THE EFFECT OF MASONRY INFILLS ON SEISMIC RESPONSE OF RC STRUCTURES

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ABSTRACT

The performance of masonry infilled frames during the past earthquakes shows that the infill panels play a major role as earthquake-resistant elements. The present study examines the influence of infill panels on seismic behaviour of RC frame structures. For this purpose, several low- and mid-rise RC frames (two-, four-, seven-, and ten-story) were numerically investigated. Reinforced masonry infill panels were then placed within the frames and the models were subjected to several nonlinear incremental static and dynamic analyses. The results of analyses showed that the use of reinforced masonry infill panels in RC frame structures can have beneficial effects on structural performance. It was confirmed that the use of masonry infill panels results in an increment in strength and stiffness of the framed buildings, followed by a reduction in displacement demand for the structural systems.

INTRODUCTION

In recent years, a couple of studies have been conducted in the field of seismic rehabilitation and strengthening of buildings(Binici et al., 2007; Ozden et al., 2011; Akın and Ozcebe, 2013; Akın et al., 2014). The results prove that reinforced masonry infill panels alter the response of reinforced concrete frame structures in terms of stiffness, strength and ductility(Dolsek and Fajfar, 2008; Uvaet al., 2012; Celareca et al., 2012; Cavaleri et al., 2014). Moreover, infill panels can cause significant changes in dynamic properties of the structure such as period, ductility, and seismic performance factor. The question of whether or not these changes are considered as beneficial is usually dependent on the distribution of infill panels in plan and elevation. A regular distribution of infill panels generally indicates, especially for non-seismic designed buildings, a beneficial effect, increasing global bearing capacity and stiffness under lateral actions. On the other hand, irregular distributions of panels may be dangerous, often being the cause of additional torsional effects, in the case of planar irregularities, and of soft-story mechanisms in the case of elevation irregularities (Cavaleri and Trapani, 2014). Various methods have been developed for finite element modeling of infill panels, in order to determine the actual strength and stiffness of the structures. A particularly effective and widespread approach for representing the combined response of the frame and the masonry infill panels under the seismic actions is the use of equivalent diagonal struts(Saneinejadand Hobbs, 1995). According to previous studies, the initial stiffness of frames can be calculated by using this methodology with reasonable accuracy.

The present study examines the impact of infill panels on seismic response of RC frame structures. For this purpose, several low- and mid-rise RC frames (two-, four-, seven-, and ten-story) were modeled in SAP2000 software. Reinforced masonry infill panels were then placed within the frames and the models were subjected to several nonlinear incremental static and dynamic analyses. It should be noted that the guidelines adopted in this research so as to define the acceptance criteria as well as modeling parameters for frames and reinforced masonry panels include the Iranian Guideline for Seismic Rehabilitation of Existing Masonry Buildings (SREUMB-376, 2007), the Iranian Guideline for Seismic Rehabilitation of Existing Structures (SRES-360, 2006), and FEMA Guidelines (FEMA-273, 1997; FEMA-356, 2000).

MODELLING AND ANALYSIS

Models studied in this research consist of four two-dimensional reinforced concrete frames with two-, four-, seven-, and ten-stories, and with the average story height of 3.2 meters. Gravity and seismic loads were assigned to the frames according to the criteria in the 6th section of the Iranian National Building Code (INBC-06, 2006) and the Iranian Code of Practice for Seismic Resistant Design of Buildings (BHRC, 2005). Moreover, the buildings were considered as ordinary buildings with residential occupancy, and are supposed to be built in a site with conditions matching ground type II. The construction site is also located in a region of high seismicity (Design Base Acceleration Ratio=0.35). The specifications of the beams and columns used in the structures under study are appeared in Fig. 1 and Table 1.

