

Comparative Study on High-Rise RCC and Steel Seismic-Resistant Structures Using Bracing Systems

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Abstract - The need of high-rise buildings in seismically active areas predetermines the necessity of effective lateral load-resisting systems. The present study assesses the seismic behaviour of the reinforced concrete (RCC) and steel buildings of ten and fifteen storeys with four types of bracing options: Cross-bracing, V-bracing, Chevron-bracing and single-bracing. The models were analysed as per IS 1893:2016. The equivalent static method and response spectrum method were used to evaluate the seismic response parameters such as the storey displacement, inter-storey drift, base shear, and the fundamental time period. The Cross-bracing and Chevron-bracing were found to be most effective among the systems studied and minimised the drifts, whereas the V-bracing and the single-bracing performed poorly. It is concluded that the choice of the best bracing arrangements is critical for the stability of high-rise buildings in seismic-prone areas.

Key Words: Seismic design; High-rise buildings; Bracing systems; RCC structures; Steel structures

1. INTRODUCTION

High-rise buildings have become one of the most characteristic features of the new urban development. Building Construction is growing vertically due to the high rate of population growth and scarcity of land. The lateral forces acting due to wind and earthquake are critical to high-rise structures, which are characterised by buildings raised above 15 m by the National Building Code of India (NBC) [1]. In contrast to gravity loads, which are non-dynamic and predictable, seismic forces are dynamic and disastrous and, therefore, one of the main focus areas of structural design.

One of the most effective solutions to the issue of seismic resistance has been recognised as bracing systems that increase the stiffness and strength without being too costly [2]. These systems are fabricated out of thin steel members, and they transmit lateral forces mainly by axial tension and compression. Bracing systems can significantly reduce inter-storey drift, lateral displacement and basic time periods depending on their arrangement [2].

According to IS 1893:2016, seismic zoning of India defines four zones, and such areas as the Himalayan belt, North-East India, and Gujarat are the most susceptible ones [3]. It has been observed that bare frames are not sufficient to resist seismic forces and that they require auxiliary systems like shear walls, outriggers, and bracing [4,5]. Shear walls are stiffening and may have restrictive effects on architecture, as compared to bracing systems, which are flexible and available as retrofit options [6].

The study explores the relative effectiveness of Cross-bracing, V-bracing, Chevron bracing, and single bracing used in RCC and steel buildings with ten and fifteen storeys. Their effectiveness in the seismic response can be assessed using structural modelling using ETABS.

2. LITERATURE REVIEW

Seismic loading of high-rise structures has received extensive research on performance. Norharsi *et al.*, [7] showed that ultrasonic pulse velocity, as another non-destructive testing method, can be used to evaluate in-situ concrete properties effectively in tall buildings, which is why strong materials are vital in seismic performance. A comparison of seismic design provisions in the Indian and European standards by Tapkire and Birajdar [6] indicated that, in the Indian and European standards, ductility classes and factors of response reduction differed directly, and this impacts seismic resilience.

Various bracing designs are investigated. Shahrzad *et al.*, [5] discovered that inverted V-bracing was the most efficient in terms of utilisation of material and still offered sufficient stiffness, but single bracing offered better energy absorption, with the displacements being greater. Maheri and Sahebi [2] experimentally demonstrated that Cross-bracing was capable of increasing the lateral load resistance of RC frames three times that of unbraced systems. Subsequent research, like

Nauman and Islam [8], verified that cross-bracing and chevron bracing had a great effect on minimising the displacements in fifteen-storey RCC frames.

Maheri and Hadjipour [9] experimentally assessed direct steel brace connections to RC frames, and Maheri and Yazdani [10] showed that the Uniform Force Method could be applied in designing brace connections with RC frames. It has also been demonstrated that composite structural systems, including concrete-filled steel tubes (CFST), can provide enhanced seismic resiliency because of confinement effects and enhanced energy dissipation [11,12].

The application of ETABS has enabled the precise prediction of seismic response. Sallal [13] and Guleria [14] emphasised that the computational models offer crucially important information on the drifts, displacements and torsional irregularities of storey, allowing for making reliable comparative analysis on bracing systems.

On the whole, the literature points to three consistent conclusions: (i) bare frames do not work well when subjected to seismic loading, (ii) cross-bracing and inverted V-bracing tend to be most efficient, and (iii) good connection detailing and composite elements add to the resilience of the structure.

