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Earthquake-Induced Behaviour Study of Multi-Storey Irregular Buildings Using ETABS

Prof. Shyam Prasad H R[1], Rakshitha V[2], Rohan K M[3], Naveen S[4], Supriya R S[5]
[1]Assistant Professor, Dept. of Civil Engineering, P.E.S. College of Engineering, Mandya, India
[2,3,4,5]UG Students, Dept. of Civil Engineering, P.E.S. College of Engineering, Mandya, India

Abstract- The increasing development of urban areas and architectural requirements often lead to the construction of multi-storey reinforced concrete (RC) structures that do not comply with the symmetric and uniform structure that was assumed in classical seismic design theory.Multi-storey reinforced concrete (RC) structures are commonly built with an eccentric and non-uniform structure due to urban developments and architectural requirements, which do not match the symmetric and uniform structure used in classic seismic design theory. In this study, the behaviour of a G+7 RC building with an L-shaped plan irregularity and soft-storey vertical irregularity is studied under three structural configurations: Bare Frame, Infill Wall Frame and Shear Wall Frame and modeled in ETABS. The response spectrum analysis has been done according to IS 1893 (Part 1):2016, gravity loads as per IS 875 (Parts 1-3):1987, RC design as per IS 456:2000, ductile detailing as per IS 13920:2016. These values of storey drift ratio, lateral stiffness, storey shear and storey displacement were extracted and compared. The Shear Wall structure reduced the roof level lateral displacement by ~99.9% and storey drift by ~99.8–99.9% compared to the Bare Frame, and provided around five times the stiffness. The displacement reduction for the Infill Wall model ranged from intermediate (62–78%). A clear performance hierarchy was generated: Shear Wall > Infill Wall > Bare Frame, with shear wall being the critical member in an irregular building in high seismic zone construction, to ensure safety.

Keywords- Irregular Buildings, Seismic Analysis, ETABS, Response Spectrum Method, Shear Wall, Infill Wall, Bare Frame, Storey Drift, IS 1893:2016, Earthquake Engineering.

I. INTRODUCTION

Earthquakes are one of the most powerful natural hazards faced by the built environment. The complex inertial forces from ground shaking are transferred to structures, which must withstand the shaking as well as absorb the forces, while resisting deformations. The uniform distribution of stiffness and mass in the plan and elevation of a structure greatly influence its seismic performance. But in reality, buildings seldom are as regular as these illustrated examples. The functional requirements, site conditions and architectural desires often result in buildings having an L- shaped or T-shaped floor plan, upper floors set-back or floating columns, or open ground storey, each of which increases the seismic vulnerability through the introduction of non-uniform stiffness and non-uniform mass.

Irregularity moves the centre of rigidity off the centre of mass, creating torsional moments that are not easily captured by orthodox analysis methods. With vertical irregularities, there are sudden changes in stiffness from the top to the bottom of the building, which results in damage focusing on the weak storey. IS 1893 (Part 1):2016 includes both categories and prescribes a dynamic analysis for buildings that are within its scope, but fails to provide comparative performance targets for each structural system for the same irregular configuration.

The three predominant approaches adopted in India for the construction of RC buildings are Bare moment-resisting frame, Infill wall frame and Shear wall frame. Each has certain connotations of lateral stiffness, ductility, cost and constructability. Such knowledge of their performance when used together in the presence of geometric irregularity fills in a void that is common, but not well understood by practising engineers, and is poorly reported in existing literature that provides quantitative guidance.

This work models the G+7 RC building, (L-shaped plan and soft-storey irregularity) and conducts Response Spectrum Analysis in ETABS for all three cases and extracts the storey displacement, drift, stiffness and shear. The study is meant to give engineers/architects evidence-based advice on lateral system selection in irregular buildings in Zone V in India.

The principal contributions are:

- Three ETABS models — Bare Frame, Infill Wall, Shear Wall — with identical geometry, materials, and seismic loading for unbiased comparison.
- Quantitative storey-level response comparison under IS 1893 (Part 1):2016 Response Spectrum Analysis.
- Identification of the most seismically efficient and cost-viable structural system for Zone V irregular RC buildings.
- A validated dataset suitable for future AI/ML-based seismic response prediction frameworks.

