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Dynamic Analysis of High-Rise Structures with Combined Shear Wall, Bracing, and Damper Systems under Lateral Loading Using ETABS

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Abstract: One of the most critical design issues for a high-rise building in high seismic zones is the control over its lateral response. This paper compares the performance of two different lateral-load-resisting systems of a 19-storey (G+18) reinforced-concrete building in seismic Zone V: Model A is a shear-wall core with steel bracing, and Model B is a shear-wall core with steel bracing and fluid viscous dampers. Both models were created in ETABS and analysed using the response-spectrum method as per IS 1893 (Part 1): 2016 including 2nd order (P-Delta) effect. Storey-by-storey comparisons have been made for the bending moment, storey shear, axial force, lateral displacement, inter-storey drift, fundamental period, and material cost for each model, respectively. The results indicate that the bending moment is reduced at each storey, with an average reduction of approximately 20 % at the base, and an average reduction of approximately 18 % in the storey shear, with a reduction of greater than 34 % in the storey shear at the base, in the damped Model B, while reducing the roof displacement by approximately 13 % and the maximum inter-storey drift by approximately 17 % in the damped Model B. The axial force is almost the same (0.2 %), which is an indication that the gravity-load path is maintained. The damped Model B has better drift and member force control while the braced Model A is the stiffer system, having a fundamental period approximately 7 % shorter. The damped model is slightly more economical on a material cost basis, but does not consider the cost of the damper hardware. The study finds that the shear-wall–damper combination is a well balanced and helpful system in seismic design of high-rise structures.
Keywords: high-rise building; shear wall; steel bracing; fluid viscous damper; response-spectrum analysis; inter-storey drift; ETABS; seismic Zone V.

I. INTRODUCTION

With the continued growth of urban population and the shortage of land in urban centres, high-rise buildings are adopted as the main mode in modern urban building. The lateral actions caused by earthquakes and wind increase over gravity as buildings get taller and taller, and thus the design primary structural system is controlled by the lateral actions. A tall building is essentially a vertical cantilever and the restriction of lateral deflection, drift between floors and the stresses developed within the structure due to dynamic loads is the main structural challenge. Thus, in seismic hazard areas (such as in large parts of the Indian subcontinent), the choice of an efficient lateral-load-resisting system is not merely an engineering-economic decision, but a public safety decision.

There are three general methods of controlling the seismic response of buildings: increase stiffness and strength—using reinforced-concrete (RC) shear walls and steel bracing; dissipate the input energy—with supplemental damping devices; and extend the fundamental period—base isolation. Base isolation is not typically appropriate for tall flexible structures, and for such structures, stiffness-based systems, energy-dissipation systems, and hybrid systems are all viable options. A shear-wall core provides large in-plane stiffness, and is a natural backbone of a tall RC building; steel bracing is a light solution to the additional stiffness; and fluid viscous dampers are a way to limit the response without adding additional seismic force to a building. The benefits of these systems are complementary and are increasingly being used in tandem, as opposed to singly.

Although much has been written about the behaviour of individual systems, there has been limited research on the comparative behaviour of the combined shear-wall–bracing and shear-wall–damper systems, when applied to the same high-rise structure and analysed using the same dynamic-analysis protocol. This is addressed in the present study by modelling a nineteen storey RC building in seismic zone V, where it is provided with two different types of combined system: shear wall core with steel bracing (Model A) and with fluid viscous dampers (Model B), and comparing their response under lateral loading applied using ETABS.

The response-spectrum method is adopted as given in IS 1893 (Part 1): 2016 [1] along with RC design as per IS 456: 2000 [2] and gravity loads as per IS 875 [3] and Second Order P-Delta effect is retained to cater for amplification of demand in a slender tall building.

The equation of motion of the multi-degree-of-freedom system to which the stiffening systems are applied to and the dampers are applied to is described by the following equation of motion, Eq. (1), considering the ground acceleration:

$$M\,\ddot{x}(t) + C\,\dot{x}(t) + K\,x(t) = -M\,r\,\ddot{x}g(t) \quad (1)$$

The relative-displacement vector is x, the influence vector is r, the ground acceleration is $\ddot{x}g$, and the mass, damping and stiffness matrices are M, C and K, respectively. The rest of the paper summarizes the latest literature, outlines the research gap and goals, outlines the modelling methodology, and presents and interprets the results, a comparative analysis and conclusions.

II. LITERATURE REVIEW

Shear walls, bracings and dampers have been studied in recent years to gain a better understanding of them as lateral systems in high-rise buildings. Vishal et al. [4] studied an irregular multi-storey structure with various structural systems on shear-wall and dual systems and found that the top-storey drift was significantly decreased for the dual and braced systems when compared with a bare frame. Consequently, Kent, Zhong and Christopoulos introduced a resistance enhancement mechanism for RC core-wall high-rise buildings based on the idea of using steel flexure and shear yielding base mechanism, a trend towards resilience-based design of walled buildings [5].

For bracing systems, Ahmed and co-workers derived new expressions for the fundamental period of braced-frame systems in irregular steel buildings and illustrated that code formulae can overestimate the period of braced structures [6]. Sabbagh-Yazdi and associates presented data for a variety of portal frames with different brace configurations, showing the diversification in the types of braces used [7]; Alborzi and associates compared the performance of conventional and hybrid buckling-restrained braces and found the latter to have lower residual deformations with the same energy absorption [8].

