

Seismic Performance of Reinforced Concrete Buildings with Masonry Infill

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Abstract: Unreinforced masonry infills modify the behavior of framed structures under lateral loads; however, in practice, the infill stiffness is commonly ignored in frame analysis, resulting in an under-estimation of stiffness and natural frequency. The structural effect of hollow concrete block infill is generally not considered in the design of columns as well as other structural components of RC frame structures. The hollow concrete block walls have significant in-plane stiffness contributing to the stiffness of the frame against lateral load. The scope of present work was to study seismic performance of reinforced concrete buildings with masonry infill in medium rise building. The office medium rise building is analyzed for earthquake force by considering three type of structural system. i.e. Bare Frame system, partially-infilled and fully- Infilled frame system. Effectiveness of masonry wall has been studied with the help of five different models. Infills were modeled using the equivalent strut approach. Nonlinear static analyses for lateral loads were performed by using standard package ETABS, 2015 software. The comparison of these models for different earthquake response parameters like base shear vs roof displacement, Story displacement, Story shear and member forces are carried out. It is observed that the seismic demand in the bare frame is significantly large when infill stiffness is not considered, with larger displacements. This effect, however, is not found to be significant in the infilled frame systems. The results are described in detail in this paper.

Keywords: Bare Frame, Infilled Frame, Equivalent Diagonal Strut, Infill, Plastic Hinge

1. Introduction

Infill have been generally considered as non-structural elements, although there are codes such as the Eurocode-8 that include rather detailed procedures for designing infilled R/C frames, presence of infill has been ignored in most of the current seismic codes except their weight. However, even though they are considered non-structural elements the presence of infill in the reinforced concrete frames can substantially change the seismic response of buildings in certain cases producing undesirable effects (tensional effects, dangerous collapse mechanisms, soft story, variations in the vibration period, etc.) or favorable effects of increasing the seismic resistance capacity of the building.

The present practice of structural analysis is also to treat the masonry infill as non- structural element and the analysis as well as design is carried out by only using the mass but

neglecting the strength and stiffness contribution of infill. Therefore, the entire lateral load is assumed to be resisted by the frame only.

Contrary to common practice, the presence of masonry infill influence the over- all behavior of structures when subjected to lateral forces. When masonry infill are considered to interact with their surrounding frames, the lateral stiffness and the lateral load capacity of the structure largely increase.

The recent advent of structural design for a particular level of earthquake performance, such as immediate post-earthquake occupancy, (termed performance based earthquake engineering), has resulted in guidelines such as ATC-40 (1996) [14], FEMA-273 (1996) [26] and FEMA-356 (2000) [13] and standards such as ASCE-41 (2006), among others. The different types of analyses described in these documents, pushover analysis comes forward because of its optimal accuracy, efficiency and ease of use.

The infill may be integral or non-integral depending on the

connectivity of the infill to the frame. In the case of buildings under consideration, integral connection is assumed. The composite behavior of an infilled frame imparts lateral stiffness and strength to the building. The typical behavior of an infilled frame subjected to lateral load is illustrated in Figures 1 (a) and (b).

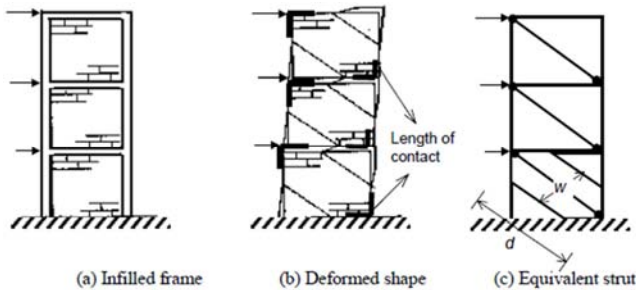


Figure 1. Behavior of infilled frames (Govindan, 1986).

In this present paper five models of office building with different configuration of masonry infill are generated with

the help of ETABS 2015 and effectiveness has been checked. Pushover analysis is adopted for the evaluation of the seismic response of the frames. Each frame is subjected to pushover loading case along negative X-direction.

2. Building Description

Multi-storey rigid jointed frame mixed use building G+9 (Figure 2), was selected in the seismic zone (Zone IV) of Ethiopia and designed based on the Ethiopian Building Code Standard ESEN: 2015 and European Code-2005. ETABS 2015 was used for the analysis and design of the building by modeling as a 3-D space frame system.

Seismic performance is predicted by using performance based analysis of simulation models of bare and infilled non ductile RC frame buildings with different arrangement of masonry wall. The structure will be assumed to be new, with no existing infill damage.

