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# Seismic Response Control of a G+20 RC High-Rise Building Using X-Bracing and X-Bracing-Shear Wall Hybrid Systems

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**Abstract:** This paper presents a focused seismic response-control study of a regular G+20 reinforced concrete high-rise building strengthened with X-bracing and an X-bracing-shear wall hybrid system. The work is derived from a broader lateral-system investigation, but is intentionally limited to three configurations - Bare Frame (BF), X-Bracing (XB), and X-Bracing with Shear Wall (XSW) - to examine the structural role of diagonal axial action and wall-based overturning resistance under identical modelling assumptions. A 35 m x 35 m square-plan building with a total height of 74.5 m was modelled in ETABS and analysed by Response Spectrum Analysis as per IS 1893 (Part 1): 2016 for Seismic Zone V, Soil Type II, Z = 0.36, I = 1.5, R = 5 and 5% damping. The response was evaluated using fundamental period, maximum storey displacement, inter-storey drift, storey stiffness and base shear. The BF model showed the most flexible behaviour, with T1 = 2.379 s and average maximum displacement of 54.215 mm. XB reduced T1 to 0.836 s and lowered average displacement by 47.09%, but attracted the largest base shear. XSW further reduced T1 to 0.774 s, limited average displacement to 17.421 mm and reduced average drift by 70.12% relative to BF while producing a lower force demand than XB. The results demonstrate that the XSW system gives a more balanced stiffness-force response for the selected high-rise building.

**Keywords -** X-bracing, shear wall, response spectrum analysis, high-rise RC building, storey drift, seismic stiffness

## I. INTRODUCTION

The seismic design of a high-rise reinforced concrete building is governed by a combination of lateral stiffness, deformation control, strength demand and dynamic stability. In severe seismic regions, a bare moment-resisting frame may be structurally feasible, but its flexural mechanism can allow large roof displacement and inter-storey drift as height increases. These response parameters are important because drift-sensitive damage may appear in beams, columns, infill panels, partitions and service components even when global collapse is not reached.

Reinforced concrete shear walls and steel bracing systems are commonly adopted to improve this behaviour. Shear walls act as vertical cantilever elements and provide strong resistance against global overturning and lateral bending. Steel X-bracing creates a direct diagonal load path, so a major portion of storey shear is transferred by axial tension and compression rather than by beam-column flexure. Earlier numerical studies on RC buildings with wall and bracing systems have also shown reduction in fundamental period, displacement and inter-storey drift when lateral stiffness is increased [1], [5].

However, improved stiffness does not automatically mean an efficient seismic solution. Stiffer lateral systems may attract higher design base shear and may increase member force demand if the strengthening arrangement is not proportioned carefully [5]. For this reason, the present paper does not judge the selected systems only by displacement reduction. It evaluates deformation control and force attraction together so that the response-control benefit of the X-bracing-shear wall hybrid system can be interpreted more clearly.

The paper is developed from a larger thesis-level comparison of lateral load-resisting systems, but the manuscript is intentionally limited to BF, XB and XSW. This focused selection provides a distinct research identity: it evaluates whether adding shear walls to a highly stiff X-braced frame improves the overall stiffness-force balance, rather than simply demonstrating that any strengthened system performs better than a bare frame.

## II. LITERATURE REVIEW

Laissy [1] investigated RC buildings resting on sloped terrain with different bracing and shear wall arrangements using ETABS and response spectrum analysis. The study evaluated shear force, displacement, drift, fundamental period, base shear and storey stiffness, and reported that combined strengthening systems can improve stiffness and seismic stability. Although the terrain condition differs from the present regular square-plan model, the work supports the need to assess bracing and wall systems using several response quantities instead of a single parameter.

Azodi et al. [2] assessed a 30-storey high-rise building with a reinforced concrete core wall and steel moment frame using nonlinear time history analysis. Their results indicated that the RC core wall absorbed a major portion of the base shear over the lower height of the building and helped keep inter-storey drift within allowable limits. This confirms the structural importance of wall-based overturning and shear resistance in tall buildings.

