

Comparative analysis of seismic response in reinforced concrete buildings with and without infill walls using adaptive pushover analysis

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Abstract—Infill walls significantly enhance the seismic execution of reinforced concrete (RC) building by increasing stiffness and strength. This study conducts a comparative analysis of RC buildings with and without infill walls using the Adaptive Pushover Analysis (APA) method. The infill wall is modelled as an equivalent strut following the ASCE 41-06 (2007) guidelines. Nonlinear static adaptive pushover analysis is conducted on two building models using the finite element software SeismoStruct. The impact of structural models on various factors was evaluated from the pushover curve (i.e., ductility (μ), overstrength factor (R_o), and ductility reduction factor (R_d)). Furthermore, the response reduction factor (R) was determined through adaptive pushover analysis to evaluate the performance of both models. The findings indicated that the computed response reduction factor (R) value is greater for a fully infilled wall RC building compared to an RC frame without an infill wall (bare frame). The performance of the RC frame with infill is better than the bare frame. The finding of this study suggests the R-value used in the design of infilled RC frame buildings is probably going to be underestimated when the impact of infill is taken into consideration (i.e. the calculated R-value exceeds the value typically used in design).

Index Terms— RC frame, strut infill wall, pushover curve, Response reduction factor.

I. INTRODUCTION

Reinforced concrete structures are commonly used in earthquake-prone regions due to their strength and durability. However, their seismic performance depends on various factors, including the presence of non-structural components like infill walls. Infill walls are often used to divide interior spaces but play a complex role in the overall structural behaviour during

seismic events. These walls, though considered non-structural, interact with the frame and can significantly affect the load distribution, stiffness, and energy dissipation during an earthquake.

II. METHODOLOGY

This section provides an overview of the structural analysis methods employed and the seismic design parameters determined from the analysis.

A. Adaptive pushover analysis (APA)

Generally, pushover analysis is a numerical technique used to evaluate the progressive variation in stiffness and strength of a structure under incrementally applied lateral loads. This method incorporates the nonlinear behaviour of building components and determines performance levels based on specific criteria. Adaptive pushover analysis, an enhanced version of the standard approach, updates the applied load pattern at each analysis step. This advanced method considers the influence of ground motion frequency content and structural deformations on the dynamic response to assess the structure's capacity against lateral forces more accurately. [2]. The analyses are conducted by analyzing mode shapes and participation factors obtained from eigenvalue assessments at each stage of the procedure, so structural behaviour can be effectively evaluated. This approach enables the determination of load distributions and strain profiles for the structure. [3].

B. Seismic design parameters

This study analyses and compares the response reduction factor (R) for two different structural models. The R-factor denotes the ratio of a structure's elastic strength to its inelastic design strength. It is

primarily affected by essential parameters like overstrength and ductility reduction factors. According to the BIS code (IS 1893, 2016), the recommended R-value is 3 and 5 for an ordinary moment-resisting frame and a special moment-resisting frame respectively. The BIS code specifically provides the response reduction factor's mathematical formulation. [4], [5], [6], [7], [8] as,

$$2R = R_d \times R_o \tag{1}$$

In this context, R_o denotes the overstrength factor, whereas the ductility reduction factor is denoted by R_d . The interrelation between these three key seismic design parameters is illustrated in Fig. 3.

According to the following Eq. 2., the overstrength factor (R_o) is the ratio of the actual strength (V_y) to the design strength (V_d)

$$R_o = \frac{V_y}{V_d} \tag{2}$$

The R_d factor is derived based on the Newmark–Hall theory [9], which considers the structure's ductility and fundamental time period, and is calculated as follows:

$$\text{If (time period} < 0.2 \text{ s) then } R_d = 1 \tag{3}$$

$$\text{If } (0.2 \text{ s} < \text{time period} < 0.5 \text{ s) then } R_d = \sqrt{2\mu - 1}$$

$$\text{If (time period} > 0.5 \text{ s) then } R_d = \mu$$

Ductility (μ) is the ratio of the maximum displacement (Δ_{max}) to the yield displacement (Δ_y) of the structure as expressed in Eq.4. The displacement that corresponds to the peak base shear is considered the structure's maximum displacement.

