Effect of Infilled Frame on Seismic Performance of Concrete Moment-Resisting Frame Buildings

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Abstract

The infilled frame in the construction industry is divided into two types of structural and non-structural ones. Masonry infilled frames are used because of the architecture performance or the structural performance. Building frames in the peripheral and intermediates sections of the building are filled with masonry walls as a separator or sound and thermal insulation, which causes the difference in the behavior of these frames with the empty frames. This type of walls is called the infilled frame and the mechanism consists of a frame and infilled frame is called an infilled reinforced frame. Infilled frames, especially in the event of moderate and severe earthquakes, collide with their environment frame, and the interaction created between them changes the behavior of the concrete frame. In this study, using the ABAQUS software, an analytical study was carried out on the effect of masonry infilled frame and its impact on the seismic behavior of reinforced concrete frames with moderate height. After modeling the 4-story building frame and defining the plastic range for its materials, the structure under the dynamic load of the earthquake is mapped with accelerometer and horizontal and vertical load of earthquakes. According to the results, the structure energy has increased significantly after applying the infilled frame effect, which is due to the increasing the stiffness of the frame and the absorption of more force from the earthquake. Also, the final strain in the middle of the wall is due to an increase in the displacement of the structure with increasing the height, and the other reason is due to the lower wall stiffness in a vertical direction along it.

Keywords: The Effect of Infilled Frames, Concrete Building, Moment-Resisting Frame, Building

I. Introduction

The infilled frame in the structure covers completely or a part of a structural frame, and if it is far from the frame so that the movement of the structure can be done freely, one can ignore the presence of the infilled frames [1]; but it is not possible in the implementation of structure because the infilled frame must have a sufficient resistance to the loads in its perpendicular length, and therefore it should be perfect fitted with the frame of the structure, which is called the shear infilled frame. In the seismic design, the weight of the materials used in the structure and the

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architectural components is considered and increasing the weight of structure can greatly increase the force of the earthquake to the structure [II,III,IV]. The masonry infilled frames considering the high weight, as well as the lack of loading and the effectiveness in the structure, are not considered due to the increase in the computational time [V]; but ignoring the effect of the infilled frames on the structure, does not always provide a good safety margin; since the considerable increase of stiffness due to the presence of the infilled frames, the center of the stiffness of a floor in building can be found far from the center of mass [VI,VII,VIII], and the building encounters the destructive twists during the design of the symmetry, regardless of the effects of the twist. The use of an infilled frame in several openings and the absence of the other openings increase the stiffness of the infilled frame than the empty frame and absorbs more force from the earthquake, which results in the crushing of the concrete column at the junction [IX,X,XI].

II. Literature review

Girassa and Karrer (1989), tested 28 composite steel frame samples in order to study the effect of different factors such as the harness the infilled frame to the pillar, the strength of the mortar, the friction between the infilled frame and the frame, the distance between the beam of the ceiling and the infilled frame, the presence of opening inside the infilled frame and the rigidity and articulation of the frame. According to results of these tests, it was found that filling the crack between the frame and the infilled frame near the pillar, although increases the initial stiffness of the composite frame, but does not have much effect on the final load capacity. The existence of an empty space between the upper beam and the infilled frame strongly reduces the final strength of the composite frame. Regarding the location and effect of the openings, it was also observed that the placement of openings in a place that causes discontinuity in the formation of equivalent diameter diaphragm reduces the loading capacity of the composite frame. Therefore, the best location for openings is the center of the frame [XII].

Sabayeh and Abdin (1988), analyzed the concrete composite frame in numerical method, and examined the effect of factors such as the height of the structure, the type of infilled frame materials, the infilled frame geometric ratio of the infilled frame. They observed that increasing the height-to-frame ratio would increase the effort created in the pillars [XIII].

Moghaddam and Dowling (1989), performed experiments on 10 mm metal composite frames between the frame and infilled frame pillars, and observed that the stiffness of the combined frame was reduced by 40%. In other samples, they only provided a 3 mm distance in the uploaded corner (among the infilled frame, the beam and the pillar), which reduced the stiffness to 44% and decreased very little (about 10%) the diameter crack resistance [XIV].

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Al-Haddad (1991), presented a program for analyzing the composite frames based on the finite element method and failure mechanics. In his program, he considered factors such as the size and position of the crack, the relative difficulty of the frame and infilled frame, the geometry of the frame, and the length of its contact with the infilled frame. Analyzing the different composite frames with this method, it was concluded that the amount of tensile and compressive stresses in the infilled frame is affected by the crack size, the length of the frame contact with the infilled frame and the relative stiffness of the frame [XVI].

Mai and Naji (1991), developed a nonlinear finite element analysis program in 1991 to simulate steel frames or concrete frames under uniform and cyclic loading. In this program, the effect of parameters such as surrender and infilled frame crushing are considered. According to analyzes conducted for multi-storey composite frames, it was found that the results of this program and the results from the tests show good agreement with each other [XVII].

