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Seismic Performance Evaluation Of G+15 Soft Storey RC Buildings: A Comparative Study of Confined Masonry Infill Walls and RC Shear Walls Using Nonlinear Time History Analysis

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Abstract*—Soft storey buildings with open ground floors represent one of the most seismically hazardous structural configurations in Indian urban areas. This study presents a comprehensive seismic performance evaluation of a G+15 reinforced concrete moment-resisting frame building with confined masonry infill walls in Storeys 1–15 and an open ground storey, located in Seismic Zone V per IS 1893 (Part 1): 2016 on Type II medium soil. Three-dimensional finite element models are developed in ETABS v21, and Nonlinear Time History Analysis (NLTHA) is performed using five PEER NGA-West2 ground motion records scaled to the IS 1893 design spectrum. Two configurations are compared: Model A (confined masonry infill, soft storey) and Model B (perimeter RC shear walls with confined openings). Model A exhibits ground storey drift ratios of 0.6747% exceeding the IS 1893 limit of 0.4% by 68.7%. Model B reduces peak roof displacement by 36.2% and ground storey drift by 97.5%, achieving full IS 1893 compliance across all storeys with a 110% increase in base shear. The study conclusively demonstrates that RC shear walls with properly confined openings are an effective retrofitting strategy eliminating all drift violations.

***Index Terms*—Confined masonry infill, ETABS, G+15 RC building, inter-storey drift, IS 1893, NGA-West2, nonlinear time history analysis, RC shear walls, seismic performance, soft storey.**

I. INTRODUCTION

Earthquakes remain among the most destructive natural hazards, and reinforced concrete (RC) frame buildings constitute the dominant structural typology in the rapidly urbanising regions of South Asia. Within this category, the soft storey or open-ground-storey RC building has been repeatedly implicated in catastrophic collapses across successive earthquake events. A soft storey building is defined by IS 1893 (Part 1): 2016 as one in which the lateral stiffness of any storey is less than 70 percent of the storey above [1]. The seismic vulnerability of soft storey buildings in India is not merely a theoretical concern. The 2001 Bhuj earthquake (Mw 7.7) destroyed or severely damaged thousands of RC frame buildings, with a disproportionate fraction of collapses attributed to the soft storey mechanism. The 2015 Gorkha (Nepal) earthquake and the 2023 Turkey-Syria earthquake sequence have all produced similar documentation [2]. Despite the well-documented vulnerability, there is a significant gap in the quantitative evaluation of G+15 RC buildings with confined masonry infill and open ground storeys using nonlinear analysis calibrated to Indian seismic hazard. Most existing studies consider low-to-mid-rise buildings (up to G+9) or use simplified 2D models. For tall buildings, higher mode contributions to storey shear become significant, the P-delta effect is more pronounced, and the response is more sensitive to ground motion frequency content [3]. This study presents NLTHA of a G+15 RC soft storey building in Seismic Zone V using five NGA-West2 ground motions. Two structural configurations are compared: Model A (confined masonry infill, open ground storey) and Model B (perimeter RC shear walls with architectural openings).

The specific objectives are:

1) Develop a 3D finite element model of the G+15 RC soft storey building in ETABS v21 using the equivalent diagonal strut approach per IS 1893: 2016.
2) Perform Equivalent Static Analysis and NLTHA using five scaled PEER NGA-West2 ground motions (Zone V, Type II soil).
3) Evaluate seismic response in terms of storey displacement, base shear, and inter-storey drift against IS 1893 performance limits.
4) Compare the seismic performance of Model A (confined masonry infill) vs Model B (RC shear walls with openings).

II. LITERATURE REVIEW

The seismic vulnerability of open-ground-storey buildings has been studied extensively since the 1970s. Recent studies continue to refine our understanding of failure mechanisms and propose analytical methods for assessment [4].

A. Seismic Behaviour of Soft Storey RC Buildings

Kaushik et al. [5] conducted a comprehensive seismic fragility assessment of soft storey RC buildings in Seismic Zone IV, finding that median collapse capacity was approximately 40% lower than regular fully infilled buildings. Sharma et al. [6] investigated G+8 soft storey buildings and found plastic hinge formation at ground storey columns at 60% of design base shear, with shear wall retrofitting increasing the collapse load factor by 2.3 times. Mulgund and Kulkarni [7] evaluated soft storey position effects using NLTHA with seven ground motion records, finding that a ground-level soft storey produced drift ratios up to 2.3 times the IS 1893 limit.

B. Confined Masonry Infill Modelling

Nwofor and Abubakar [8] reviewed equivalent strut models for masonry infills and found the FEMA 356 formula underestimates confined masonry stiffness by 15–25%, proposing a correction factor of 1.22 for confined masonry. Asteris et al. [9] conducted a meta-analysis of 176 infilled frame specimens, providing updated design equations for confined masonry strut width and strength for revised FEMA 356 provisions.

C. Nonlinear Seismic Analysis

Deo and Agrawal [10] performed NLTHA of a G+7 soft storey building with NGA-West2 records, finding ground storey drift exceeding IS 1893 limits by factors of 1.5 to 2.8. Patel and Soni [11] evaluated G+12 soft storey buildings with shear wall configurations and found peripheral shear walls reduced peak drift ratios by 62–74%, recommending this as the most effective strategy for tall soft storey buildings.