Osman and Farouk [3] studied the use of steel X-bracing combined with shear links for upgrading deficient RC frames. Their findings showed that X-bracing can control lateral drift and distribute inelastic demand more favourably, but the added stiffness also increases the lateral force attracted by the structure. This point is directly relevant to the present comparison because the XB model in this study reduces displacement significantly while attracting the highest base shear among the selected models.

Ji et al. [4] evaluated a high-rise building with novel hybrid coupled walls and compared the performance with conventional RC coupled walls. Their research showed that hybrid wall systems can improve seismic resilience by assigning different response roles to different structural components. The present XSW system is not the same structural form, but it follows the same principle of hybrid action: X-braces control inter-storey shear deformation while shear walls stabilize the global lateral bending mode.

Kontoni and Farghaly [5] examined high-rise buildings strengthened with bracings, shear walls and tuned mass dampers while considering soil-structure interaction. Their study emphasized that stiffness-modifying systems reduce top displacement and fundamental period but may alter base shear and base moment demand. Tajzadah et al. [6] also compared high-rise buildings with bracings, shear walls and combined systems under Zone V response spectrum loading and observed that these systems must be compared through displacement, drift, base shear and overturning response. Beiraghi and Kheyroddin [7] further reported that different concentric steel-brace configurations change the nonlinear response of retrofitted RC frames, showing that brace configuration and response mechanism are important design variables.

The above studies establish that shear walls, X-bracings and hybrid systems are effective for seismic response reduction, but the available literature often treats the strengthened alternatives as separate broad options or evaluates irregular terrain, retrofit cases, or nonlinear wall systems. A focused comparison of BF, XB and XSW under identical geometry, loading, material properties and response spectrum assumptions is therefore useful. The gap addressed in this manuscript is the interpretation of whether the XSW system can provide deformation reduction close to or better than a bracing-only system while avoiding excessive force attraction.

## III. RESEARCH SCOPE AND NOVELTY

The study is limited to a regular square-plan G+20 RC building located in Seismic Zone V. Only linear dynamic Response Spectrum Analysis is used, and all selected models are developed with identical geometry, loading, material properties and seismic parameters in accordance with IS 1893 (Part 1): 2016 [8]. This ensures that differences in response are caused by the lateral load resisting system rather than by changes in mass, height, plan shape or loading assumptions.

The novelty of this focused paper lies in its reduced but sharper scope. The BF model is treated as the deformation-sensitive reference case, the XB model represents a direct axial-load-path strengthening system, and the XSW model represents a hybrid mechanism combining axial bracing action with wall-based overturning resistance. The comparison is therefore not a broad catalogue of alternatives; it is a targeted assessment of the transition from frame action to braced action and then to hybrid braced-wall action.

## IV. NUMERICAL MODELLING

### *A. Building Configuration*

A three-dimensional analytical model of a G+20 reinforced concrete high-rise building was developed in ETABS. The plan dimension is 35 m x 35 m with seven bays in both principal directions and a uniform bay spacing of 5 m. The total height is 74.5 m, consisting of a 4.5 m ground storey and 3.5 m typical storey height. The use of a symmetrical plan reduces the influence of geometric torsion and allows a clearer interpretation of the lateral-system effect.

The structural members were kept identical in all models. Beams were modelled as 1000 mm x 600 mm members, columns as 1200 mm x 1200 mm members, slabs as 150 mm thick, and shear walls as 230 mm thick where present. M50 concrete was used for RC components, Fe500 reinforcement for RCC members and Fe345 steel for bracing members. The general RC design assumptions follow IS 456:2000 [9], ductile detailing requirements are referred to IS 13920:2016 [10], and steel member assumptions are consistent with IS 800:2007 [11].

TABLE I
MODELLING AND SEISMIC PARAMETERS

| Parameter | Value |
|---|---|
| Building type | G+20 RC high-rise building |
| Plan and height | 35 m x 35 m; H = 74.5 m |
| Bay system | 7 x 7 bays; 5 m bay spacing |
| Member sizes | Beam 1000 x 600 mm; column 1200 x 1200 mm; slab 150 mm |
| Wall and bracing | Wall 230 mm; RHS steel brace |
| Materials | M50 concrete; Fe500 rebar; Fe345 steel |
| Seismic input | Zone V; Soil II; Z = 0.36; I = 1.5; R = 5; 5% damping |
| Analysis method | RSA as per IS 1893 (Part 1): 2016 |
| Selected systems | BF, XB and XSW |

### *B. Structural Systems Considered*

The Bare Frame (BF) model contains only the reinforced concrete frame and serves as the baseline system. The X-Bracing (XB) model introduces steel X-bracing on selected frame lines to create direct axial load paths for resisting lateral shear. The X-Bracing with Shear Wall (XSW) model combines X-bracing with reinforced concrete shear walls so that the structure can mobilize both diagonal axial action and wall flexural-shear resistance.

