

# Influence of Masonry Infill on the Linear Seismic Response of Reinforced Concrete Frame

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## ABSTRACT

The present study involves a comparison of the linear seismic responses of reinforced concrete frame structures. These responses result from two different modeling approaches for masonry infill walls: one employing a single equivalent diagonal strut, and the other following the guidelines of the current Algerian seismic code (RPA99/version 2003). The latter considers the infill wall stiffness solely through the global behavior coefficient R, without introducing any diagonal strut.

Using the SAP2000 software, modal analyses with respect to the Algerian response spectrum were conducted on various three-dimensional (3D) Gf+6 story building models. These models included: (1) a bare frame, (2) a frame with infill panels extending throughout the height, and (3) frame models with infill panels and a flexible floor located at various levels of the structure.

Various response parameters, such as fundamental natural periods, floor displacements, inter-story displacements, P- $\Delta$  effects, shear forces, and bending moments at different floors, were computed for all considered configurations and presented in a comparative manner. The results obtained from the models employing the equivalent diagonal strut significantly deviate from those obtained using the current Algerian seismic code. The latter yields result that do not accurately reflect the influence of infill walls on the overall structural behavior when subjected to lateral forces. These findings underscore the importance and necessity of incorporating the modeling of infill wall effects using an equivalent diagonal strut in the current Algerian seismic code.

**Keywords:** infill masonry wall, equivalent diagonal strut method, RPA99/version 2003, soft story, transparency, spectral modal method.

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## INTRODUCTION

Reinforced concrete (RC) frame structures with full or partial brick masonry infill walls are widely used in both urban and rural areas of Algeria. Brick masonry is the predominant infill material due to its availability, low cost, and favorable acoustic and thermal performance. However, despite their high vulnerability under lateral seismic actions, multi-story RC buildings with soft or transparent ground floors (such as parking garages and entrance halls) have become increasingly common, especially in large cities where land is limited. Although design codes generally consider infill walls as non-structural components and therefore ignore their contribution to lateral resistance, numerous studies have shown that, during earthquakes, these walls interact with the surrounding RC frames and can significantly influence the global seismic response of the structure due to their in-plane stiffness. As a result, they affect the overall strength, stiffness, and ductility of the building.

The aim of the present paper is to demonstrate, through spectral modal analysis, the inadequacy of the current Algerian seismic code RPA99/version 2003 in properly representing the influence of masonry infill walls on the linear seismic behavior of RC frame structures. To this end, two modeling approaches are compared: (i) a model that incorporates infill walls using a single equivalent diagonal strut based on Mainstone's formulation, with a constant

global behavior coefficient of  $R = 5$  for all models; and (ii) a model that follows the recommendations of RPA99/version 2003, in which infill walls are not represented by diagonal struts and different behavior coefficients are adopted depending on the configuration of infills ( $R = 3.5$  for fully infilled frames,  $R = 2$  for soft/transparent story configurations, and  $R = 5$  for bare frames without rigid infill), as specified in Table 4.3 of RPA99/version 2003 (categories 1a, 1b, and D17).

### MODELLING OF MASONRY INFILL WALLS

During experimental tests conducted by Mainstone [8], Klingner, and Bertero [6] on masonry-filled frames subjected to lateral loads, a notable phenomenon emerged. Diagonal cracks began to manifest at the center of the infill panel, and gaps formed between the frame and the panel along the unloaded diagonal, while complete contact was observed in both corners of the loaded diagonal, as illustrated in Figure 1 [1].

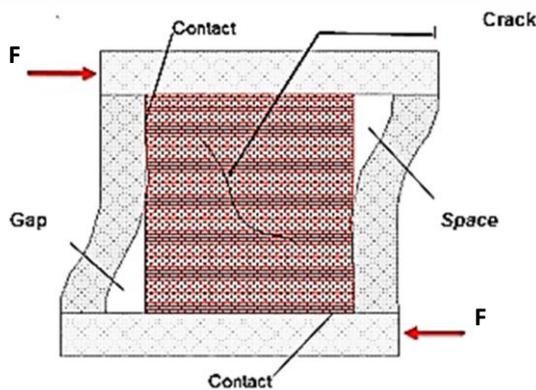


Fig1: Masonry-Filled Frame Under Lateral Force

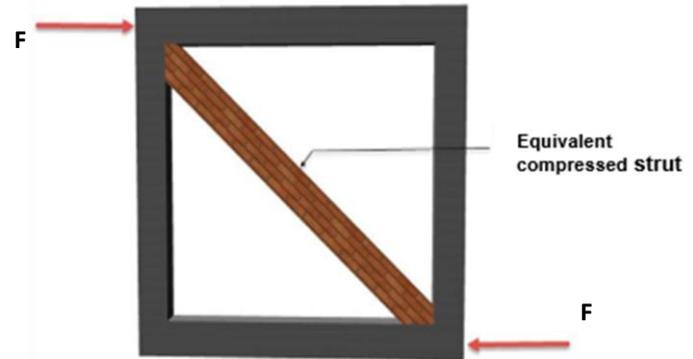


Fig2: Equivalent Diagonal Strut

Polyakov [11] introduced the macro-modeling method, also known as the equivalent diagonal strut method, in 1966, wherein masonry infill was replaced by an equivalent compressed masonry strut to analyze the overall response of masonry-filled frame buildings (Figure 2). The primary limitation of this method lies in its deficiency in accurately modeling openings [8]. Nevertheless, some progress has been made concerning infill wall openings, where a number of struts can be employed to account for the effect of openings [3]. In this study, only the exterior infill walls are modeled as solid infill panel elements without any openings.