In order to include the effect of infill panels' stiffness in the structural model, an equivalent compressive strut according to the Iranian Guideline for Seismic Rehabilitation of Existing Structures (SRES-360, 2006) was used. Moreover, the modulus of elasticity and thicknesses for the equivalent strut and the infill panel were considered identical. The in-plane stiffness of the uncracked masonry infill panel can be estimated through Eq. (1), by applying an equivalent compressive diagonal strut. It should be noted that in current study the effective width of equivalent struts was calculated considering the changes in the infill panel material strength, bay length, and stiffness of columns adjacent to the infill panels.

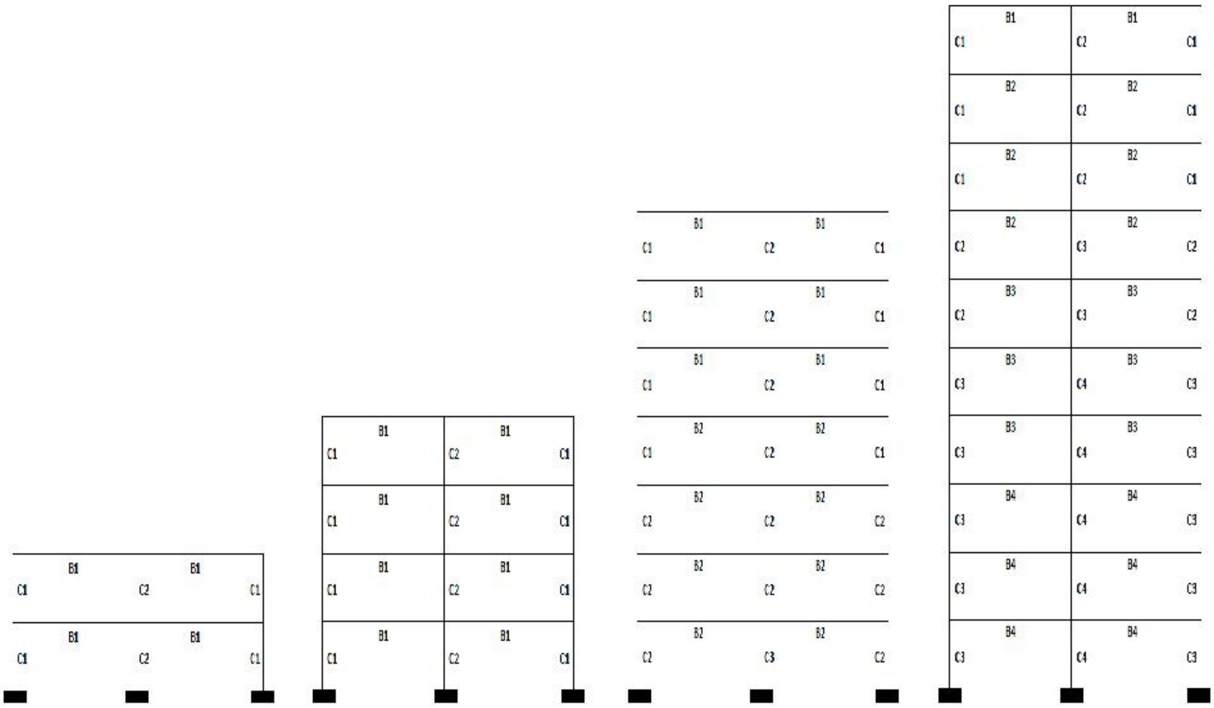


Figure 1. Schematic view of the frame structures

Table 1.Beams and columns used in frames

Section name	Dimensions (cm)
Two-story frame	
C1	40 × 40
C2	45 × 45
B1	40 × 40
Four-story frame	
C1	40 × 40
C2	45 × 45
B1	40 × 40
Seven-story frame	
C1	40 × 40
C2	45 × 45
C3	50 × 50
B1	40 × 40
B2	45 × 45
Ten-story frame	
C1	45 × 45
C2	50 × 50
C3	55 × 55
C4	60 × 60
B1	40 × 40
B2	45 × 45
B3	50 × 50
B4	55 × 55

$$W = 0.254[\lambda h]^{-0.4} d, \lambda = \left[10 E_i t \sin 2\theta / E_f I_{col} h\right] \quad (1)$$

in the above equation:

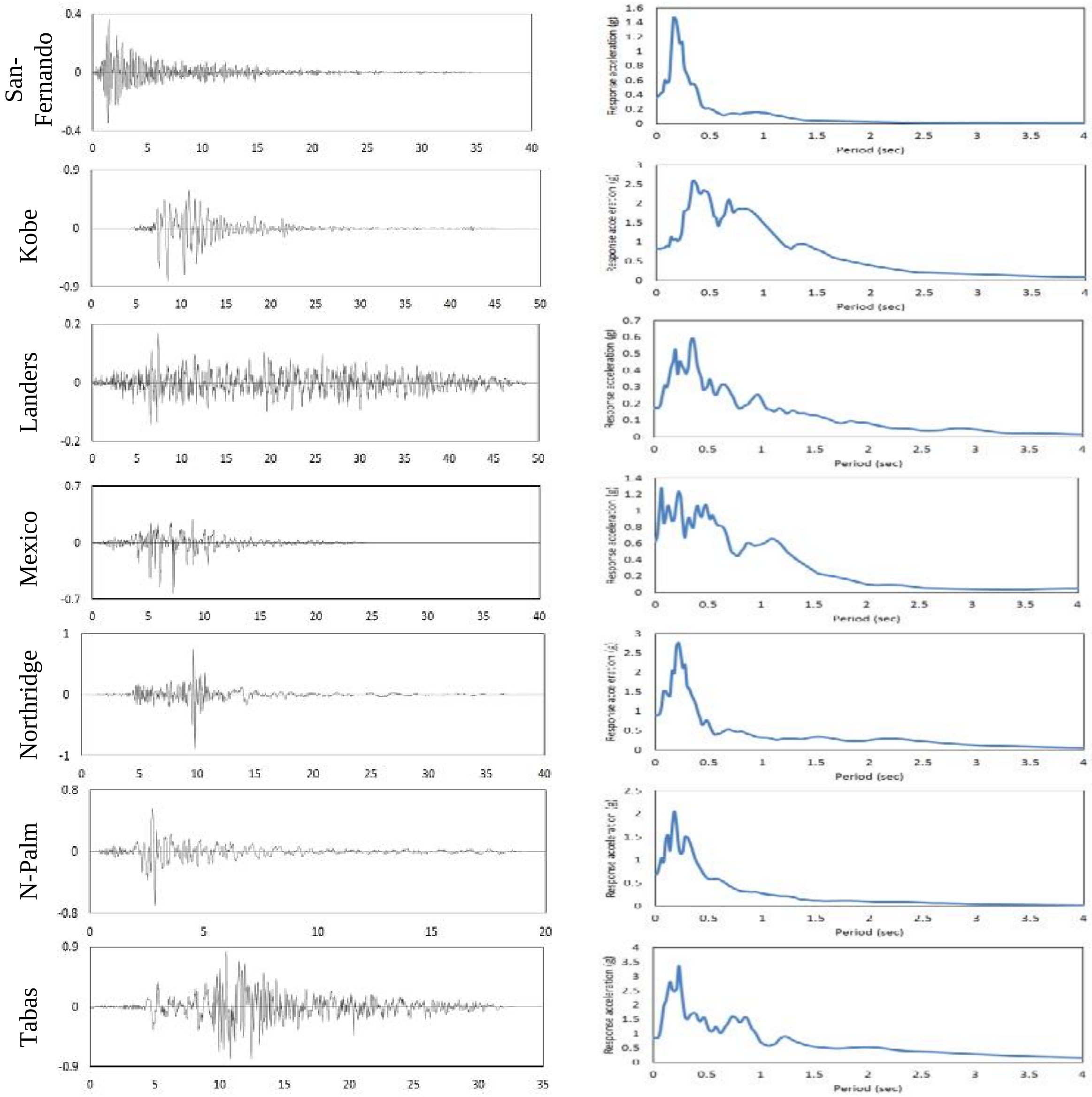
h is the height of the infill panel (cm),
d is the length of the equivalent strut (cm),
E_f is the modulus of elasticity for the frame materials (kg/cm^2),
E_i is the modulus of elasticity for the infill panel materials (kg/cm^2),
I_{col} is the moment of inertia for the column (cm^4),
t is the thickness of the infill panel and the equivalent diagonal strut (cm),
θ is an angle with a tangent equal to the ratio of the height to the length of infill panel's span and,
w is the effective width of the equivalent strut.

