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Nonlinear Numerical Study of Infilled RC Frames with Openings and Wall-Posts

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Abstract

Masonry infill walls, although commonly treated as non-structural elements in reinforced concrete (RC) buildings, have a significant influence on the lateral response of RC frames. This study investigates the effects of masonry infills, opening configurations, and wall-post systems on the nonlinear lateral behavior of RC moment-resisting frames under quasi-static loading using advanced numerical modeling. Three-dimensional finite element models were developed in ABAQUS and validated against reliable experimental results. The numerical program includes bare frames, fully infilled frames, infilled frames with various opening sizes, and wall-post–strengthened configurations, all subjected to displacement-controlled quasi-static lateral loading up to large deformation levels. The results indicate that masonry infills considerably increase the initial stiffness and lateral strength of RC frames, while simultaneously increasing the potential for brittle behavior and stress concentration in the columns. The presence of openings reduces stiffness and disrupts the load transfer mechanism, leading to localized damage concentration around opening corners. In contrast, wall-post systems effectively mitigate these adverse effects by redistributing stresses, improving damage uniformity, and enhancing post-peak stability. The combined use of wall-posts and infilled walls with openings provides a more controlled lateral response in terms of strength, stiffness, and ductility, highlighting wall-posts as an efficient solution for improving the structural performance of infilled RC frames under lateral loading conditions.

Keywords

masonry infill wall, RC moment-resisting frame, wall openings, wall-post system, nonlinear analysis

1 Introduction

The seismic behavior of reinforced concrete (RC) structures, particularly conventional buildings employing moment-resisting frame systems, has long been a central concern in earthquake engineering. Evidence from recent damaging earthquakes has demonstrated that structural losses are not solely governed by deficiencies in primary load-bearing members; rather, non-structural components most notably masonry infill walls can play a decisive role in the overall seismic response. Although infill walls are generally neglected as lateral load-resisting elements in seismic design codes, they inevitably interact with RC frames during earthquakes, significantly influencing global stiffness, strength, and failure mechanisms under lateral loading conditions associated with seismic demand.

The earliest systematic investigations into frame–infill interaction were conducted by Polyakov [1] and Mainstone [2], who demonstrated that masonry infill walls actively participate in resisting in-plane lateral loads. Mainstone's equivalent diagonal strut model provided a simplified yet practical framework for incorporating infill effects in structural analysis. Subsequent experimental studies revealed that the presence of infill walls substantially increases initial lateral stiffness and load-carrying capacity; however, this enhancement is often accompanied by unfavorable brittle behavior, including stress concentration and shear failure of columns [3, 4]. Such adverse interaction may inhibit the development of desirable plastic mechanisms and significantly reduce the global ductility of RC frames under increasing lateral deformation demands.

Later investigations identified various infill failure modes, including diagonal cracking, corner crushing, and separation at the frame–infill interface [5]. Moreover, experimental evidence has shown that construction details and frame–infill connection conditions strongly

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influence force transfer paths and damage evolution [6, 7]. The presence of openings such as doors and windows further complicates infill behavior by weakening load transfer mechanisms, reducing stiffness and strength, and inducing stress concentration around opening corners [8]. Additionally, several studies have reported that masonry infills may significantly increase column shear demand, thereby aggravating the risk of brittle column failure under lateral loading conditions [9].

To mitigate these detrimental effects, a variety of strategies have been proposed, including modifications to construction details, infill configurations, and material properties [10]. Advances in numerical modeling have enabled more accurate investigation of both in-plane (IP) and out-of-plane (OOP) responses of infill walls. Recent studies have emphasized the strong coupling between IP damage and OOP capacity, showing that in-plane degradation can lead to a substantial reduction in out-of-plane resistance under lateral displacement-controlled loading conditions [11].

In recent years, modern strengthening techniques such as textile-reinforced mortars (TRM), fiber-based composites, and lightweight high-strength panels have been introduced to improve the seismic performance of masonry infills [12–15]. Despite their effectiveness, many of these solutions are associated with economic and practical limitations. In contrast, wall-post systems have emerged as a simple and efficient constructional solution. Experimental and numerical investigations have demonstrated that wall posts can modify load transfer mechanisms, restrain out-of-plane deformations, reduce stress concentration in adjacent columns, and enhance post-peak stability and ductility of infilled RC frames under monotonic, cyclic, and quasi-static lateral loading conditions [16–18]. Furthermore, recent studies have highlighted the necessity of explicitly accounting for wall-post effects in numerical models to achieve reliable seismic response predictions based on lateral force–displacement behavior rather than direct dynamic simulation [19, 20].

Based on the above considerations, it is evident that masonry infill walls, despite being classified as non-structural components, play a complex and influential role in the seismic behavior of RC moment-resisting frames. Accordingly, the present study aims to comprehensively investigate the effects of masonry infill walls with openings and wall-post systems on the lateral response characteristics relevant to seismic performance of RC frames. Validated three-dimensional numerical models are employed to evaluate the influence of wall posts on lateral stiffness, strength, ductility, failure patterns, and out-of-plane behavior through displacement-controlled quasi-static analyses, thereby providing a scientific basis for improved seismic design and detailing of reinforced concrete structures.

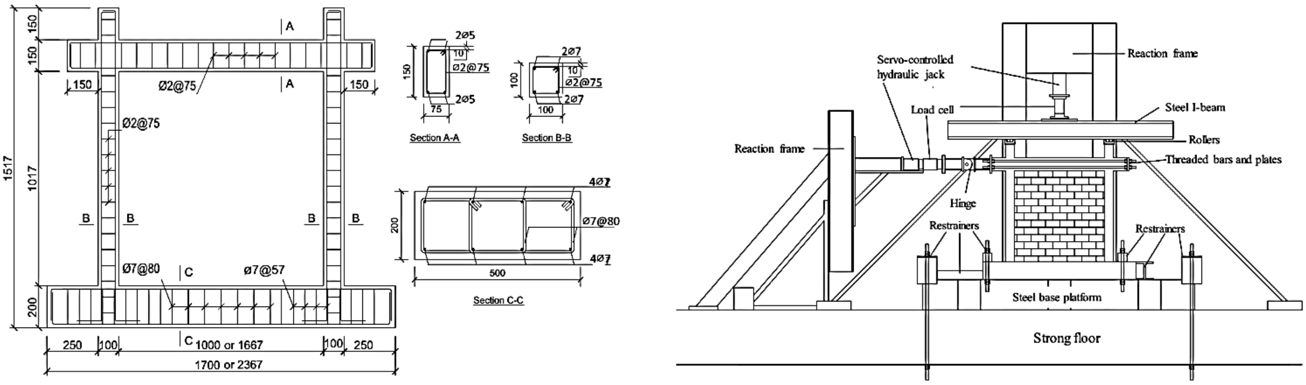
2 Numerical model validation

To validate the accuracy of the numerical modeling and its capability to replicate the actual structural response, the finite element analysis (FEA) results for the bare frame (BF1) and the masonry-infilled frame (IF1) specimens were directly compared with the experimental data reported by Van and Lau [21]. The reference test specimens were subjected to monotonic quasi-static lateral loading and maintained a height-to-span ratio of 1.017, making them suitable for validating the lateral response characteristics relevant to seismic performance assessment.

