Effect of Masonry Infill Panels on the Seismic Response of Reinforced Concrete Frame Structures

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Abstract

The present work concerns the numerical investigation of reinforced concrete frame buildings containing masonry infill panel under seismic loading that are widely used even in high seismicity areas. In seismic zones, these frames with masonry infill panels are generally considered as higher earthquake risk buildings. As a result there is a growing need to evaluate their level of seismic performance. The numerical modelling of infilled frames structures is a complex task, as they exhibit highly nonlinear inelastic behaviour, due to the interaction of the masonry infill panel and the surrounding frame. The available modelling approaches for masonry infill can be grouped into two principal types; Micro models and Macro models. A two dimensional model of the structure is used to carry out non-linear static analysis. Beams and columns are modelled as non-linear with lumped plasticity where the hinges are concentrated at both ends of the beams and the columns. This study is based on structures with design and detailing characteristics typical of Algerian construction model. In this regard, a non-linear pushover analysis has been conducted on three considered structures, of two, four and eight stories. Each structure is analysed as a bare frame and with two different infill configurations (totally infilled, and partially infilled). The main results that can be obtained from a pushover analysis are the capacity curves and the distribution of plastic hinges in structures. The addition of infill walls results in an increase in both the rigidity and strength of the structures. The results indicate that the presence of non-structural masonry infills can significantly modify the seismic response of reinforced concrete "frames". The initial rigidity and strength of the fully filled frame are considerably improved and the patterns of the hinges are influenced by structural elements type depending on the dynamic characteristics of the structures.

Keywords: Reinforced Concrete Frames; Masonry Infill; Panels; Pushover Analysis; Plastic Hinges.

1. Introduction

Interior partitions and exterior masonry walls used as an infill between the beams and columns of a reinforced concrete framing are generally considered non-structural elements in design despite the experience of past earthquakes and events. Test results suggest that masonry infill generally exhibits an important influence on the seismic response of reinforced frame buildings. Reinforced concrete frame buildings with masonry infill panels in seismic areas are generally considered to be seismic risk buildings. As a result there is a growing need to evaluate their level of seismic performance. In most seismic codes, it is assumed that the infill has only influence on the mass of the composite structure. This would be a good hypothesis if the frame and the infill are well separated by providing a sufficient gap between them; however, in practice gaps are not usually specified.

Over the past decades, much work has been devoted to the experimental study of this complex behaviour. Sasani (2008) [1] had conducted on site tests to study the dynamic response of a reinforced concrete building made with masonry infill brick panels revealing sudden damages in columns. The brick wall was modelled by a shell or equivalent compression strut members and the simulation results were compared. For conventional reinforced concrete buildings, brick infill panels are generally adopted for interior partitions. Negro & Colombo (1997) [2] noted that the partially filled wall can create a short column effect. The study by Mociran & Cobîrzan (2021) [3] designed to verify the effect of the mechanical properties of masonry infill materials used in reinforced concrete frame structures, as well as the seismic performance of buildings.

Syrmakezis & Asteris (2001) [4] focused on the seismic performance of partially filled multi-storey reinforced concrete frames, using the contact point method to analyze the filled masonry frame and the effect of masonry panels with openings on variation o of the stiffness of the filled frames. Perera (2005) [5] studied the performance evaluation of reinforced concrete structures filled with masonry under cyclic loading based on damage mechanics. Proposal of a damage model to characterize masonry walls subjected to lateral cyclic loading. The model includes simulations of phenomena such as the degradation of stiffness, strength and pinching behavior. The macro model is integrated into the nonlinear structural analysis program to analyze the reinforced concrete frame filled with masonry

Polyakov (1960) [6] proposed to first place the concept of diagonal spacer for the analysis of filled frames. (Tsai & Huang (2009) [7] carried out a study on masonry infill panels composed of compression struts to clarify their influence on the possibility of progressive collapse of a reinforced concrete building resistant to earthquakes. Syrmakezis & Asteris (2001) [4] have contributed that the main objective is to establish the relationships between the parameters of a wall opening (such as the position and the percentage of opening), as well as the study of the redistribution of action-effects (shear force diagram) of filled plane frames under earthquake loads. Zine et al. (2007) and Mao et al. (2008) and Kadid & Boumrkik (2008)[8-10], concluded that the step-by-step pushover analysis procedure shows the performance level of building components as well as the maximum shear load capacity of the structure.

Crisafulli and Carr (2007) [11] noted that the resistance of a frame filled with masonry depends on the interaction between these two elements and that it is possible to modify their load resistance mechanism and their failure model. The research work of Rai (2009) [12] contributed to the idea that many traditional methods have been used to strengthen reinforced concrete structures such as the addition of reinforced concrete infill walls, prefabricated panels, steel bracing and concrete cladding element of the steel frame. Negro & Colombo (1997) and Mehrabi et al. (1996) [2, 13] noted that different infill frame damage mechanisms are possible, depending on the relative stiffness, the resistance of the filling and the delimiting frame border. Lourenço et al. (1998) [14] noted that strength and stiffness are greatly affected by infills. Maheri & Akbari (2003) [15] considered that the impact of the applied load and the type of support frame have a logically small effect on the estimates. Dautaj et al. (2018) and Villaverde (1997) [16, 17] concluded that over the past decades masonry infill walls have been used extensively in residential reinforced concrete frame structures, but their seismic effects are weak.

Aliaari & Memari (2005) and Liu & Manesh (2013) [18, 19] noted that opening in frames filled with masonry reduces the strength, stiffness and energy dissipation of these frames. Koutromanos et al. (2011) [20] noted that significant damage to the filled wall creates a risk of falling. Benavent-Climent et al. (2018) [21] noted that the proximity of the infill dividers can adjust the global seismic conduct of the encircled structures and further modify the removals and the base shear of the edge. Inel & Ozmen (2008) [22] saw that delicate story due to padding dividers could be as damaging as a delicate story due to the increased height of the story.

The study by Shafaei et al. (2014) [23] evaluated the effects of flexible joints on the lateral response of reinforced concrete frames. Rahem et al. (2021) [24] have come to say that a number of static and nonlinear dynamic analyzes of the tensile history have been performed to assess the seismic vulnerably. Noui et al. (2019) [25] were able to assess the infill behaviour of reinforced concrete frames, focusing on the impact of infill openings of three types of reinforced concrete structures: rigid, semi-rigid and flexible, which were designed according to the Algerian seismic code, after a pushover analysis was carried out. They believe that the main parameters are related to the size, location and aspect ratio of the opening.

The study conducted by Mondal et al. (2013) [26] evaluated the behaviour factor of reinforced concrete structures of two, four, eight and twelve storeys. The objective of their research is to estimate the actual values of the response reduction / modification factor (R) of actual reinforced concrete frame buildings, which are designed, detailed in accordance with Indian reinforced concrete seismic design standards, while comparing these values with those suggested in the design code. Ricci et al. (2013) [27] reported that filled masonry walls are supplied in reinforced concrete frames worldwide for insulation against temperature, humidity, noise and fire [1]. Tavakoli & Akbarpoor (2014) [28], according to their research which focuses attention on the seismic performance and shear resistance of reinforced concrete frames filled with bricks under various lateral load models. This evaluation is carried out by nonlinear static analysis.

