



International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 19 No. 4 (2023)



ijerst.editor@gmail.com
editor@ijerst.com

COMPARATIVE EXPERIMENTAL ANALYSIS OF RCC STRUCTURES WITH AND WITHOUT MASONRY INFILL IN VARIOUS SEISMIC ZONES

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Abstract

Reinforced cement concrete (RCC) framed buildings are conventionally designed and analyzed as bare moment-resisting frames, even though masonry infill walls are almost universally present as architectural partitions and are known to contribute substantially to lateral stiffness, strength, and energy dissipation during earthquake shaking. Current design practice under IS 456:2000 and IS 1893:2016 generally treats infill as a non-structural element, a simplification that can misrepresent the true seismic demand and capacity of a building, particularly in the higher seismic zones of the Indian subcontinent. This paper presents SIRA (Seismic Infill Response Assessment), a comparative experimental-cum-analytical investigation of a representative eleven-storey (G+10) RCC framed building modeled with and without masonry infill walls across the four seismic zones (Zone II to Zone V) defined by IS 1893:2016. Masonry infill panels were idealized as equivalent diagonal struts following the Mainstone/FEMA 356 formulation, with strut properties derived from laboratory prism-compression and diagonal (racking) shear tests on brick masonry assemblages. Linear equivalent-static and response-spectrum analyses, together with nonlinear static pushover analysis, were performed in ETABS for both configurations in each zone. Across all four zones, inclusion of masonry infill reduced the fundamental translational period by approximately 30%, increased the code-based design base shear demand by about 56%, and reduced the maximum storey drift ratio and roof displacement

by approximately 30% relative to the bare frame. Nonlinear pushover analysis showed a 45% increase in lateral capacity at the performance point, accompanied by a 36% reduction in displacement ductility capacity. In Zone V, the bare frame exceeded the IS 1893:2016 storey drift limit of 0.004, whereas the infilled frame remained within the permissible limit, underscoring the practical significance of the infill contribution in severe seismic zones. The results confirm that neglecting masonry infill in seismic analysis and design produces an unconservative estimate of stiffness-related demand and an overestimation of deformation capacity, and the study provides quantified, zone-wise comparative data to support more realistic seismic evaluation of infilled RCC buildings.

Keywords: Masonry Infill; Reinforced Concrete Frame; Seismic Zones; Equivalent Diagonal Strut; Pushover Analysis; IS 1893:2016; Storey Drift; Base Shear

1 Introduction

Reinforced cement concrete (RCC) moment-resisting frames constitute the predominant structural system for multi-storey residential and commercial construction across India and other seismically active regions of South Asia. In almost every such building, the bays of the RCC frame are subsequently filled with unreinforced brick or concrete-block masonry to form external walls and internal partitions. Structural design codes such as IS 456:2000 and IS 1893:2016, however, generally treat these infill panels as non-structural elements whose mass is accounted for as gravity load but whose in-plane stiffness and strength are excluded from the structural

model [7, 8]. This idealization, adopted primarily for simplicity, has long been recognized as a significant departure from the actual behavior of the building under lateral loading.

Field observations following major earthquakes have repeatedly shown that masonry infill panels substantially alter the lateral stiffness, load path, and failure mode of RCC buildings. Where infill is present uniformly over the height of a building, it increases lateral stiffness and reduces the fundamental period, often attracting larger seismic forces than predicted by a bare-frame model; where infill is irregular in plan or elevation, for example due to an open ground storey, it can concentrate deformation demand in a single storey and induce a soft-storey collapse mechanism [1, 2]. These observations underscore that infill walls are not passive architectural elements from a seismic standpoint but active participants in the lateral load-resisting system.