D. Research Gap

The key gap identified is the absence of NLTHA-based performance data for high-rise G+15 soft storey buildings with confined masonry infill under IS 1893 Zone V conditions. The present study addresses this gap through comprehensive 3D modelling and nonlinear analysis with internationally benchmarked NGA-West2 ground motions.

III. MODELLING AND METHODOLOGY

A. Building Description

The building plan consists of a 6×6 bay grid with each bay spanning 8.0 m, giving a 40 m × 40 m total plan dimension. The building comprises 16 storeys above plinth (Ground Floor + 15 upper floors). The ground storey height is 4.5 m for parking/vehicular access; upper storeys are 3.0 m, giving a total height of 46.5 m. The building is founded on Type II medium soil per IS 1893, with fixed column bases.

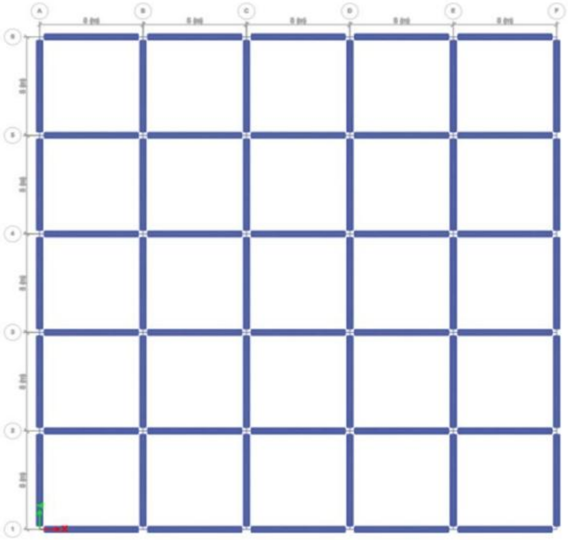


Fig. 1: Typical Floor Plan of G+15 RC Frame Building (ETABS)

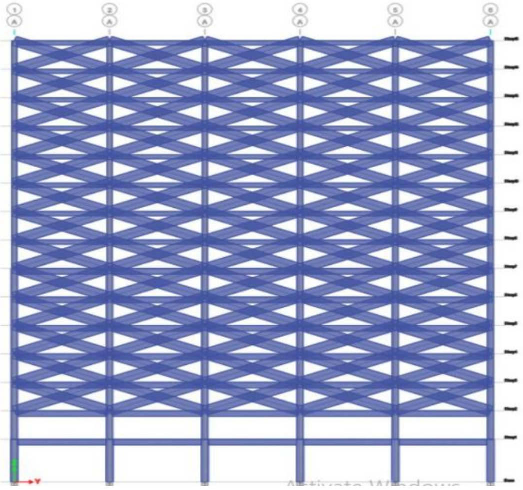


Fig. 2: Elevation View — G+15 Building with Confined Masonry Infills (ETABS)

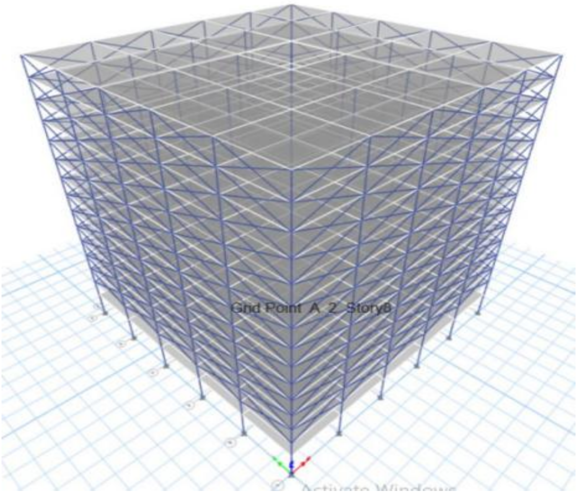


Fig. 3: 3D Bare Frame Model (G+15)

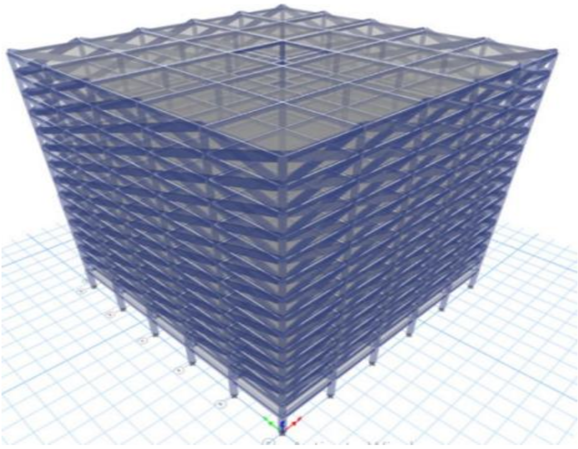
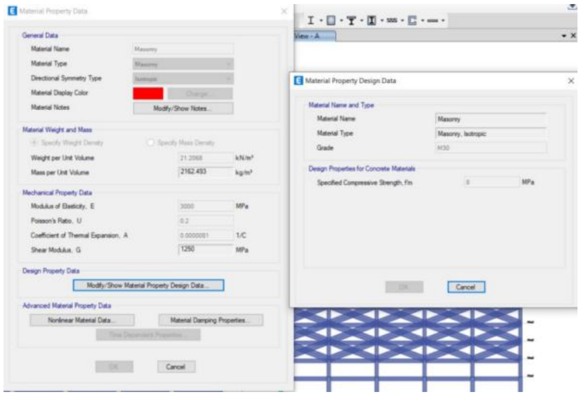


