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# The Effect of Masonry Infill Walls on the Seismic Response of Reinforced Concrete Frames

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Abstract: In the last few years, the scientific community has been hardly involved in the investigation about the interaction between infill masonry walls and Reinforced Concrete (RC) frames in the seismic structural behaviour, and thus for both new and existing buildings. Despite significant research effort dedicated to such buildings, the understanding of seismic behaviour of infilled frames is still not mastered and guidelines for their modeling and analysis are lacking in the design codes. The present paper presents a numerical study using the software computer package SAP 2000 to investigate the effects of masonry infill on the seismic performance of RC framed buildings located in a moderate seismic risk area in Algeria. For this purpose, a number of nonlinear static (pushover) analyses have been performed on spatial bare structures, fully and partially infilled structures. The infills have been modeled with two crossed diagonal struts able to represent the contribution under compression of the panels subjected to dynamic loading along two main directions. The results of the analyses indicate that the infills can have a beneficial effect on the structural response, provided that they are placed regularly throughout the structure. Furthermore, the probability of failure of the infilled frames with regularly distributed infill is smaller than that of the bare frames. Finallay, it has been concluded that some of the provisions of Algerian seismic code RPA99 seem too conservative especially when structures are not very high.

**Keywords:** Reinforced concrete frames; infill masonry; bare framed structure; diagonal struts; non-linear static (pushover) analysis.

#### 1. Introduction

Masonry-infilled reinforced concrete (RC) frames can be found in many parts of the world. There is a lack of structural design standards for masonry infill walls since they are normally treated as non-structural components. However, they will interact with the bounding frame in the event of an earthquake. The ability to assess the seismic performance of these structures is of great importance from the standpoint of hazard mitigation and life safety. Many old structures of this type have non-ductile RC frames, whose interaction with the masonry infill walls may result in complicated failure mechanisms, such as shear failures of the columns, cracking of the masonry mortar joints, and crushing of the masonry units. This presents a significant challenge in the modelling and performance assessment of these structures [1].

The present paper presents a numerical study to investigate the effect of masonry infill on the seismic performance of a RC framed building subjected to dynamic loading taking into account the effects of infills at all three stages, namely, by computing seismic loading, by predicting response of the infilled frame, and by determining the strength of the infilled frame.

# 2. Approach of the analysis

Non Linear Static analysis or Pushover analysis is a technique by which a computer model of the building is subjected to a lateral load of a certain shape (i.e., parabolic, triangular or uniform). The intensity of the lateral load is slowly increased and the sequence of cracks, yielding, plastic hinge formations, and failure of various

structural components is recorded. In the structural design process, a series of iterations are usually required during which, the structural deficiencies observed in iteration is rectified and followed by another. This iterative analysis and design procedure continues until the design satisfies pre-established performance criteria.

The performance criteria for pushover analysis are generally established as the desired state of the building, given roof-top displacement amplitude. The non-linear static analysis is then revisited to determine member forces and deformations at target displacement or performance point. This analysis provides data on the strength and ductility of the structure which otherwise cannot be predicted. Base shear versus top displacement curve of the structure, called pushover curves, are essential outcomes of pushover analysis. These curves are useful in ascertaining whether a structure is capable of sustaining certain level of seismic load or not. This method is considered as a step forward from the use of linear analysis, because they are based on a more accurate estimate of the distributed yielding within a structure, rather than an assumed, uniform ductility. The generation of the pushover curve also provides the nonlinear behaviour of the structure under lateral load. However, it is important to remember that pushover methods have no rigorous theoretical basis, and may be inaccurate if the assumed load distribution is incorrect. For example, the use of a load pattern based on the fundamental mode shape may be inaccurate if higher modes are significant, and the use of any fixed load pattern may be unrealistic if yielding is not uniformly distributed, so that the stiffness profile changes as the structure yields [2]. Here the lateral load obtained by dynamic analysis based on response spectra provided by (RPA 2003) [3] is used.

# 3. Modeling of infill walls

In-plane, lateral stiffness of an infilled frame is not simply the addition of the lateral stiffnesses of the bare frame and the infill wall due to interaction between the frame and the infill wall. Under lateral loading of an infilled frame system, high compression stresses form across the diagonal of an infill. Tensile strains are transverse to these principal compression stresses and strains.

