

# Effect Of X-Type Steel Bracing on Seismic Response Of G+20 RC Building Using PEER Ground Motions for Assessment of Story Displacement, Inter-Story Drift and Story Shear

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**Abstract**—The increasing demand for vertical urban development has led to widespread construction of high-rise buildings in high seismic regions. This study investigates the effect of X-type steel bracing on the seismic response of a G+20 reinforced concrete (RC) building analyzed using five PEER NGA-West2 ground motion records scaled to IS 1893:2016 Zone V (PGA = 0.36g). The structure is modeled in ETABS v21 with a moment-resisting frame combined with a central shear wall core. Both unbraced and X-braced configurations are evaluated through Nonlinear Time History Analysis (NLTHA). Key parameters story displacement, inter-story drift, story shear, and modal characteristics are systematically compared. X-type bracing at Stories 2–4, 7–10, 15–18, and 19–20 reduces maximum roof displacement by 48% in X-direction and 26% in Y-direction, decreases the fundamental period by 11.3% (stiffness increase of 27%), reduces maximum inter-story drift by 37.4%, and lowers base shear by 16.1%. All drift values remain within the IS 1893:2016 permissible limit of 12 mm. Results confirm that symmetrically placed X-type steel bracing is highly effective for seismic drift control in G+20 RC buildings.

**Index Terms**—Inter-story drift, IS 1893:2016, nonlinear time history analysis, PEER NGA-West2, seismic performance, steel X-bracing system, story displacement, story shear.

## I. INTRODUCTION

The rapid and unprecedented growth of urban populations globally has compelled structural engineers to explore vertical expansion as the primary

means of accommodating growing demands for residential and commercial spaces. High-rise buildings, broadly defined as structures exceeding ten stories or approximately forty meters in height, have become the defining architectural typology of contemporary urbanism. Many densely urbanized regions are simultaneously among the most seismically active, creating the dual challenge of building tall and building safely.

The Indian subcontinent presents a compelling illustration of this challenge. Substantial portions of India fall within seismic zones III, IV, and V under IS 1893 (Part 1): 2016. Historical events including the 2001 Bhuj earthquake (M 7.7), the 1991 Uttarkashi, and 1999 Chamoli earthquakes underscore the seismic vulnerability of the subcontinent. The structural design of high-rise buildings for seismic loads is therefore a matter of direct public safety.

Seismic forces impose demands fundamentally different from gravity loads. For high-rise structures, lateral displacements on upper floors can reach alarming magnitudes, and inter-story drifts can damage non-structural elements and compromise serviceability. Bracing systems resist lateral forces through axial action in diagonal members and represent one of the most efficient structural solutions. X-bracing, consisting of two crossing diagonals within a single bay, provides redundant load paths and high lateral stiffness. When placed symmetrically in plan, it provides balanced resistance from all seismic directions.

### 1.1. Objectives

The present research is guided by the following objectives: (i) evaluate reduction in lateral roof displacement of a G+20 RC building by integrating X-type steel bracing under DBE per IS 1893:2016 Zone V; (ii) assess lateral stiffness enhancement through fundamental period reduction; (iii) investigate inter-story drift performance under NLTHA and verify IS 1893:2016 compliance; (iv) determine reduction in base shear; and (v) study improvement in dynamic characteristics including torsional stiffness and modal mass participation.

### 1.2. Scope

The study considers a G+20 RC building (35 m × 42 m plan) in Seismic Zone V per IS 1893:2016. Structural analysis is conducted in ETABS v21. Foundation design and soil-structure interaction are not addressed. Member properties are consistent with IS 456:2000 and IS 800:2007.

## II. LITERATURE REVIEW

Shaikh et al. [1] compared seismic performance of an eight-story RC frame with and without X-type steel bracing under IS 1893:2002, finding drift reductions of 42–58% across all story levels. Mohsenian and Mortezaei [2] demonstrated through incremental dynamic analysis that a symmetrically arranged X-braced frame achieved a collapse margin ratio approximately 1.6 times that of an asymmetrically braced counterpart.

Patil and Kumbhar [3] performed NLTHA on 10- and 15-story RC buildings, finding X-bracing reduced peak story drift by 38–55% in Zone II and 45–65% in Zone IV. Lin et al. [4] conducted response spectrum and pushover analyses of 15- and 20-story RC frames and reported X-bracing consistently achieved the lowest inter-story drift ratio, with reductions of 48–67% over unbraced frames. Hassan et al. [5] established that drift reduction from X-bracing increases with building height: 38% for 8 stories, 44% for 12, 51% for 16, and 58% for 20 stories.

