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Seismic Performance of Infilled Reinforced Concrete Buildings

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A R T I C L E I N F O

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A B S T R A C T

In the Moroccan seismic code, infill walls are considered as secondary elements and their lateral strength and stiffness are neglected in the design when considering horizontal seismic loads. In this article we propose to investigate the effect of infill on the seismic performance of the buildings. A 6-stories reinforced concrete frame building is investigated. The concept of equivalent strut is used for infill panel. Diagonal strut carries only compression forces. Strut properties are calculated according to the FEMA306.Software analysis SAP2000 is used to conduct numerical simulations. Numerical results show that there is a change in the internal forces, in the fundamental period of vibration and in the lateral story drift when masonry infill is included in the design. Seismic behavior of infill frame is different from that predicted by bare frame.

1. Introduction

Earthquakes occurred recently in the world, Northridge1994, Kobe 1995, Izmit1999 and Alhoceima2004, have shown that presence of masonry infill walls interact with the surrounding frames and change the seismic response of framed reinforced concrete buildings [1,2]. Behavior of masonry wall infilled frames have been investigated by many researchers, Polyakov1960 [3], Holmes1963 [4], Stafford1969 [5], Paulay and Pristly1992[6], Mehrabi1994[7],Negro1997[8], G. Al-Chaar2002 [9], P.G.Asteris2003 [10]. Most of these studies are focused on the behavior of single-frame single-bay infilled by unreinforced masonry under monotonic or cyclic lateral loading. The results of these studies indicate that masonry infill walls change the dynamic behavior of the building in terms of stiffness, strength, natural frequency and overall structural behavior.In Moroccan seismic code RPS2000 [11], infill walls are considered as secondary elements, their lateral stiffness and strength are neglected when considering loading due to horizontal components of ground motion earthquake.The aim of this paper is to investigate the influence of infill panels on the seismic performance. Lateral strength and stiffness of infill walls is considered by the concept of equivalent diagonal strut. Diagonal strut carries only compression forces. Pushover analysis is used to assess the seismic performance of building. Software analysis Sap2000 [12] is used to perform numerical simulations.

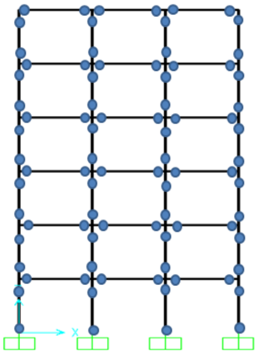

Figure 1: Bare frame with plastic hinges

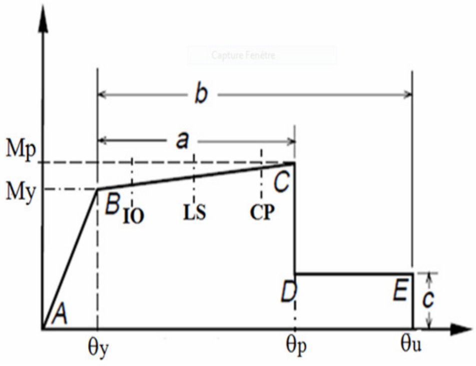

Figure 2: Moment –rotation relation of plastic hinge

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2. Materials and methods

2.1. Modeling of concrete members

Frame members are idealized as elastic elements with a plastic hinge at each end. All material nonlinearities are concentrated in the plastic hinges. The properties of plastic hinges are defined as per FEMA 356 [13].

2.2. Modeling of infill wall

Lateral strength of infill wall is introduced in the analysis by modeling the infill wall by two diagonal struts. Diagonal strut carries only compression force. Properties of equivalent strut are calculated according to FEMA306 [14].

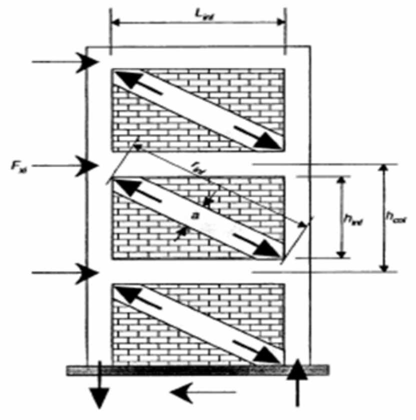


Figure 3: Diagonal strut for infill wall

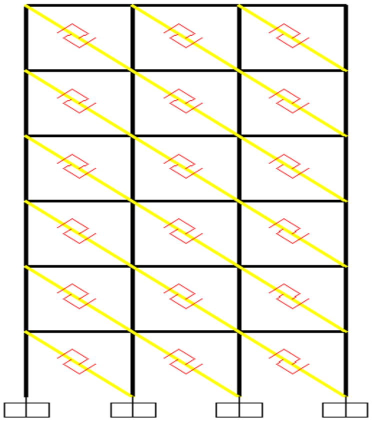


Figure 4: Link element idealization for compression strut

2.3. Parameters of diagonal strut

The width w of the equivalent strut is estimated according to Fema306. Nonlinearity is introduced in each diagonal strut by providing axial compression hinge.