II. STRUCTURAL SYSTEMS OVERVIEW

A. Shear Wall Structure

Reinforced concrete shear walls are vertical in-plane elements placed at lift cores, stairwells, or perimeter bays to carry lateral loads induced by wind and earthquakes. Their primary advantage is the high lateral stiffness they impart, which limits inter-storey drift and protects both structural and non-structural components. In earthquake-prone regions, shear wall buildings have historically outperformed bare frame structures by a significant margin. Optimal placement — symmetric about the plan centroid — is essential to prevent torsional amplification of response.

B. Infill Wall Structure

Masonry infill panels occupy the bays of an RC frame and are customarily ignored during design, yet they inevitably interact with the surrounding frame under lateral loading. This interaction is captured through the equivalent diagonal strut model, in this which each panel is represented as a compression strut joining diagonally to opposite frame joints. Uniform infill distribution across all bays and floors improves stiffness and reduces drift relative to a bare frame. Irregular infill patterns, however, can generate soft-storey or torsional irregularities that worsen local seismic demand.

C. Bare Frame Structure

A bare frame depends entirely on beam-column bending action to resist lateral forces, making it the most flexible and most economical of the three systems. Under seismic loading, bare frames tend to exhibit the largest lateral displacements and storey drifts. Ductile detailing per IS 13920:2016 improves inelastic deformation capacity without significantly raising elastic stiffness. The bare frame model serves as the reference baseline in this comparison.

III. LITERATURE SURVEY

The theoretical background of dynamic structural response, which describe the changes in modal participation, damping and fundamental periods, was presented by Chopra [1]. In the Indian code standards,Agarwal and Shrikhande [2] derived how the methods quantify dynamic amplification, associated to stiffness discontinuity.

Jayachandran and Anitha [3] designed setback buildings in ETABS and concluded that the irregularity in the plan of the building generates more torsional action and stress at the re-entrant corners. This was indeed proving that the buildings should be equivalent in terms of stiffness along elevation. The work follows the idea of building G+10 shear wall structures, which was substantiated by Ravi Kumar and Reddy [4] who analysed and compared various G+10 structure designs with and without shear walls to show that a significant reduction in storey drift and in displacement can be achieved by placing shear walls in the structures.

Divya and Karthikeyan [5] compared the L, T and U shaped plans and found that the base shears and displacements of all the other plan type other than the symmetric plan type are considerably high. The uniform infill distribution results in a lesser amount of deformation as compared to bare frame, but irregular infill distribution may result in soft-storey effects as confirmed by Ramesh Babu and Deepa [6].

Singh and Goyal [7] proved that to reduce eccentricity the placement of symmetric shear wall results in reduction of torsional drift. Pritesh Sharma and Debyashish Patel [8] arrived at the conclusion that the storey drift in an irregular building as compared with regular building is 25–40%. Bhatia and Gupta [9] suggested that the influence of irregularities of mass mainly on storey drift is base shear and in other buildings it is elastic stiffness discontinuity which affects the storey drift. Patel and Shah [10] suggested that in all the buildings having plan and vertical irregularities, shear walls modal combined with ductile detailing should be adopted.

Evidence in the literature indicates that a high incidence of structural forms in the irregular configuration and comparison and code compliance situations do not usually occur, particularly for Zone V. This aberration inspired the study below.

IV. THE PROBLEM DEFINITION AND RESEARCH GAP

As important as this progress in seismic engineering is, design practice for irregular buildings remains very much to this day rooted in regular building design guidelines. IS 1893 (Part 1):2016 outlines irregularity of plan and vertical irregularity, and provides for the need to conduct dynamic analysis but failed to provide any comparative performance measures between any pair of structural systems for any particular irregular configuration.