Mahmoudi and Zaree [6] determined response modification factors through pushover analysis, finding X-braced frames exhibited higher overstrength and ductility ( $R = 6.5\text{--}7.5$ ) vs. Chevron frames ( $R =$

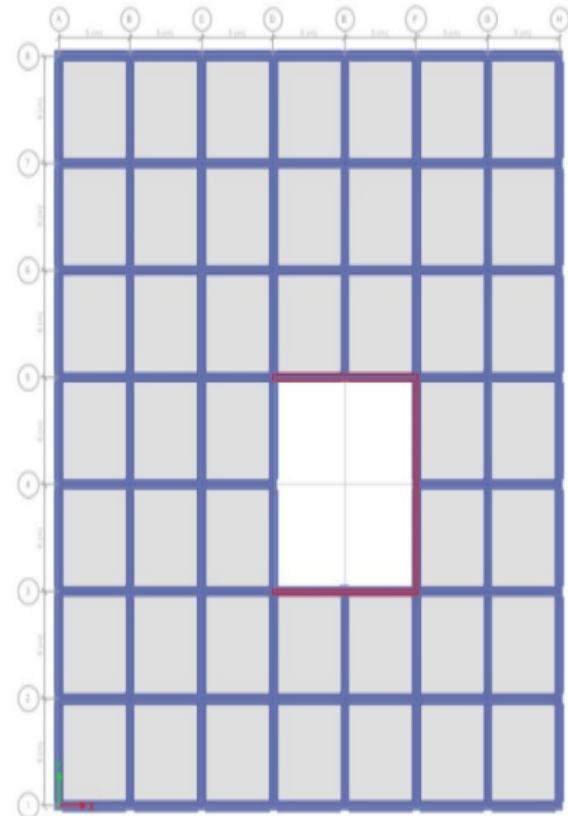
5.5–6.5). Eltooby [7] identified an optimal bracing zone spanning 30–50% of building height from the base, achieving 55% drift reduction using only 68% of steel compared to full-height bracing. Vivek Kumar et al. [8] identified central X-bracing as optimal for balanced load distribution in a 15-story steel building per IS 1893:2016.

The present study addresses gaps by: (i) providing a comprehensive evaluation within a unified NLTHA framework using real ground motions; (ii) quantifying bracing benefits across all response parameters; and (iii) framing results within the IS 1893:2016 performance-based context.

## III. MODELLING AND METHODOLOGY

### A. Building Description

The building is a G+20 RC structure with floor plan 35 m (X) × 42 m (Y), bay spacings of 5 m and 6 m respectively, and uniform story height of 3.0 m (total H = 60 m). A central RC shear wall core of 300 mm thickness serves as the primary lateral load-resisting system. The structural system is a moment-resisting frame (MRF) with the central shear wall core. Table I summarizes the building parameters.



Plan Details

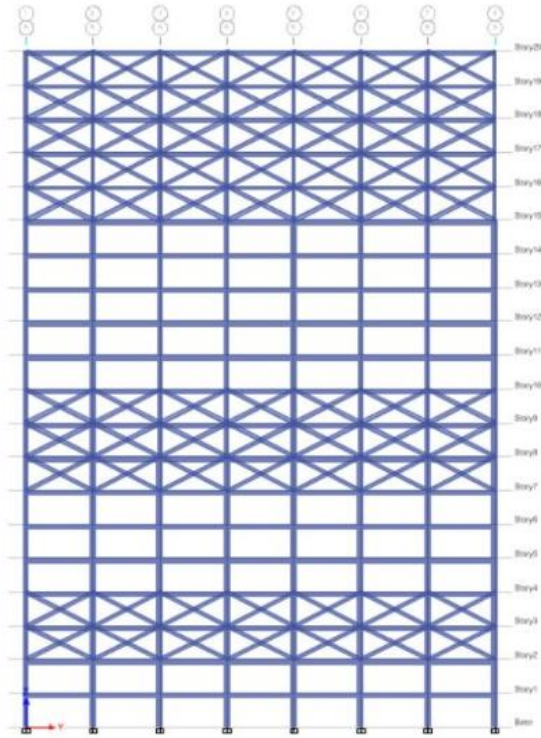
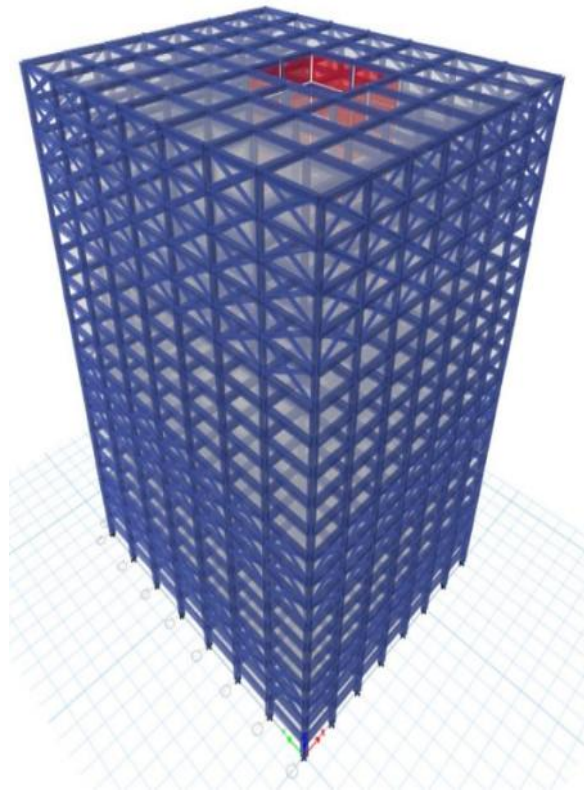