#### 1. Geometric and Mechanical Characteristics of the Equivalent Diagonal Strut

Various formulations have been devised to ascertain the width of the diagonal strut and the panel's strength. Some of these recommendations have been incorporated into national building codes, yet a unified approach to the issue remains elusive [3]. In this study, we will adhere to the FEMA 356 guidelines [4], which embrace the Mainstone formulation, for modeling masonry infill walls.

##### a. Width of the Equivalent Diagonal Strut

According to FEMA 356, masonry infill walls before cracking are represented using an equivalent diagonal compression strut with a width denoted as 'a'. The thickness and elastic modulus of the strut match those of the depicted infill panel of (Figure 3). The mathematical expression for the width of the equivalent diagonal strut, 'a,' according to Mainstone [9], can be written in terms of the height between the axes of column and beam,  $h_{col}$  and the length of the infill panel diagonal,  $r_{inf}$  and the coefficient  $\lambda_1$  as follows:

$$a = 0,175(\lambda_1 h_{col})^{-0,4} \tag{1}$$

Where  $r_{inf}$  is expressed in accordance with the equation. (2)

$$r_{inf} = \sqrt{(L_{inf})^2 + (h_{inf})^2} \tag{2}$$

The coefficient  $\lambda_1$  is computed based on several parameters, including the height of the infill panel  $h_{inf}$ , the elastic moduli of both the frame material  $E_{fe}$  and the infill panel material  $E_{me}$ , the moment of inertia of the columns  $I_{col}$ , the length of the infill panel  $h_{inf}$ , the thickness of the infill panel  $t_{inf}$  and the angle  $\Phi$  formed by the diagonal strut and the horizontal axis. This calculation is performed according to the equation (3) presented below:

$$\lambda_1 = \left[ \frac{E_{me} t_{inf} \sin 2\Phi}{4 E_{fe} I_{col} h_{inf}} \right]^{1/4} \tag{3}$$

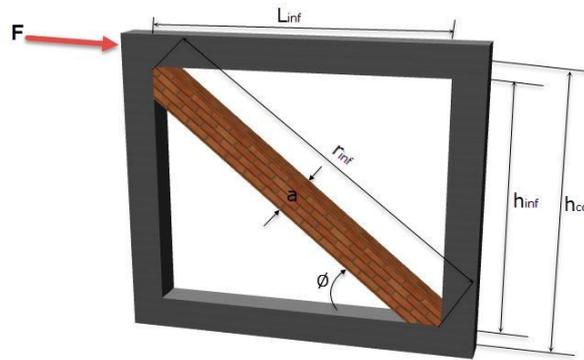


Fig3: Parameters characterizing the equivalent compressed strut

b. resistance of the diagonal strut

The following equations describe the behavior of this type of structure under seismic action and establish the resistance capacity of infill walls for each mode of failure. These formulas relate exclusively to in-plane failure modes. The equations in this subsection are primarily derived from [1] and [5]. The strength of the strut is determined by calculating the force required to reach the masonry's crushing strength and the force required to attain its shear resistance. The components of these forces, projected in the direction of the strut, are used to assign a compressive strength,  $R_{strut}$ , to the strut.

$$R_{strut} = \min \left\{ R_{scrushing} \times \frac{R_{strut}}{\cos \Phi} \right\} \tag{4}$$

c. Compression rupture

The resistance of masonry to crushing, denoted as  $R_{scrushing}$  corresponds to the compressive load that the equivalent masonry strut can withstand before the masonry fails due to excessive compression. It is determined as follows [6]:

$$R_{scrushing} = a t f'_m \tag{5}$$

Where  $a$  represents the width of the equivalent strut,  $t$  the thickness of the filler panel, and  $f'_m$  the compressive strength of masonry, as determined by the following equation

$$f'_m = \frac{(\sigma'_{Cb}(\sigma'_{tb} + \alpha f'_j))}{U_u (f'_{tb} + \alpha f'_{Cb})} \tag{6}$$

$$\alpha = \frac{J}{4.1 h_b} \tag{7}$$

Where:

$J$ : The mortar joint thickness, set at 1.5 cm;  $h_b$  representing the height of a masonry block (brick), assumed to be 20 cm;  $f'_{Cb}$  denoting the compressive strength of a masonry block, set at 10 MPa;  $f'_{tb}$  representing the tensile strength of a masonry block, assumed to be 0.1 times  $f'_{Cb}$ ;  $U_u$  is the coefficient of stress non-uniformity, set to 1.5; and  $f'_j$  is the compressive strength of the mortar, assumed to be 8 MPa.

d. Shear rupture

The ability of masonry to withstand shear forces relies upon the strength of the mortar joints between masonry blocks and the friction between the masonry and the mortar. The Mohr-Coulomb criterion is employed to compute the

maximum shear resistance, denoted as  $R_{shear}$ , for this particular mode of failure. Consequently, we utilize this criterion to ascertain the shear strength of the material, considering factors such as the angle of internal friction and cohesion properties, which play pivotal roles in determining the masonry's resistance to shear stresses. This approach allows us to evaluate and ensure the structural integrity and safety of masonry constructions when subjected to shear forces:

$$R_{shear} = \frac{\tau_0 \cdot t \cdot l}{(1 - \mu \tan \phi)} \tag{8}$$

Where:  $\tau_0$  represents the cohesion of the mortar bed, defined as follows:

$$\tau_0 = 0.05 f'_m \tag{9}$$

$l$  represents the length of the wall and  $t$  is the thickness of the filler wall taken equal to 30 cm, the coefficient of friction along the mortar bed, denoted as  $\mu$ , is determined using the following relationship:

$$\mu = 0.654 + 0.0000515 f_j \tag{10}$$

### DESCRIPTION OF THE STUDIED STRUCTURES

The building structure under examination in this research study, for the purpose of generating all models both with and without a strut, is a typical reinforced concrete (RC) frame building consisting of a ground floor plus 6 additional stories (G+6). This building has been designed in accordance with the reinforced concrete design code, BAEL 91 [2], and follows the Algerian seismic code, RPA 99/version 2003.

