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Analytical Investigation of Buckling Restrained Braces and Steel Plate Shear Walls for G+10 Steel Building in Zone V

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Abstract: This study provides a systematic comparison of Buckling-Restrained Braces (BRB) and Steel Plate Shear Walls (SPSW) for a mid-rise building under seismic loading. The findings offer practical guidance to structural engineers in selecting an appropriate lateral load-resisting system based on performance indicators such as story displacement and natural time period. The results contribute to the design of safer, more economical, and more resilient buildings in high seismic regions by identifying the structural system that provides the most effective seismic performance for the selected building configuration. This study compares Buckling-Restrained Brace (BRB) and Steel Plate Shear Wall (SPSW) systems for a regular G+10 mid-rise steel building in a high seismic zone using an ETABS-based analytical framework. A G+4 steel building with a 29.26 m × 29.26 m plan, three 9.75 m bays in each direction, a 4.572 m storey height, and an 18.28 m total height was first reproduced for validation. The ETABS displacement values differed from the benchmark by 4.64–10.40%, with an average difference of approximately 6.49%, supporting use of the modelling sequence for the comparative models. Under the reported EQX response, the roof displacement decreased from 10.746 mm to 4.681 mm; both reductions were approximately 56.4%.

Keywords: *Buckling-Restrained Brace; Steel Plate Shear Wall; ETABS; Mid-Rise Steel Building; Model Validation; Story Displacement.*

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I. INTRODUCTION

The Buckling-Restrained Brace (BRB) system is a modern structural lateral load-resisting system used in earthquake-resistant buildings. A BRB consists of a steel core that carries tensile and compressive forces, enclosed within a restraining mechanism that prevents buckling under compression. Unlike conventional braces, BRBs can yield in both tension and compression, providing stable and predictable energy dissipation during seismic events. This improves the ductility of the structure, reduces damage, and enhances overall safety. BRB systems are widely used in high-rise buildings, hospitals, bridges, and retrofitting projects because they are efficient, economical, and easy to replace after a major earthquake.

The Steel Plate Shear Wall (SPSW) system is another advanced seismic force-resisting system that uses thin steel plates connected to beams and columns. These steel plates act like a vertical cantilever, resisting lateral loads caused by earthquakes and strong winds. During seismic loading, the plates develop a tension field action, which effectively dissipates energy and increases the building's stiffness and strength. SPSW systems offer high load-carrying capacity, reduced structural weight, and better space utilization compared to reinforced concrete shear walls. They also simplify construction because steel components can be prefabricated and assembled quickly on site.

Both BRB and SPSW systems are highly effective for improving seismic performance. BRBs primarily enhance ductility and energy absorption through yielding braces, while SPSWs provide excellent lateral stiffness and strength using steel plates. Engineers select either system based on building height, architectural requirements, cost, and expected seismic hazards. These systems are increasingly adopted in modern earthquake-resistant design because they improve structural reliability, minimize damage, and help buildings remain functional after severe earthquakes.

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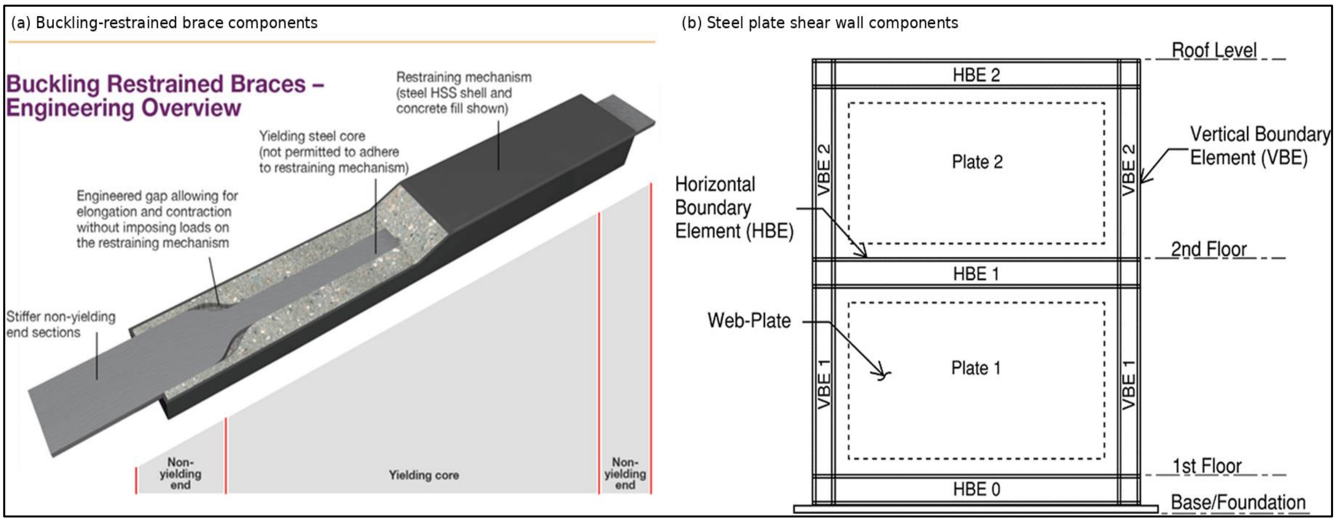

Fig 1 Components of the Buckling Restrained Braces and Steel Plate Shear Wall Systems

The two systems therefore meet different performance objectives. BRBs emphasize ductility, predictable yielding, stable hysteresis, and replaceability, whereas SPSWs emphasize high initial stiffness, global stability, and drift control. SPSWs require careful boundary-frame design and may affect architectural openings; BRBs are more compatible with open framing and retrofit applications. The present work compares the systems under the same G+10 building arrangement after validating the analytical procedure against a G+4 benchmark.