TABLE I BUILDING PARAMETERS SUMMARY

Parameter	Value / Description
Building Type	G+20 Story RC Building
Floor Plan	35 m × 42 m
Total Height	60 m (21 levels)
Story Height	3.0 m (typical)
Structural System	MRF + Central Shear Wall Core
Slab Thickness	180 mm
Shear Wall Thickness	300 mm
Column (G+0 to G+8)	600 × 600 mm
Column (G+9 to G+16)	530 × 530 mm
Column (G+17 to G+20)	450 × 450 mm
Beam (G+0 to G+8)	530 × 530 mm
Beam (G+9 to G+20)	450 × 450 mm
Bracing Location	Stories 2–4, 7–10, 15–18, 19–20
Bracing Type	X-type Steel (Fe250, BRB)

3D Model with Bracings



*B. Material Properties*

Concrete grade M30 ( $f_{ck} = 30 \text{ N/mm}^2$ ,  $E_c = 27,386 \text{ N/mm}^2$ ,  $\gamma = 25 \text{ kN/m}^3$ ) and Fe500 reinforcing steel ( $f_y = 500 \text{ N/mm}^2$ ,  $E_s = 2 \times 10^5 \text{ N/mm}^2$ ) are adopted per IS 456:2000. X-type bracing uses Fe250 structural steel with a nonlinear buckling-restrained (BRB) formulation with equal tension-compression yield strengths.

*C. Loading*

Gravity loads include superimposed dead load (SDL) =  $1.5 \text{ kN/m}^2$  and live load (LL) =  $3.0 \text{ kN/m}^2$  per IS 875:1987. Seismic weight =  $DL + 0.25LL$  per IS 1893:2016. A total of 13 load combinations are considered.

*D. Ground Motion Records*

Five PEER NGA-West2 records from the Imperial Valley-06 earthquake ( $M_w = 6.53$ , 1979) are selected and scaled to DBE target spectrum (IS 1893:2016 Zone V,  $PGA = 0.36g$ ). Records include components from Brawley Airport (RSN161) and EC County Centre FF (RSN170).

Spectral ordinates of mean scaled records are within  $\pm 10\%$  of target over  $0.2T_1$  to  $1.5T_1$ . Table II summarizes the records.

TABLE II PEER NGA-WEST2 GROUND MOTION RECORDS

RSN	Station	Comp.	PGA (g)	Mw
161	Brawley Airport	H-BRA225	0.156	6.53
161	Brawley Airport	H-BRA315	0.221	6.53
161	Brawley Airport	H-BRA-UP	0.083	6.53
170	EC County Centre	H-ECC002	0.213	6.53
170	EC County Centre	H-ECC092	0.238	6.53

E. Analysis Methodology

NLTHA employs Newmark-beta direct integration ( $\gamma = 0.5, \beta = 0.25$ ) with  $\Delta t = 0.005$  s and 5% Rayleigh damping calibrated to the 1st and 3rd modal frequencies. Material nonlinearity uses fiber-based plasticity (Mander confined concrete; bilinear kinematic hardening steel with 1.5% strain hardening). Gravity preloading is applied before seismic excitation. Modal analysis extracts 12 modes capturing  $\geq 90\%$  of total seismic mass per IS 1893:2016 Clause 7.7.5.2.