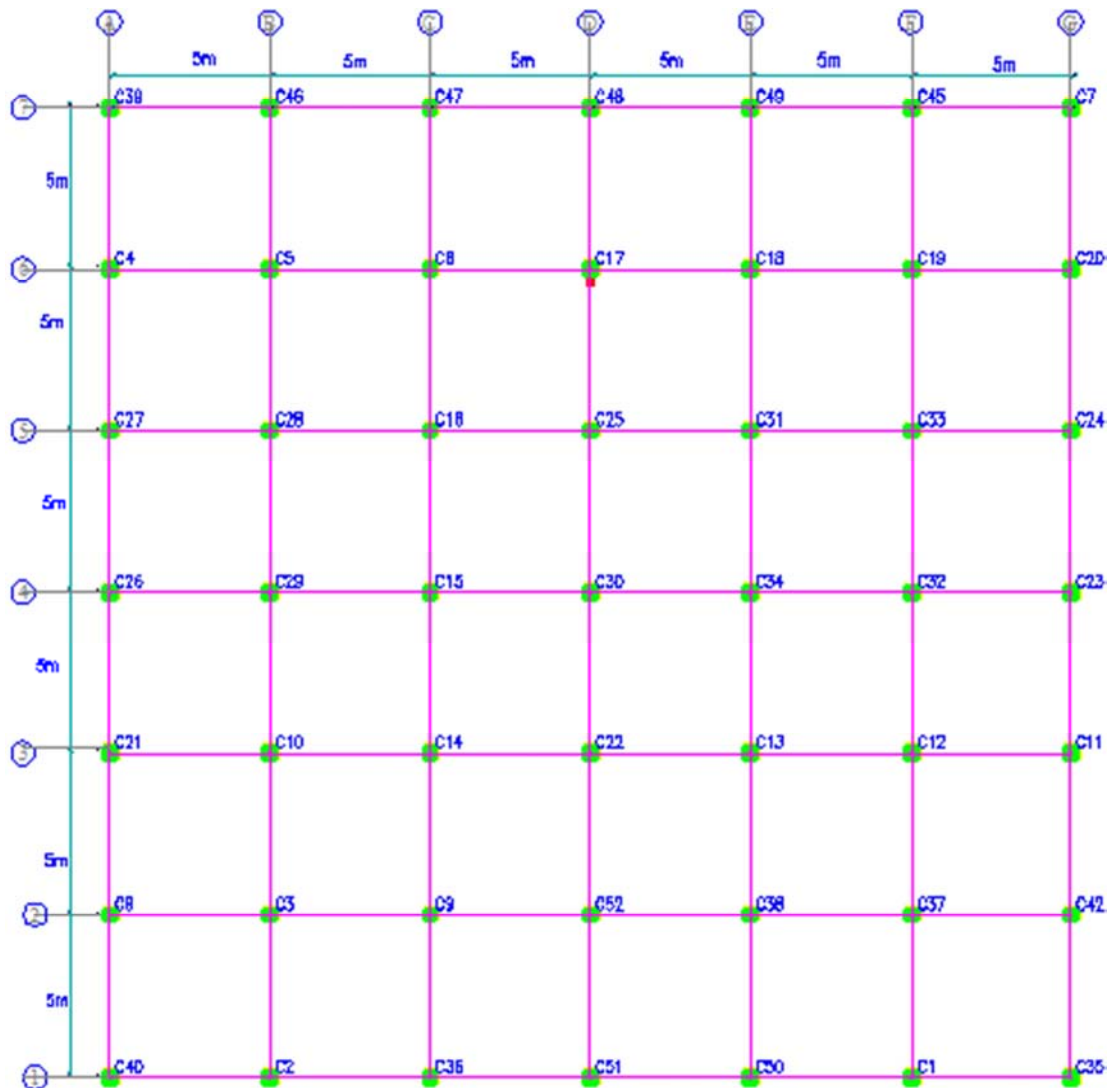


Figure 2. Typical building plan.

Building Data

1. Type of structure = Multi-storey rigid jointed frame
2. Layout = as shown in figure 2
3. Zone = Iv
4. Importance Factor = 1
5. Soil Condition = hard
6. Number of stories = Ten (G+9)
7. Height of Building = 30 m
8. Floor to floor height = 3 m
9. External wall thickness = 20cm
10. Internal wall thickness = 15cm
11. Depth of the floor slab = 15cm
12. depth of roof slab = 12cm
13. Size of all columns = 70×70cm
14. Size of all beams = 70 × 40cm
15. Door opening size = 100×200cm
16. Window opening size = 200×120cm

3. Structural Modeling and Analysis

To understand the effect of masonry wall in reinforced concrete frame, with a total of five models are developed and

pushover analysis has been made in standard computer program ETABS2015. In this particular study pushover loading case along negative X-axis is considered to study seismic performance of all models. Since the out of plane effect is not studied in this paper, only the equivalent strut along X-axis are considered to study the in plane effect and masonry walls along Y-axis are not considered in all models. From this different condition, all models are identified by their names which are given below.

3.1. Different Arrangement of the Building Models

To understand the effect of masonry wall in reinforced concrete frame, with a total of five models are developed and pushover analysis has been made in standard computer program ETABS2015. In this particular study pushover loading case along negative X-axis is considered to study seismic performance of all models.