Seismic performances of reinforced concrete frames with masonry infill slabs under cyclic loading were studied by Jiang et al. (2015) [29]. They examined the impact of the construction details of the infill wall on the seismic performance of the reinforced concrete frame. They noticed that after adding masonry infill walls to the frame, the lateral strength, rigidity, and energy dissipation capacity of the exposed reinforced concrete frame were significantly improved, while the displacement ductility ratio was significantly reduced in the laboratory of the University of Bucharest, the seismic response of a reinforced concrete frame with masonry infill slabs was verified by Bolea (2016) [30]. Dautaj et al. (2019) [31] noticed that if separation joints are not provided between the walls and the frames filled with masonry, under seismic excitations, these walls could contribute to the mechanism of resistance to loads and to the fracture pattern of the frames in reinforced concrete constructions. Made the condition that if separation joints are not provided between the walls and the filled frames, under seismic excitations, these walls could contribute to the load resistance mechanism and the failure pattern of reinforced concrete frames.

Bamdad et al. (2016) [32], have studied the impact behaviour of solids and structures. Two common methods are the finite elements and the experimental method. The nonlinear finite element method has become one of the most efficient methods for predicting the behaviour and extreme strength, elasticity and strength of reinforced concrete beams from load pitch to failure. The nonlinear finite element method is one of the most effective methods for predicting the behaviour of reinforced concrete beams from load pitch to failure and its ultimate strength, elasticity and strength. The advantage of this method is its ability to make this prediction for all sections of the evaluated reinforced concrete beam and all loading stages. It is noted that the absence of infill walls at the bottom of the mediating floor will result in the formation of a soft floor mechanism [33]. (Ahiwale et al. 2020)[34] studied open-story structures, the ground floor is exposed and the upper floors are filled with bricks. Have examined these structures and focused their exposure during an earthquake by demonstrating them as bare frames and as open story frames. Such a review was done to separate the presentation of the open story frame and the bare frame. (Vahidi and Moradi. 2019) [35]; (Feenstra and de Borst. 1993) [36] reported that at the lower level of the gallery, the masonry infill frame behaves like a monolithic composite wall; at higher drift levels (when the infill wall is separated from the boundary frame), compressive contact stresses will occur between the frame and the wall.

Ahiwale et al. (2020) [34] conducted a study to obtain the reaction of an open-story reinforced concrete building exposed to seismic tremor loads. Considered twelve storey structures on an inclined floor (150 horizontally). The reaction of the structure is evaluated in SAP 2000 software using a performance-based seismic design. Rahem et al. (2021) [24] opted for the ADINA software to verify the influence of the opening zone and the configuration of the window on the seismic performance of the steel frame. Non-linear digital static analysis and non-linear time history analysis are performed. Ahiwale et al. (2020) [34] research work ported on the evaluation of the seismic response of the existing reinforced concrete structure with an open history employing the design based on seismic performance. They proposed to think about the modernization of an open story using a reinforced concrete shear wall, steel bracing and infill wall.

Umar et al. (2020) [37] studied the effect of openings in infill walls on the performance of filled reinforced concrete frames, in other words, this research studies the number of infill walls in infill walls filled reinforced concrete frames. Rahem et al. (2021) [24] specified that the aim of the study is to examine the role of masonry infill on the damage response of steel framing without and with different types of opening systems subjected to nonlinear static analysis and to a nonlinear temporal analysis. Having studied, a complete evaluation is carried out using twelve types of steel framing without masonry, with complete masonry and with different heights and widths of openings. Hence the main objective is to present a seismic assessment framework approach for undamaged and damaged reinforced concrete structures. Umar et al. (2020) [37] studied two samples which were tested with reverse cyclic loading (quasi-static test). Also, they found, during experimental tests on the filled reinforced concrete frame having less opening in the infill wall, that this frame has more resistance to lateral loads, more rigidity and dissipated more energy compared to the frame having a large opening in the infill wall. Likewise, the displacement ductility (μ D) and the response modification factor (R) also depend on the amount of opening in the infill wall of a reinforced concrete frame.

Tiedeman (1980) [38] concluded that about 80% of the cost of structural damage caused by earthquakes is due to damage to infill walls and consequential damage to doors, windows, electrical installations and hydraulic equipment. Ahiwale et al. (2020) [34] concluded that there are plastic deformation formations at the level of the ground floor column. To counter the total collapse of soft story structures, it is necessary to modernize open story. Therefore, alternative measures are recommended to improve the reaction of the soft floor like reinforced concrete shear wall, steel bracing and infill wall.

Dya & Oretaa. (2015) [39] have come to say that the seismic demand resides at the level of the soft phase, and different are the levels of severity of this same phase which is manifested from the Pushover analysis used in the preliminary risk assessment tool. Jiang et al. (2015) [29] were able to conclude that reinforced concrete frames with masonry infill walls are widely used in buildings. The layout and construction details of infill walls have significant impact on the seismic performance of the reinforced concrete frame.

Other works have been devoted to the experimental study of this complex behaviour such as Smith (1962), Mainstone (1971), Klingner & Bertero (1978), and Flanagan & Bennett (1999) [40-43] analytically) and numerically using the finite element method by Dhanasekar & Page (1986) and Stavridis & Shing (2010) [44, 45]. The strong influence of the mechanical properties of the materials used for masonry infills, on the seismic performance of reinforced concrete frame structures with masonry infill panels, located in different seismic zones, requires careful study of the seismic response to such structures.

In seismic areas, reinforced concrete frame buildings with interior partitions and exterior masonry walls, used as infill, are generally considered to be non-structural elements in the design despite the experience of past earthquakes and the results of past earthquakes. Tests suggest that masonry infill generally has a significant influence on the seismic response of such buildings. In this regard, there is a growing need to assess their level of seismic performance. The research flow chart is shown in Figure 1.

2. Modelling Aspects

2.1. Modelling of Infills

Numerical modelling of filled frames is a complex task, as these structures exhibit highly nonlinear inelastic behaviour, due to the interaction of the masonry infill panel and the surrounding frame. In general, the presence of the masonry infill panel and the interaction with the concrete frame changes the failure mechanism of the filled frame relative to the bare frame. To simulate the behaviour of the masonry wall, two available modelling approaches can be grouped into macro-models and micro-models. Macro-models, which attempt to capture the raw behaviour of the infill, by viewing the masonry as a homogeneous continuum with no distinction between individual units and approximate joints, are computationally efficient. On the other hand, micro-models capture the behaviour of the infill and its interaction with the frames in great detail, but these models are computationally expensive, because the masonry elements, the mortar, and the element interface masonry / mortar are modelled separately. A number of models using both approaches have been proposed by various researchers. In this study, the nonlinear layered shell element, implemented in SAP 2000 is used to model the infill panels. This approach allows any number of layers to be defined in the thickness direction, each of which has an independent material, thickness, behaviour, and location that may be non-linear.

