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Importance of Infill Masonry Walls in Improving the Seismic Response of Reinforced Concrete Buildings

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***Abstract*—The treatment of masonry infill walls as non-structural elements in the design of reinforced concrete buildings has been refuted by the losses and damage recorded when these buildings were exposed to seismic loads. Between these walls, there is a type widely used in reinforced concrete buildings in Algeria. This article aims mainly to highlight the role of the infill masonry walls in improving the seismic response of reinforced concrete buildings to resist seismic loads. To demonstrate the above role, we have analyzed several models of two-dimensional frames of a multi-storey building located in a high seismic site, according to the classification of the current Algerian seismic code, with double-leaf hollow brick masonry, which is the most used infill material in Algeria. This analysis is based on the response spectrum method using the finite element software ETABS, taking into account the most important requirements of the current Algerian seismic code. We used the parameters of period, base shear, maximum displacement, and stiffness to evaluate the ability of these frames to respond to seismic loading; we analyzed several models in terms of the number of storeys. After analyzing all the models, we compared the results obtained, and then we were able to define this role and see what contribution these walls can make to the analytical aspect. Finally, we were able to know the positive role that these walls can play in improving the seismic performance of this type of building.**

***Keywords*—Infill masonry walls; reinforced concrete; Algerian seismic code; hollow brick; response spectrum.**

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I. INTRODUCTION

The wide use of reinforced concrete buildings infilled with masonry, in several regions of the world, including Algeria, as well as the great possibility that these buildings are exposed to earthquakes, have prompted many researchers in the field of construction to study this type of building, in order to reduce the risk of these earthquakes. Successive earthquakes have demonstrated the significant damage that masonry infill walls can cause to a building in general. Masonry infill walls can change the seismic behavior of reinforced concrete buildings, it can cause the collapse of some of the load-bearing elements of the building and can reach the complete collapse of the building as a whole.

If we look at the direct causes related to earthquake losses, we found that they do not deviate from two main causes: First, there is a large difference between the numerical models used to simulate the behavior of buildings and civil engineering structures in general, either through a simplification by which a distance from the appropriate representation of the building to be studied and designed before its implementation or a complex representation difficult to achieve given the numerical capabilities available to designers, where we have seen a clear difference between what has been studied and realized in situ. Secondly, the lack of strict application of these studies and non-compliance with the codes that govern the issues of implementation, whether due to the poor choice of materials used or the incompetence of engineers and workers in charge of the implementation process.

It is no longer acceptable to consider masonry infill walls as non-structural elements, considering the degradations observed. It has become necessary to intensify experimentation and research new design methods to study the actual behavior of reinforced concrete buildings infilled with masonry. Research should focus on determining numerical models that simulate the behavior of masonry infill walls in order to cope with possible earthquakes and contribute to the stability of buildings if they were exposed to such natural disasters. Due to the great development in the field of technology, it is possible to conduct experiments on real models or miniature models, draw conclusions from them, and then develop the appropriate numerical models.

In the literature, different modeling techniques that simulate the behavior of the infill's panel can be found and are divided into three categories: micro-modeling, meso-modeling, and macro-modeling. The masonry panel is divided into numerous elements in the micro-modeling approach, considering the local effects in detail. On the other hand, macro-models are simplified models based on the physical understanding of the behavior of the infill's panel. In these models, the masonry infill panel is replaced by an equivalent strut member along the loading direction. For large structures, it is more reasonable to use the meso-model, which is between micro and macro-modeling approaches. This study employs a meso-modeling approach to model the masonry infill.