Model 1:- Bare reinforced concrete frame: masonry infill walls are removed from the building along all stories

Model 2:-Reinforced concrete frame with 75% of masonry wall removed from fully infilled frame

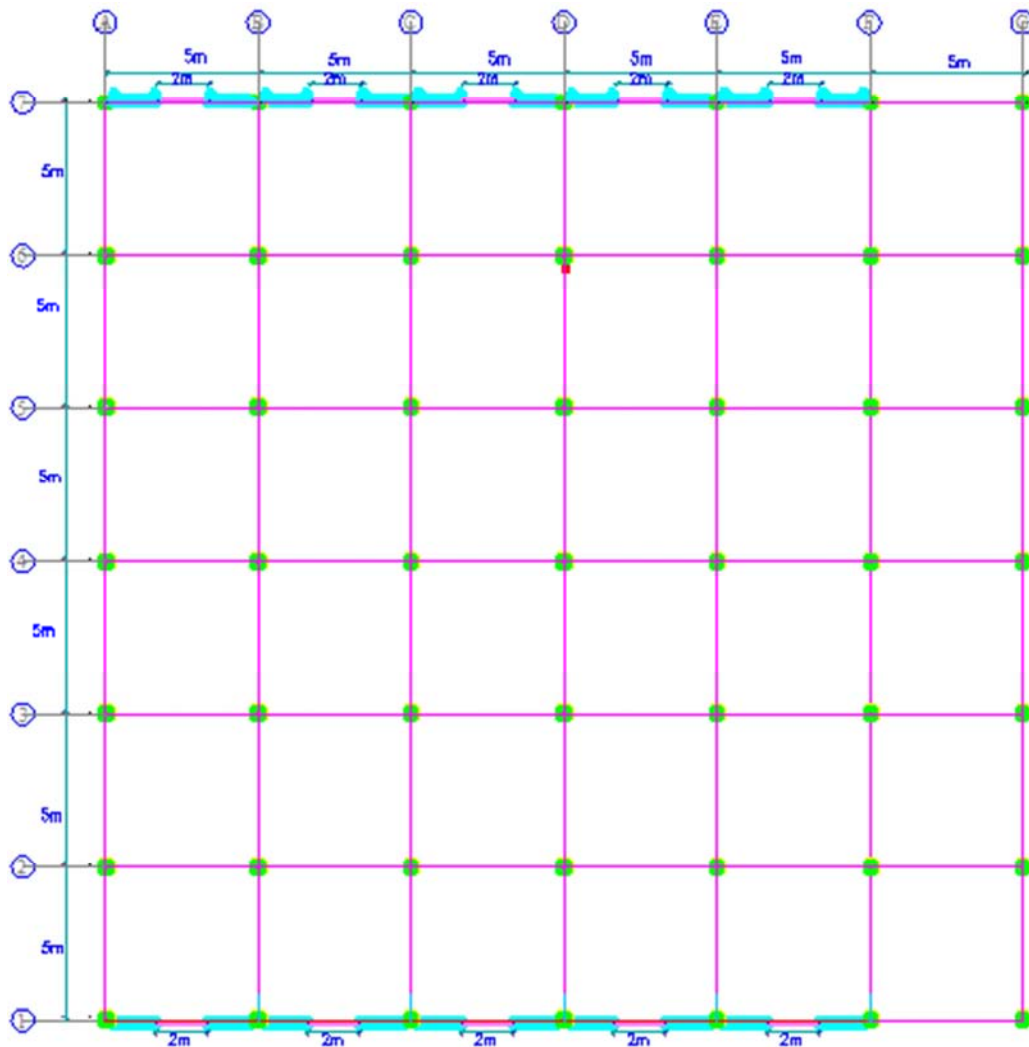


Figure 3. Plan View Model 2.

Model 3:- Reinforced concrete frame with half of of masonry wall removed from fully infilled frame

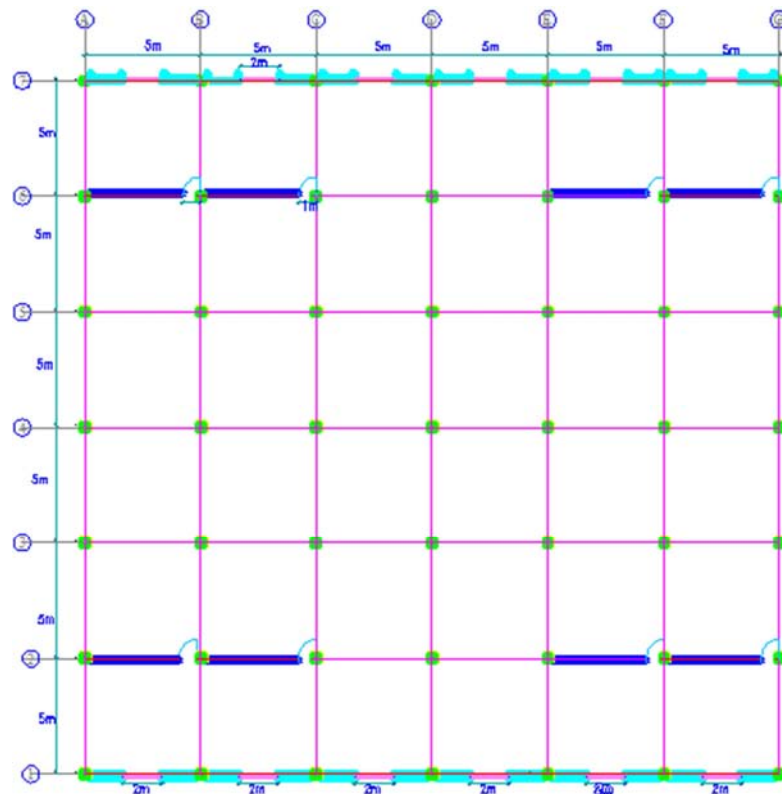


Figure 4. Plan View of Model 3.

