

PERFORMANCE ASSESSMENT OF MASONRY INFILLED RC FRAME BY PUSHOVER ANALYSIS

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ABSTRACT

The infill masonry wall in reinforced concrete (rc) structures increases stiffness and strength, specifically in seismically active zones. It enhances the load-bearing capacity and reduces the deflection under ultra-high loading by adding extra lateral stiffness and strength to the frame. In this research, the structural contribution of infill walls to the rc building frames with various ratios of infill walls (100%, 70%, 50%, 33% infill for single-bay and multi-bay models) is compared with bare framed rc buildings. Nonlinear pushover analysis has been performed to understand the performance parameters such as stiffness, story drift, and load-carrying capacity, using commercial software etabs. Partial infill dramatically increases global strength, more than doubling the stiffness and load-carrying capacity. Significant improvements are observed when different infill wall configurations are compared with the bare frame. Although the smaller infills (i.e., 70%, 50%, and 33%) provide notable increases in capacity, the fully infilled wall offers the greatest improvement. The infill masonry wall is part of an efficient and economical structural component. It provides important information for the optimum design of structures in seismic regions. This study demonstrates how the application of infill walls contributes to the stability, safety, and durability of rc frames. The infilled walls are important in constructing safe and cost-effective structures.

Keywords: *infill walls, strength and stiffness, cost-effective, earthquake-prone areas, pushover analysis.*

1. INTRODUCTION

Reinforced concrete structures have become the fundamental components of modern infrastructure globally nowadays. Durability, materials versatility, and cost effectiveness have made these components more essential. During the catastrophic seismic events that have occurred in the last decades, the world has revealed the importance of infill walls for the global responses of RC frames (Furtado et al., 2021). Masonry walls were considered a part of architecture to ensure the partition, insulation, and aesthetic aspects of the building. Nevertheless, recent studies have shown that these factors dramatically alter stiffness, strength, and energy dissipation capacity, which affects earthquake safety (Asteris, 2003b; Dolšek & Fajfar, 2008).

During lateral loading, masonry infill walls provide bracing properties and enhance the capacity of the frame with their compression strut mechanisms (Kaushik et al., 2006). Improvement of inter-story drift, performance, and reduction of lateral displacement can be attained, consequently. Most current seismic codes overlook infill walls other than their weight and provide methodical instructions in some building codes only.

The Bangladesh National Building Code (BNBC 2020) considered it as a non-structural component, although infills in RC frames can significantly alter a building's seismic response, leading to either positive effects by increasing the seismic resistance capacity or negative effects by providing torsional effects, soft story, and periods of vibration. The omission of the contribution of infill walls can affect the outcome of predicted and real-time performances throughout the seismic event (Surendran & B Kaushik, 2012a).

Studies have been conducted by some researchers to reveal the behavior of RC frames that have been filled with masonry (Bertero & Brokken, 1983; Fiorato, 1971; Klingner & Bertero, 1978; Madan et al., 1997; Momin et al., 2024). The contribution of walls to increasing the seismic capacity has been confirmed by experimental and analytical studies. The improvement is non-uniform due to the presence of a number of factors comprising the wall thickness, density, arrangement, openings, and interaction with the surrounding frame (Crisafulli & Carr, 2007; G Asteris et al., 2012). Soft-story mechanism and torsional irregularities may be impaired due to the presence of partial or irregular infill arrangement that influences the overall capacity (Decanini et al., 2004). Though the full infills maximize the lateral resistance, architectural requirements such as doors, windows, and utility shafts create obstacles to maintain the continuity, which demands the urgency of assessing the partial infill ratio on global performances.

Nonlinear pushover analysis has emerged as one of the most prevalent, trustworthy, and widely used techniques for assessing seismic performance (Comartin, 1996; Mitchell et al., 2005). Pushover capacity curves, hinges, and performance points are the ultimate results that depend on the ductility and collapse mechanisms of the structure. Pushover analysis might be a great tool to determine how masonry walls alter the load path, energy dissipation, and force redistribution for various arrangements of infills. This research work explores the contribution of various percentages of infill ratios ranging from 33% to 100%. Nonlinear pushover analysis process has been implemented to evaluate performance criteria (i.e., displacement, drift, base shear, stiffness, etc). The results demonstrated not only the beneficial effects of infill but also the potential drawbacks of irregular arrangements. The research enhances structural sustainability by enabling nonlinear seismic assessment of existing RC buildings, supporting repair over demolition, reducing waste and embodied carbon, and promoting resilient, resource-efficient infrastructure. This work advances safer and more economic techniques by bridging the gap between the assumption of code and actual behaviors.

2. LITERATURE REVIEW

Research on the seismic stability of RC frames with the presence of infill masonry walls has been carried out over the last three decades. According to previous studies, infills can enhance the lateral stiffness and base shear capacity, which improves the resistance to earthquake-induced stress (Ghosh & Amde, 2002). Previous field earthquakes (Nepal 2015, Italy 2009, and Turkey 1999) presented a positive comment about the response of the infill wall compared to the bare frames. The frame with continuous and well-distributed infill provided undoubted extra resistance to lateral forces (Furtado & Teresa de Risi, 2020).

The natural period of any structure is inversely proportional to stiffness. The higher the stiffness of the structure, the lower the natural period, thus increasing the frequency, which lowers the seismic demands (Asteris, 2003a). However, insufficient details at the beam-column interface with excessive stiffness may result in brittle shear failure. Due to the presence of these dual characteristics, building codes are very cautious about incorporating the contributions of infill walls.