In this study, the pushover analysis was used as a complete practical method to identify the overall capacity curve of structures. In this method, the amount of lateral loads increases gradually until the drift of the roof of the building reaches a significant level or the building loses its stability. Since the lateral load distribution should be similar to what happens during a real earthquake, it is usually recommended to use at least two types of load distribution pattern while performing such analysis. These load distribution patterns used in this research are as following:

- Uniform lateral force distribution pattern (Accel)
- Equivalent lateral force distribution pattern (Push)
- Lateral force distribution according to the first mode shape (Mode 1)

Besides, the incremental dynamic analysis (IDA) has been used as another method of analysis in this research. As the nonlinear response of buildings is highly sensitive to the modeling parameters and ground motion characteristics, a single-record IDA cannot fully represent the behavior of a building under the impact of possible future earthquakes. In other words, a set of various ground motion records should be used in order to cover the whole range of responses. The results of the incremental dynamic analysis indicate that this method can be turned into a potentially valuable tool in earthquake engineering.

In the present study, seven ground motion records were used to perform incremental dynamic analysis, and individual capacity curves were obtained from each analysis. General specifications of earthquakes including the magnitude and Peak Ground Acceleration (PGA) of selected records are also shown in Table 2. Moreover, the acceleration time histories of applied ground motions as well as their corresponding response spectrum with 5% damping ratio are depicted in Fig. 2.



Acceleration time history Acceleration response spectrum

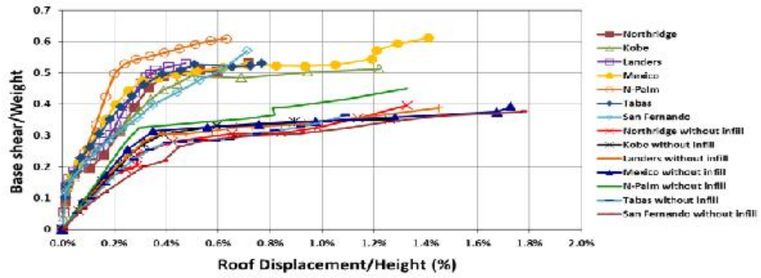
Figure 2. Acceleration time history and response spectrum of earthquakes

Table 2. General specifications of earthquakes

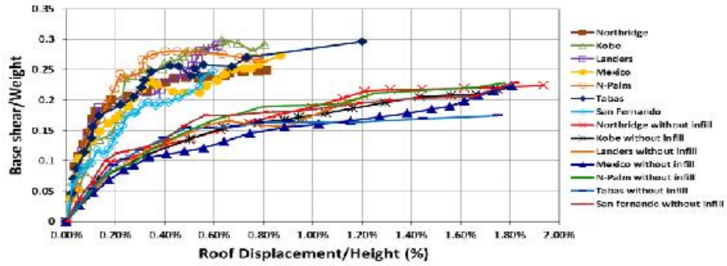
Region	Date	PGA (g)	Magnitude		
			M	Ml	Ms
San Fernando	1971/02/09	0.366	6.6	-	6.6
Kobe	1995/01/16	0.821	6.9	-	-
Landers	1992/06/28	0.171	7.3	-	7.4
Mexico	1980/06/09	0.621	-	6.1	6.4
Northridge	1994/01/17	0.883	6.7	6.6	6.7
N-Palm	1986/07/08	0.694	6.0	5.9	5.0
Tabas	1978/09/16	0.852	7.4	7.7	7.4