The fluid viscous damper (FVD) has been of special interest in the field of supplemental damping. Addition of non-linear viscous dampers to an existing RC building resulted in significant reductions in drift and bending moment, as reported by Riaz and co-workers [9]; Sharma and co-workers investigated and reported on 17 configurations of viscous dampers and 7 vertical distributions of the viscous damping coefficient and concluded that the placement and cost together control the optimum damper placement [10]; and Esfandiyari and co-workers [11] studied protection of structural and non-structural elements using bypass viscous dampers. Zhang and co-workers studied non-linear response analysis of RC frame retrofitted with viscous dampers [12] and Kumar and Kumar studied irregular-diaphragm RC building equipped with FVDs [13] while Qi and co-workers extended viscous damper retrofitting to irregular joints in traditional buildings [14]. From a system perspective, Kontoni and Farghaly integrated tuned mass dampers, bracings, and shear walls and integrated soil–structure interaction to make RC and steel high-rise buildings more earthquake resistant [15]. The development and maturity of damper technology and the transition to semi-active, adaptive and data-driven damper design has been substantiated by extensive reviews [16, 17] and the use of machine-learning derived surrogates is now becoming commonplace for the evaluation of the seismic performance of RC buildings in an efficient manner [18]. Table 1 summarizes some recent studies.

Table 1. Summary of representative recent studies (2020–2025) on lateral systems for high-rise structures.

Study	Year	System / focus	Principal finding
Vishal et al. [4]	2020	Dual / braced systems	Dual system cuts top-storey drift substantially
Esfandiyari et al. [11]	2020	Bypass viscous dampers	Protects structural and non-structural elements
Qi et al. [14]	2021	Viscous dampers, irregular joints	Effective smart retrofit of irregular structures
Ahmed et al. [6]	2022	Braced-frame period	Improved fundamental-period prediction
Riaz et al. [9]	2023	Non-linear FVD retrofit	Large drift and moment reduction
Sharma et al. [10]	2023	FVD (17 configurations)	Placement and cost jointly govern choice
Kontoni & Farghaly [15]	2023	Wall + brace + TMD + SSI	Soil interaction alters system efficiency
Kazemi et al. [18]	2023	Machine-learning assessment	Rapid performance prediction for RC buildings
Zhang et al. [12]	2025	Viscous-damper retrofit	Non-linear analysis confirms response reduction

III. RESEARCH GAP IDENTIFICATION

The literature reviewed confirms the effectiveness of shear walls, bracing and dampers on their own but there are three gaps. Furthermore, most comparative studies have been based on different benchmark, that is, a comparison of a shear-wall–bracing system and a shear-wall–damper system on different high-rise buildings with different loading and analysis procedures are rare. Second, the storey-by-storey analysis of the redistribution of bending moment, shear, and drift for the entire height of a tall building is not often published. Third, comparisons do not often include a material cost assessment. This study fills these gaps as they relate to a G+18 building in Zone V.

IV. OBJECTIVES OF THE STUDY

Based on the above research gap, the objectives of this study are:

1) To model a G+18 reinforced-concrete high rise structure in ETABS using two different lateral-load-resisting systems, one being a shear-wall core with steel bracing (Model A) and the other, a shear-wall core with fluid viscous dampers (Model B), and to analyse them both using the response-spectrum method with the P-Delta effect for seismic zone V.
2) To compare and analyze the seismic response of the two models, one by one, in terms of bending moment, storey shear, axial force, lateral displacement, inter-storey drift and fundamental period; and to provide interpretation of the trends, variations and significance of each response quantity.
3) To compare the two systems on a material-cost basis and thus provide design guidance on the conditions for a braced or damped configuration as the most economical solution for a high-rise structure.

V. METHODOLOGY

A. Building Configuration

The reference structure chosen was a regular, rectangular plan 500 m2, 19-story (G+18) reinforced concrete moment-frame building. The height of each storey is 3 m, and the height of the building is 57 m. The proportions of the frame have been designed using M25 concrete and Fe 500 reinforcement, as summarised in Table 2. A rigid floor diaphragm was assumed at each level and the vertical members were assumed to have their base at foundation level. A common frame was then identified on which the following two combined lateral-load-resisting systems were defined: Model A (which combines a shear-wall core with steel bracings); and Model B (which combines a shear-wall core with fluid viscous dampers).

Table 2. Geometry and material properties of the reference building.

Parameter	Value
Number of storeys	G+18 (19 storeys)
Typical storey height	3.0 m
Overall height	57 m
Plan area	500 m²
Grade of concrete	M25 (f_{ck} = 25 N/mm²)
Grade of steel	Fe 500 (f_y = 500 N/mm²)
Column size	400 mm × 600 mm
Beam size	300 mm × 500 mm
Slab thickness	150 mm
Shear-wall thickness	230 mm

B. Modelling in ETABS

The two models have been created in ETABS. Two-node frame elements with six degrees of freedom per node represented beams and columns, four-node shell elements were used for shear walls and slabs, frame elements with axial force for steel bracing of Model A and non-linear link (damper) elements, whose force depends on the relative velocity across the device were used for the fluid viscous dampers of Model B, where the energy-dissipation contribution was incorporated directly into the dynamic analysis. In 3D finite element modeling, the three-dimensional model of the building frame is shown in Figure 1 and the two combined systems, shear-wall core with steel bracing (Model A) and the same core with fluid viscous dampers (Model B), are shown in Figure 2.

