International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:9, No:5, 2015

Effect of Infill Walls on Response of Multi Storey Reinforced Concrete Structure

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***Abstract*—**The present research work investigates the seismic response of reinforced concrete (RC) frame building considering the effect of modeling masonry infill (MI) walls. The seismic behavior of a residential 6-storey RC frame building, considering and ignoring the effect of masonry, is numerically investigated using response spectrum (RS) analysis. The considered herein building is designed as a moment resisting frame (MRF) system following the Egyptian code (EC) requirements. Two developed models in terms of bare frame and infill walls frame are used in the study. Equivalent diagonal strut methodology is used to represent the behavior of infill walls, whilst the well-known software package ETABS is used for implementing all frame models and performing the analysis. The results of the numerical simulations such as base shear, displacements, and internal forces for the bare frame as well as the infill wall frame are presented in a comparative way. The results of the study indicate that the interaction between infill walls and frames significantly change the responses of buildings during earthquakes compared to the results of bare frame building model. Specifically, the seismic analysis of RC bare frame structure leads to underestimation of base shear and consequently damage or even collapse of buildings may occur under strong shakings. On the other hand, considering infill walls significantly decrease the peak floor displacements and drifts in both X and Y-directions.

***Keywords*—**Masonry infill, bare frame, response spectrum, seismic response.

I. Introduction

REINFORCED CONCRETE (RC) frame buildings with MI walls are commonly built throughout the world. MI walls are widely used as partitions, and used either to divide the spaces to any required purposes or to protect inside of the structure from environment. Although the structural contribution of MI walls is rarely taken into consideration of such structures, it affects both the structural and non-structural performance of RC structures [1], [2].

Most of the previously conducted research works support that infill walls enhance the resisting capacity to dynamic lateral loads up to a certain level of structural response. The interaction between masonry infills and RC structures highly affects the dynamic characteristics of the structures such as stiffness and natural period of the structure, which might be beneficial or in some cases detrimental depending on the frequency of the applied ground excitation. In addition, since the interaction between MI walls and the building's frames affects the stiffness distribution of the structure, it tends to change the building's overall strength [3], [4].

In spite of considering MI as non-structural elements which are used for architectural purposes and neglected in the frame design, there is a growing need for researchers to evaluate the performance of MI frame buildings in the major earthquake [5]–[7].

The current research work investigates the interaction effect between the MI walls and RC on the dynamic response of RC framed structures with and without masonry infilled through conducting a comparative study between bare frame and infill frame structures. The interaction between MI walls and the analyzed RC structures are modelled with the finite element modeling technique. The infill masonry walls are idealized using the equivalent strut methodology to account for the specific behavior of MI walls. Response spectrum analysis is carried out to assess the behavior of MI-RC structures. The results for the considered RC framed structure considering and ignoring the MI walls action under dynamic response spectrum analysis are introduced in a comparative way in the form figures and tables for of base shear storey shear, displacement, drift, and stiffness.

II. Modelling of Infill Wall

The MI walls are usually modeled as equivalent diagonal compression strut as shown in Fig. 1. In this method the infill wall is idealized as diagonal strut and the frame is modelled as truss element. *FEMA-306* [8] recommends the following equations, which are based on the early studies [9], [10] to calculate the properties of diagonal compression strut where the area A_e as a function of the width of the strut w_e and the thickness of the infill panel t can be written as:

$$A_e = W_e t \tag{1}$$

The width of the strut in terms of the height of the panel h and panel length l can be expressed as:

$$W_e = 0.175(\lambda h)^{-0.4}\sqrt{h^2 + l^2} \tag{2}$$

where the value of λ can be calculated as:

$$\lambda = \sqrt[4]{\frac{E_m t \sin(2\theta)}{4 E_c I_c H_w}} \tag{3}$$

where E_c and E_m respectively denote the elastic moduli of the column and the masonry wall, θ is the angle defining

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diagonal strut inclination, I_c is the moment of inertia of the column and H_w is the height of the infill wall.