However, when building an irregular structure in Indian cities they have to choose between these methods; bare frames, infill frames and shear wall frames and they lack any quantitative information of the benefits that each of these systems will provide. Even in Zone V, the bare frame may be the standard option if no comparative data is available and it could be the most economical option. The second gap is integration of data-driven tools: sometimes it is said that the datasets that were used for the comparative study for the same type of structures must be validated with ETABS to develop the seismic prediction that is based on machine learning, but in few studies, these datasets are provided.

The present study will tackle both outstanding issues by (i) comparing the three structural systems with a rigorous and code-compliant approach for the same irregular geometry and loading, and (ii) organizing the results in a manner as applicable to future structural analysis by AI systems in this loading and geometry.

V. OBJECTIVES

- Develop accurate 3D ETABS models for the G+7 irregular RC building in all three structural configurations, with consistent geometry, materials, and loading.
- Apply gravity loads per IS 875 (Parts 1–2):1987 and seismic loads via the Response Spectrum Method per IS 1893 (Part 1):2016.
- Extract and compare storey-level displacement, drift ratio, lateral stiffness, and storey shear in both principal directions.
- Derive practical recommendations for structural engineers selecting lateral systems for irregular RC buildings in India’s high seismic zones.

VI. METHODOLOGY

A. Architectural Planning

Building geometry was first developed in Autodesk Revit to establish a spatially accurate irregular layout before transfer to ETABS. Revit enabled verification of column-grid alignment, storey configurations, and the extents of the L- shaped plan. The architectural model from Revit is shown in Fig. 1

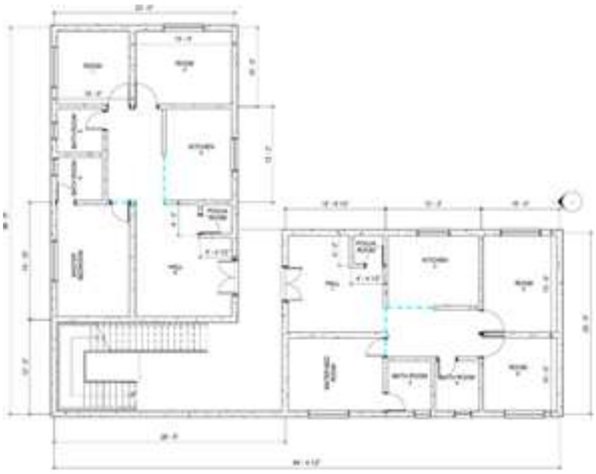


Fig. 1. Architectural Plan and 2D View Developed in Autodesk Revit

B. Building Parameters

Table I lists the geometric and seismic parameters adopted uniformly across all three models. All parameter values were fixed before modelling commenced to ensure that observed performance differences stem solely from the choice of lateral load-resisting system.

TABLE I Building Configuration Adopted for the Study

No.	Parameter	Value / Detail
1	Structure Type	Multi-storey RCC frame
2	Storeys	G + 7
3	Base Storey Ht.	3.3 m
4	Typical Storey Ht.	3.0 m

5	Plan Irregularity	L-shaped plan
6	Vertical Irregularity	Soft-storey at ground
7	Soil Type	Medium soil — Type II
8	Seismic Zone	Zone V
9	Structural System	RCC moment-resisting frame

C. Load Assignment

All loads were assigned following the relevant IS codes. Self-weight of structural members was computed automatically by ETABS based on assigned material densities. Superimposed dead loads, live loads, wall loads, and parapet loads were entered manually. Table II details the applied load intensities.