II. LITERATURE REVIEW

The Phase-I literature review identifies a broad development from conventional bracing toward self-centering, rocking, hybrid, and durability-oriented steel seismic systems. Lal et al. [1] compared resilient slip-friction joint and BRB frames and observed comparable peak displacement and base-shear response, while the self-centering arrangement reduced residual drift. Huang et al. [2] reported that controlled rocking in steel shear-wall systems can improve ductility and energy absorption, and Yasa [3] showed that SPSWs can increase stiffness and reduce inter-storey drift in multistorey steel buildings.

Gholami et al. [4] combined an eccentric BRB configuration with a post-tensioned frame to control maximum and residual drift. Talebi et al. [5] found that BRB frames improve load redistribution and progressive-collapse resistance under fire. Jalali and Darvishan [6] evaluated self-centering SPSWs and reported improved plasticity distribution and reduced ductility demand at beam ends. Ayash et al. [7] used BRB outriggers with SPSWs to redistribute overturning effects in tall buildings. Chen et al. [8] combined BRBs and self-centering braces to retain energy dissipation while reducing residual deformation.

Additional studies in the report confirm the versatility of BRBs. Razzaghi [9] reported improved hysteretic response and displacement control compared with conventional bracing in tall buildings. Hussain and Kim [10] emphasized corrosion resistance and long-term durability, Ramadevi [11] summarized the structural-fuse behaviour of BRBs, and Aziz [12] compared steel bracing and shear-wall arrangements using ETABS response parameters. Collectively, these studies support separate advantages for BRBs and SPSWs but also reveal a shortage of direct, nonlinear, same-building comparisons for the mid-rise category.

➢ *Research Gap, Problem Statement and Objectives*

The Phase-I report identifies four principal gaps: most available mid-rise studies concentrate on lower seismic zones; damage-aware comparisons using drift, force demand, ductility, and energy dissipation remain inadequate; direct analytical comparison between BRB and SPSW systems is limited; and studies focused specifically on the mid-rise category are insufficient. Consequently, designers lack a clear basis for selecting between the greater flexibility and stable yielding of BRBs and the higher stiffness and drift control of SPSWs when both systems are assessed under identical structural and seismic assumptions.

The research problem is therefore defined as:

- Mid-rise steel buildings in high seismic zones are prone to excessive lateral displacements and insufficient energy dissipation under strong earthquakes.
- Traditional bracing systems often fail to satisfy performance-based seismic requirements, leading to the use of advanced systems such as Buckling-Restrained Braces (BRBs) and Steel Plate Shear Walls (SPSWs).
- Although both systems improve seismic performance, they exhibit distinctly different behaviours in terms of stiffness, ductility, and energy dissipation.
- However, limited studies provide a direct nonlinear comparison of BRB and SPSW systems under identical seismic conditions for mid-rise buildings. Consequently, clear guidance on the optimal system selection for enhanced seismic resilience remains lacking.

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The specific objectives are:

- Validate the analytical model of a regular multi-story steel building using ETABS and values reported in previous literature.
- Prepare G+10 steel-building models incorporating BRB and SPSW lateral systems, Compare story displacement under the reported high-seismic loading framework.

III. METHODOLOGY

The methodology follows two controlled stages. A G+4 steel building was first reproduced with the same plan geometry, material definitions, section assignments, boundary conditions, and seismic-analysis logic as the selected benchmark. Storey displacement was used as the direct validation parameter. After acceptable agreement was obtained, the procedure was extended to two G+10 models having the same global building arrangement: one with user-defined BRBs and the other with shell-thin SPSW panels. Keeping the common frame geometry unchanged enables the response differences to be attributed primarily to the lateral system.

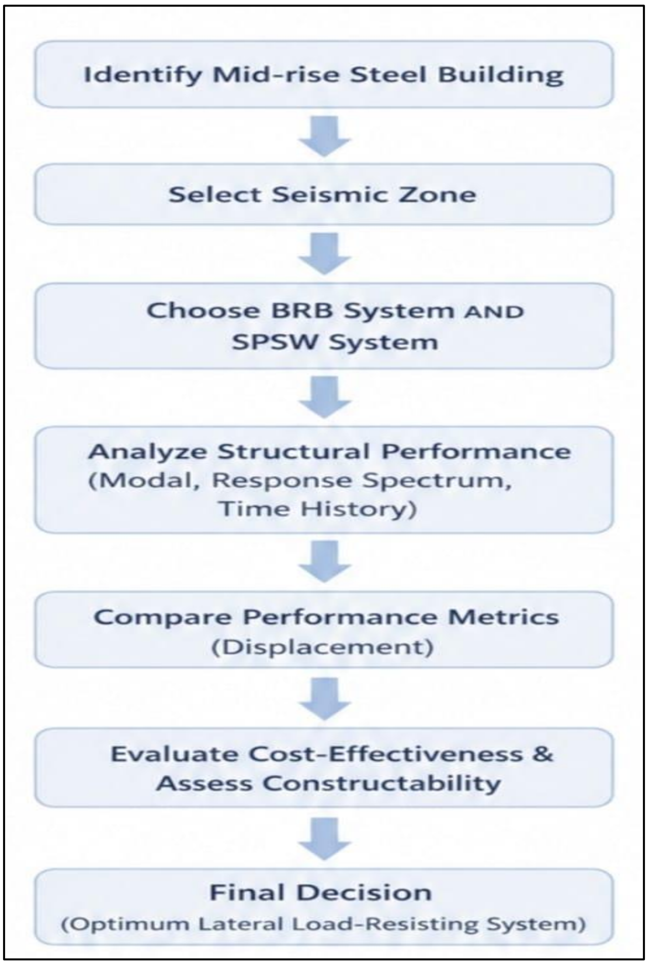

Fig 2 Methodology Flowchart

➢ *Building Geometry and Model Configuration*

Table 1 Geometry and Modelling Parameters of the Validation and Comparative Models