Five distinct in-plane failure mode categories are identified in the infilled frames [19]. Firstly, frame failure modes consist of the formation of plastic hinges in the beams and columns near the joints, the failure of beam-column joints, or, in very few cases, at the column mid-height. Frame failure may take place together with infill failure. Secondly, infill sliding shear failure mode where the panel experiences horizontal sliding through multiple bed joints. It can occur when the mortar has poor mechanical properties and the infill aspect ratio is quite low, implying a significant horizontal component of the truss action. Thirdly, the infill diagonal cracking failure mode consists of diffuse cracking along the compressed diagonal panel, which may occur when the frame is more flexible than the infill. It presents a stepped diagonal pattern along the mortar bed and the head joints. The cracking of the compressed diagonal does not imply the collapse of the panel, which may develop a further resisting capacity. Sliding shear and diagonal cracking may take place as a mixed-mode. Fourthly, the infill diagonal compression failure mode consists of crushing the panel center. This failure mode usually occurs in slender infills, placed eccentrically concerning the axis of the frame, and is accompanied by out-of-plane deformations and eventually collapse. Fifthly, the infill corner crushing failure mode consists of crushing in a loaded corner area of the infill panel due to a biaxial compression state. This normally occurs when the structure has a weak infill panel surrounded by strong columns and beams with weak infill-frame interface joints.

After reviewing the most important research related to masonry infill walls, as well as experimental tests, we can divide the most important numerical approaches that are interested in this type of wall into 03 sections, which are simplified models (macro-model) [1]-[12] medium models (meso-models) [13]-[17], and detailed models (micro-models) [18]-[28]. This article has come to study only one type of masonry infill wall, which is summarized as a hollow clay brick wall without treating the interaction between the wall and the surrounding portal frame i.e. a rigid connection.

The type to be studied in this article is a reinforced concrete building filled with a hollow brick wall without gaps, neither on the side of the beams nor on the side of the columns, which represents the type commonly used in our country [29].

II. Materials and Methods

Through this scientific paper, several models proposed a two-dimensional reinforced concrete portal frame, which is part of a multi-story reinforced concrete building. The proposed models have been analyzed in a linear dynamic analysis through the method of response spectrum integrated into the finite element software ETABS [15]. These models have been studied in compliance with the criteria of the Algerian seismic code (RPA99v2003). After analysis of the proposed models, the period, base shear, maximum displacement, and stiffness were extracted.

A. *Presentation of the Analyzed Models*

All the models to be analyzed have the same span length of 4.50 m, as well as the same number of bays, i.e. 4. 3-storey, 5-storey, 7-storey, 9-storey, and 11-storey models were chosen. The floor height is set at 3.06m for all models. The Algerian code of reinforced concrete was respected [30], to choose the properties of materials used, the compressive strength of concrete is 25 MPa and the elastic limit of steel is 500 MPa.

In this study, the Algerian masonry code was fully respected [29], to choose the characteristics of the masonry infill walls. The most common type was selected, is the hollow brick, which has the following characteristics, a modulus of elasticity of 2000 MPa, compressive strength of 2 MPa. The thickness of the masonry infill wall is 300 mm, i.e., a double-leaf wall, with a 100 mm block, a 150 mm block, and a distance of 50 mm between two pieces of hollow bricks, as shown in Table I.

TABLE I

GEOMETRIC AND MECHANICAL CHARACTERISTICS OF FRAMES

Designation	**Values or type**
Concrete strength (Mpa)	25
Modulus of elasticity of concrete, E_c (Mpa)	32164
Steel tensile yield strength (Mpa)	500
Storey height (m)	3.06
Number of storey	3, 5, 7, 9 & 11
Span length (m)	4.5m
Number of spans	4
Masonry compressive strength, f_m (Mpa)	2.0
Modulus of elasticity of masonry, E_m (Mpa)	2000
The thickness of masonry walls, t_m (mm)	300

TABLE II

CROSS SECTIONS OF BEAMS AND COLUMNS

Number of storey	**11-storeys**	**9-storeys**	**7-storeys**	**5-storeys**	**3-storeys**
	Beam's dimensions (cm²): 30x40				
	Column's dimensions (cm²)				
11	45x45				
10	45x45				
9	50x50	45x45			
8	50x50	45x45			
7	50x50	45x45	40x40		
6	55x55	50x50	45x45		
5	55x55	50x50	45x45	40x40	
4	55x55	50x50	45x45	40x40	
3	60x60	55x55	50x50	45x45	40x40
2	60x60	55x55	50x50	45x45	40x40
1	60x60	55x55	50x50	45x45	40x40

The columns and beams have the sections that are shown in Table II. The loads applied in the analysis of the proposed models, it was chosen as a dead load of 6 kN/m² and 1.50kN/m² as live loads. According to the Algerian seismic code [31], a response spectrum for a region of high seismicity was selected according to the seismic map of Algeria with the following coefficients a structured group of 2, a soft soil (S3), and a behavior factor of 3.5. For the vibrating mass, the complete dead load was taken in addition to 20% of the live load, and this is always according to the Algerian seismic code [31].

