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Comparative Seismic Performance Evaluation of Peripheral X-Type Steel Bracing in a Twenty-Storey Reinforced Concrete Building

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Abstract — Reinforced concrete (RC) multi-storey buildings are highly susceptible to lateral forces induced by earthquakes, which can cause excessive storey displacement, inter-storey drift and structural damage. Steel bracing is a widely used and economical means of improving the lateral stiffness and seismic performance of RC frames, but its effectiveness depends strongly on configuration. This paper presents a comparative seismic evaluation of a three-dimensional twenty-storey (G+20) RC building modelled with and without peripheral X-type steel bracing, analysed under Seismic Zones II, III, IV and V using the Equivalent Static Method in STAAD.Pro CONNECT Edition, in accordance with IS 456:2000, IS 875 (Parts 1 and 2):1987 and IS 1893 (Part 1):2016. Eight structural cases were compared in terms of maximum bending moment, axial force, shear force, support reaction, overall roof displacement, storey displacement and inter-storey drift. The results show that peripheral X-type bracing reduced every response parameter examined in all four seismic zones. The largest and most consistent benefit was in lateral deformation control, with roof displacement reduced by 28.0-33.0% and maximum inter-storey drift reduced by 29.4-32.5%, both widening as seismic zone increased. Reductions in axial force (15.9-34.3%) and support reaction (15.4-34.3%) grew markedly with seismic zone, while the benefit on bending moment fell from 23.4% in Zone II to about 1.9% in Zones IV-V, and the shear-force benefit stayed nearly constant near 25%. The study concludes that peripheral X-type bracing is most reliably effective as a deformation-control measure across all seismic zones, and recommends its use as a supplementary lateral load-resisting system in multi-storey RC construction.

Keywords— Steel bracing, X-bracing, reinforced concrete frame, seismic analysis, storey drift, storey displacement, STAAD.Pro, equivalent static method.

I. INTRODUCTION

Reinforced concrete (RC) multi-storey buildings are widely constructed for their structural efficiency, durability and economic advantages, but they remain highly susceptible to lateral forces induced by earthquakes. These forces can cause excessive storey displacement, inter-storey drift and structural damage, particularly in taller buildings where lateral flexibility accumulates with height. The incorporation of steel bracing systems has emerged as an effective and economical solution for enhancing the seismic performance of RC buildings by increasing lateral stiffness, strength and energy-dissipation capacity.

The effectiveness of a bracing system depends strongly on its configuration and arrangement within the structural frame. Among the commonly used arrangements — diagonal, X-type, V-type and inverted-V — X-type bracing is repeatedly reported in the literature as providing superior stiffness and displacement control because its paired diagonals transfer lateral load principally through axial action rather than bending. However, most published comparative studies examine a single building height or a single seismic zone, leaving open the question of how the benefit of X-bracing changes as seismic demand itself changes.

This paper addresses that gap by evaluating a twenty-storey RC building, with and without peripheral X-type steel bracing, across the full range of Indian seismic zones (II–V) defined in IS 1893 (Part 1):2016. The objective is not to compare bracing types against one another, but to establish, for a single well-defined configuration, how consistently peripheral X-bracing improves structural response as seismic zone increases — information that is directly useful for engineers selecting a bracing strategy for buildings located in different seismic regions.

The remainder of this paper is organised as follows. Section II reviews the relevant literature on steel-braced RC frames and identifies the specific gap addressed here. Section III describes the building geometry, material properties, bracing system, loading and the analysis procedure adopted in STAAD.Pro. Section IV presents the comparative results for six response parameters across the four seismic zones, supported by summary tables and charts. Section V discusses the practical implications of the results for design practice and states the limitations of the study, and Section VI presents the principal conclusions.

II. LITERATURE REVIEW

Recent studies generally support the use of steel-based strengthening systems to improve the lateral response of RC frames, although the magnitude of improvement depends on the specific arrangement adopted. Wang et al. [1] compared several RC-frame strengthening approaches and found that steel jacketing produced substantial stiffness and energy-dissipation gains per unit of added material, while base isolation was more effective at reducing force transmitted to the superstructure. Oyguc et al. [2], using shake-table testing of scaled non-ductile RC frames, showed that an all-steel tube-in-tube buckling-restrained brace system improved energy dissipation and drift control while preserving beam-column joint integrity.

Bracing configuration is a recurring theme because brace geometry governs the force-transfer mechanism and therefore influences stiffness, displacement, drift and ductility. Akbari et al. [3] compared several bracing arrangements and found configuration to have a strong influence on base shear, storey drift and lateral stiffness. Kalibhat et al. [4] compared X-type and inverted-V bracing and found both to improve seismic response, with inverted-V giving marginally lower displacement in their models, whereas Viswanath et al. [5] reported X-bracing as the most effective arrangement for reducing maximum inter-storey drift in a four-storey RC building. Mohammed et al. [6], studying a G+14 building, found X-bracing particularly effective at reducing lateral displacement, column bending moment and shear force.