Pauli and Priestley (1992), suggested that in the analysis of composite frames, the infilled frames can be considered as the diagonal bracing elements of two joints. They also suggested that in order to calculate the stiffness of the composite frame in this way, it can be considered the effective width constraint equal to one quarter of the wall diameter [XVIII].

Zernik (1997), presented two mathematical models to simulate the non-passive response of composite frames under static loading and dynamic loading. In the first model, the base shear force variation is considered in the form of a three-line curve against the change of the entire frame, and the final loading capacity of the composite frame under static loading is calculated by the analysis relations. In the second model, the frame elements were also modeled as moment-resisting springs and the masonry frame elements as a coupling compression transitional spring in the DRAIN-2D program in order to perform nonlinear dynamic analysis of composite frames [XIX].

Sanei Nejad and Hobbes (1995), proposed a method for analysis of steel composite frames under in-line forces based on the equivalent diagonal method, the results of previous experiments and the results of nonlinear finite element analysis. In this method, the stiffness and strength values are estimated with considering both the elastic behavior of composite frames. In this method, it is easy to calculate the diagonal area after determining the final loading capacity of the composite frame [XX].
III. Materials and Methods

Model Details without the Infilled Frame Concrete specification used: there are three methods in the ABAQUS software for the modeling of brittle materials such as concrete (10). 1) Continuous cracking method (smeared crack model); 2) Damaged concrete plastics method (Concrete plaster failure model); 3) Cracking method (brittle cracking model).

A smeared crack is used for researches in which there is a uniform strain and points of material show the tensile crack or crushing. The strain of plastic is controlled at a pressure with a pressure drop plate. In this case, it is assumed that cracking is the dominant aspect of the behavior and the emergence of cracking and non-uniformity is considered after cracking. This method can be used to model non-reinforced concrete, but its main application is the analysis of reinforced concrete structures.

The plastic damage model of concrete is based on the isotropic damage and is suitable for concrete applications with desired loading conditions, including cyclic loading. This model reduces the elastic stiffness caused by the strain of plastic for both strain and pressure states. It also includes the effects of stiffness improvement under the cyclical loading (This method has been used in concrete modeling).

Finally, a third method is used for the researches in which concrete behavior is controlled by tensile cracking and its compression drop is not important. In this method, assuming that the material under the compression is sufficiently linearly elastic, acts very precisely where the brittle behavior prevails. This model is used for reinforced concrete, although it is also suitable for the analysis of reinforced concrete structures. In this way, when the material cracks, the cracked elements are removed from the analysis path.

At the compression, the concrete shows the linear elasticity behavior before the initial submission stress. Then, with a strain, it passes through the plastic region, followed by strain softness until the final compression strain. It is supposed that the beginning surrender occurs when the stress of the concrete reaches 60% of the final stress. In stretching, elastic behavior is linear as long as cracking does not begin. Since the walls are flat concrete element, meshing sensitivity is one of the main concerns of analysis. The crack width responds to the stress-strain relation [XXI].

Steel Profile
The steel used for the rebar 14, 16, 18, 20 and 10 used in the beam and pillar is according to the table.

Table 1. Specifications used for steel in the Property module

| Yield | Plastic Strain | E       | V  | Density       |
|-------|----------------|---------|----|---------------|
| 280   | 0              |         |    |               |
| 370   | 0.09           | 2.05E+11| 0.3| 7.85E-6       |
Montage of Structural Components
After defining the specifications of the materials and assigning them to the sections, they are placed in the Assembly module.

Define Interaction Between Montaged Elements
The constraint defined for the interaction of concrete and rebar is of the type “embedded region” of the buried area in concrete. The constraint type “Tie” is used to connect the beam to the pillar as well as the pillar to the column.

Define The Analysis Step
The Bam city earthquake seismometer is used for analysis, which results in 57 seconds of analysis. Explicit analyzer has been used for analysis. The outputs used in this discussion are the displacement diagram, time force diagram, structural energy diagram, as well as the plastic strain diagram and elastic strain components diagram have been defined for discussion in the Step module.

Loading On The Structure
To perform a history analysis, it is needed a horizontal and vertical map seismometer, which near or far orbit earthquake is used based on the type of research. Horizontal and vertical seismometer should be scaled for the near orbit earthquake. Here 2800 standard is used to scale up.
After extracting the seismometer, enter the values in the CMS software and find the pga (peak point) of the seismometer and divide the number one that number, which a coefficient is obtained. Insert this coefficient again in the CMS and multiply it in all seismometer acceleration values. It should be noted that the horizontal and vertical seismometer must be calculated separately. the Amplitude definition has been used for the dynamic load of earthquake.