$$w = 0.175d\left(\lambda H_c\right)^{-0.4} \tag{1}$$

$$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c H_m}} \tag{2}$$

$$\theta = \tan^{-1}\frac{H_m}{L_m} \tag{3}$$

Where d is the strut diagonal length, Em is the masonry modulus, Ec is the concrete modulus, Hc is the column height, Hm and Lm are the height and the width of infill wall respectively. Ic is the moment of inertia of column, t is the infill thickness, θ is the angle of inclination of diagonal strut.

3. Numerical investigations

3.1. Building description

To study the influence of infill panel on the seismic behavior of the building, a six stories reinforced concrete building is considered. The total plan dimensions are 9m x 9m. Total height of the building is 18m. The height of each storey is 3m. The columns are 30cmx30cm, 35cmx35cm and 45cmx45cm, the beams are 25cmx30cm for all floors, and the slab thickness is 13cm for all floors. The superimposed loads are 2.5KN/m2 and the live loads are 1.5KN/m2. Two models are considered, first model M1 is bare frame. The second model M2 is infill frame in which the lateral strength of infill is introduced by the concept of equivalent diagonal strut. The building is designed according to the RPS2000 and BAEL [15].

3.2. Properties of the diagonal strut

The frame properties are:

$$\begin{cases} column \quad 30.30 \\ beam \quad 25.30 \\ E_c = 32164 Mpa \\ I = 6.7510^{-0.4} m^4 \end{cases} \tag{4}$$

The infill wall properties are:

$$\begin{cases} H_m = 2.7m \\ L_m = 2.70m \\ t_m = 15cm \\ Em = 1100 Mpa \\ \theta = \tan^{-1}\dfrac{H_m}{L_m} = 45^{\circ} \end{cases} \tag{5}$$

The parameter λ is given by:

$$\lambda = \left[\frac{E_m t_m \sin 2\theta}{4E_f I_{col} H_m}\right]^{\frac{1}{4}} = 0.92 \tag{6}$$

The diagonal strut length d is given by:

$$d = \sqrt{H_m^2 + L_m^2} = 3.81m \tag{7}$$

The width w of equivalent strut is given by:

$$W = 0.175d\left(\lambda H_c\right)^{-0.4} = 44cm \qquad (8)$$

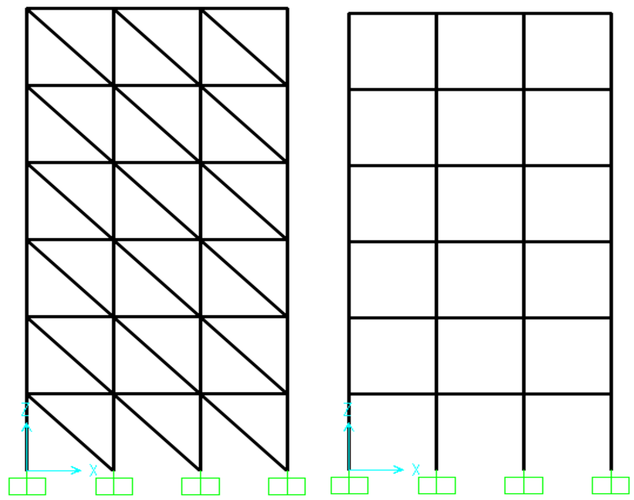


Figure 5: bare frame and infill frame models

Table 1: Mechanical properties and parameters of the study

Storey	disp (cm)	disp (cm)	Ratio
	Bare frame (BF)	Infill frame (IF)	(BF-IF)/BF
6° storey	5,02	2,14	57%
5° storey	4,48	1,94	56%
4° storey	3,54	1,61	54%
3° storey	2,52	1,21	52%
2° storey	1,36	0,72	47%
1° storey	0,47	0,28	40%