The mechanical properties of all constituent materials concrete, steel, brick, and mortar–were adopted directly from the reference study [21]. The concrete compressive strength was 22.8 MPa. Longitudinal reinforcement bars (T5 and T7) exhibited yield strengths of 581 MPa and 605 MPa, respectively, while the transverse reinforcement yielded at 306 MPa. The masonry infill assemblage demonstrated adequate lateral stiffness, with a shear strength of 0.403 MPa and a shear modulus of 0.576 MPa. The compressive strengths of the brick units and mortar were 26 MPa and 8.1 MPa, respectively. The experimental setup, including geometry and reinforcement detailing, is illustrated in Fig. 1.

The frame and infill geometries were modeled using Abaqus [22]. Concrete and masonry components were simulated using three-dimensional solid elements (C3D8R) with reduced integration. Critical nonlinear phenomena–including material inelasticity, contact interaction between brick and mortar, and the embedded-region constraint for steel reinforcement were implemented through the Interaction module. Boundary conditions and the loading protocol were defined in accordance with the experimental procedure, employing a displacement-controlled monotonic loading scheme applied incrementally up to 10 cm. The geometric configuration and contact definitions of the masonry infill were carefully replicated for the IF1 model.

The resulting deformation contours and plastic strain distributions (Figs. 2 and 3) show a satisfactory agreement between the numerical predictions and the experimentally observed damage patterns for both specimens. In the BF1 specimen, the concentration of plastic strains



(a) (b)

Fig. 1 Dimensional details of (a) the experimental specimen and (b) testing procedure [21]

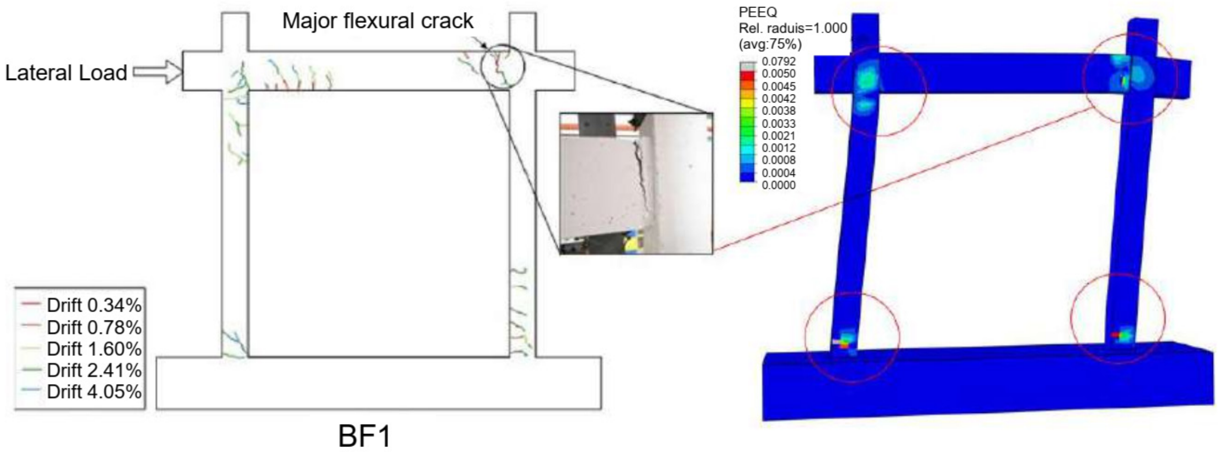


Fig. 2 Damage and cracking patterns in experimental and numerical BF1 specimens

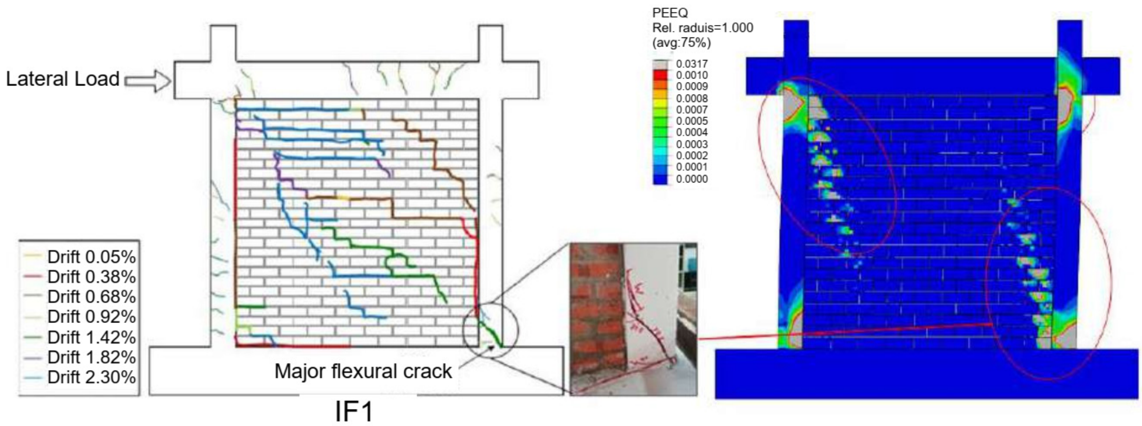


Fig. 3 Damage and cracking patterns in experimental and numerical IF1 specimens

at the column bases and the mid-span region of the top beam corresponds well with the flexural and flexural–shear cracking reported in the experimental study. For the IF1 specimen, the characteristic diagonal cracking within the infill panel, progressive separation at the frame–infill interface, and the accumulation of localized deformations were accurately reproduced, consistent with experimental observations. This strong correlation confirms the appropriate definition of material models and contact properties adopted in the numerical framework.