The literature also shows that bracing performance depends on building height, plan geometry, bracing location and connection detailing, not on configuration alone. Bagade [7] reported that the influence of X-bracing varied with storey level in a high-rise building and that lateral displacement was reduced by roughly 65% relative to the unbraced case. Ghaffarzadeh and Maheri [8], and earlier work by Maheri and Sahebi [9], established experimentally that steel bracing can be connected directly to an RC frame without an intermediate steel sub-frame, supporting the practicality of the bracing arrangement modelled in the present study.

The literature also distinguishes between deformation control and ductility/energy-dissipation objectives. Maheri and Akbari reported greater ductility for knee bracing than for both bare and X-braced RC frames, while Sugano and Fujimura found substantial increases in in-plane strength for X- and K-shaped steel bracing together with favourable post-peak deformation behaviour. This indicates that no single bracing arrangement is universally superior: X-bracing is repeatedly associated with stiffness and displacement control, while other arrangements may offer advantages for ductility, energy dissipation, or architectural planning.

Methodologically, the field has moved from purely comparative linear analysis towards nonlinear, experimental, shake-table and fragility-based approaches. Rad et al. [10] proposed an SLaMA-based procedure for braced RC-frame retrofit design, while Gorji Azandariani et al. [11] used seismic fragility assessment to evaluate collapse-related performance of retrofitted moment frames. Nevertheless, conventional linear comparative analysis — examining displacement, drift, member forces and support reactions under an equivalent static or response-spectrum procedure — continues to provide useful, computationally efficient information on basic structural-response trends, and is the approach adopted in this study.

A further theme concerns the connection between bracing and the RC frame, which governs how effectively lateral force is transferred into the bracing system. Ghaffarzadeh and Maheri [8] demonstrated that directly connected internal X-bracing could strengthen RC frames without an intermediate steel sub-frame, and Maheri and Sahebi [9] established the experimental feasibility of such direct connections. These studies confirm that force transfer between steel and concrete is an important determinant of overall system performance, even though detailed connection design lies outside the present analytical scope.

Collectively, these studies establish that steel bracing — and X-bracing in particular — is an effective supplementary lateral load-resisting mechanism, but a genuine gap remains: a controlled, zone-wise comparison of the same building, with identical geometry and member sizing, evaluated in bare and X-braced form across the full range of seismic zones. The present study addresses this gap directly.

III. METHODOLOGY

1. Building Description and Study Matrix

The building modelled is a G+20 (ground plus twenty storey) RC frame, rectangular and doubly symmetric in plan: 28 m × 40 m overall, laid out as seven bays of 4 m in one direction and ten bays of 4 m in the other, with a typical storey height of 3.5 m. Plan and elevation symmetry was adopted deliberately to remove torsional response, so that differences observed between cases could be attributed to bracing and seismic zone alone. Eight structural cases were analysed, combining two bracing conditions (bare frame and peripheral X-braced frame) with four seismic zones (II, III, IV, V), as summarised in Table I.

Table I. Study matrix of the eight structural cases analysed

Case	Bracing	Zone
1	Bare frame	II
2	X-braced	II
3	Bare frame	III
4	X-braced	III
5	Bare frame	IV
6	X-braced	IV
7	Bare frame	V
8	X-braced	V

2. Material Properties and Member Sizes

M25-grade concrete was used for beams, columns and slabs, and structural steel (250 MPa yield strength) was used for the diagonal bracing members. Beams were sized 250 × 350 mm, columns 350 × 350 mm, and the RCC slab 125 mm thick, held constant over the full building height and across all eight cases so that member sizing did not become an uncontrolled variable alongside bracing and seismic zone.

3. Bracing System

The braced cases use ISA 150 × 150 × 12 mm equal-angle sections, arranged as X-type diagonals within each peripheral bay and run uniformly over the full building height. Confining bracing to the perimeter and arranging it symmetrically keeps the braced-frame plan exactly as regular as the bare-frame plan, so that bracing does not itself introduce geometric irregularity into the comparison.

4. Loading and Seismic Parameters

Dead and live loads were computed per IS 875 (Parts 1 and 2):1987 and applied identically to all eight cases. Seismic loads were generated using the Equivalent Static Method of IS 1893 (Part 1):2016 for Seismic Zones II, III, IV and V, with zone factors of 0.10, 0.16, 0.24 and 0.36 respectively. Only the seismic load varied between the four zone-pairs of cases; gravity loading, geometry and member sizing were held fixed throughout.

5. Modelling Assumptions

All beam and column elements were modelled as prismatic frame elements with cracked-section stiffness modifiers applied per IS 456:2000 recommendations, to reflect the reduced flexural rigidity of concrete members under seismic-level loading. Floor diaphragms were assumed rigid in-plane, so that lateral load at each level was distributed to the vertical elements in proportion to their stiffness. Both plan and mass were symmetric about both principal axes, eliminating torsional coupling and isolating the influence of bracing and seismic zone. Supports were modelled as fixed at the base, and a response reduction factor and damping ratio consistent with IS 1893 (Part 1):2016 were adopted for both the bare and braced configurations, so that any difference in computed response arises from the structural system itself rather than from the reduction and damping assumptions.