Parameter	Phase-I Value	Metric Value / Modelling Note
Building type	Steel MRF / braced / diagrid benchmark	Same validation plan
Plan size	96 ft × 96 ft	29.26 m × 29.26 m
Bays	3 in X and 3 in Y	Four gridlines in each direction
Bay spacing	32 ft	9.75 m in X and Y
Typical storey height	15 ft	4.572 m
Validation model	4 storeys	Total height 18.28 m
Comparative models	G+10 steel building	BRB and SPSW alternatives
Software	ETABS Ultimate 22.7.0	Three-dimensional analytical models
Common outputs	—	Story Displacement

The validation plan is square and regular, with equal bay dimensions in both principal directions. Regularity reduces the influence of geometric torsion and makes the displacement comparison sensitive mainly to the modelling assumptions. The G+10 alternatives retain a symmetrical layout, uniform floor-to-floor height, rigid floor action, fixed base support, and the same moment-resisting frame arrangement. The BRB and SPSW systems are placed in selected perimeter bays and continued over the building height.

➢ *Material, Section, Slab, and Grid Definition*

The ETABS material database visible in the report contains Fe345 structural steel, M30 concrete, HYSD415 reinforcement, tendon material, and HYSD500 reinforcement. Steel beam, column, and bracing sections are created in the frame-section library, and a slab area property is assigned to the floor system. The repeated 9.75 m grid spacing is verified in plan before analysis. The report does not provide a complete numerical schedule of beam and column sizes; therefore, no unsupported section dimensions are introduced in this paper. Fe250 is used for the displayed BRB yielding core and SPSW panel definitions.

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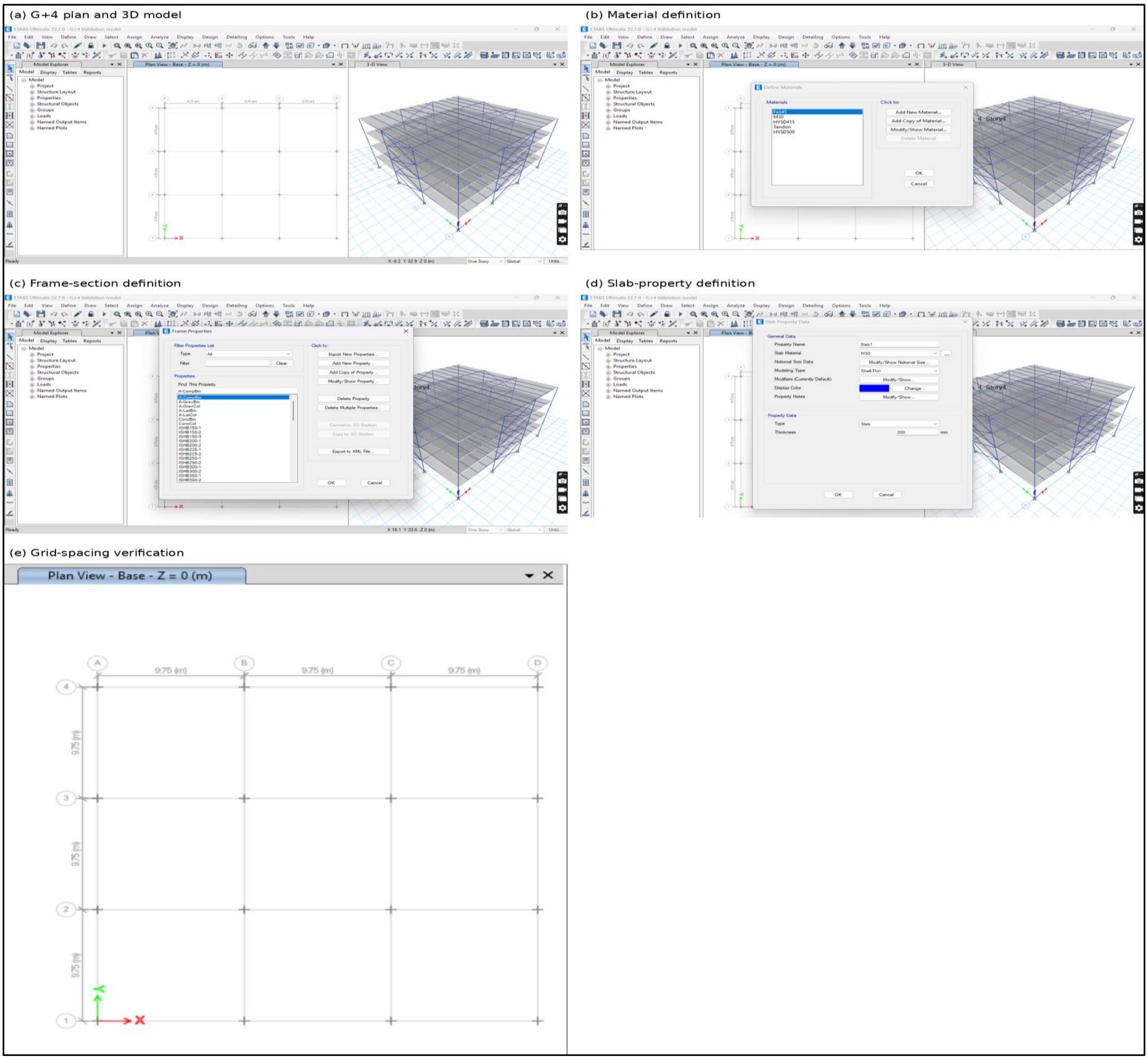

Fig 3 G+4 Validation Geometry, Material, Frame-Section, Slab-Property, and Grid-Definition Inputs.