Model 4:- Reinforced concrete frame with 25% of masonry wall removed from fully infilled frame

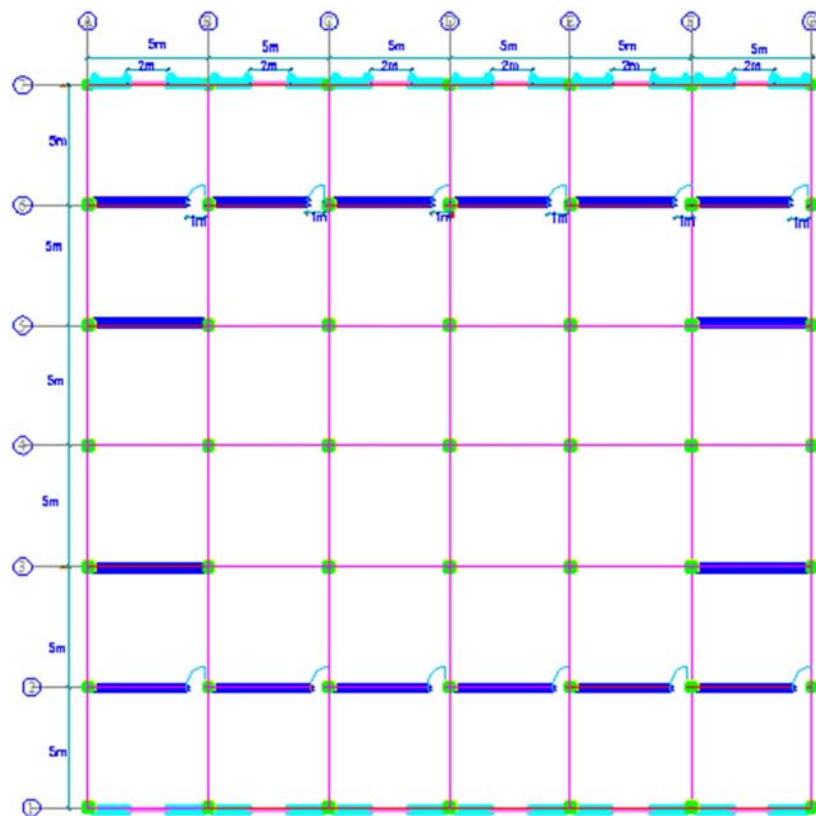


Figure 5. Plan view of Model 4.

Model 5:- Fully infilled reinforced concrete frame (Base frame)

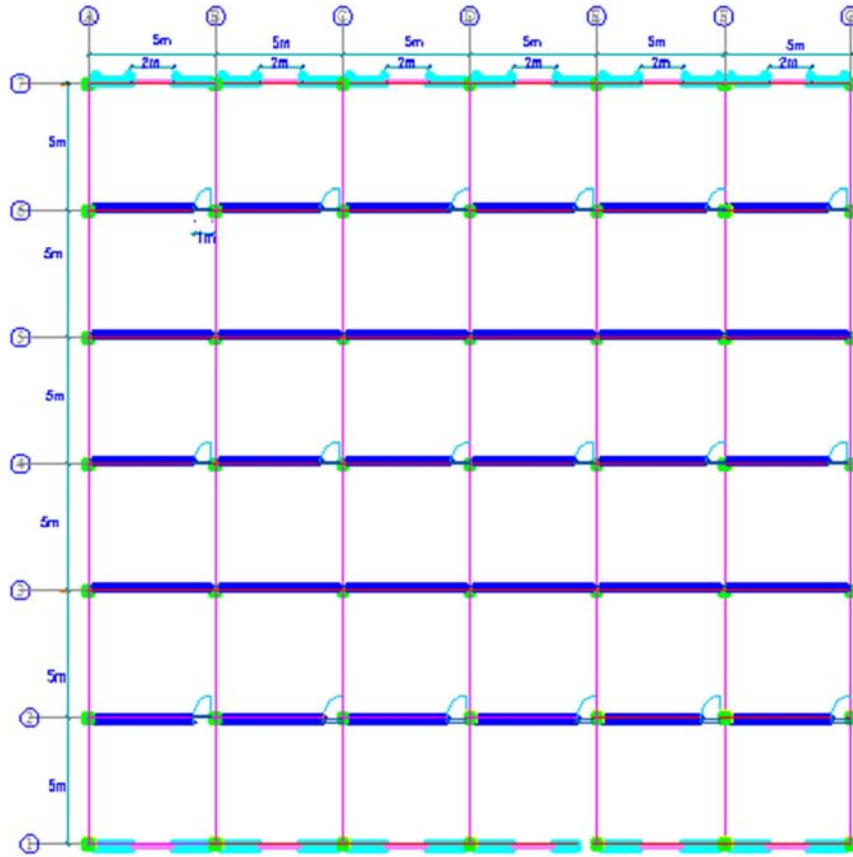


Figure 6. Plan view of Model 5.