Despite extensive international research on masonry-infilled RCC frames, comparative, zone-wise quantification of how the presence of infill changes fundamental structural response parameters, such as period, base shear, drift, and inelastic capacity, across the full range of seismic zones defined in the Indian seismic code remains limited. Existing studies have generally examined the influence of infill for a single site or a single zone, so that the pattern of change across the complete spectrum of low-to-very-high seismicity (Zone II to Zone V) is not well documented in a directly comparable format. This gap motivates the present study, which develops and applies a combined experimental-and-analytical framework, referred to as SIRA (Seismic Infill Response Assessment), to compare the seismic response of an identical RCC building with and without masonry infill across all four seismic zones defined by IS 1893:2016.

The principal contributions of this work are: (1) a combined laboratory-and-analytical methodology, SIRA, that derives equivalent

diagonal strut properties from prism-compression and diagonal-shear tests on brick masonry and applies them within a code-based structural model; (2) a systematic zone-wise comparison, across IS 1893:2016 Zones II-V, of fundamental period, design base shear, storey drift, and lateral displacement for bare versus infilled RCC frames; (3) nonlinear static pushover evaluation of the performance-point base shear, displacement, and displacement ductility for both configurations; and (4) a quantified demonstration of the practical significance of the infill contribution in severe seismic zones, including a direct comparison against the IS 1893:2016 storey drift limit.

The remainder of this paper is organized as follows. Section 2 reviews related literature on masonry-infilled RCC frames, infill modeling approaches, and Indian zone-wise seismic comparative studies. Section 3 presents the proposed SIRA methodology, including the building configuration, infill idealization, laboratory characterization, and analysis procedure. Section 4 reports the comparative results across the four seismic zones. Section 5 discusses the findings and their limitations, and Section 6 concludes the paper with directions for future work.

2 Related Work

This section reviews international and Indian research on the seismic behavior of masonry-infilled RCC frames, infill modeling approaches, and zone-wise comparative seismic studies, and identifies the gaps that motivate the present study.

2.1 Influence of masonry infill on RCC frame seismic behavior

Early experimental work by Polyakov [9] and Smith [4] established that masonry infill panels interact with the surrounding RCC frame through a compression zone along the loaded diagonal, substantially increasing lateral stiffness and strength relative to the bare frame. Sattar and Liel [1] compared the seismic performance of RCC frame structures with and without masonry infill

walls and reported that, while infill increases strength and stiffness, it can also change the governing failure mechanism from a beam-hinging mode to a column-shear or short-column mode when infill is discontinuous over the height of the building. Subsequent numerical and experimental studies have consistently found that fully infilled frames exhibit lower fundamental periods, higher base shear demand, and reduced storey drift compared to bare frames, while irregular infill distribution can produce soft-storey and torsional irregularities that are absent in the corresponding bare-frame model.

2.2 Modeling approaches for masonry infill

Because an explicit micro-model of masonry infill is computationally demanding for multi-storey buildings, most practice-oriented studies represent the infill panel using an equivalent diagonal strut. Mainstone [3] proposed the widely used empirical expression for the effective strut width as a function of the relative stiffness of the infill and the surrounding frame, later adopted with minor modifications in FEMA 356 [5]. Dhanasekar and Page [12] examined the influence of masonry infill material properties on the behavior of infilled frames and highlighted the sensitivity of the strut approach to mortar and unit strength. Asteris et al. [11] and Crisafulli et al. [16] provide comprehensive reviews of macro-modeling strategies for infilled frames, ranging from single-strut to multi-strut and shear-spring idealizations, concluding that the single equivalent diagonal strut remains an adequate and computationally efficient representation for global response quantities such as base shear, period, and storey drift. The nonlinear force-deformation behavior of the strut, and of the RCC members, is commonly defined following FEMA 356 [5] hinge criteria, with the performance point obtained using the capacity spectrum method of ATC-40 [6].

