Impact of Irregularity of Infill Walls on the Seismic Performance of Reinforced Concrete Frame Structures

Mohammad Razeq Shakhan

H S Abdulrahman

Ali Almusawi

Abstract: The impact of infill walls on the seismic performance of reinforced concrete frame structures (RCFS) is usually ignored, and the infill walls are considered as non-structural elements. Therefore, the bare frame structures are designed to resist the whole lateral loads. In practice, the presence of infill walls increases the strength and stiffness of the building. It is believed that neglecting infill stiffness leads to a conservative design, but it can be not always true, especially in vertically irregular buildings with discontinuous infill walls. The objective of the study is to evaluate the impact of the irregularity of infill walls on the seismic performance of the RCFS. Therefore, a 6-story building was analyzed in three different models (with an open ground story, with infill walls, and without infill walls) to evaluate the seismic performance of RCFS. The analysis was done based on the ACI 318-14 and the ASCE 7-16 codes using ETABS v17. The results show that in the presence of infill walls, the lateral stiffness of the structure is increased, in-contrast time-period, lateral displacement, and story drift is decreased. In the vertically irregular buildings in the open space floor, the story drift is increased, and the amount of bending moment in columns is higher compared to the other models. A safety factor can be recommended to be applied to compensate for the weakness of the open space floor.

Keywords: Frame Structure, Infill Wall, Seismic Performance, Story Drift

Introduction

Most of the construction codes neglect the interaction between infills and frames. Therefore, the bare frame is usually designed to take all lateral loads. If the lateral stiffness of infill walls is considered in the design, the frame dimension would be decreased and lead to more economic design [1, 2]. In contrast, the ignoring of infill walls strength and stiffness seem to may increase the dimension of the frame and increase the strength of the moment-resisting frame and finally end to a conservative design. But this viewpoint can be true only for vertically regular RCFS that all infill walls are vertically continuous [3]. But, most of the multi-story buildings have some open space, especially on the ground floor, which is used for parking and commercial purposes. Usually, this type of buildings is classified as vertically irregular buildings. The existence of an open space floor in a building makes this floor more flexible and weaker than adjacent floors that is called Soft Story. A story is called soft story when its lateral stiffness is less than 70% of the story above or less than 80% of the three stories above. Due to the sudden reduction of stiffness in a soft story, the columns and beams become more stressed than other stories when an earthquake happens. Therefore, in a soft story, it is required that columns and beams should be stronger than other stories. If the interaction between infills walls and frame is ignored, and infill walls are counted as non-structural elements and applied as the dead load on the frame, this requirement would be not achieved. The objective of this study is to evaluate the impact of discontinuity of infill walls on the seismic performance of reinforced concrete frame structures.

Modeling and Analysis

In this study, a special moment resisting frame is analyzed in full 3D model using ETABS v17. The reinforced concrete floor slaps are considered to be full rigid and act as diaphragms. To examine the impact of irregularity of infill walls, three different models were selected such as first model with open ground floor, second model has full infill walls, and third model is bare frame (without infill walls).

The stiffness of infill walls is represented by diagonal struts. The thickness of struts is equal to infill wall thickness. To determine the width of struts, many investigations have been done. Holmes recommended a width of the diagonal strut equal to one third of the diagonal length of the panel[4], whereas New Zealand Code (NZS 4230) specifies a width equal to one quarter of its length[5]. In this study, FEMA-356 was used to determine the width of struts.

$$w = 0.172(\lambda_h H)^{-0.4} d_{\inf} \qquad \textbf{(1)}$$

$$\lambda_h = \left[\frac{E_{\inf} t_{\inf} \sin 2\theta}{4 E_c I_c h} \right]^{0.24} \quad (2)$$

Where; H is the height of the column, d_{inf} is the diagonal the length of infill, E_{inf} is the modulus elasticity of infill, θ is the angle of the diagonal strut, t_{inf} is the thickness of the infill panel, E_c is the modulus elasticity of the column, I_c is the moment inertial of the column, h is the height of the column.