3.2. Modeling of Masonry Infill

In the case of an infill wall located in a lateral load resisting frame the stiffness and strength contribution of the infill are considered by modelling the infill as an equivalent compression strut (Smith [3]).

Because of its simplicity, several investigators have recommended the equivalent strut concept. In the present analysis, a trussed frame model is considered. This type of model does not neglect the bending moment in beams and columns. Rigid joints connect the beams and columns, but pin joints at the beam-to-column Junctions connect the equivalent struts.

Infill parameters (effective width, elastic modulus and strength) are calculated using the method recommended by Smith [3]. The length of the strut is given by the diagonal distance D of the panel (Figure 7) and its thickness is given by the thickness of the infill wall. The estimation of width w of the strut is given below. The initial elastic modulus of the strut E_i is equated to E_m the elastic modulus of masonry. As per UBC (1997), E_m is given as $750f_m$, where f_m is the compressive stress of masonry in MPa. The effective width was found to depend on the relative stiffness of the infill to the frame, the magnitude of the diagonal load and the aspect ratio of the infilled panel.

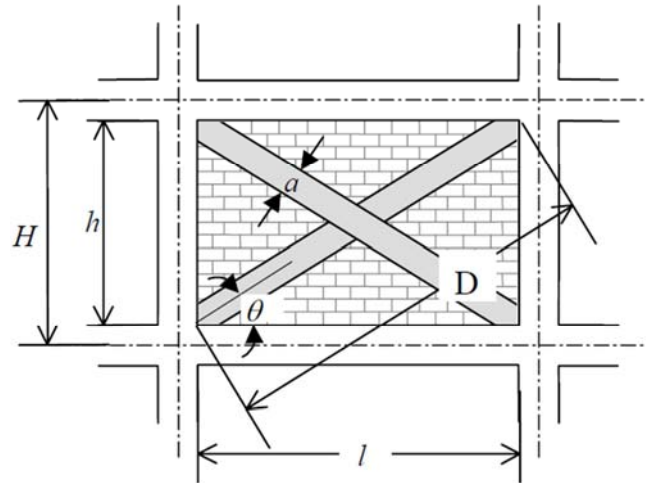


Figure 7. Strut geometry (Ghassan Al-Chaar).

The equivalent strut width, a , depends on the relative flexural stiffness of the infill to that of the columns of the confining frame. The relative infill to frame stiffness shall be evaluated using equation 1 (Stafford-Smith and Carter 1969) [2]:

$$\lambda_1 = \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_c I_{col} h}} \quad (1)$$

Using this expression, Mainstone (1971) [4] considers the relative infill to frame flexibility in the evaluation of the equivalent strut width of the panel as shown in equation 2

$$a = 0.175D(\lambda_1 H)^{-0.4} \quad (2)$$

Where:

λ_1 = Relative infill to frame stiffness parameter

a = Equivalent width of infill strut, cm

E_m = modulus of elasticity of masonry infill, MPa

E_c = modulus of elasticity of confining frame, MPa

I_{column} = moment of inertia of masonry infill, cm^4

t = Gross thickness of the infill, cm

h = height of the infill panel, cm

θ = Angle of the concentric equivalent strut, radians

D = Diagonal length of infill, cm

H = Height of the confining frame, cm

3.3. Eccentricity of Equivalent Strut

The equivalent masonry strut is to be connected to the frame members as depicted in Figure 8. The infill forces are assumed to be mainly resisted by the columns, and the struts are placed accordingly. The strut should be pin-connected to the column at a distance l_{column} from the face of the beam. This distance is defined in Equations 3 and 4 and is calculated using the strut width, a .

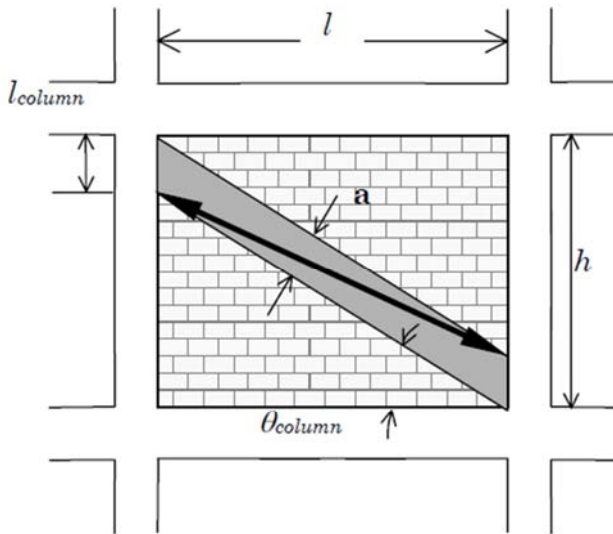


Figure 8. Placement of strut (Ghassan Al-Chaar).