#### 1. Geometry and Structural Configuration

The structural models under investigation serve as office spaces, featuring a floor system with hollow-core slabs of the (16+4) type, and sharing a common plan view (see Figure4). The typical floor plan for the considered building models consists of four spans, each measuring 5 meters in the X-direction, and three spans, each measuring 4 meters in the Y-direction.

The ground floor (Gf) has a floor-to-ceiling height of 4 meters, while all the other floors maintain a consistent height of 3 meters (refer to Figure5).

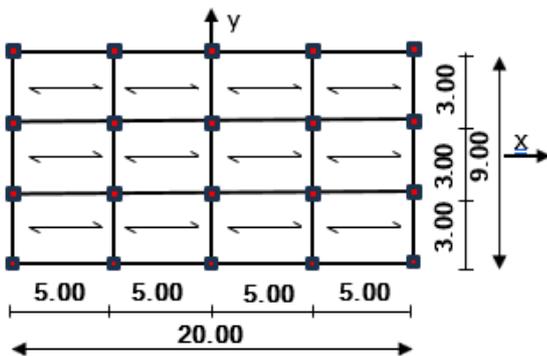


Fig4: Plan View of the Studied Structures

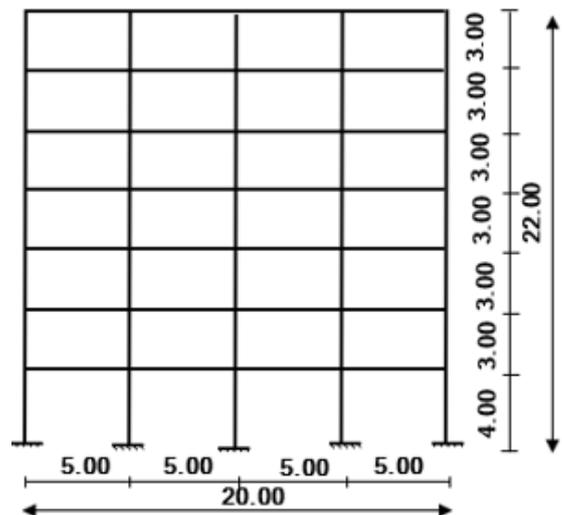


Fig5: Elevation View of the Studied Structures

#### 2. Calculation data for the investigated structures

In order to determine the lateral loads, it is assumed that the six building models under consideration are located in a high seismic zone (Zone III according to RPA 99/version 2003). They fall under occupancy group 2 and are situated on an S3 type soil (soft soil). A quality factor  $Q$  of 1 is considered. The material properties for concrete and masonry,

including elastic modulus, unit weight, and Poisson's ratio, are as follows: 32,164 MPa, 25.0 kN/m<sup>3</sup>, and 0.20 for concrete, and 3,550 MPa, 15.0 kN/m<sup>3</sup>, and 0.15 for masonry. The yield strength of the steel used for longitudinal and transverse reinforcements is 400 MPa.

The thickness of the exterior filler walls is assumed to be 30 cm, and the compressive strength of a masonry block is set at 10 MPa. The permanent loads (G) for the terrace floor are estimated at 6.2 kN/m<sup>2</sup>, and for the typical floor, they are 5.6 kN/m<sup>2</sup>. The live loads (Q) for the terrace floor are 1 kN/m<sup>2</sup>, and for the typical floor, they are 1.5 kN/m<sup>2</sup>. In accordance with RPA 99/version 2003, the values of the overall behavior factor (R) for design, as well as the damping coefficient ( $\xi$ ) for the studied models, are summarized in Table 1 below.

	RPA Recommendations		Mainstone	
	R	$\xi$	R	$\xi$
Model 1(SRR)	5	6	5	6
Model 2(ARR)	3.5	7	5	6
Model 3(S1)	2	7	5	6
Model 4(S3)	2	7	5	6
Model 5(S5)	2	7	5	6
Model 6(S7)	2	7	5	6

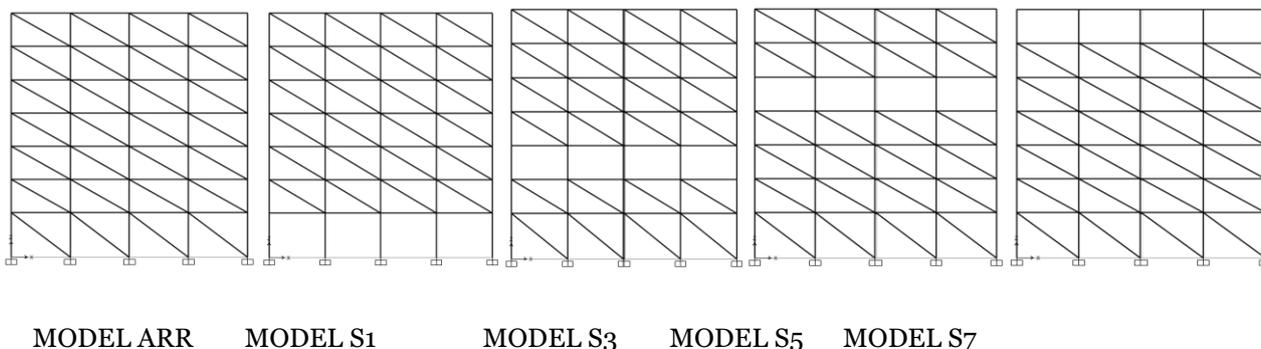
**Table 1: R and  $\xi$  values of the models studied in both configurations**

