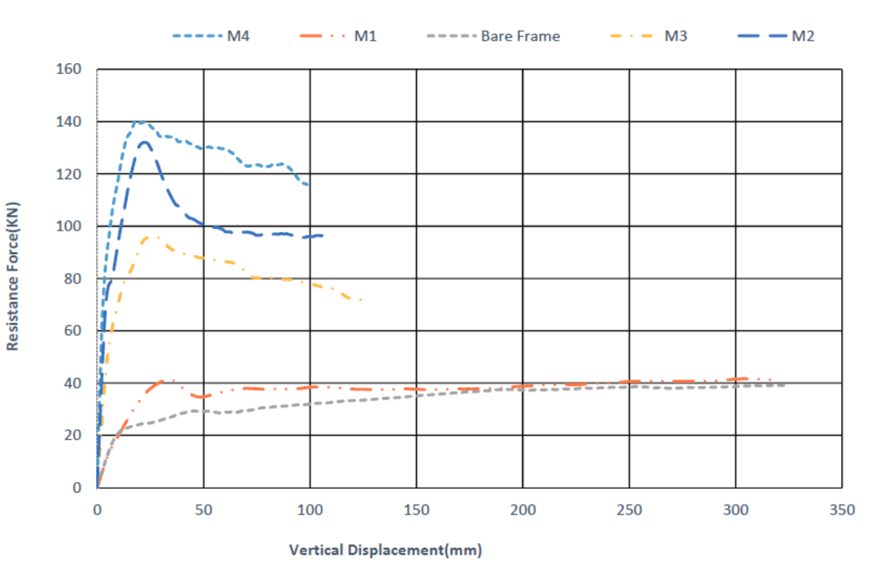

Figure 1.Vertical displacement (mm) verses resistance force (Kn)

4 REINFORCED CONCRETE FRAME M1 ANALYSIS

Figure 1 shows the vertical displacement force for central concrete column without masonry infill wall which was called bare frame. Resistant force at the compression stage of 109.8 mm in vertical displacement reached to the maximum of 32.29 Kn. Then, it gradually increased to 39.24 (up to a displacement of 325.41 mm) at the end of the compression stage. At this stage, the development of maximum deflection was revealed in the damaged structure and the resistance strength was increased again in the maximum deflection until the end of the test. However, in some stage, this force slightly reduced due to the breakdown of the meshes. The vertical displacement for frame M1 reached to 325.41 mm.

Figure 2 shows the vertical displacement under the central concrete column. The failure of central column and impacted areas in the adjacent beams is shown in the Bare Frame (without infill walls). The displacement along central column increased until the yield of structural column was occurred. Consequently, the connected beams were affected with high displacement in the column-beam connection.

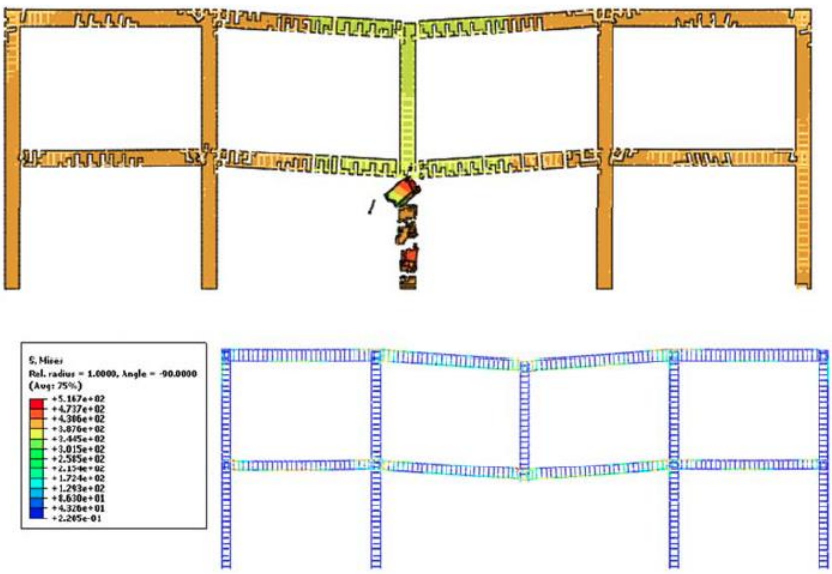

Figure 2. Crack development and failure pattern for bare model

4.1 BARE MODEL ANALYSIS

The numerical analysis indicated the vertical displacement is 37.5-53.29 mm because of crack propagation within the masonry infill wall in the reinforced concrete frame which caused notable reduction in the resistance force. After this stage of failure, the resistance force increased again in the model and remained constant until the ultimate load was applied. The maximum resistance force reached to 37.52 mm at the vertical displacement of 41.31 mm.