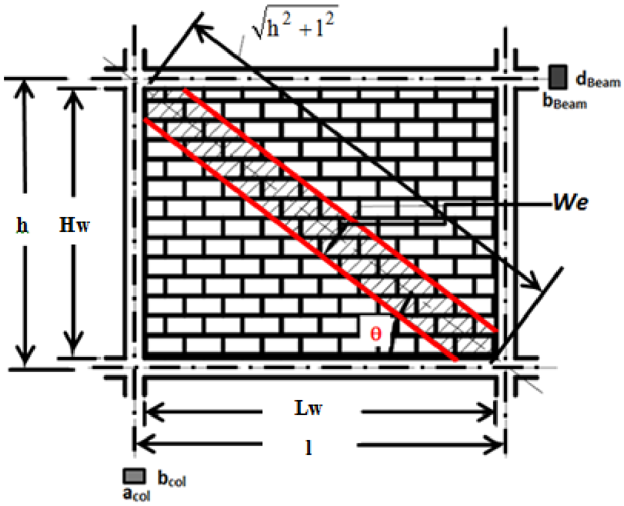

Fig. 1 Equivalent Strut Model for Masonry Infill Walls in Frame Structures

III. Earthquake Analysis Method

Most of the used design codes provide the minimum standards required for providing life safety but not for preventing damage.

Response spectrum analysis is used for analysing the performance of the considered building models under earthquake motions. The abscissa of the spectrum is the natural period (or frequency) of the system and the ordinate is the maximum response.

In order to perform RS analysis, important parameters in terms of expected earthquake intensity in the considered zone, the supporting base soil behaviour and damping have to be considered. One of the other parameters related to the computation process is the modal analysis in which the RS analysis computes the structure's response through considering the significant modes. In the present study, the elastic response spectrum for 5 percent equivalent viscous damping is used. In the current study, the applied response spectrum curves calculated according to the requirement of the Uniform Building Code (UBC97). In addition, the studied building is assumed to be in seismic zone 2B which is remarkable with acceleration equal 0.2g, and the subsoil under the building is considered to be of class S_D.

IV. Building Model

This study investigates the seismic behaviour of multi-storey reinforced concrete frame building with 6-storey for residential use. The building is with plan dimensions of 20.0 m in longitudinal direction and 12.0 m in the lateral direction as shown in Fig. 2. In order to avoid torsional response under the applied lateral load, the plan of the building models has been chosen to symmetric in both X-direction and Y-direction. The typical bay dimension is 4.0 m in both directions as shown in Fig. 2. The typical floor height is 3m, except for the first floor height which is considered to be 4m. The cross section of the columns is reduced every 3 stories towards the roof of the building. All columns are assumed to be of fixed condition at the foundation level. The dimensions of all frame members are presented in Table I.

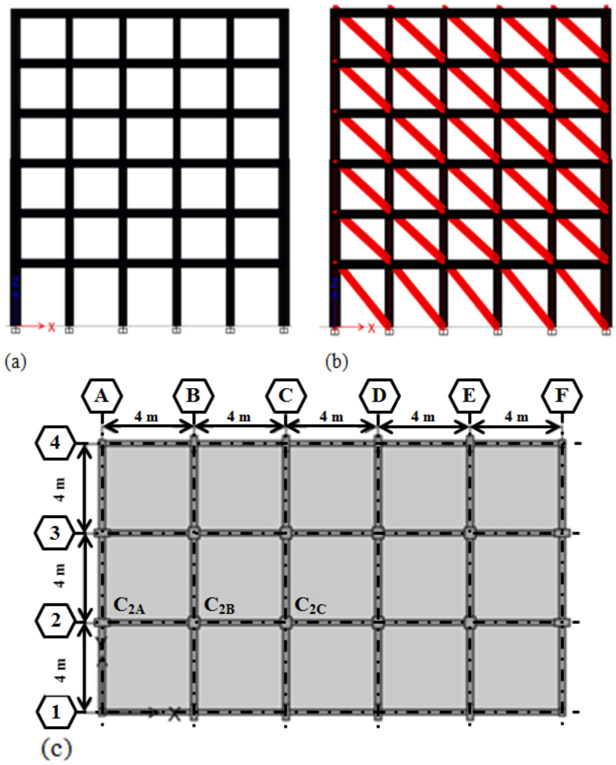

Fig. 2 Schematic representation of (a) Bare frame (b) Masonry Infill Frame (c) and typical floors Plan of the 6-storey residential building

The building models without and with MI walls are presented in Fig. 2 (a). All the considered building models are designed according to the requirements of the EC.