B. Validation of proposal model

In order to validate the model presented in this study, the SEISMOSTRUCT software, was been used, which provides relatively acceptable solutions in modeling masonry infill walls. Using the mentioned software, a 7-storeys two-dimensional reinforced concrete masonry infilled frame was modeled. After that, the same frame was modeled using the finite element software ETABS. The results showed acceptable convergence of the results in terms of the building period.

III. Results and Discussions

In this section, we present the results, compare them, comment, and discuss the results. This section presents the results of two frames of the same number of storeys. Also, this section compares the results according to the period, the base shear, the maximum displacement, and stiffness.

A. Case of 03 Storeys frame

TABLE III
PERIOD, BASE SHEAR, MAXDISPL AND STIFFNESS OF 3-STOREYS FRAME

	Bare frame	**Fully infilled**	**Ratio**
Period (sec)	0.448	0.131	70.76%
Base shear (kN)	307.078	408.811	1.33
Max Displacment (mm)	13.441	1.268	90.57%
Stiffness (kN/m)	71971.842	776642.217	10.79

Based on the results presented in Table III for a 3-stage tire, it can be said that the duration of a fully infilled frame is significantly reduced (about 70%) compared to a bare frame. The primary shear for a fully infilled frame increased by 1.73 times compared to its bare counterpart. Compared to its bare counterpart, there is a significant reduction in lateral displacement for a fully infilled frame, compared to its bare counterpart, of over 87%. The stiffness of the fully infilled frame has increased by more than nine times compared to its bare counterpart.

After this analysis of the obtained results, it can be said that the introduction of infill masonry walls directly in the modeling process has greatly contributed to improving the seismic capacity of reinforced concrete frames, giving a very clear remark on the role that these walls can play in improving the seismic performance of this type of building.

B. Case of 05 Storeys frame

Based on the results presented in Table IV for a 3-story frame, it can be said that the period of the fully infilled frame decreased significantly (about 70%) compared to the bare frame. The base shear of the fully infilled frame has increased by 1.73 times compared to its bare counterpart. There is a significant reduction in the lateral displacement of the fully infilled frame, compared to its bare counterpart, by over 87%. The stiffness of the fully infilled frame has increased by more than 9 times compared to its bare counterpart.

TABLE IV
PERIOD, BASE SHEAR, MAXDISPL AND STIFFNESS OF 5-STOREYS FRAME

	Bare frame	**Fully infilled**	**Ratio**
Period (S)	0.703	0.210	70.13%
Base shear (kN)	371.546	642.787	1.73
MaxDisplacment (mm)	25.239	3.277	87.02%
Stiffness (kN/m)	89643.097	807573.535	9.01

After this analysis of the obtained results, it can be said that the modeling of infill masonry walls directly in the modeling process, has greatly contributed to improving the seismic capacity of reinforced concrete frames infilled with infill masonry walls, which gives a clear impression of the role that these walls can play in improving the seismic performance of this type of buildings.

C. Case of 07 Storeys frame

TABLE V
PERIOD, BASE SHEAR, MAXDISPL & STIFFNESS OF 7-STOREYS FRAME

	Bare frame	**Fully infilled**	**Ratio**
Period (S)	0.951	0.294	69.09%
Base shear (kN)	431.299	892.775	2.07
MaxDisplacment (mm)	38.107	6.527	82.87%
Stiffness (kN/m)	108813.587	849987.290	7.81

Table V shows the analysis results of two frames in 7-storeys, one is bare, and the other is fully infilled with masonry. From this table, we can read that the period of the fully infilled frame is reduced by more than 69% compared to the bare frame. The base shear of the fully infilled frame is amplified by 2.07 compared to the bare frame. The maximum displacement of the fully infilled frame is reduced by more than 82% compared to the bare frame. The rigidity of the fully infilled frame is amplified by 7.81 compared to the bare frame.