TABLE II Loads Considered with IS Code References

No.	Load Type	Intensity	Code
1	Dead Load	Auto (ETABS)	IS 875 Pt1
2	Live Load	2.0 kN/m²	IS 875 Pt2
3	Floor Finish	1.5 kN/m²	IS 875 Pt1
4	Wall Load	12.0 kN/m	IS 875 Pt1
5	Parapet Wall	6.9 kN/m	IS 875 Pt1
6	Seismic Load	RSA — Zone V	IS 1893:2016
7	Wind Load	Terrain-based	IS 875 Pt3
8	Staircase Load	4.57 kN/m²	IS 875 Pt1&2

D. ETABS Modelling

Three-dimensional models were built in ETABS from the Revit grid. Storey heights were set as 3.3 m (ground) and 3.0 m (upper floors). Concrete and reinforcing steel properties were defined per IS 456:2000. Slabs were modelled as rigid shell elements; beams and columns used prismatic frame sections. The three models differ only in their lateral system: (i) Bare Frame — beams, columns, and slabs, with masonry omitted; (ii) Infill Wall Frame — masonry panels represented by equivalent diagonal struts in all bays; (iii) Shear Wall Frame — 230 mm thick RC shear walls placed symmetrically to minimise plan eccentricity. Figs. 2, 3, and 4 show each model.

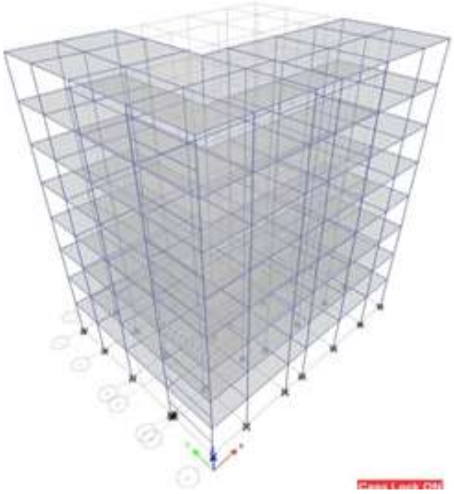


Fig. 2. Bare Frame Structural Model in ETABS

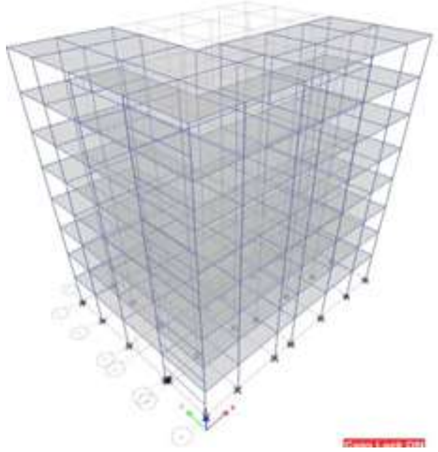
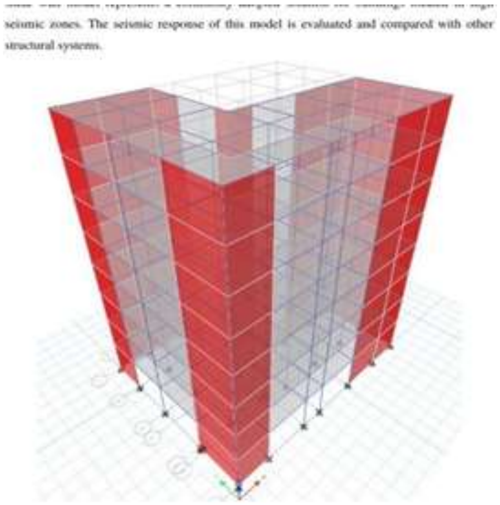


Fig. 3. Infill Wall Structural Model in ETABS



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seismic zones. The seismic response of this model is evaluated and compared with other structural systems.

Fig. 4. Shear Wall Structural Model in ETABS

Load combinations were defined per IS 1893 (Part 1):2016. The Response Spectrum function for Zone V on medium soil (Type II) was assigned; multi-modal combination used the CQC method at 5% critical damping. RC member design followed IS 456:2000 and shear wall design preferences were set to IS 456:2000 with ductile detailing per IS 13920:2016.

VII. RESULTS AND DISCUSSION

A. Lateral Load Distribution

Seismic inertia forces accumulate downward through the structural system, so lower storeys resist greater lateral loads than upper ones. Figs. 5 and 6 show diaphragm lateral load distribution along the X- and Y-directions respectively. In both directions, loads peak near Story 1 (X: ~17.5 kN; Y:~14 kN) and diminish toward the roof. The bare frame's lower stiffness amplifies force demand at each level, while the shear wall system redistributes load more evenly over the building height.