Determining the basic mechanical properties of masonry is a very difficult task due to the large uncertainties. The dispersion of the measured values is very important. Kaushik et al. (2007) [46], conducted experimental studies on an analytical model to correctly plot stress-strain curves for masonry using six control points on the curves and resulted in a simplified tri-linear stress-strain model for masonry as shown in Figure 2.

2.2. Modelling of Reinforced Concrete Frame Elements

Nonlinear Static Analysis (Pushover Analysis) is a procedure presented and developed over the past three decades by many researchers. It is mainly based on the assumption that the response of the structure is controlled by the first mode or by the first modes of vibration, and that this shape remains constant throughout the elastic and inelastic responses of the structure. A two-dimensional model of the structure is used to perform a nonlinear static analysis, and the pattern of increasing lateral forces should be applied to the mass points of the system. The purpose of this is to represent all the forces that are produced when the system is subjected to seismic excitation.

2.3. Plastic Hinge Mechanisms

In this study, beams and columns, whose hinges are concentrated at their ends, are modelled as nonlinear with localized plasticity. SAP2000 implements the properties of plastic hinges described in FEMA 356. (2000) or ATC-40 (1996) [47, 48]. Figure 2, illustrates the five materialized points A, B, C, D and E which define the force-deformation, illustrated by SAP 2000, implementing the properties of plastic hinges described in FEMA 356. (2000) or ATC-40 (1996) [47, 48]. The following points should be targeted:

- Point A is continuously the origin;

- Point B represents the efficiency, whatever the value of the deformation specified for that point and the hinge up to point B will not be deformed. The displacement (rotation) of point B will be subtracted from the strain of points C, D and E. The single plastic strain beyond point B can be exposed by the hinge;

- Point C represents the ultimate analytical capacity;

- Point D indicates the analysis of the residual resistance;

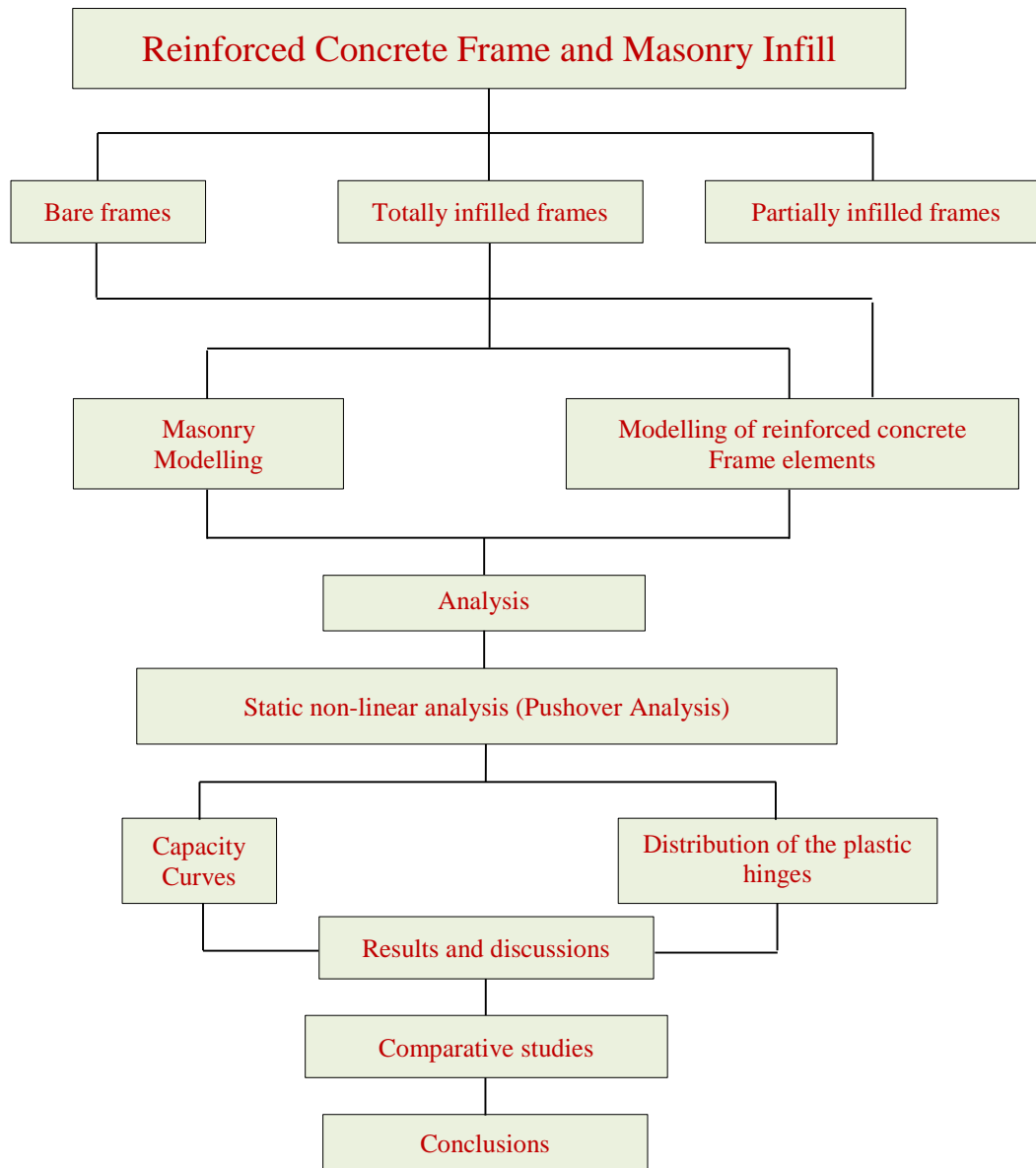- Point E defines the limit for a total failure.