Fig. 4 compares the numerical and experimental load–displacement relationships, demonstrating a satisfactory

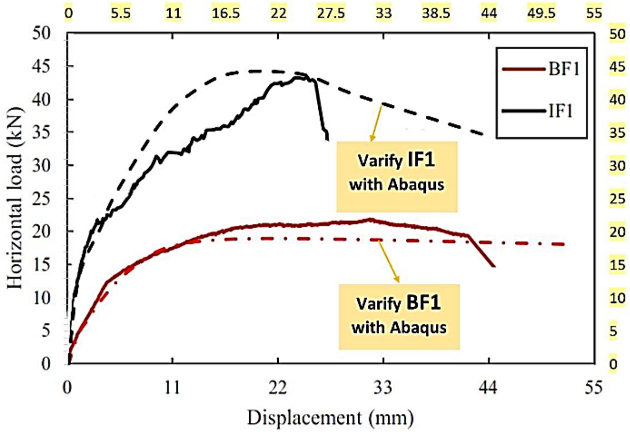


Fig. 4 Comparison of lateral load-displacement response between numerical model and experimental specimen

level of agreement. The initial stiffness, peak lateral strength, and post-peak degradation trends are well captured for both BF1 and IF1 specimens. Minor discrepancies observed in the ultimate strength and post-peak displacement ranges can be attributed to unavoidable numerical idealizations and potential variability in material properties between the experimental specimens and their numerical counterparts. Nevertheless, the overall correspondence between the curves indicates that the model reliably reproduces the ductile response of the bare frame and the brittle-dominated response of the infilled frame under monotonic lateral loading.

Overall, the validation results demonstrate that the adopted finite element model has a robust capability to represent the lateral behavior of reinforced concrete frames, both with and without masonry infills. The close agreement in cracking patterns, plastic strain localization, stress contours, and load–displacement responses confirm the reliability of the modeling strategy. Consequently, the validated numerical model provides a sound basis for subsequent parametric investigations into the influence of wall-post systems on the lateral response characteristics associated with seismic performance of RC frames.

3 Investigated models

In this research, a set of three-dimensional numerical models was developed using ABAQUS software to investigate the effects of masonry infill walls, opening configurations, and wall-post systems on the lateral response characteristics relevant to seismic performance assessment of reinforced concrete (RC) moment-resisting frames. The general geometry of the models consists of a single-bay, single-story RC frame with a bay length and story height of 3.0 m, representative of typical low-rise urban buildings. Although simplified, this configuration allows for a clear interpretation of the fundamental interaction mechanisms between the RC frame, masonry infill, and wall-post systems. All beams and columns were modeled with realistic cross-sectional dimensions to enable accurate simulation of nonlinear structural behavior. Nevertheless, the behavior of multi-story and multi-bay buildings requires further investigation; therefore, this study is limited to a single-story, single-bay frame to allow a focused fundamental assessment.

The nonlinear behavior of concrete was represented using the Concrete Damaged Plasticity (CDP) model, accounting for compressive hardening, tensile cracking, stiffness degradation, and triaxial stress effects. Steel reinforcement was modeled using a multi-linear elasto-plastic constitutive law with strain hardening to capture post-yield behavior. Masonry materials, including brick units and mortar, were defined using appropriate non-linear constitutive models capable of reproducing brittle behavior, diagonal cracking, brick–mortar separation, and progressive detachment of the infill from the surrounding RC frame. Frictional contact interfaces were defined between masonry units and between the infill wall and the frame to realistically simulate sliding, separation, and local damage evolution under lateral loading.

The models were defined in several states to allow for the analysis of the role of each structural parameter:

1. Bare Frame (BF): First, the bare frame was modeled without any infill to determine the fundamental behavior and ductility capacity of the moment frame in the absence of non-structural elements. This model serves as the primary reference for comparison.
2. Fully-Infilled Frame (MIF): The fully-infilled frame was then investigated to evaluate the effects of increased initial stiffness, changes due to frame-infill interaction, and the potential for brittle behavior.
3. Infill with Openings (D/W): Subsequently, models with infills containing various door (D) and window (W) openings were developed. These openings, detailed in Fig. 5, were chosen with different dimensions and locations to examine how the reduction in wall area and the creation of weaker regions affect stress concentration, cracking paths, and load-bearing capacity.
4. Infill with Wall Posts: Considering that masonry infills may transfer significant lateral forces directly to the RC columns, potentially leading to premature shear failure, additional models incorporating wall-post systems were developed (Fig. 6). The wall posts

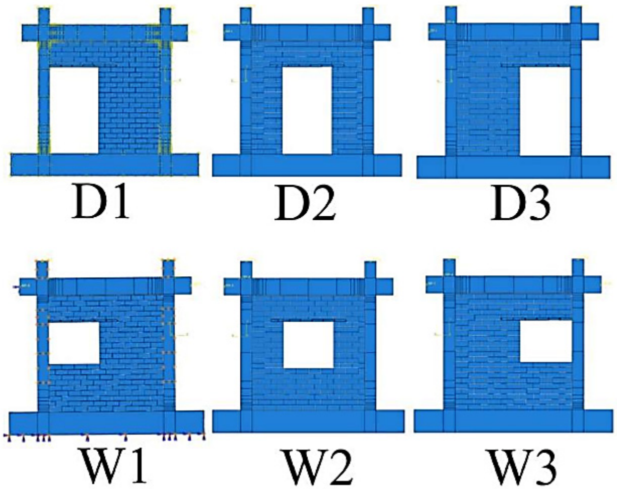


Fig. 5 Naming convention for different sizing and positioning of openings in the RC frame with masonry infill

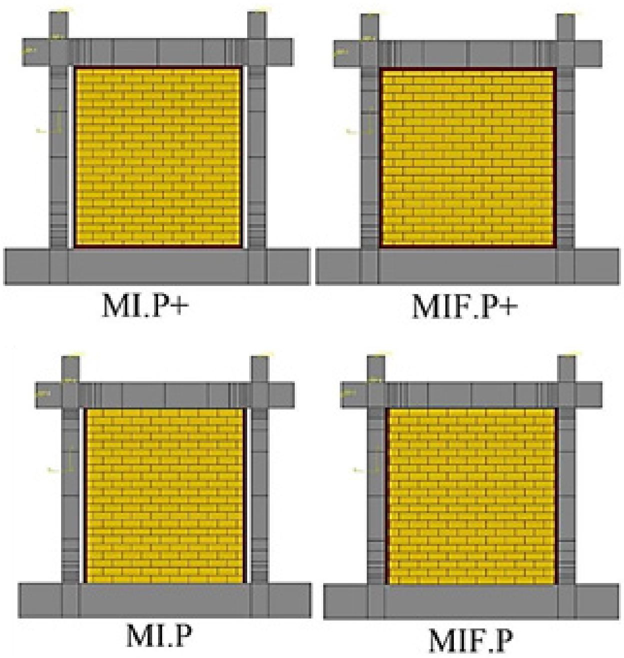


Fig. 6 Naming convention for different configurations of RC frames with masonry infill including wall posts

were modeled as vertical steel elements structurally connected to the top beam while remaining intentionally detached from the RC columns. This modeling assumption reflects common construction practice, where wall posts are anchored to the beams to ensure vertical and out-of-plane stability of the infill wall while avoiding rigid force transfer to the columns. The wall–post to beam connection was idealized as a rigid connection, whereas the separation from the columns allows relative deformation and limits unintended stress concentration in the frame members. This configuration enables the wall posts to participate in lateral load redistribution within the infill while mitigating adverse column demands.