*3. Formwork and reinforcement of beams and columns of the studied structures'*

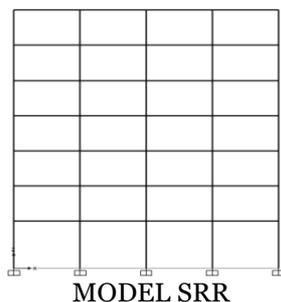
The design of the beams and columns (concrete and steel sections) is carried out considering the structure in its basic configuration. In this context, the masonry walls are only considered as vertical loads acting upon the structure, with their contribution to the stiffness and strength of the frame being neglected. The design of the frame adheres to the guidelines of the BAEL 91 reinforced concrete design code and complies with the Algerian seismic regulations outlined in the RPA 99/version 2003.

**MODELS CONSIDERED FOR ANALYSIS**

The developed models encompass the following configurations: (1) a frame without rigid infill, including the masses of the infill walls (SRR); (2) a building model with integral rigid masonry infill (ARR); (3) a building model with integral rigid masonry infill, except for the ground floor (S1); (4) a model of a fully rigid masonry-filled building with an open floor on the 3rd level (S3); (5) a model of a fully rigid masonry-filled building with an open floor on the 5th level (S5); and (6) a model of a fully rigid masonry-filled building with an open floor on the 7th level (S7). The models developed using the equivalent diagonal strut are illustrated in Figure6, while those developed without the strut in accordance with RPA 99/version 2003 are shown in Figure 5. It is worth noting that, for all the developed building models, the practical restriction imposed by RPA 99/version 2003, which limits the height of frame buildings, whether equipped with masonry infill walls or not, to 3 levels in high seismic risk zones, has been deliberately ignored to facilitate comprehensive exploration in the course of this research.



**Fig6. The different models developed with diagonal strut (Mainstone).**

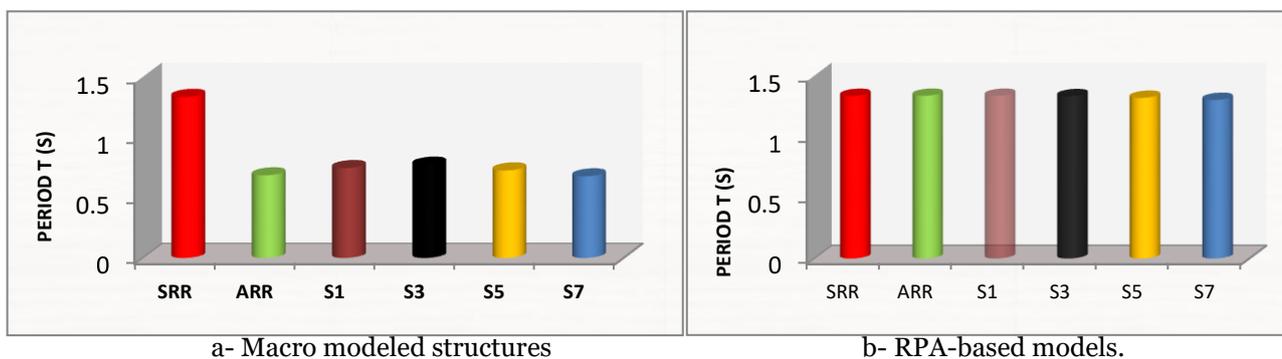


**Fig6: The typical model developed for all structures according to the Algerian seismic code RPA (without diagonal strut).**

### RESULTS AND DISCUSSION

In the following, we present and discuss the results of the spectral modal analyses conducted in the longitudinal X-direction for the six previously introduced models. These models were subjected to different treatments, involving the inclusion or exclusion of connecting diagonal struts, in accordance with the Algerian Seismic Code RPA99/2003. This study focuses on assessing the influence of infill, flexible stories, and their vertical positions on the linear dynamic responses of reinforced concrete frame buildings. The evaluation of these effects is thoroughly examined and compared within this section.

#### 1. Response in terms of the fundamental natural period



**Fig.7. Longitudinal fundamental periods for the studied models.**

From Figure 7.a, it can be observed that the SRR model, representing the model without rigid infill, exhibits a longer period compared to the other models considered in the analysis. The results suggest that the introduction of infill significantly reduces the vibration period in all construction models. The results for the model with integral rigid infill (ARR) show a slightly lower value, averaging around 7% less than the other models with flexible stories (S1, S3, S7).

Moving on to Figure7.b, it becomes evident that the SRR model without rigid infill provides almost the same natural vibration period as all the other models that account for infill stiffness. This indicates that the presence of infill walls has no effect on the main period value for structures designed according to the current Algerian seismic code (RPA99/version2003).