When the resistance force was reduced, the displacement simultaneously had a slight increase due to deflection of the beam at the 41.65 kN ultimate load. However, the displacement data was fluctuated during applying the load at this stage especially where the deflection was maximum. This reduction may occurs due to rebar failure. The test was completed when the vertical displacement reached to 316.4 mm.

Figure 3 indicates the vertical displacement and the failure of the concrete frame in M1(infill walls in the adjacent spans). The rebar stress reached to more than yielding stress. The major difference between the non-masonry models is that the concrete frames in both side remained horizontally. Additionally the maximum tension in the model meshes with the masonry infill wall was 488 MPa, while the tension in the model without masonry walls was close to the ultimate stress of 516 MPa. Furthermore, the amount of resistance force at the beginning of the failure mode in this model with the masonry infill wall is 58% higher than the non-masonry infill wall model.

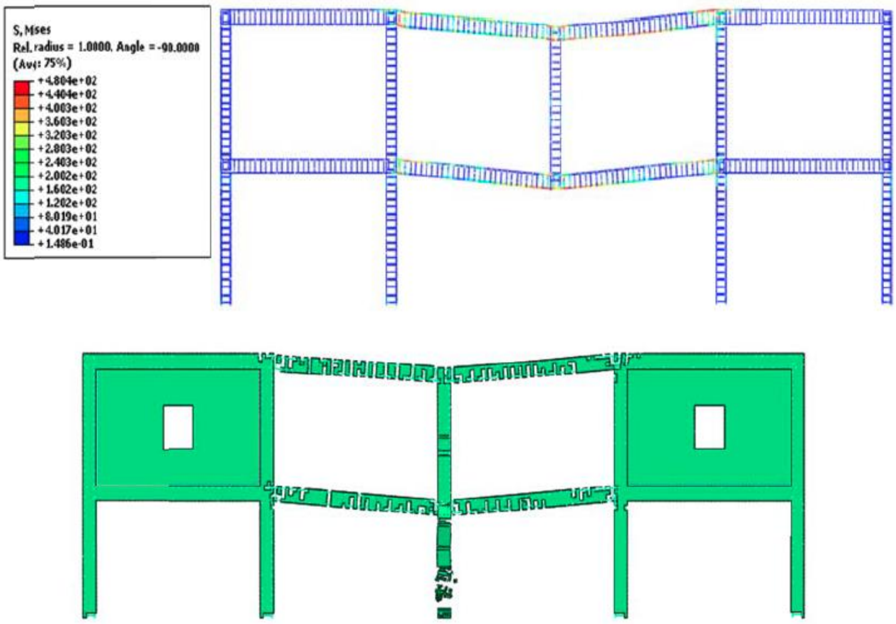

Figure 3. Crack development and failure pattern for M1 model (infill walls in the adjacent spans)

4.2 MODEL 2 ANALYSIS

The second model had infill walls in the same span as the central column was located. In M2 model, the resistance force against displacement of central column with masonry infill wall is given in Figure 4. The vertical displacement of the central column reached to 29.45 mm and vertical load reached to 95.3 Kn.. Immediately, after failure of the central concrete column, the cracks were developed in the masonry infill wall. Concurrently, the members of the concrete beam were cracked with dropping in the force resistance. In this model, no resistance increase occurred after the failure of the concrete beams.

In Figure 4, the crack propagation increased by the factor of 1.5 in the adjacent masonry infill walls. Despite the relatively high strength of the M2 model compare to M1 model it showed a 25% decrease in resistance at ultimate applied load. In this model, the concrete frame collapsed after failure of masonry infill wall because of the vertical displacement in the middle of the beam. After failure of masonry infill walls, cracks due to tension stress exceeded the maximum allowable stress in the rebar in beam-to-column connection. In this scenario, the theoretical plastic hinge was created.