3. METHODOLOGY

The methodology used in this study is to obtain the seismic performance in terms of inter-storey drift of high-rise buildings with and without a bracing system. The general strategy entailed in the process was the choice of the representative models of buildings, the definition of geometric and material properties, using different types of bracing configurations, application of gravity and seismic loads as per IS codes, and the structural analysis implementation in ETABS software. The obtained results were compared to evaluate the relative effectiveness of various bracing systems on both reinforced concrete (RCC) and steel frames of different heights.

Two different heights of the building models were used to capture the contribution of slenderness and dynamic behaviour. The former model was a ten-storey building, and the latter was a fifteen-storey building. The plan dimensions of $13.04\text{m} \times 14.71\text{m}$ were used in both models, and the typical storey height of the building is 3.2m. M30 grade concrete and Fe500 grade steel reinforcement were used in RCC models, and steel models were developed with E350 structural steel as per IS 2062:2011 [15]. Structural elements were established based on preliminary design, where the slabs are of a thickness of 150 mm, the external wall is 230 mm thick, and the internal wall and parapet wall are 115 mm thick. In the present study, the influence of four kinds of bracing was investigated: Cross-bracing, V-bracing, Chevron-bracing and single bracing. The sectional sizes of bracing members are selected based on IS codes for ductile detailing of both RCC and Steel structures.

Seismic analysis was carried out as per IS 1893:2016. A zone factor (Z) was taken as 0.16 for seismic zone III, which is a medium seismic hazard. An important factor (I) of 1.0 and a response reduction factor (R) of 5.0 and 4.5 for Special Moment Resisting Frame (SMRF) and Special Concentric Braced Frame (SCBF), respectively [3].

Two types of analysis techniques were used: the Equivalent Static Method (ESM) and the Response Spectrum Method (RSM). In the corresponding equivalent static method (ESM), the natural period of the buildings was estimated empirically with the expression of IS 1893:2016 [3]. This produced periods of 0.80 s (X) and 0.75 s (Y) in the Ten-Storey structure, and 1.196 s (X) and 1.126 s (Y) in the Fifteen-Storey structure. These were the values employed to calculate design seismic forces and their vertical distribution through the storeys. In the response spectrum analysis, a minimum of twelve modes were taken into account to obtain over 90% cumulative mass participation as per IS 1893:2016 [3]. The mode shapes were associated with the translational motions in X and Y directions, and torsional motions were observed in the higher modes.

The Gravity loads were adopted according to IS 875:1987 [16]. Self-weight of structural elements, 1.5 kN/m^2 for floor finishes, and wall loads were included as dead loads. Live load was assumed to be 3.0 kN/m^2 on typical floors and 1.5 kN/m^2 on the roof. Gravity and seismic loads combinations were considered based on IS 456:2000 and IS 800:2007, they are $1.5(\text{DL} + \text{LL})$, $1.2(\text{DL} + \text{LL} \pm \text{EQ})$ and $1.5(\text{DL} + \text{LL} \pm \text{EQ})$, as well as $0.9\text{DL} \pm 1.5\text{EQ}$.

The evaluation of the seismic performance of the structures was done regarding four important parameters: Maximum storey displacement, Inter-storey drift, base shear and fundamental natural period. The allowable drift was restricted to 0.004 times the storey height, and this building model had 12.8 mm, corresponding to a 3.2 m storey height of the building. Equally, the displacement of the top storey of the structure was compared against the limit of $H/250$, which gives the values of 128 mm in the case of the Ten-storey structure and 192 mm in the case of the Fifteen-storey structure. It can be seen that the codal requirements are satisfied.

4. ANALYSIS

Seismic analyses were carried out on building models using both the equivalent static method and the response spectrum method as per IS 1893:2016 [3].