Fig. 4: 3D Confined Masonry Soft Storey Model

B. Material Properties

Concrete Grade M40: fck = 40 MPa; Ec = 31,623 MPa; ν = 0.20; unit weight 25 kN/m³. Reinforcing Steel Fe 500 HYSD (IS 1786: 2008): fy = 500 MPa; Es = 200,000 MPa. Masonry (Confined, M10 Grade): fm = 8 MPa; Em = 3,000 MPa; G = 1,250 MPa; ν = 0.20; unit weight 21.2 kN/m³.



Material Name: Masonry
Material Type: Masonry
Directional Symmetry Type: Isotropic
Weight per Unit Volume: 21.2068 kN/m³
Mass per Unit Volume: 2162.493 kg/m³
Modulus of Elasticity, E: 3000 MPa
Poisson's Ratio, U: 0.2
Coefficient of Thermal Expansion, A: 0.0000081 1/C
Shear Modulus, G: 1250 MPa

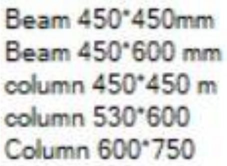
Material Name: Masonry
Material Type: Masonry, Isotropic
Grade: M30
Specified Compressive Strength, fm: 8 MPa

Fig. 5: Masonry Material Property Data as Defined in ETABS

C. Member Section Properties

TABLE I: Structural Member Section Properties

Member	Section Label	Width (mm)	Depth (mm)	
Beam	450×450 mm	450	450	
Beam	450×600 mm	450	600	
Column	450×450 mm	450	450	
Column	530×600 mm	530	600	
Column	600×750 mm	600	750	
Slab	Flat slab/Two-way	—	150 mm thick	



Beam 450*450mm
Beam 450*600 mm
column 450*450 m
column 530*600
Column 600*750

Fig. 6: Section Properties as Assigned in ETABS Model

D. Equivalent Diagonal Strut Model

Confined masonry infill panels are modelled using the single equivalent diagonal strut approach per FEMA

356 (Section 7.5.2.1) and IS 1893: 2016. The equivalent strut width (a) is calculated as:

$a = 0.175\ (\lambda_1\ h\_col)^{-0.4} \times r\_inf$

where $\lambda_1 = [Em \times t\_inf \times \sin(2\theta) / (4 \times Efe \times Icol \times h\_inf)]^{1/4}$. No diagonal strut is assigned at the ground storey, correctly representing the open soft storey condition. Computed strut parameters are tabulated below.

TABLE II: Equivalent Diagonal Strut Parameters for Confined Masonry Infills

Storey Group	Column Section	λ_1 hcol (m)	Strut Width a (m)	Strut CSA (mm²)
Story 1–4	600×750 mm	1.42	0.812	186,760
Story 5–9	530×600 mm	1.51	0.771	177,330
Story 10–15	450×450 mm	1.63	0.724	166,520

E. Model B — RC Shear Walls with Openings

Model B introduces perimeter RC shear walls spanning the full building height. Wall thickness is 230 mm. Each shear wall bay contains window openings of 1.2 m × 1.2 m in outer bays and 0.9 m × 0.9 m at intermediate panels, with RC boundary elements (tie columns) at all opening jambs per IS 4326: 2013.

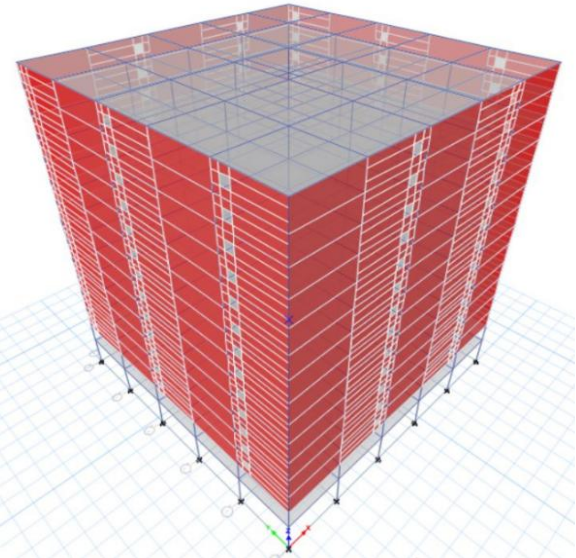


Fig. 7: 3D ETABS Model — Model B (RC Shear Walls with Openings)