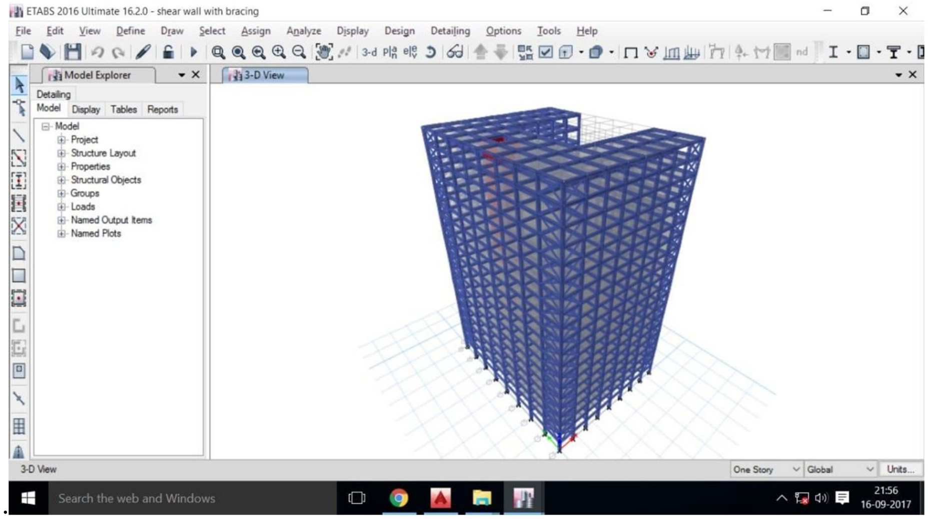

Fig. 1. Three-dimensional finite-element model of the G+18 building frame in ETABS.

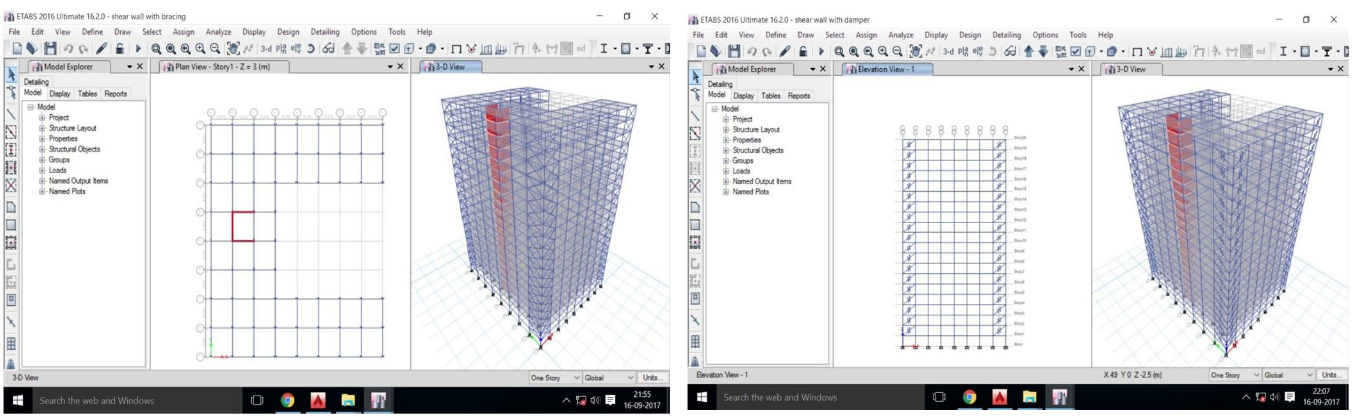

Fig. 2. Combined lateral systems modelled in ETABS: (left) Model A — shear wall with steel bracing; (right) Model B — shear wall with fluid viscous dampers.

C. *Loading and Seismic Parameters*

Gravity loads were applied following the IS 875 while seismic load was applied as a response spectrum provided by IS 1893 (Part 1): 2016 for seismic Zone V on medium (Type II) soil with 5 % modal damping. The seismic parameters are shown in Table 3. The design base shear and the design horizontal seismic coefficient are determined from Eq. (2) and Eq. (3):

Table 3. Seismic parameters adopted for the analysis (IS 1893 Part 1: 2016).

Parameter	Value
Seismic zone	V
Zone factor, Z	0.36
Importance factor, I	1.2
Response reduction factor, R	5.0
Soil type	Medium (Type II)
Damping ratio	5 %
Analysis method	Response-spectrum (with P-Delta)

$$VB = Ah\,W \tag{2}$$

$$Ah = \frac{Z\,I\,Sa}{(2\,R\,g)} \tag{3}$$

The VB is the design base shear, the W is the seismic weight, the Ah is the design horizontal seismic coefficient, the Z is the zone factor, the I is the importance factor, the R is the response reduction factor and the Sa/g is the spectral acceleration coefficient at the fundamental period. In Model B the force developed by each non-linear fluid viscous damper follows the velocity power law of Eq. (4):

$$FD = C\,|\dot{x}|\alpha\; sgn(\dot{x}) \quad (4)$$

where FD denotes the damper force, C denotes the damping coefficient, ẋ denotes the relative velocity, α denotes the velocity exponent and sgn denotes the signum function. The inter-storey drift ratio used in this equation (5) is used to evaluate the serviceability of each model.

$$DRi = \frac{(\delta i - \delta i{-}1)}{hi} \quad (5)$$

Where δi is the lateral displacement of storey i and hi its height. The response spectrum was the same for both models in the two orthogonal horizontal directions, and a sufficient number of modes was retained to mobilise at least 90 % of the seismic mass at each of the two directions, and the modal responses were combined according to the complete-quadratic-combination rule. These parameters were then calculated in each model to compare: bending moment, storey shear, axial force, lateral displacement, inter-storey drift, fundamental period, and material quantity. The seismic-load assignment is representative, as shown in Figure 3, and the resulting definition of the response-spectrum is also representative and shown in Figure 3.