The technique used to ascertain the structural systems' response to earthquakes is called nonlinear structural analysis. The methodology of this approach differs from that of nonlinear dynamic time history analysis and nonlinear static pushover analysis. One of the most trustworthy structural nonlinear studies is nonlinear dynamic time history analysis, but it is also quite time-consuming and difficult (FEMA356, 2000). Such challenges make nonlinear static pushover analysis more effective and widespread. Assessing the reinforced concrete structure under seismic stresses has grown considerably in recent times. Pushover analysis applies lateral loads incrementally until reaching global failure, which provides insight into plastic hinge formation, capacity curves, and performance points (Engineers, 2017). Stiffness degradation and energy dissipation properties of pushover analysis help to capture post-elastic behavior that is suitable for studying the interaction between RC frames and infill walls. Research has identified the role of pushover analysis to find out the influence of infill arrangements for global ductility, collapse point, and overall seismic resilience (Angelucci et al., 2025; Bratu et al., 2025; Kamil et al., 2025; Srechai et al., 2023).

One of the biggest challenges to confirm the infill-frame interaction is the accuracy of its modelling. The equivalent diagonal model is the most popular method, which was first proposed in the 1960s and improved through multiple iterations (Dias-Oliveira et al., 2022; Kakaletsis & Karayannis, 2008; Kappos & Ellul, 2000). It uses the equivalent width of the compression strut that depends on panel stiffness, geometry, and boundary conditions. Nonlinear failure modes, i.e., diagonal cracking, corner crushing, and sliding along mortar joints, are being oversimplified, though it is a very efficient method. According to some researchers, the Finite Element Method (FEM) offers detailed analysis for concentration and progressive damage stress. A finite element model for infills is necessary in order to conduct a performance-based analysis of infilled frame structures. Individual bricks and mortar can be simulated by Micro-modeling, which is highly accurate and cost-effective. Macro-modeling is very effective for efficiency and realism balancing (Effendi et al., 2025; Georgiou et al., 2022; Yilmaz, 1982). Moreover, Hybrid methods are very effective in calculating stiffness and ductility by combining strut models with nonlinear hinges (Abdelkareem et al., 2013; Asteris et al., 2013; Gergely et al., 1994). Architectural requirements, i.e., doors, windows, and service ducts, are responsible for reducing the efficiency, the stiffness, and the Strength of infills dramatically (Surendran & B Kaushik, 2012b). According to studies, walls with more than 40% openings can alter the pattern of crack propagation and reduce the lateral resistance by more than half. Partial infill arrangement at the same time produces irregular stiffness distribution, which is often responsible for increasing deformations in soft stories and collapse vulnerability (Inel et al., 2016). Moreover, torsion, which is the result of plan-irregularity, may be intensified due to a lack of symmetric infill layout. Furthermore, the lack of formal design guidelines in building codes for partial infill is one of the most important gaps in seismic design (Dias-Oliveira et al., 2022).

Lack of formal building design code, limited understanding of partial infill effects, and oversimplified modeling techniques are some of the key research gaps that still need to be overcome. Infill walls with different ratios (100%, 70%, 50%, 33%, and 0%) are studied and compared here to understand the contribution of infills by using pushover analysis. The study describes the effects of infill on displacement, base shear, stiffness, and energy dissipation.

3. STRUCTURAL MODELING

A 3D finite element computational model of a 10-storied RC building with infill masonry walls of various arrangements has been developed using commercial building design software ETABS of CSI Inc. (Fu, 2015). Six different bracing arrangements (100%, 70%, 50%, 33%, and 0%) in place of a masonry wall (Figure 1) have been considered for analysis. The bay spacing and height of the frame are 3.6m and 3m, respectively. Both geometric and material non-linearity are considered in the analysis. Displacement-based performance (pushover) analysis has been carried out.

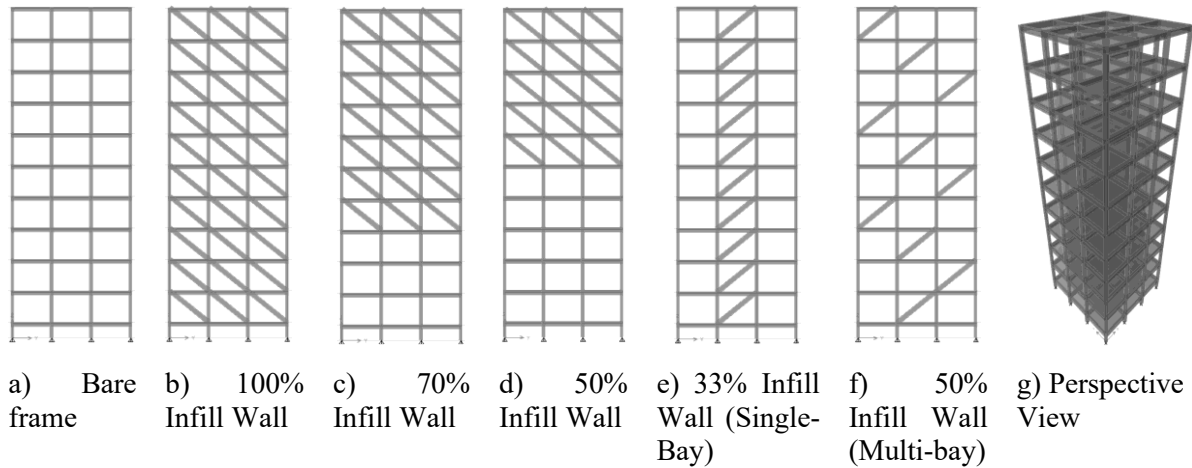


Figure 1: Studied frame with different infill quantities and arrangements

3.1 Section and Material Properties

The dimensions of the column for corner, periphery, and middle locations are 300x300 mm, 375x375 mm, and 450x450 mm, respectively, whereas the sizes of the floor and grade beams are 250x500 mm and 300x500 mm. For simplicity, every column section is selected to be the same across the building. The considered densities of masonry and concrete are 20 kN/m³ and 24 kN/m³, respectively. Table 1 demonstrates the precise requirements for reinforcement, while Table 2 provides a summary of the mechanical characteristics of building materials.