Design Inputs

In this study, all models were analyzed and designed based on American Concrete Institute [6] and American Society of Civil Engineering [7]. Therefore, all material properties and design inputs were extracted from those codes. All are illustrated in Table 1.

Design inputs	Value
Compression strength of concrete, fc', (MPa)	25
Modulus of elasticity of concrete, Ec, (MPa)	23500
Poison's ratio	0.2
Tensile strength of reinforced steel rebars, fy, (MPa)	420
0.2 Sec spectral acceleration, Ss	1.13
1 Sec spectral acceleration, S1	0.57
Site class	D
Response modification factor, R	8
System overstrength factor, ω	3
Deflection amplification factor, Cd	5.5
Occupancy importance factor, I	1
Live load, LL (KN/Sqm)	2.5
Roof Live Load, RLL (KN/Sqm)	1
Snow Load, S (KN/Sqm)	0.75
Modulus of elasticity of masonry, E_{inf}, (MPa)	9300
External strut width, (mm)	390
Internal strut width, (mm)	400

Table 1 *Material Properties And Design Inputs*

Result and Discussion

Due to existing of open space in the 1st model, the story drift is so high. Story drift is small in the 2nd model compared to other models, and in the 3rd model, the story drift is maximum because the lateral stiffness of infill walls was neglected. See Figure 1.

Story shear is minimum in the bare frame model because the stiffness of infill walls was not considered in the analysis. When the lateral stiffness of a model is decreased the time period is increased, finally the story share is decreased too. See Figure 2.

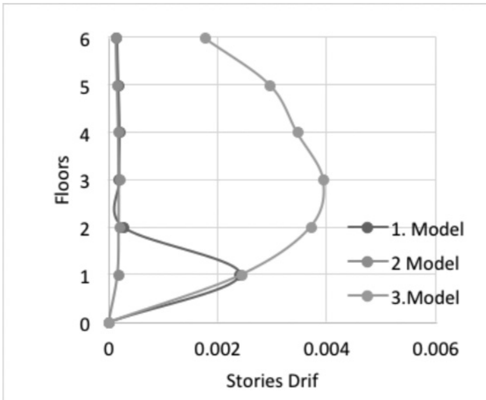

Figure 1 *Story Drift*

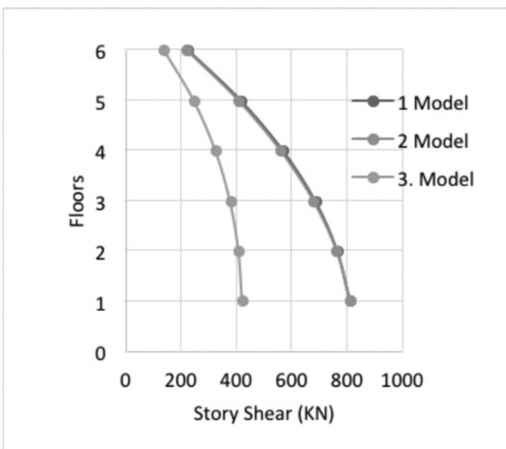

Figure 2 *Story Shear*

The lateral displacement is large in bare frame model compared to two other models. Figure 3.

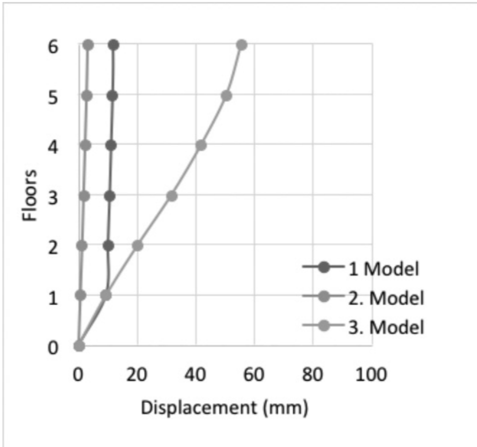

Figure 3 *Lateral Displacement*

Time period is maximum in bare frame model but it is decreased in first model. The time period is minimum in 2nd model because the stiffness of infill walls was considered.

See table 2.