6. Load Cases and Combinations

Seismic load was combined with dead and live load following the load combinations of IS 456:2000 and IS 1893 (Part 1):2016, including 1.5(DL+LL), 1.2(DL+LL±EL), 1.5(DL±EL) and 0.9DL±1.5EL, applied in both principal horizontal directions. Every response parameter reported in Section IV is the governing envelope value obtained across this complete set of combinations, rather than the result of a single load case, so that the comparison reflects realistic design-level demand rather than seismic action in isolation.

7. Analysis Procedure

All models were analysed in STAAD.Pro CONNECT Edition using the Direct Stiffness Method under a linear-elastic assumption. The governing response for each parameter was taken as the envelope value across the complete set of load combinations specified above. Storey drift was calculated as the difference in lateral displacement between two vertically adjacent storeys, derived directly from the corresponding storey-displacement results to ensure internal consistency between the displacement and drift profiles reported in Section IV.

IV. RESULTS AND DISCUSSION

This section compares the bare-frame and X-braced-frame configurations across the four seismic zones in terms of maximum bending moment, axial force, shear force, support reaction, overall roof displacement and inter-storey drift. All reported values are governing envelope results from the complete set of load combinations considered in the analysis.

1. Maximum Bending Moment

Table 2. Maximum bending moment across the four seismic zones

Zone	Braced (kN·m)	Bare (kN·m)	Reduction
II	39.85	52.05	23.4%

Zone	Braced (kN·m)	Bare (kN·m)	Reduction
III	51.20	53.10	3.6%
IV	76.90	78.40	1.9%
V	115.10	117.30	1.9%

The braced frame recorded a lower maximum bending moment than the bare frame in every zone, but the benefit fell sharply with increasing seismic zone — from 23.4% in Zone II to about 1.9% in Zones IV and V — indicating that the governing bending-moment envelope becomes progressively less sensitive to bracing as seismic demand rises.

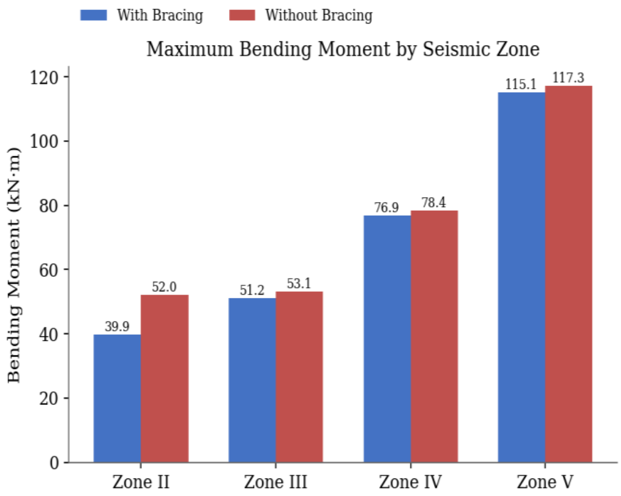

Fig. 1. Maximum bending moment by seismic zone

2. Maximum Axial Force

Table 3. Maximum axial force across the four seismic zones

Zone	Braced (kN)	Bare (kN)	Reduction
II	2995.00	3560.00	15.9%
III	2670.00	3560.00	25.0%
IV	2340.00	3560.00	34.3%
V	2338.00	3560.00	34.3%

Unlike bending moment, the axial-force reduction grew with seismic zone, from 15.9% in Zone II to 34.3% in Zones IV and V.

The bare-frame envelope value remained fixed at 3560.00 kN across all zones, while the braced-frame value fell steadily, reflecting redistribution of internal column forces once bracing provides an alternative load path.

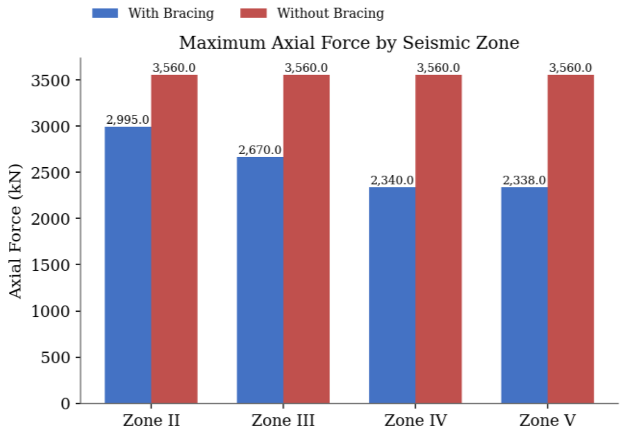

Fig. 2. Maximum axial force by seismic zone

3. Maximum Shear Force

Table 4. Maximum shear force across the four seismic zones

Zone	Braced (kN)	Bare (kN)	Reduction
II	19.55	26.40	25.9%
III	19.70	26.40	25.4%
IV	19.80	26.40	25.0%
V	19.82	26.40	24.9%

Shear force behaved differently from the other force parameters: the bare-frame value remained essentially constant (26.40 kN) across all zones, and the braced-frame value rose only marginally. The percentage reduction was therefore the most stable of all parameters examined, holding within a narrow 24.9–25.9% band regardless of seismic zone.