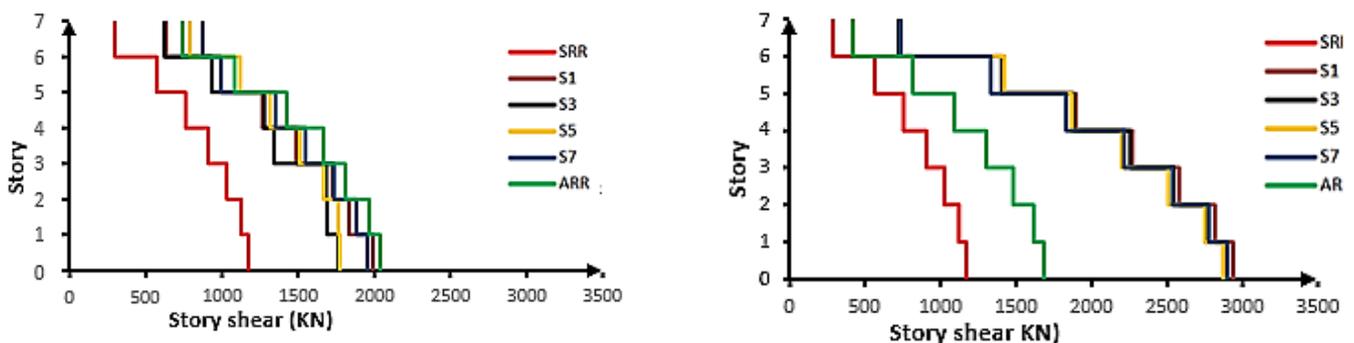
Comparing the two histograms represented in Figures7 8.a and 78.b, it can be observed that the fundamental period value for the ARR model and the models containing a flexible story analyzed with equivalent struts is approximately two times lower than that obtained for the same models analyzed according to the current Algerian seismic code (without struts).

2. Response in terms of story shear.

shown in Figure8 9.a, the response in terms of story shear forces for the model without rigid infill, SRR, reveals a transmission of shear forces that is, on average, approximately half as much at the base and superstructure compared to those transmitted in construction models with rigid masonry infill. The presence of flexible stories at the base or at any other level generally reduces the shear forces transmitted to the stories of the construction models by approximately 8% on average, in contrast to the model with integral infill, ARR. From a seismic design perspective, neglecting the action of masonry infill significantly underestimates the shear force at the base, which is considered one of the crucial parameters during the design phases and can consequently lead to unsafe design. It is also worth noting that the shear force values at the stories of models with a flexible story slightly differ at lower stories compared to the upper stories.

Examining Figure8 9.b, it becomes evident that the response in terms of story shear forces for the model without rigid infill, SRR, exhibits a transmission of shear forces that is, on average, 42% smaller at the base and superstructure than those transmitted in construction models with integral masonry infill, ARR, and 150% smaller for models with a flexible story (S1, S3, S5, and S7). However, the presence of flexible stories at the base or at any other level, in contrast to models with braces, increases the shear forces transmitted to the stories of the construction models by an average of 75% compared to the model with integral infill, ARR.

This behavior challenges logical reasoning and does not accurately reflect the physical reality of the effect of integral infill walls on the response in terms of shear forces in portal structures. Furthermore, the shear force values at the stories of models with a flexible story remain consistent along the entire height.



a- Macro-Modeled Structures    b- Models According to RPA

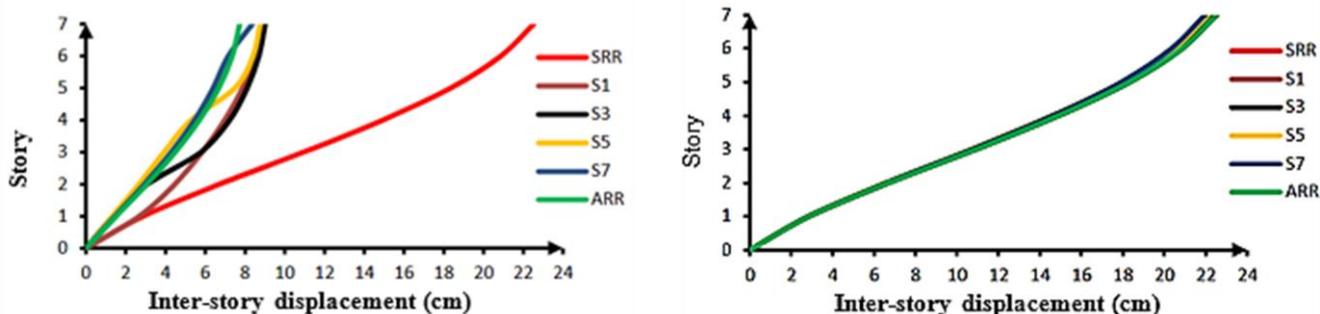
**Fig8. The shear force along the height of the building for the studied models**

Comparing the two curves plotted in Figures 8a and 8b, it is noticeable that the shear force values at the stories for the ARR model analyzed with equivalent diagonal struts are, on average, 60% higher than those obtained for the same model analyzed according to the current Algerian seismic code (without struts). Conversely, the shear forces at the stories for models with a flexible story at different levels, analyzed with equivalent diagonal struts, are, on average, almost 46% lower than those obtained for the same models analyzed according to the current Algerian seismic code.

3. Response in terms of displacements

From Figure 9a, it can be observed that the displacements obtained at each story level are significantly higher for the model without rigid infill, SRR, compared to the other models with rigid masonry infill, especially at the upper stories of the building. This may be attributed to the increased stiffness of the building when considering the action of masonry infill. Comparing the curve plotted for the model with rigid infill, ARR, with the curves for models with flexible stories at different levels (S1, S3, S5, and S7), it becomes evident that the latter coincide with the ARR model curve and start to diverge in height with a slightly significant increase in displacements at these stories. This sudden increase in displacements is due to the absence of masonry infill action at the levels of the flexible story. The trend of

increasing displacements after passing the flexible story was found to be consistent for all locations considered as flexible stories. It is worth noting that the flexible story does not affect the displacement values obtained for the stories below it. However, a trend of increasing displacement values for the stories above it was observed.



a- Macro-Modeled Structures

b- Models According to RPA

**Fig.9. Story displacements along the building height for the studied models.**

As shown in Figure 9b, the response in terms of story displacements for the model without rigid infill, SRR, displays identical values at the base and superstructure compared to those obtained for construction models with rigid masonry infill. This perplexing behavior does not accurately reflect the physical reality of the effect of rigid infill walls on the displacement response of RC frame structures. The presence of flexible stories at the base or at any other level has absolutely no impact on the displacements of the stories of models of constructions compared to the model with integral infill, ARR. Additionally, it can be observed that the displacement values for models with a flexible story are very similar along the entire height of the structure.