D. Case of 09 Storeys frame

TABLE VI
PERIOD, BASE SHEAR, MAXDISPL AND STIFFNESS OF 9-STOREYS FRAME

	Bare frame	**Fully infilled**	**Ratio**
Period (S)	1.199	0.381	68.22%
Base shear (kN)	484.310	1145.557	2.37
MaxDisplacment (mm)	51.834	11.170	78.45%
Stiffness (kN/m)	129017.523	901646.786	6.99

Table VI shows the analysis results of two frames in 9-storeys, one is bare, and the other is fully infilled with masonry. From this table, we can read that the period of the fully infilled frame is reduced by more than 68% compared to the bare frame. The base shear of the fully infilled frame is amplified by 2.37 compared to the bare frame. The maximum displacement of the fully infilled frame is reduced by more than 78% compared to the bare frame. The rigidity of the fully infilled frame is amplified by 6.99 compared to the bare frame.

E. Case of 11 Storeys frame

TABLE VII
PERIOD, BASE SHEAR, MAXDISPL & STIFFNESS OF 11-STOREYS FRAME

	Bare frame	Fully infilled	Ratio
Period (S)	1.446	0.471	67.43%
Base shear (kN)	532.950	1263.198	2.37
MaxDisplacment (mm)	67.065	15.574	76.78%
Stiffness (kN/m)	150065.956	961866.781	6.41

Table VII shows the analysis results of two frames in 11-storeys, one is bare, and the other is fully infilled with masonry. With this table, we can say that the period of the fully infilled frame has shrunk by more than 67% compared to the bare frame. The base shear of the fully infilled frame is amplified by 2.37 compared to the bare frame. The maximum displacement of the fully infilled frame is reduced by more than 76% compared to the bare frame. The rigidity of the fully infilled frame is amplified by 6.41 compared to the bare frame.

F. Comparison of Results in terms of Period

TABLE VIII
PERIOD OF ANALYZED FRAMES

Number of storeys	Bare frame Sec)	Fully infilled (Sec)	Ratio
3 storeys	0.448	0.131	70.76%
5 storeys	0.703	0.210	70.13%
7 storeys	0.951	0.294	69.09%
9 storeys	1.199	0.381	68.22%
11 storeys	1.446	0.471	67.43%

Based on Table VIII, Figure 1, and Figure 2, it can be seen that the presence of the infill masonry walls in the analyzed frames has reduced the period values very clearly. This reduction illustrates the contribution of these walls in improving the response of infilled frames to seismic loads. It can also be seen that all the infilled frames, without seeing the number of storeys, have a better seismic response compared to the bare frames.