➢ *Loads, Load Combinations, and Analysis Controls*

Dead load includes structural self-weight, floor finishes, wall loads, and façade components. A typical live load of 3.0 kN/m² is stated for residential or commercial occupancy. Seismic action in the two principal directions is generated by the response-spectrum procedure in accordance with the stated IS 1893:2016 framework, while wind loading is defined according to IS 875 Part 3. The Phase-I report lists the following gravity, seismic, and wind combinations.

Table 2 Load Cases and Combinations Stated in the Phase-I Report

No.	Load Case or Combination
1	DL
2	DL + LL
3	DL + EQX and DL – EQX
4	DL + EQY and DL – EQY
5	DL + WLX and DL – WLX
6	DL + WLY and DL – WLY
7	1.5(DL + LL)
8	1.5(DL + EQX/EQY)
9	1.2(DL + LL + EQX/EQY)

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Beams and columns are represented by frame elements, slabs by area elements with rigid diaphragm action, BRBs by axial link or brace elements with bilinear inelastic behaviour, and SPSWs by shell-thin elements connected to the surrounding boundary frame. The reported comparative storey response is extracted in the EQX direction. Nonlinear pushover analysis is used to obtain yield displacement, ultimate monitored displacement, ductility, base shear–displacement response, target-displacement evidence, and energy components.

$$\text{Percentage difference} = |\text{Reference displacement} - \text{ETABS displacement}| / \text{Reference displacement} \times 100$$

$$\text{Ductility factor, } \mu = d_u / d_y$$

IV. MODEL VALIDATION

The G+4 benchmark was validated using the storey-displacement profile because both reference and ETABS values were available. The ETABS model reproduces the square grid, regular framing, perimeter diagonal members, four elevated storeys, and continuous floor system. Storey coordinates, member connectivity, material and section properties, and support conditions were checked before the response comparison.

Table 3 Storey-Displacement Validation of the G+4 Steel Building

Storey	Reference Displacement (in)	ETABS Displacement (in)	Difference (%)
Story Level 4	0.280	0.267	4.64
Story Level 3	0.220	0.207	5.90
Story Level 2	0.140	0.133	5.00
Story Level 1	0.067	0.058	10.40
Base	0.000	0.000	—

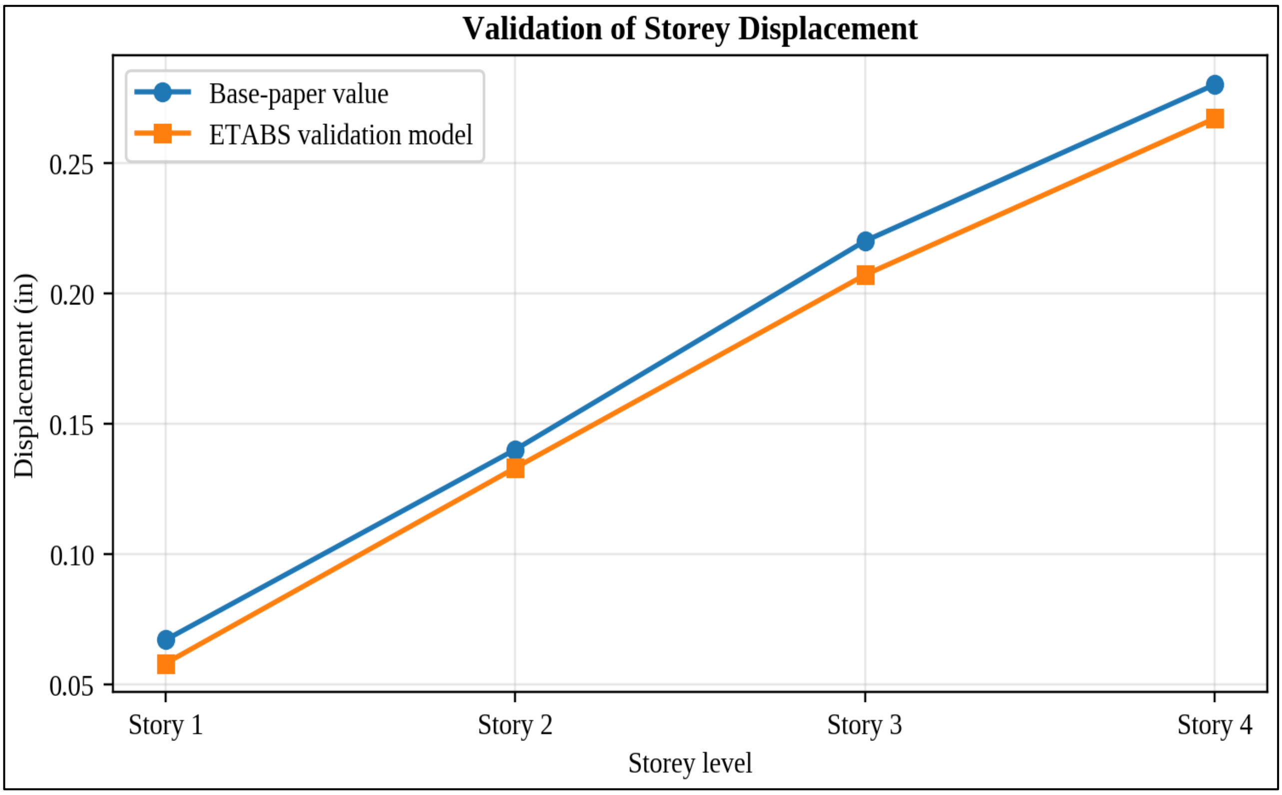

Fig 4 Comparison of ETABS Storey Displacements.

