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Seismic Performance Evaluation of an Irregular Steel–Concrete Composite Building Incorporating Steel Bracings and Shear Walls

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Abstract

Objectives: Irregular buildings are highly prone to torsional effects and excessive lateral deformations during earthquakes due to the non-uniform distribution of mass and stiffness. Although in Reinforced Cement Concrete (RCC) frame steel bracing systems and shear walls are widely used to enhance seismic performance, comprehensive comparative studies involving multiple bracing configurations and shear walls with identical location and orientation in irregular Steel–Concrete Composite (SCC) buildings remain limited. This study evaluates the effectiveness of different seismic resistance techniques in improving the seismic behaviour of an irregular SCC building. **Method:** A G+15 storey L-shaped SCC building was modelled and analysed in ETABS 22.0. For the same SCC structure five steel bracings Diagonal, Inverted V, V, K and X bracing and Reinforced Concrete (RC) shear walls were incorporated at identical locations. Response Spectrum Analysis (RSA) was performed in accordance with IS 1893(Part 1):2016. Seismic performance was assessed using storey displacement, storey drift, storey stiffness, fundamental time period and torsional irregularity ratio. **Findings:** The integration of seismic resistance techniques significantly improved the seismic performance of the irregular composite building. Among the bracing systems, X-bracing showed the best performance by reducing storey displacement, storey drift and fundamental time period by 56.06%, 60.42% and 37.88%, respectively. Inverted V-bracing provided the highest storey stiffness, whereas K-bracing achieved the lowest torsional irregularity ratio. The shear wall system showed best overall improvement, reducing displacement, drift, fundamental time period and torsional irregularity ratio by 70.29%, 76.52%, 51.63% and 40.87%, respectively, while achieving the highest storey stiffness. **Novelty:** Unlike previous studies focused on RCC and regular buildings or individual strengthening systems, the present study provides a comprehensive comparison of SCC structure with five steel bracing configurations and RC shear walls placed at identical locations under identical modelling, loading and seismic conditions to identify the most effective seismic resistance strategy.

Keywords: Steel-Concrete Composite structure; Plan Irregularity; Steel Bracing; Shear Wall; Response Spectrum Analysis

1 Introduction

The rising demand for urban infrastructure and limited availability of land in largely populated areas have led to adoption of multi-storey buildings with complex architectural setup. But structural irregularities affect the seismic behaviour of structure by causing non-uniform distribution of mass, stiffness and strength throughout the structure. Specifically, L-shaped buildings are highly vulnerable to torsional effects due to the presence of re-entrant corners, which results in extreme lateral deformation and concentration of seismic demands during earthquake hence structure safety, serviceability and financial feasibility is crucial. Irregular buildings show more complicated seismic responses than regular configurations because of increased torsional behaviour and non-uniform force distribution(1). Similar results were reported in(2),(3) in which it is highlighted the vulnerability of irregular structures subjected to lateral loading conditions. SCC construction has seen as a most effective solution as it combines the characteristics of both reinforced concrete and structural steel(4). Composite members provide high strength-to-weight ratios, improved ductility, enhanced energy dissipation capacity and superior construction efficiency compared with conventional structural systems. SCC structures exhibit favourable seismic performance due to their enhanced stiffness and ductile behaviour(5). More recently the studies describe the growing importance of composite construction in seismic regions because of its ability to effectively resist lateral loads while reducing overall structural weight(6),(7).

To improve the seismic resistance, various lateral load-resisting systems have been incorporated into structural frameworks. Steel bracing systems are widely recognized as economical and effective seismic resistance techniques due to their ability to increase lateral stiffness and reduce deformation demands. Different bracing configurations influence structural behaviour differently because of variations in load-transfer mechanisms and stiffness distribution. S. Khattar et al.(8) reported significant reductions in displacement and drift through the incorporation of steel bracing systems in multi-storey structures. Similarly, Kumar. V. C et al.(9) also concluded that proper arrangement and placement of bracing systems can significantly increase the lateral load resisting capacity and overall seismic performance of buildings. Among the different shapes assessed, Diagonal Bracing (DB), Inverted V Bracing (IVB), V Bracing (VB), K Bracing (KB) and X Bracing (XB) are adopted considering their practical feasibility and structural efficiency. RC shear walls are also widely used to enhance the seismic response of the structure and serves significantly to stiffness improvement, displacement control and stability improvement. Thes addition of shear walls effectively reduces lateral displacement and storey drift in multi-storey structures(10). Parallel results were reported in(11), which also determined that strategically placed shear walls can successfully mitigate seismic response in irregular buildings. S. A. Ahmed et al.(12) also demonstrated that shear wall systems improve global structural performance by reducing torsional effects and enhancing overall lateral rigidity.

L-shaped building possesses various types of problems under seismic loading, major problems are linked with opening and closing mode which leads to high-frequency oscillatory mode due to slender projection of the structure. It creates stress concentration at corners which leads to structural damage of the structure. Other problem is torsional effect created in L-shaped buildings(13). Many researchers observed the seismic effects in RCC irregular structures with seismic resisting techniques, A. R. Simon et al.(10) studied effect of shear walls at different locations in regular RCC structure. Bohra et al.(13) studied on RCC irregular structure with Inverted V bracings at different locations using ETABS software. Manish. H et al.(4) studied composite structure with base isolation system, but it is limited to regular structure and also it was not focused on stiffness strengthening techniques. Although research has been conducted on irregular buildings, composite structures, steel bracing systems and shear walls individually, several research gaps remain. There are lakh of research works on SCC structure with seismic resistance techniques, especially comprehensive comparative investigations involving multiple bracing configurations and shear walls in irregular SCC structure under identical modelling and loading conditions remain as a major research gap. The influence of different seismic resistance techniques on displacement, drift, stiffness, dynamic characteristics and torsional behaviour of irregular composite buildings therefore remains insufficiently understood. In particular, the comparative effectiveness of DB, IVB, VB, KB, XB and shear wall systems in controlling the seismic response of L-shaped composite buildings requires further investigation.