5. Combined Models: Finally, combined configurations consisting of infilled frames with openings and wall-post systems were investigated (Fig. 7). These models were designed to evaluate whether wall posts can compensate for the adverse effects of openings – such as stiffness reduction and localized damage – and restore an acceptable level of lateral load-carrying capacity and deformation performance under monotonic loading.

All models were subjected to quasi-static monotonic lateral loading using a displacement-controlled protocol. Lateral displacement was gradually imposed at the beam level, while constant axial gravity loads were applied to the columns to simulate realistic service conditions. The base supports of the frame were defined as fully fixed, and geometric nonlinearity (P–Δ effects) was activated in all analyses to capture large-deformation behavior and second-order effects.

In the infilled configurations, contact interactions between the masonry infill and the RC frame allowed for natural development of sliding, separation, and progressive damage during loading. All models were analyzed up to a target lateral displacement of 10 cm, ensuring observation of the full response range from elastic behavior to strength degradation and failure.

This modeling framework, based on controlled and systematically varied configurations, enables a clear assessment of the individual and combined effects of masonry infills, openings, and wall-post systems on the lateral response characteristics associated with seismic performance of RC moment-resisting frames. The comparative

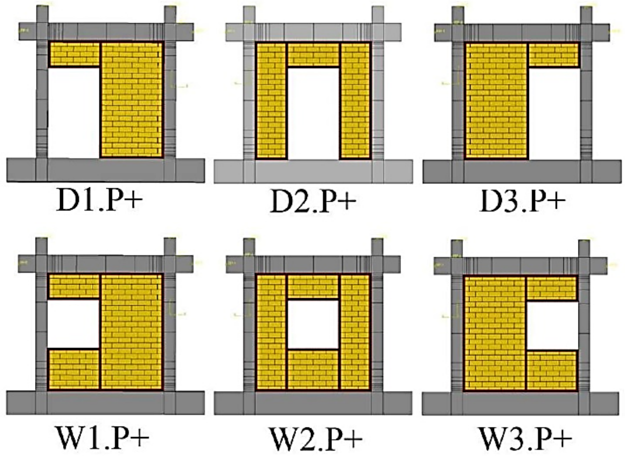


Fig. 7 Naming convention for different sizing and positioning of openings in the RC frame with masonry infill, considering wall posts

evaluation of these models provides valuable insight into the role of wall posts as an effective and practical measure for controlling infill–frame interaction.

4 Numerical analysis results

This section focuses on reviewing the numerical analysis results of the developed models, analyzing the nonlinear lateral response of reinforced concrete (RC) moment-resisting frames in the presence or absence of masonry infills, openings, and wall-post systems (vertical stiffeners). The results are presented in terms of frame–infill interaction mechanisms, global and local deformations, crack development patterns, stress distribution contours, and monotonic load–displacement relationships. The comparative evaluation of the models is conducted based on initial stiffness, lateral load-carrying capacity, displacement ductility, and governing failure modes under quasi-static monotonic loading.

4.1 Overall deformation behavior and failure modes

The numerical analysis results indicate that the presence or absence of masonry infill, as well as the method of its reinforcement with wall-post systems (vertical stiffeners), significantly influences stress distribution, force transfer mechanisms, and the governing failure modes of RC frames under lateral loading. As illustrated in Fig. 8, the bare frame (BF) exhibited a predominantly flexural response, characterized by the formation of plastic hinges at the column bases and beam–column joint regions. The gradual increase in lateral displacement resulted in progressive flexural deformation and stable development of plastic zones without sudden strength loss, thereby demonstrating the adequate displacement ductility of the primary structural system under monotonic loading.

In contrast, the fully infilled frame exhibited a marked increase in initial stiffness, accompanied by a significant modification of the force transfer path from the RC frame to the masonry infill. As the response entered the nonlinear range, diagonal cracking initiated within the infill wall, and its progressive propagation led to concentrated stress transfer to the adjacent columns. These stress concentrations induced high diagonal compressive forces in the columns, resulting in a pronounced brittle response.

In several models, premature shear failure developed in the columns, underscoring the potentially hazardous consequences of incorporating masonry infills without appropriate detailing or load-control mechanisms under monotonic lateral loading.

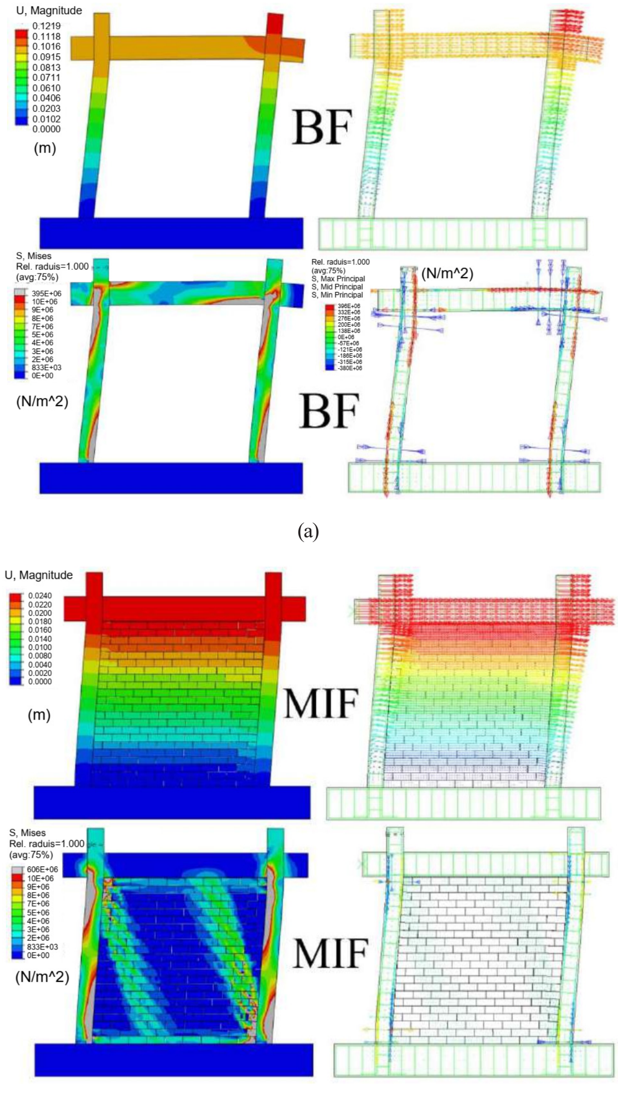


Fig. 8 Displacement and stress contours for (a) the bare frame (BF) and (b) the RC frame with masonry infill (MIF)