Figure 1. Flow chart of the study

The three dots: IO, LS and CP, used to define the acceptance criteria for hinges, represent immediate occupancy, personal safety and collapse prevention, respectively, and are defined by FEMA-356. SAP 2000 provides default hinge properties and recommends PMM hinges for columns and M3 hinges for beams. Once the steel content, the properties of the section and the loads acting on the structure are known, then default hinges are assigned to the elements. Thus, axial-flexible plastic hinges (PMM) are assigned to the ends of the columns while plastic bending hinges (M3) are assigned to the ends of the beams. The plastic hinges in the filled frames are concentrated in the lower levels of the structures, while in the bare frames the plastic hinges are distributed over the height of the structures, especially for the solid infills.
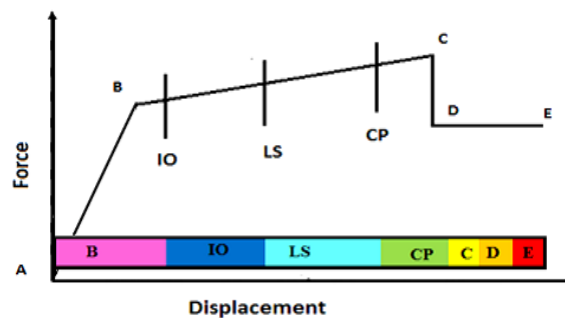

Figure 2. Force-displacement curves of the hinges with colour codes

2.4. Structures Used

This study is based on structures with design features and details typical of Algerian construction modes. For the evaluation of the behaviour of the masonry infill of the reinforced concrete frames, provided by exterior walls and interior masonry partitions, we then considered three structures, of two, four and eight storeys. Each structure is analysed as a bare frame with two different infill configurations (fully filled and partially filled), as shown in Figures 3 to 5. The dimensions in plan, (6.00×6.00) m^2 and the story height is 3.00 m, are the same for the three structures.
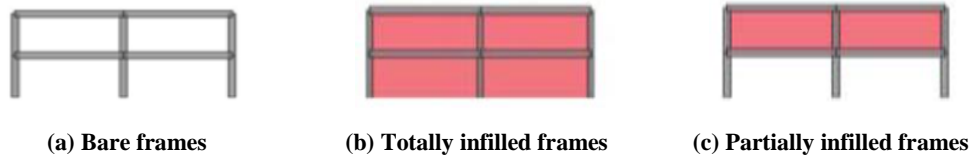
| (a) Bare frames | (b) Totally infilled frames | (c) Partially infilled frames |

Figure 3. Structure 1: Two storey

| (d) Bare frames | (e) Totally infilled frames | (f) Partially infilled frames |

Figure 4. Structure 2: Four storey

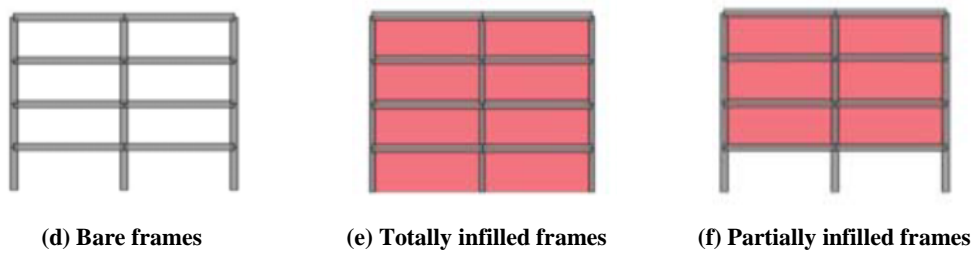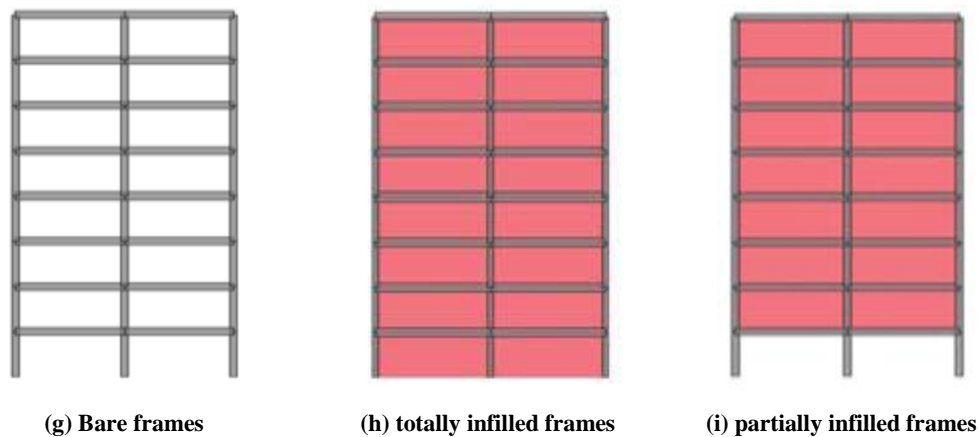| (g) Bare frames | (h) totally infilled frames | (i) partially infilled frames |

Figure 5. Structure 3: Eight storey

The properties of the material retained in this study; are for the concrete, a compressive strength of 25 MPa, a Young's modulus of 32,000 MPa, and for masonry, a compressive strength of 1 MPa, a modulus of Young equal to 1100 MPa.

2.5. Pushover Analysis

Pushover analysis is a nonlinear static analysis that involves the application of gravity loads and a representative lateral load model. The frames were subjected to simultaneous side loading and gravity loads, the latter being in place during side loading. Lateral forces were applied monotonically in a step-by-step static nonlinear analysis. The applied lateral load model consists of a unit of acceleration multiplied by the mass at each stage level. In nonlinear static analysis, the capacity curve represents the relationship between base shear and roof displacement as well as characterizes the behaviour of the structure.

3. Results and Discussions

3.1. Results

The results of the nonlinear static analysis of the present study show that the hinge state indicates the level of performance of the structure identified by the figure of force-displacement curves of the hinges with colour codes as shown in Figure 2. At each step, the location of the plastic hinges is shown in Figures 6 to 14. The plastic hinges in the

bare frames are distributed over the height of the structures, while in the filled frames; the plastic hinges tend to be concentrated in the lower levels, in particular for solid infills. For the bare two-storey frame, the beams of all spans do not exceed the performance level (IO), for the ground floor, but for the columns, the performance level exceeds (CP), for the ground floor, as shown in Figure 6.
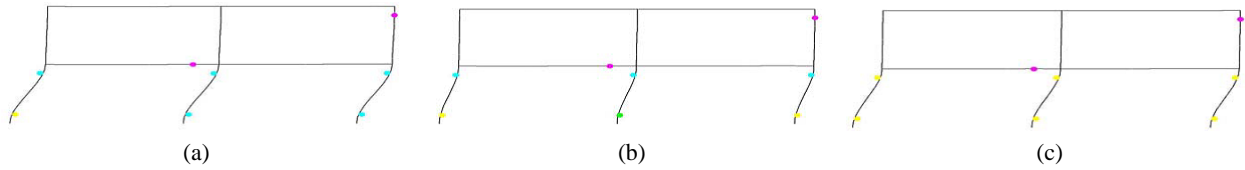