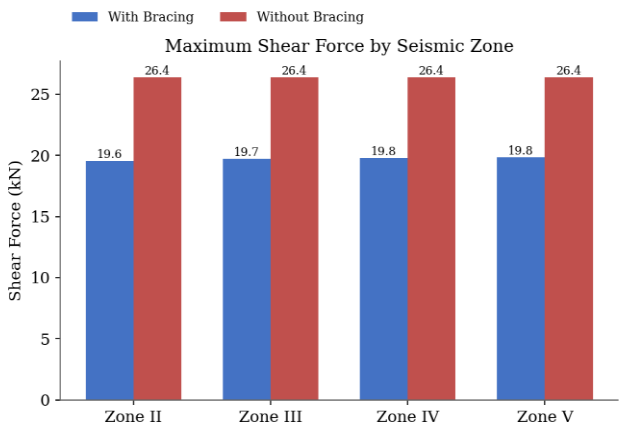

Fig. 3. Maximum shear force by seismic zone

4. Maximum Support Reaction

Table 5. Maximum support reaction across the four seismic zones

Zone	Braced (kN)	Bare (kN)	Reduction
II	2998.00	3560.00	15.8%
III	3010.00	3560.00	15.4%
IV	2342.00	3560.00	34.2%
V	2340.00	3560.00	34.3%

As with axial force, the reduction in maximum individual support reaction jumped from roughly 15% in Zones II–III to roughly 34% in Zones IV–V. Since this is a peak individual-support value rather than a total base reaction, the pattern reflects redistribution among supports rather than a reduction in total vertical load reaching the foundation.

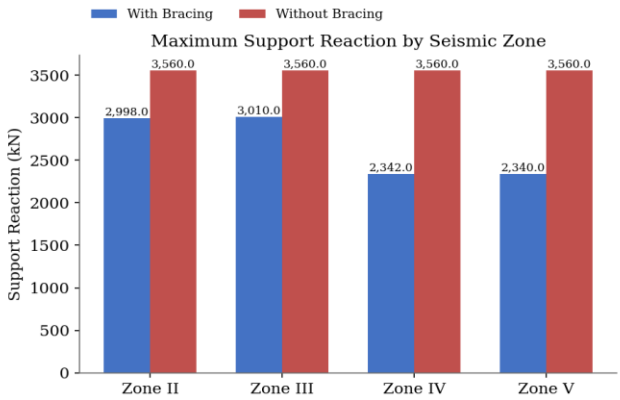

Fig. 4. Maximum support reaction by seismic zone

5. Maximum Overall Displacement

Table 6. Maximum overall (roof) displacement across the four seismic zones

Zone	Braced (mm)	Bare (mm)	Reduction
II	33.10	46.00	28.0%
III	51.50	73.60	30.0%
IV	75.60	110.40	31.5%
V	111.00	165.60	33.0%

Roof displacement showed the clearest and most consistent benefit of bracing: the percentage reduction rose steadily from 28.0% in Zone II to 33.0% in Zone V, while the absolute displacement controlled by bracing grew from 12.90 mm to 54.60 mm over the same range — the practical value of the bracing increases, rather than merely holding steady, as seismic demand rises.

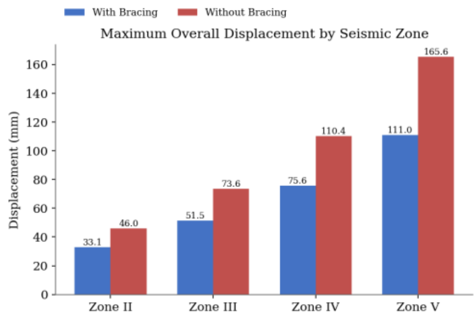

Fig. 5. Maximum overall displacement by seismic zone

6. Storey-Wise Displacement Profiles

This subsection reports the full storey-wise lateral displacement obtained for the bare-frame and braced-frame configurations in each of the four seismic zones. In every zone, displacement is zero at the base and increases progressively with storey height, reaching its maximum at the roof for both configurations.

Table 7. Storey displacement — Seismic Zone II (mm)

Storey	Bare	Braced
20	46.000	33.100
19	44.555	32.062
18	42.858	30.813
17	40.896	29.376
16	38.662	27.766
15	36.168	25.948
14	33.371	23.932
13	30.457	21.824
12	27.413	19.565
11	24.212	17.334
10	21.021	15.079
9	18.041	12.898
8	15.138	10.843
7	12.477	8.910
6	9.992	7.120
5	7.743	5.556
4	5.813	4.172
3	4.139	2.953
2	2.742	1.971
1	1.596	1.144
GF	0.694	0.500
BASE	0.000	0.000

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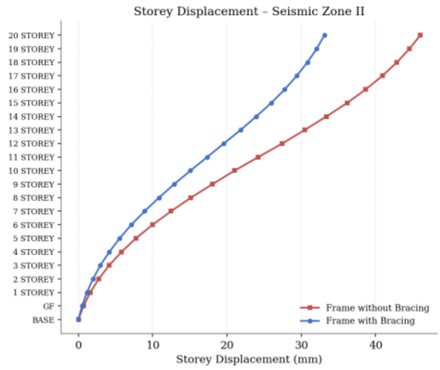

Fig. 6. Storey displacement profile — Seismic Zone II

The maximum roof displacement of 46.00 mm (bare) and 33.10 mm (braced) corresponds to a 28.0% reduction. The braced configuration remains below the bare-frame profile at every storey, with the gap between the two curves widening progressively towards the upper storeys, confirming that the bracing's stiffening effect accumulates with height rather than acting only at the top.