To address this research gap, the present study investigates the seismic performance of a fifteen-storey L-shaped irregular steel–concrete composite building strengthened using five commonly adopted steel bracing configurations, namely Diagonal Bracing (DB), Inverted V Bracing (IVB), V Bracing (VB), K Bracing (KB), and X Bracing (XB), together with Reinforced Concrete Shear Walls (SW). All strengthening systems are incorporated at identical locations while maintaining the same structural geometry, material properties, loading conditions, boundary conditions, and seismic analysis procedure. This approach enables a fair and unbiased comparison of the effectiveness of each strengthening technique by eliminating the influence of location-dependent stiffness variations. Response Spectrum Analysis (RSA) is performed using ETABS 22.0 in accordance with IS 1893 (Part 1): 2016, and the seismic performance of all structural models is evaluated in terms of storey displacement, storey drift, storey stiffness, fundamental time period, and torsional irregularity ratio. The findings of this study provide practical guidance for selecting suitable seismic strengthening techniques for irregular steel–concrete composite buildings located in high seismic regions.

2 Methodology

The SCC structure which is BCF is accurately modelled in the ETABS. The composite sectional members are defined and assigned to the G+15 L-shaped building and the details of geometry, loading and material property are described in section 2.1. Then steel bracings and RC shear walls are strategically placed in the BCF for analysis and systematic comparison of seismic performance. This research adopts a systematic approach of modelling and analysis of five steel bracing and shear wall systems strategically placing in BCF at same locations and loading conditions, making it unique approach.

2.1 Modelling of Composite Structure

A fifteen-storey irregular SCC building having an L-shaped plan configuration is modelled using ETABS software. The building consists of three bays in each wing with a uniform bay spacing of 5 m in both principal directions. Each wing has a length of 35 m, while a typical storey height of 3 m was adopted throughout the structure. Composite columns were modelled using a (450 mm × 450 mm) reinforced concrete section encasing an ISMB 250 steel section and composite beams of a (300 mm × 450 mm) reinforced concrete section with ISMB 225 steel section. A slab thickness of 150 mm was considered for all floors. The material properties include M30 grade concrete, Fe 550 grade reinforcement steel. The loads considered includes live load of 3 kN/m^2 and a floor finish load of 2.3 kN/m^2 for all typical floors. On the terrace level, a live load of 2 kN/m^2 and a floor finish load of 1.5 kN/m^2 were applied. Wall loads were calculated considering a wall thickness of 200 mm which is 12.2 kN/m^2. The structure was assumed to be located in Seismic Zone V with a zone factor of 0.36, medium soil conditions conforming to Soil Type II were considered. An importance factor of 1.0 and a response reduction factor of 5 were adopted. For dynamic analysis RSA was performed in accordance with IS 1893 (Part 1): 2016 using ETABS software to evaluate the dynamic seismic behaviour of the investigated structural models. RSA was selected because it provides a reliable representation of the dynamic response of multi-storey irregular structures subjected to earthquake excitation while accounting for the contribution of multiple vibration modes. Methodology for SCC and Bracing is developed in accordance with the procedure reported in [4], [13]. Plan and 3D model of BCF is shown in [Figure 1].

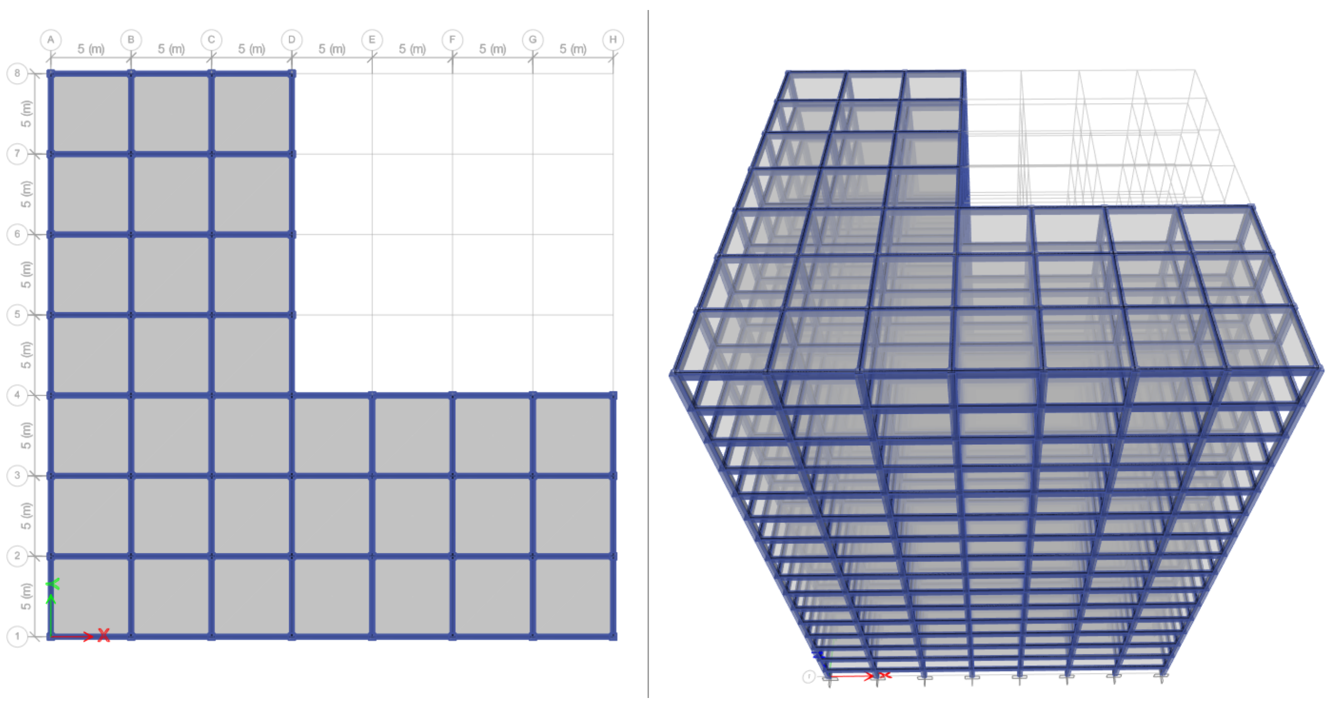

Fig 1. Plan and 3D Model of the Irregular Composite Building

A total of 12 modes were considered in the analysis. The number of modes was selected such that the cumulative modal mass participation exceeded 90% in both principal directions, satisfying the requirements of IS 1893 (Part 1): 2016 for dynamic analysis of irregular buildings. Modal responses were combined using the Complete Quadratic Combination (CQC) method, while directional effects were considered using the Square Root of Sum of Squares (SRSS) approach and mass source is also added as per IS 1893 (Part 1): 2016 guidelines in which live load factor is taken as 0.25 for loads less than and up to 3kN/m^2 and a factor of 1 for dead loads, base shear matching after analysis also carried out to ensure codal requirements, the seismic performance of the investigated models was assessed in terms of storey displacement, storey drift, fundamental time period, storey stiffness and torsional irregularity ratio. These parameters were used because they provide a complete investigation of lateral deformation features, dynamic behaviour, stiffness strengthening and torsional response of irregular composite structures subjected to seismic loading. RSA procedure adopted is reported in [13], the placement and orientation of seismic resistance techniques at identical locations is strategically planned and modelled to strengthen the BCF.