| (a) | (b) | (c) |

Figure 6. Location of plastic hinges on two storey bare frames

For the reinforced concrete framework, with two floors, totally filled, the beams of all the spans do not exceed the performance level (IO), for the ground floor and the first floor, but for the columns , the performance level does not exceed (CP), for the ground floor, as shown in Figure 7.
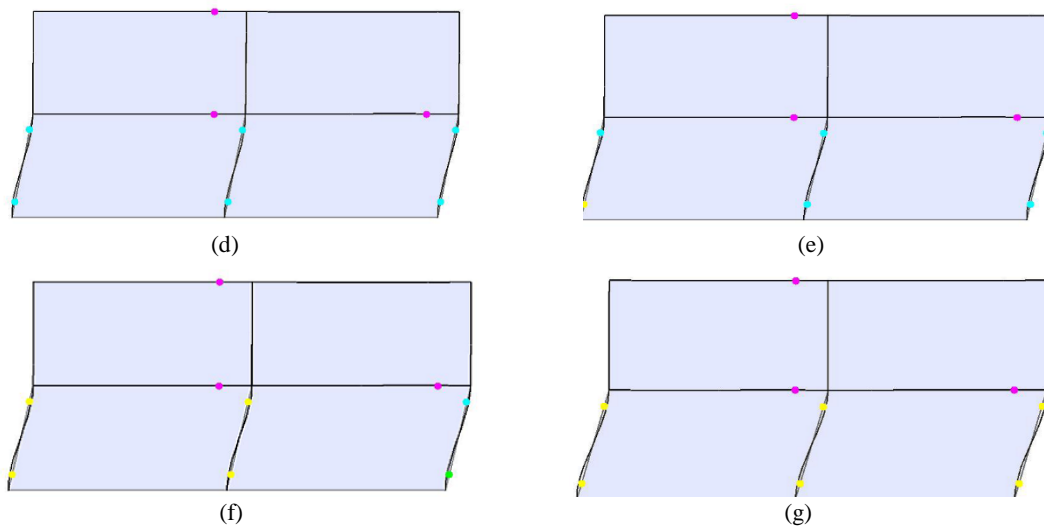

| (d) | (e) |
| (f) | (g) |

Figure 7. Location of plastic hinges on two storey fully infilled frames

For the reinforced concrete frame, two-storey, partially filled, the beams of all the spans do not exceed the performance level (IO), but for the columns, the performance level does not exceed (CP), for the ground floor, as shown in Figure 8.
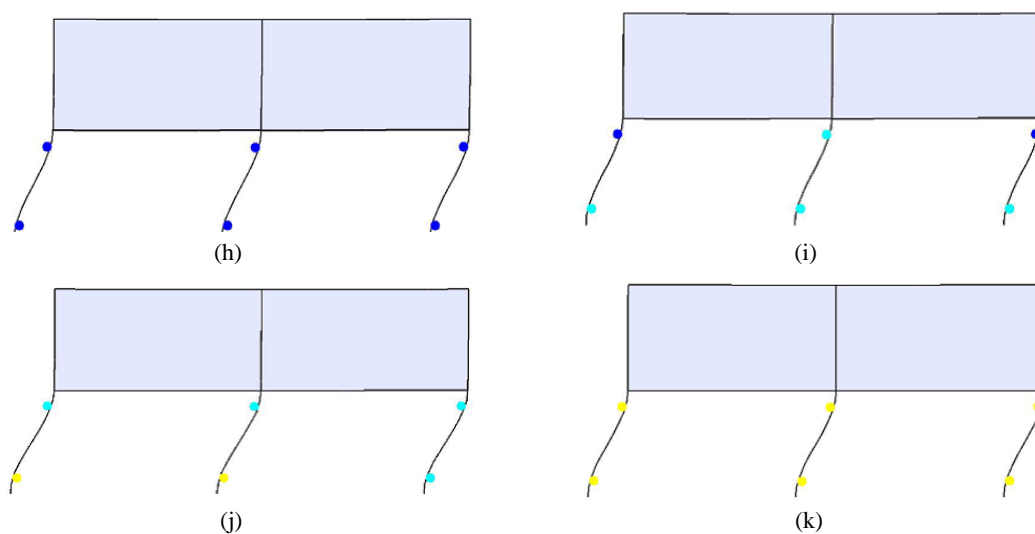

| (h) | (i) |
| (j) | (k) |

Figure 8. Location of plastic hinges on two storey partially infilled frames

For the bare four-storey frame, the beams of all spans do not exceed the performance level (IO), for the ground floor and the first floor, but for the columns; the performance level does not exceed (CP), for the ground floor and the first floor, as shown in Figure 9.
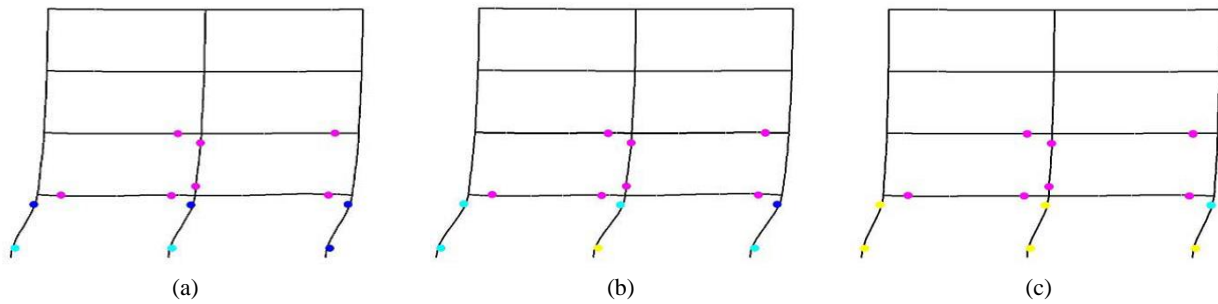
Figure 9. Location of plastic hinges on four storey bare frames

For the reinforced concrete framework, with four floors, totally filled, the beams of all the spans do not exceed the performance level (IO), for the ground floor and the first floor, but, for the columns , the performance level does not exceed (CP), for the ground floor and the first floor, as shown in Figure 10.
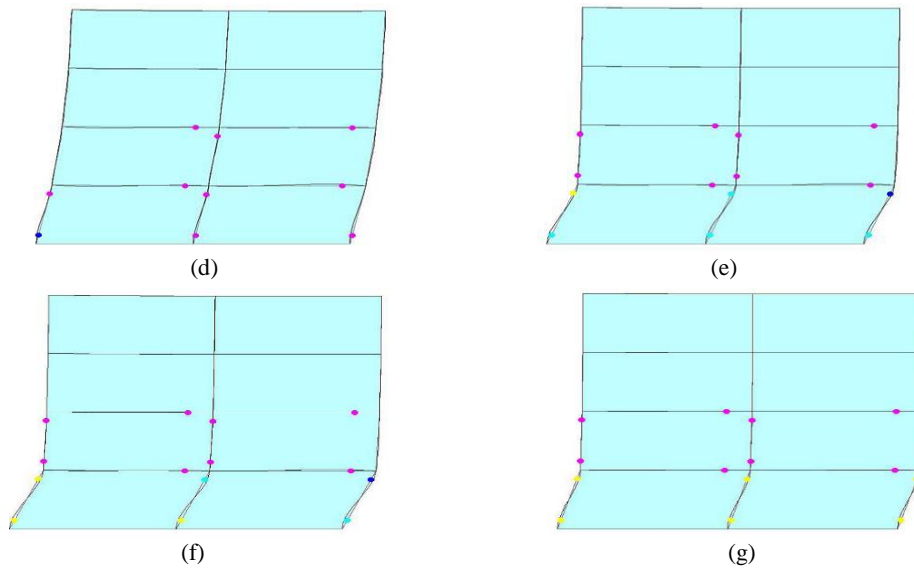