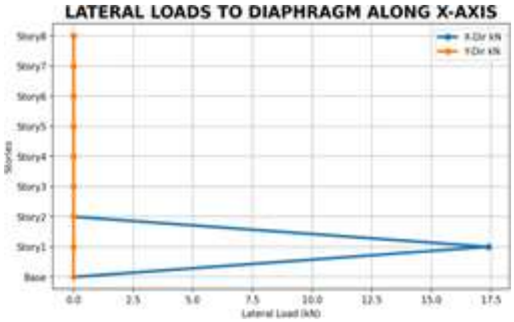

Fig. 5. Lateral Load Distribution Along X-Direction

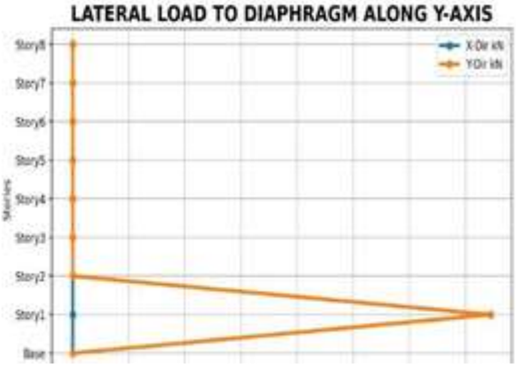

Fig. 6. Lateral Load Distribution Along Y-Direction

B. Storey Drift

Storey drift ratio is the most direct indicator of seismic damage to non-structural components. IS 1893 (Part 1):2016 limits drift to 0.004 times the storey height. Figs. 7, 8, and 9 plot maximum drift over the building height for all three models. The bare frame recorded peak drift of approximately 0.0009 in X and 0.0029 in Y, with Y- direction values approaching the codal threshold. The infill wall model reduced drift meaningfully through diagonal strut stiffness. The shear wall model achieved drift values of the order 0.000001 (X) and 0.000002 (Y) — roughly three orders of magnitude lower than the bare frame and comfortably within all code limits.

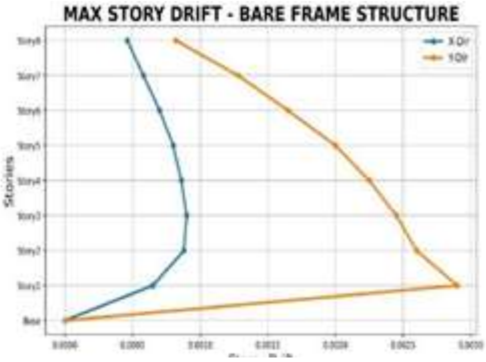

Fig. 7. Maximum Storey Drift – Bare Frame Structure

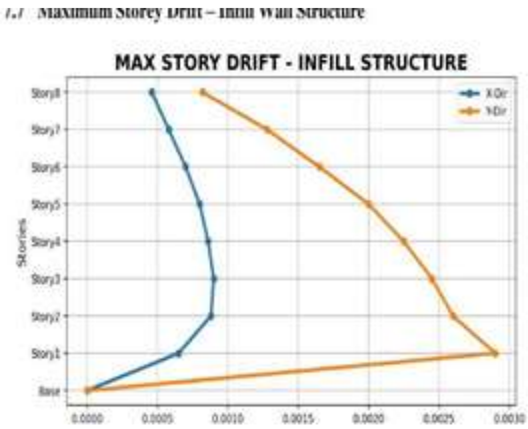

Fig. 8. Maximum Storey Drift – Infill Wall Structure

Fig. 9. Storey Drift – Shear Wall Structure

TABLE III Maximum Storey Drift Ratio Comparison

System	X-Dir	Y-Dir	Status
Bare Frame	~0.0009	~0.0029	Near limit (Y)
Infill Wall	Moderate	Moderate	Within limit
Shear Wall	$\sim 1\times10^{-6}$	$\sim 2\times10^{-6}$	Far below limit