Table 2: Reinforcement of beams

Storey	Drift (%)	Drift (%)	RPS2000
	Bare frame	Infill frame	Drift limit (%)
6° storey	0,18	0,06	0,5
5° storey	0,31	0,11	0,5
4° storey	0,34	0,13	0,5
3° storey	0,38	0,16	0,5
2° storey	0,29	0,14	0,5
1° storey	0,15	0,09	0,5

Table 3: Reinforcement of columns

Column	Section	Long- reinf	Stirrups
1° Storey	45x45	12ϕ16	ϕ6 E=15cm
2° Storey	45x45	12ϕ16	ϕ6 E=15cm
3° Storey	35x35	12ϕ16	ϕ6 E=15cm
4° Storey	35x35	8ϕ16	ϕ6 E=15cm
5° Storey	30x30	8ϕ16	ϕ6 E=15cm
6° Storey	30x30	8ϕ16	ϕ6 E=15cm

4. Results and discussion

4.1. Lateral storey displacements

Maximum displacement at different stories is presented in the table 4 and 5. Figures, from 6 to 11 show the base shear versus storey drift. It can be seen that displacements decrease when lateral strength of masonry infill is considered in the model. There is a major reduction in the lateral storey displacements and storey drifts.

Table 4: Lateral storey displacements

Parameter	Value	Unit
Concrete grade	25	Mpa
Steel grade	500	Mpa
Seismic Zone	3	***
Site Factor	1.2	***
Behavior Factor	2	***
Importance Factor	1	***
Infill thickness	15	cm
Masonry strength	2	Mpa
Slab thickness	13	cm
Concrete modulus	32164	Mpa
Masonry modulus	1100	Mpa
Steel Modulus	200000	Mpa

Table 5: Storey drift of bare and infill frames

Beam	Section	Top- reinf	Bottom- reinf
1° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12
2° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12
3° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12
4° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12
5° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12
6° Storey	25x30	4ϕ16+4ϕ12	4ϕ16+4ϕ12