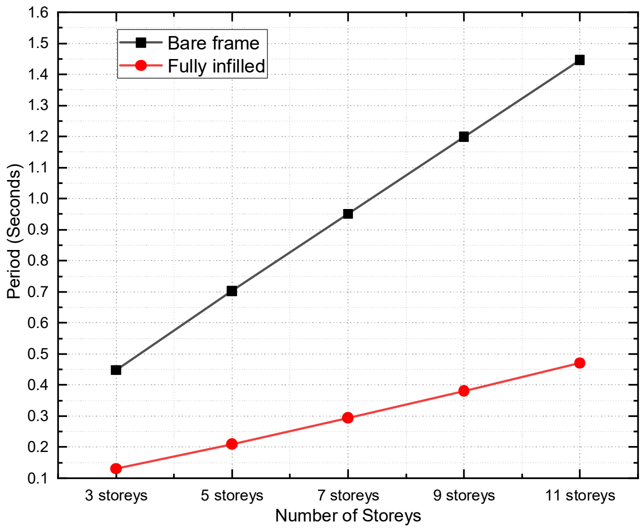

Fig. 1 Periods of analyzed frames

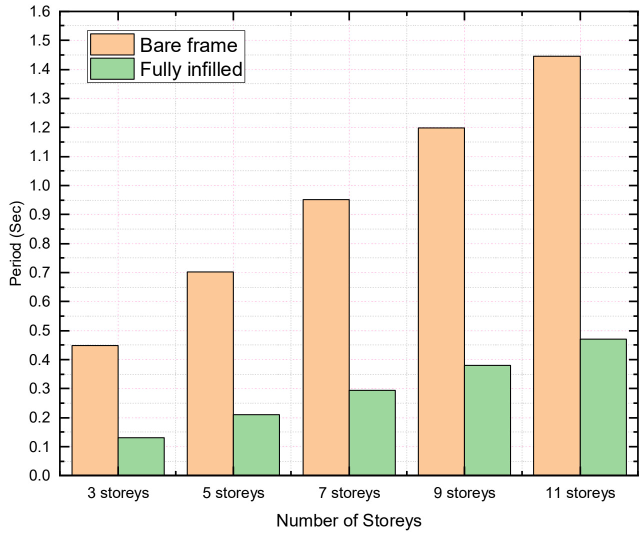

Fig. 2 Periods of analyzed frames

From this point, it can be said that the infill masonry walls of all frames have decreased the period values by about 70%, which implies the need to take these walls into account in the modeling process in reinforced concrete buildings.

G. Comparison of Results in terms of Base Shear

TABLE IX
BASE SHEAR OF ANALYZED FRAMES

Number of storeys	Bare frame (kN)	Fully infilled (kN)	Ratio
3 storeys	307.078	408.811	1.331
5 storeys	371.546	642.787	1.730
7 storeys	431.299	892.775	2.070
9 storeys	484.310	1145.557	2.365
11 storeys	532.950	1263.198	2.370

Based on Table IX, Figure 3, and Figure 4, it can be seen that the base shear recorded higher values for all infilled frames compared to bare frames. If we refer to the height of storeys, we can clearly see that the values of the base shears of the infilled frames move away from those of the bare frames as the height increases (see the ratios given in the table cited above).

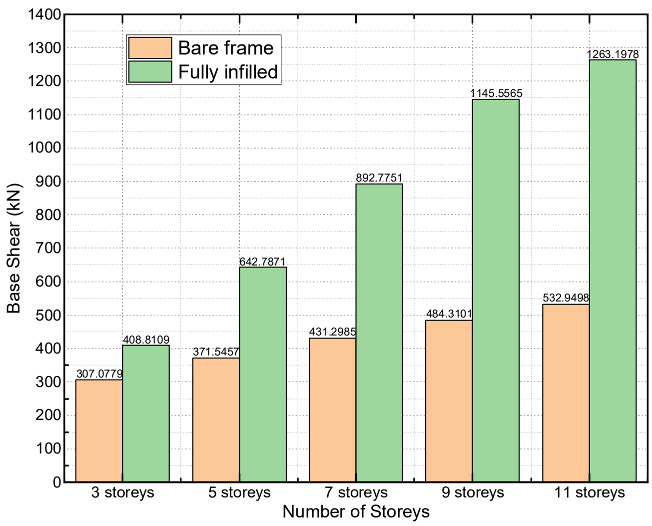

Fig. 3 Base shear of analyzed frames

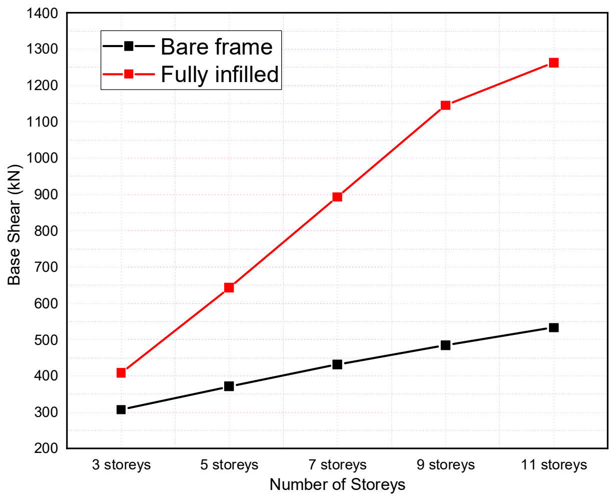

Fig. 4 Base shear of analyzed frames

Therefore, the modeling of infill masonry walls provides significant additional base shear, which in turn improves the resistance of these frames when exposed to seismic loading.