C. Storey Stiffness

Lateral stiffness governs both the natural period and the displacement response of the building. Figs. 10, 11, and 12 show storey stiffness plots over the building height. Stiffness grows toward the base in all models as accumulated seismic forces are resisted by lower floors. The shear wall system reaches approximately 1.65×10^7 kN/m in X and 1.03×10^7 kN/m in Y — close to five times the bare frame's peak of 3.2×10^6 kN/m. The infill wall model lies between these two extremes with a peak Y-direction stiffness of roughly 7.0×10^5 kN/m.

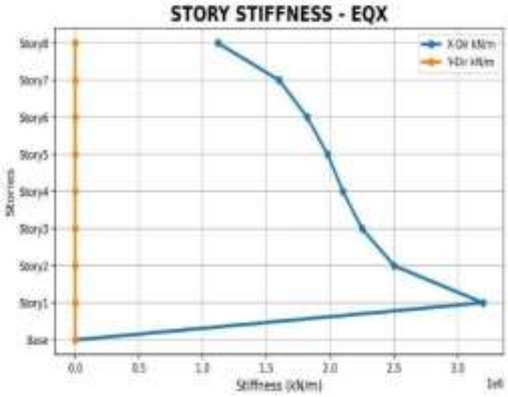

Fig. 10. Storey Stiffness – Bare Frame Structure

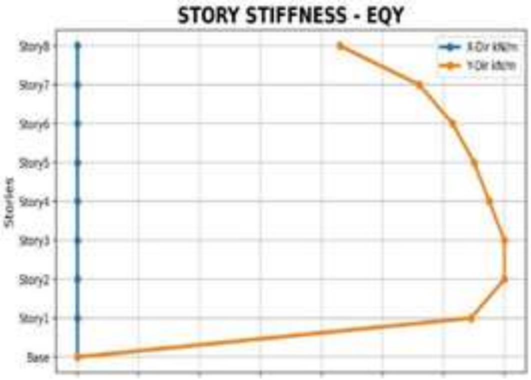

Fig. 11. Storey Stiffness – Infill Wall Structure

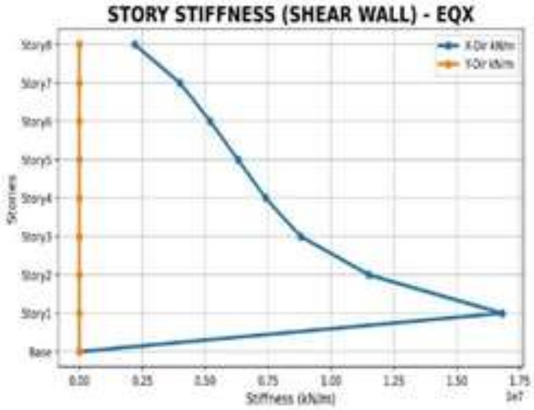

Fig. 12. Storey Stiffness – Shear Wall Structure (EQX)

TABLE IV Peak Storey Stiffness Comparison (kN/m)

System	X-Dir (kN/m)	Y-Dir (kN/m)	Rank
Bare Frame	$\sim 3.2\times10^{6}$	Lower	3rd
Infill Wall	Moderate	$\sim 7.0\times10^{5}$	2nd
Shear Wall	$\sim 1.65\times10^{7}$	$\sim 1.03\times10^{7}$	1st

D. Storey Displacement

Lateral displacement accumulates from the fixed base upward, reaching its maximum at roof level. Figs. 13, 14, and 15 display storey displacement profiles for each structural system. The bare frame recorded roof-level displacements of approximately 18 mm (X) and 49 mm (Y). The infill wall model cut these to roughly 6.8 mm (X) and 10.8 mm (Y), representing reductions of 62% and 78% respectively. The shear wall model pushed displacement down to about 0.013 mm (X) and 0.041 mm (Y) — a reduction of approximately 99.9% in both directions.