Table-1: Natural Time Period for RCC structures with various Bracing systems

S.No	Type of Bracing System	Natural Time Period (Sec)			
		Concrete Structure		Steel Structure	
		Ten-Storeyed	Fifteen-Storeyed	Ten-Storeyed	Fifteen-Storeyed
1	Without Bracing	3.00	2.95	2.86	4.17
5	Single Bracing	3.47	2.58	2.09	3
2	Cross-Bracing	3.83	2.36	1.69	2.43
3	V- Bracing	3.60	2.46	1.95	2.87
4	Chevron Bracing	3.62	2.50	1.95	2.85

5. RESULTS AND DISCUSSION

Table-2: Comparison of Seismic Parameters of a Ten-storeyed Concrete Structure with Various Bracing Systems

	Ten-Storeyed Concrete Structure					
	Earthquake in X-Direction			Earthquake in Y-Direction		
	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)
Without Bracing	7.3	888.6	60.3	7.6	947.8	63.5
Single Bracing	6.1	980.5	50.2	5.9	1045.8	49.4
Cross-Bracing	4.7	979.6	40.1	4.5	1044.9	38.3
V- Bracing	5.5	980.5	45.0	5.8	1045.9	48.8
Chevron Bracing	5.4	980.2	46.6	5.8	1045.6	46.6

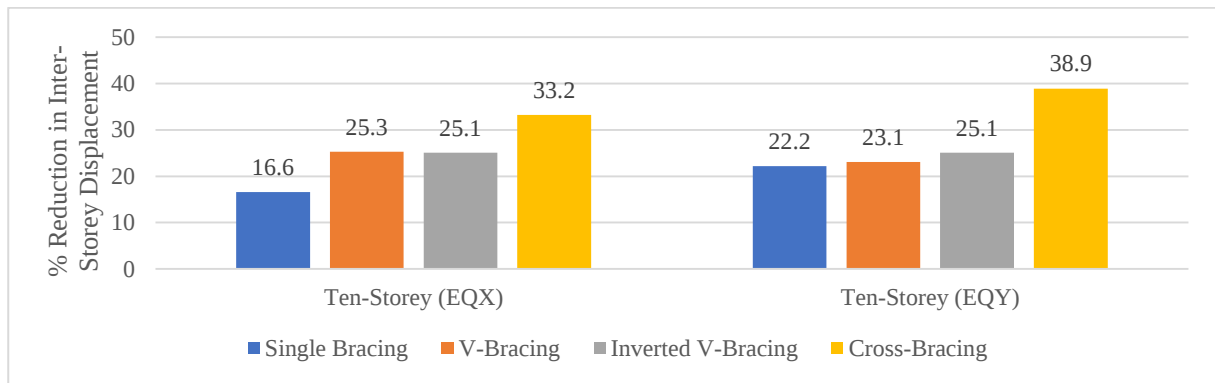


Chart -1: Percentage Reduction of Maximum Storey Displacement Across Various Bracing Systems in a Ten-story Concrete Structure in EQX and EQY Forces

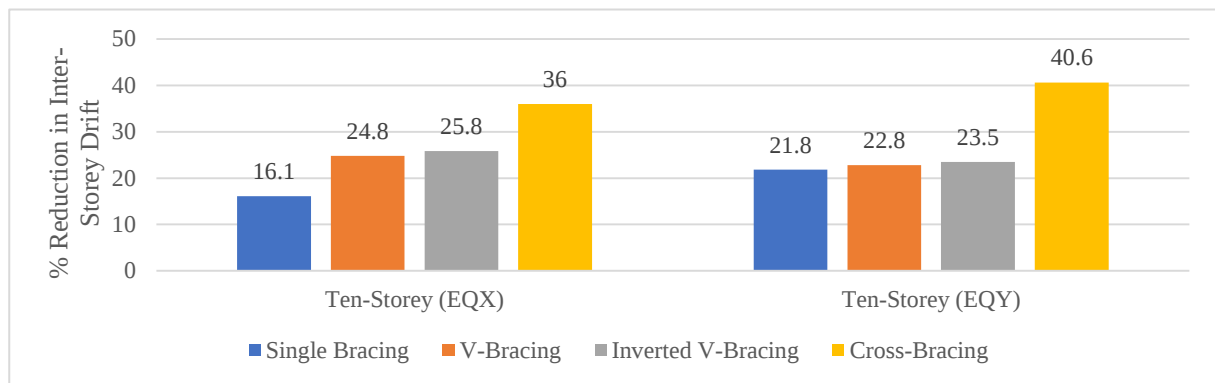


Chart-2: Percentage Reduction of Maximum Inter-Storey Drift Across Various Bracing Systems in a Ten-storeyed Concrete Structure in EQX and EQY Forces

Table-3: Comparison of Seismic Parameters of a Fifteen-storey Concrete Structure with Various Bracing Systems