Figure 10. Location of plastic hinges on four storey totally infilled frames

For the reinforced concrete framework, with four floors, partially filled, the beams of all the spans do not exceed the performance level (IO), for the ground floor, but for the columns, the level of performance does not exceed (CP), for the ground floor, as shown in Figure 11.
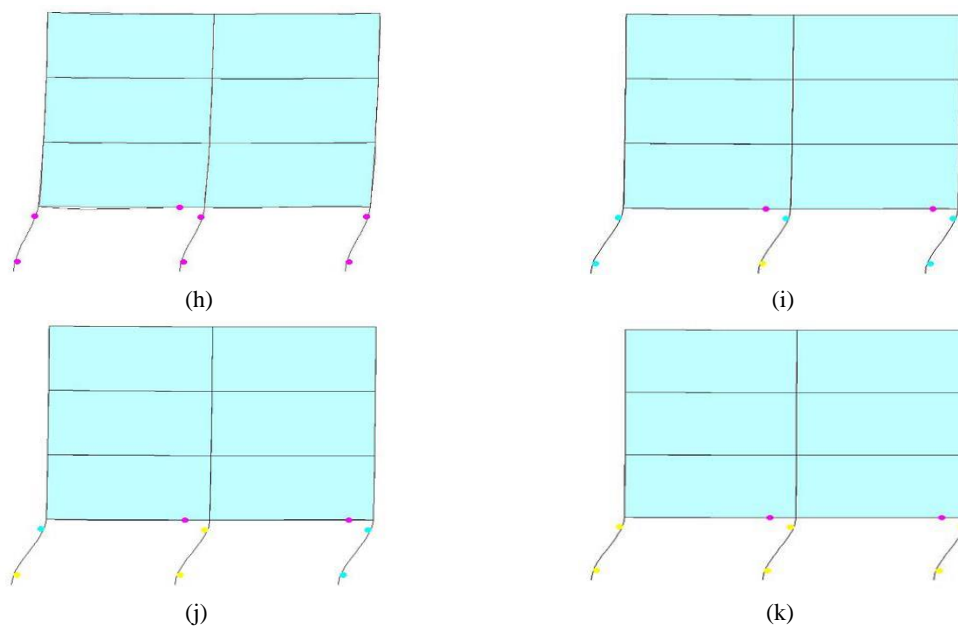

Figure 11. Location of plastic hinges on four storey partially infilled frames

For the bare eight-storey frame, the beams of all spans do not exceed the performance level (CP), for the ground floor and the seven floors, but for the columns, the performance level does not exceed (LS), for the for the ground floor and the three floors, as shown in Figure 12.
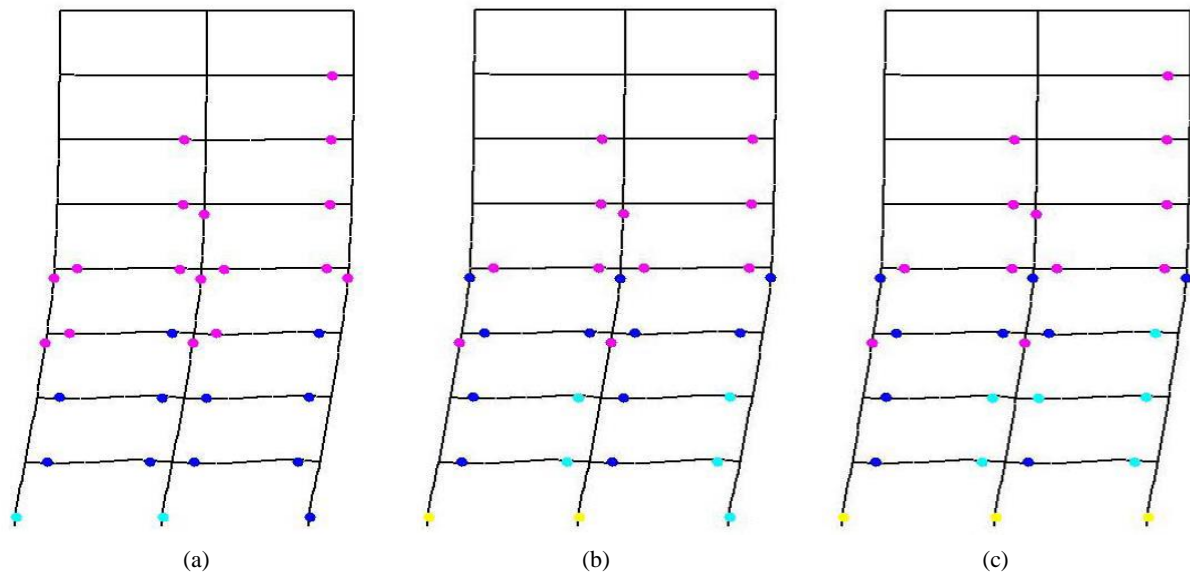

(a)   (b)   (c)

Figure 12. Location of plastic hinges on eight storey bare frames

For the reinforced concrete frame, with eight floors, totally filled, the beams of all the spans do not exceed the performance level (IO), for the ground floor and the seven floors, however, for the columns , the performance level does not exceed (LS), for the ground floor and the first floor, as shown in Figure 13.
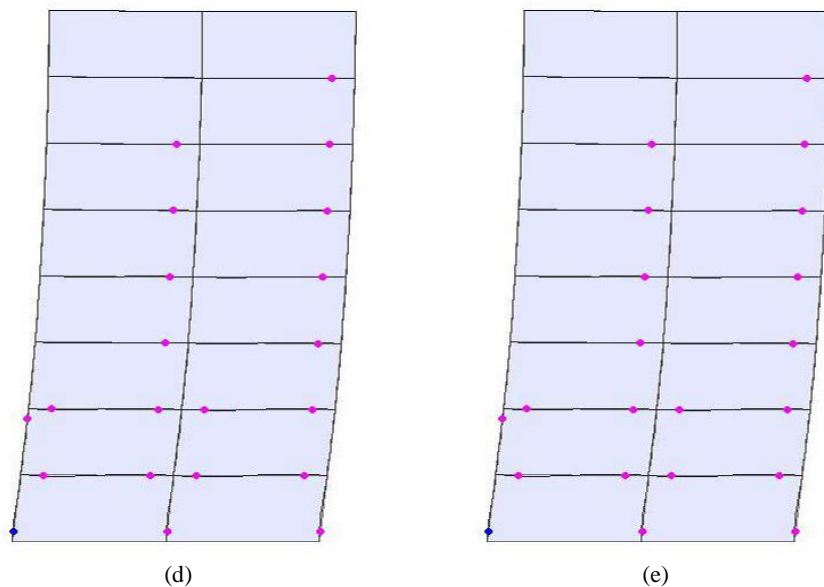