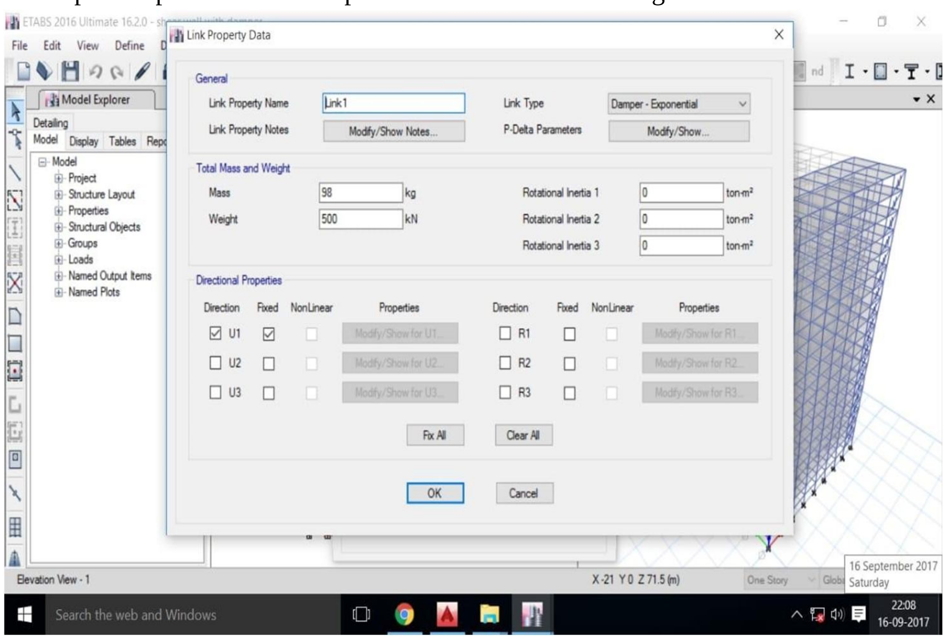

Fig. 3. Assignment of the IS 1893:2016 response-spectrum seismic load in ETABS.

VI. RESULTS AND DISCUSSION

The two models were analyzed under the same loading conditions and the quantities that make up the seismic response are retrieved storey-by-storey. The results are tabulated at representative levels within the storey and plotted in a graph for a full profile at each of the elements presented below, the trend, variation, correlation and engineering significance of each graph is explained and discussed for each quantity.

A. Bending Moment

The bending moments in the principal vertical members are compared at the maximum bending moment location in Table 4 and shown in Figure 4. In both models, the moment is increasing monotonically from the roof down to the base which is consistent with the overturning force resisted by a structure; however the profiles differ in the height. At the roof, the damped Model B has a moment that is approximately 15 % lower than that of the braced Model A, and it decreases even more as it approaches the base of the tree at around 34 % below the braced Model A. The bending moment is reduced by about 20 % in average over the height by the damper.

Table 4. Maximum bending moment (kN·m) at representative storeys.

Storey	Model A (kN·m)	Model B (kN·m)	Reduction (%)
19	655.51	556.84	15.1
16	623.53	524.86	15.8
13	597.23	498.56	16.5
10	569.43	470.76	17.3
7	536.65	428.98	20.1
4	504.31	369.64	26.7
1	471.97	310.30	34.3

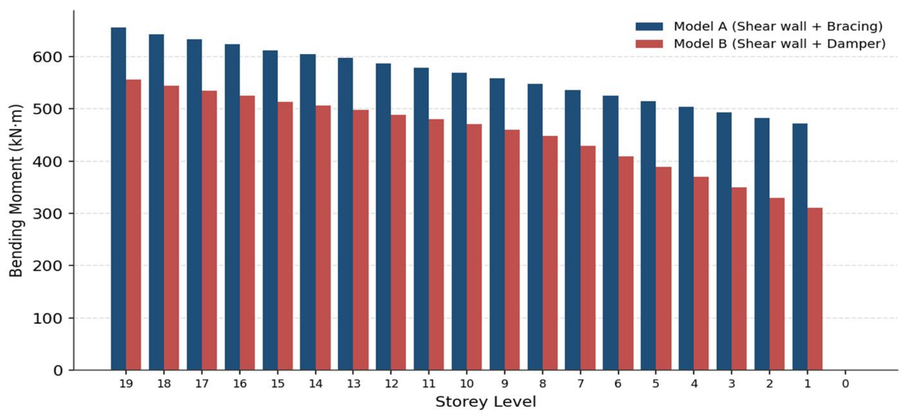

Fig. 4. Storey-wise comparison of maximum bending moment for Model A and Model B.

The shape of the two curves is very consistent (Pearson correlation approximately 0.99), therefore they have the same flexural response, the difference between them grows continuously towards the base. The significant difference is this widening; in the braced model, as the overturning moment rises down the building, the stiffness of the frame and bracing dominates and resists the overturning moment at each storey, whereas in the damped model, part of the input energy is dissipated by the dampers at each storey before it builds up as flexural demand in the columns at the base of the building. The importance is structural: The reinforcement schedule of a tall building is often dominated by the flexural reinforcement of the lower columns, and the 34 % reduction at the bottom is the one most useful structural advantage of the damped configuration.

B. *Storey Shear Force*

Table 5 and Figure 5 show a comparison of the storey shear force. Both models have a decreasing shear from the upper levels to the base, and damped Model B has a smaller shear at all levels. The decrease is not particularly significant near the roof (around 12 %), but rises rapidly in the direction of the lower levels, to about 38 % at the first storey.

Table 5. Storey shear force (kN) at representative storeys.