RESULTS OF ANALYSES

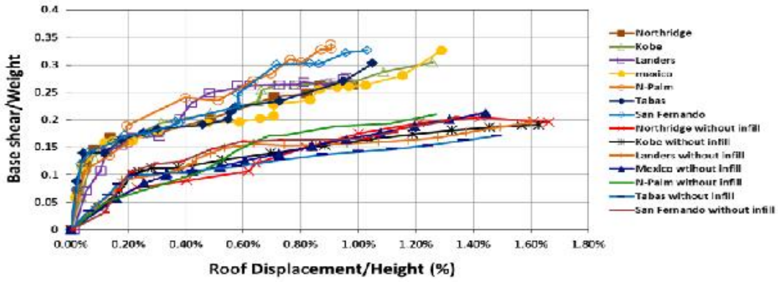
In current study, several 2D frames with and without infill panels were designed and analyzed through SAP2000 software. The side frames were regarded to be entirely infilled by reinforced masonry panels, considering the fact that the middle frames are rarely completely filled by infilling walls. Comparison of results obtained from incremental dynamic analyses has been shown in Fig. 3. Moreover, the results of nonlinear static analyses have been illustrated in Fig. 4. The capacity ratios as well as relative displacement ratios of the infilled frames to corresponding bare frames have also been presented in Table 3.