The response parameters extracted from ETABS were the first modal time period, maximum storey displacement, maximum storey drift, average storey stiffness and response spectrum base shear. These parameters were selected because they capture both serviceability and force-demand aspects of seismic behaviour.

## V. RESULTS AND DISCUSSION

### *A. Dynamic Characteristics*

The first modal period of the BF model was 2.379 s, confirming the relatively flexible behaviour of the bare moment-resisting frame. The period reduced to 0.836 s for XB and to 0.774 s for XSW. The reduction indicates that both strengthening systems considerably increased lateral stiffness, but the XSW system provided the highest dynamic stiffness among the selected models.

The important point is that the period reduction in XSW is not caused only by adding more material. It results from the complementary action of bracing and walls. The bracing controls storey shear deformation through axial forces, whereas the walls reduce the global bending component of lateral displacement. This combined mechanism shifts the structure from a flexure-dominated frame response to a more stable braced-wall response.

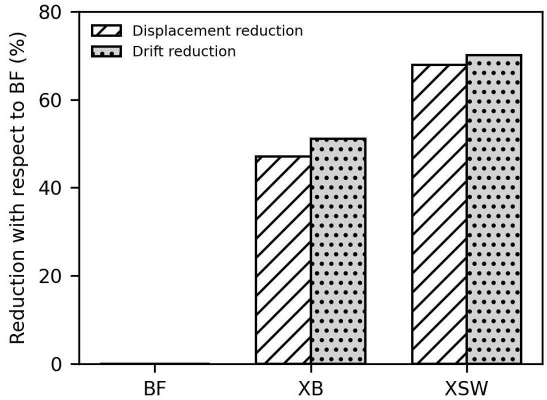


Fig. 1 Displacement and drift reduction of selected systems with respect to BF

### *B. Displacement and Drift Control*

The average maximum displacement of the BF model was 54.215 mm. XB reduced this value to 28.687 mm, corresponding to a 47.09% reduction. The XSW system provided a stronger improvement, limiting the average maximum displacement to 17.421 mm and achieving a 67.87% reduction relative to BF.

A similar trend was observed for storey drift. The average maximum drift of BF was approximately 0.000920. XB reduced it by 51.17%, while XSW reduced it by 70.12%. All selected models remained below the IS 1893 drift limit of 0.004, but the performance hierarchy is still important because lower drift implies lower expected damage to structural and non-structural components during design-level shaking [8].

TABLE II
DYNAMIC AND DEFORMATION RESPONSE OF SELECTED MODELS

| Model | T1 (s) | Disp. (mm) | Drift | Red. (%) |
|---|---|---|---|---|
| BF | 2.379 | 54.215 | 0.000920 | 0.00 / 0.00 |
| XB | 0.836 | 28.687 | 0.000450 | 47.09 / 51.17 |
| XSW | 0.774 | 17.421 | 0.000275 | 67.87 / 70.12 |

### *C. Stiffness-Force Balance*

The stiffness results explain the deformation trend. The average storey stiffness increased from 3.590 x 10^6 kN/m in BF to 31.277 x 10^6 kN/m in XB and 35.626 x 10^6 kN/m in XSW. However, base shear also changed substantially because stiffer systems attract larger seismic force. The average response spectrum base shear increased from 12,898.90 kN in BF to 63,881.17 kN in XB and 44,739.79 kN in XSW.

This is the key design interpretation. XB provides high stiffness, but it also attracts the largest force demand among the selected systems. XSW produces slightly higher stiffness than XB, but its average base shear is lower than that of XB. This indicates a more favourable stiffness-force balance. Structurally, the shear wall participates in resisting overturning and stabilizes the global sway shape, while X-bracing distributes inter-storey shear through axial action. Their interaction reduces deformation without forcing the frame into an excessively force-attracting bracing-only response.