$$l_{column} = \frac{a}{\cos\theta_{column}} \quad (3)$$

$$\tan\theta_{column} = \frac{h - \frac{a}{\cos\theta_{column}}}{l} \quad (4)$$

3.4. Plastic Hinge Placement

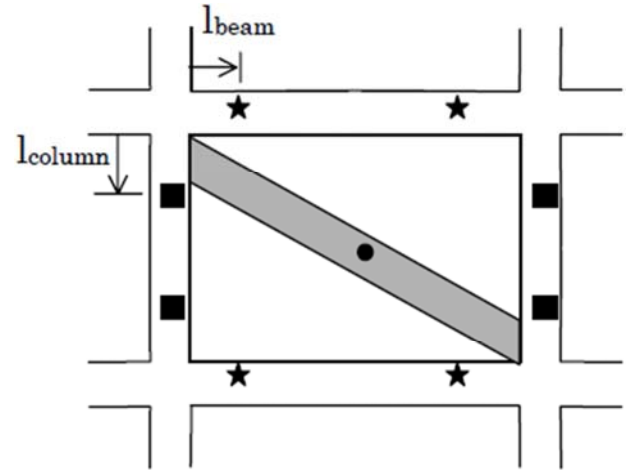
Plastic hinges in columns should capture the interaction between axial load and moment capacity. These hinges should be located at a minimum distance l_{column} from the face of the

beam as shown in figure 9. Hinges in beams need only characterize the flexural behavior of the member.

These hinges should be placed at a minimum distance l_{beam} from the face of the column. This distance is calculated from Equations 5 and 6 where θ_{beam} is the angle at which the infill forces would act if the eccentricity of the equivalent strut was assumed to act on the beam as depicted in Figure 9.

$$l_{beam} = \frac{a}{\sin\theta_{beam}} \quad (5)$$

$$\tan\theta_{beam} = \frac{h}{l - \frac{a}{\sin\theta_{beam}}} \quad (6)$$



■ Axial-Moment and Shear Hinge

★ Moment and Shear Hinge

● Axial Hinge Only

Figure 9. Plastic hinge placement (Ghassan Al-Chaar).

3.5. Analysis of the Building Models

The non-structural elements and components that do not significantly influence the building behavior were not modeled. The floor slabs are assumed to act as diaphragms, which ensure integral action of all the vertical lateral load-resisting elements. Beams and columns were modeled as frame elements with the centerlines joined at nodes. Rigid offsets were provided from the nodes to the faces of the columns or beams. The stiffness for columns and beams were taken as $0.7E_cI_g$, $0.35E_cI_g$ respectively accounting for the cracking in the members and the contribution of flanges in the beams.

The weight of the slab was distributed to the surrounding beams as per ESEN1992:2015[21]. The mass of the slab was lumped at the Centre of mass location at each floor level. This was located at the design eccentricity from the calculated centre of stiffness. Design lateral forces at each storey level were applied at the Centre of mass locations independently in two horizontal directions (X- and Y- directions).

Staircases and water tanks were not modeled for their stiffness but their masses were considered in the static and

dynamic analyses. The design spectrum for hard soil as specified in ESEN1998:2015 [19] was used for the analysis. The effect of soil-structure interaction was ignored in the analyses. The columns were assumed to be fixed at the level of the bottom of the base slabs of respective isolated footings.

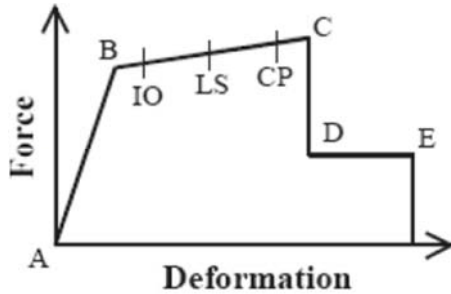


Figure 10. Force-Deformation Relation for Plastic Hinge in Pushover Analysis (Habibullah, et al., 1998).

4. Analysis Results and Discussions

The results of pushover analysis of reinforced concrete frame with different configuration of masonry wall are presented. Analysis of the models under the static and dynamic loads has been performed using Etabs 2015 software. All required data are provided in software and analyzed for

total five models to get the result in terms of Base shear vs monitored roof displacement, Storey shear, story displacement and Element force. Subsequently these results are compared for reinforced concrete frame with different configuration of masonry wall.

4.1. Base Shear vs Monitored Roof Displacement Curve

Based up on the Displacement coefficient method of ASCE 41-13 [24] all the five building models are analyzed in ETABS 2015 standard structural software and the static pushover curve is generated as shown in figure 11.

The presence of the infill wall both strengthens and stiffens the system, as illustrated in figure 11. For the case study building, the fully-infilled frame has approximately 3 times larger initial stiffness and 1.5 times greater peak strength than the bare frame. In figure 11, the first drop in strength for the fully and partially-infilled frame is due to the brittle failure of masonry materials initiating in the first-story infill walls. This behavior after first-story wall failure is due to wall-frame interaction and depends on the relative strength of the infill and framing.

So, based on these results, infill walls can be beneficial as long as they are properly taken into consideration in the design process and the failure mechanism is controlled.