Diagonal cracking occurs when the tensile strains exceed the cracking strain of the infill wall material. Diagonal cracking behaviour usually signals the formation of a new strut behaviour mode. After the formation of the equivalent compression strut, corner crushing is often the next and final limiting condition. In modelling of infill walls, only the walls, which were enclosed by two columns/shear walls and two beams, were taken into consideration. Rigidity of infill walls were modelled as equivalent diagonal compression struts and the mass of infill walls were modelled as area sections with mass and zero stiffness. Additional mass of the infill wall increased the total mass of the structure and consequently increased the inertia force on the structure during an earthquake. Diagonal struts elements were connected to beam\_column joints with hinge, moment-free connections, so they could only take compressive forces. The tensile strength of the equivalent diagonal compression strut was neglected, [4].

The stiffness and strength of an equivalent diagonal compression strut was determined using the recommendation given by [5]. These provisions were based on the early studies of [6], [7]. The equivalent diagonal compression strut shown in Fig.1 was represented by the actual infill thickness,  $t_{inf}$ , which was in contact with the frame, and the diagonal length,  $r_{inf}$ . The equivalent width of a diagonal compression strut, a, is given by:

$$a = 0.175 (\lambda_1 h_{col})^{-0.4} r_{inf}$$
 (1)

Where

And

$$\lambda_{1} = \left[\frac{E_{me}t_{\inf}\sin 2\theta}{4E_{fe}I_{col}h_{\inf}}\right]^{1/4}$$

$$\theta = \tan^{-1}(\frac{h_{\inf}}{L_{\inf}})$$

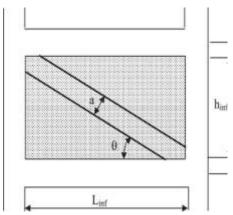


Fig. 1: Equivalent diagonal compression strut model for infill walls

Finally in what refers to the masonry infill panel models, using SAP 2000 [8], it is necessary to define the behaviour model specified in such programs as was done by [9] and more recently by [10]. Those models consist in the introduction of equivalent ties which only work in compression.

Table 1 presents all the values given to the forces and displacements necessary for the definition of the masonry model.

TABLE I: Values related to the forces and displacements of the masonry model

Fc (kN)	$D_{c}(m)$	$F_m(kN)$	D <sub>c</sub> (m)	$F_{u}(kN)$	$D_{u}(m)$
110	0.001	135	0.075	0	0.3

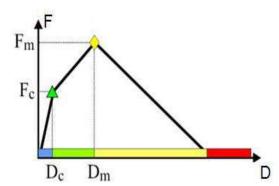


Fig. 2: Masonry infill model introduced in SAP 2000

#### 4. The case studied

#### 4.1. General description of the structure

The three story concrete structure shown in Fig. 3 is designed according to the Algerian building and seismic code, RPA99 V2003. It is assumed that structure is built on soft soil in zone 2 of Algerian seismic map (moderate risk seismicity). This building is 12 m x 10 m in plan, and 3 m x 3 floors in elevation. The bays are 4m center to center in X direction and 5m in Y direction, with four bays in X direction and two bays in Y direction. To assess the influence of the masonry infills, three structural configurations have been used: fully infilled frames (FIF3), partially infilled frames in the two first stories (PIF2) and partially infilled frames only in the first storey (PIF1). The infilled frame is assumed to exist only in the exterior frames, as shown in Fig. 3. This case corresponds to buildings in which the interior infills have been removed in the modelisation. In this case, the exterior frames are modelled as the perimeter frames, due to their much higher strength and stiffness compared to the punched interior frames. Infill panels with openings are not considered here, for simplification purposes.

The structure of reference in the present study is the bare frame, i.e without any infill walls.

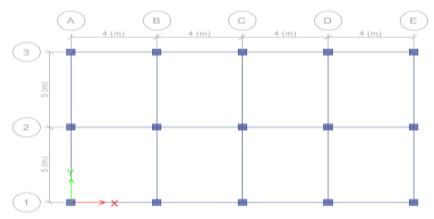


Fig. 3: Plan of the typical floor of the structure

## 4.2. Mechanical properties of materials

The compressive strength of the concrete fck is 25 MPa for all the frame elements while the yield strength of the longitudinal and transverse steel reinforcement fyk is assumed to be 400 MPa.

The average compressive strength of masonry infill walls was much lower, only 10 MPa, and tensile strength is neglected.

