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Role of masonry infill wall on the seismic behavior of typical four-storey building in Pakistan

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Abstract. Masonry infill walls are used as partition in reinforced concrete frames and are considered as a non-engineering structure for design and analysis purposes. The goal of this study is to compare different response parameters such as displacement, storey drift, base shear and ground overturning moment of a multi-storey RC frame structure with and without infill walls. For this purpose, a four-storey building is selected, which is supposed to be situated on stiff soil type (S_D) and seismic zone 2B according to the Building Codes of Pakistan. Openings are neglected in the building. Non-linear static pushover analysis method is used to check the behavior of building during earthquake using SAP-2000. To find the width of compression struts, FEMA-356 is used. The results are compared and shown in the form of graphs. It is concluded that the masonry infill walls may have significant effects on the seismic response of the reinforced concrete frame structures, therefore, infill walls need to be considered during the design and analysis of the building.
Keywords: Seismic, Pakistan, reinforced concrete, SAP-2000

1. Introduction

Masonry infill walls are used all over the world and are a common practice in developing countries for partition purposes due to their better functionality, accessibility and less cost. They are used to enclose the frame structure or divide the structure. Infill walls are made of bricks, concrete blocks, hollow concrete blocks or any solid material. Design standards for infill walls cannot be found because infill walls are considered as non-structural. Many researchers have termed infilled frame structures as “Earthquake Risk” structures. Masonry infill walls may alter the behavior of frame structure during earthquakes and respond to characteristics like energy dissipation and stiffness. Masonry infill walls in RC frame structure might also decrease the displacement of the structure. The effect of masonry infill walls on seismic response of RC frame buildings and concluded that the infill walls contribute significantly to lateral stiffness, strength and overall ductility, [1, 2]. The earthquake analysis of mutli-storey building with and without infill walls and concluded that the presence of infill walls reduces the displacement and increases the base shear, [3] The response of infilled panels and found that it is necessary to include masonry infill’s in analysis of Reinforced Concrete (RC) moment resisting frame structure. The seismic assessment of RC structures with infill panels and concluded that relative storey displacement is significantly affected by earthquake [4]. The seismic behavior of RC frame structure with masonry infills, [5]. He concluded that the presence of infill wall significantly affects the base shear. The Waleed (2012) [6] conducted the parametric study on masonry infill walls and concluded that masonry infill walls can increase the base shear capacity and reduce the displacement capacity of masonry reinforced frame buildings. The Ioannis (2011) [7] performed numerical modeling of RC frames with infill walls and concluded that finite element method shows that the masonry infill walls significantly affect the resistance to seismicity of RC frame structure.

Multi-storey buildings with infill walls subjected to dead and live load do not pose too much threat. The problem arises when earthquake generate lateral force on the RC frame structures with infill walls. The buildings are normally designed with the assumption that the total lateral load is absorbed by bare frame during earthquake without considering the effect of infill walls in RC frames. If masonry infill walls are modeled and analyzed with frame only, then they may add beneficial effects on the earthquake response behavior of the RC frame building.

2. Modeling and Analysis of Reinforced Cement Concrete Building

2.1 General description

The building is a reinforced concrete frame building structure. The dimensions of the building are 110’x56’. The height of each storey is 12’ and the height of total building is 64’ including mumty and base storey. The building was designed for zone 2B and stiff soil type S_D. The building was modeled and analyzed using SAP2000 according to building code of Pakistan and UBC-97. The plan of the building is as shown in Figure-1 and the data of the building is shown in Table-1 and Table-2. The Time Period of the modeled building without infill wall is 1.22 second and for infilled frame is 0.52 seconds. The peak ground acceleration for the respective zone 2B is 0.20g. Push over load cases were defined by introducing target displacement. The formula to calculate the target displacement is mentioned below which is taken from FEMA-356.