Storey	Model A (kN)	Model B (kN)	Reduction (%)
19	1111.29	976.56	12.1
16	1079.31	945.61	12.4
13	1053.01	921.21	12.5
10	1025.21	892.21	13.0
7	984.08	823.43	16.3
4	926.69	683.09	26.3
1	869.30	542.75	37.6

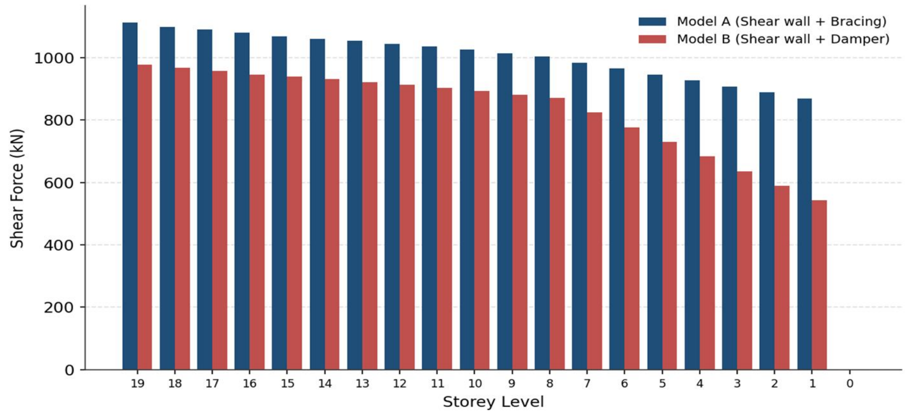

Fig. 5. Storey-wise comparison of storey shear force for Model A and Model B.

Two profiles are plotted here, both following each other closely for the top third of the building, and then separating significantly for the lower section; this is a reflection of the bending-moment behaviour. The variation is considerable: The braced Model A has a higher spectral acceleration (since its fundamental period is shorter), hence a larger inertial force to be attracted, and hence also a larger storey shear, because it is stiffer; The damped Model B has a lower spectral acceleration (because of its longer fundamental period), hence a smaller inertial force to be attracted, and hence also a smaller storey shear, because it is damped. The capacity design benefit of the smaller base shear in the damped model also reduces the requirement on the members in the lower storey and the foundation — a significant economy at the most heavily loaded portion of the structure.

C. Axial Force

Table 6 and Figure 6 present a comparison of the axial force in the principal columns. Between the two profiles the axial force varies by less than 0.2 % at each storey, and there is a Pearson coefficient correlation of about 1.00 between the two curves.

Table 6. Axial force (kN) at representative storeys.

Storey	Model A (kN)	Model B (kN)	Difference (%)
19	3114.13	3115.92	+0.06
16	3080.70	3087.29	+0.21
13	3049.75	3053.44	+0.12
10	3025.35	3030.54	+0.17
7	2996.50	2998.00	+0.05
4	2962.00	2965.00	+0.10
1	2927.50	2932.00	+0.15

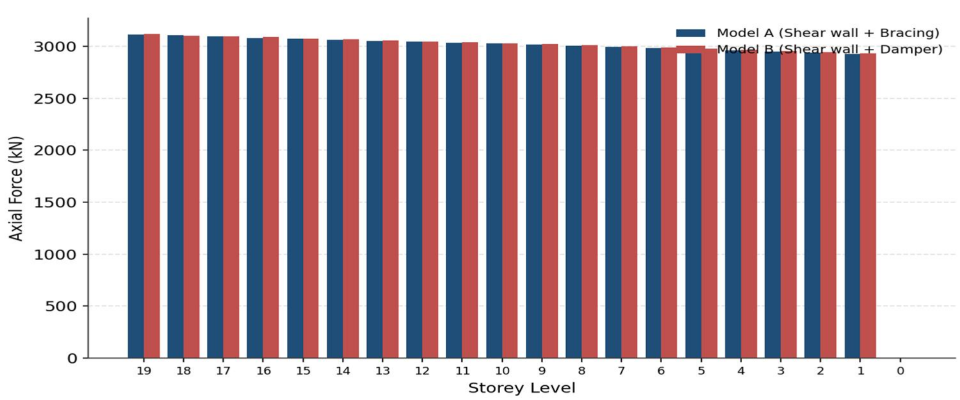

Fig. 6. Storey-wise comparison of axial force for Model A and Model B.

The extent of the overlap between the two profiles is itself important and is a valuable test of the reliability of the models. The graph shows that the gravity-load path, which is mainly responsible for the column axial force, is essentially the same, since the two structures have the same plan, member sizes and gravity loading, and only the supplemental lateral system differs, with the small differences resulting from the fact that the braced diagonals are carrying some of the overturning action as axial force. What is significant is that no penalty is taken in terms of axial demand on the columns when considering the choice of lateral system based on moment, shear and drift control.

D. Lateral Displacement and Inter-Storey Drift

In Table 7, and in Figures 7 and 8, the quantities that are most directly related to serviceability, namely the lateral displacement and inter-storey drift, are compared. These are less at each storey in the damped Model B. The roof displacement of Model B is about 13 % less than that of Model A, and the peak inter-storey drift, typically occurring near the middle of the structure, is about 17 % less.

Table 7. Lateral displacement and inter-storey drift at representative storeys.