Table 1: Reinforcement details of frame members

Mark	Member Type	Size	Main rebar up to the 3 rd Floor	Main rebar above 3 rd Floor	Shear Reinforcement
C1	Column (Corner)	300x300	8-d16	8-d16	d10@100/150/100 c/c
C2	Column (periphery)	375x375	4-d20+8-d16	12-d16	d10@100/150/100 c/c
C3	Column (mid)	450x450	4-d20+12-d20	16-d16	d10@100/150/100 c/c
FB	Floor Beam	300x450	6-d20(support) 3-d20(mid)	6-d20(support) 3-d20(mid)	d10@100/175/100 c/c
GB	Grade Beam	250x450	6-d16(support) 3-d16(mid)	-----	d10@100/175/100 c/c

Table 2: Summary of material properties

Material	Properties	Values	Unit
Concrete	Compressive Strength	24	MPa
	Modulus of elasticity	23.25	GPa
Masonry	Compressive Strength	3	MPa
	Modulus of elasticity	1.65	GPa
Reinforcement	Yield strength	413	MPa
	Tensile Strength	620	MPa
	Modulus of elasticity	200	GPa

Load combination and seismic design parameters for the preliminary force-based analyses are shown in Table 3. The maximum weight of the building considered is 28000 kN. Before performing the nonlinear analysis of the structure, the PMM ratio for the concrete columns was examined, considering the framing system of IMRF (R=4.5 according to ASCE 7-10) at the Dhaka zone (Z=0.2g) and soil type C (ASCE 7-10) of Bangladesh.

Table 3: Load combination and seismic design parameters

Load Combination	Seismic Design Parameter
1.4DL ^a 1.2 DL + 1.6Lf + 0.5 Lr ^b 1.2DL + 1.6 Lr + Lf ^c 1.2DL + 1.0 Lf + 0.5 Lr + 1.0E _{x/y} ^d ± 0.3E _{y/x} 0.9DL + 1.0E _{x/y} ^d ± 0.3E _{y/x} ^a Dead Load; ^b Roof Live Load; ^c Floor Live Load; ^d Earthquake Load;	S ₁ = 0.2, S _s = 0.50; Site Class: C; SDC: C; Importance factor, I=1; Response modification factor, R=4.5; Deflection factor, C _d =4.5, *SDC- structural design category

Structural members (beams and columns) were maintained within their maximum capability. Figure 2 illustrates the material's nonlinear behavior. For the hysteretic responses of concrete and rebar, the Takoda model and the Kinematic Hardening model are taken into consideration, respectively.