$$\mu = \frac{\Delta_{max}}{\Delta_y} \tag{4}$$

Table 1 Details of structure

Type of Structure	SMRF
Total no. of story	4
Seismic zone factor (Z)	IV (Z=0.24)
Height of each story	3m
No. of bays	4(3m each in both X and Y directions)
Soil type	Medium stiff soil
Column size	300mm × 450mm
Beam size	250mm × 450mm
Slab depth	150mm
Thickness of wall	150mm
Live load	3kN/m ²
Material	M-25 grade concrete and Fe-415 reinforcement
Damping in structure	5%
Importance factor (I)	1.2
Response reduction factor (R)	5

C. Structural model description

Two structural models were examined: Model 1 represents a bare RC frame, while Model 2 consists of an RC frame with infill struts modeled per ASCE-41-06 (2007) guidelines. Fig. 1 and Fig. 2 illustrate the 3D models and load applications for both structural configurations, while Figure 3 presents the plan layout. Each span measures 3 m in both directions, leading to a total building length of 12 m. Structural section details and material properties are summarized in Table 1, while Table 2 provides reinforcement specifications for columns and beams.

The compressive strength of the infill, f_m is calculated using the formula specified in IS 1893 (2016) as follows:

$$f_m = 0.433 f_b^{0.64} f_{mo}^{0.36} \tag{5}$$

where the compressive strengths of brick and mortar are denoted by f_b and f_{mo} respectively.

Eq. 6 from IS 1893 Part-1 (2016) has been used to calculate the design base shear force.

$$V_d = \frac{\left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{T}\right)} \times W, \tag{6}$$

D. Properties of the infill panel component

A double-strut nonlinear cyclic approach is employed to model the masonry infill in structural analyses. This model distinctly accounts for the shear and compressive characteristics of the masonry infill as shown in Fig. 4 [10]. The model was developed by Crisafulli (1997).

According to 1893 Part-1 (2016), the equivalent strut width is calculated as $0.175d_{inf} (\lambda_h)^{-0.4}$ where λ_h (a dimensionless parameter) can be derived using Eq. 7.

$$\lambda_h = h \times \sqrt[4]{\frac{E_{inf}t \sin 2\phi}{4E_c I_c h_{inf}}}, \quad (7)$$

Here, E_{inf} stands for the elastic modulus of the infill wall material, t for the thickness of the infill, E_c for the concrete, I_c for the column's moment of inertia, d_{inf} for the infill's diagonal length and h_{inf} for the infill's overall height, and h for the column's height.

Table 2 Reinforcement details

Structural Member	Main Reinforcement	Shear Reinforcement
Columns	4 Ø16 at a corner 2 Ø16 on the longer side	Ø8/100
Beams	2 Ø16 at a corner 2 Ø16 on the bottom side	Ø8/100

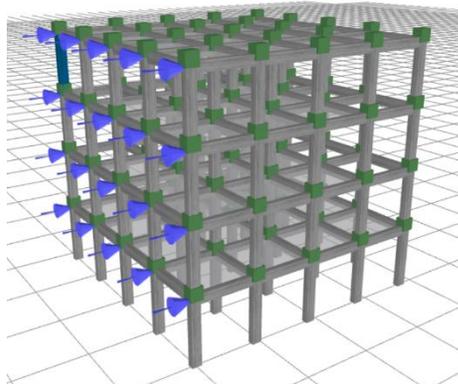


Fig. 1 3D structural finite element model of bare frame

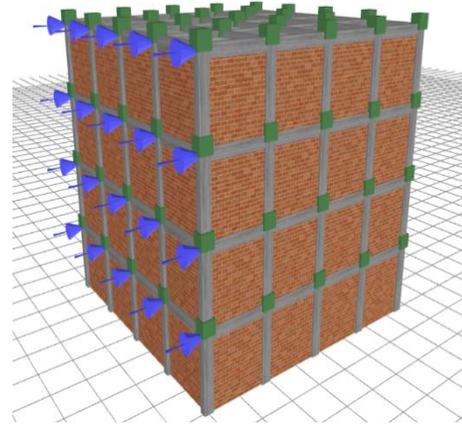
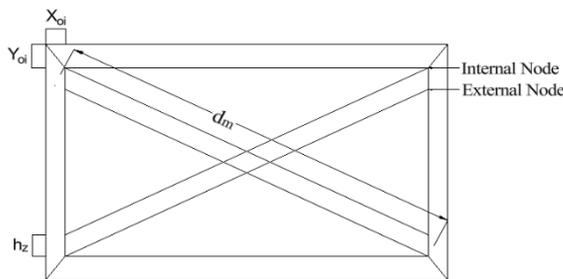