2.2 Placement and Orientation of Seismic Resistance Techniques

The placement and orientation of the seismic resistance techniques were adopted considering the torsional vulnerability and stiffness irregularity associated with the L-shaped plan. Due to the presence of re-entrant corners, L-shaped buildings are prone to stress concentration and non-uniform distribution of seismic forces during earthquake. To mitigate these effects, the seismic resistance techniques were strategically positioned along the peripheral frames and re-entrant corner regions of the structure, as shown in [Figure 2]. Similar placement strategies have been reported in existing research works in which it is demonstrated that peripheral and corner locations are effective in enhancing lateral stiffness and reducing torsional response in irregular buildings [13], [14]. The incorporated orientation was aimed to provide an effective lateral load-resisting system in both principal directions while ensuring a balanced stiffness distribution throughout the structure. Existing researches also reported that seismic resistance systems incorporated near exterior frames and at the critical corner areas deliver increased control of displacement, drift, stiffness and torsional irregularity when compared with centrally and unsymmetrically positioned formations [10], [12].

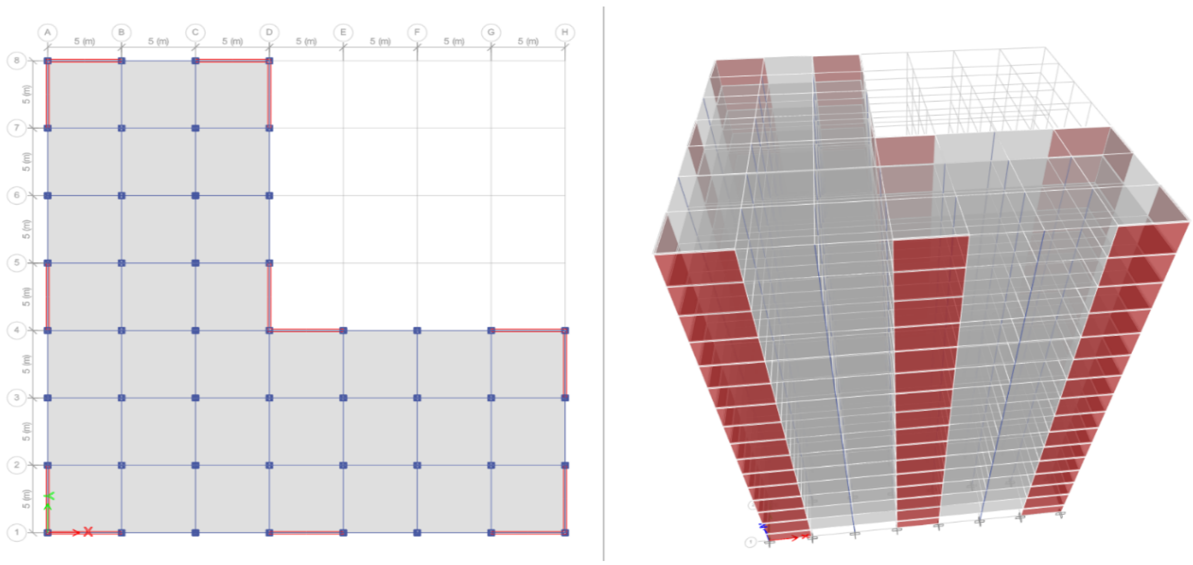

Fig 2. Arrangement of Seismic Resistance Techniques in the Composite Building

The bracing section of ISMB 200 with both ends hinged and shear wall of 200 mm thickness with proper pier labels is considered and assigned to the model at the selected locations. To ensure effective and fair comparison, same locations and orientations were selected for all investigated seismic resistance techniques, such as DB, IVB, VB, KB, XB and SW systems as shown in [Figure 3] making it a unique comparative methodology which is not adopted in many existing works. Keeping the same placement setup removes the influence of location dependent stiffness variations and permits the identified differences in seismic response to be attributed primarily to the characteristics of the seismic resistance technique itself. In the same way comparative strategies have been used in [9] and [10] for assessing the effectiveness of different seismic resistance systems under similar structural and loading conditions for RCC building. Consequently, the adopted placement strategy provides a reliable basis for assessing the relative effectiveness of different seismic resistance techniques in improving the seismic performance of the irregular composite building.