(d)   (e)

Figure 13. Location of plastic hinges on eight storey totally infilled frames

For the reinforced concrete frame, with eight floors, partially filled, the beams of all the spans do not exceed the performance level (IO), for the ground floor and the seven floors, but for the columns , the performance level does not exceed (CP), for the ground floor and the seven floors, as shown in Figure 14.
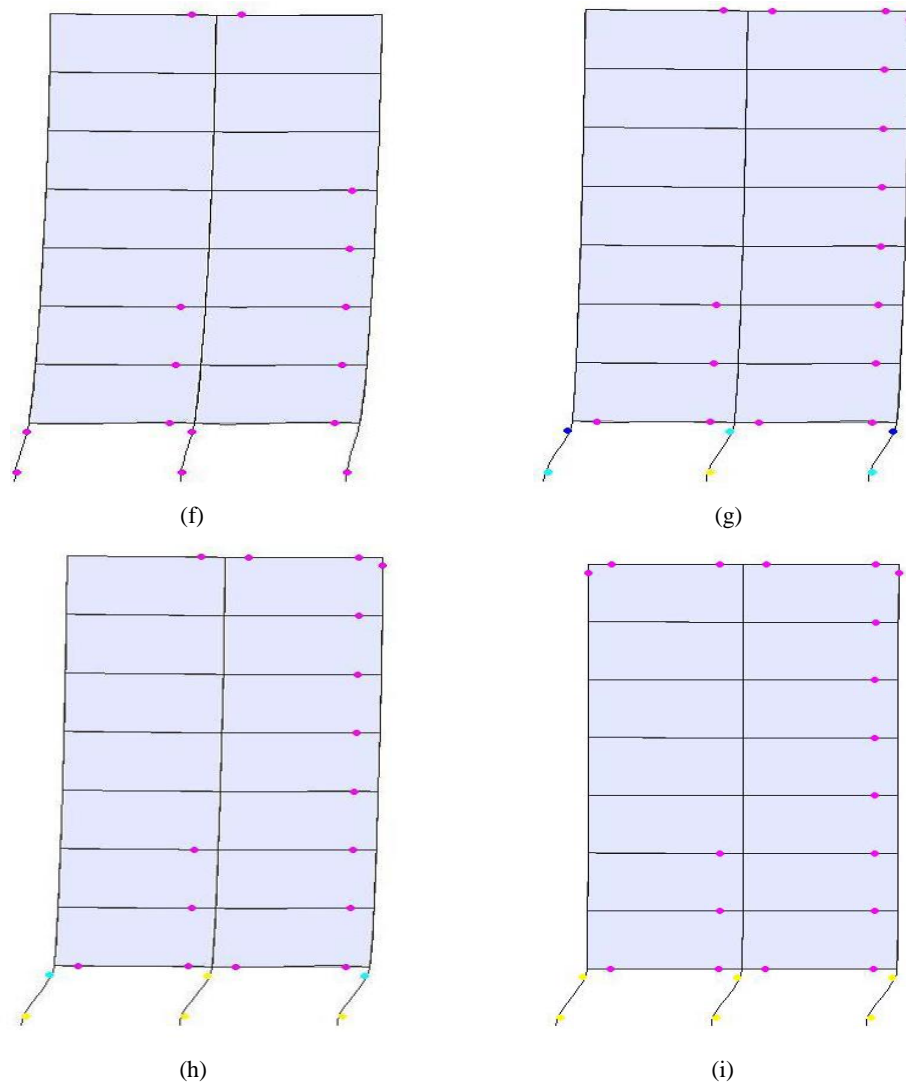
(f)

(g)

(h)

(i)

Figure 14. Location of plastic hinges on eight storey partially infilled frames

3.2. Discussions

A Pushover Analysis, known as nonlinear static analysis, was carried out on three reinforced concrete frames of two, four and eight floors, Each structure is analysed as a bare frame with two different infill configurations (totally filled and partially filled). The capacity curves and the distribution of the plastic hinges in the different structures are the important results that can be obtained from this analysis, as shown in Figures 15 to 17. The capacity curves show that the infill walls allow the frames to support greater lateral loads. The patterns of the hinges are influenced by the presence of infills according to the dynamic characteristics of the structures.
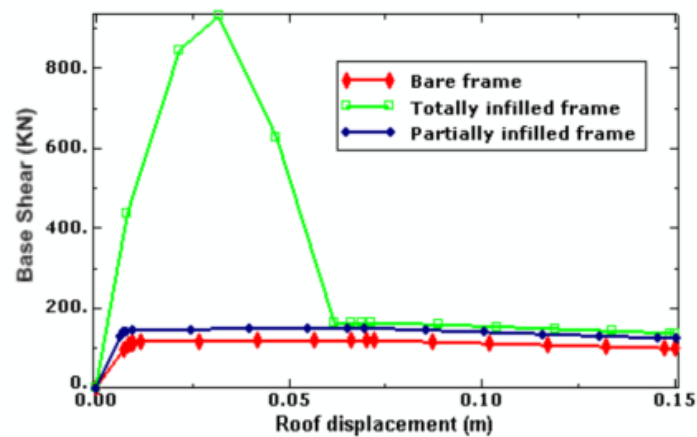

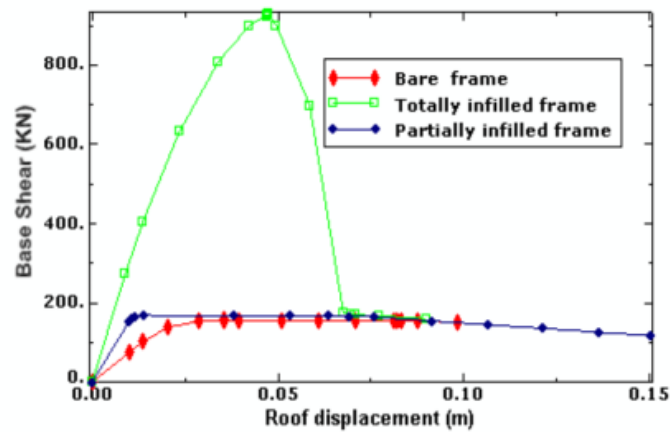**Figure 15. Capacity curves of two storey building frames**