Table 8. Storey displacement — Seismic Zone III (mm)

Storey	Bare	Braced
20	73.600	51.500
19	71.309	49.910
18	68.548	48.019
17	65.381	45.808
16	61.745	43.304
15	57.714	40.440
14	53.230	37.392
13	48.609	34.090
12	43.764	30.655
11	38.852	27.136
10	33.726	23.699
9	28.908	20.265
8	24.198	16.945
7	19.887	13.908
6	15.965	11.093
5	12.462	8.614
4	9.332	6.424
3	6.684	4.546
2	4.420	3.014
1	2.565	1.779
GF	1.138	0.775
BASE	0.000	0.000

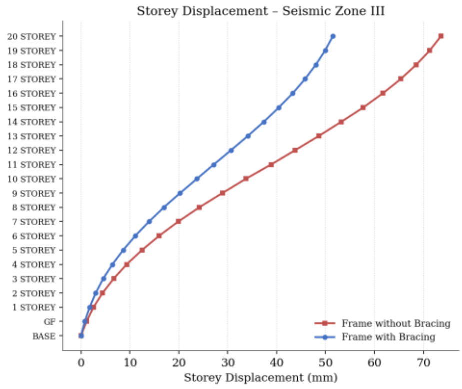

Fig. 7. Storey displacement profile — Seismic Zone III

The roof displacement falls from 73.60 mm (bare) to 51.50 mm (braced), a reduction of 22.10 mm (30.0%). As in Zone II, the braced-frame profile lies below the bare-frame profile at every storey level, and the separation between the two curves increases towards the roof, reflecting the greater cumulative lateral deformation carried by the upper storeys.

Table 9. Storey displacement — Seismic Zone IV (mm)

Storey	Bare	Braced
20	110.400	75.600
19	106.970	73.222
18	102.849	70.389
17	98.029	67.128
16	92.504	63.476
15	86.552	59.363
14	80.031	54.757
13	73.024	49.929
12	65.585	44.809
11	57.942	39.650
10	50.450	34.531
9	43.102	29.609
8	36.119	24.833
7	29.758	20.483
6	23.793	16.345
5	18.452	12.726
4	13.840	9.478
3	9.854	6.743
2	6.506	4.510
1	3.842	2.666
GF	1.664	1.174
BASE	0.000	0.000

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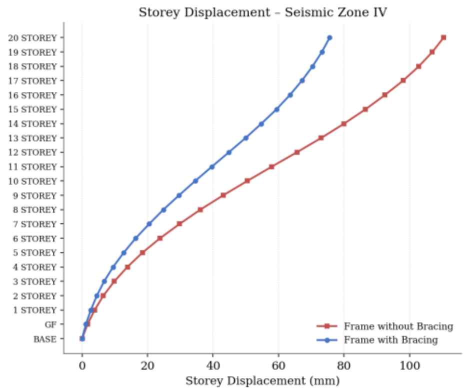

Fig. 8. Storey displacement profile — Seismic Zone IV

The roof displacement is reduced from 110.40 mm to 75.60 mm, a reduction of 34.80 mm (31.5%). The bracing's benefit again grows with storey height, and the overall shape of both profiles mirrors that seen in the lower zones, with the rate of change in displacement between adjacent storeys being greatest in the middle and upper-middle portion of the building.

Table 10. Storey displacement — Seismic Zone V (mm)

Storey	Bare	Braced
20	165.600	111.000
19	160.487	107.501
18	154.292	103.446
17	147.217	98.678
16	139.163	93.278
15	130.131	87.232
14	120.385	80.428
13	109.565	73.326
12	98.617	66.081
11	87.527	58.397
10	76.441	51.031
9	65.206	43.751
8	54.473	36.651
7	44.701	30.039
6	35.894	24.034
5	27.835	18.613
4	20.978	13.931
3	15.078	9.894
2	10.016	6.613
1	5.882	3.879
GF	2.619	1.667
BASE	0.000	0.000

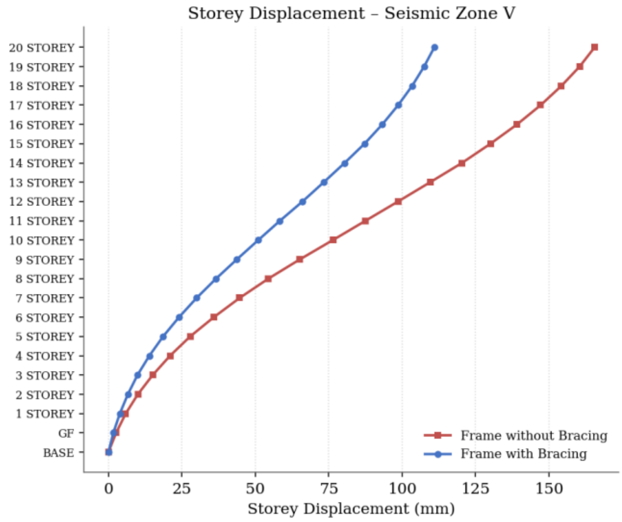

Fig. 9. Storey displacement profile — Seismic Zone V

The roof displacement falls from 165.60 mm to 111.00 mm — a reduction of 54.60 mm, the largest absolute reduction among the four zones, and at 33.0% also the largest percentage reduction. Taken together, Tables VII–X show that the braced configuration outperforms the bare frame at every storey in every zone, not only at the governing roof value, and that the margin of improvement is consistently largest towards the top of the building.