Introducing openings within the infill wall resulted in a noticeable alteration of the structural response and a reduction in initial stiffness. As shown in Fig. 9, stress concentration at the corners of the openings led to the initiation of localized cracking and accelerated separation of the infill from the surrounding frame. An increase in opening size further amplified stiffness degradation and reduced lateral load-bearing capacity, while damage localization around the opening corners became more pronounced. Although partial removal of the infill mitigates the excessive brittle stiffness associated with fully infilled frames, the altered stress transfer paths produced more complex and nonuniform damage patterns within the wall surface (Fig. 10).

Fig. 11 illustrates that in models incorporating wall-post systems (vertical stiffeners), stress distribution in regions adjacent to the columns became significantly more

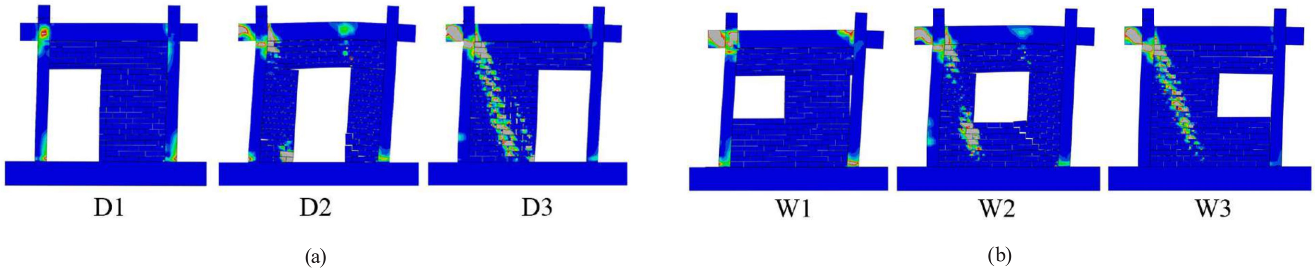


Fig. 9 Developed permanent strain (non-dimensional – maximum 2%) in the RC frame with masonry infill and large opening (a) door opening, (b) window opening

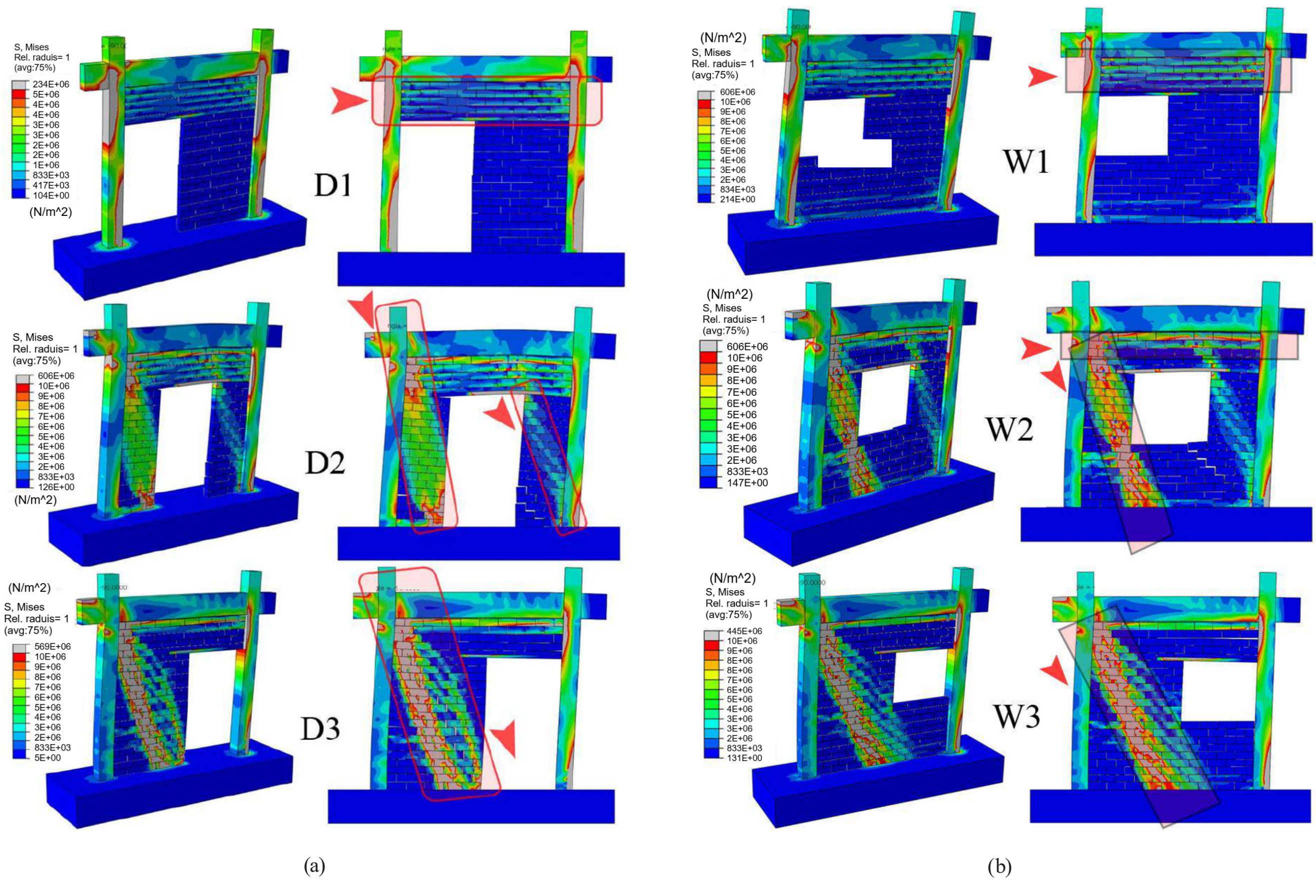
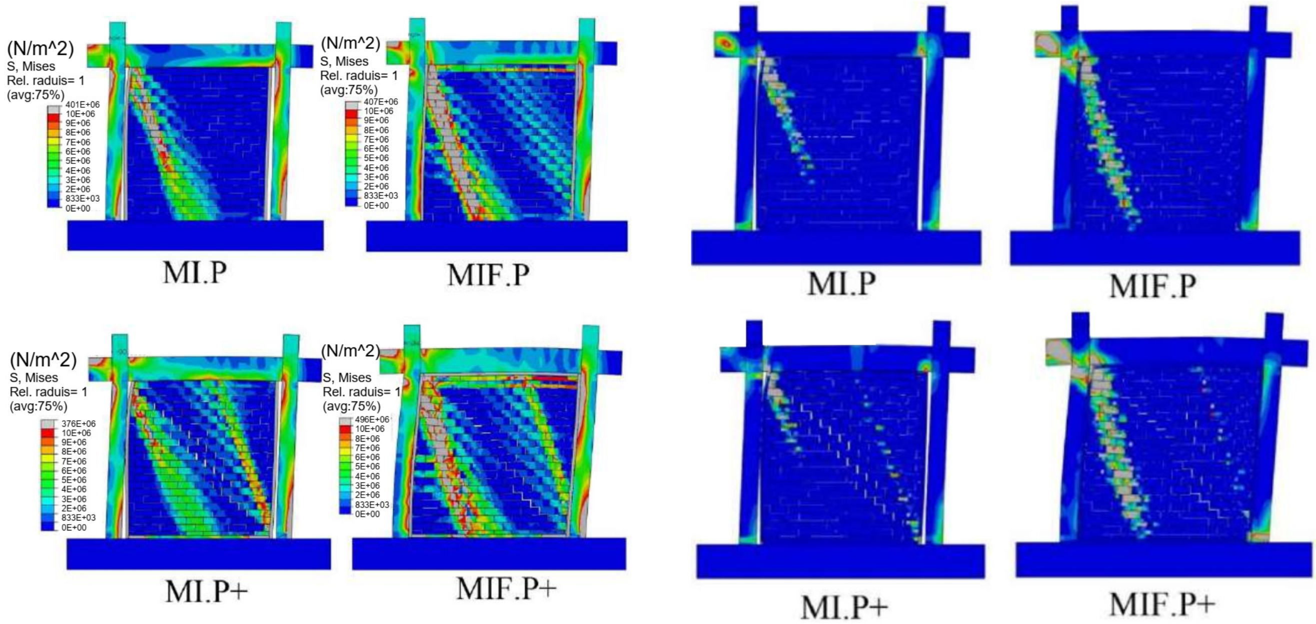