The geometrical parameters of the frame members are presented in Table 2, and the properties of the materials are indicated in Table 3.

Moment of Frame element Transverse section Transverse section inertia dimension [m] area [m²] Longitudinal beams 0.3x0.40.120 0.0016 0.3x0.450.135 0.0023 Transversal beams Columns 0.4x0.40.160 0.0021

TABLE II: Geometrical parameters of frame members

TABLE III: The properties of the materials

Frame element	Modulus of elasticity [kN/m²]	Poisson coefficient	Tension steel A <sub>s</sub> [cm <sup>2</sup> ]	Compressive steel A' <sub>s</sub> [cm <sup>2</sup> ]
Concrete Longitudinal beams C25/30	32 10 <sup>6</sup>	0.20	6.03	4.62
Concrete Transversal beams C25/30	32 10 <sup>6</sup>	0.20	7.16	6.03
Concrete Columns C25/30	$32\ 10^6$	0.20	8.04	8.04
Masonry	$1.1  10^6$	0.18	/	/

#### 4.3. Numerical models

All computer models were generated and analysed by (SAP 2000) using finite element approach, in order to perform the preliminary assessment, the modal analysis and the specific investigation of the non linear behaviour.

To perform a pushover analysis a load pattern which is equivalent to the earthquake load is required. This load is applied laterally to the structure by increment. The spectrum response analysis of the structure is done and the lateral load distribution on the structure is obtained according to Algerian seismic code (RPA99 V2003).

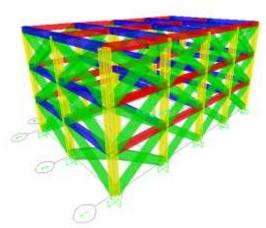


Fig. 4: The 3D frame Model

#### 5. Results and discussions

### **5.1 Dynamic properties**

The response of a structure subjected to a dynamic loading is strongly dependent on such basic properties as the fundamental period of vibration and the dumping of the structure. These properties are dependent on the mass, strength and stiffness of the structure and is thus affected by many factors such as structural regularity, number of stories and bays, section dimensions, infill panel properties, axial load level, reinforcement ratio and extent of concrete cracking. In general, a significant increase in the stiffness of the system could be induced, with a consequent decrease of the natural vibration periods of the structure.

In order to assess the dynamic behaviour of the building, a modal analysis has been performed by implementing an elastic model and assuming the hypothesis of rigid floors. This allowed to investigate the features of the first vibration modes. The basic modal properties of the building are shown in Fig. 5 while the storey displacements of each model is plotted in Fig.6, both in the case of structure with infill and in the case of the bare frame. It can be seen that the fundamental period of vibration of the bare frame is 0.384 s and 0.286 s for the fully infilled frame, which means that the infills contribute in the stiffening of the structure pointed out by the decrease of the fundamental periods. With regard to the structure without infills, the values obtained are in a good agreement with the estimates provided by the method of Rayleigh  $T = 0.075H^{0.75} = 0.389s$ . With regard instead of the infilled structure, the formulas reported in Algerian seismic code RPA99v2003 and EC8 (2004) can be assumed as a reference point  $(T = 0.050H^{0.75} = 0.260s)$ .

Finally, a comparison has been carried out also in terms of displacements. It is possible to observe that the presence of infills is crucial. Moreover, it is observed a reduction of about 246% of the maximum displacement in X direction between the bare and the fully infilled frame and about 178% in Y direction.

#### **5.2 Pushover analyses**

Pushover analysis has been conducted for the four model buildings. The material nonlinearities are assigned as hinges; M3 flexural hinges for beams and PMM flexural hinges for columns. Then each lateral load pattern is applied. The pushover curves for the two main directions X and Y are presented in Fig. 8. It can be seen that the four curves show similar features and the presence of masonry infill increases slightly the strength of the structure but the stiffness and ductility remain practically unchanged. For example, the difference between the maximum base shear of the fully infilled frame and the bare frame is only (1%) in the X direction. This is because the structure is already not high and it was designed according to Algerian seismic code which contains very conservative provisions, i.e in RPA99v2003 the number of stories in moderate seismicity areas is limited to 3 but for study purposes, it was decided for the present study to add three stories above the initial structure for better assessment of the effect of the infill masonry, with the following configurations:

- Bare frames of six (06) stories;
- Fully infilled frames of six (06) stories (FIF6);

- Partially infilled frames of six (06) stories (PIF6) which the masonry is distributed in all stories except in the third story.