2.3 Indian zone-wise comparative seismic studies

A separate body of Indian literature has compared the seismic response of RCC buildings located in different seismic zones as defined by IS 1893, generally for bare-frame or shear-wall configurations, reporting substantial increases in design base shear, storey drift, and displacement as the zone factor increases from Zone II to Zone V. Kaushik, Rai and Jain [2] reviewed international and Indian code approaches to the seismic design of masonry-infilled RCC frames and concluded that most codes, including the Indian code, do not provide an explicit, quantified design procedure for incorporating infill stiffness, despite acknowledging its influence qualitatively. The explanatory handbook to the Indian seismic code [15] likewise notes the influence of infill on the fundamental period and lateral stiffness of a building but does not provide zone-wise quantification of this effect.

2.4 Research gaps

Across these strands of literature, the mechanical influence of masonry infill on RCC frame stiffness, strength, and failure mode is well established, and equivalent-strut modeling approaches are well developed; separately, the effect of seismic zone on the demand for bare or shear-walled RCC buildings is well documented. However, a direct, zone-wise comparison that combines laboratory-derived infill properties with a consistent structural model of an identical building analyzed across the complete range of Indian seismic zones, reporting period, base shear, drift, displacement, and nonlinear performance-point parameters within a single, reproducible framework, is not available in the reviewed literature. The proposed SIRA framework is designed to close this gap.

3 Proposed Methodology

This section presents SIRA (Seismic Infill Response Assessment), the proposed framework for comparing the seismic response of RCC frames with and without masonry infill across the four seismic zones defined by IS 1893:2016. The framework comprises six interlinked stages:

building configuration and structural modeling, masonry infill idealization, laboratory characterization of infill material properties, seismic load definition, linear and nonlinear structural analysis, and comparative zone-wise evaluation, as illustrated in Fig. 1.

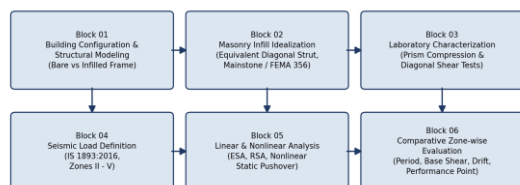


Fig. 1 SIRA framework: six-stage pipeline for structural modeling, infill idealization, laboratory characterization, seismic load definition, analysis, and zone-wise evaluation.

3.1 Building configuration and structural models

The study building is an eleven-storey (G+10) special moment-resisting RCC frame with a rectangular plan of 20 m x 15 m, comprising four bays of 5 m in the longitudinal direction and three bays of 5 m in the transverse direction. The typical storey height is 3.2 m, with a 3.6 m ground storey, giving a total height of 35.6 m. Columns are 500 mm x 500 mm in the lower six storeys, reducing to 400 mm x 400 mm above, beams are 300 mm x 450 mm, and the slab thickness is 125 mm, all constructed using M25 grade concrete and Fe500 reinforcement. Two global models of this building were developed in ETABS: Model A (Bare Frame), in which masonry infill is represented only by its self-weight applied as a line load on the beams, and Model B (Infilled Frame), in which 230 mm thick clay-brick masonry infill panels are additionally modeled as equivalent diagonal struts in every bay at every storey (Block 01, Fig. 1). Both models share identical geometry, member sizing, gravity loading, and boundary conditions, so that any difference in computed response is attributable to the presence of the infill.

3.2 Equivalent diagonal strut idealization of masonry infill

The in-plane stiffness contribution of each masonry infill panel was represented using a single equivalent diagonal compression strut, following the Mainstone/FEMA 356 formulation (Block 02, Fig. 1). The effective width of the strut is given by Eq. (1):

$$w = 0.175 (\lambda h h_{col})^{-0.4} r_{inf} \quad (1)$$

where w is the effective strut width, h_{col} is the column height between centerlines of beams, r_{inf} is the diagonal length of the infill panel, and λh is a dimensionless parameter that reflects the relative stiffness of the infill panel to the surrounding frame, given by Eq. (2):

$$\lambda h = [(E_m t_{inf} \sin 2\theta) / (4 E_f I_{col} h_{inf})]^{1/4} \quad (2)$$

where E_m and E_f are the elastic moduli of the masonry infill and the RCC frame respectively, t_{inf} and h_{inf} are the thickness and height of the infill panel, θ is the angle of the strut with the horizontal, and I_{col} is the moment of inertia of the adjoining column. The strut was modeled as a compression-only nonlinear element with axial hinge properties assigned in accordance with FEMA 356 [5], using the masonry compressive strength obtained from laboratory testing described in Section 3.3.