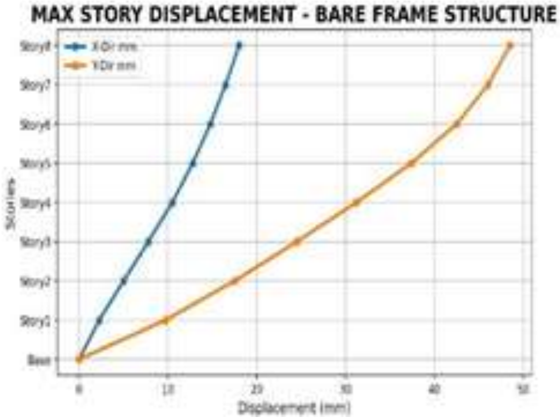

Fig. 13. Maximum Storey Displacement – Bare Frame Structure

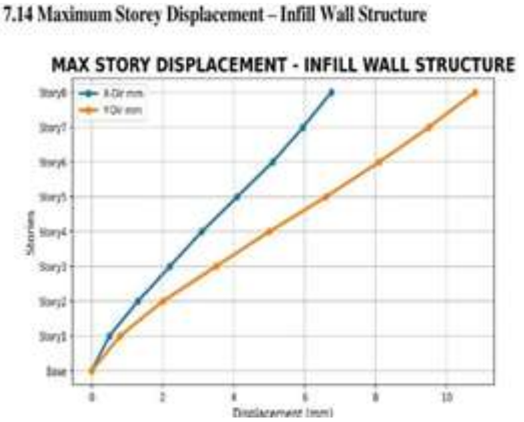

Fig. 14. Maximum Storey Displacement – Infill Wall Structure

Fig. 15. Maximum Storey Displacement – Shear Wall Structure

TABLE V Roof-Level Storey Displacement Comparison

System	X (mm)	Y (mm)	ΔX (%)	ΔY (%)
Bare Frame	~18	~49	—	—
Infill Wall	~6.8	~10.8	−62%	−78%
Shear Wall	~0.013	~0.041	−99.9%	−99.9%

E. Storey Shear

Storey shear builds from the roof downward as cumulative inertia forces are transferred through beams and columns to the foundation. Figs. 16, 17, and 18 show storey shear distributions. Base shear magnitudes are comparable across models — reaching roughly 5600 kN (X) and 5200 kN (Y) — since base shear is primarily a function of building mass and spectral acceleration rather than structural stiffness. The fundamental distinction lies in how efficiently each system transfers these forces to the foundation: shear walls achieve this with negligible deformation, whereas bare frames develop significant displacement and drift despite carrying the same total shear.

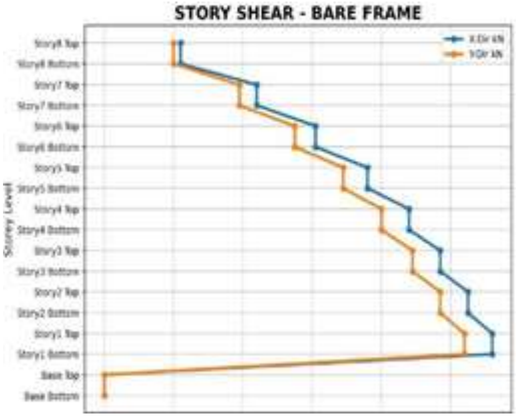

Fig. 16. Storey Shear – Bare Frame Structure

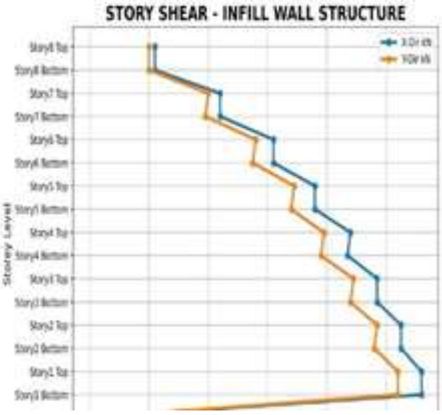

Fig. 17. Storey Shear – Infill Wall Structure

Fig. 18. Storey Shear – Shear Wall Structure

F. Overall Performance Comparison

Across every evaluated response parameter, the ranking that emerged from ETABS is consistent:

Shear Wall > Infill Wall > Bare Frame

Table VI summarises the overall performance order and the magnitude of improvement each system delivers over the bare frame baseline.