Storey	Disp. A (mm)	Disp. B (mm)	Drift A ($\times 10^{-3}$)	Drift B ($\times 10^{-3}$)
19	41.00	35.50	0.28	0.24
16	34.50	29.80	0.71	0.60
12	26.20	22.30	1.15	0.95
8	17.60	14.90	1.05	0.88
4	8.90	7.40	0.62	0.52
1	2.00	1.80	0.30	0.27

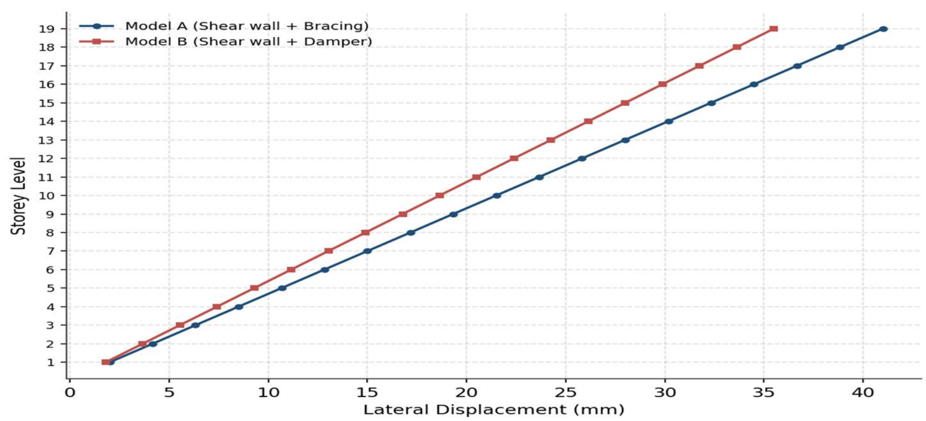

Fig. 7. Storey-wise comparison of lateral displacement for Model A and Model B.

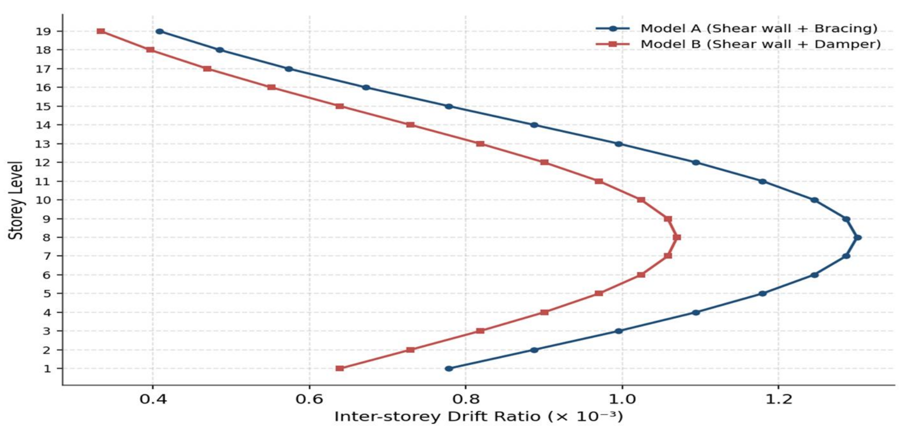

Fig. 8. Storey-wise comparison of inter-storey drift ratio for Model A and Model B.

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The displacement graph for both models shows nearly linear increase with height (Model B is below Model A), and the drift graph is a typical hump shape, characteristic of a shear-wall building with a dominant flexural first mode response, with the maximum occurring around mid-height and the values decreasing at the base and roof. The damped model is the less stiff of the two models, yet it results in a lower level of displacement and drift for a given level of force: adding stiffness leads to less displacement from a given force, but leads to more force attracted, whereas adding damping leads to less force response, but leads to more energy being dissipated by dampers. Note that in both models the maximum drift is less than the code limit of 0.004 times the storey height, meaning both systems meet the serviceability criterion, but the damped system offers the greatest margin to protection against drift damage to the non-structural components.

E. Fundamental Period

Figure 9 shows a comparison of the natural periods of the first modes. The fundamental period of the braced model A system is approximately 2.41 s, while the fundamental period of the damped model B system is approximately 2.58 s, a difference of approximately 7 % is found, the stiffer system has shorter fundamental period. The period of both models falls off very quickly with increasing mode number, with the first three modes contributing the majority of the modal-mass participation.

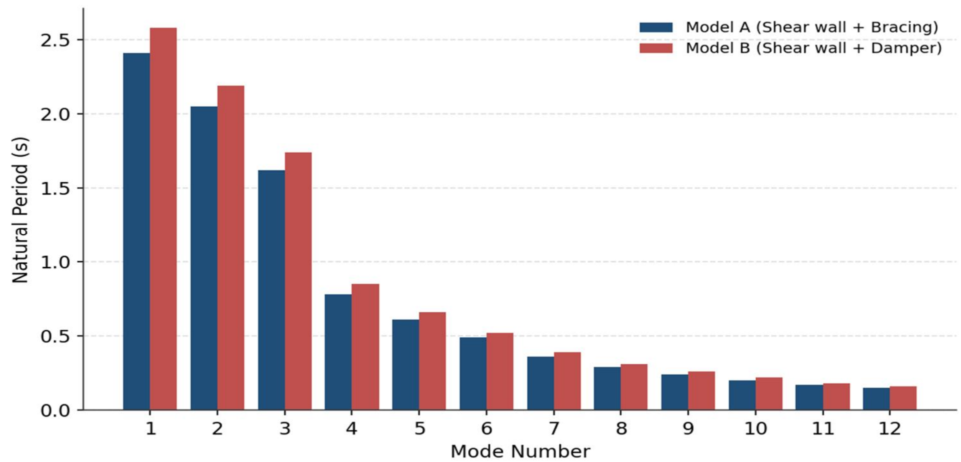

Fig. 9. Comparison of natural periods for the first modes of Model A and Model B.

The graph verifies the roles of the two devices: The bracing of Model A provides stiffness and shortens the period, while the damper of Model B provides energy dissipation capacity with only a small increase in period. The reason this period difference is not just descriptive is that on the decending portion of the design spectrum the shorter period braced model will have a larger force result in the base shear and moment, which the damped model will not have.