TABLE I
Dimensioning and Reinforcement of Building Elements

Structural Element		Story number 1, 2, 3	Story number 4, 5, 6
Beams	Cross section (m^2)	0.25 x 0.50	0.25 x 0.50
	Reinforcement	4 Φ 16	4 Φ 16
Edge Columns	Cross section (m^2)	0.30 x 0.80	0.30 x 0.70
	Reinforcement	12 Φ 16	10 Φ 16
Inner Columns	Cross Section (m^2)	0.60 x 0.60	0.50 x 0.50
	Reinforcement	20 Φ 16	16 Φ 16
Corner Columns	Cross Section (m^2)	0.40 x 0.40	0.30 x 0.30
	Reinforcement	12 Φ 16	4 Φ 16

V. Dynamic Analysis Results

In order to investigate the lateral response of 6-storey RC framed building considering the effect of MI walls, the finite element analysis software ETABS is employed to create the building models and perform the dynamic analysis of the models and get the seismic response of RC frame building considering and ignoring the effect of MI walls. The dynamic analysis is carried out using response spectrum analysis in X direction. The considered vertical loads in the analysis are the dead loads and live loads. The dead loads include the weight of flooring cover as 1.5 KN/m^2 and the weight of partitioning elements as 2 KN/m^2. The live load for residential RC building is taken equivalent to 2.5 KN/m^2. Concrete having a characteristic strength f_{cu} of 25 N/mm^2, and high-grade steel with yield strength f_y = 360 N/mm^2 are used in the analysis and design. The specific weight of reinforced concrete is taken as γ_c = 25 KN/m^3 and modulus of elasticity E_c is 22x10^6 KN/m^2. For masonry infills; the compressive strength is taken as 5 x10^6 KN/m^2 which are modeled as equivalent diagonal strut, with width of 0.484 m and thickness of 0.12 m for interior walls and with width of 0.450 m and thickness of 0.25 mm for exterior walls.

The results of the dynamic analysis under response spectrum are obtained for both models in presented in a comparative way. Moreover, the shearing forces and bending moments as representatives for the internal forces for the two different models are also presented comparatively.

It is evident from Fig. 3 that interaction between infill walls and frames have pronounced effect on the overall strength of the structure. Generally, the presence of MI walls increases the stiffness of the building.

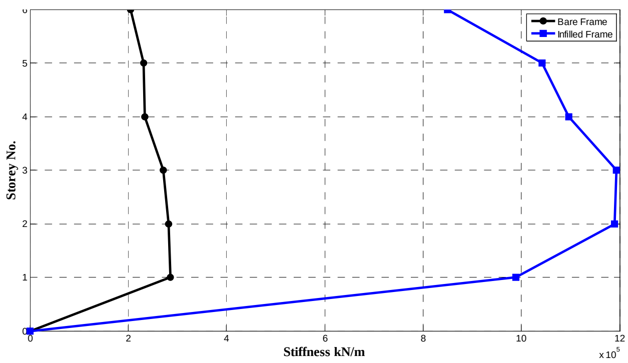

Fig. 3 Storey stiffness under dynamic RS X-dir

The natural periods of the building models are presented in the Table II. It is observed from Table II and Fig. 3 that the presence of masonry infill reduces the time period of infill frame and also enhances the stiffness of the structure. The period of infilled structure is less than bare frame; this is because the stiffness of masonry infill being ignored in bare frame during analysis. Moreover, bare frame idealization leads to overestimation of natural periods and under estimation of the design lateral stiffness.

TABLE II
FUNDAMENTAL NATURAL PERIOD FOR TWO BUILDING MODELS

Building Model / Natural period (Sec)	Bare frame	Infill frame
X- Dir	0.958	0.5049
Y- Dir	0.9376	0.5528

Storey shear is an important parameter from the structural designer's point of view. For the purpose of comparisons, the storey shear distribution throughout the height of building with and without masonry infill under dynamic load acting in X direction is presented in Fig. 4. It is observed from the figure that there is a significant difference between the values of storey shear due to treating RC frames as ordinary frames and those due to considering MI walls especially at the lower storeys of the structure. From percentage point of view, the base shear for the cases of bare frame and masonry infill respectively are: 2414.45 kN and 3017.28 kN; which show significant increase of about 25% of bse shear of building model with MI walls compared to bare frame building model, while an increase in the value of shear of about 4.5% has been noticed at the upper storeys. From results shown in Fig. 4 it can be conclude that, considering MI walls increases the design base shear and vice versa.