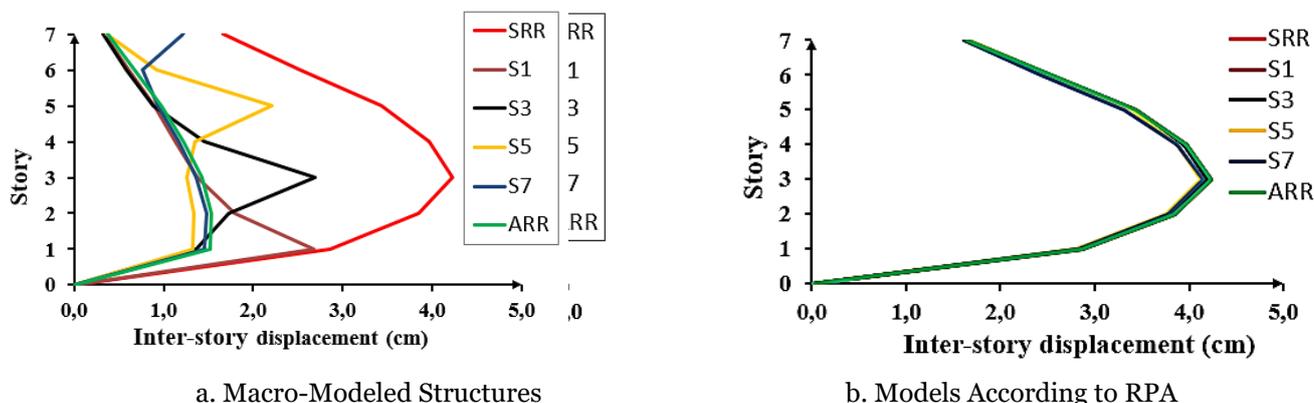
Comparing the two curves plotted in Figures 9.a and 9b, it is noticeable that the displacement values for the ARR model and the models with a flexible story at different levels analyzed with equivalent diagonal struts are, on average, 2.3 times and 2 times lower, respectively, than those obtained for the same models analyzed according to the current Algerian seismic code (without struts)

4. Response in terms of inter-story displacements.

As evident from Figure 10a, the inter-story displacements obtained at each floor level for the model without rigid infill, SRR, are significant and exceed, at certain levels, notably the 3rd floor of the building, the permissible limit suggested by the RPA, which is 1% of the floor height. It is also noticeable that the inter-story displacements obtained at each floor level for the model without rigid infill, SRR, are considerably higher compared to the other models with rigid masonry infill, particularly for the model with integral infill, ARR. This is likely due to the increased stiffness of the building when considering the action of masonry infill. Additionally, from the figure, it can be observed that the inter-story displacement values for all building models with flexible stories display almost similar values to those obtained for the ARR model, which considers the action of integral masonry infill, except at the location of the flexible story where a significant increase in inter-story displacement can be observed. When considering the action of masonry infill walls in building modeling, it decreases the values of induced inter-story displacements. However, the presence of a flexible story at any level increases the inter-story displacement value at that story and may exceed the permissible limits suggested by design codes.

Examining Figure 10b, it becomes evident that the response in terms of inter-story displacements of stories for the model without rigid infill, SRR, displays identical values at the base and superstructure compared to those obtained for construction models with rigid masonry infill. This unrealistic behavior does not accurately reflect the physical reality of the effect of rigid infill walls on the inter-story displacement response of RC frame structures. The presence

of flexible stories at the base or at any other level has absolutely no impact on the inter-story displacements of the stories of construction models compared to the model with integral infill, ARR. Additionally, it can be observed that the inter-story displacement values for models with a flexible story are very similar along the entire height of the structure.



**Fig. 10. Inter-story displacements along the building height for the studied models.**

Comparing the two curves plotted in Figures 10a and 10b, it can be noticed that the inter-story displacement values for the ARR model and the models with a flexible story at different levels analyzed with equivalent diagonal struts are significantly lower on average (about 3 times) than those obtained for the same models analyzed according to the current Algerian seismic code (without struts). Furthermore, it is observed that the inter-story displacement values for models with a flexible story, analyzed without struts, remain close along the entire height of the structure, while those modeled without struts are similar except at the location of the flexible story where a sudden divergence occurs (a peak). As evident from Figure 10a, the inter-story displacements obtained at each floor level for the model without rigid infill, SRR, are significant and exceed, at certain levels, notably the 3rd floor of the building, the permissible limit suggested by the RPA, which is 1% of the floor height. It is also noticeable that the inter-story displacements obtained at each floor level for the model without rigid infill, SRR, are considerably higher compared to the other models with rigid masonry infill, particularly for the model with integral infill, ARR. This is likely due to the increased stiffness of the building when considering the action of masonry infill. Additionally, from the figure, it can be observed that the inter-story displacement values for all building models with flexible stories display almost similar values to those obtained for the ARR model,

which considers the action of integral masonry infill, except at the location of the flexible story where a significant increase in inter-story displacement can be observed. When considering the action of masonry infill walls in building modeling, it decreases the values of induced inter-story displacements. However, the presence of a flexible story at any level increases the inter-story displacement value at that story and may exceed the permissible limits suggested by design codes.