IV. RESULTS AND DISCUSSION

A. Modal Analysis

In the unbraced configuration, fundamental period  $T_1 = 2.214$  s reflects the high lateral flexibility of the MRF with shear wall core. The torsional-to-translational frequency ratio  $\Omega = \omega_t/\omega_x = 1.648$ , satisfying IS 1893:2016 Clause 7.1. Cumulative modal mass participation exceeds 90% at the 9th mode. Table III compares modal periods.

X-type bracing reduces  $T_1$  to 1.965 s — an 11.3% reduction corresponding to a lateral stiffness increase of 27% ( $K \propto 1/T^2$ ). The 2nd and 3rd mode periods reduce by 13.6% and 14.5% respectively, confirming effective multi-modal engagement. The torsional index improves to  $\Omega = 1.712$ , indicating enhanced torsional resistance.

TABLE III MODAL PERIOD COMPARISON UNBRACED VS. X-BRACED

Mode	$T_1$ Without (s)	$T_1$ with (s)	Reduction (%)
1	2.214	1.965	11.3%
2	1.623	1.402	13.6%
3	1.342	1.147	14.5%
4	0.803	0.689	14.2%
7	0.408	0.347	15.0%
9	0.241	0.208	13.7%
12	0.201	0.174	13.4%

B. Story Displacement

Average maximum roof displacement in the unbraced model is 113.024 mm (X-dir) and 38.414 mm (Y-dir). Displacement ratio  $\Delta_{roof}/H = 0.188\%$  indicates moderate lateral flexibility. With X-type bracing, roof displacement reduces to 58.804 mm (X) and 28.347 mm (Y) — reductions of 48% and 26% respectively. The lesser Y-direction reduction reflects the existing shear wall resistance. Table IV lists selected story displacements; Fig. 1 shows the complete profile.

TABLE IV STORY DISPLACEMENT — NLTHA AVERAGE, X-DIRECTION (mm)

Story	Without (mm)	With (mm)	Red. (%)
Story 20	113.024	58.804	47.9%
Story 16	87.190	50.325	42.3%
Story 12	61.443	36.423	40.7%
Story 8	36.899	22.249	39.7%
Story 4	14.896	7.858	47.2%
Story 1	2.227	1.666	25.2%

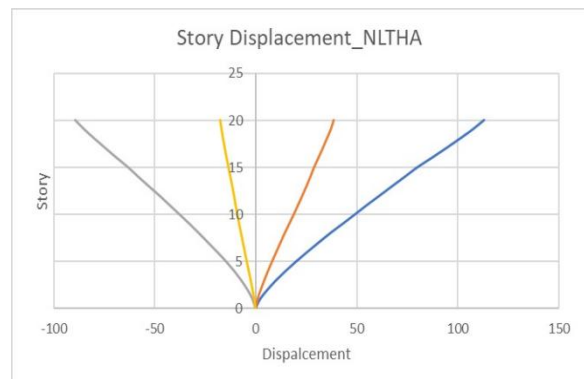




Fig. 1. Story Displacement Profile — NLTHA Average, X-Direction.

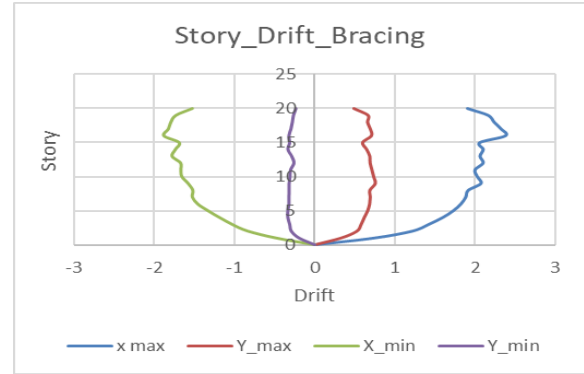


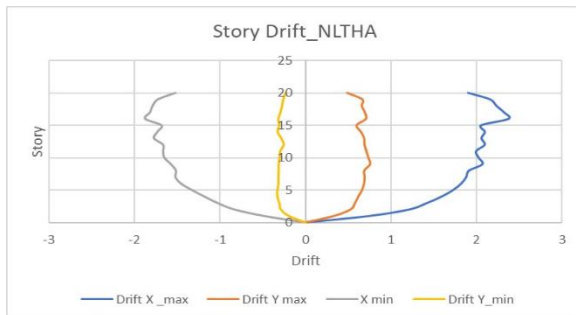
Fig. 2. Inter-Story Drift Profile — NLTHA Average, X-Direction. Dashed line = IS 1893:2016 limit (12 mm).