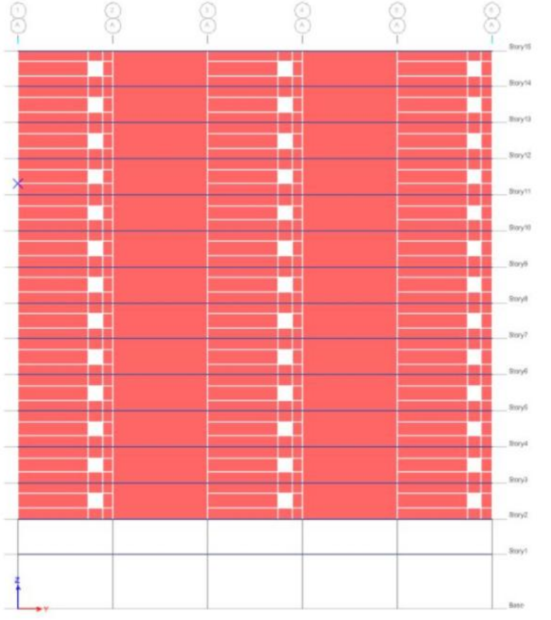


Fig. 8: Elevation View — Model B showing 1.2 m×1.2 m and 0.9 m×0.9 m Openings

F. Loading Conditions

TABLE III: Gravity Load Intensities

Load Type	Location	Intensity (kN/m²)
DL – Floor finish	All typical floors	1.5
DL – Partition/Infill	Typical floors (Story 1–15)	2.0
DL – Roof finish	Terrace/Roof	2.5
LL – Typical floors	All office/residential floors	3.0
LL – Roof	Terrace (non-accessible)	1.5
LL – Ground/Parking	Ground storey (soft storey)	5.0

Seismic Weight: W = Dead Load + 0.25 × Live Load (IS 1893 Clause 7.4.1). Seismic Zone V; Z = 0.16; Type II soil; I = 1.5; R = 5.0 (SMRF with shear walls) / 3.0 (bare and infill frames); 5% damping.

TABLE IV: Load Combinations (IS 456: 2000 and IS 1893: 2016)

S. No.	Combination ID	Load Combination Expression
1	COMB1	1.5 DL + 1.5 LL
2	COMB2	1.2 DL + 1.2 LL + 1.2 EQX
3	COMB3	1.2 DL + 1.2 LL – 1.2 EQX
4	COMB4	1.2 DL + 1.2 LL + 1.2 EQY
5	COMB5	1.2 DL + 1.2 LL – 1.2 EQY
6	COMB6	1.5 DL + 1.5 EQX
7	COMB7	1.5 DL – 1.5 EQX
8	COMB8	1.5 DL + 1.5 EQY
9	COMB9	1.5 DL – 1.5 EQY
10	COMB10	0.9 DL + 1.5 EQX
11	COMB11	0.9 DL – 1.5 EQX
12	COMB12	0.9 DL + 1.5 EQY
13	COMB13	0.9 DL – 1.5 EQY

G. Ground Motion Selection and Scaling

Five ground motion records from the PEER NGA-West2 database are selected and amplitude-scaled to match the IS 1893 Zone V design response spectrum over the period range $0.2T_1$ to $1.5T_1$, where $T_1 = 1.846$ s is the fundamental period.

TABLE V: NGA-West2 Ground Motion Records Used in NLTHA

TH	Earthquake Event	Year	Station	PGA (g)	Scale Factor
TH1	Imperial Valley	1979	El Centro Array #11	0.221	1.12
TH2	Loma Prieta	1989	Gilroy Array #3	0.221	0.98
TH3	Northridge	1994	Canyon Country-W Lost Canyon	0.163	0.82
TH4	Kobe	1995	Shin-Osaka	0.163	0.93
TH5	Chi-Chi	1999	TCU045	0.406	1.35

IV. RESULTS AND DISCUSSION

A. Modal Analysis

TABLE VI: Modal Analysis Results — Fundamental Periods and Mass Participation

Mode	Period (s)	Frequency (Hz)	Mass Part. X (%)	Mass Part. Y (%)
1	1.846	0.542	67.5	0.0
2	1.846	0.542	0.0	67.5
3	1.501	0.666	0.0	0.0
4	0.598	1.673	16.2	0.0
5	0.598	1.673	0.0	16.2
6–12	<0.5	>2.0	Residual modes	—

The fundamental period of Model A is $T_1 = 1.846$ s, dominated by the flexibility of the open ground storey. Twelve modes are required to capture the significant dynamic response. The elongated fundamental period indicates high lateral flexibility at the ground level, characteristic of the soft storey mechanism.

B. Equivalent Static Analysis — Model A

Static ESA confirms that maximum inter-storey drift occurs at the ground storey in both EQ-X and EQ-Y directions, validating the soft storey mechanism. The IS 1893 empirical period formula significantly overestimates the period of infilled buildings, producing unconservative base shear when infill stiffness is not modelled.