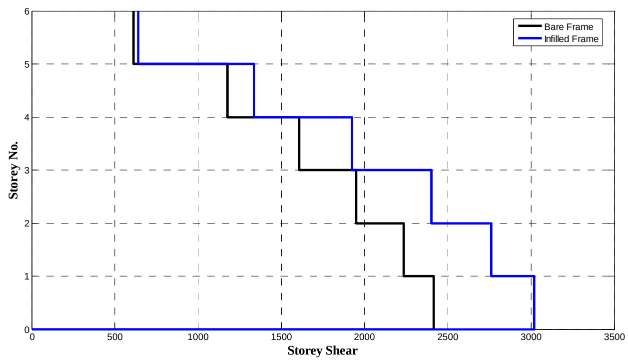

Fig. 4 Storey shear forces dynamic RS X-dir

The effect of masonry infill on storey displacements U_X and U_Y in both X and Y directions respectively under the dynamic RS load in X direction are presented in Fig. 5. From the plots in Fig. 5, it was observed that introduction of masonry infill in the RC frame reduce the lateral displacement considerably due to increasing the lateral stiffness. As it also can be seen, although the direction of loading is in X-direction, the dynamic RS induced storey displacements in both X and Y-directions. From percentage point of view, the percentage decrease in displacement in X-direction at upper storey level is about 70%. For induced displacement in Y-direction the percentage decrease is found to be of about 45%. These percentages decrease as the storey levels decrease.

Storey drift, which can be defined as the lateral displacement of one level relative to the level above or below, is an important parameter to measure displacement changing characteristics to judge the damage of structures.

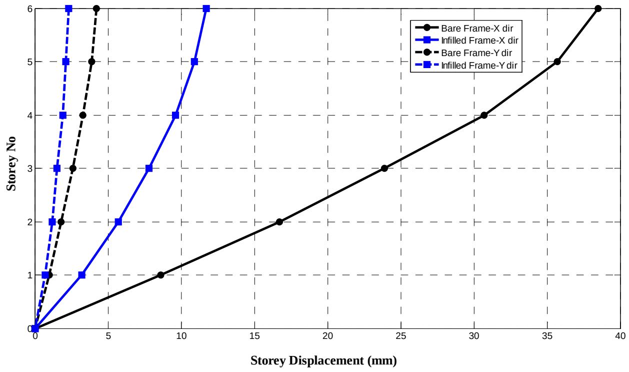

Fig. 5 Storey displacements in X and Y direction throughout the height of building for two building models under RS loading in X-dir

The profile of storey drifts in X and Y direction under the dynamic RS load in X direction are shown in Fig. 5. From the presented plotted curves, it can be seen that, there is an increase in the storey drift of bare frame compared to the infilled frame in both X and Y-directions. This emphasis that modelling the MI walls may ensure that the induced drifts at each storey level does not exceed the allowable limits by the design codes. However, the ignorance of walls modelling overestimates the drifts and the design costs.

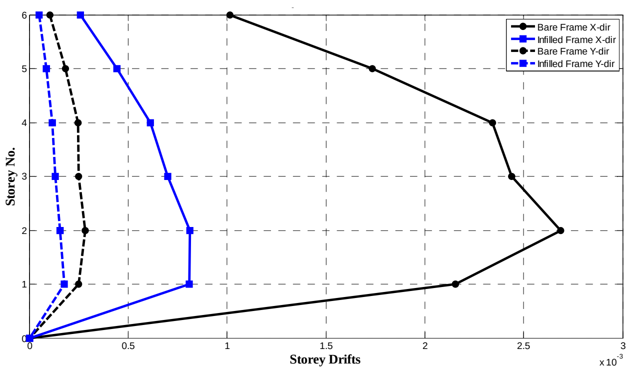

Fig. 6 Storey driftss in X and Y direction throughout the height of building for two building models under RS loading in X-dir

The internal forces for the two different models are presented comparatively for shearing forces and moments in Figs. 7 and 8 respectively. It is observed from figures that there is a Substantial change in the internal force values in columns in case of considering and ignoring modelling MI walls in RC framed buildings. The severe reduction in bending moment and shear force due to the inclusion of MI walls in framed buildings is highly pronounced in columns at base. For bare frame, the shear forces in the columns of the first storey are about 2.7 times those in the columns of fully infilled frame, similarly, the bending moments are also about 2.7 times those in the case of fully infilled frame.

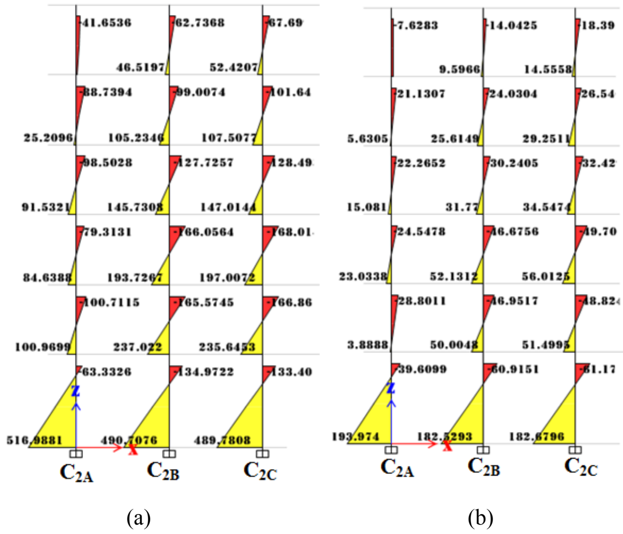

Fig. 7 Column bending moment distribution for two models (a) Bare frame (b) Masonry infill frame