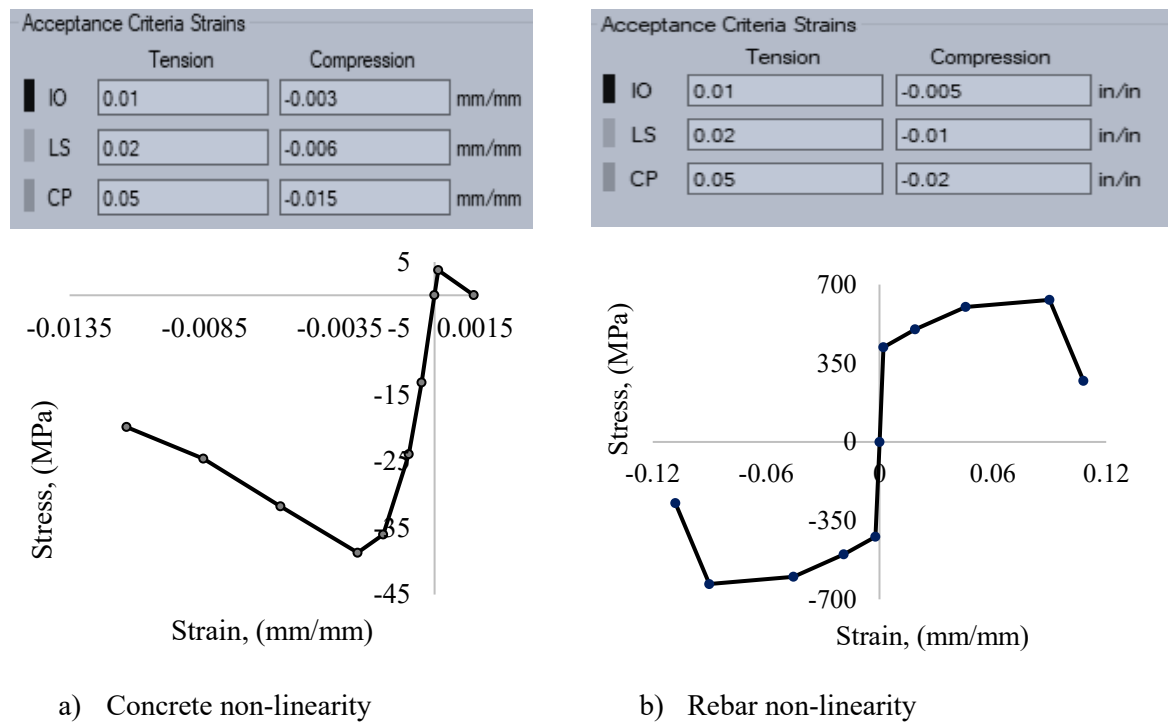


Figure 2: Material non-linearity; (a) Concrete and (b) Rebar

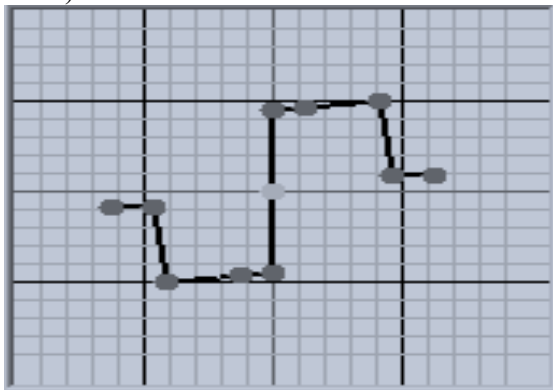
3.2 Hinge Properties

To describe the beams and columns as nonlinear frame elements with lumped plasticity, plastic hinges were defined at both ends. User-defined hinge properties were used in this investigation. The position of the plastic hinges on the column and beam segments was assumed to be at both ends. In compliance with FEMA 356 criteria, the seismic performance evaluation was conducted. Plastic hinges have been utilized for beams and columns in accordance with ASCE, which is illustrated in Figure 3. Additionally, it is preferable to keep shear demand below shear capacity in order to guarantee that ductile flexural behavior is the governing action, as shear behavior is typically not associated with bending. The backbone curve of the nonlinear hinge behavior, the strain limit for different performance objectives, and the hinge properties of columns and beams are presented in Figure 3.

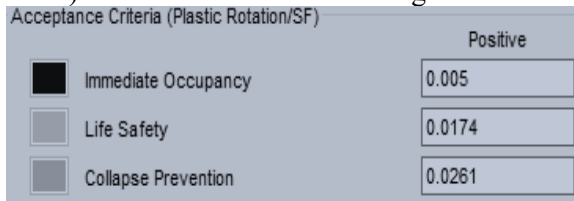
Beam

Point	Moment/SF	Rotation/SF
E-	-0.2	-0.0261
D-	-0.2	-0.0191
C-	-1.1	-0.0174
B-	-1	0
A	0	0
B	1	0
C	1.1	0.0174
D	0.2	0.0191
E	0.2	0.0261

a) Moment-rotation limit



b) Backbone curve of the hinge



c) Strain levels

Column

A	0	0
B	1	0
C	1.1	0.015
D	0.2	0.015
E	0.2	0.025

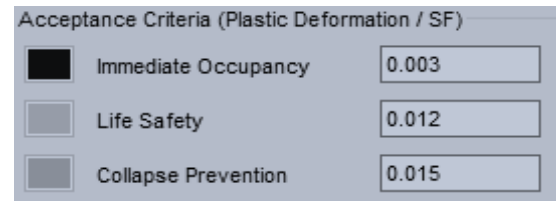
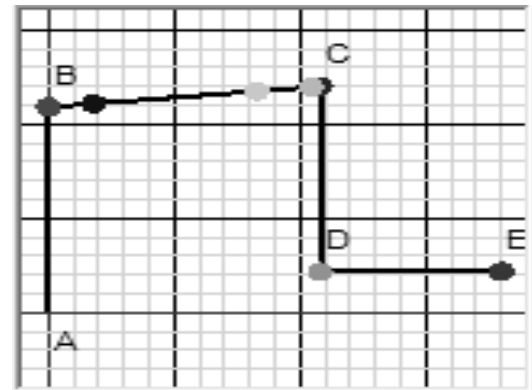


Figure 3: Hinge properties of beam and column for (a) moment-rotation; (b) backbone curve; (c) strain levels.

3.3 Masonry-infilled walls

A diagonal compression strut is often used to simulate the masonry infills instead of a brick wall. ETABS has been used to model the corresponding strut as a pin attached to the RC frame and a brittle axial hinge in the middle. The comparable strut's width has been calculated based on the Indian building code for infill walls with or without openings.

4. RESULTS AND DISCUSSIONS

Figure highlights the variation of displacement along the height of the building under lateral loads. The structure with an infill wall exhibits reduced displacement at all heights compared to bare-frame buildings that depict improved stiffness and lateral stability. The building frame without any infill wall shows maximum displacement compared to the infill members. There is an inverse relationship between the displacement and the number of openings present. The top displacement of a building with a single-bay infill is greater than the scattered (multi-bay) arrangement of infills.