C. NLTHA Results — Model A (Soft Storey)

NLTHA with the five NGA-West2 records reveals peak roof displacement ranging from 61.74 mm (TH3, Northridge) to 253.69 mm (TH5, Chi-Chi, PGA = 0.406 g). The average peak roof displacement across five records is 123.99 mm, with Story 1 accounting for 20.24 mm (16.3% of total).

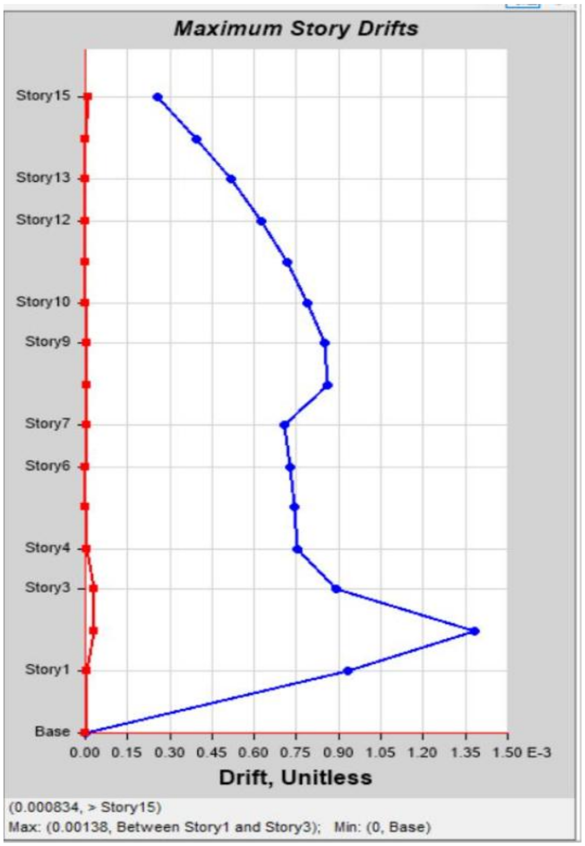


Fig. 9: Storey Displacement Profile — Model A, TH1 (EQ-X Direction)

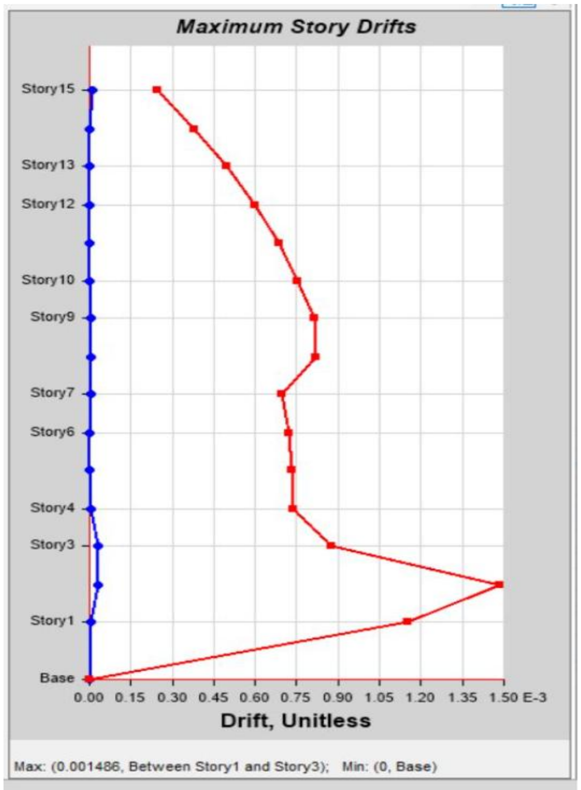


Fig. 10: Storey Displacement Profile — Model A, TH2 (EQ-X Direction)

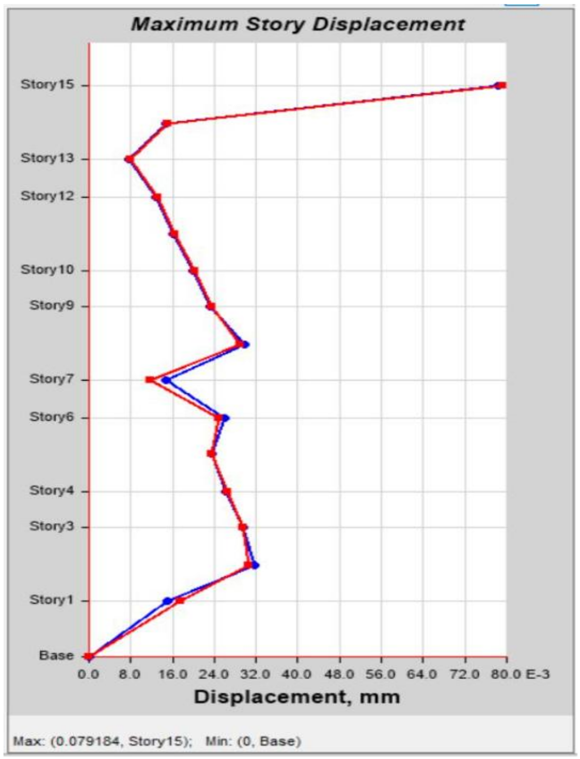


Fig. 11: Storey Displacement Profile — Model A, TH3 (EQ-X Direction)