Fig. 10 Developed stress contours in the RC frame with masonry infill and large opening (a) door opening, (b) window opening

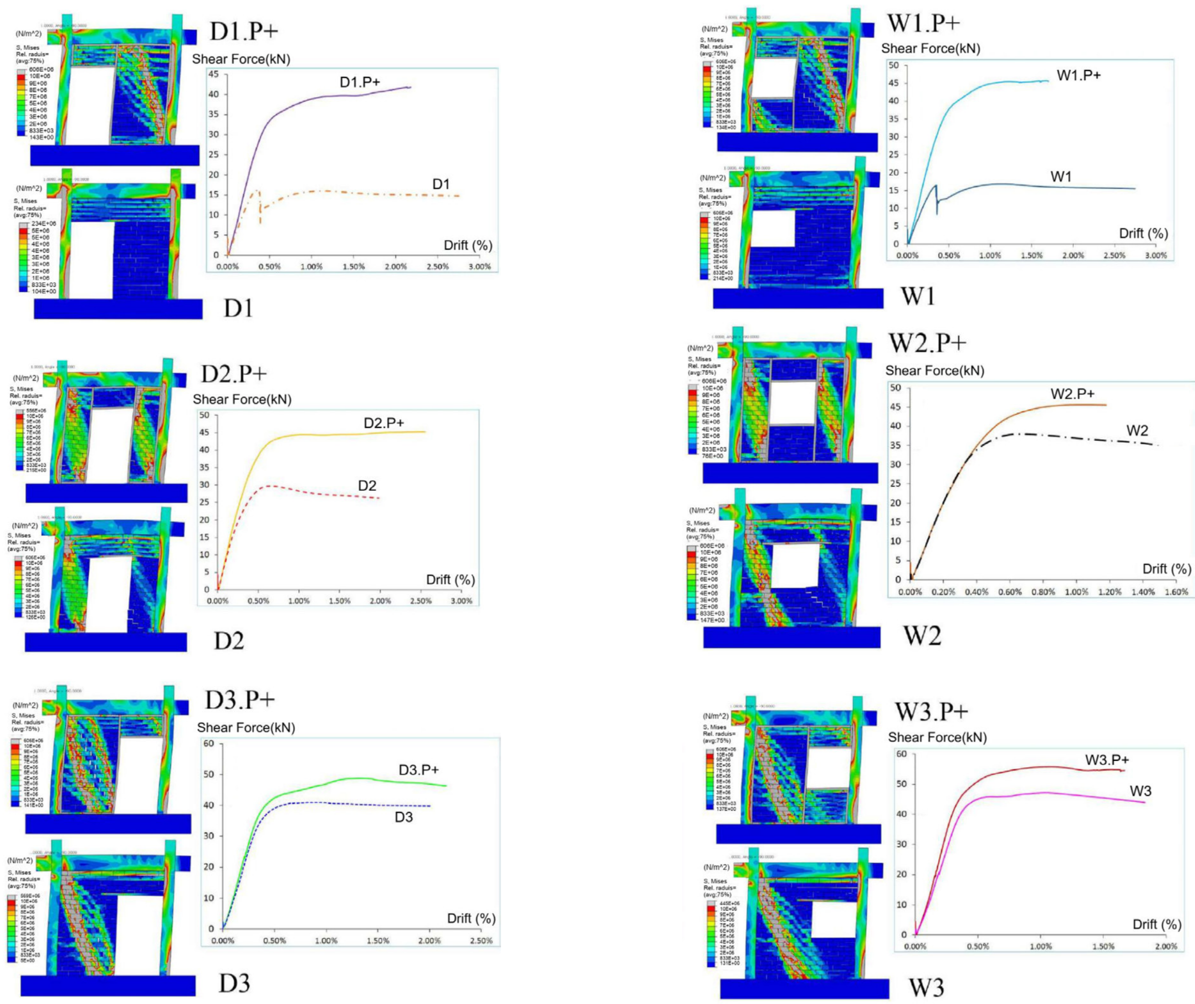
uniform. The wall posts absorbed a substantial portion of the applied lateral forces and established an alternative load-transfer path, thereby preventing excessive stress concentration at the column bases. As a result, the column shear failures observed in models without wall posts were largely suppressed. Furthermore, the cracking pattern shifted from the RC columns to the infill wall, and the dominant failure mechanism transitioned from a column shear-controlled mode to a flexural–diagonal cracking response within the masonry under monotonic loading. This response highlights the effectiveness of wall posts in improving structural robustness and controlling unfavorable interaction mechanisms.