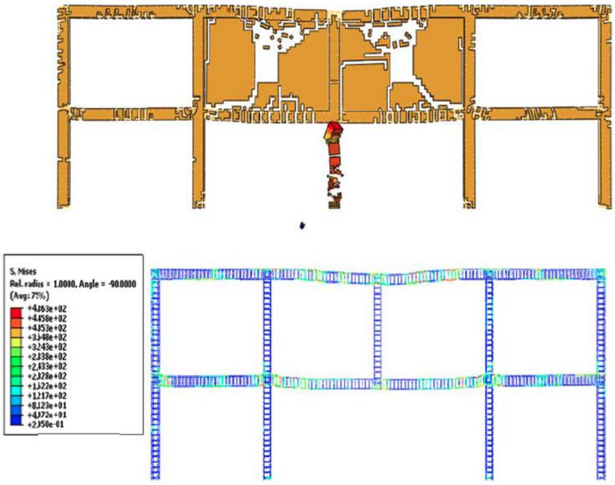

Figure 4. Crack development and failure pattern for M2 model

4.3 MODEL 3 ANALYSIS

The vertical displaced force for a frame with masonry infill wall (M3) with four masonry infill walls on the second floor is also shown in Figure. 1. The vertical displacement of the central column is 24.45 mm, the maximum load that the concrete frame carried is 130 kN. Soon after the central column was failed, the cracks were rapidly developed in the masonry infill walls, adjacent walls, and the concrete members. Upon removal of central column, the resistance force considerably decreased.

In M3 model, resistance force reduction was severe compared to other models. The reduction was estimated approximately 26%.When the concrete frame had 50 mm displacement, gradually resistance decreased. In this model, the beams and side columns on the second floor remained safe without any major damage, but the beam in the first floor collapsed. As can be seen in Figure 5, the cracks diagonally developed in middle of the wall.

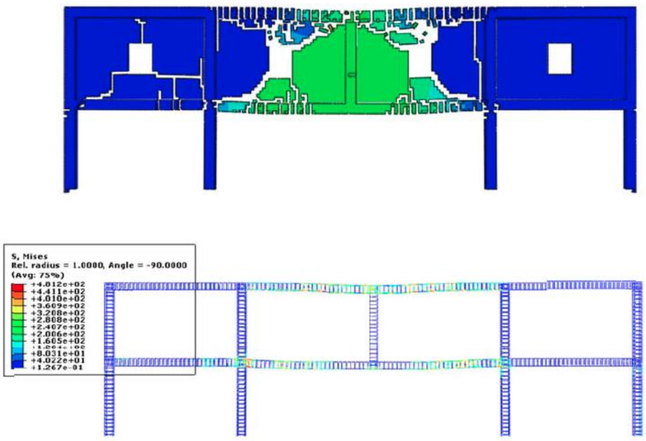

Figure 5. Crack development and failure pattern for M3 model

4.4 MODEL 4 ANALYSIS

The vertical displaced force for a frame with masonry infill wall (M4) with four masonry infill walls on the second and two infill walls in the floor is shown in Figure 7. The vertical displacement of the central column is 23.45 mm, and the maximum load that the concrete frame carried is 139 kN. Soon after the central column was failed, the cracks were rapidly developed in the masonry infill walls, adjacent walls, and the other concrete members. Upon failure of central column, the resistance force considerably decreased.

M4 model compared to Model 3 had less reduction in resistance force. When the concrete frame had 50 mm displacement, frame resistance remained constant. Then, it gradually decreased. In this model, the beams and side columns on the second floor remained safe without any major damage, but the beam in the first floor collapsed.

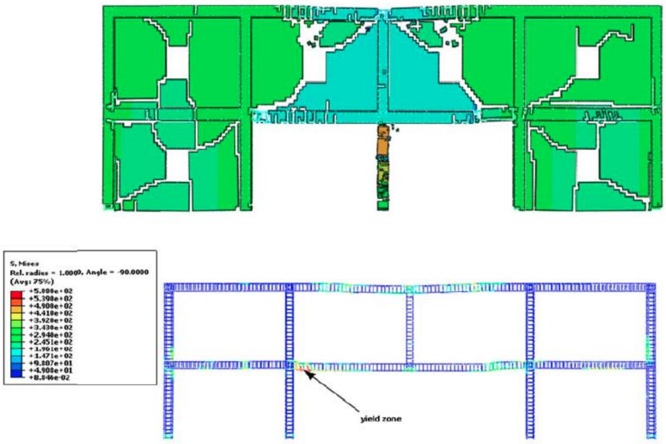

Figure 6. Crack development and failure pattern for M4 model

5 RESULTS OF ANALYZING DISPLACEMENT AND VERTICAL ROTATION

Figure 7 shows the vertical displacement graph verses rotation of the beam. The behaviour of the concrete frame without masonry infill wall is slightly different than the concrete frames with masonry infill walls in the side spans. However, in models M2, M3, and M4, there is significantly different in vertical displacement and beam rotation angle. In M2 and M3, the rotation angel was small. Therefore, these model revealed greater force resistance. Additionally, the correlation between vertical displacement and rotation angle in M2 and M3 was nonlinear while in M4 this correlation was linear.