The largest absolute displacement occurs at Story Level 4, where the benchmark value is 0.280 in and the ETABS value is 0.267 in. The percentage differences at Story Levels 4, 3, and 2 are 4.64%, 5.90%, and 5.00%, respectively. Story Level 1 has the largest percentage difference, 10.40%, because the absolute values are small; the actual difference is only 0.009 in. The roof difference is 0.013 in, and the average of the four reported percentage differences is approximately 6.49%. The consistent profile shape and close magnitude support the geometry, connectivity, property assignment, and analysis sequence used for the G+10 models.

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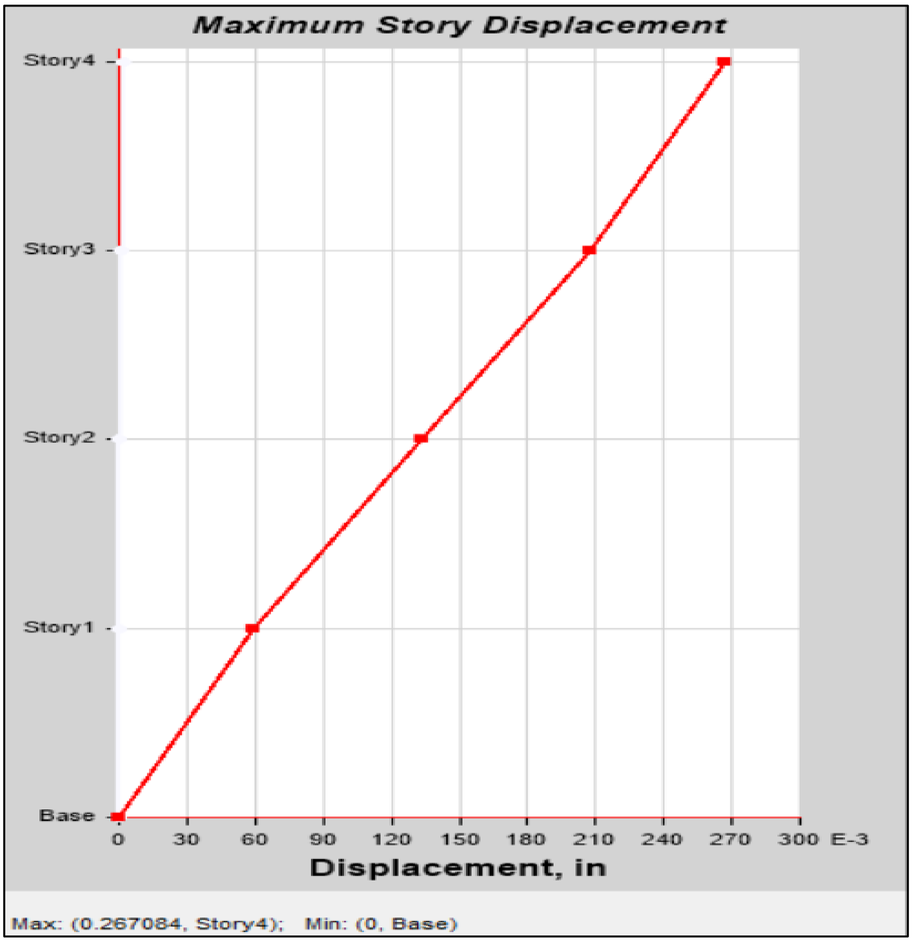

Fig 5 ETABS Story-Wise Displacement Output

V. MODELLING OF THE G+10 BRB AND SPSW SYSTEMS

➢ *ETABS Modelling Procedure*

- Select Grid
- Give Coordinates
- Assign Material Properties
- Assign Section Properties (BRB & SPSW)
- Select Load Cases, Define and Assign Load Cases on Structure
- Define and Assign Time-History Function and Pushover Function
- Assigning Time Step (132 Seconds)
- Perform Analysis

Table 4 Proprty Definitions and Their Values

Property	**Value**
Beam Section	ISLB600
Column Section	ISWB550
Seismic Zone	Zone V
Importance Factor	1.5
Response Reduction Factor	5

➢ *G+10 Buckling-Restrained Brace Model*

The BRB model uses diagonal braces in selected perimeter bays over the full G+10 height. The repeated brace pattern creates an axial-force path for resisting lateral loading. The displayed ETABS property is defined as a Buckling Restrained Brace with a Fe250 yielding core and user-defined geometry. The yielding core is intended to deform in tension and compression while the surrounding restraint prevents global brace buckling.