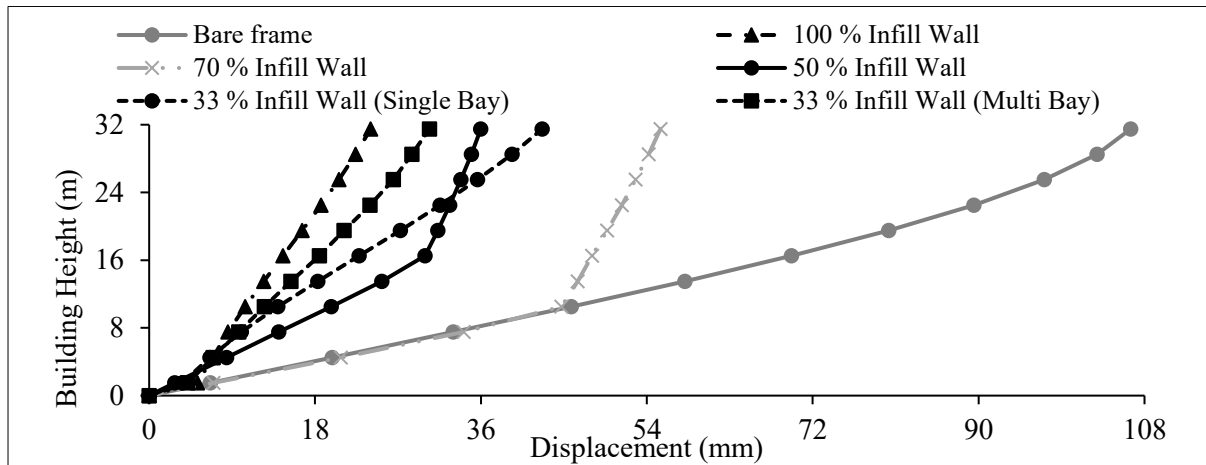


Figure 4: Variation of roof (maximum) displacement with infill

The inter-story drift is an important parameter for understanding and qualifying the changing displacement characteristics of any building. Non-linear pushover analysis, as performed in this study, can determine the behavior. Inter-story drift is the ratio of the displacement of any storey divided by the height of that storey, i.e., storey drift ratio of the 3rd floor = (total displacement of 3rd floor - total displacement of 2nd floor)/ 3rd floor height. Progressive displacement adjustments reduce the likelihood of non-uniform plastic hinge formation and guarantee structural stability and consistent stiffness. The behaviour of infilled masonry walls was found to be worse due to sudden changes in the soft storey under specific lateral load conditions. An excessive drift ratio was found in soft-storey cases. The drift ratio, as shown in Figure for 100% infill and 33% infill wall (multi-bay), shows a lower value compared to other configurations.

The pushover curves, as illustrated in Figure 6, highlight the building's capacity to resist increasing lateral loads. The arrangement and quantity of infill masonry influence the pushover curves. The shear capacity of infilled frames is higher than that of the bare frame. Moreover, the displacement of framed infill masonry walls decreases significantly. Walls with 100% and 33% infill (single-bay) provide maximum capacity and minimum displacement. The modifications between configurations can disclose the role of infill walls that affect the ductility and stability to sustain large deformation without degrading strength, which is essential for seismic resilience. Figure shows the correlation between base shear and energy dissipation. Due to the absorption and redistribution of large seismic energy, the infill wall exhibits higher energy dissipation. The more infill walls there are, the more energy is dissipated. The infill wall arranged vertically dissipates the most energy. This property mitigates maximum force and reduces the damage during an earthquake. The infill masonry wall exhibits bracing behavior when confined by framing.

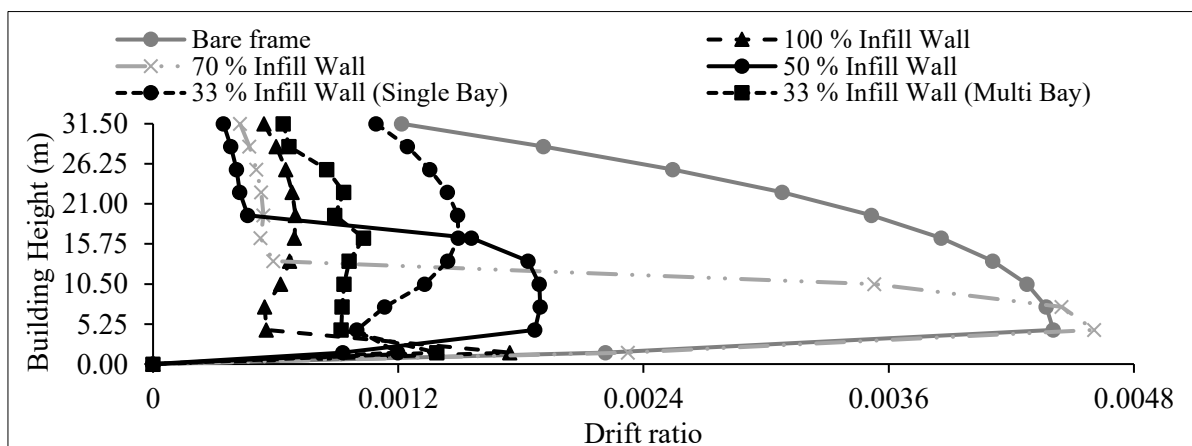


Figure 5: Comparison of inter-story drift ratios between infilled and bare frames