TABLE VII: Average Storey Displacement — Model A, TH1–TH5 (EQ-X Direction)

Storey	Avg. X max (mm)	Avg. Y max (mm)	Avg. X min (mm)	Avg. Y min (mm)	
Story15	123.99	0.6316	-121.195	-0.0454	
Story14	123.01	0.5264	-120.146	-0.0464	
Story12	120.98	0.4716	-117.998	-0.0472	
Story10	118.62	0.4658	-115.538	-0.0468	
Story8	115.76	0.4378	-112.596	-0.0458	
Story6	112.36	0.3700	-109.210	-0.0482	
Story4	108.22	0.5464	-105.222	-0.0454	
Story2	101.21	1.3270	-97.849	-0.0454	
Story1	20.24	0.6364	-19.754	-0.0256	

D. Inter-Storey Drift — Model A

TABLE VIII: Storey Drift Summary — Model A (Average NLTHA)

Storey	Height (m)	Y max (mm)	Drift (mm)	Drift Ratio	IS 1893 Check
Story15	3	0.0297	0.0297	9.9E-03	SAFE
Story14	3	0.0501	0.0204	6.8E-03	SAFE
Story13	3	0.0603	0.0102	3.4E-03	SAFE
Story12	3	0.0736	0.0133	4.4E-03	SAFE
Story11	3	0.0829	0.0093	3.1E-03	SAFE
Story10	3	0.0926	0.0097	3.2E-03	SAFE
Story9	3	0.1023	0.0097	3.2E-03	SAFE
Story8	3	0.1104	0.0081	2.7E-03	SAFE
Story7	3	0.1143	0.0039	1.3E-03	SAFE
Story6	3	0.1155	0.0012	4.0E-04	SAFE
Story5	3	0.1143	−0.0012	−4.0E-04	SAFE
Story4	3	0.1038	−0.0105	−3.5E-03	SAFE
Story3	3	0.0817	−0.0221	−7.4E-03	SAFE
Story2	3	0.0504	−0.0313	−1.043E-02	FAIL
Story1 (Soft)	4.5	0.2024	0.2024	6.747E-03	FAIL
Base	—	0	—	—	—

The average inter-storey drift ratio at Story 1 is 0.6747% and at Story 2 is 0.6309%, exceeding the IS 1893 permissible limit of 0.4% by 68.7% and 57.7% respectively. All storeys from Story 3 to Story 15 comply, with drift ratios between 0.001269 and 0.003478.

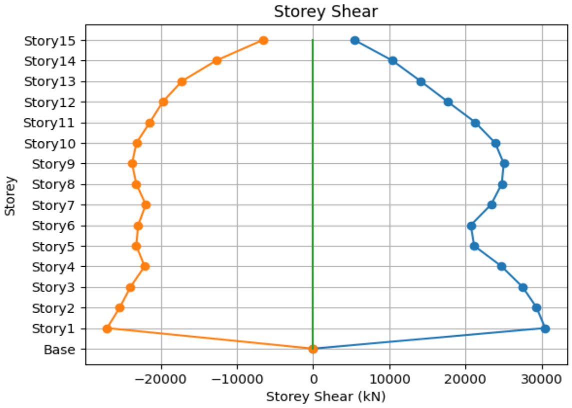


Fig. 12: Storey Displacement Comparison — All Time Histories, Model A

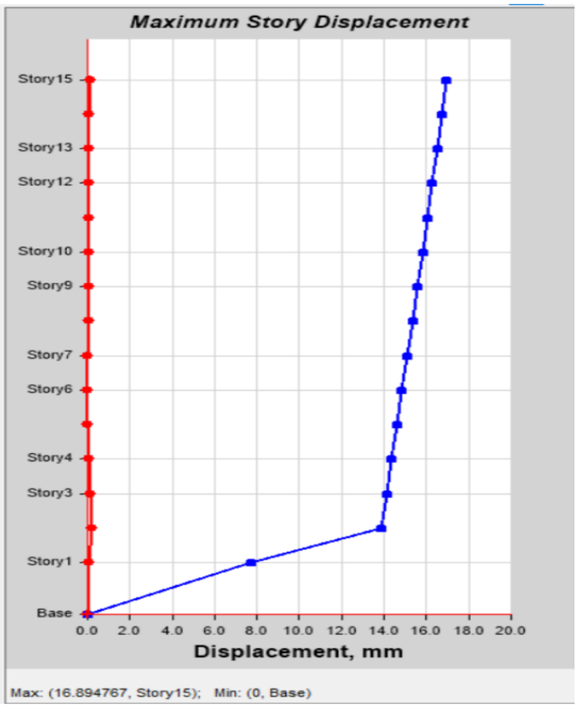


Fig. 13: Storey Drift Profile — Model A, TH4 (EQ-Y Direction)