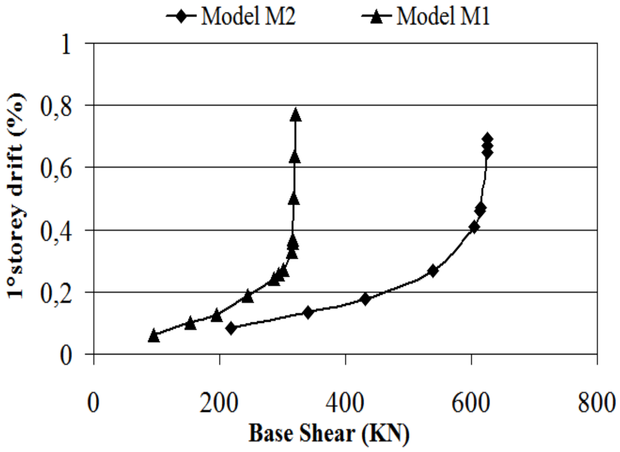


Figure 6: Base shear versus storey drift.1° storey

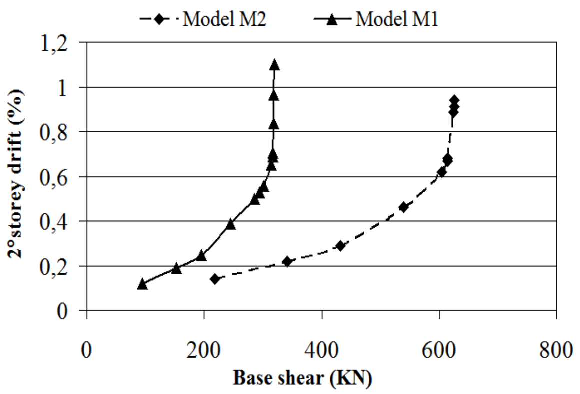


Figure 7: Base shear versus storey drift.2° storey

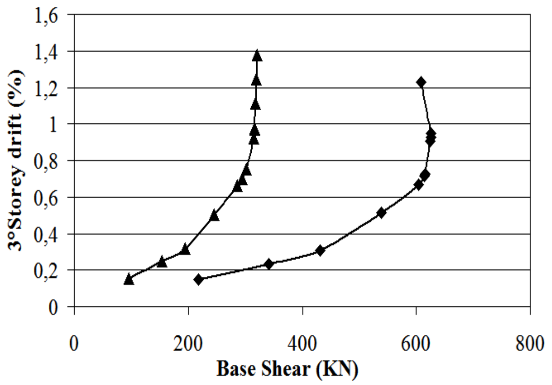


Figure 8: Base shear versus storey drift.3° storey

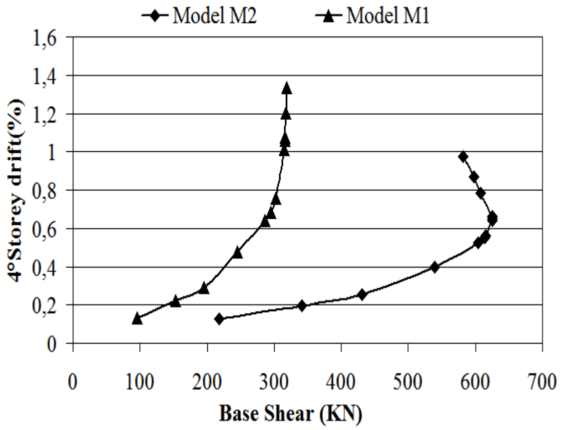


Figure 9: Base shear versus storey drift.4° storey

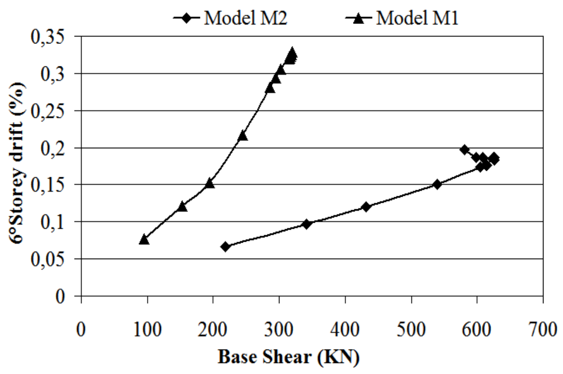


Figure 10: Base shear versus storey drift.5° storey

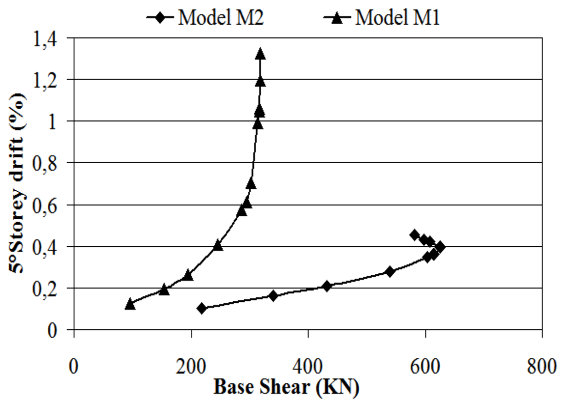


Figure 11: Base shear versus storey drift.6° storey

4.2. Natural periods of vibration

Table 6 shows vibration periods of bare frame and infill frame. It is found that introduction of masonry infill wall increases the lateral rigidity of bare frame; consequently fundamental period of vibration will be decreased. Bare frame idealization, under estimates the seismic design base shear.

Table 6: Natural periods of vibration

Mode number	Infill frame	Bare frame
6° storey	0,251	0,419
5° storey	0,083	0,136
4° storey	0,049	0,078
3° storey	0,036	0,054
2° storey	0,029	0,042
1° storey	0,027	0,036

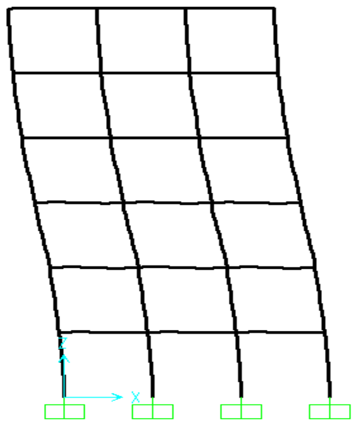


Figure 12: First mode of vibration (frequency=2.38Hz)

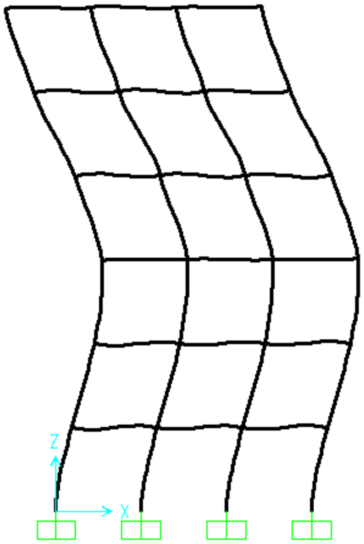


Figure 13: Second mode of vibration (frequency=7.35Hz)