Fig.9 illustrates the effect of infill on the pushover response, showing the base shear versus displacements response for the six stories case. Although all of these buildings fail in the first story, the addition of infill to the frame increases both stiffness and strength. Indeed, the fully-infilled frame shown has approximately a stiffness equal to 3.2 that of the bare frame and a strength equal approximately to 2.2 that of the bare frame in X direction, and it has 2.46 times larger stiffness and 1.44 times greater peak strength than the bare frame in Y direction. The response of the partially-infilled frame is between the fully-infilled and bare frame case, such that, the partially-infilled frame has about double the stiffness and slightly greater peak strength than the bare frame.

However, the presence of infill decreases the structures ductility due to rapid degradation of the infill walls and neighbouring frame elements once the base shear capacity is reached. The attention is focused on framed structure characterised by a soft third storey, which has a very brittle behaviour. In this case, the displacements decrease by about 50% relatively to that of bare structure, especially in X direction where the distribution of infill walls is higher compared with Y direction.

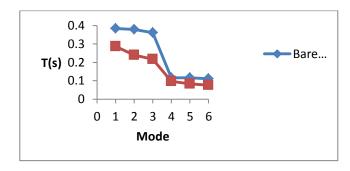


Fig. 5: Periods of vibration for the six vibration modes

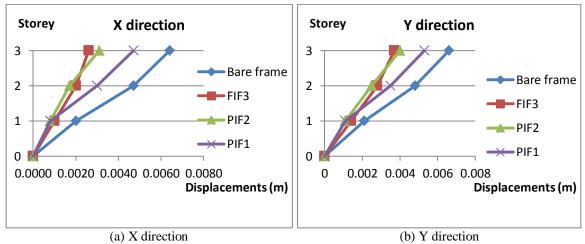


Fig. 6: Storey displacements for each model

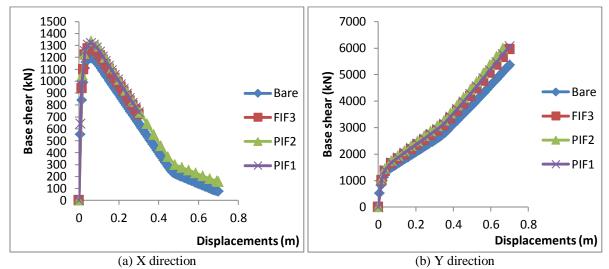


Fig. 8: Pushover curves of all the models of 03 stories

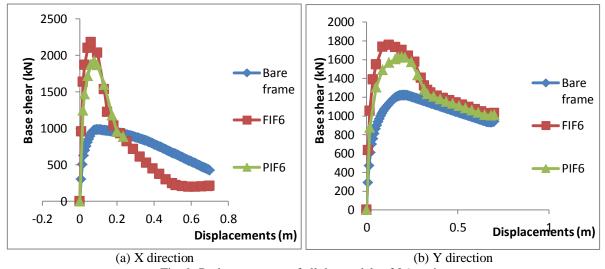


Fig. 9: Pushover curves of all the models of 06 stories

#### 6. Conclusions

Under the light of the results of the present numerical study, the following conclusions may be stated:

The distribution of the masonry infill walls throughout the story has insignificant effect on seismic behaviour of reinforced concrete buildings provided that symmetric plan layout of a building and symmetric arrangement of the infill walls are satisfied.

The behaviour of an infilled frame is dependent on the properties of frame and infill; hence, the response of such frames should be based on overall frame to infill composite action rather than on isolated bare frame behaviour.

The collapse mechanisms of the three models of six stories clearly show that the presence of the infills affect in negative way the ductility of the whole structure.

The presence of the infills reduces considerably the displacements at all stories compared with the bare structure (246%).

The fundamental period of infilled structures is in a good agreement with the estimated value provided by RPA99 and EC8 (T=0.050H0.75).

The results of the study demonstrate that masonry infill highly increases the stiffness and strength of a structure as long as the seismic demand does not exceed the deformation capacity of the infills. After that, both the global stiffness and the global strength strongly deteriorate.

The Algerian seismic code RPA99 seems to be very conservative especially when structures are not very high (less than three levels or a total high of 14 meters). This has been very relevant for ductility and when comparing the response and the demand, the RPA99 predictions have always been found on the very safe side.

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