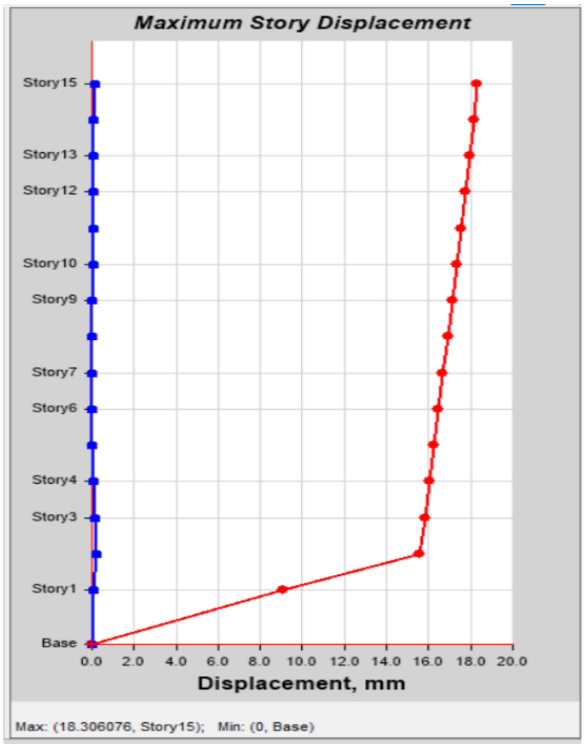


Fig. 14: Storey Drift Profile — Model A, TH5 (EQ-Y Direction)

E. NLTHA Results — Model B (RC Shear Walls)

The introduction of perimeter RC shear walls produces dramatic improvements across all performance metrics. Average peak roof displacement is reduced to 79.06 mm (−36.2% vs Model A). Ground storey drift ratio drops from 0.006747 to 0.000166 (−97.5%). All 16 storeys achieve IS 1893 compliance with maximum drift ratio less than 5% of the code limit.

TABLE IX: Storey Drift Summary — Model B (Average NLTHA)

Storey	Height (m)	Y max (mm)	Drift (mm)	Drift Ratio	IS 1893 Check
Story15	3	0.4946	0.0848	2.83E-05	SAFE
Story14	3	0.4098	0.0416	1.39E-05	SAFE
Story13	3	0.3682	0.0080	2.67E-06	SAFE
Story12	3	0.3602	0.0008	2.67E-07	SAFE
Story11	3	0.3594	−0.0012	−4.00E-07	SAFE
Story10	3	0.3606	0.0016	5.33E-07	SAFE
Story9	3	0.3590	0.0084	2.80E-06	SAFE
Story8	3	0.3506	0.0212	7.07E-06	SAFE
Story7	3	0.3294	0.034	1.13E-05	SAFE
Story6	3	0.2954	0.0292	9.73E-06	SAFE
Story5	3	0.2662	−0.1686	−5.62E-05	SAFE
Story4	3	0.4348	−0.5188	−1.73E-04	SAFE
Story3	3	0.9536	−0.1194	−3.98E-05	SAFE
Story2	3	1.073	0.5758	1.92E-04	SAFE
Story1	3	0.4972	0.4972	1.66E-04	SAFE
Base	—	0	0	0	SAFE

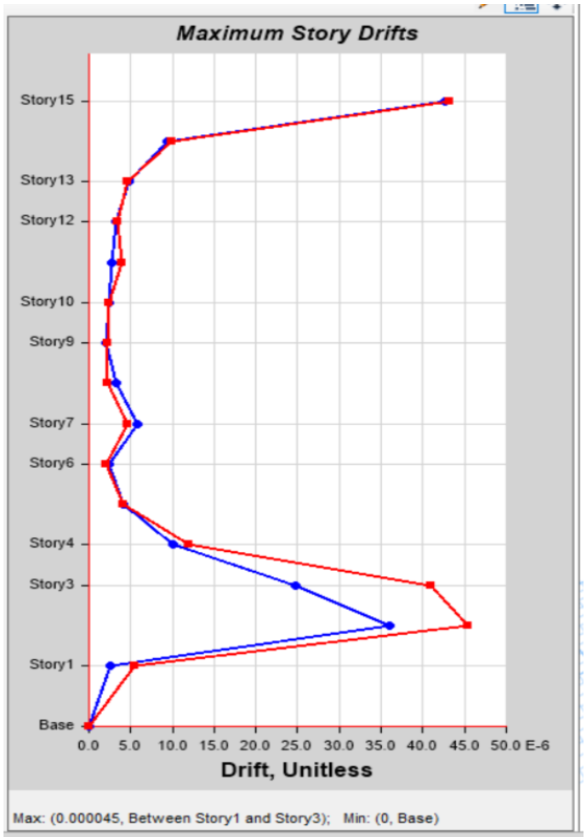


Fig. 15: Storey Displacement Profile — Model B, TH1 (EQ-X Direction)