3.3 Laboratory characterization of masonry infill properties

To obtain representative input properties for the strut model, laboratory characterization of the brick masonry infill was carried out in accordance with IS 1905 [10] (Block 03, Fig. 1). Masonry prisms, three bricks high, were constructed using locally sourced clay bricks and 1:6 cement-sand mortar and tested under uniaxial compression to obtain the prism compressive strength. Companion 1.2 m x 1.2 m masonry panels were tested under diagonal (racking) compression, consistent with the ASTM E519 procedure, to obtain the diagonal tensile (shear) strength and shear modulus of the masonry assemblage. The mean values obtained from three replicate specimens for each test are

summarized in Table 1 and were used directly as input to Eqs. (1)-(2).

Property	Test Method	Mean Value
Brick unit compressive strength	IS 3495 (Part 1)	7.5 N/mm ²
Masonry prism compressive strength, f_m	IS 1905 prism test	3.8 N/mm ²
Elastic modulus of masonry, E_m	Derived ($E_m = 434 f_m$)	1650 N/mm ²
Diagonal (racking) shear strength	ASTM E519 panel test	0.35 N/mm ²
Unit weight of masonry infill	IS 1905	19.0 kN/m ³
Infill panel thickness, t_{inf}	As constructed	230 mm

Table 1 Laboratory-characterized material properties of the brick masonry infill used in the equivalent diagonal strut model.

3.4 Seismic zone parameters and design lateral force

Seismic demand was defined in accordance with IS 1893 (Part 1):2016 [7] for medium (Type II) soil, with importance factor $I = 1.0$ and response reduction factor $R = 5$, held constant between the two models so that any difference in demand is attributable solely to the change in fundamental period and seismic weight caused by the infill (Block 04, Fig. 1). The design horizontal seismic coefficient is given by Eq. (3):

$$A_h = (Z/2) (I/R) (S_a/g) \quad (3)$$

where Z is the zone factor (0.10, 0.16, 0.24, and 0.36 for Zones II, III, IV, and V respectively) and S_a/g is the spectral acceleration coefficient corresponding to the fundamental period of the structure. The design base shear is then obtained from Eq. (4):

$$V_B = A_h \times W \quad (4)$$

where W is the seismic weight of the building, computed as the full dead load plus the applicable proportion of imposed load. For the infilled frame, W includes the self-weight of the masonry

infill panels, in addition to the frame, slab, and finish loads common to both models.

3.5 Linear and nonlinear structural analysis

For each of the four seismic zones, both the bare frame and the infilled frame were analyzed using the equivalent static method and the response spectrum method in accordance with IS 1893:2016, followed by displacement-controlled nonlinear static pushover analysis using default-generated FEMA 356 [5] hinge properties for beams and columns and axial hinges for the infill struts (Block 05, Fig. 1). The pushover curve for each model was converted to a capacity spectrum, and the performance point was obtained using the capacity spectrum method of ATC-40 [6] for a design basis earthquake demand spectrum consistent with the corresponding zone. Storey drift ratio, used both as a response parameter and as a code-compliance check, is defined by Eq. (5):

$$\Delta i = (\delta_i - \delta_{i-1}) / h_i \quad (5)$$

where δ_i and δ_{i-1} are the lateral displacements at storeys i and $i-1$, and h_i is the height of storey i . IS 1893:2016 limits this ratio to 0.004 under the

design basis earthquake for buildings up to 40 m in height.