TABLE VI Overall Seismic Performance Summary

Parameter	Bare Frame	Infill Wall	Shear Wall
Displacement	Highest	Moderate	Minimum (~99.9% lower)
Drift Ratio	Highest	Moderate	Minimum (~99.8% lower)
Stiffness	Minimum	Moderate	Maximum (~5× bare frame)
Storey Shear transfer	Flexible	Moderate	Rigid and efficient
Overall Rank	3rd	2nd	1st

VIII. CONCLUSION

This research made a code-compliant seismic comparison on three RC structural systems (Bare Frame, Infill Wall Frame and Shear Wall Frame) with a G+7 building which is a soft storey vertical irregularity building plan.This study systematically performed code-compliant seismic comparison of three RC structural systems (Bare Frame, Infill Wall Frame and Shear Wall Frame) in a G+7 building, which is a soft storey building with vertical irregularity in plan. ETABs was used to perform Response Spectrum Analysis as per IS 1893 (Part 1):2016, which resulted in the following major conclusions:

Compared to the Bare Frame, the roof displacement at the lateral (X/Y) was reduced by ~99.9% at the roof level in the Shear Wall structure (18 mm, 49 mm to 0.013 mm, 0.041 mm). The Infill Wall model demonstrated a moderate reduction in both the X reduction (62%) and the Y reduction (78%).

In the Shear Wall model, the Storey drift is 103 times less than the Bare Frame (0.000001 X vs 0.0009 X; 0.000002 Y vs 0.0029 Y) and is still less than the allowable value specified by IS 1893 of 0.004.

This high lateral stiffness for the Shear Wall system is 1.65 x 10^7 kN/m in X, which is about five times that of the Bare Frame of 3.2 x 10^6 kN/m.

Base shear magnitudes were found to be on the whole similar in different models (typical values for both directions: ~5600 kN in X; ~5200 kN in Y), with the former models reflecting the influence of building mass and the latter models of spectral acceleration. The shear wall system had much less movement into the foundation, even though it was handling the same amount of shear, whilst the bare frame allowed for a large amount of drift even with the same total amount of shear.

In all of the metrics assessed this order is found: Shear Wall, Infill Wall, Bare Frame. The Shear Wall system is definitely the most reliable and economical one for the irregular building in Zone V investigated. Infiliton wall frames represent a worthwhile intermediate solution when it is not possible to have full shear wall usage and where the distribution of infill is regarded as even to limit the secondary soft-storey and torsional effects.

The findings once again show Response Spectrum Method used in ETABS based on IS code is a reliable platform that can be used to analyze the seismic performance of irregular multi-storey RC buildings.

IX. FUTURE SCOPE

These analyses would be carried into the inelastic range of the response using this methods of Nonlinear Pushover Analysis and Time History Analysis which can provide insight into ductility demand, failure mechanisms and performance levels under the recorded ground motions.

The generality of the observed performance hierarchy should be checked by analysing taller buildings (G+12 and G+20) and alternative irregularity types (e.g. T-shaped and U-shaped plans, mass irregularities, floating columns).

A series of parametric analyses varying shear wall thickness, aspect ratio and plan position would identify configurations for best seismic performance for minimum material cost.

The output ETABS dataset created here can be used to train machine learning regression or classification models to predict the response at any storey in a new configuration of a building in the conceptual design phase, which could be used for the rapid seismic screening of an architecturally designed building. Future studies could be extended to additional RC-Steel/RC composite structural combination of RC shear walls to steel/RC composite frames and use of energy dissipation systems like base isolation or fluid viscous dampers.

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