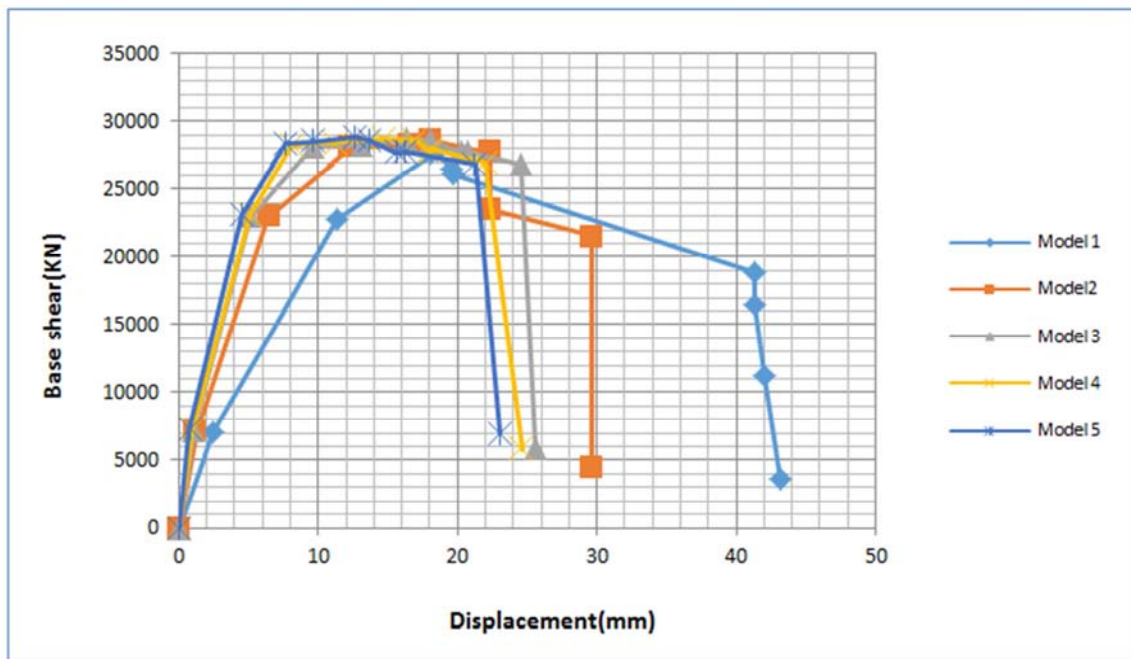


Figure 11. Pushover analysis result for 10-story RC building.

4.2. Story Displacement for Different Models

Figure 12. shows the comparative study of seismic demand in terms of lateral story displacement amongst all the five types of reinforced concrete frame with different configuration of infill. The lateral displacement obtained from the bare frame model is the maximum which is about 60% greater than that of fully infilled frame, nearly 50% greater than that of frame with 25% of the masonry wall reduced,

about 40% greater than that of frame with 50% of the masonry wall reduced and 30% greater than that of frame with 75% of the masonry wall reduced.

Thus, the infill panel reduces the seismic demand of reinforced concrete buildings. The lateral story displacement is dramatically reduced due to introduction of infill. This probably is the cause of building designed in conventional way behaving near elastically even during strong earthquake.

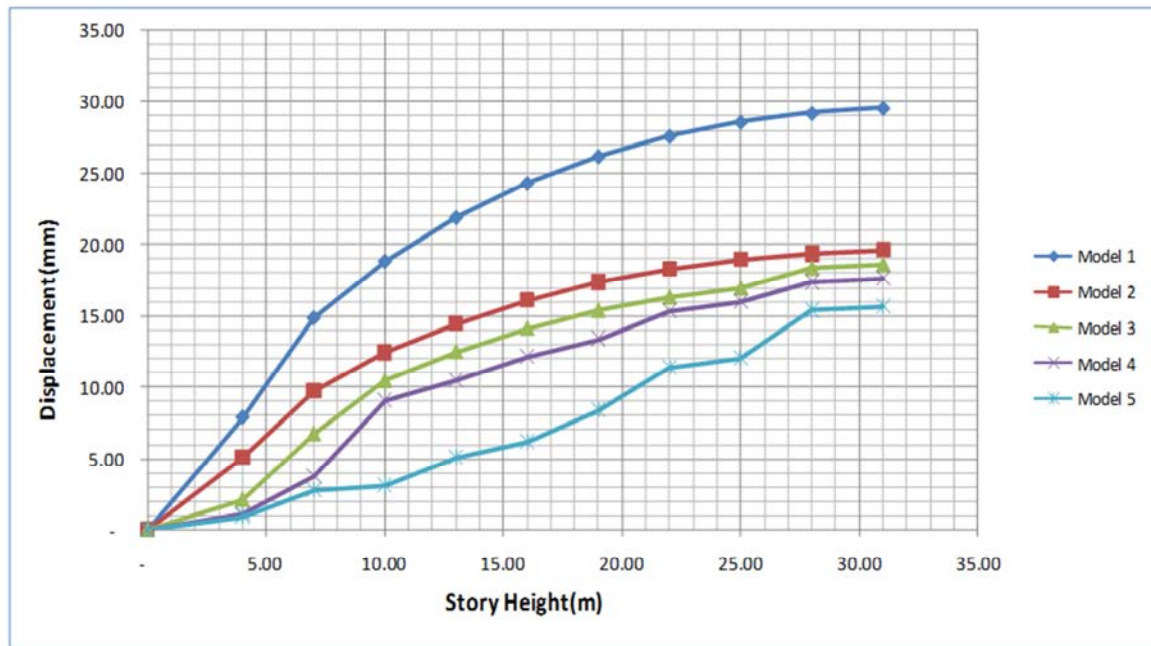


Figure 12. Comparison of Story displacements for different models.