Table 5 BRB Properties Visible in the Etabs Definition Window

BRB Property	Value
Yielding-core material	Fe250
Total BRB weight	126.1 kN
Overall depth	406 mm
Overall width	304 mm
Yielding-core area	187.1 cm²
Elastic-segment stiffness	407,997.3 kN/m
Yielding-core length	4.2672 m
Elastic-segment length	1.4413 m
Effective linear axial stiffness	282,721.729 kN/m

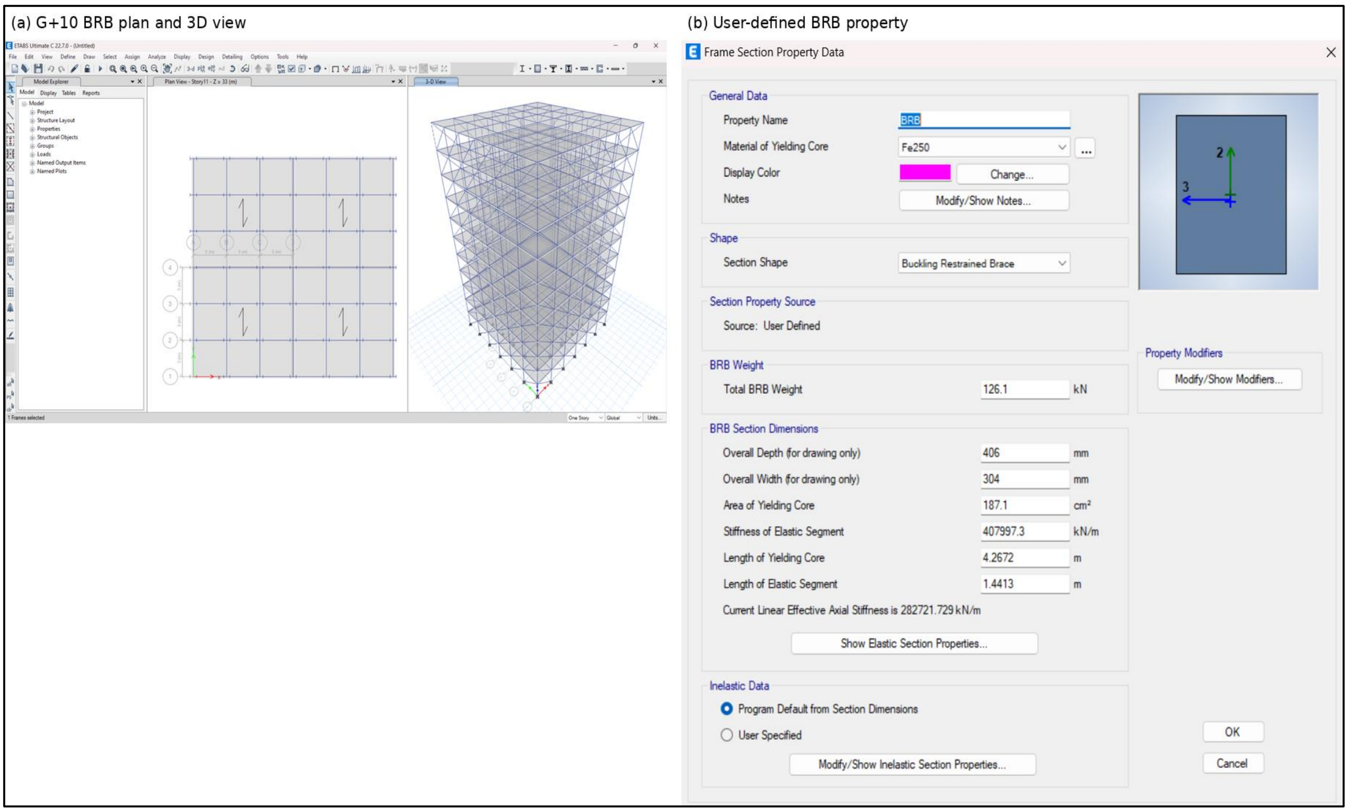

Fig 6 G+10 Buckling Restrained Brace Model and User-Defined Brace Property.

➢ *G+10 Steel Plate Shear Wall Model*

The SPSW alternative places continuous steel wall panels in selected exterior bays in a symmetrical arrangement. The surrounding beams and columns act as horizontal and vertical boundary elements and transfer panel forces to the frame and foundation. The displayed area property is a Fe250 shell-thin element with a 100 mm thickness. Because the Phase-I report does not provide an independent panel slenderness or fabrication design calculation, the value is reported as the analytical input used in the model.

Table 6 SPSW Properties Visible in the ETABS Definition Window

SPSW Property	ETABS Definition
Property name	SPSW
Property type	Specified
Wall material	Fe250
Modelling type	Shell-Thin
Panel thickness	100 mm
Property modifiers	Default, as displayed
Rigid-zone option	Not selected in displayed window