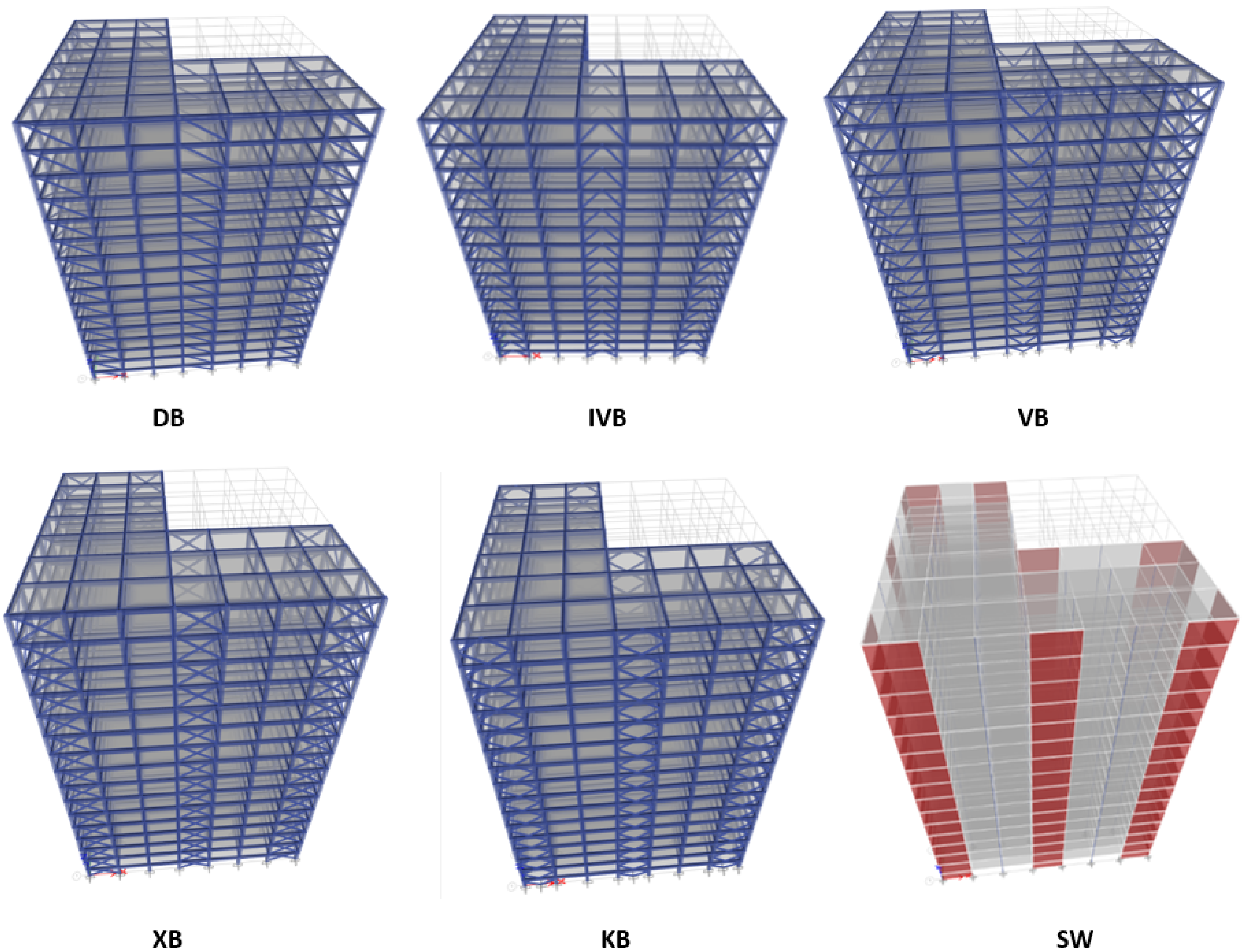

Fig 3. Composite Building Models Incorporating Different Seismic Resistance Techniques

3 Results and Discussion

3.1 Validation of Numerical Modelling Approach

The numerical results achieved for G+15 composite structure is validated with the developed structural modelling method and procedure adopted in literature study titled "Comparative Dynamic Response Analysis of Fixed-Base vs. Base-Isolated Steel-Concrete Composite Frames Under Seismic Excitation"[(4)]. The results arrived are compared with the results reported in reference model. Storey displacement, drift and time period for composite structure reported in reference literature are 46 mm, 0.001158 and 1.959 sec respectively. Observed displacement, drift and time period for G+5 BCF are 122.5 mm, 0.004131 and 3.279 sec respectively, which strongly aligns with the reference literature indicates the reliability of modelling methodology adopted for composite building.

Similarly, methodology adopted for integration of bracing systems is validated with the literature titled "Effect of position of steel bracing in L-shape reinforced concrete buildings under lateral loading"[(13)]. The study focused on integration of inverted V bracings to L-shaped RCC structure at different locations, when bracings placed along the peripheral frame of the building the results show strong alignment with the results arrived for G+15 IVB structure. Seismic parameters such as displacement, drift, time period and Torsional ratio are 16 mm, 0.000845, 0.764 sec and 1.21 respectively are in favourable with the results obtained for IVB structure with displacement (54.8 mm), drift (0.001542), time period (2.335 sec) and torsion ratio (1.199). This alignment of results confirms the accuracy and reliability of the adopted methodology and dynamic principles of the present study.

3.2 Comparison of Structural Results

A comprehensive comparison of structural parameters is carried out namely storey displacement, storey drift, time period, storey stiffness and torsional irregularity ratio of all developed models keeping BCF as the reference model for comparison. In addition, a detailed comparison between five bracing systems adopted are also compared to evaluate the effective bracing system. This detailed comparative approach not only addresses the effective importance of seismic resistance techniques, also highlights the effective bracing system by comparing among the bracing systems.

Table 1. Maximum Storey Displacement and Storey Drift of Composite Building Models

Structural Models	Maximum Storey Displacement (mm)		Maximum Storey Drift	
	In X-Direction	In Y-Direction	In X-Direction	In Y-Direction
BCF	122.5	124.8	0.004131	0.004223
DB	67.6	68.2	0.001901	0.001915
IVB	54.8	55.3	0.001542	0.001552
VB	58.3	58.9	0.001549	0.001562
KB	53.8	54.3	0.001414	0.001426
XB	53.7	54.2	0.001411	0.001423
SW	36.4	33.1	0.00097	0.000883

Table 2. Fundamental Time Period, Maximum Storey Stiffness and Torsional Irregularity Ratio of Composite Building Models

Structural Models	Time Period (sec)	Maximum Storey Stiffness (kN/m)		Torsional Irregularity Ratio
		In X-Direction	In Y-Direction	
BCF	3.279	1709698.494	1657034.724	1.852
DB	2.533	2778359.277	2712437.186	1.375
IVB	2.35	3871568.225	3797901.782	1.199
VB	2.414	3525828.448	3026203.272	1.192
KB	2.332	3642413.692	3562315.787	1.177
XB	2.33	3625931.534	3545619.25	1.179
SW	1.586	23990207.622	23840112.63	1.095

3.2.1. Storey Displacement

The maximum storey displacement obtained for all investigated structural models is presented in [Table 1]. Storey displacement is one of the most important indicators of seismic performance, as excessive lateral displacement may lead to structural instability, serviceability issues and increased damage to both structural and non-structural components during earthquake excitation. Bare Composite Frame (BCF) exhibited the highest displacement values of 122.5 mm and 124.8 mm in the X and Y-directions, respectively. The incorporation of seismic resistance techniques resulted in significant reductions in displacement in both principal directions. The DB model reduced the maximum displacement to 67.6 mm and 68.2 mm in the X and Y-directions, corresponding to reductions of 44.82% and 45.35%, respectively, compared with BCF. Similarly, IVB reduced the displacement to 54.8 mm and 55.3 mm, resulting in reductions of 55.27% and 55.69%, respectively. The VB model achieved reductions of 52.41% and 52.80%, while KB reduced the displacement by 56.08% and 56.49% in the X and Y-directions, respectively. The XB model showed comparable performance among the bracings, minimizing the displacement by 56.16% and 56.57% relative to BCF. A comparison of the analysed models indicates that the SW system provided the greatest reduction in lateral displacement. Relative to the BCF model, displacement values decreased to 36.4 mm in the X-direction and 33.1 mm in the Y-direction, which results in reductions of 70.29% and 73.48%, respectively. The best response of the SW model is due to the increased lateral rigidity introduced by the shear walls, which limited seismic deformation and promoted a more efficient distribution of earthquake forces within the structure. Details of the maximum storey displacement response of all models are given in [Figure 4].