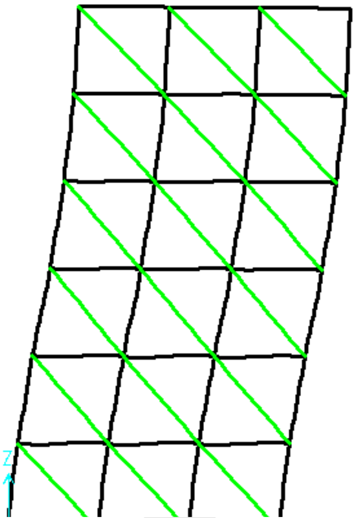


Figure 14: First mode of vibration (frequency=4Hz)

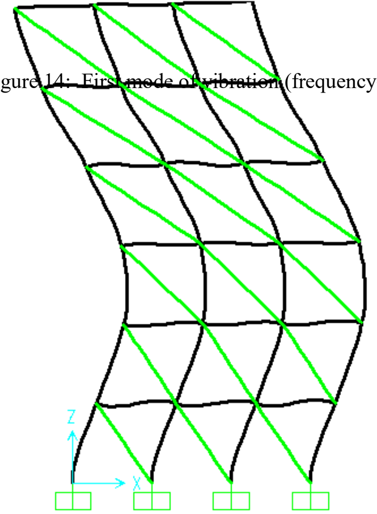


Figure 15: Second mode of vibration (frequency=12Hz)

4.3. Lateral strength and stiffness

Figure 16 shows capacity curves of bare and infill frames. It is found that lateral strength of infill frame is higher as compared to that of bare frame. The increasing in lateral stiffness reaches 2.5 times that of bare frame. Maximum strength of infill frame reaches 1.9 times that of bare frame. These numerical results obtained from this study agree with the experimental studies conducted by M.N Fardis et al [16], A.Hashemi et al [17] and A.Madan et al [18]. Experimantal results indicate that, inclusion of masonry infill increases both lateral stiffness and strength of bare frame.

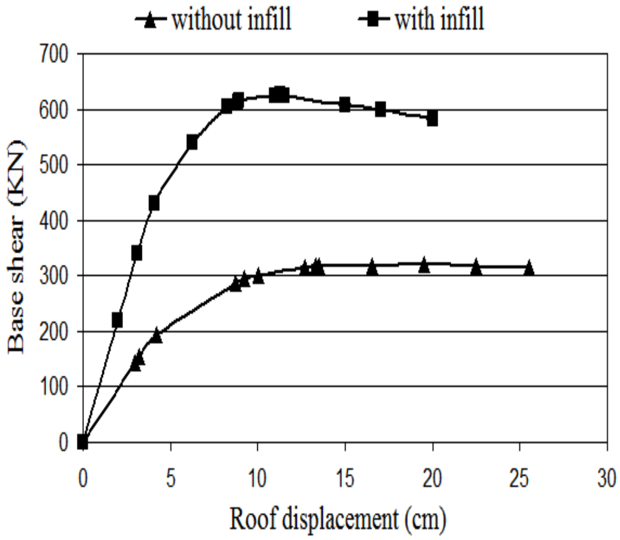
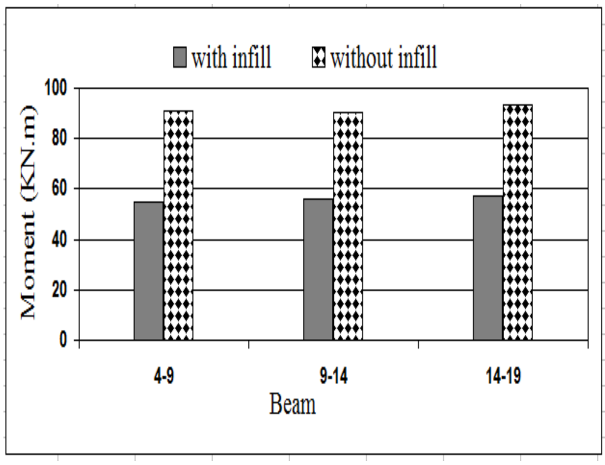


Figure 16: Pushover curves for bare and infill frame

4.4. Internal forces in the frame members

Figures 17, 18, 19 and 20 show the results of shear forces and bending moments obtained when lateral strength of infill is included or when it is ignored. It can be seen that there is an important change in the shear forces and bending moments in the frame members.