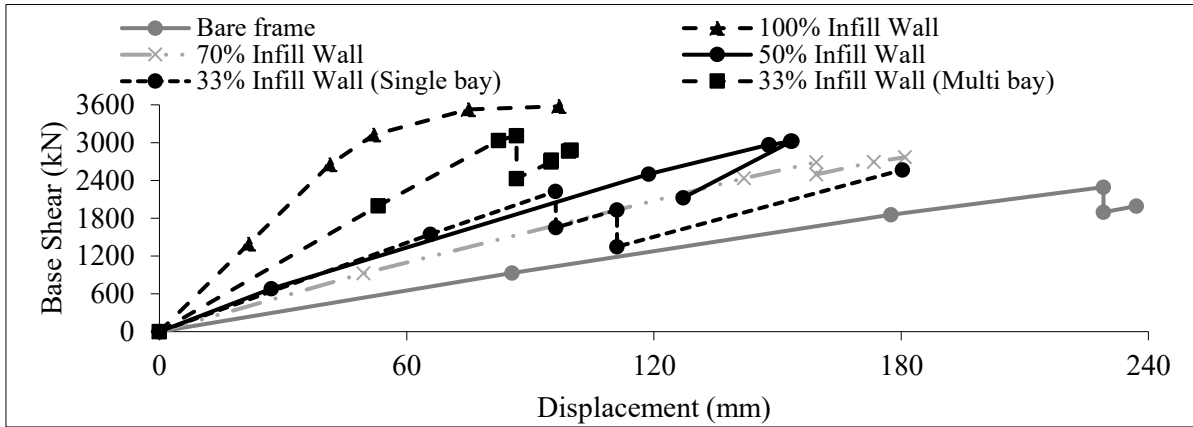


Figure 6: Pushover curve for different infill configurations

Figure shows the comparison of displacements under different framing conditions at performance points. The maximum target displacement is found in a bare frame, whereas the displacement in a 100% infill wall is minimal. The displacement for infill walls arranged in a scattered pattern is also compared with the same amount of vertically arranged infill. This analysis underscores the importance of infill walls for achieving the performance goals. The graph (Figure) illustrates the distribution of bracing forces. The model is confined to four sides. The 100% infill wall exhibits maximum, whereas the 33% infill wall (multi-bay) presents minimum bracing forces.