7. Maximum Inter-Storey Drift

Storey drift, defined as the difference in lateral displacement between two vertically adjacent storeys, provides a more direct measure of relative deformation demand than total displacement. Maximum inter-storey drift did not occur at the roof in either configuration in any zone; it consistently peaked in the middle-to-upper-middle storeys (10th–13th storey) before decreasing again towards the top.

Table 11. Maximum inter-storey drift across the four seismic zones

Zone	Braced (cm)	Bare (cm)	Reduction
II	0.2259	0.3201	29.4%
III	0.3519	0.5126	31.3%
IV	0.5159	0.7643	32.5%
V	0.7684	1.1235	31.6%

Inter-storey drift followed the same broadly favourable pattern as roof displacement: the reduction rose from 29.4% in Zone II to a peak of about 32.5% in Zone IV, before easing slightly to 31.6% in Zone V.

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8. Storey-Wise Inter-Storey Drift Profiles

Table 12. Storey-wise inter-storey drift — Seismic Zone II

Storey	Bare	Braced
20	0.1445	0.1038
19	0.1697	0.1249
18	0.1962	0.1437
17	0.2234	0.1610
16	0.2494	0.1818
15	0.2797	0.2016
14	0.2914	0.2108
13	0.3044	0.2259
12	0.3201	0.2231
11	0.3191	0.2255
10	0.2980	0.2181
9	0.2903	0.2055
8	0.2661	0.1933
7	0.2485	0.1790
6	0.2249	0.1564
5	0.1930	0.1384
4	0.1674	0.1219
3	0.1397	0.0982
2	0.1146	0.0827
1	0.0902	0.0644
GF	0.0694	0.0500
BASE	0.0000	0.0000

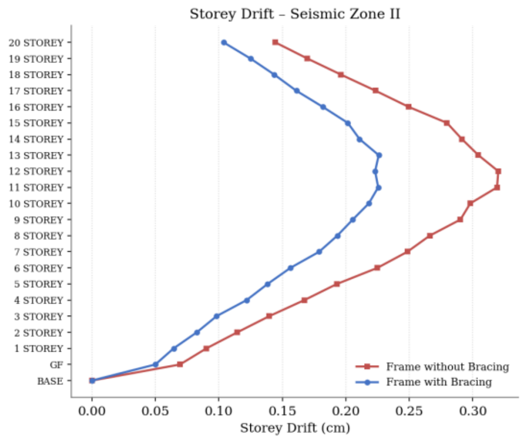

Fig. 10. Storey drift profile — Seismic Zone II

For the bare frame, the maximum drift is 0.3201 cm at the 12th storey; for the braced frame it is 0.2259 cm at the 13th storey — a reduction of about 29.4%. The braced configuration records lower drift than the bare frame at every storey level, and the peak-drift location shifts up one storey once bracing is introduced, indicating a mild redistribution of deformation demand along the height.

Table 13. Storey-wise inter-storey drift — Seismic Zone III (cm)

Storey	Bare	Braced
20	0.2291	0.1590
19	0.2761	0.1891
18	0.3167	0.2211
17	0.3636	0.2504
16	0.4031	0.2864
15	0.4484	0.3048
14	0.4621	0.3302
13	0.4845	0.3435
12	0.4912	0.3519
11	0.5126	0.3437
10	0.4818	0.3434
9	0.4710	0.3320
8	0.4311	0.3037
7	0.3922	0.2815
6	0.3503	0.2479
5	0.3130	0.2190
4	0.2648	0.1878
3	0.2264	0.1532
2	0.1855	0.1235
1	0.1427	0.1004
GF	0.1138	0.0775
BASE	0.0000	0.0000

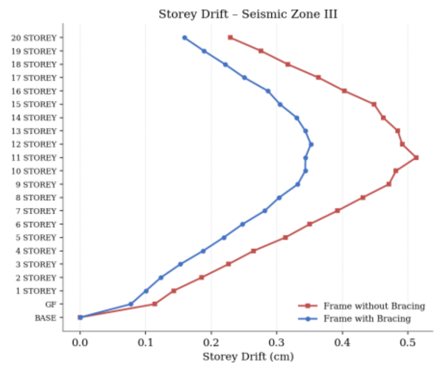

Fig. 11. Storey drift profile — Seismic Zone III

The bare-frame maximum of 0.5126 cm occurs at the 11th storey, while the braced-frame maximum of 0.3519 cm occurs at the 12th storey — a reduction of about 31.3%. The braced configuration remains below the bare frame at every storey, and, as in Zone II, the location of the peak drift shifts upward by one storey once bracing is added.