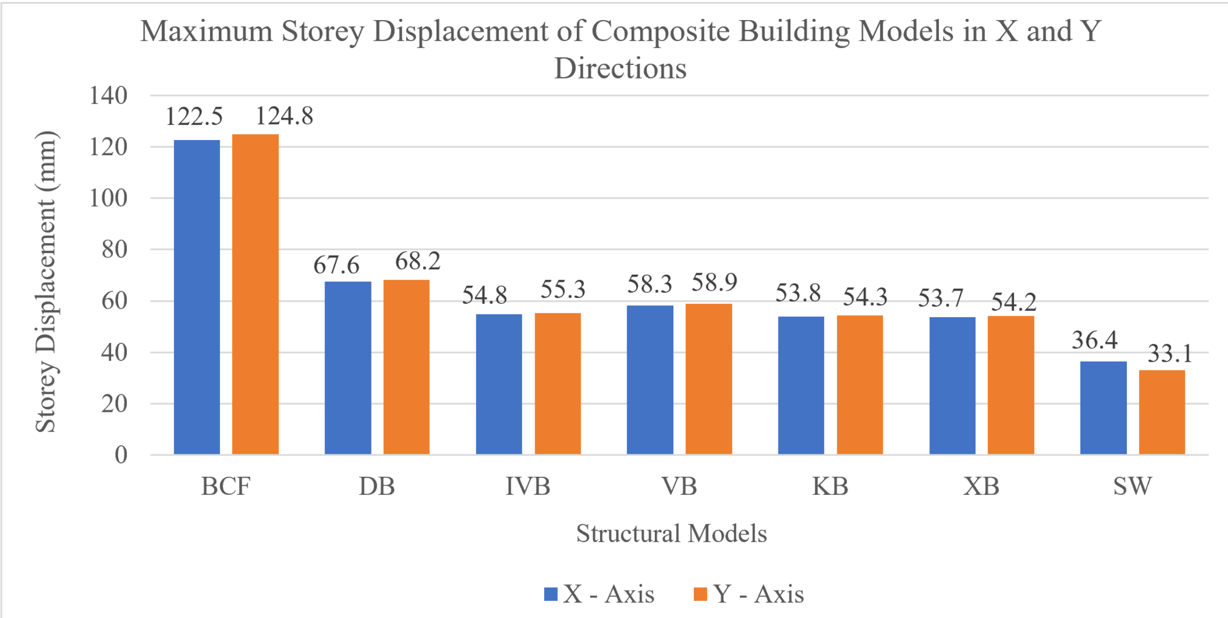

Fig 4. Maximum Storey Displacement of Composite Building Models in X and Y Directions

3.2.2. Storey Drift

The maximum storey drift response obtained from the RSA is summarized in [Table 1]. Storey drift is one of the major indicators of seismic performance, as higher inter-storey deformation can lead to structural damage and also deterioration of non-structural members. As specified in IS 1893 (Part 1): 2016, the permissible storey drift under design-level earthquake loading should not surpass 0.004 times the storey height. The bare composite frame (BCF) exhibited peak drift values of 0.004131 and 0.004223 in the X and Y-directions, respectively. Both the values are within the prescribed limit by IS code i.e. 0.012. The adoption of seismic resistance techniques resulted in reduction in drift demand. The diagonal bracing (DB) system limited the maximum drift to 0.001901 in the X-direction and 0.001915 in the Y-direction, representing decreases of 53.98% and 54.65%, respectively, compared to the BCF model. Additional improvement was achieved through the inverted V-bracing (IVB) system, which reduced the drift values to 0.001542 and 0.001552, corresponding to reductions of 62.67% and 63.25%. Likewise, the V-bracing (VB) system achieved reduction of drift response by 62.50% and 63.01% in the X and Y-directions, respectively. Higher drift mitigation was observed for the K-bracing (KB) which achieved reductions of 65.77%, 66.23% and X-bracing (XB) systems 65.84%, 66.30%, in X and Y direction respectively. Among all the systems, the shear wall (SW) model achieved the most favourable drift performance. Maximum drift values were restricted to 0.00097 in the X-direction and 0.000883 in the Y-direction, showing a reduction of 76.52% and 79.09%, respectively, compared with the BCF model. In addition, every strengthened configuration satisfied the drift limitation prescribed by IS 1893 (Part 1): 2016, confirming the effectiveness of the adopted techniques in controlling inter-storey deformation. A comparison of the drift response of all analysed models is presented in [Figure 5].

3.2.3. Fundamental Time Period

The fundamental time period is a key dynamic parameter of a structure and it represents duration required to complete one cycle of natural vibration. Since it is closely related to the stiffness characteristics of a structural system, it is commonly used to assess the vulnerability of a building to seismic-induced lateral movements. In general, structures having greater stiffness tend to exhibit shorter vibration periods and improved resistance to lateral deformation during earthquake. The fundamental time periods evaluated for the investigated models are described in [Table 2]. The BCF exhibited the highest fundamental time period of 3.279 s, indicating comparatively lower stiffness of the structural system. The incorporation of seismic resistance