Examining Figure 10b, it becomes evident that the response in terms of inter-story displacements of stories for the model without rigid infill, SRR, displays identical values at the base and superstructure compared to those obtained for construction models with rigid masonry infill. This unrealistic behavior does not accurately reflect the physical reality of the effect of rigid infill walls on the inter-story displacement response of RC frame structures. The presence of flexible stories at the base or at any other level has absolutely no impact on the inter-story displacements of the stories of construction models compared to the model with integral infill, ARR.

Additionally, it can be observed that the inter-story displacement values for models with a flexible story are very similar along the entire height of the structure.

Comparing the two curves plotted in Figures 10a and 10b, it can be noticed that the inter-story displacement values for the ARR model and the models with a flexible story at different levels analyzed with equivalent diagonal struts are significantly lower on average (about 3 times) than those obtained for the same models analyzed according to the current Algerian seismic code (without struts). Furthermore, it is observed that the inter-story displacement values for models with a flexible story, analyzed without struts, remain close along the entire height of the structure, while those modeled without struts are similar except at the location of the flexible story where a sudden divergence occurs (a peak).

5. Response in terms of P-Δ effect.

As it can be observed in Figure 11a, the P-Δ effects obtained at each floor level for the model without rigid infill, SRR, are substantial and exceed, at certain levels, notably the 2nd floor of the building, the permissible limit suggested by the RPA, which is 0.1. It is also noticeable that the P-Δ effects obtained at each floor level for the model without rigid infill, SRR, are considerably higher compared to the other models with rigid masonry infill, especially for the model with integral infill, ARR. This is likely due to the increased stiffness of the building when considering the action of masonry infill. Additionally, from the figure, it can be observed that the P-Δ effect values for all building models with flexible stories display almost similar values to those obtained for the ARR model, which considers the action of integral masonry infill, except at the location of the flexible story where a significant increase in the P-Δ effect for the stories can be observed. When considering the action of masonry infill walls in building modeling, it decreases the values of induced P-Δ effects. However, the existence of a flexible story at any level increases the P-Δ effect value at that story and may exceed the permissible limits suggested by the current RPA.

Examining Figure 12.b, it becomes evident that the P-Δ effects obtained at each floor level for the model without rigid infill, SRR, and the ARR model are significant and exceed, at certain levels, notably the 2nd floor of the building, the permissible limit suggested by the RPA, which is 0.1. It can also be observed that the response in terms of P-Δ effects of the stories for the model without rigid infill, SRR, displays values higher at the base and superstructure compared to those obtained for construction models with rigid masonry infill, especially for models with a flexible story. Additionally, the P-Δ effect values for the stories of the model with rigid infill, ARR, are considerably lower than those for models with a flexible story, indicating that this behavior, which defies logical reasoning, does not accurately reflect the physical reality of the effect of rigid infill walls on the P-Δ effect response of RC frame structures. Furthermore, it is observed that the P-Δ effect values for models with a flexible story remain consistent along the entire height of the structure, while those modeled without struts are similar except at the location of the flexible story where a sudden divergence occurs (a peak).

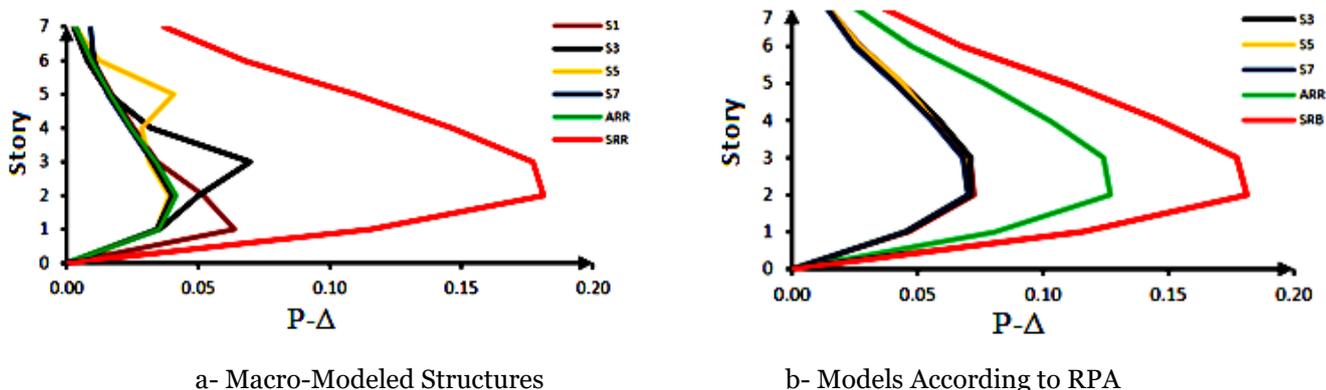


Fig11. P-Δ effect at each floor along the building height for the studied models.

Comparing the two curves plotted in Figures 11a and 11b, it is noticeable that the P-Δ effect values for the ARR model analyzed according to the RPA (without diagonal struts) are more significant (about 3 times) than those of the same model analyzed with struts. Models with a flexible story at different levels analyzed with equivalent diagonal struts

have significantly lower average P-Δ effect values than those obtained for the same models analyzed according to the current Algerian seismic code (without struts).

6. Response in terms of story overturning moment

As illustrated in Figure 12a, the SRR model, which neglects the action of masonry infill walls, significantly underestimates the overturning moments compared to the other models that consider the infill action. The induced overturning moments for the RC frame building model with fully filled masonry walls, ARR, and those with flexible stories at various locations show insignificant changes in the values obtained at the upper stories. However, there is a slightly pronounced change in moments at the lower stories.