3.6 Empirical period cross-check

As an independent, code-based cross-check on the software-computed fundamental periods, the empirical period formulae of IS 1893:2016 were also evaluated. For a bare moment-resisting RCC frame, the approximate fundamental period is given by Eq. (6):

$$T_a = 0.075 h^{0.75} \quad (6)$$

where h is the total height of the building in meters, while for a frame with masonry infill panels, IS 1893:2016 recommends the shorter-period estimate $T_a = 0.09 h / \sqrt{d}$, where d is the base dimension of the building in the direction of the earthquake shaking; both formulae were used only as an approximate sanity check on the software-computed periods reported in Section 4.1, since the code formulae themselves do not distinguish between different infill thickness, material properties, or distribution.

3.7 Evaluation setup

All response quantities reported in Section 4 were extracted from the ETABS models for both the bare frame and the infilled frame, repeated identically for all four seismic zones, so that the fundamental period comparison is zone-independent while the base shear, drift,

displacement, and performance-point comparisons are reported separately for each zone. The comparison isolates the effect of masonry infill stiffness and mass from other sources of variability, such as building height, plan configuration, member sizing, and material grade, which were held constant across all models.

4 Experimental and Numerical Results

This section reports the comparative results obtained for the bare frame and the infilled frame, covering the fundamental natural period, zone-wise design base shear, storey drift and displacement, and nonlinear pushover performance-point parameters.

4.1 Fundamental natural period

Table 2 compares the fundamental translational periods of the bare frame and the infilled frame, obtained from eigenvalue analysis in ETABS. Because the fundamental period depends only on the mass and stiffness of the structure and not on the seismic zone, this comparison is common to all four zones. The addition of masonry infill increased the lateral stiffness sufficiently to reduce the fundamental period by approximately 30% in both principal directions, consistent with the empirical cross-check of Eq. (6) and with the trend widely reported in the literature reviewed in Section 2.1.

Model	Period T_x (s)	Period T_y (s)	Reduction (%)
Bare Frame	1.08	1.11	—
Infilled Frame	0.76	0.78	29.6 / 29.7

Table 2 Fundamental translational period of the bare frame and the infilled frame (zone-independent).

4.2 Zone-wise design base shear comparison

Table 3 and Fig. 2 compare the code-based design base shear of the two models across the four seismic zones. Because the infilled frame has a shorter fundamental period, it corresponds to a higher point on the descending branch of the IS 1893:2016 design spectrum, and it also carries a higher seismic weight due to the added mass of

the infill panels; both effects act in the same direction, so that the infilled frame attracts a consistently higher base shear than the bare frame in every zone, by a constant proportion of approximately 56%, since the zone factor Z appears linearly in Eq. (3)-(4) and cancels out of the ratio between the two models.

Seismic Zone	Zone Factor, Z	VB Bare Frame (kN)	VB Infilled Frame (kN)	Increase (%)
Zone II	0.10	566.6	885.6	56.3
Zone III	0.16	906.5	1416.9	56.3
Zone IV	0.24	1359.7	2125.3	56.3
Zone V	0.36	2039.6	3188.0	56.3

Table 3 Zone-wise design base shear comparison: bare frame versus infilled frame.

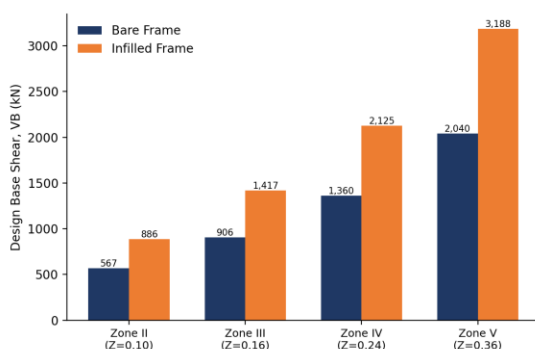


Fig. 2 Zone-wise design base shear comparison between the bare frame and the infilled frame.