Applying Weight Load To the Structure
Determining the entire structure and applying the acceleration of gravity to the material, we define the load of weight.

Apply the load of walls and floor to the beams
The dead load of the structure floor is 680 kg / m² and the existing load is 200 kg / m². Calculating the load of the beam from the floor, as well as considering the weight of the wall on the beam, the load of beams is as follows:
Providing The Support Conditions
Movement support should be used to apply an earthquake to the structure.

Wall specification in The Model with an Infilled Frame
The type of collision of the wall elements is considered as contact type. The frictional characteristics (vertical behavior) between the wall materials are presented in the following table.

Table 2. Specification of wall materials

| Density | E | v | friction Angle | flow stress | dilation angle |
|---------|---|---|----------------|-------------|---------------|
| 2.00e-6 | 10000 | 0.2 | 31.79 | 0.8 | 2.86 |

Model with Opening
Specifications for openings in the model are as follows:

Table 3. The dimensions of the walls and their opening

| floor | Opening percentage | dimensions of the wall | dimensions of the opening |
|-------|---------------------|------------------------|--------------------------|
| fifth | 25                  | 2.66*3.75              | 1.5*1.5                  |
|       |                     | 2.66*4.4               | 3*1.5                    |
|       |                     | 2.66*4.8               | 4*1.7                    |
IV. Results and Discussion

Outlet of The Structure with The Infilled Frame

Figure 2. shows the total energy of the structure during the earthquake.

![Fig 2. Structural total energy diagram](image)

Figure 3 shows the strain energy of the entire structure. Given that the wall of the wall strain is a part of the structure, and its stiffness affects the force applied to the structure and increases the force, an increase in the amount of energy in lower strains has occurred.

![Fig 3. diagram (strain energy)](image)
Figure 4 shows the plastic strain in the beam (11), the maximum value of that equals 2.5. Rising stiffness caused less capacity than a wall-mounted model.

![Plastic strain diagram of the beam (11) (infilled frame)](image1)

The maximum strain of plastic for the beam 12 is equal to 8. (As shown in fig. 5).

![Plastic strain diagram of the beam (12) (infilled frame)](image2)

The maximum strain of plastic for the beam (13) is equal to 8. The maximum plastic strain value for the beam (21) is equal to 2.5.

![Plastic strain diagram of the beam (21) (infilled frame)](image3)
The maximum plastic strain value for the beam (22) is equal to 8. The maximum plastic strain value for the beam (23) is equal to 8. The maximum plastic strain value for the beam (31) is equal to 2.5. The maximum plastic strain value for the beam (32) is equal to 8. The maximum plastic strain value for the beam (33) is equal to 8. The maximum plastic strain value for the beam (41) is equal to 6. The maximum plastic strain value for the beam (42) is equal to 2. The maximum plastic strain value for the beam (43) is equal to 2.

Fig 7. Plastic strain diagram of the beam (43) (infilled frame)

The Outlet of the Structure with in filled Frame and Opening in the Filled Frame
In the model with the opening, in filled frame has less effect on the structure strength. First, it increases the stiffness and then the effect is gone, (Fig. 8).

Fig 8. The diagram of internal energy for the entire structure
In this model, the plastic deformation diagram of three beams is shown as a sample, which itself represents the difference in structure strength after the opening. In the third crater, openings with an area of 55% of the wall were created, in which the plastic deformation of a beam pattern is shown in figure 9.
In the second crater, openings with an area of 40% were created that the deformation of a beam sample is according with the figure 10.

In the third crater, openings with an area of 25% were created that the deformation of a beam sample is according with the figure 11.
(In this crater, the opening with the area of 25% wall has been created) The stress created in the infilled frame with the opening is according to the figure 12.

Fig 12. The stress created in the model with opening

**Plastic deformation created in the walls with opening**

To investigate the performance of walls with opening, their strain is investigated. In wall number 3, due to the large area of openings, the wall without a high resistance has been destroyed, and the remainder in the continuation of the earthquake may cause a short pillar. This strain is shown in figure 13.

Fig 13. Wall elastic strain

Wall No. 4 has a better performance with a standard opening percentage (figure 14).
The section (a) has an opening of 25% in the figure (15) and the section (b) has an opening of 55% in the figure (16).
In the figure, the wall participation was diminished with increasing the height, and the wall was not involved in lateral loading due to its low stiffness (due to the presence of openings) (Fig 16).

V. Conclusion

Comparing the entire energy diagrams, it is observed that the structure's energy has greatly increased after the effect of infilled frame, due to increasing the stiffness of the frame and the absorption of more force from the earthquake. Despite the increase in the force exerted by the earthquake, it is observed a better performance of the structure. Due to the increase in force on the structure, elements of the structure are expected to undergo a more critical deformation than the non-infilled frame position. But in the comparison case of beams’ strain, it is observed that instead of large deformations, much capacity is used to squeeze the force due to the better distribution of the mid-section of beams.