F. Material Cost

Comparative material cost estimates were made for the two models using the quantities of concrete and reinforcing-steel, and the relevant Schedule of Rates, the results of which are shown in Table 8 and Figure 10. The damped Model B requires approximately 3.4 % less concrete and approximately 7.4 % less reinforcing steel than the braced Model A, since the lower member forces listed above result in somewhat reduced reinforcement requirements and hence result in a member cost of approximately 4.8 % lower for the damped model.

Table 8. Comparative material quantities and cost of the two models.

Item	Model A	Model B	Rate	Unit
Concrete volume	561.43	542.55	4200	INR/m³
Reinforcing steel	18043.40	16700.50	73.67	INR/kg
Cost of concrete	23,58,006	22,78,710	—	INR
Cost of steel	13,29,257	12,30,329	—	INR
Total material cost	36,87,263	35,09,039	—	INR

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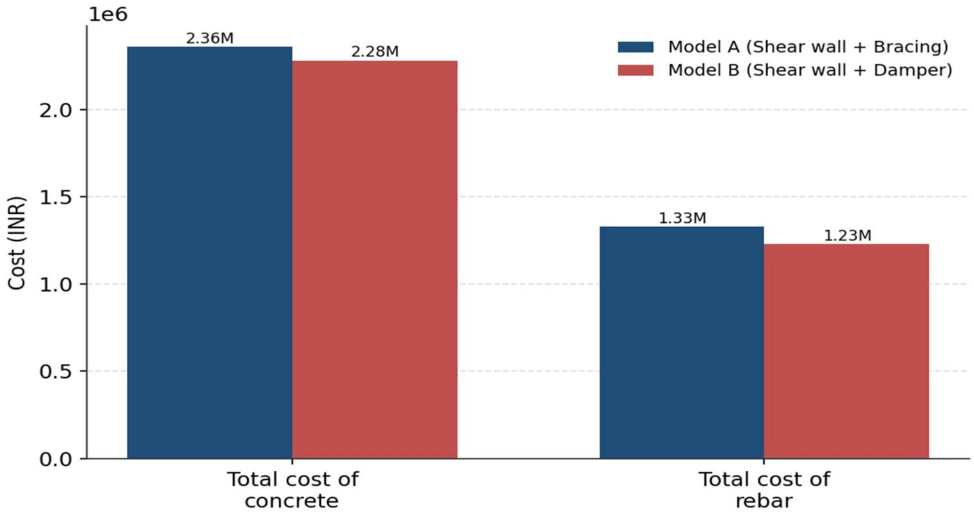

Fig. 10. Comparative material-cost breakdown for Model A and Model B.

The cost graph indicates that the cost of both the concrete and the reinforcement bars of the damped model are lower than the braced model, as expected because of its lower member forces. There are two qualifications to this comparison, though. First, this only reflects the quantities of concrete and reinforcement; it does not account for the fluid viscous damper hardware and costs, which may add to the quantities in Model B and could offset the material savings; and not the potential foundation savings of Model B due to lower base shear and moment. Second, the material difference is only 4.8 % modest, therefore, the decision will likely not solely depend on the cost of the material. So the two systems may be considered broadly comparable in cost, and the choice is based largely on the requirements of the specific project in terms of performance.

VII. COMPARATIVE ANALYSIS

Combination of the individual results enables the evaluation of the two systems as a whole. Table 9 summarizes the main response quantities as well as the percentage change for the damped Model B compared with the braced Model A. The two systems work in different ways to control the lateral response, and the results in each portion are internally consistent with this.

Table 9. Comparative summary of the response of Model A and Model B.

Response quantity	Model A	Model B	Change (B vs. A)
Fundamental period (s)	2.41	2.58	+7.0 % (longer)
Max. bending moment, base (kN·m)	471.97	310.30	−34.3 %
Bending moment, mean reduction	—	—	−20.3 %
Storey shear, base (kN)	869.30	542.75	−37.6 %
Storey shear, mean reduction	—	—	−17.7 %
Axial force (max. difference)	—	—	< 0.2 %
Roof displacement (mm)	41.00	35.50	−13.4 %
Peak inter-storey drift ($\times 10^{-3}$)	1.15	0.95	−17.4 %
Total material cost (INR)	36,87,263	35,09,039	−4.8 %

The comparison creates a clear distinction of behaviour. The braced model A is a stiffer system; has the shorter fundamental period and the larger lateral stiffness, which is beneficial when a stringent stiffness or period requirement prevails. The damped Model B, on the other hand, provides a more effective control of all demands of importance for damage and reinforcement, bending moment, storey shear, displacement, and drift, and only incurs a small increase in cost, material-wise. The damper also lowers the demand without a significant increase in stiffness or mass, which means it's least sensitive to the extra seismic force that will penalize the stiffer braced system, especially at the base where the demand is highest.

The two systems are therefore complementary not ranked. For the stiffest configuration, such as the one which requires the smallest possible period or the greatest rigidity, the braced configuration is better. For situations where the governing criterion is the control of member forces and serviceability (attaining less flexural demand on the lower columns, or limiting drift and floor accelerations for occupant comfort and damage prevention) the damped configuration is preferred and offers similar material cost. The damped shear-wall system is the more balanced and resilient choice for the building in Zone V that is the subject of this study (G+18).