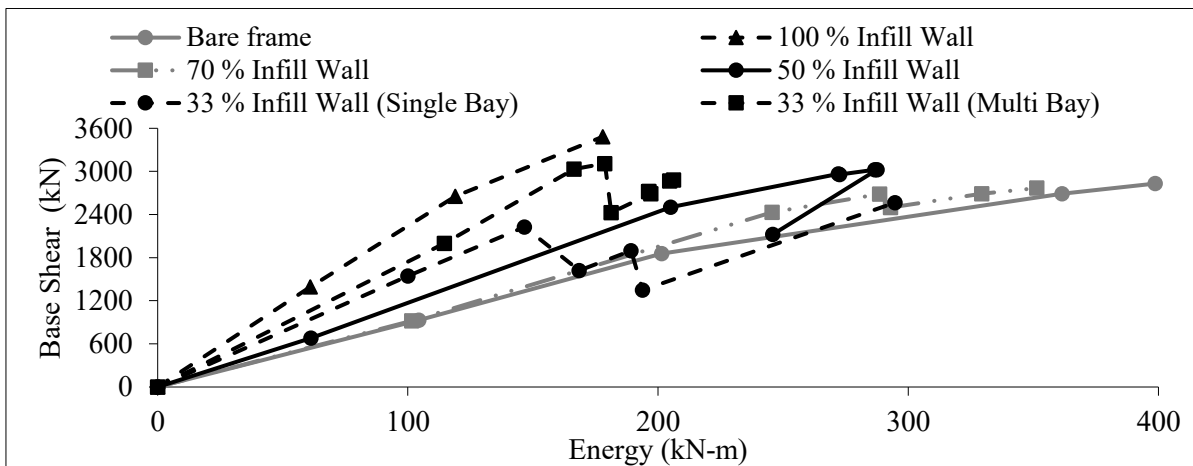


Figure 7: Comparison of energy dissipation between infill and bare frames

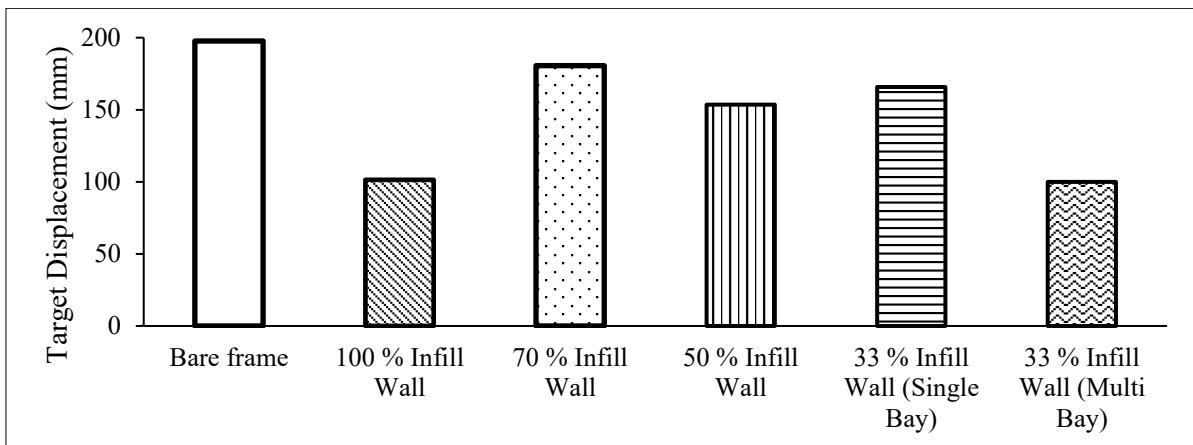


Figure 8: Target displacement for different types of framing conditions

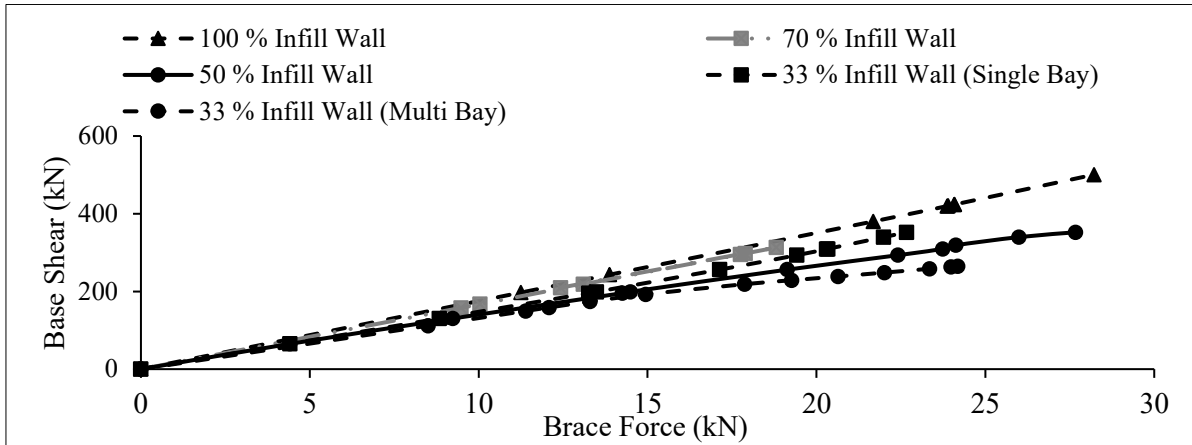


Figure 9: Bracing force for different infill quantities and arrangements

Figure and 11 illustrate the stiffness and period of structures. The effective period influences the natural frequency of the structure, which depends on its mass and stiffness. The period is inversely proportional to the stiffness of the structure. Walls with 100% infill exhibit maximum stiffness and minimum period. The minimal period reduces the lateral displacement under seismic load, suggesting improved dynamic performance.

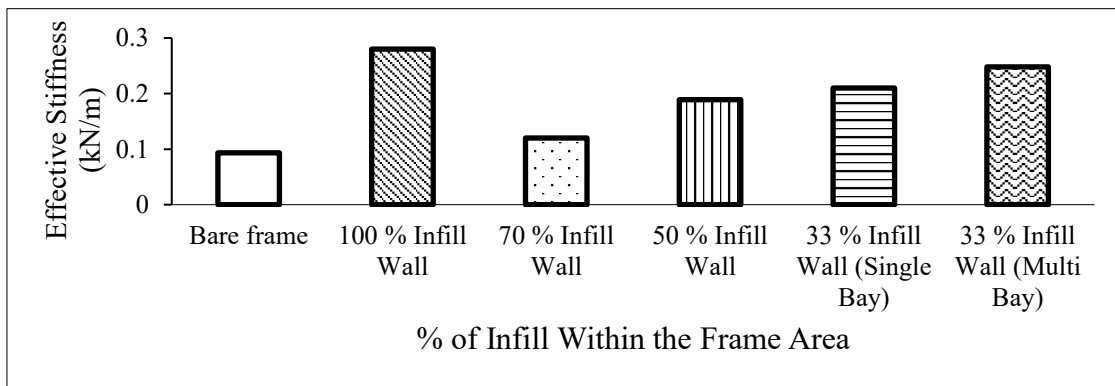


Figure 10: Effective stiffness for different types of framing conditions

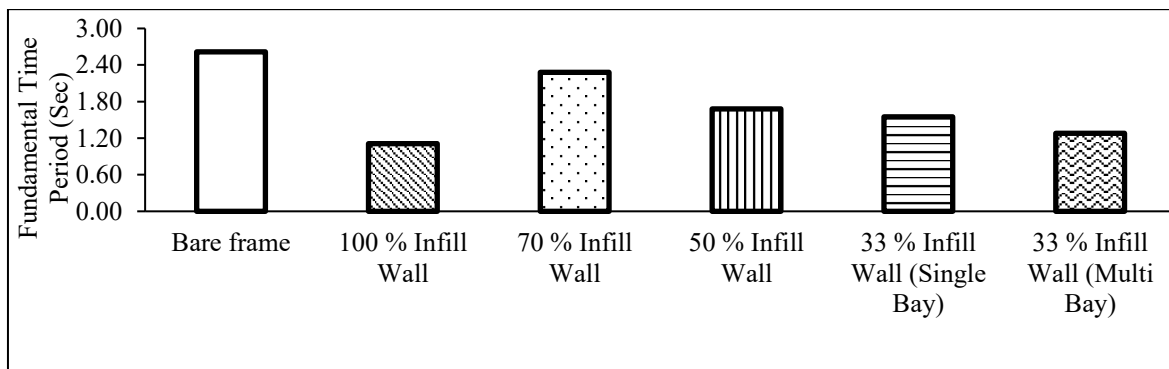


Figure 11: Effective time period for different types of framing conditions

The base shear ratios (lateral shear capacity of infill frame divided by bare frame) for the bare frame and infill wall frames are shown in Figure 4. The variation demonstrates the effectiveness of various structural enhancements for improving seismic capacity. The base shear ratio increases with the percentage increase of infill wall area. It is also dependent on the arrangement pattern of the infill wall.

The staggered pattern of infill opening provides lower base shear ratios compared to infill stacked in a single bay.

Figure 5 shows the comparative measurement of peak acceleration response of the structure at the performance point during seismic events. The value of spectral acceleration depends on the amount of continuous infill wall in the vertical direction. More specifically, it can be explained that the increase of the infill wall on the ground floor increases the spectral acceleration, which reduces the intensity of damage. The 100% infill model has the largest infill area on the lower floor, which increases spectral acceleration.

Shear capacity is a critical parameter for estimating the stability of any structure.