Fig. 2 3D structural finite element model of fully infilled RC frame

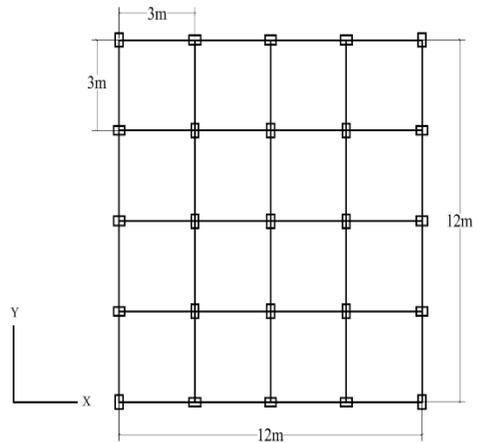


Fig. 3 Building plan

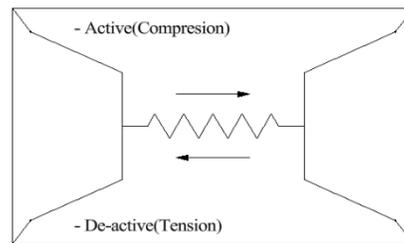


Fig. 4 The infill panel element

III. RESULTS AND DISCUSSION

1. Pushover (capacity) curve comparison

The structural analyses resulted in pushover curves in both the X and Y directions are shown in Fig. 5. It is evident that the fully infilled RC structure model exhibits the highest stiffness and strength in both directions, underscoring the important role that infill walls play in RC structure performance, especially in seismically active areas.

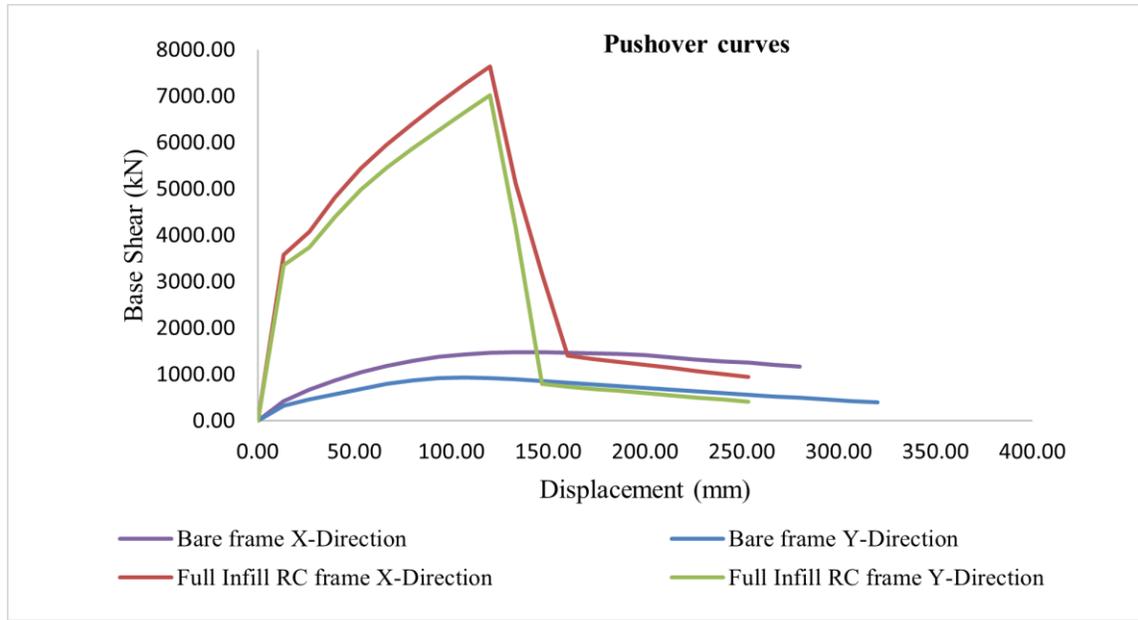


Fig. 5 The pushover curves comparison in the X and Y directions

2. Base shear forces comparison

The base shear forces for the two structural models are contrasted in Fig. 6. It is evident that the average value of base shear of the bare frame is lower than that of the RC frame with infill. The fully infilled RC frame with strut modelling has an average base shear that is 5.15 times greater in the X direction and 7.47 times greater in the Y direction than the bare frame.