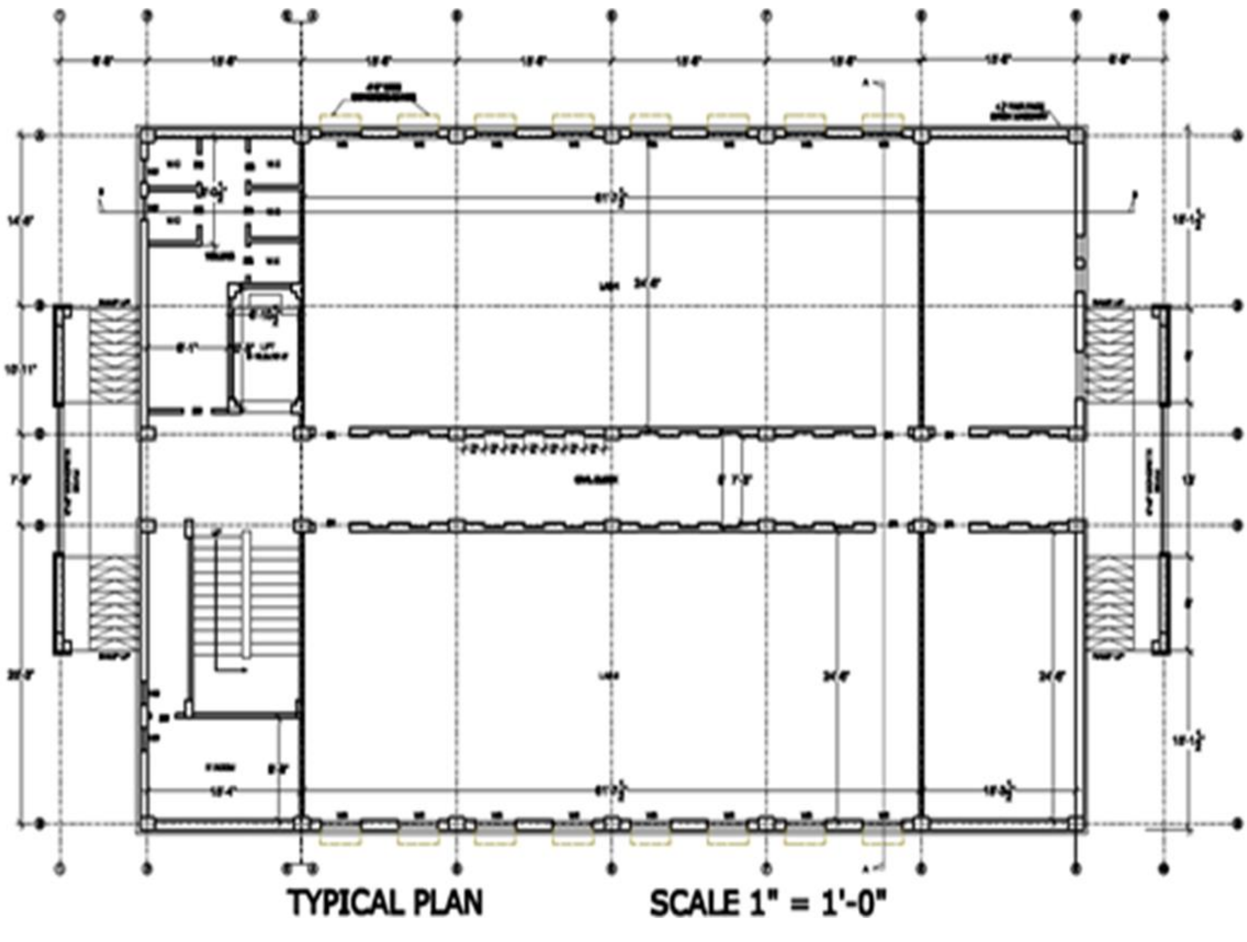


Figure 1. Plan of Building

Table 1. Geometrical parameters of frame members

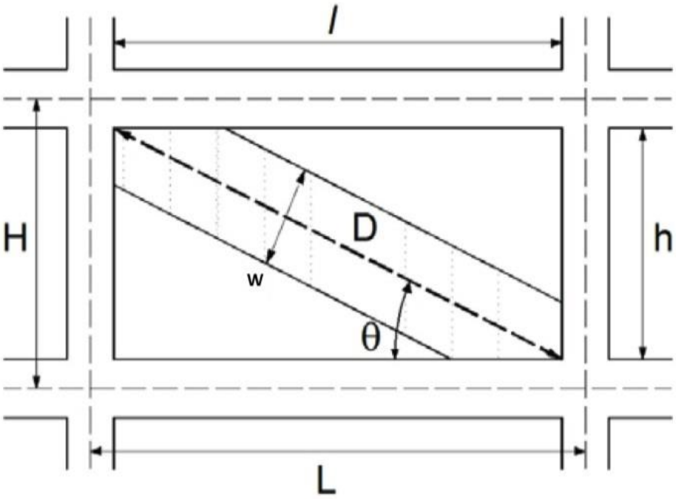
Structural element	Transverse Section (in)	Transverse section area (in^2)	Stiffness modification factor
Longitudinal beams	15”x18”	270	0.35
Transverse beams	18”x21”	378	0.35
Column	21”x24”	504	0.7
Slab	6” thick	-	0.35

Table 2. Properties of the material

Frame element	Compressive strength (ksi)	Modulus of elasticity	Poison ratio
Longitudinal beam	3	3122	0.2
Transverse beam	3	3122	0.2
Column	3	3122	0.2
Masonry	1.7	598.28	0.25
Slab	3	3122	0.2

2.2 Calculation for Compression Strut

Various equivalent diagonal strut formulas and methods are available to find the width of compression struts. Diagonal struts were connected to beam column joint with hinge moment free connection, so they could take only compressive forces. In this study, FEMA-356 is used to find the width of compression struts.