Table 14. Storey-wise inter-storey drift — Seismic Zone IV (cm)

Storey	Bare	Braced
20	0.3430	0.2378
19	0.4121	0.2833
18	0.4820	0.3261
17	0.5525	0.3652
16	0.5952	0.4113
15	0.6521	0.4606
14	0.7007	0.4828
13	0.7439	0.5120
12	0.7643	0.5159
11	0.7492	0.5119
10	0.7348	0.4922
9	0.6983	0.4776
8	0.6361	0.4350
7	0.5965	0.4138
6	0.5341	0.3619
5	0.4612	0.3248
4	0.3986	0.2735
3	0.3348	0.2233
2	0.2664	0.1844
1	0.2178	0.1492
GF	0.1664	0.1174
BASE	0.0000	0.0000

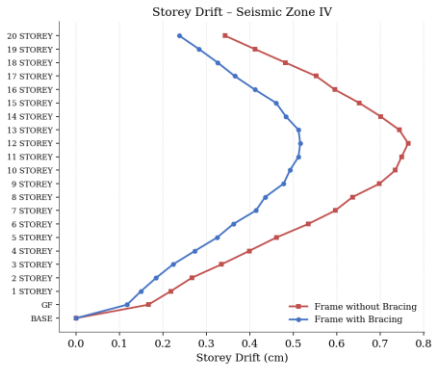

Fig. 12. Storey drift profile — Seismic Zone IV

Both the bare-frame maximum (0.7643 cm) and the braced-frame maximum (0.5159 cm) occur at the 12th storey — a reduction of about 32.5%, the largest percentage reduction among the four zones. Unlike Zones II and III, the peak-drift location does not shift with the addition of bracing in this zone, indicating that the 12th storey is the governing location for deformation demand regardless of configuration at this seismic intensity.

Table 15. Storey-wise inter-storey drift — Seismic Zone V (cm)

Storey	Bare	Braced
20	0.5113	0.3499
19	0.6195	0.4055
18	0.7075	0.4768
17	0.8054	0.5400
16	0.9032	0.6046
15	0.9746	0.6804
14	1.0820	0.7102
13	1.0948	0.7245
12	1.1090	0.7684
11	1.1086	0.7366
10	1.1235	0.7280
9	1.0733	0.7100
8	0.9772	0.6612
7	0.8807	0.6005
6	0.8059	0.5421
5	0.6857	0.4682
4	0.5900	0.4037
3	0.5062	0.3281
2	0.4134	0.2734
1	0.3263	0.2212
GF	0.2619	0.1667
BASE	0.0000	0.0000

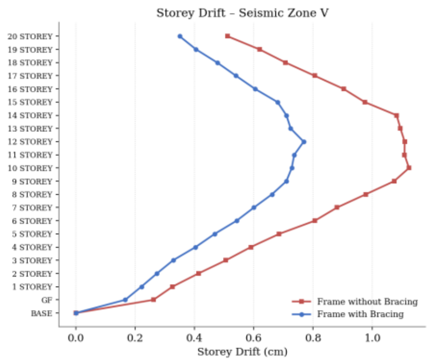

Fig. 13. Storey drift profile — Seismic Zone V

The bare-frame maximum drift is 1.1235 cm at the 10th storey, while the braced-frame maximum is 0.7684 cm at the 12th storey — a reduction of about 31.6%. Together with Tables XII–XIV, this confirms that the braced configuration reduces inter-storey drift at every storey in every zone studied, and that the location of peak drift demand remains within the 10th–13th storey range throughout, rather than shifting toward the roof as seismic intensity increases.

Synthesis of Results

Viewed as a set, the six response parameters divide into three behavioural groups. Deformation parameters (roof displacement, inter-storey drift) show the largest and steadiest percentage benefit from bracing, widening slightly as seismic zone increases. Force-redistribution parameters (axial force, support reaction) show a benefit that starts modest in Zones II–III and roughly doubles in Zones IV–V, consistent with the bracing taking on a larger share of load transfer as lateral demand grows. Frame-internal-force parameters (bending moment, shear force) are markedly less sensitive to bracing: the bending-moment benefit collapses from 23.4% to about 1.9% as zone increases, while the shear-force benefit stays almost flat near 25%, suggesting these envelopes are dominated by a governing load combination not strongly altered by the added bracing.

This grouping is the central engineering conclusion of the results: peripheral X-type bracing is most reliably justified as a deformation-control measure across the full range of seismic zones, and its value for reducing peak internal member forces — bending moment in particular — should not be assumed to scale with seismic demand in the same way.

V. PRACTICAL IMPLICATIONS AND LIMITATIONS

Practical Implications

For practising engineers, the clearest recommendation arising from these results is that peripheral X-type bracing should be evaluated primarily as a deformation-control retrofit or design measure, since its benefit for roof displacement and inter-storey drift is both the largest in magnitude and the most consistent across seismic zones. This is consistent with the drift-control benefits reported for X-bracing by Viswanath et al. [5] and Bagade [7] in shorter buildings, and extends their finding to a taller, twenty-storey structure across the full range of Indian seismic zones. Designers working in higher seismic zones (IV–V) can additionally expect a substantially larger benefit in axial force and support reaction than designers working in lower zones (II–III), which has direct implications for foundation and column design economy. By contrast, the comparatively small and diminishing benefit on bending moment at higher zones means that flexural member sizing should not be assumed to relax proportionally once bracing is introduced.