As indicated in Figure 12b, the SRR model underestimates the overturning moments compared to the other models that consider the infill action. The overturning moments of the stories induced by the RC frame building model with fully filled masonry walls, ARR, display significantly lower values than those obtained by those with flexible stories at various locations, and this holds true for all stories, which does not reflect the expected real physical behavior. It can be also noticed that the overturning moments induced by the RC frame building models with flexible stories at various locations show insignificant changes in the values obtained at all story levels.

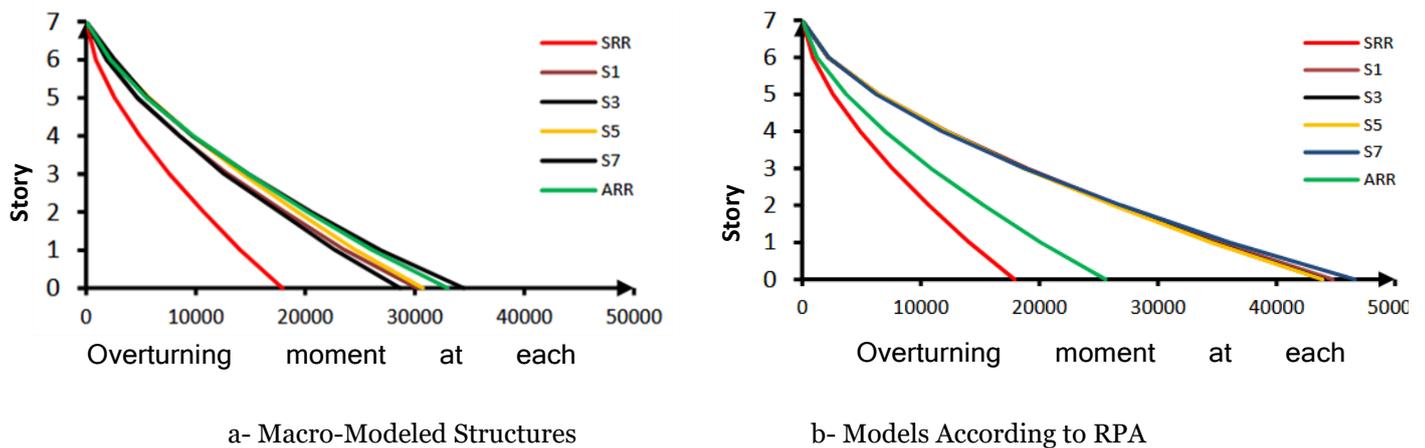


Fig.12. Overturning moment at each story along the building height for the studied models

Comparing the two curves plotted in Figures 12a and 12b, it is evident that the overturning moment values for the ARR model analyzed with equivalent diagonal struts are approximately 40% higher than those of the same model analyzed without struts. Models with flexible stories modeled without struts provide overturning moment values that are 30% higher than those of the same models analyzed without struts. Additionally, it is observed that the overturning moment values for models with a flexible story, analyzed without struts, remain consistent along the entire height of the structure, whereas those modeled with struts are consistent at the upper stories and diverge at the lower story levels.

CONCLUSION

In the present study, a comparative analysis is conducted to assess the impact of masonry infill walls on the linear seismic behavior of a 6-story reinforced concrete frame building, considering the ground floor (Gf+6). Two modeling approaches are employed: one incorporates masonry infill walls using an equivalent diagonal strut, while the other follows the guidelines of the current Algerian seismic code (RPA99/version2003). To achieve this, a spectral modal analysis of various three-dimensional building models with Gf+6 stories, including (1) a bare frame, (2) a RC frame with infill panels spanning the full height, and (3) RC frame models with infill panels and a flexible story at different levels of the structure, was conducted.

The analysis results obtained in this study reveal that the linear seismic response of reinforced concrete building models analyzed with the modeling of masonry infill walls using an equivalent diagonal strut is significantly more realistic and representative of the frame-infill interaction than that of constructions modeled according to the current Algerian seismic code (RPA99/version2003). In conclusion, the current Algerian seismic code (RPA99/version2003):

Overestimates the fundamental period value for all constructions with integral rigid infill or transparency by an average of more than 200%. It provides an identical period value for all models, which does not accurately reflect the mechanical effects of the presence or absence of infill.

Relatively underestimates the shear forces on the floors by approximately 60% for constructions with integral rigid infill, which is conceptually unacceptable, and significantly overestimates the shear forces on the floors by about 42% for constructions with rigid infill or a flexible story, which is economically intolerable.

Significantly undervalues the floor displacement values by more than 200% on average for constructions with integral rigid infill as well as for constructions with transparency or a flexible story. It provides identical floor displacement values for all models, indicating its insensitivity to the presence of integral infill or the existence of a flexible story.

Overestimates the inter-story displacement values by approximately 300% on average, both for structures with integral infill throughout their height and for structures with a flexible story at different levels. It does not reveal the amplification of inter-story displacement values at the geometric locations of flexible stories. It provides identical inter-story displacement values for the model without rigid infill and for models with rigid masonry infill, which does not accurately reflect the physical reality of the frame-infill interaction.

Significantly overestimates the story  $P-\Delta$  effect values by approximately 300% on average, both for structures with integral rigid infill throughout their height and for structures with a flexible story at different levels. It does not emphasize the amplification of the story  $P-\Delta$  effect values at the geometric locations of flexible stories. This current code provides significantly higher  $P-\Delta$  effect values for stories in structures with rigid integral masonry infill than those provided for structures with transparency, which contradicts the expected effect of the integral presence of infill walls.

Underestimates the values of overturning moment by approximately 40% on average for structures with integral filling throughout their height, and by over 30% on average for flexible-story structures. This RPA regulation provides significantly lower overturning moment values for stories in structures with rigid filling, nearly 200% lower than those provided for structures with transparency, which contradicts the expected effect of the integral presence of infill walls.

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