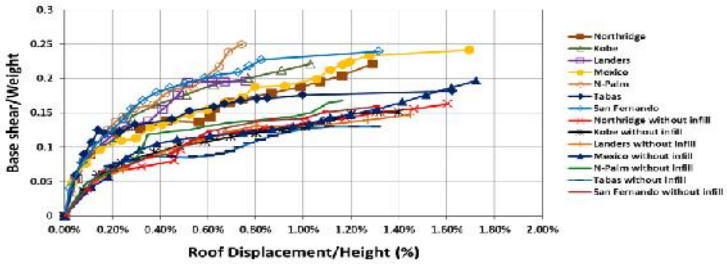
Two-story frames



Four-story frames



Seven-story frames

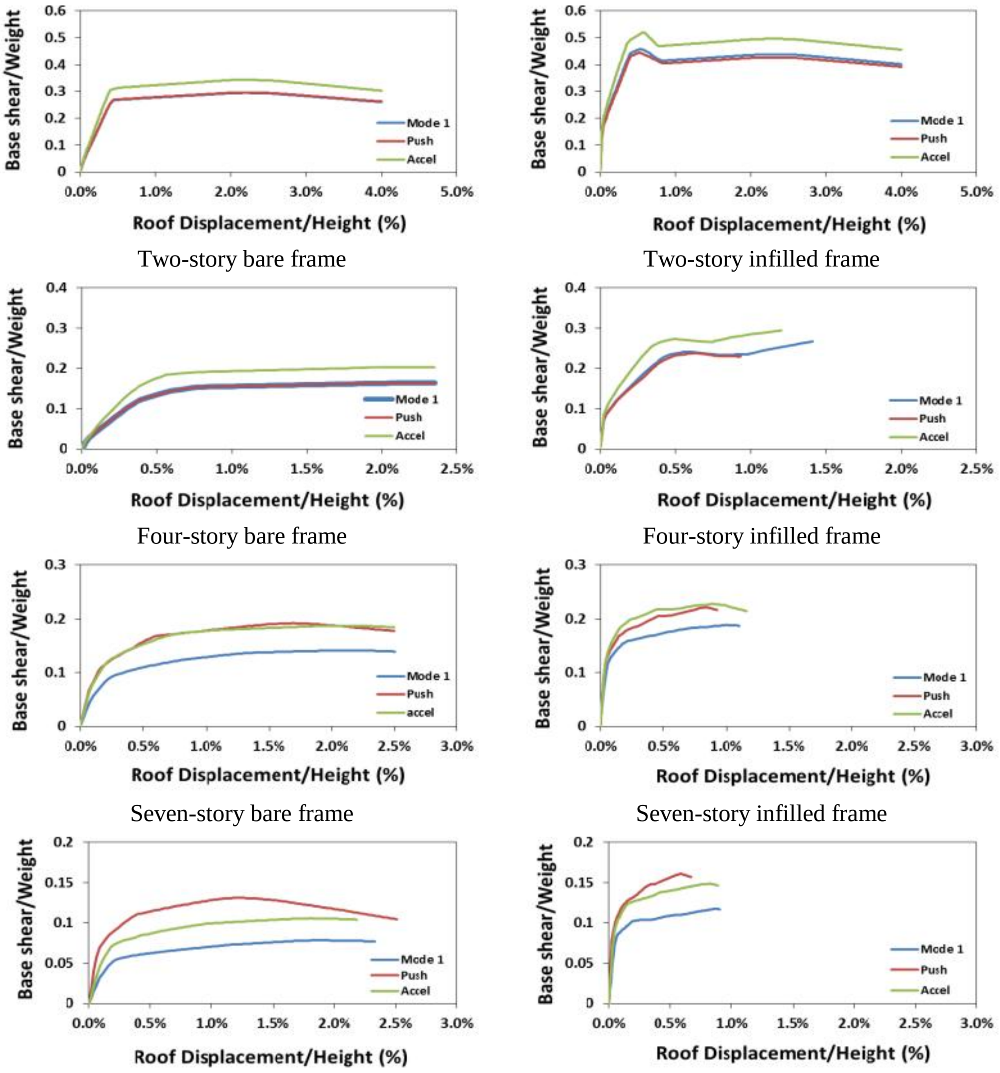


Ten-story frames

Figure 3.Comparison of the capacity curve for the bare and infilled frames

Table 3. Capacity and displacement ratios of the infilled frames to corresponding bare frames

incremental dynamic analysis:	capacity ratio		relative displacement ratio
	linear range	nonlinear range	
two-story frames	1.7	1.4	0.6
four-story frames	1.5	1.3	0.5
seven-story frames	1.7	1.25	0.65
ten-story frames	1.5	1.2	0.8
nonlinear static analyses:	**capacity ratio**		**relative displacement ratio**
	linear range	nonlinear range	
two-story frames	1.6	1.4	0.9
four-story frames	1.4	1.3	0.5
seven-story frames	1.5	1.35	0.45
ten-story frames	1.5	1.3	0.3



Two-story bare frame Two-story infilled frame

Four-story bare frame Four-story infilled frame

Seven-story bare frame Seven-story infilled frame

Ten-story bare frame Ten-story infilled frame

Figure4.Comparison of the pushover capacity curve for the bare and infilled frames

CONCLUSIONS

In this study, finite element models of four low- to mid-rise RC fame structures with and without reinforced masonry infill panels were made. A compression strut model for masonry panels was employed in order to describe the behavior of the infill panels. In brief, it is concluded that using reinforced masonry infill panels in RC frame structures can have beneficial effects on structural performance, and considerably changes the nonlinear behavior of the structure. It is confirmed that use of masonry infill panels results in an increment in strength and stiffness of the framed buildings, followed by a reduction in displacement demand for the structural systems. It is also worth mentioning that infill panels have a more positive influence on strength and stiffness of the structures in two-, four-, and seven-story frames compared to the ten-story frame. This shows that the use of infill panels in low-rise RC frame structures is an effective way of improving structural performance during earthquakes, because of the fact that stiffness is a crucially important characteristic of low-rise earthquake resistant buildings.

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