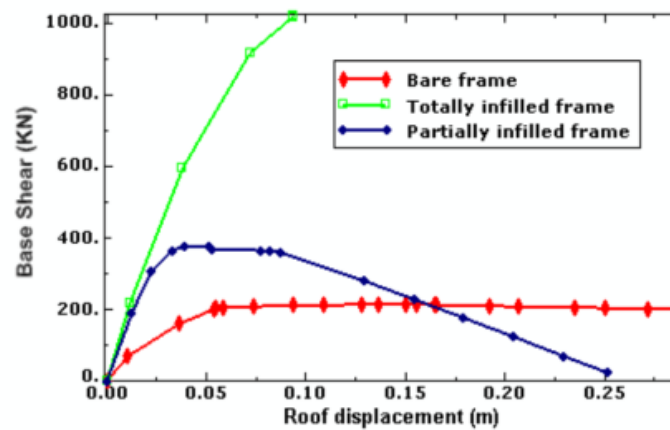**Figure 16. Capacity curves of four storey building frames**

Figure 17. Capacity curves of eight storey building frames

For two-storey buildings, the fully filled frame results in an increase in stiffness and strength respectively by factors of: 4.0, 7.8 compared to the bare frame. These factors are at values equal to 3.72, 3.50 for four-storey buildings and 2.0, 3.0 for eight-storey buildings, respectively, relative to the bare frame. The addition of masonry infill walls increases both the rigidity and strength of the structures. The responses of the two- and four-storey structures are somewhat different from that of the eight-storey structure. The thrust curves of the fully filled reinforced concrete frame and the bare frame are identical, showing that after the filling has broken, the building's response is that of the bare frame. The behaviour of the partially filled reinforced concrete frame lies between the case of the fully filled reinforced concrete frame and the case of the bare frame with a sudden decrease in masonry infill walls have a significant effect on the seismic response of reinforced concrete framing. In four- and eight-storey reinforced concrete frame structures, a strong decrease in strength for the fully filled frame which can be attributed to brittle fracture of the masonry. The presence of masonry walls has a significant effect on the observed collapse mechanism.

4. Comparative Studies

In any scientific research, it is suggested to compare with other studies to be able to assess the authenticity of the work carried out. Thus, we could be offered a comparison of similar results made by researchers worldwide with our study finding carried out by the analysis nonlinear static (Pushover Analysis). Our study (named A) is based on three reinforced concrete structures of two, four and eight storey. That of Mociran & Cobîrzan (2021) [3] (named B) is the study of a five-storey reinforced concrete framework. The third, (named C) of Tavakoli & Akbarpoor (2014) [28] deals with reinforced concrete buildings with five and ten storey and finally the last (named D) undertaken by Noui et al. (2019) [25], this study concerns three reinforced concrete frames of two, five and ten storey. These various reinforced concrete frames are designed in accordance with the regulations in use with two, three spans of 4.00 m to 6.00 m in length and the height of the floor is identical ranging from 3.00 m to 3.20 m.

The main results obtained from such studies, for a nonlinear static analysis (Pushover Analysis) by evaluating the seismic performance of buildings are:

- For two-story buildings, study (A) concluded that the fully filled frame results in an increase in stiffness and strength respectively by factors of 4.0 and 7.8 compared to the bare frame.

- While, study (D) states that the existence of masonry infill panels in a frame increases the structural strength and rigidity compared to a bare frame, but at the same time the interaction must be taken into account. Similarly, the difference in the fundamental period between the bare frame (100% opening) and the fully filled frame (0% opening) is around 27%.

- For four-storey buildings, study (A) has shown that the fully filled frame results in an increase in stiffness and strength respectively by factors of 3.72 and 3.50 compared to the bare frame. Also, it should be noted that for these structures, there is a strong decrease in resistance for the completely filled frame which is attributed to the brittle fracture of the masonry.

- For five-storey buildings, study (B) concludes that the infills have been completely destroyed in the first three floors and on the fourth level only a partial damage noticed. While study (C) states that the failure of reinforced concrete elements is localized in the lower floors and limits the spread of local damage and it is evident that increasing the level of the floor improves the performance of the structure, in particular, in the lower floors. On the other hand, study (D) confirms that the difference in the fundamental period between the bare frame (100% opening) and the fully filled frame (0% opening) is about 31%. Similarly, the percentage difference in resistance capacity between the fully filled frame and the bare frame is around 84%.

- For eight-story buildings, study (A) concludes that the fully filled frame results in an increase in stiffness and strength respectively by factors of 2.0 and 3.0 compared to the bare frame, as it is important to note that for these structures a strong decrease in strength for the fully filled frame attributed to brittle fracture of the masonry is observed. While, the response of the eight-storey structure is somewhat different from that of the two- and four-storey structures.

- Finally, for ten-storey buildings, study (D) approves that the difference in the fundamental period between the bare frame (100% opening) and the fully filled frame (0% opening) is near of percentage of 37 %. Likewise, the percentage difference in resistance capacity between fully filled and bare frames is higher about 82%.

These various studies have shown that the addition of infill walls increases both the rigidity and the strength of the structure. The behaviour of the structural members is similar in all cases, with plastic hinges at the ends of the beams in the first three levels and at the base of the columns. The existence of a filler panel prevents the progression of the failure by limiting its development in a localized area. The evaluation of the capacity curves and the shear strength index (R) of the frames studied shows that the addition of infill panels increases the shear strength of the structure and improves the performance of structures in the upper floors, by preventing the propagation of the failure development and by locating the damage imposed on the lower floors. We have noticed, finally, an increase in the initial rigidity and the resistance capacity of the filled reinforced concrete frame compared to the bare frame, despite the brittle failure modes of the masonry walls.

5. Conclusion

A nonlinear static analysis (Pushover Analysis) was carried out on three reinforced concrete frames of low, medium and higher levels, the infill panels are modelled using a nonlinear stratified shell with the constitutive law of the masonry. The main results of which are the capacity curves and the distribution of the hinges in the different structures. These results indicate that the presence of the non-structural masonry infill can significantly alter the seismic response of reinforced concrete frames. The implemented infill walls increases the rigidity and resistance of the structures. The rigidity and strength of the fully filled frame is greatly improved despite the fact that masonry infills can show brittle failure. The response of the eight-storey structures is somewhat different from that of the two- and four-storey structures. The patterns of the hinges are influenced by the presence of infills according to the dynamic characteristics of the structures. The capacity curves show that the infill walls allow the frames to support greater lateral loads. The behaviour of the partially filled frames is close to that of the bare frames except for the eight-storey building case. The thrust curves of the bare frame and the fully filled frame are identical, showing that after the infill breaks, the building's response is that of a bare frame structural element. Finally, it could be that the contribution of infill panels should therefore be considered since they can have a positive or negative effect.

6. Declarations

6.1. Author Contributions

Conceptualization, A.Z. and A.K.; methodology, A.Z.; software, A.Z.; validation, A.Z., A.K. and Ab.Z.; formal analysis, A.Z. and A.K.; investigation, A.Z.; resources, A.Z. and A.K.; data curation, A.Z.; writing—original draft preparation, A.Z.; writing—review and editing, A.Z., A.K. and Ab.Z.; visualization, A.Z.; supervision, A.Z., A.K. and Ab.Z.; project administration, A.Z.; funding acquisition, A.Z. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

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6.4. Acknowledgements

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

7. References

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