H. Comparison of results in terms of Max Displacement

TABLE X
MAXIMUM DISPLACEMENT OF ANALYZED FRAMES

Number of storeys	**Bare frame (mm)**	**Fully infilled (mm)**	**Ratio**
3 storeys	13.441	1.268	90.57%
5 storeys	25.239	3.277	87.02%
7 storeys	38.107	6.527	82.87%
9 storeys	51.834	11.170	78.45%
11 storeys	67.065	15.574	76.78%

In the context of commenting on Table X, Figure 5, and Figure 6, we can say that the maximum displacement recorded lower values for all the infilled frames than the bare frames because of the presence of the infill masonry walls. We also fear that there is an inverse relationship between storey height and maximum displacement; that is, when the number of stories increases, displacement decreases. These remarks lead us to say that the introduction of infill masonry walls in the numerical simulation operation can improve the seismic response of infilled reinforced concrete structures.

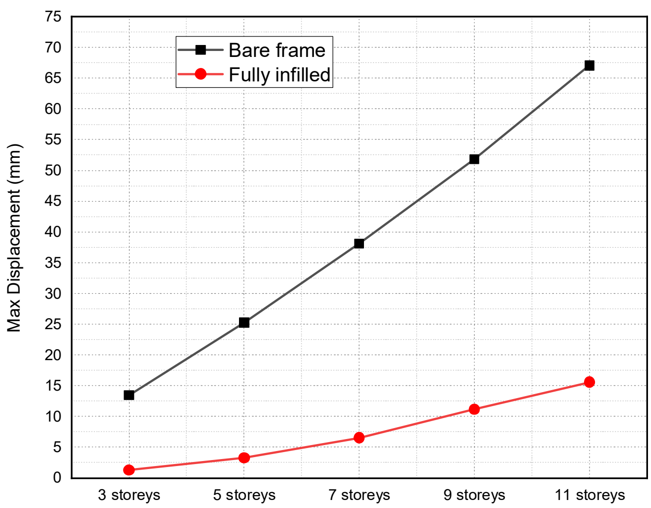

Fig. 5 Maximum displacement of analyzed frames

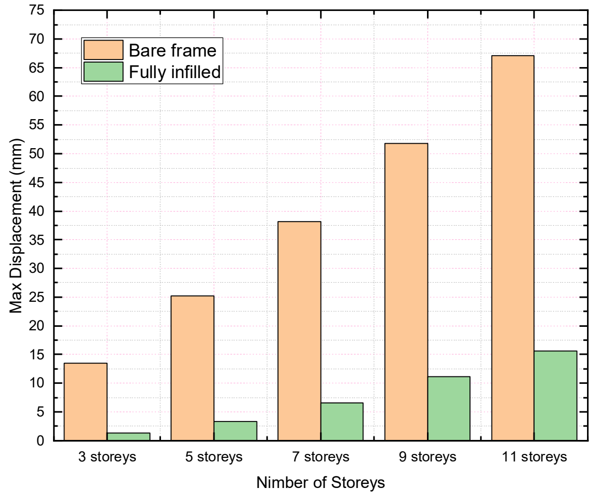

Fig. 6 Maximum displacement of analyzed frames

I. Comparison of Results in terms of Stiffness

TABLE XI
STIFFNESS OF ANALYZED FRAMES

Number of storeys	**Bare frame (kN/m)**	**Fully infilled (kN/m)**	**Ratio**
3 storeys	71971.842	776642.217	10.791
5 storeys	89643.097	807573.535	9.009
7 storeys	108813.587	849987.290	7.811
9 storeys	129017.523	901646.786	6.989
11 storeys	150065.956	961866.781	6.410