Limitations

The present findings are subject to several limitations inherent in the adopted scope. First, the analysis is linear-elastic and uses the Equivalent Static Method; nonlinear static (pushover) and nonlinear dynamic (time-history) analysis may reveal different relative performance once inelastic behaviour and higher-mode effects are considered. Second, the building geometry is a single regular, doubly symmetric G+20 configuration; the results may not transfer directly to buildings of different height, plan irregularity, or bay spacing. Third, the study does not model brace-to-frame connection detailing, foundation flexibility, or soil–structure interaction, each of which can influence the force redistribution reported here. Finally, only peripheral X-type bracing is examined; other configurations such as diagonal, V-type and inverted-V bracing, while discussed in the literature review, remain outside the present analytical scope and are natural candidates for future comparative work using the same building and zone matrix.

VI. CONCLUSION

This study evaluated the seismic response of a twenty-storey RC building with and without peripheral X-type steel bracing across Seismic Zones II–V using a linear-elastic equivalent static analysis. Peripheral X-type bracing reduced every response parameter examined — bending moment, axial force, shear force, support reaction, roof displacement and inter-storey drift — relative to the bare frame, in all four zones.

Lateral deformation control was the most consistent and increasing benefit, with roof-displacement reduction rising from 28.0% to 33.0% and inter-storey-drift reduction rising from 29.4% to about 32.5% across Zones II to V. Reductions in axial force and support reaction were strongly zone-dependent, roughly doubling from about 15–16% in Zones II–III to about 34% in Zones IV–V. In contrast, the bending-moment benefit fell from 23.4% in Zone II to about 1.9% in Zones IV–V, while the shear-force benefit remained nearly constant near 25% in all zones. Maximum inter-storey drift consistently peaked in the middle-to-upper-middle storeys rather than at the roof, in both configurations.

Within the linear-elastic, equivalent-static scope of this study, peripheral X-type bracing is most reliably effective as a deformation-control system across all seismic zones; its effect on peak internal forces is beneficial but uneven and should be checked parameter-by-parameter rather than assumed uniform. Future work should extend this comparison to nonlinear static and dynamic analysis, alternative bracing configurations, and foundation- and connection-level design to generalise these findings to a broader class of buildings.

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REFERENCES

1. W. Wang, M. Xie, Z. Xu, J. Liao, M. Abdullah, and M. Zhang, "A comparative experimental study on seismic retrofitting techniques for RC frames: RC jacketing, steel jacketing, and base isolation," Buildings, vol. 15, no. 19, Art. no. 3539, 2025.
2. E. Oyguc, R. Oyguc, A. Hayir, O. Seker, J. Shen, and B. Akbas, "Seismic retrofitting of substandard RC frames using tube-in-tube buckling-restrained braces: Shake table evaluation and field insights," Bulletin of Earthquake Engineering, vol. 23, pp. 4565–4608, 2025.
3. P. Akbari, A. Miya, and P. Agrawal, "Comparative study on seismic performance of RC frame with different types of steel bracing system," in Proc. 17th Symp. Earthquake Engineering, vol. 1, pp. 761–776, 2023.
4. M. S. Kalibhat et al., "Comparative study on seismic performance of RC frame with X-type and inverted-V steel bracing," 2018.
5. K. Viswanath et al., "Seismic response of RC frame with peripheral steel bracing," 2018.
6. S. Mohammed et al., "Seismic performance of G+14 RC building with steel bracing," 2013.
7. A. Bagade, "Seismic analysis of high-rise building with X-bracing," 2015.
8. H. Ghaffarzadeh and M. R. Maheri, "Investigation on the seismic behaviour of internally X-braced RC frames," 2006.
9. M. R. Maheri and A. Sahebi, "Use of steel bracing in reinforced concrete frames," Engineering Structures, vol. 19, no. 12, pp. 1018–1024, 1997.
10. M. Rad, S. Pampanin, and G. W. Rodgers, "SLaMA-based retrofit of RC frame buildings using alternative bracing systems," Journal of Structural Engineering, vol. 150, no. 11, 2024.
11. M. Gorji Azandariani, A. Gorji Azandariani, A. M. Rousta, and H. Malek Nia, "Seismic fragility assessment of reinforced concrete moment frames retrofitted with strongback braced system," Results in Engineering, vol. 20, Art. no. 101504, 2023.
12. Bureau of Indian Standards, IS 1893 (Part 1):2016: Criteria for Earthquake Resistant Design of Structures — Part 1: General Provisions and Buildings, New Delhi, India: BIS, 2016.
13. Bureau of Indian Standards, IS 456:2000: Plain and Reinforced Concrete — Code of Practice, New Delhi, India: BIS, 2000.
14. Bureau of Indian Standards, IS 875 (Parts 1 and 2):1987: Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures, New Delhi, India: BIS, 1987.
15. Bureau of Indian Standards, IS 800:2007: General Construction in Steel — Code of Practice, New Delhi, India: BIS, 2007.