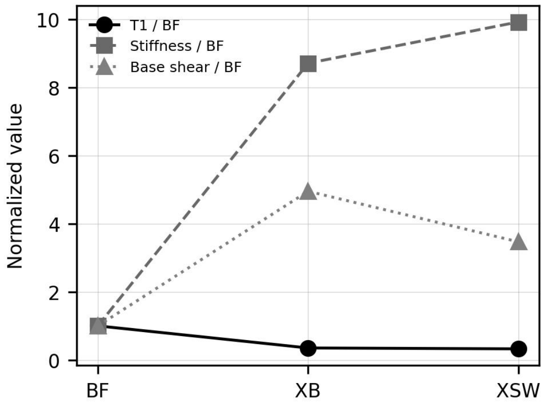


Fig. 2 Normalized period, stiffness and base shear response of BF, XB and XSW

TABLE III
STIFFNESS, BASE SHEAR AND RESPONSE EFFICIENCY

| Model | Stiff. | Base shear | Stiff. inc. | Eff. |
|---|---|---|---|---|
| BF | 3.590 | 12,898.90 | 0.00 | - |
| XB | 31.277 | 63,881.17 | 771.23 | 0.129 |
| XSW | 35.626 | 44,739.79 | 892.35 | 0.284 |

### *D. Response-Control Mechanism*

The superiority of XSW is physically reasonable. In a bare frame, lateral loads are resisted mainly through beam-column bending, and the structure deforms through global sway. In XB, diagonal braces introduce a direct truss-like action, which shortens the lateral load path and reduces storey distortion. However, because the braced frame becomes very stiff, it also attracts high base shear.

In XSW, the shear wall and X-bracing share the response. The wall acts as a continuous vertical element that resists overturning moment and restrains the global bending mode. The X-bracing controls shear deformation between storeys and reduces the demand on beam-column flexure. This separation of structural roles is why XSW simultaneously achieves the lowest drift and a lower base shear than XB. The mechanism is therefore more balanced than simply adding bracing stiffness.

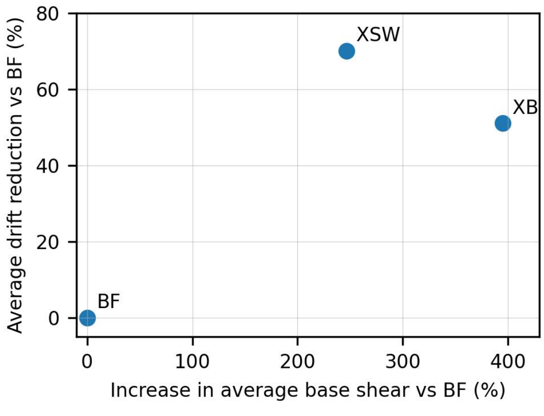


Fig. 3 Drift reduction versus increase in average base shear

## VI. CONCLUSIONS

1) The BF model showed the most flexible response, with T1 = 2.379 s, average maximum displacement of 54.215 mm and average maximum drift of about 0.000920.

2) X-bracing substantially improved the response by reducing T1 to 0.836 s, average displacement by 47.09% and average drift by 51.17% relative to BF.

3) The XSW system gave the most effective response-control performance. It reduced T1 to 0.774 s, limited average displacement to 17.421 mm and reduced average drift by 70.12% compared with BF.

4) Although XB provided major stiffness enhancement, it attracted the largest base shear. XSW produced a better stiffness-force balance by combining wall-based overturning resistance with brace-based shear control.

5) For the selected G+20 RC high-rise building in Zone V, the XSW system is the preferred configuration among the focused models considered in this paper. The conclusion is limited to the adopted geometry, material properties, linear response spectrum method and selected bracing-wall layout.

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## DECLARATIONS

Funding: No external funding was received for this study.

Conflict of interest: The authors declare that there is no conflict of interest.

Data availability: The numerical data are available from the corresponding author on reasonable request. The results were generated from ETABS analytical models prepared for the M.Tech dissertation work.

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