In configurations combining wall posts with infill openings, a more balanced lateral response was achieved. The comparison of stress contours and monotonic load–displacement relationships presented in Fig. 12 indicates that wall posts effectively compensated for a substantial portion of the adverse effects introduced by openings. By reducing stress concentration around opening corners, wall posts promoted a more uniform damage distribution and delayed strength degradation. Consequently, models reinforced with wall posts in the presence of openings exhibited higher lateral load-bearing capacity and improved post-peak stability compared to their counterparts without wall-post reinforcement.



(a) (b)

Fig. 11 (a) Developed stress and (b) permanent strain in the RC frame with masonry infill including wall posts



(a) (b)

Fig. 12 Load-displacement diagram and developed stress contours in specimens with openings, in both cases with and without wall posts, (a) door opening, (b) window opening

4.2 Investigation of strain and stress contours

An investigation of the plastic strain and von Mises stress contours obtained from the numerical models indicates that the structural response undergoes fundamental changes depending on the presence of masonry infill, the size and configuration of openings, and the incorporation of wall-post systems (vertical stiffeners) under monotonic lateral loading.

An investigation of the plastic strain and von Mises stress contours obtained from the numerical models indicates that the structural response undergoes fundamental changes depending on the presence of masonry infill, the size and configuration of openings, and the incorporation of wall-post systems (vertical stiffeners) under monotonic lateral loading.

In the bare frame (BF), the highest plastic strain concentrations are observed at the column bases and beam–column joint regions, reflecting the dominance of a flexural-controlled response mechanism. This behavior confirms the expected ductile performance of the RC moment-resisting frame in the absence of infill interaction.

In the fully infilled model, diagonal compressive stresses within the masonry wall intensify rapidly, leading to the formation of a pronounced diagonal load-transfer path. This stress trajectory governs the initiation and propagation of diagonal cracking within the infill and ultimately results in a brittle failure mode. Moreover, stress concentration at the wall–column interface subjects the adjacent columns to elevated shear demands, increasing their vulnerability to shear damage (Fig. 8).

For models incorporating openings, significant localization of plastic strains is observed at the opening corners, where damage consistently initiates (Fig. 9). The removal of a portion of the infill disrupts structural continuity and leads to the formation of alternative stress paths, resulting in complex stress redistribution and accelerated damage accumulation within the wall surface (Fig. 10).

In contrast, models equipped with wall-post systems exhibit a marked shift in stress concentration away from the columns toward the wall posts and the central region of the infill. By establishing a parallel load-bearing mechanism, wall posts effectively reduce adverse stress demands on the columns and promote a more uniform stress distribution within the masonry wall, thereby mitigating brittle failure mechanisms under monotonic loading (Fig. 11). A similar trend is observed in configurations combining wall posts and openings, highlighting the ability of wall posts to alleviate stress concentration effects induced by openings and to improve overall response uniformity (Fig. 12).

4.3 Load-displacement results

An investigation of the load–displacement curves demonstrated that the addition of masonry infill walls, openings, and wall-post systems results in diverse mechanical behaviors within the frame under monotonic lateral displacement-controlled loading. As shown in Fig. 13, the bare frame (BF) exhibits the lowest initial stiffness and the highest displacement ductility (μ), characterized by a shallow initial slope and an extended post-elastic range in its load–displacement response.

With the presence of a fully infilled frame (MIF), the initial stiffness of the structure increases significantly; however, a more brittle behavior emerges, such that the load–displacement curve experiences a sudden strength drop following the formation of diagonal cracks in the infill, leading to a noticeable reduction in overall ductility.

The load–displacement diagrams for all specimens incorporating openings are presented in Fig. 14. In the case of an infilled frame with an opening, both the initial stiffness and lateral load-bearing capacity are reduced compared to the fully infilled frame, resulting in a softer global response. The addition of a wall-post system leads to a significant improvement in ultimate strength, a controlled increase in

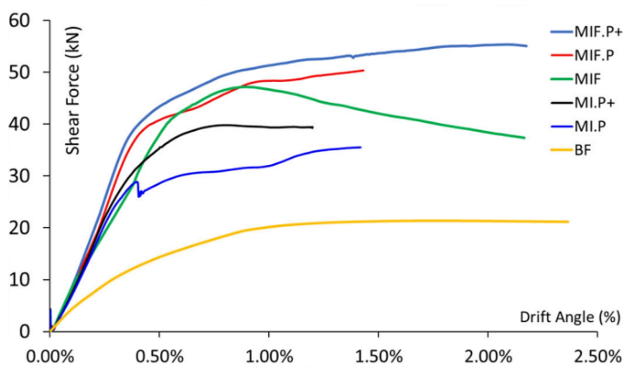


Fig. 13 Load-displacement diagram of the RC frame with masonry infill, considering wall posts

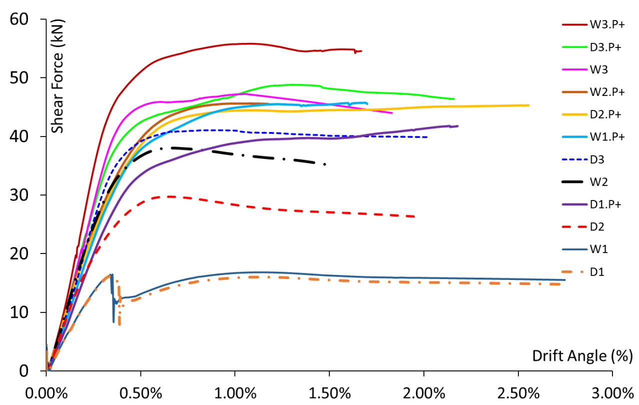


Fig. 14 Load-sisplacement diagram for all specimens with openings

initial stiffness, and a reduction in the abrupt strength drop after initial cracking. Models featuring both an opening and a wall post demonstrate the most balanced performance in terms of stiffness, strength, and displacement ductility, effectively moving away from the brittle behavior of fully infilled frames while achieving higher strength than infilled frames with openings but without reinforcement.