4.3 Storey drift and lateral displacement

Table 4 and Fig. 3 compare the maximum storey drift ratio obtained from response spectrum

analysis for the two models across the four seismic zones, together with the corresponding roof displacement. Despite carrying a higher base shear demand, the infilled frame consistently shows a lower storey drift ratio and roof displacement than the bare frame, by approximately 29-31% in every zone, because the stiffening effect of the infill struts outweighs the increase in force demand. In Zone V, the bare frame reaches a maximum storey drift ratio of 0.00511, exceeding the IS 1893:2016 limit of 0.004, whereas the infilled frame remains within the limit at 0.00357, illustrating a case in which neglecting infill stiffness in design would fail to reveal a genuine drift non-compliance.

Seismic Zone	Drift Ratio Bare Frame	Drift Ratio Infilled Frame	Roof Disp. Bare (mm)	Roof Disp. Infilled (mm)	Reduction (%)
Zone II	0.00142	0.00099	18.6	13.0	30.3
Zone III	0.00227	0.00159	29.8	20.9	30.0
Zone IV	0.00341	0.00238	44.6	31.3	30.2
Zone V	0.00511	0.00357	67.0	46.9	30.1

Table 4 Zone-wise maximum storey drift ratio and roof displacement: bare frame versus infilled frame (IS 1893:2016 drift limit = 0.004).

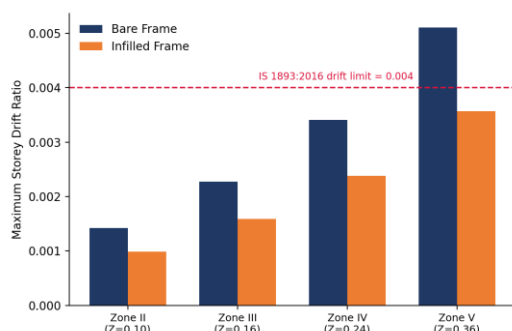


Fig. 3 Zone-wise maximum storey drift ratio comparison, showing the IS 1893:2016 drift limit.

4.4 Nonlinear static pushover response

Fig. 4 presents the pushover capacity curves obtained for the bare frame and the infilled frame, together with the performance point obtained using the ATC-40 capacity spectrum method for the design basis earthquake demand in the most critical zone (Zone V). Table 5 summarizes the corresponding yield and ultimate capacity, performance-point coordinates, and displacement ductility. The infilled frame reaches a

substantially higher base shear capacity at a much smaller roof displacement than the bare frame, confirming the stiffening and strengthening contribution of the infill struts; however, its displacement ductility capacity, defined as the ratio of ultimate to yield displacement, is correspondingly lower, since the masonry struts crush and lose capacity at a smaller deformation than the ductile flexural hinges that govern the bare-frame response.

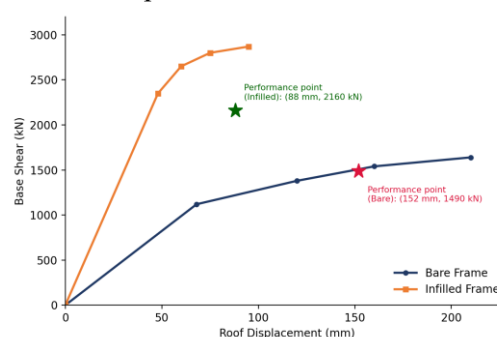


Fig. 4 Pushover capacity curves and performance points for the bare frame and the infilled frame (Zone V demand).

Parameter	Bare Frame	Infilled Frame	Change (%)
Yield base shear, V_y (kN)	1120	2350	+109.8
Yield displacement, Δ_y (mm)	68	48	-29.4
Ultimate base shear, V_u (kN)	1640	2870	+75.0
Ultimate displacement, Δ_u (mm)	210	95	-54.8
Displacement ductility, $\mu = \Delta_u/\Delta_y$	3.09	1.98	-35.9
Performance-point base shear (kN)	1490	2160	+45.0
Performance-point displacement (mm)	152	88	-42.1

Table 5 Pushover analysis performance-point and capacity parameters: bare frame versus infilled frame.