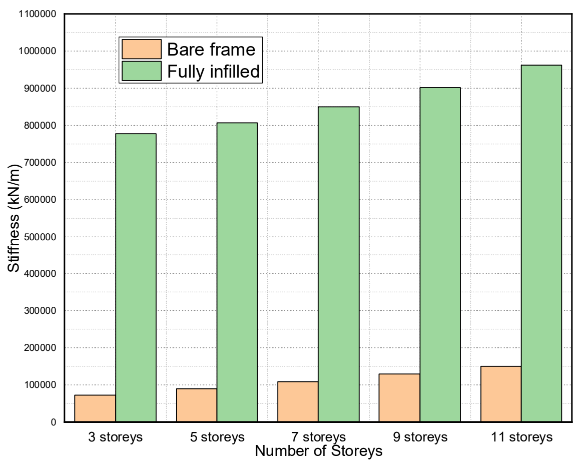

Fig. 7 Stiffness of analyzed frames

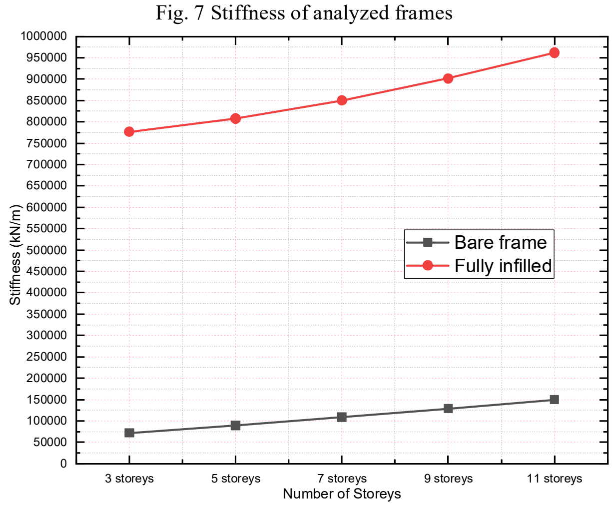

Fig. 8 Stiffness of analyzed frames

In the light of Table XI, Figure 7, and Figure 8, there is a big difference between infilled and bare frames in terms of stiffness. This significant difference is directly linked to the infill masonry walls. The analyzed results of all the proposed frames in this example show that the infilled frames are 6 times stiffer than their bare counterparts. These findings prove that masonry walls do a good job of helping frames withstand seismic loads.

IV. Conclusions

After this modest parametric study, which focused on the role of infill masonry walls in improving the capacity of reinforced concrete buildings to resist seismic loadings, through numerical analysis of several two-dimensional models, we can draw the following points. There is a big difference between neglecting the infill masonry walls and including them in the numerical simulation process in terms of period, base shear, maximum displacement, and stiffness. As a result of the analysis, comments, and comparison of the results, it was found that the neglect of direct modeling of these walls in the design of buildings, either as non-structural elements or by roughly representing them, can negatively affect the seismic behavior of reinforced concrete buildings, which is proven by the losses recorded through multiple earthquakes that have struck several regions. The results obtained, even if they remain limited concerning what to do, and given the numerous experiments, which have been carried out in this field, have proved beyond any doubt that masonry infill walls can radically modify the seismic behavior of reinforced concrete buildings. The need has become more and more urgent to overcome the problem of neglecting the role of these walls, whether positively or negatively. It is important to look for numerical models that simulate the real behavior of these buildings in the face of seismic loadings. In conclusion, despite its simplicity, it has allowed us, albeit approximately, to know the difference recorded through the results that we have achieved. The fact that the masonry infill walls are taken into account and their negligence. It pushes all researchers in this field to intensify research and experiments to improve the precise representation of such buildings. The most important incentive in this research should be the attempt to improve the performance of this type of buildings to achieve two main objectives: First, to protect the existing urban park by looking for calculation methods and practical experiences adapted to the buildings already built. Second, to attempt to reduce the influence of expected earthquakes by intensifying efforts to accurately understand the behavior of reinforced concrete buildings infilled with infill masonry walls to be executed in the future.

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