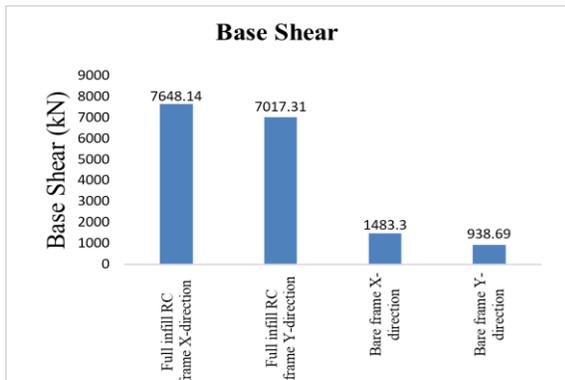


Fig. 6 Base shear forces comparison

3. Ductility comparison

The ductility comparison for the structural models is presented in Fig. 7. According to the figure, the fully infilled RC frame has a lower ductility level than the RC frame with masonry infill. The inclusion of a strut infill in the RC frame enhances its ductility, making it, on average, 1.02 times greater than that of a bare frame

due to the notable difference between the yield point and maximum displacement.

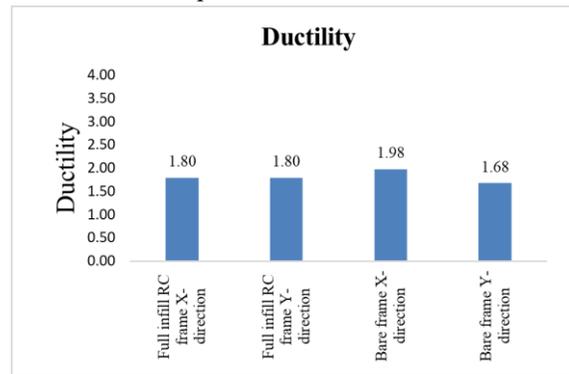


Fig. 7 Ductility comparison

4. Ductility reduction factor comparison

The comparison of each structural model's ductility reduction factor is shown in Fig. 8. The structure's ductility and fundamental time period have an impact on this factor. Fig. 8 illustrates that, in comparison to the RC frame with strut infill, the ductility reduction factor of the bare frame is, on average, 1.01 times greater.

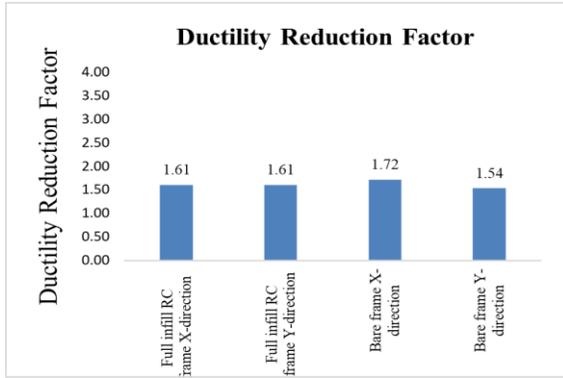


Fig. 8 Ductility reduction factor comparison

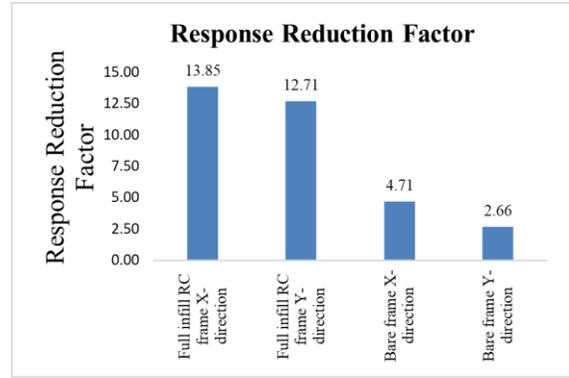


Fig. 10 Response reduction factor comparison

5. Overstrength factor comparison

Comparing the overstrength factor for each structural model is shown in Figure 9, emphasizing how masonry infill affects this value. As depicted in Figure 9, the bare RC frame exhibits a lower overstrength factor compared to the RC frame with masonry infill. The fully infilled RC frame with strut infill exhibits an overstrength factor that is, on average, 3.69 times greater than that of the bare frame.