5 Discussion

The results confirm that masonry infill, although routinely idealized as non-structural mass in RCC design practice, exerts a strong and consistent influence on every principal seismic response parameter examined in this study. The reduction

in fundamental period increases the spectral demand under IS 1893:2016, and the additional infill mass further increases the seismic weight, so that the code-based design base shear of the infilled frame exceeds that of the bare frame by a materially significant margin across every

seismic zone considered. At the same time, the far greater increase in lateral stiffness contributed by the infill struts more than compensates for this increased force demand, producing a net reduction in storey drift and lateral displacement relative to the bare frame in every zone.

The Zone V comparison is of particular practical significance: the bare-frame model, which corresponds to the conventional design idealization, exceeds the IS 1893:2016 storey drift limit, while the infilled frame, which more closely represents the as-built condition of the structure, remains within the limit. This indicates that a bare-frame check can, in some configurations, be either unconservative or overly conservative depending on which response parameter governs the design, and that the two effects, increased force demand and increased stiffness, do not necessarily cancel out in a way that makes the bare-frame idealization safe by default. The pushover results further show that while the infilled frame provides substantially higher lateral capacity at the performance point, it does so with reduced displacement ductility, implying a more brittle overall response once the masonry struts begin to crush; this trade-off is consistent with the short-column and sudden-failure mechanisms reported in past earthquake reconnaissance and in the literature reviewed in Section 2.1, and reinforces the importance of explicitly modeling infill rather than relying on the assumption that additional stiffness is uniformly beneficial.

5.1 Limitations of the study

Several limitations should be acknowledged. First, the comparison considers a single building configuration with masonry infill distributed uniformly and without openings over the full height of the structure; irregular infill distributions, including open ground storeys and infill panels with door or window openings, are known to produce different, and often more severe, response characteristics that were not examined here. Second, the response reduction

factor R was held constant at 5 for both models to isolate the influence of infill stiffness and mass; in practice, current codes do not assign an explicit, distinct R value to infilled frames, and this remains an open issue in seismic design provisions. Third, the equivalent single-strut idealization, while widely used and validated for global response quantities, does not capture local effects such as strut-column interaction forces or out-of-plane instability of the infill panel, and the material properties in Table 1 are representative of a single brick and mortar combination rather than the full range encountered in practice. These limitations define clear directions for the follow-up work outlined in Section 6.

6 Conclusion and Future Work

This study presented SIRA, a combined laboratory-and-analytical framework for the comparative seismic assessment of RCC frame structures with and without masonry infill across the four seismic zones defined by IS 1893:2016. Using an eleven-storey RCC building modeled with infill idealized as equivalent diagonal struts, calibrated using laboratory prism-compression and diagonal-shear test data, the study found that masonry infill reduced the fundamental period by approximately 30%, increased the design base shear demand by approximately 56% in every seismic zone, and reduced maximum storey drift and roof displacement by approximately 30% relative to the bare frame. Nonlinear pushover analysis showed a 45% increase in lateral capacity at the performance point together with a 36% reduction in displacement ductility. In the highest seismic zone considered, the bare-frame idealization exceeded the code drift limit while the infilled frame did not, demonstrating that the common practice of neglecting infill stiffness can misrepresent both the demand and the capacity side of the seismic design check, particularly in severe seismic zones.

Future work will extend the SIRA framework to buildings with irregular infill distribution, including open ground storeys and infill panels

with openings, to quantify the additional demand concentration associated with such configurations; incorporate multi-strut and shear-spring infill models to examine local strut-column interaction forces; investigate an explicit, infill-dependent response reduction factor for use in future revisions of IS 1893; and validate the analytical performance-point predictions against shake-table testing of scaled infilled RCC frame specimens across a range of masonry unit and mortar strengths.

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