The vertical displaced force for a frame with masonry infill wall (M4) with four masonry infill walls on the first and second floor is also shown in Figure 7. The vertical displacement of the central column is 23.45 mm, the maximum load that the concrete frame carried is 139 kN. Soon after the central column was failed, the cracks were rapidly developed in the masonry infill walls, adjacent walls, and the concrete members also cracked. Upon failure of central column, the resistance force considerably decreased.

M4 model compared to Model 3 had less reduction in resistance force. When the concrete frame had 50 mm displacement, frame resistance remained constant. Then, it gradually decreased. In this model beams and side columns on the second floor remained safe without any major damage, but the beam in the first floor collapsed.

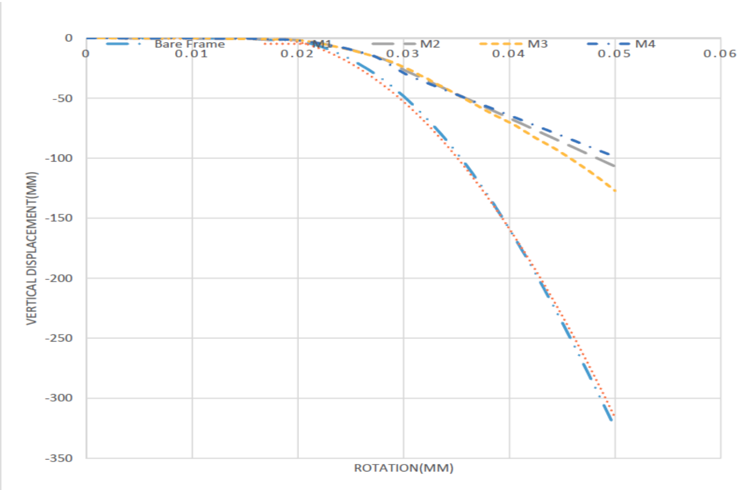

Figure 7.The beam rotation (mm) verses vertical displacement (mm)

According to the data presented in Figure 7, when the vertical displacement increases in the initial stage and compression stage simultaneously with the development of the cracks width in beam-to-column connection with the limited damage in the concrete. The full involvement of the rebar's in the bearing and re-loading of the load. The virtual plastic hinge was created into columns in the vicinity of the beam connection to the column and reach to the rupture during constant applying the load. The displacement of 12.7 mm was produced with crack penetration in the tensile region of the concrete members. This phenomena continued to shift to 57.14 mm with a low gradient relatively before extensive cracking. The displacement of 57.14 millimetres was practically transferred to tensile rebar.

6 SUMMARY AND RECOMMENDATION FOR FUTURE RESEARCH

In this numerical research, the behavior of reinforced concrete frames with masonry infill walls subjected to progressive failure were assessed and compared. The behavior of concrete crack propagation after collapsing central column was simulated and analyzed. Then the system of forces, vertical displacement, and rotation were investigated after column removal. The correlation between vertical displacement and rotation angle in M2 and M3 was nonlinear while in M4 this correlation was linear. M4 model compared to Model 3 had less reduction in resistance force. This fining indicated the importance of infill walls in the RC resisting frame and postpone the progressive failure.

The results of the computational analysis indicated that loads were transferred from the beams. The masonry infill walls decreased the deformation of reinforced concrete frames under lateral loads and change failure mechanism. However, the masonry infill walls had considerable contribution in postponing progressive failure as well as improving the reinforced concrete strength behavior in sudden failure.

7 RECOMMENDATION FOR FUTURE RESEARCH

Further experimental and numerical research is required to investigate all aspects of the masonry infill wall effect on the reinforced concrete frames. It is recommended that this computational research is conducted with increasing the number of floors with more beam spans. Investigation of masonry infill walls stiffness is one of the key components in the reinforced concrete structures behavior. Additionally, the effect of compression and tensile strength in the concrete during progressive failure should be taken into consideration.

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