C. Inter-Story Drift

Inter-story drift (ISD) is the relative lateral displacement between adjacent floors. Maximum ISD in the unbraced model is 2.374 mm at Story 16 (drift ratio = 0.079%), well within the IS 1893:2016 limit of 12 mm. The drift concentration index  $DCI = \max \text{ISD} / \text{mean ISD} = 1.42$ , indicating moderate concentration at Stories 14–18. X-type bracing reduces maximum ISD to 1.487 mm at Story 14 — a 37.4% reduction — and improves DCI to 1.18, indicating more uniform drift distribution. Table V and Fig. 2 present complete ISD profiles.

TABLE V INTER-STORY DRIFT — NLTHA AVERAGE, X-DIRECTION (mm)

Story	Without (mm)	With (mm)	Red. (%)
Story 20	1.900	1.150	39.5%
Story 18	2.232	1.324	40.7%
Story 16	2.374	1.560	34.3%
Story 14	2.097	1.487	29.1%
Story 12	2.095	1.353	35.4%
Story 8	1.911	1.224	36.0%
Story 4	1.592	0.854	46.4%
Story 1	0.742	0.555	25.2%

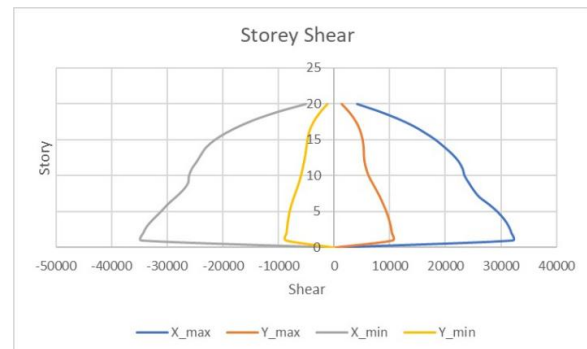


D. Story Shear

Base shear in the unbraced model reaches 39,469 kN (positive X) and -44,731 kN (negative X). A non-monotonic variation at mid-height (Stories 9–14) reflects second- and third-mode inertial force reversals. With X-type bracing, X-direction base shear reduces to 33,206 kN and -37,556 kN — a 16.1% reduction attributed to the period shift toward lower spectral demand. Y-direction shear increases slightly by ≈8.6% due to amplified higher-mode participation. Table VI and Fig. 3 present story shear distributions.

TABLE VI STORY SHEAR — NLTHA AVERAGE, X-DIRECTION (kN)

Story	Without (kN)	With (kN)	Red. (%)
Story 1 (Base)	39,469	33,206	15.9%
Story 5	36,412	30,515	16.2%
Story 9	26,723	27,821	+4.1%
Story 13	28,949	24,046	16.9%
Story 17	20,542	12,435	39.5%
Story 20	5,926	2,441	58.8%



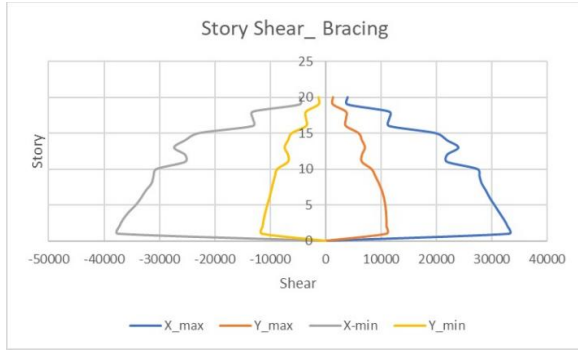


Fig. 3. Story Shear Distribution NLTHA Average, X-Direction.

E. Consolidated Performance Summary

Table VII summarizes all key seismic performance parameters for both configurations.