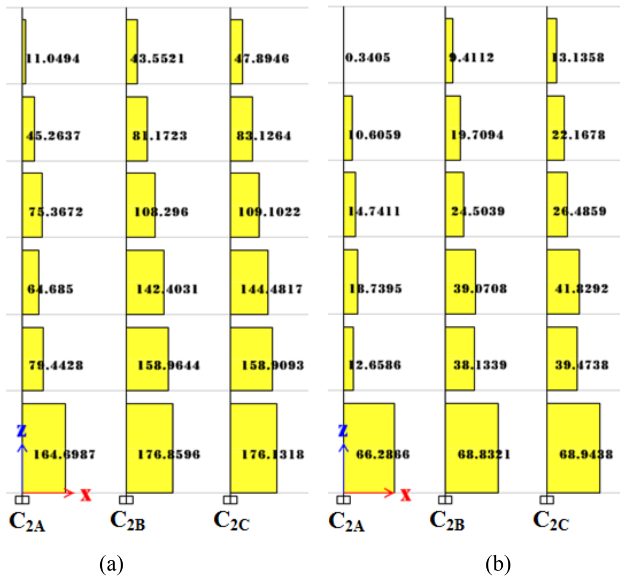

Fig. 8 Column shearing force distribution for two models (a) bare frame (b) masonry infill frame

VI. Conclusion

A dynamic response spectrum analysis is carried out to investigate the effect of MI walls on the response of multistory RC framed building. For comparison purposes, the study considers a 6-storey moment resisting frame without and with MI walls. The results of the study indicate that modelling RC frames as bare frames without regards to infill walls leads to underestimation of base shear and consequently damage or even collapse of buildings may occur under strong shakings. Moreover, the total storey shear force increases considerably as the stiffness of the building increases due to presence of masonry infill. It has been found that MI Walls decrease the displacements, drifts and building natural period, due to the increase in overall stiffness for the building. It has also been observed that incorporation of MI in modeling results in reduction in bending moment and shear force demands acting on the columns especially at the first storey in infill frame as compared to bare frame. Hence, incorporation the wall in the analysis and design leads to slender frame members, reducing the overall cost of the structural system.

References

[1] Flanagan, R.D., Bennett, R.M.: "In-plane Behavior of Structural Clay Tile Infilled Frames" *Journal of Structural Engineering*, Vol. 125, No. 6, pp. 590-599, 1999.
[2] Hao, H., Ma, G., Lu, Y.: "Damage Assessment of Masonry Infilled RC Frames Subjected to Blasting Induced Ground Excitations" *Journal of Engineering Structures*, Vol. 24, pp. 799-809, 2002.
[3] Kodur, V.K.R., M.A. Erki, and J.H.P. Quenneville, Seismic design and analysis of masonry-infilled frames. Canadian Journal of Civil Engineering, 1995. 22(3): p. 576-587.
[4] Humar, J.M., D. Lau, and J.-R. Pierre, Performance of buildings during the 2001 Bhuj earthquake. Canadian Journal of Civil Engineering, 2001. 28(6): p. 979-991.
[5] Saatcioglu, M., et al., The August 17, 1999, Kocaeli (Turkey) earthquake — damage to structures. Canadian Journal of Civil Engineering, 2001. 28(4): p. 715-737.
[6] Korkmaz, K.A., F. Demir, and M. Sivri, Earthquake Assessment of R / C Structures with Masonry Infill Walls. International Journal of Science and Technology, 2007. 2: p. 155-164.
[7] Taher, S.E.-D.F. and H.M.E.-D. Afefy, Role of masonry infill in seismic resistance of RC structures. The Arabian Journal for Science and Engineering, 2008. 33: p. 291-306.
[8] FEMA - 306: "Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings - Basic Procedures Manual" *Federal Emergency Management Agency*, 1999.
[9] Mainstone, R. J.: ''Supplementary Note on the Stiffness and Strength of Infilled Frames.'' Building Research Station, Garston, Watford, 1974.
[10] Smith, B.S.: ''Lateral Stiffness of Infilled Frames'' *Journal of Structural Division*, Vol. 88, No. 6, pp. 183-199, 1962.