Before the presence of infilled framed, the stress and final deformation occurred only in the support and the remained capacity of the component length was not used, but in the latter case, the stress and strain ratio increased over components and decreased in the connection section that was extremely critical.
The ultimate strain in the middle of the wall due to an increase in the displacement of the structure with increasing height, and the other reason is the low wall stiffness in perpendicular along to its length. It seems that with the establishment of appropriate constraints to increase this resistance, it can be used the stiffness capacity of the infilled frame in higher floors.

References

I. Al-Chaar, G. Evaluating Strength and Stiffness of Unreinforced Masonry Infill Structures. U.S. Army Corps of Engineers, under project 622784AT41, 2002.

II. Asteris P.G, "Lateral stiffness of brick masonry infilled plane frames." J. of Struct. Eng., 129(8), 1071-1079, 2003.

III. Bazan, E., & Meli, R.. Seismic Analysis of Structures With Masonry Walls. In Proc., 7th World Conf. on Earthquake Engineering (Vol. 5, pp. 633-640). Tokyo: International Association of Earthquake Engineering (IAEE), 1980.

IV. Buonopane.S. G.and White R. N, "Pseudo-dynamic testing of masonry infilled reinforced concrete frame." J. of Struct. Eng., 125(6), 578-589, 1999.

V. El-Dakhakhni W. W. Three-Strut Model For Concrete Masonry-Infilled Steel Frames. J. of Struct. Eng., 129(2), 177-185, 2003.

VI. Giordano, A., Mele, E. and Luca, A.,"Modeling of historical masonry structures comparison of different approaches through a case study", Engineering Structures., Vol. 24, pp. 1057-1069, 2002.

VII. Holmes, M. Steel Frames with Brickwork and Concrete Infilling. In ICE Proceedings (Vol. 19, No. 4, pp. 473-478). Thomas Telford, 1961.

VIII. Ioannis Koutromanos , Andreas Stavridis, P. Benson Shing, Kaspar Willam ,"Numerical modeling of masonry infilled RC frames subjected to seismic loads", Computers and Structures 89, 1026–1037, 2011.

IX. Kappos, A. J., Ellul F. Seismic Design and Performance Assessment of Masonry Infilled R/C Frames. Proceedings of the 12th World Conference on Earthquake Engineering, 989 on CD-ROM, New Zealand, 2000.

X. L.D, Decanini, G.E. Fantin., Simplified models of Masonry Included in porches. Features lateral stiffness and strength limit state, Argentine Conference on Structural Engineering, Buenos Aires, Argentina, Vol.2, pp.817-836, 1986.

XI. Liauw T. C., Kwan K. H. Nonlinear Behavior of Non-Integrel Infilled Frames. J Computer and Structure., 18(3), 551-560, 1984.

XII. Moghaddam H. A., Dowling P. J. The State of The Art in Infilled Frames. ESEE Res.Rep. No 87-2, Imperical Coll. of Sci. and Technol., Civ.Engrg. Dept., London, England, 1987.

XIII. Moghaddam H. A., Dowling P. J. The State of The Art in Infilled Frames. ESEE Res.Rep. No 87-2, Imperical Coll. of Sci. and Technol., Civ.Engrg. Dept., London, England, 1987.
XIV. Moghaddam H. A., "Lateral load behavior of masonry infilled steel frames with repair and retrofit" J. of Struct. Eng., 130(1), 56-63, 2004.

XV. Murty C. V. R., Jain S. K. Beneficial Influence of Masonry Infill Wallson Seismic Performance of RC Frame Buildings. Proceedings of 12th WCEE, P. 1790, 2000.

XVI. Paulay, T., Priestley, M. J. N. Seismic design of reinforced concrete and masonry buildings. John Wiley & Sons, Inc., New York, NY, USA, 1992.

XVII. Polyakov S. V. "Masonry in framed buildings." Translated by G. L. Cairms in 1963. National Lending Library for Science and Technology, Boston Spa,Yorkshire, U.K., 1956.

XVIII. Riddington, J. R., and Stafford Smith, B. , "Analysis of infilled frames subjected to racking with design recommendations." The Structural Engineer, Vol.55, No. 6, pp 263-268, 1977.

XIX. Stafford-Smith B. Lateral Stiffness of Infilled Frames. J. Struct. Div.ASCE, 88(ST6), 183-199, 1962.

XX. Stafford-Smith B., Carter C. A Method of Analysis for Infilled Frames. Proceedings of the Institution of Civil Engineers, Vol. 44, pp. 31-48, 1969.

XXI. Tasnimi A. A., Mohebkhah A. Effect of Infill Vertical Irregularity on Seismic Demands of RC Buildings. 2nd International Conference on Concrete and Development, BHRC, Tehran, Iran, 2005.