4.3. Member Forces

In this project to understand the effect of different configuration of infill in reinforced concrete frame; study of the behavior of the column in all models for axial loads was conducted. Total of five nonlinear models are analyzed in ETABS 2015 and all models have same plan of building, therefore the position and label of columns are same in all plans of models which is shown in figure 2. After analysis consider the column no. 1(C1) shown in figure 2. from all models for pushover load case and get the axial forces of column at performance point at every story from software, which is given in table 1 and the values for each model is compared with the bare frame model.

From this observation, it is evident that when an infilled frame is loaded laterally, the columns take the majority of the

force and shear force exerted on the frame by the infill which is modeled as the eccentric equivalent struts. Generally, the relative increase of axial force is observed when the percentage of infill in reinforced concrete frame increases. It is observed that fully infilled reinforced concrete frame showed around 10% increase in axial force relative to bare frame model. The other infill models showed a lesser increase. The effect of infill on columns is to increase the shear force and to reduce bending moments.

In general compared to bare frame model, the infilled models predicted higher axial and shear forces in columns but lower bending moments in both beams and columns. Thus, the effect of infill panel is to change the predominantly a frame action of a moment resisting frame system towards truss action.

Table 1. Comparison of axial force for different models. (KN)

Story	Elevation (m)	Model 1	Model 2	Model 3	Model 4	Model 5
Story 10	31	161	168	170	180	192
Story 9	28	444	454	459	470	488
Story 8	25	728	740	748	763	780
Story 7	22	1011	1025	1035	1052	1070
Story 6	19	1290	1309	1320	1340	1358
Story 5	16	1569	1589	1605	1628	1646
Story 4	13	1842	1865	1882	1907	1927
Story 3	10	2120	2145	2168	2192	2212
Story 2	7	2384	2412	2435	2467	2485
Story 1	4	2577	2608	2635	2662	2682

4.4. Story Shear

Story shear is the total horizontal seismic shear force at the base of structure. Results from static pushover analysis at performance point for the case study buildings are shown in figure 13.

As observed from the figure 13 the story shear calculated on the basis of bare frame model gave a lesser value than the other infilled frames; It was observed that the story shear in fully infilled frame is nearly 15% greater compared to bare frame model and frame with 25% of the masonry wall reduced was nearly 10% greater compared to the bare frame, frame

with 50% of the masonry wall reduced is nearly 8% greater compared to the bare frame and frame with 75% of the masonry wall reduced is about 5% greater compared to the bare frame.

Since the bare frame models do not take in to account the stiffness rendered by the infill panel, it gives significantly longer time period. And hence smaller lateral forces. And when the infill is modeled, the structure becomes much stiffer than the bare frame model. Therefore, it has been found that calculation of earthquake forces by treating RC frames as ordinary frames without regards to infill leads to underestimation of base shear. This is because of bare frame is having larger value of fundamental natural time period as compared to other models due to absence of masonry infill walls. Fundamental natural period get increased and therefore base shear get reduced.

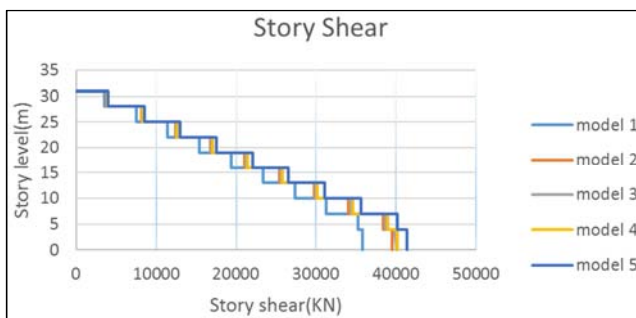


Figure 13. Comparison of story shear for different model.

5. Conclusions

From above results it is clear that pushover curve show an increase in initial stiffness, strength, and energy dissipation of the infilled frame, compared to the bare frame, despite the wall's brittle failure modes.

Due to the introduction of infill the displacement capacity decreases as depicted from the displacement profile (Figure 12). The lateral displacement obtained from the bare frame model is the maximum which is about 60% greater than that of infilled frame.

The presence of masonry walls is to change a frame action of a moment resisting frame structure towards a truss action. When infills are present, shear and axial force demands are considerably higher leaving the beam or column vulnerable to shear failure. The axial force and shear force of the bare frame is less than that of the infilled frame. Columns take the majority of the forces exerted on the frame by the infill because the eccentrically modeled equivalent struts transfers the axial load and shear force transferred from the action of lateral loads directly to the columns.

The story shear calculated on the basis of bare frame model gave a lesser value than the other infilled frames. It was observed that fully infilled frame is nearly 15% greater compared to bare frame model; frame with 25% of the masonry wall reduced was nearly 10% greater compared to the bare frame; frame with 50% of the masonry wall reduced

is nearly 8% greater compared to the bare frame and frame with 75% of the masonry wall reduced is about 5% greater compared to the bare frame. This is because the bare frame models do not takes in to account the stiffness rendered by the infill panel, it gives significantly longer time period.

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