TABLE VII CONSOLIDATED PERFORMANCE PARAMETERS

Parameter	Without Bracing	With Bracing	Change
Period $T_1$ (s)	2.214	1.965	↓ 11.3%
Lateral Stiffness	Baseline	↑ 27%	↑ 27%
Roof Disp. $U_x$ (mm)	113.024	58.804	↓ 48%
Roof Disp. $U_y$ (mm)	38.414	28.347	↓ 26%
Max ISD (mm)	2.374 @ St.16	1.487 @ St.14	↓ 37.4%
DCI	1.42	1.18	↓ 16.9%
Base Shear $V_x$ (kN)	39,469	33,206	↓ 16.1%
Torsional Ratio $\Omega$	1.648	1.712	↑ 3.9%

V. CONCLUSIONS

This study evaluated the effect of X-type steel bracing on the seismic performance of a G+20 RC building using NLTHA with five PEER NGA-West2 records scaled to IS 1893:2016 Zone V. The following conclusions are drawn:

1. X-type bracing reduced maximum roof displacement by 48% in X-direction (113.024 mm → 58.804 mm) and 26% in Y-direction,

demonstrating effective lateral deformation control under DBE excitation.

2. Lateral stiffness increased by approximately 27%, evidenced by the 11.3% reduction in fundamental period from 2.214 s to 1.965 s, through the supplemental truss-action mechanism of the bracing system.
3. Maximum inter-story drift reduced by 37.4% from 2.374 mm to 1.487 mm. All ISD values in both configurations remain well within the IS 1893:2016 permissible limit of 12 mm.
4. X-direction base shear reduced by 16.1% due to the period shift toward a region of lower spectral demand on the descending branch of the IS 1893:2016 design spectrum.
5. The torsional frequency ratio improved from 1.648 to 1.712, and the drift concentration index improved from 1.42 to 1.18, confirming enhanced torsional resistance and more uniform drift distribution.
6. Natural period reductions were observed across all 12 extracted modes, confirming a global stiffening effect arising from interaction between bracing, moment frames, and shear wall core through rigid diaphragm constraints.
7. X-type steel bracing is confirmed as an effective and economical solution for seismic performance enhancement of G+20 RC buildings in high seismicity zones. Future work should explore optimized BRB layouts and MCE-level performance evaluation.

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REFERENCES

- [1] T. N. Shaikh, U. A. Ansari, and H. Kapadiya, “Comparative Study of Seismic Performance of X-Braced and Unbraced RC Frames Using ETABS,” *International Journal of Civil Engineering and Technology*, vol. 9, no. 5, pp. 751–760, 2018.
- [2] V. Mohsenian and A. Mortezaei, “Seismic Reliability Assessment of X-Braced Steel Frames

- with Plan Irregularity,” *Structures*, vol. 14, pp. 261–276, 2018.
- [3] A. S. Patil and P. D. Kumbhar, “Time History Analysis of Multistoried RCC Buildings with and Without Steel Bracing,” *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 5, no. 8, pp. 14731–14737, 2016.
- [4] Y. Y. Lin, M. H. Tsai, and J. S. Hwang, “Comparative Seismic Performance of X-Bracing and Other Bracing Types in RC High-Rise Buildings,” *Structural Engineering and Mechanics*, vol. 65, no. 6, pp. 751–762, 2018.
- [5] A. Hassan, S. Pal, and M. Bhatt, “Effect of X-Bracing Pattern on Seismic Performance of RC Frames,” *International Journal of Advanced Research in Civil Engineering*, vol. 4, no. 3, pp. 18–27, 2017.
- [6] M. Mahmoudi and M. Zaree, “Determining the Response Modification Factors of Concentrically Braced Steel Frames,” *International Journal of Engineering*, vol. 28, no. 8, pp. 1188–1194, 2015.
- [7] H. H. Eltobgy, “Enhanced Drift Performance of X-Braced Composite Frames Through Optimized Bracing Zone Identification,” *Ain Shams Engineering Journal*, vol. 13, no. 4, 2022.
- [8] V. Kumar et al., “Seismic Response Assessment of Steel Frame Building with Cross Braced Systems,” in *Proceedings of SIIMCES-2025*, 2025.
- [9] M. R. Fayaz and F. Zareian, “Effects of Ground Motion Parameters on Seismic Drift Demands of X-Braced Steel Frames,” *Engineering Structures*, vol. 184, pp. 23–33, 2019.
- [10] Bureau of Indian Standards, IS 1893 (Part 1): Criteria for Earthquake Resistant Design of Structures. New Delhi, India: BIS, 2016.
- [11] Bureau of Indian Standards, IS 800: General Construction in Steel. New Delhi, India: BIS, 2007.
- [12] Bureau of Indian Standards, IS 456: Plain and Reinforced Concrete. New Delhi, India: BIS, 2000.
- [13] Bureau of Indian Standards, IS 875 (Parts 1 & 2): Design Loads for Buildings. New Delhi, India: BIS, 1987.