Modes	1st model (Sec)	2nd model (Sec)	3rd model (Sec)
1	0.652	0.28	1.601
2	0.642	0.275	1.476
3	0.564	0.212	1.285
4	0.139	0.096	0.512
5	0.133	0.095	0.482
6	0.093	0.075	0.426
7	0.076	0.072	0.274
8	0.063	0.06	0.262
9	0.059	0.053	0.234
10	0.057	0.053	0.175
11	0.052	0.051	0.17
12	0.049	0.045	0.153

Table 2 *Comparison Of Time Periods*

In model 1, at first-story, columns are subjected to large moments compared to the columns in the above story and other models. The infill walls act like bracing in a building and seismic load is dispersed between frame and infill walls. In a vertically irregular building due to discontinuous of infill walls, only columns and beams should carry the whole lateral loads. Therefore, the moment and shear are increased in this type of structures. See Figures 3-5.

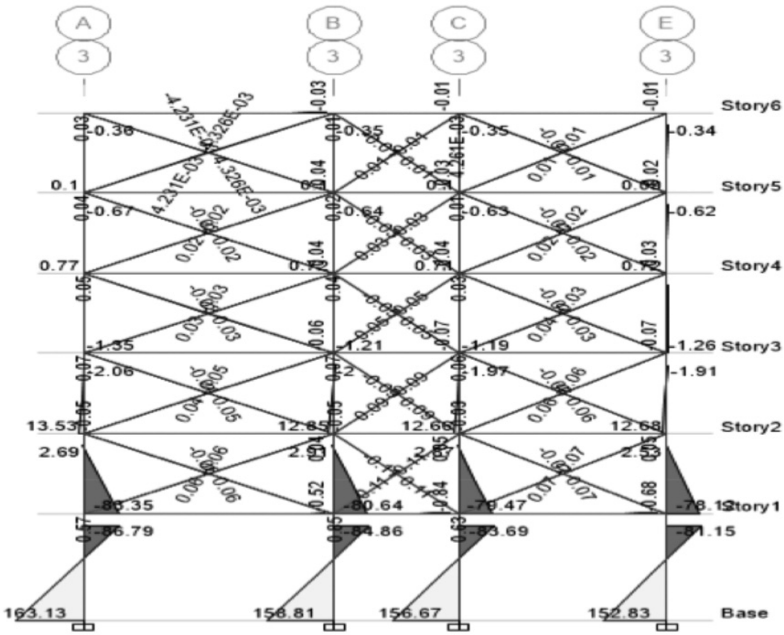

Figure 3 *Model 1, Moment In Columns*

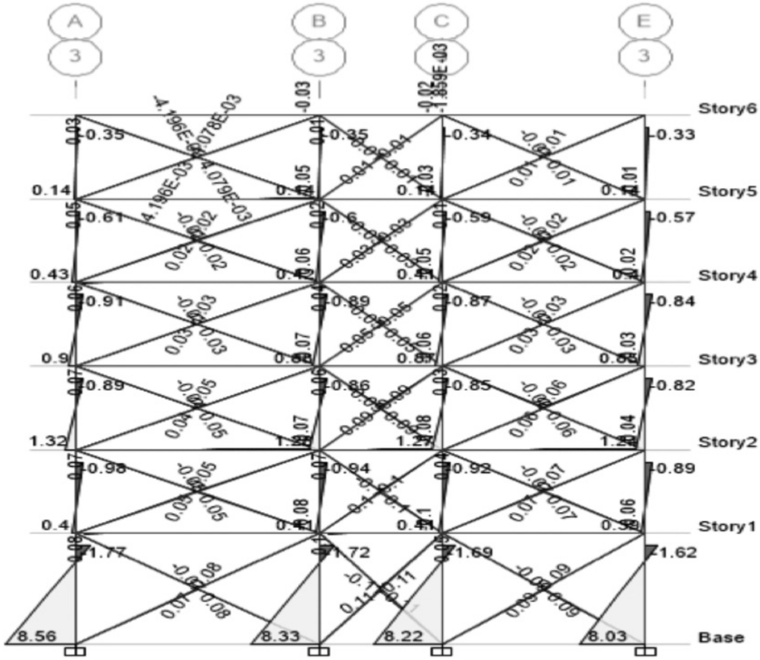

Figure 3 *Model 2, Moment In Columns*

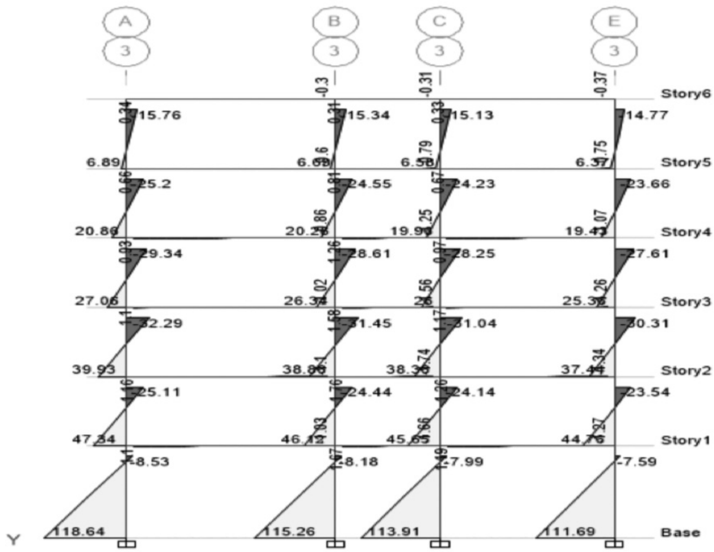

Figure 4 *Model 3, Moment In Columns*

Conclusion and recommendation

In this study, a 6-story reinforced concrete frame structure was analyzed in three models (open space ground floor model, infilled model, and bare frame model) to evaluate the impact of discontinuity of infill walls on seismic performance of the vertically irregular building. The results of the study are summarized as follows.

The story drift of the bare frame model is large than other models. In the second model that is a vertically regular building, story drift is small. In the first model in the open space ground story drift is quite large compared to the second model.

Lateral displacement is so large in bare frame model compared to others.

Story shear force is high in 3rd model than 1st and 2nd models.