Figure 6 shows the variation of shear capacity at the performance point of the bare frame and infill frames with varying percentages. This figure demonstrates that the bare frame has the lowest shear capacity among all models.

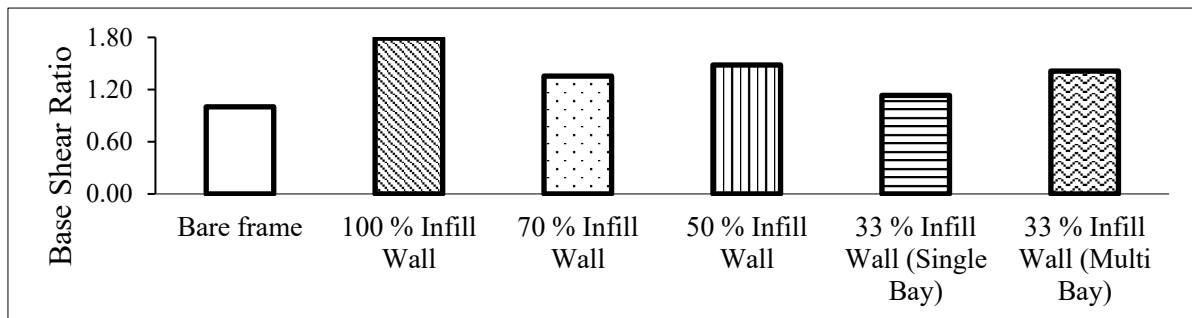


Figure 4: Base shear ratio for different types of framing conditions

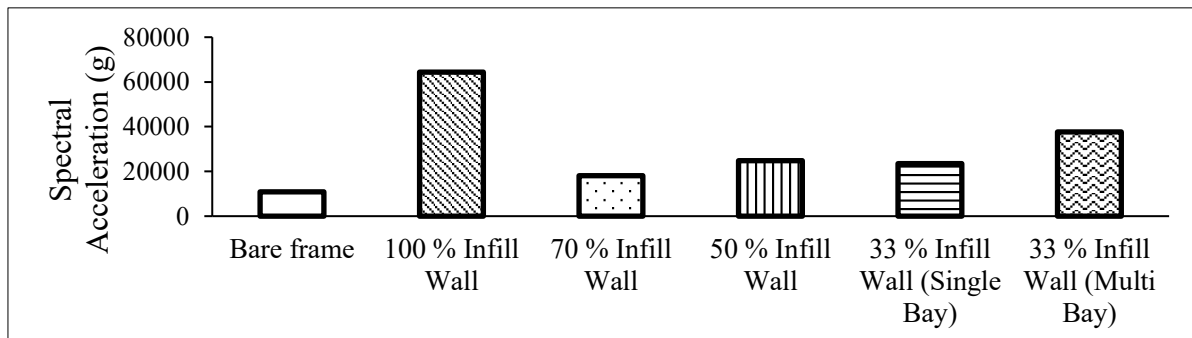


Figure 5: Spectral acceleration for different types of framing conditions

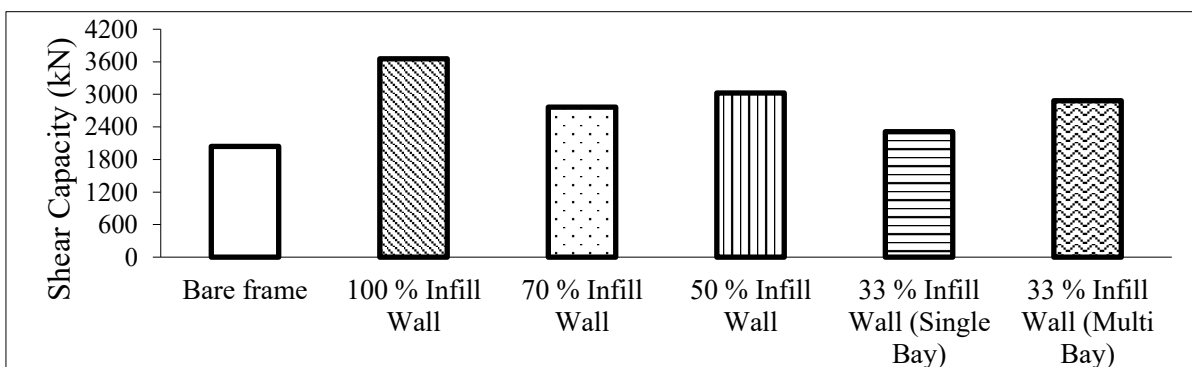


Figure 6: Shear capacity for different types of framing conditions

5. CONCLUSIONS

The study mentioned above yielded the following conclusions:

- a) The amount of base shear depends on the arrangement and the quantity of infilled masonry walls. Fully infilled walls provide maximum shear capacity that helps to reduce the drift and deflection of structures. Due to the absence of stiffened members, bare-frame structures show maximum roof displacements.
- b) A deficiency in the stiffness of a building enhances the probability of a soft storey. Buildings with bare frames on the ground floor decrease the overall stiffness of the lower storey compared to the upper rigid storey.
- c) Proper arrangements of infill masonry enhance the performance of buildings. Buildings with more openings perform worse during any natural hazards (earthquake, wind, etc.)
- d) Moreover, the presence of infill masonry allows for more realistic and optimized designs. Most building codes encourage the use of realistic modeling by considering an equivalent diagonal strut, which predicts the building's fundamental period accurately, ensuring a safe and cost-effective design. The contribution of infill walls in resisting a significant amount of lateral loads reduces the size of structural members (Column, Beam).

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