The load–displacement curves in Fig. 14 further demonstrate the significant influence of wall posts on the performance of frames with openings in masonry infills. Specimens without wall posts (Series D and W) generally exhibit lower initial stiffness and shear capacity and experience more rapid strength degradation as drift increases. This behavior primarily stems from stress concentration at opening corners and weak wall-to-frame interaction, which accelerates diagonal cracking and premature infill failure.

In contrast, specimens reinforced with wall posts (D.P+ and W.P+) show a more stable and resilient response. Their initial stiffness is enhanced, peak strength reaches higher values, and the post-peak region of the curve exhibits a more uniform and gradual degradation trend. By creating an auxiliary load-bearing path, the wall post prevents stress concentration in critical regions and, while limiting localized deformations, promotes a more uniform stress distribution within the masonry wall.

The best overall performance is observed in specimen W3.P+, which demonstrates superior behavior in terms of both shear capacity and post-peak stability. In summary, reinforcing masonry infills with openings using wall-post systems not only increases lateral stiffness and strength but also stabilizes the monotonic structural response and prevents sudden loss of load-carrying capacity, thereby enhancing the overall reliability of the structural system.

4.4 Lateral performance of specimens

The numerical results for the lateral performance of the frames, presented in Fig. 15, demonstrate the significant influence of masonry infills, openings, and wall-post systems on the monotonic lateral response parameters relevant to seismic performance of the structural system. Compared to the bare frame (BF), the presence of masonry infill leads to a pronounced increase in initial lateral stiffness (K), maximum lateral force capacity (V), and energy dissipation capacity (E), accompanied by a reduction in displacement ductility (μ). In contrast, the introduction of openings results in a relative decrease in these performance indicators due to the disruption of the infill load-transfer mechanism.

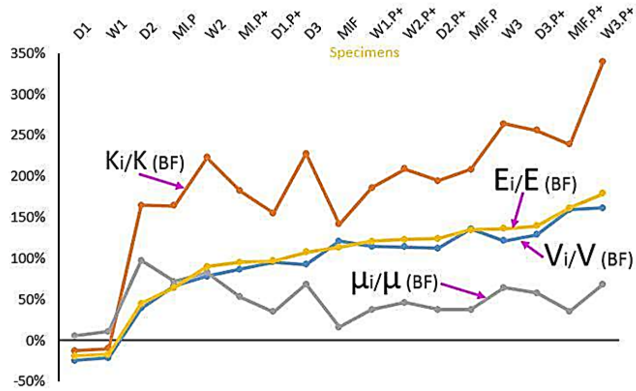


Fig. 15 Comparison of the lateral performance of specimens relative to the bare frame (BF)

The incorporation of wall-post systems in all investigated specimens leads to the recovery, and in some cases enhancement, of stiffness, strength, and dissipated energy relative to the corresponding configurations without wall posts. A comparison of the normalized performance indices (K_i/K_{BF}, V_i/V_{BF}, E_i/E_{BF}, and μ_i/μ_{BF}) with respect to the bare frame confirms that wall posts play a decisive role in improving the lateral load-bearing capacity, deformation stability, and monotonic performance characteristics associated with seismic demand of frames with infill openings.

5 Conclusions

The main objective of this research was to investigate the lateral structural response characteristics relevant to the seismic performance of reinforced concrete (RC) moment-resisting frames in the presence of masonry infills, various opening configurations, and wall-post systems (vertical stiffeners), and to evaluate the influence of these components on the frame's load-bearing capacity, stiffness, displacement ductility, and failure patterns.

In the first step, a detailed three-dimensional numerical model was developed using ABAQUS software. Following successful validation against available experimental results, a series of models—including the bare frame (BF), the fully infilled frame, infilled frames with openings of various dimensions, and configurations reinforced with wall posts were analyzed under quasi-static monotonic lateral loading. The results indicate that the monotonic response parameters associated with seismic demand of RC frames are strongly governed by the complex interaction between the frame, the masonry infill, and the wall-post system. Each of these components significantly alters the load-transfer mechanism, failure mode, and overall structural performance, highlighting the necessity of explicitly accounting for their combined effects in numerical assessments.

- The investigations showed that the bare frame (BF), as the baseline case, exhibits a dominant flexural response and satisfactory displacement ductility under monotonic lateral loading, while its initial stiffness and lateral load-bearing capacity remain limited.
- The presence of a fully infilled frame leads to a significant increase in initial stiffness and lateral capacity; however, this improvement occurs at the expense of reduced ductility and the emergence of brittle behavior. The concentration of diagonal compressive stresses within the infill and the undesirable transfer of lateral forces to the columns may trigger premature shear failures, which is considered an unfavorable response with respect to seismic performance requirements. Therefore, although the infill enhances the initial resistance of the system, its uncontrolled interaction with the frame may adversely affect the monotonic response characteristics associated with seismic demand.
- The existence of openings in the infill, particularly in models D and W, results in a reduction in initial stiffness, a decrease in ultimate strength, and pronounced stress concentration at the opening corners. Plastic strain contours indicate that damage initiation consistently occurs at these regions, where cracking and failure first develop. The reduction in effective wall area weakens the load-transfer mechanism, leading to a softer structural response with a shallower load–displacement slope and lower capacity compared to the fully infilled frame, thereby reducing the reliability of the system under lateral loading.
- The use of wall-post systems as a strengthening measure plays a decisive role in modifying the structural response. By creating an alternative lateral load-transfer path, wall posts shift stress concentration away from the columns and significantly reduce shear demand in the primary frame members.
- Models reinforced with wall posts (P+) exhibit enhanced initial stiffness compared to unreinforced models with openings, while preventing the sudden loss of resistance after initial cracking. Load–displacement responses confirm that wall posts not only increase lateral strength but also promote a more uniform post-peak behavior and improved deformation stability.
- Specimen W3.P+ demonstrates the most favorable monotonic lateral performance characteristics among all configurations with openings, highlighting the high efficiency of wall posts in controlling stress concentration and upgrading the load-bearing capacity of the system.

In general, the results clearly demonstrate that masonry infills, with or without openings, are highly influential elements governing the lateral response relevant to seismic performance of RC frames, and neglecting their effects in analysis and design may lead to significant misestimation of stiffness and strength. Openings weaken the infill and increase its vulnerability; however, the implementation of wall-post systems effectively mitigates these adverse effects. In addition to enhancing load-bearing capacity, wall posts improve energy dissipation capacity inferred from monotonic response and prevent stress concentration in columns, thereby substantially reducing the likelihood of sudden and brittle failures.

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