Where:
w= width of equivalent strut
λ_h=width of diagonal strut
H=height of column
d_{inf}=diagonal length of infill panel
$t_{inf.}$=thickness of infill panel
E_c=elastic modulus of frame
I_c=moment of inertia of column
h=height of infill panel
θ=angle of diagonal strut
L=center to center distance of frame
l=inner length of frame

Figure 2. Diagonal Strut Parameters

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

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

From the above given formula, the width of compression struts were calculated, the value of which is given below in the Table-3.

Table 3. Strut details

S No.	Width (in)	Thickness(in)
1	17.76”	9”
2	20.35”	9”
3	40.85”	9”
4	36.00”	9”

2.3 Non-Linear Modeling

Mathematical model was developed in SAP2000. Hinges were assign using Auto hinge FEMA-356 option. After which Pushover load cases were generated. The modal was analyzed, without pushover load case. Then modals were analyzed again using pushover load cases, following concrete check. After the results were extracted (pushover curve, displacement, storey drift, shear and over turning moment). Above procedure is adopted for infilled frame, compression struts as link elements are assigned. Stress-strain masonry curve (1:3 mortar ratio) is converted into force-displacement curve respectively which is than further assigned to link elements.

$$F = \delta.A$$

$$\Delta = \varepsilon.l$$

Where,

F = Force, A = Cross-Sectional Area of Strut, δ = Stress

Δ = Displacement, ε = Strain, l = Diagonal Length of infill

2.4 Target Displacement

The target displacement of the bare and infill frame was calculated using the following formula from FEMA 356. The following parameters were substituted; the target displacement for bare frame is 0.41’ and 0.14’ with infill walls which shows that the stiffness of structure is increased. The reinforcement of the building remained unchanged due to existing structure.

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g$$

Where, δ_t= target displacement
C_0=$C_1 = C_2 = C_3$ = modification factors
S_a = response spectrum acceleration
Te= time period
g= gravitational acceleration

3. Results and Discussion

Following results are extracted from both infill and without infill models. The results are shown for pushover curve, displacement, storey drift, storey shear and storey turning moment in Fig-3 to 7 for these structural responses.

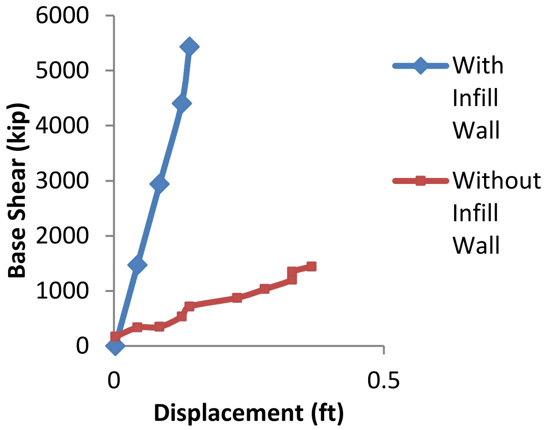


Figure 3. Displacement vs. Base Shear

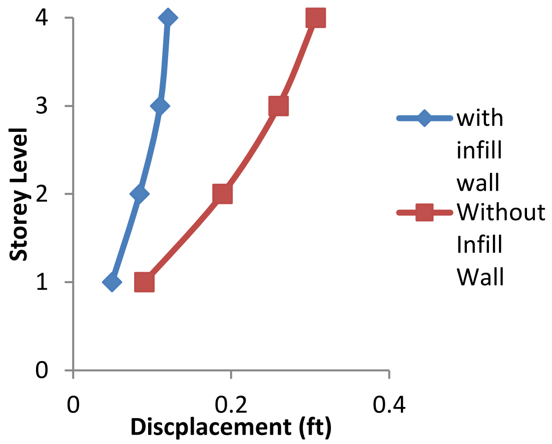


Figure 4. Displacement vs. Storey Level

Figure 3 shows the pushover curve. The base shear of infilled frame is 72% more than that of bare frame. Figure 4 shows the relationship between displacements versus storey level. The difference between displacements of bottom and top storey of bare and infilled frame is 22% and 66% respectively. Figure 5 represents the trends between storey drift and storey level. Bare frame storey drift is 48% more than that of infilled frame. The graph between storey shear and storey level is shown in figure 6. The storey shear of infilled is 83% more than that of bare frame.