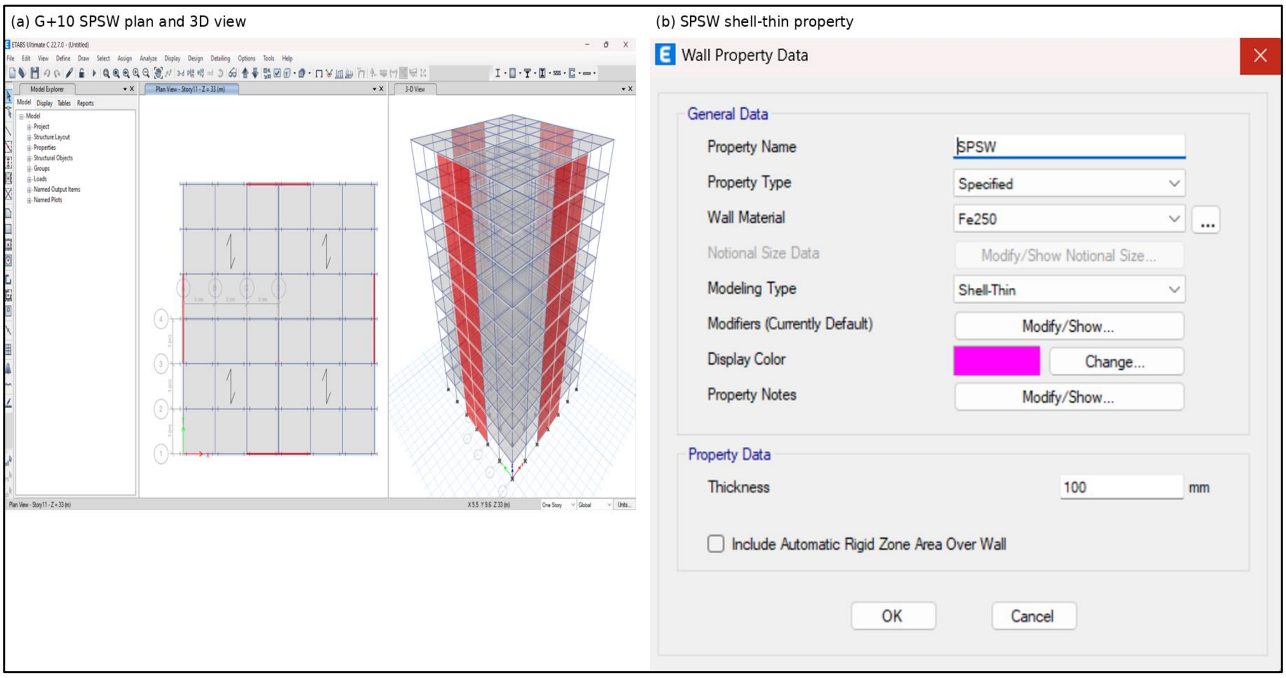

Fig 7 G+10 Steel Plate Shear Wall Model and Shell-Thin Panel Property.

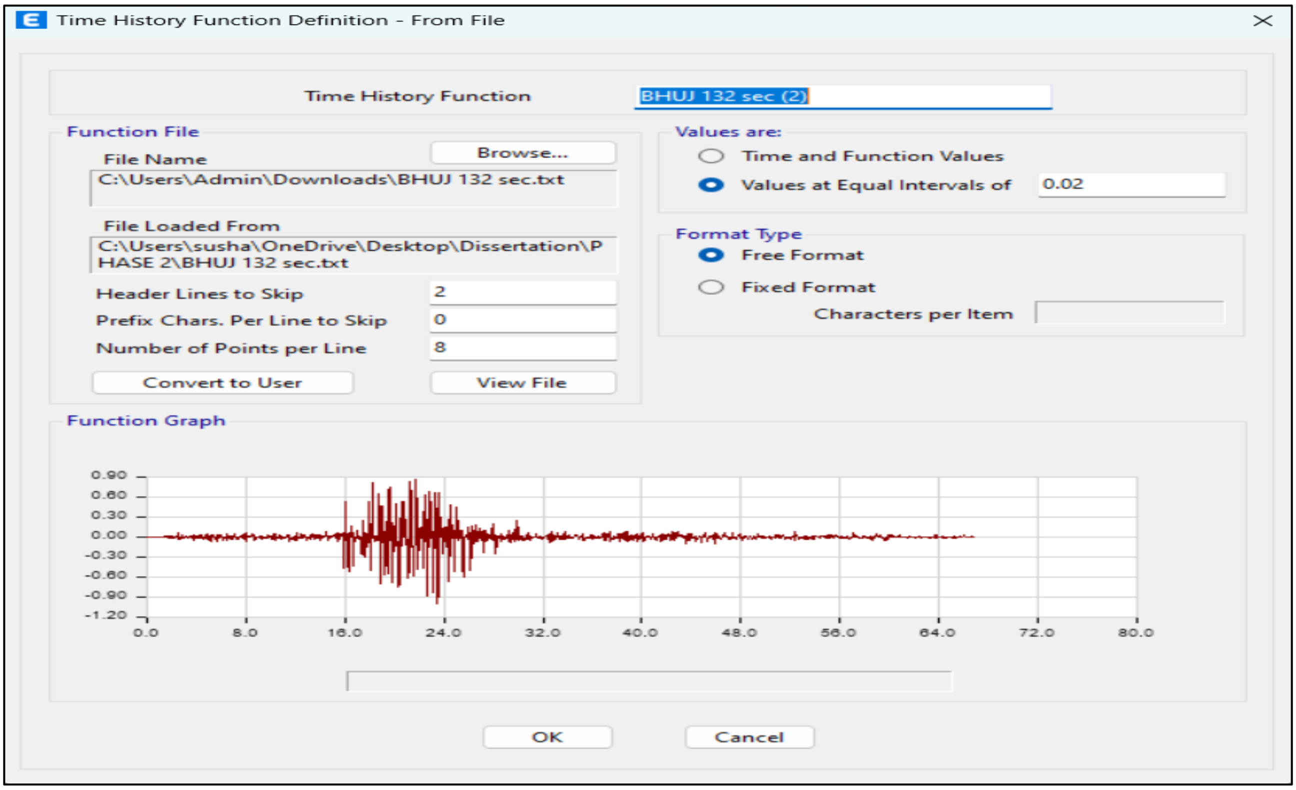

Fig 8 Time History Definition

Table 7 Load Cases and Combinations

No.	Load Case or Combination
1	1.2(DL)
2	1.2(LL)
3	1.2(EQX)
4	EQY
5	Time History
6	PUSHX
7	1.2(DL + LL + EQX)

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VI. RESULT AND DISCUSSION

The numerical results compare the two G+10 models using storey drift, storey displacement, and storey shear in the reported EQX direction. Nonlinear pushover outputs are then used to compare yield displacement, ultimate monitored displacement, ductility, and energy components. The interpretation distinguishes analytical force demand from structural capacity and does not assign one system as universally superior.