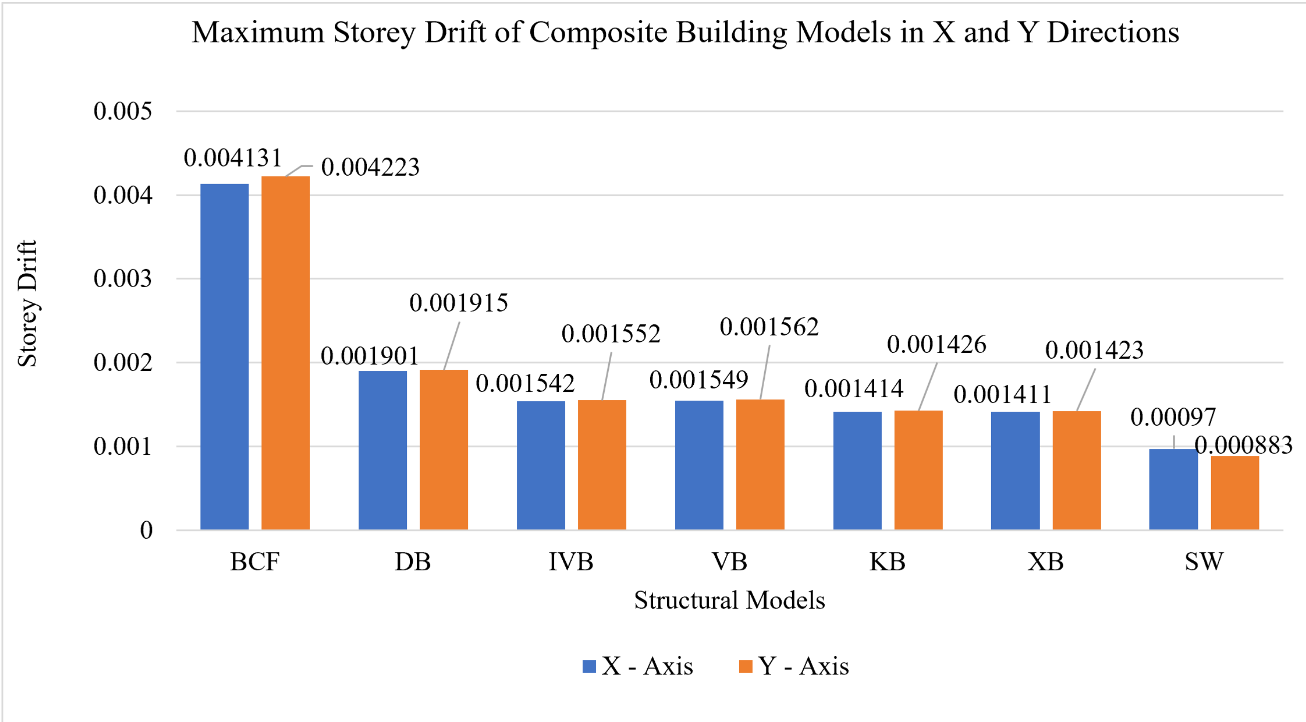

Fig 5. Maximum Storey Drift of Composite Building Models in X and Y Directions

techniques showed improved dynamic behaviour of the building by increasing lateral rigidity, which resulted in a reduction of time period. For the diagonal bracing (DB) configuration, the fundamental time period decreased to 2.533 s, corresponding to a 22.75% reduction relative to the BCF model. The inverted V-bracing (IVB) system further reduced the period to 2.350 s, representing a decrease of 28.33%, while the V-bracing (VB) arrangement yielded a period of 2.414 s, showing 26.38% reduction. Highest improvements among bracings were observed for the K-bracing (KB) and X-bracing (XB) systems. The corresponding fundamental time periods were 2.332 s and 2.330 s, indicating reductions of 28.88% and 28.94%, respectively when compared with the BCF structure. The most improved change in dynamic response was recorded for the shear wall (SW) model, which shows a fundamental time period of 1.586 s. This value represents a reduction of 51.63% relative to the BCF and reflects a substantial increase in overall stiffness accompanied by a reduction in structural flexibility. The comparative variation in fundamental time period for all investigated models is presented in [Figure 6].

3.2.4. Storey Stiffness

Storey stiffness is a major parameter in determining the seismic behaviour of a building, as it affects lateral displacement, inter-storey drift and overall structural stability. Buildings with higher stiffness generally exhibit greater resistance to lateral forces resulting in improved seismic performance and reduced deformation demand. The maximum storey stiffness values obtained from the analysed models are summarized in [Table 2]. Among the investigated configurations, the BCF exhibited the lowest stiffness with values of 17,09,698 kN/m and 16,57,034 kN/m in the X and Y-directions respectively. Adoption of seismic resistance techniques led to improvements in stiffness in both principal directions for the DB system, the maximum stiffness increased to 2,778,359 kN/m in the X-direction and 27,12,437 kN/m in the Y-direction, corresponding to increases of 62.51% and 63.69% respectively, compared to the BCF model. Further improvement was provided by the inverted IVB configuration which achieved stiffness values of 38,71,568 kN/m and 37,97,908 kN/m in the X and Y-directions, indicating increases of 126.45% and 129.20% respectively. The VB system achieved stiffness improvements of 106.23% and 82.63%, whereas the KB system increased stiffness by 113.05% and 115.00% in the respective directions. A similar improvement is observed for the XB system, which yielded increases of 112.08% and 113.98% in the X and Y-directions, respectively. The most promising improvement in stiffness was established with the shear wall (SW) model. Maximum stiffness values of 2,39,90,207 kN/m and 2,38,40,112 kN/m were recorded in the X and Y-directions, respectively. In comparison with the BCF model, these values correspond to increases of 1303.21% and 1338.78%, indicating the significant contribution of the shear wall system to the

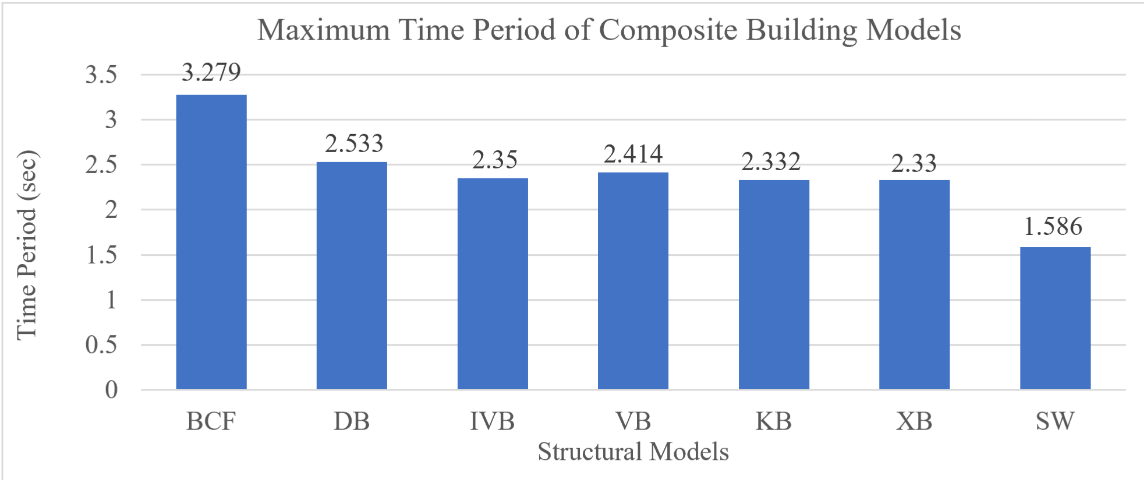

Fig 6. Fundamental Time Period of Composite Building Models

lateral rigidity of the structure. A comparison of the maximum storey stiffness values for all investigated models is presented in [Figure 7].