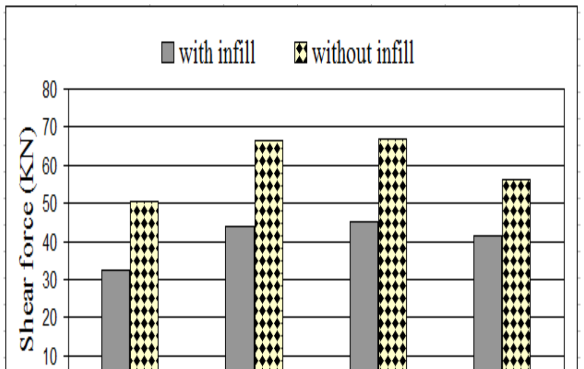


Figure 17: Change in the shear forces. Columns

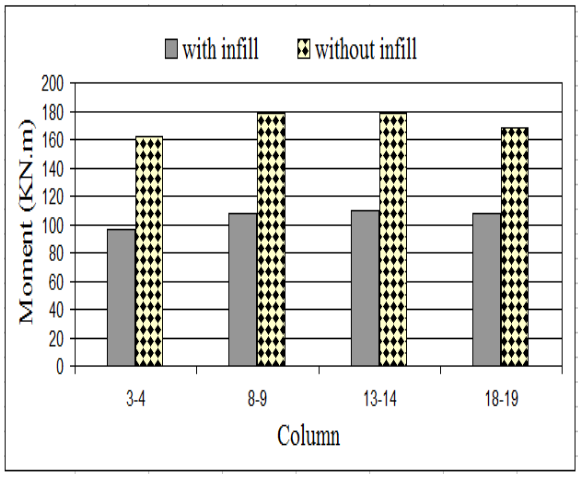


Figure 18: Change in the bending moments. Columns

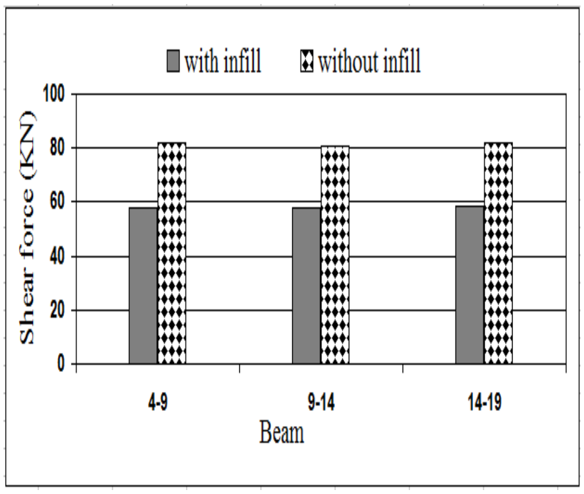


Figure 19: Change in the shear forces. Beams

5. Conclusion

In this study, the influence of infill walls on the seismic response of reinforced concrete buildings was investigated. The principal conclusions can be summarized as follows:

- Numerical simulations show that inclusion of masonry infill reduces significantly fundamental period. The maximum reduction reaches 40%. According to the response spectrum, when period decreases spectral acceleration increases, consequently the base shear design will be increased.
- Introduction of infill wall in the analysis reduces significantly seismic demands. The maximum reduction reaches 50% for lateral storey displacement and 66% for inter-storey drift.

Figure 20: Change in the bending moments. Beams

- Inclusion of infill wall enhances lateral capacity of building. Initial stiffness reaches 2.5 times that of frame without infill, while maximum strength of infill frame reaches 1.9 times that of bare frame.
- Numerical investigations show also that there is a change in the internal forces in the frame members when lateral strength of infill walls was included. Bending moments of bare frame reached 1.60 times that of infill frame, while shear forces of bare frame reached 1.50 times that of infill frame. The infill frame resists lateral loads as a trussed frame then, flexural effects will decrease significantly.

Finally, the results of this study as presented in previous tables and figures, suggest that masonry infill walls change the response of the building when subjected to horizontal seismic forces. Seismic response of infill frame is too much different from that predicted by bare frame.

Conflict of Interest

The authors declare no conflict of interest.

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