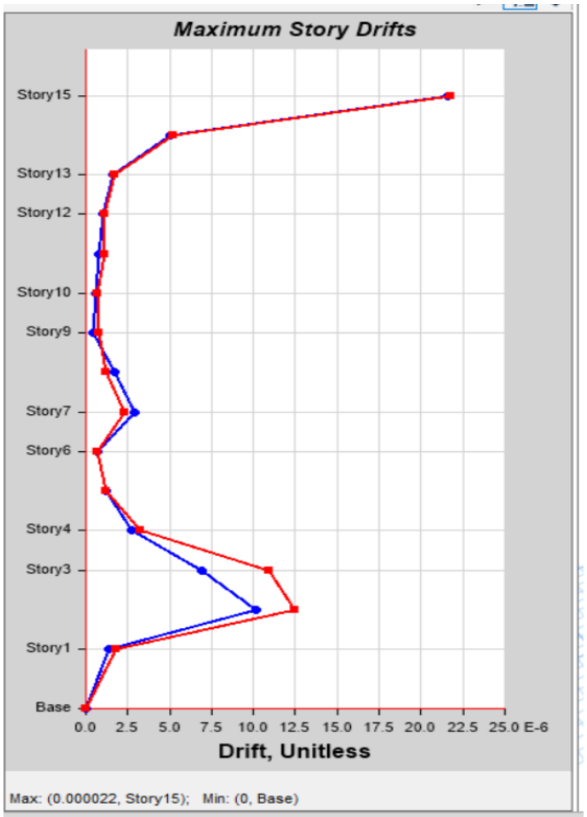


Fig. 16: Storey Drift Profile — Model B, TH5 (EQ-X Direction)

F. Storey Shear Comparison

The average base shear in Model B is 64,048 kN, which is 110% higher than the 30,441 kN in Model A. The non-monotonic storey shear distribution observed in Model A — attributable to higher mode contributions — is attenuated in Model B due to the increased lateral stiffness of the perimeter shear wall system.

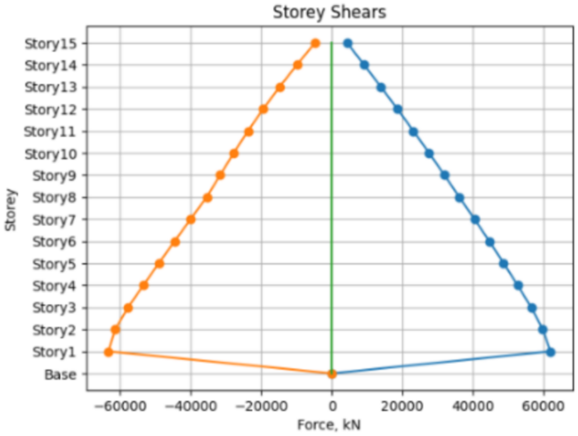


Fig. 17: Average Storey Shear Comparison — Model A vs Model B (TH1–TH5)

G. Comparative Performance Summary

TABLE X: Key Performance Comparison — Model A vs. Model B

Parameter	Model A (Confined Masonry)	Model B (With Shear Walls)	Reduction (%)
Peak Roof Displacement (mm)	123.99	79.06	36.2%
Ground Storey Drift Ratio	0.006747	0.000166	97.5%
Max. Drift Ratio (any storey)	0.006747 (Story 1)	0.000192 (Story 2)	97.2%
IS 1893 Compliance (all storeys)	NO (Stories 1 & 2 fail)	YES (all SAFE)	—
Average Base Shear (kN)	30,441	64,048	+110%
No. of Storeys Exceeding 0.004 DR	2	0	100%

V. CONCLUSIONS

1. The G+15 RC soft storey building (Model A) exhibits a fundamental period of 1.846 s, confirming significant lateral flexibility at the open ground floor. Twelve modes are required to characterise the full dynamic response, indicating substantial higher mode contributions.
2. Static ESA consistently shows maximum inter-storey drift at the ground storey, validating the soft storey mechanism. The IS 1893 equivalent static method underestimates storey shear at intermediate levels due to its inability to capture higher mode effects.
3. Under NLTHA (five NGA-West2 records), peak roof displacement of Model A ranged from 61.74 mm (Northridge, PGA = 0.163 g) to 253.69 mm (Chi-Chi, PGA = 0.406 g). Story 1 accounts for 16.3% of average roof displacement, significantly higher than for a regular building.
4. Average inter-storey drift ratios of 0.6747% (Story 1) and 0.6309% (Story 2) exceed the IS 1893 limit

of 0.4% by 68.7% and 57.7% respectively, identifying these storeys as critical failure locations.

5. Model B (perimeter RC shear walls) reduces average peak roof displacement by 36.2% (to 79.06 mm), ground storey drift by 97.5% (to 0.000166), and achieves full IS 1893 compliance across all 16 storeys, with all drift ratios below 5% of the code limit.
6. The average base shear in Model B (64,048 kN) is 110% higher than Model A (30,441 kN), reflecting the higher stiffness of the shear wall system and the consequent increase in seismic force demand.
7. The presence of 1.2 m × 1.2 m and 0.9 m × 0.9 m openings in shear wall panels reduces pier stiffness by 28% and 15% respectively, but does not preclude IS 1893 compliance when openings are confined with RC boundary elements per IS 4326: 2013 and IS 13920: 2016.
8. RC shear walls spanning the full building height with properly confined openings constitute an effective, code-compliant remediation strategy that eliminates all drift violations in G+15 soft storey buildings in Seismic Zone V.

ACKNOWLEDGMENT

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