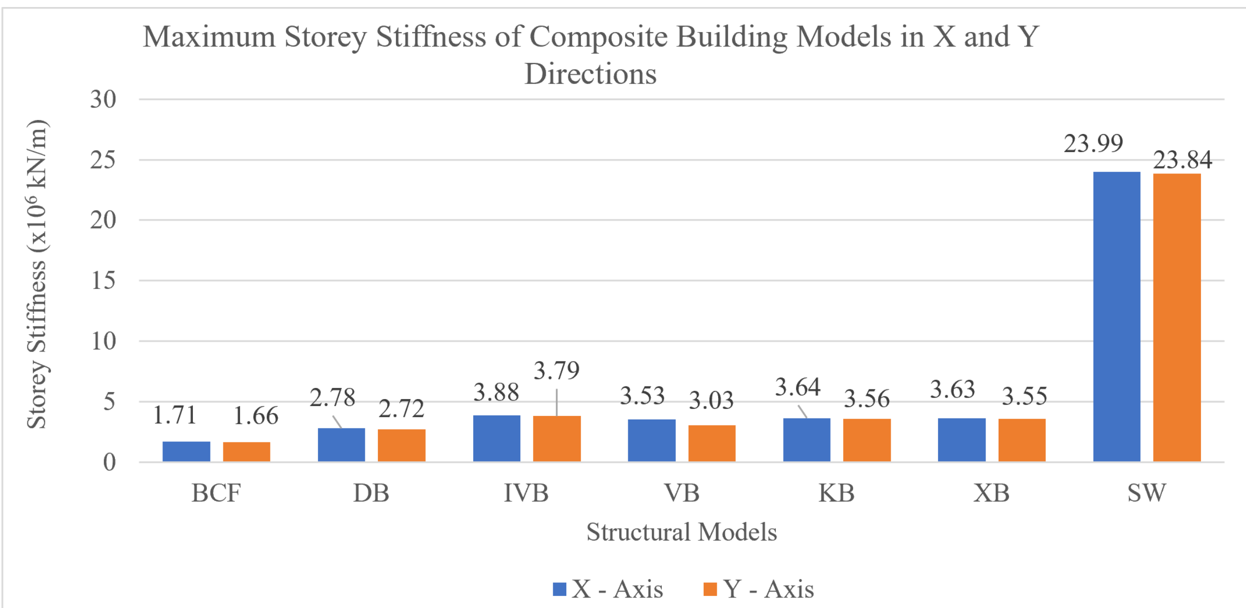

Fig 7. Maximum Storey Stiffness of Composite Building Models in X and Y Directions

3.2.5. Torsional Irregularity Ratio

Torsional irregularity represents important aspect of seismic performance in irregular buildings, as it specifies the degree of non-uniform lateral response resulting from the distance between the centre of mass and the centre of rigidity. The torsional irregularity ratios determined for the investigated structural models are summarized in [Table 2]. According to IS 1893 (Part 1): 2016, torsional irregularity exists when the torsional irregularity ratio exceeds 1.2. Among the analysed configurations, the BCF recorded the highest torsional irregularity ratio of 1.852, showing a highest torsional response. The incorporation of DB system reduced this ratio to 1.375 representing a decrease of 25.76% compared to the BCF model. However, the ratio remained greater than the codal threshold of 1.2, indicating that torsional irregularity was still present in the structure. Other seismic resistance techniques successfully reduced the torsional irregularity ratio below the codal limit. The IVB model achieved a ratio of 1.199 representing a reduction of 35.26% relative to BCF. Similarly, VB reduced the ratio to 1.192 corresponding to a reduction of 35.64%, while KB and XB achieved ratios of 1.177 and 1.179, representing reductions of 36.45% and 36.34%, respectively. The SW model reported the lowest torsional irregularity ratio of 1.095 corresponding to the maximum reduction of 40.87% compared with BCF. The variation in torsional irregularity ratio for the investigated models is illustrated in [Figure 8].