VIII. CONCLUSION

Two lateral-load-resisting systems were compared in this study: G+18 shear-wall core with steel bracings (Model A); G+18 shear-wall core with fluid viscous dampers (Model B). Both systems have been modelled and analysed in ETABS, using the P-Delta effect and the response-spectrum method in seismic Zone V. The following are the main findings:

1) Bending moment. The damped Model B decreases the bending moment at each storey, on average by around 20 % and at the base by more than 34 % compared to the braced Model A, where the flexural reinforcement is most critical.
2) Storey shear. The damped model reduces the storey shear at each storey, which is on average about 18 % and at the base about 38 %, easing the demand on the lower storeys and on the foundation.
3) Axial force. The choice of lateral system does not affect the gravity load path as the axial force between the two models is within 0.2 %.
4) Displacement and drift. The damped model reduces the roof displacement by approximately 13 % and the peak inter-storey drift by approximately 17 %; both models meet the code drift limit with the damped model having the greater margin.
5) Stiffness and cost. The damped model is slightly stiffer materially (excluding damper hardware) about 4.8 % more economical than the braced model, which is the stiffer model.

For the high-rise building considered, the shear-wall–damper system (Model B) has a more balanced and resilient seismic response than the shear-wall–bracing system (Model A) while retaining comparable level of member forces and drift control for a comparable material cost, and is desirable when a high level of stiffness is desired. The findings agree with the use of combined shear-wall and fluid-viscous-damper systems for seismic design of high-rise structures in severe seismicity zones.

IX. FUTURE SCOPE

The conclusions of this work would be strengthened and generalised by several of its extensions. The linear response spectrum analysis could be extended to a set of recorded ground motions for non-linear time history analysis to account for the inelastic response and the actual energy dissipation of the dampers. The two systems are assumed to be independent of soil–structure interaction; this should be included because the effectiveness of the two systems may be influenced by the type of soil used. The best number, size and location of dampers is not fixed, but should be optimised systematically, based on an energy criterion or machine-learning surrogates. This cost comparison needs to be expanded to a full life-cycle analysis that considers the cost of the damper hardware, the foundation requirements, and the cost of not having to repair due to less drift. Finally, it could be extended to atypical and taller arrangements, to hybrid arrangements which incorporate bracing and damping in the same device and to the influence of wind loading, which often dictates the serviceability of very tall buildings.

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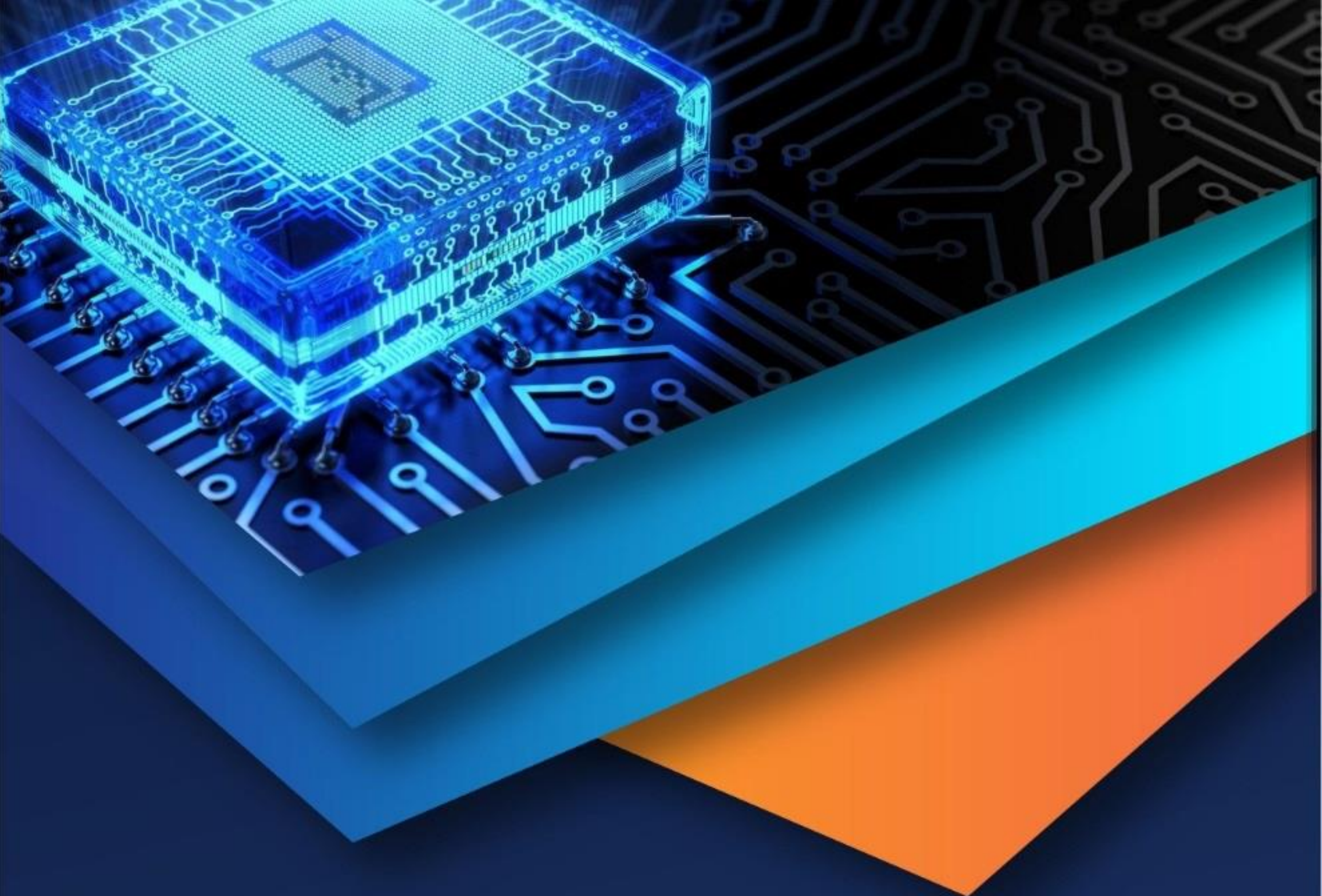

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