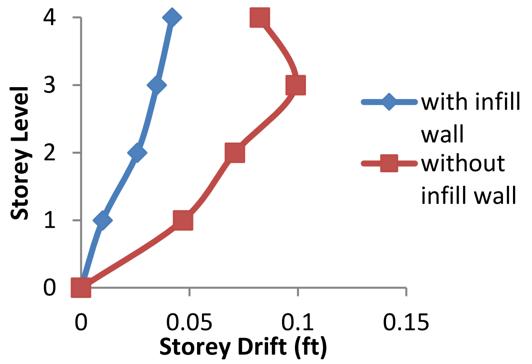


Figure 5. Storey Drift vs. Storey Level

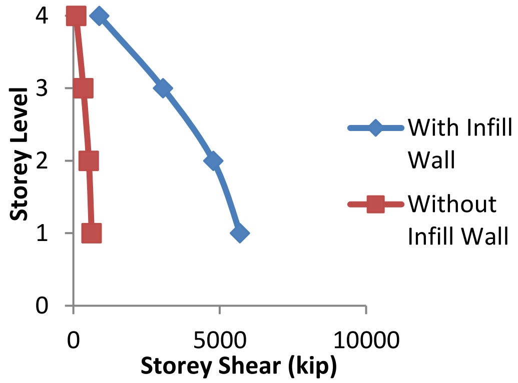


Figure 6. Storey Shear vs. Storey Level

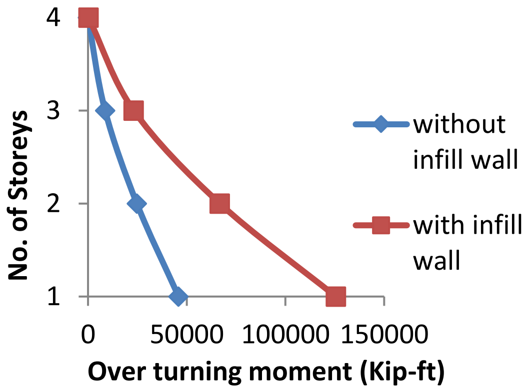


Figure 7. Storey Moment vs. Storey Level

Figure 7 shows the relationship between over-turning moment and number of storeys. Over-turning moment is maximum on ground storey and minimum on the top storey. There is an increase of 77% of over-turning moment of fully infill frame.

Figure 8 and figure 9 represent the area of steel of bare and fully in-filled frame and it can be seen that there is significant difference in the area of steel. Difference of 22% was observed between the bare frame and in-filled frame due to the braced frame action.

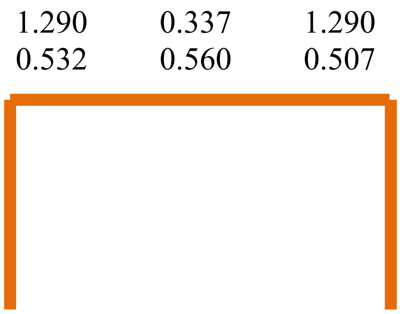


Figure 8. Area of steel in bare frame.

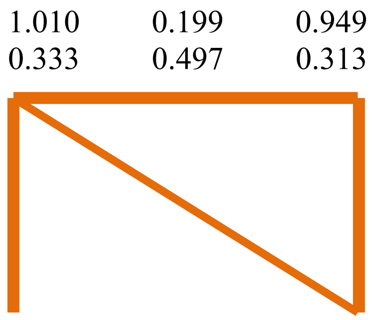


Figure 9. Area of steel in Fully In-filled Frame.

4. Conclusion and Recommendation

The important conclusions of this study are elaborated as: The base shears of fully in-filled frame is 2.5 times more than that of bare frame. This is due to the braced frame action which obviously is stiffer than the bare frame. The displacement of bare frame is more than that of fully in-filled panels. The result shows a difference of 66% on the highest floor, respectively.

Ground over turning moment of fully in-filled frame has higher values than that of bare frame. There is an increase of 77% of over-turning moment of fully infill frame. Storey shear decreases of each storey as the number of floors are increased. Relative storey displacement is the least in fully in-filled frame and for bare frame have higher values of drift. The area of steel in beams in bare frame is more than that of the in-filled frame structure a difference of 22% was observed, it's due to the braced frame action. The structure is more-stiff. As stated in the above-mentioned results, there are significant differences in seismic response of frames with and without in-fill walls. Building analysis and design shows that in-fill walls can also economize the cost of structures as the in-fill walls contribute towards lateral stiffness due to braced frame action. The results also show that area of steel can be reduced. Moreover, due to availability of advanced analysis and design tools it is recommended to include the effect of in-fill walls for determining the realistic behavior as well as to achieve economy.

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