Time period is minimum in 2nd model but has maximum value in 3rd model.

On the first floor of the 1st model, the amount of moment in columns is significantly larger than the second model in the same story. The average difference of moment in columns, between the first model and the third model, is 1.437.

In vertically irregular buildings with soft-story, if the interaction between infill walls and frames are ignored, a safety factor should be used to compensate for the weakness of the soft-story. According to this study result, 1.5 can be used as safety factor.

References

[1] A. Ahmed, A. Ali, H. Khalid, and M. Ahmad, "Role of masonry infill wall on the seismic behavior of typical four-storey building in Pakistan," in *Materials Science and Engineering*, 2018, pp. 1–6. Available: https://iopscience.iop.org/article/10.1088/1757-899X/414/1/012017/meta

[2] O. Bolea, "The Seismic Behaviour Of Reinforced Concrete Frame Structures With Infill Masonry In The Bucharest Area," *Energy Procedia*, vol.

85, no. November 2015, pp. 60–76, 2016. Available: https://www.sciencedirect.com/science/article/pii/S1876610215029409

[3] Paudel, "Effect of Infill Walls in Performance of Reinforced Concrete Building Structures," *Int. J. Eng. Res. Gen. Sci.*, vol. 5, no.4 February, pp. 24–27, 2017, http://ijergs.org/Archives#section24

[4] M. Holmes, "Steel frames with brick and concrete infilling," *Proc. Inst. Civ. Eng.*, vol. 19, pp. 473–578, 1961, https://www.icevirtuallibrary.com/doi/abs/10.1680/iicep.1961.11305

[5] Standards New Zealand, *Design of Reinforced Concrete Masonry Structures*. Standards New Zealand, 2004.

[6] ACI 318, *Building Code Requirements for Structural Concrete (ACI 318M-14)*, 14th ed. USA: ACI Committee 318, 2014.

[7] ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. USA: American Society of Civil Engineers, 2017.