➢ *Storey Displacement Response*

Table 8 Storey Displacement Comparison in the EQX Direction

Storey	BRB Displacement (mm)	SPSW Displacement (mm)
S1	0.976	0.126
S2	2.068	0.368
S3	3.216	0.715
S4	4.407	1.138
S5	5.614	1.621
S6	6.803	2.134
S7	7.944	2.665
S8	9.007	3.200
S9	9.959	3.726
S10	10.773	4.238
S11	11.451	4.717

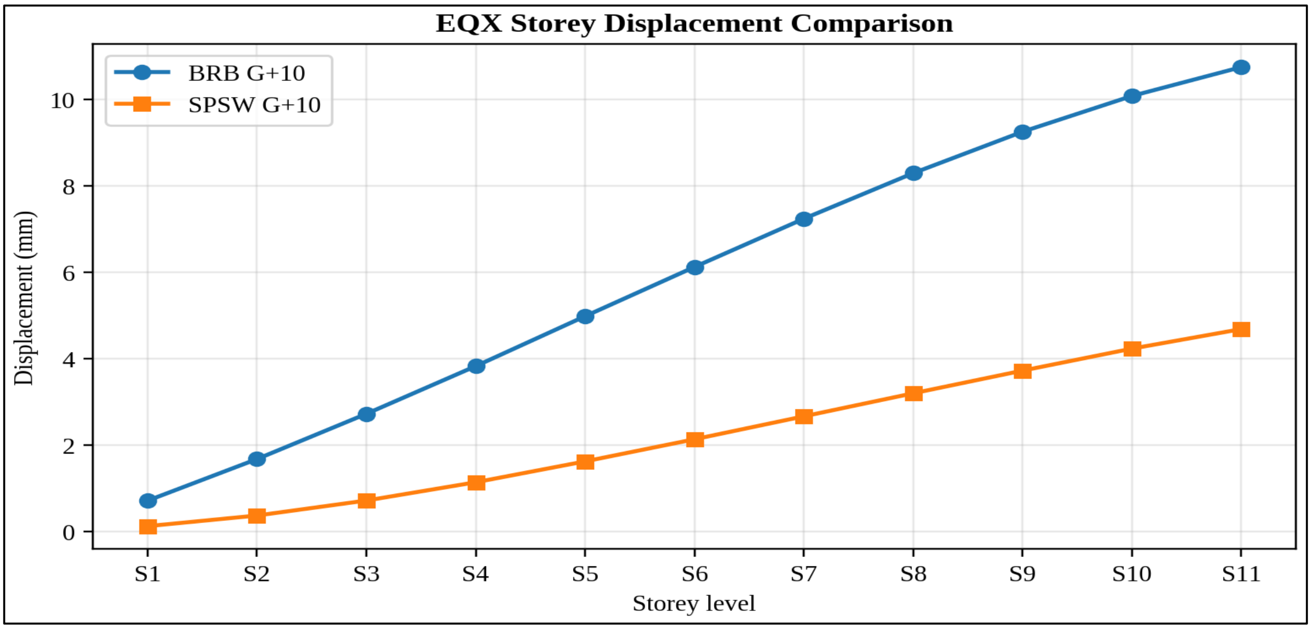

Fig 9 Story Displacement for EQX.

Both displacement profiles increase smoothly toward the roof and show no abrupt concentration in the reported response. The BRB roof displacement is 11.451 mm, while the SPSW roof displacement is 4.717 mm. The SPSW reduction is approximately 58.80%, the same order as the peak-drift reduction. The increasing separation between the profiles with height reflects the greater accumulated flexibility of the BRB frame and the continuous stiffness supplied by the wall panels.

VII. CONCLUSIONS

The G+4 validation model reproduced the benchmark displacement trend with reported differences of 4.64%, 5.90%, 5.00%, and 10.40% from the roof toward the first storey and an average difference of approximately 6.49%. This agreement supports use of the ETABS modelling sequence for the G+10 alternatives. Roof displacement from 10.746 mm to 4.717 mm, corresponding to reductions of approximately 58.80%.

➢ SPSW reduced the reported roof displacement by approximately 58.80%.

LIMITATIONS AND FUTURE SCOPE

The conclusions are limited to the geometry, analytical properties, loading representation, and ETABS outputs documented in the Phase-I report. The source information does not provide a complete beam and column schedule, detailed connection design, panel slenderness verification, numerical seismic coefficients, or an experimental validation programme. Storey shear is therefore interpreted as analytical demand and not as a direct measure of capacity. The reported energy quantities are analysis-dependent and should be compared only within the stated modelling framework.

Future work should perform nonlinear time-history analysis using multiple earthquake records, evaluate residual drift, stiffness degradation, damage concentration, and low-cycle fatigue, and include detailed modelling of BRB connections, yielding-core behaviour, SPSW boundary elements, and panel connections. Experimental or advanced finite-element verification can strengthen the analytical conclusions. Construction cost, repairability, component replacement, maintenance, and architectural flexibility should also be compared. A hybrid BRB–SPSW configuration may combine the wall system's drift control with the brace system's ductility and hysteretic energy dissipation.

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