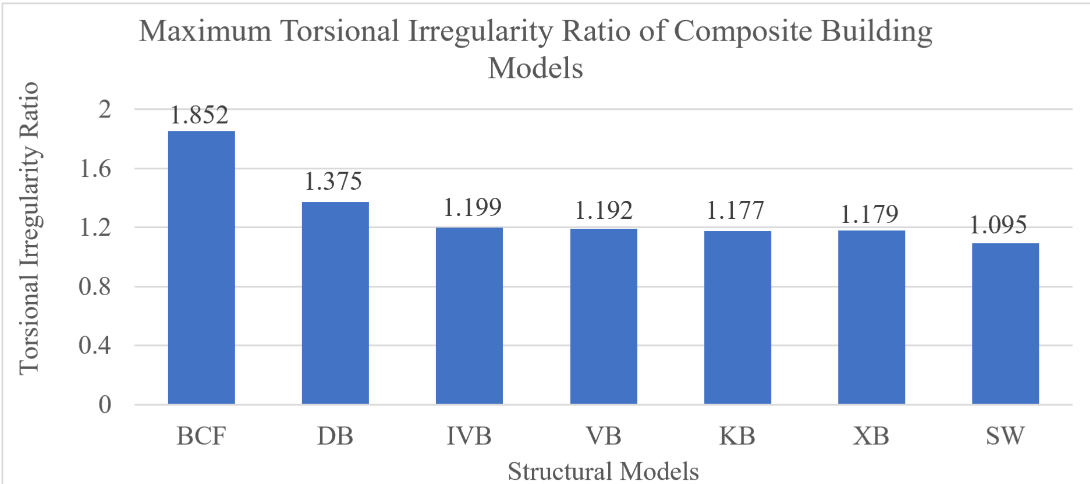

Fig 8. Maximum Torsional Irregularity Ratio of Composite Building Models

3.3 Discussion

The results obtained from the current study shows that the adoption of seismic resistance techniques significantly increase the performance of L-shaped irregular SCC structures. The observed decrease in seismic parameters such as storey displacement, storey drift, fundamental time period and torsional irregularity ratio with increase in storey stiffness indicates that the adoption of the seismic resistance techniques significantly enhanced the lateral load carrying capacity of the structure. Although all examined techniques improved the seismic behaviour compared with the BCF, their effectiveness varied depending on their stiffness contribution and load transfer mechanism. The decrease in displacement and drift on incorporation of seismic resistance techniques mainly connected to increase in lateral stiffness. Steel bracing systems improved structural behaviour by enhancing axial force resisting mechanism that helps in transfer of lateral forces efficiently to the foundation which reduces lateral deformation demand. Among various bracing systems XB achieved the most favourable overall response because its intersecting diagonal members creates an effective truss mechanism which provides load path and enhanced stiffness distribution throughout the structure. Similar findings are reported by Khattar and Muthumani [(8)] and Bohra et al. [(13)], who quantified reductions in lateral displacement and inter-storey drift in the range of approximately 15–35% for braced systems, depending on bracing configuration and placement. The shear wall system attained the most promising improvement among all investigated seismic resistance techniques. This behaviour is mainly due to the substantial in-plane stiffness of RC shear walls which act as continuous vertical cantilever elements resisting lateral forces. As a result, lateral deformations are significantly reduced and seismic forces are transferred more uniformly throughout the structural system. Similar trends were reported by Simon et al. [(10)] and Ahamad and Pratap [(12)], who reported that strategically located shear walls can decrease storey displacement and drift by about 20 to 45%, while also reducing torsional effects. The present results further confirm the suitability of steel bracings and shear wall systems for improving the seismic response of irregular composite structures.

The reduction in fundamental time period achieved in strengthened models specifies significant increase in overall structural stiffness. Since the time period is inversely proportional to the stiffness, the reduce in vibration period assures that the adoption of seismic resisting techniques increased the capacity of the structure against lateral movements. Existing studies involving bracing and shear wall systems also reported decrease in fundamental time period in the range of 10-30% depending upon location, indicates the structural stiffness is increased on introduction of these techniques [(10)], [(13)]. The increase in storey stiffness and consistent reduction in torsional irregularity ratio also highlight the effectiveness of the techniques adopted. Torsional response is one of the serious concerns in L-shaped irregular structures due to eccentricity between centre of mass and centre of rigidity. The adoption of bracings and shear walls enhanced stiffness distribution and decreased torsional sensitivity of the structure by providing additional resistance in high seismic regions. Bohara et al. [(13)] reported that placing strengthening systems at peripheral frames can decrease torsional irregularity ratios by 15–25%, representing the importance of stiffness redistribution in irregular buildings. The lower torsional irregularity ratios obtained in the present study indicate a more balanced seismic response and reduced vulnerability to localized stress concentrations.

An important contribution of the present study is that it extends the previous findings from conventional RCC structures to irregular SCC structures. Most existing researches have worked on either individual bracing systems or shear walls separately, mainly focusing on RCC buildings. In contrast, the present work provides a comprehensive comparison of five steel bracing systems and reinforced concrete shear walls within the same irregular composite building using identical geometry, loading conditions and placement locations. This approach enables a direct assessment of the relative effectiveness of different seismic resistance techniques without the influence of location dependent variations. The results indicate that while all strengthening systems improve seismic performance X-bracing provides the most efficient overall performance among the steel bracing configurations, whereas reinforced concrete shear walls provide the highest level of seismic protection.

4 Conclusion

Unlike many works are sticked to individual strengthening systems like comparison of RCC structure with a single bracing system placed at different locations and studied performance of shear walls separately. Also, no strengthening techniques are used in SCC structures, this research work develops a unique approach by incorporating five different types and steel bracings and shear walls to a SCC structure in a same research work with identical locations of all the systems for same geometry and loading conditions to study and fairly compare the effect and performance of each technique, so that best strengthening system can be easily identified based on the required intensity and economy. The seismic response of a fifteen-storey irregular L-shaped SCC building was examined by introducing different seismic resistance systems, namely DB, IVB, VB, KB, XB and Reinforced Concrete Shear Walls (SW). All models were analysed using RSA in ETABS following the provisions of IS 1893 (Part 1): 2016. The assessment focused on key response parameters including storey displacement, storey drift, fundamental time period, storey stiffness and torsional irregularity ratio. A comparison of the analysed models showed that the BCF system experienced the largest displacement, drift, time period and torsional response, indicating a greater exposure to seismic effects. The adoption of lateral load-resisting systems altered the structural response considerably by increasing stiffness and limiting deformation. Among the steel bracing configurations XB emerged as the most favourable option when the overall structural response was considered. Compared to the BCF model, displacement reduced by 56.16% in the X-direction and 56.57% in the Y-direction, while storey drift was reduced by 65.84% and 66.30%, respectively. The fundamental time period reduced from 3.279 s to 2.330 s showing increases in storey stiffness of approximately 112% and 114% in X and Y directions. A reduction in torsional irregularity ratio from 1.852 to 1.179 was also observed indicating reduction of 36.34%. Thus, these results indicate that X Bracing offers an effective combination of stiffness enhancement, deformation control and torsional stability among the investigated bracing systems compared to BCF.

The strongest overall seismic response is achieved from the shear wall model. Compared to the BCF, storey displacement was reduced by 70.29% and 73.48% in the X and Y-directions respectively, whereas drift reductions of 76.52% and 79.09% were recorded. The fundamental time period decreased by 51.63%, reflecting a substantial increase in overall stiffness and rigidity. Storey stiffness increased by more than thirteen times in comparison with the BCF model and the torsional irregularity ratio decreased to 1.095, representing an improvement of approximately 40.87%. These outcomes highlight the effectiveness of shear walls in mitigating lateral deformation, increasing structural rigidity and reducing torsional effects in irregular composite buildings. From the overall assessment, RC shear walls provided the greatest improvement in seismic performance when integrated with SCC frame and therefore represents the most effective strengthening option among the investigated systems. However, situations involving architectural constraints, space requirements, or construction-related considerations may limit the application of shear walls. Under such circumstances, X Bracing offers a practical and efficient alternative because of its favourable balance between displacement reduction, drift control, stiffness development and torsional performance along with economical point of view. The findings presented in this study may assist engineers in selecting and optimizing seismic resistance strategies for irregular composite buildings located in high seismic regions, based on the required intensity of strengthening the structure. If there is higher strengthening efficiency is required shear walls proves to be the best, but considering cost and self-weight XB system also offers a practical improvement against seismic loading. Future works may focus on non-linear dynamic analysis of irregular composite structure, compatibility of these techniques with base isolation and other plan irregularities and vertical irregularities.

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