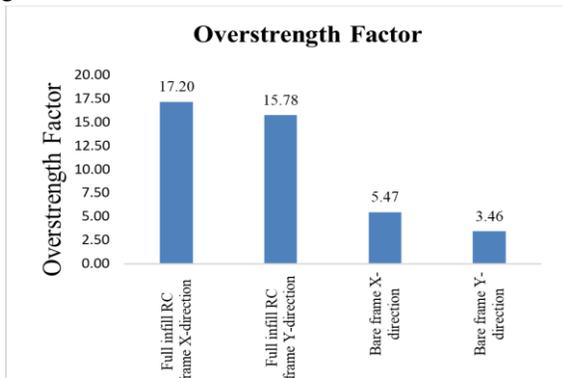


Fig. 9 Overstrength factor comparison

6. Response reduction factor comparison

Fig. 10 compares the R-factor of each structural model. This factor behaves similarly to the overstrength factor. As shown, the bare frame has a lower R factor than the RC structure with masonry infill. The width of the infill strut significantly influences the response of a fully infilled RC frame, resulting in an R-factor that is, on average, 3.6 times greater than that of a bare RC frame.

IV. CONCLUSION

1. The base shear value is maximum for RC frame with fully infilled wall than bare frame
2. The inclusion of infill walls in an RC frame decreases both the ductility and the ductility reduction factor while enhancing the overstrength factor.
3. Building with full infill wall have higher response reduction factor.

REFERENCES

- [1] ASCE 41-06, *Seismic rehabilitation of existing buildings*, no. 41–6. American Society of Civil Engineers, 2007. doi: 10.1201/9781439804810-c7.
- [2] V. K. Papanikolaou and A. S. Elnashai, “Evaluation of conventional and adaptive pushover analysis I: Methodology,” *J. Earthq. Eng.*, vol. 9, no. 6, pp. 923–941, 2005, doi: 10.1080/13632460509350572.
- [3] S. Antoniou and R. Pinho, “Advantages and limitations of adaptive and non-adaptive force-based pushover procedures,” *J. Earthq. Eng.*, vol. 8, no. 4, pp. 497–522, Jul. 2004, doi: 10.1142/S1363246904001511.
- [4] IS 1893 Part-1, “la jpukvksa osQ HkwdEijks / h fMtkbu osQ ekunaM Criteria for Earthquake Resistant Design of Structures,” vol. 1893, no. December, 2016.
- [5] M. Shendkar and R. Pradeepkumar, “Response reduction factor of RC framed structures with semi-interlocked masonry and unreinforced masonry infill,” 2018. [Online]. Available: https://www.researchgate.net/profile/Mangeshkumar_Shendkar/publication/331311037_Resp

- nse_Reduction_factor_of_RC_framed_structures_with_semi-interlocked_masonry_and_unreinforced_masonry_infill/links/5c72363e299bf1268d1ff137/Response-Reduction-factor-of-RC
- [6] M. Shendkar, R. Pradeepkumar, and P. R. Maiti, "Effect of aspect ratio on response reduction factor of rc framed structures with semi-interlocked masonry and unreinforced masonry infill," 2020.
- [7] M. R. Shendkar, D. P. N. Kontoni, S. Mandal, P. R. Maiti, and D. Gautam, "Effect of lintel beam on seismic response of reinforced concrete buildings with semi-interlocked and unreinforced brick masonry infills," *Infrastructures*, vol. 6, no. 1, pp. 1–18, 2021, doi: 10.3390/infrastructures6010006.
- [8] M. R. Shendkar, D. P. N. Kontoni, and E. Işık, "Determination of the seismic vulnerability of infilled RC buildings according to the Quadrants assessment method," *Asian J. Civ. Eng.*, vol. 25, no. 2, pp. 2209–2228, Feb. 2024, doi: 10.1007/s42107-023-00904-x.
- [9] C. Uang, "Establishing R (or R_w) and Cd Factors for Building Seismic Provisions," *J. Struct. Eng.*, vol. 117, no. 1, pp. 19–28, Jan. 1991, doi: 10.1061/(asce)0733-9445(1991)117:1(19).
- [10] F. J. Crisafulli, "Seismic behaviour of reinforced concrete structures with masonry infills," 1997. [Online]. Available: <http://hdl.handle.net/10092/1221>