Type of Bracing System	Fifteen-storey Concrete Structure					
	Earthquake in X-Direction			Earthquake in Y-Direction		
	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)
Without Bracing	7.1	888.7	85.6	7.1	943.9	87.5
Single Bracing	6.2	982.7	72.3	5.9	1043.8	70.8
Cross-Bracing	4.8	978.9	59.3	4.6	1039.8	60.0
V- Bracing	5.5	984.1	65.0	5.8	1045.3	69.3
Chevron Bracing	5.5	978.5	66.7	5.8	1039.4	70.8

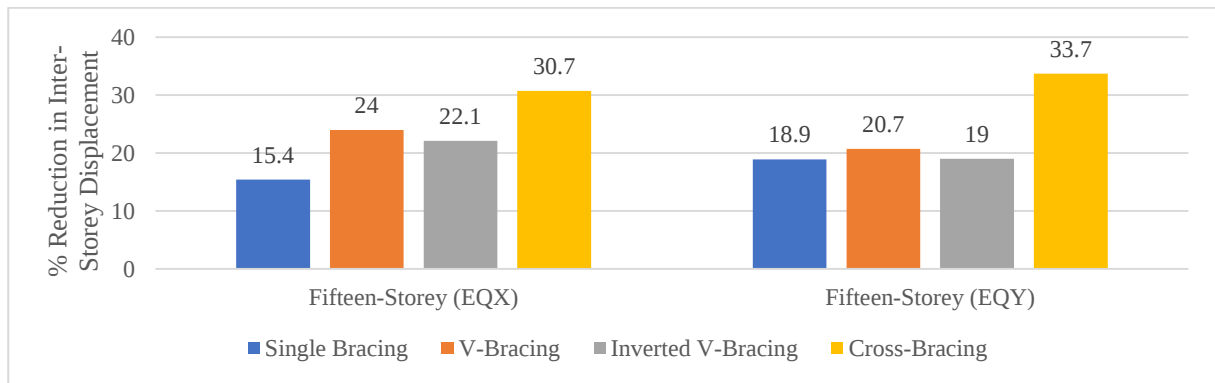


Chart-3: Percentage Reduction of Maximum Storey Displacement Across Various Bracing Systems in a Fifteen-storey Concrete Structure in EQX and EQY Forces

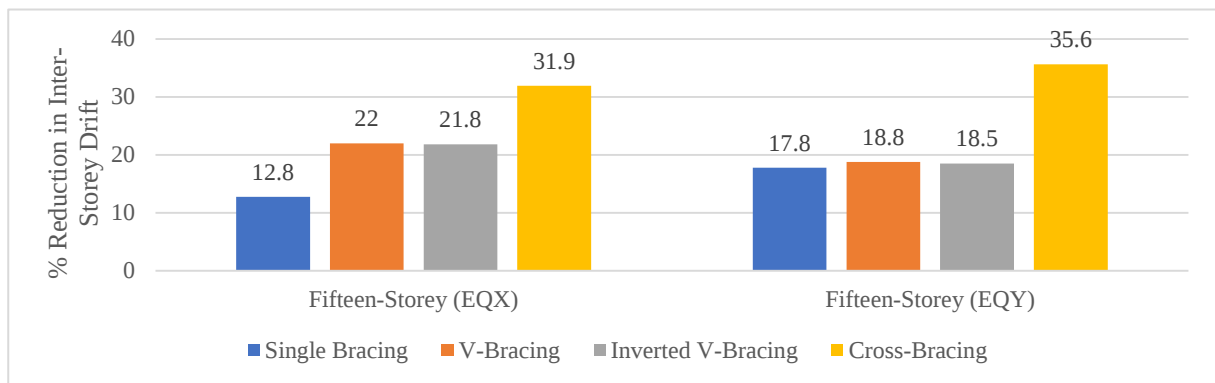


Chart-4: Percentage Reduction of Maximum Inter-Storey Drift Across Various Bracing Systems in a fifteen-storey Concrete Structure in EQX and EQY Forces

Table-4: Comparison of Seismic Parameters of a Ten-storey Steel Structure with Various Bracing Systems

	Ten-storey Steel Structure					
	Earthquake in X-Direction			Earthquake in Y-Direction		
Type of Bracing System	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)
Without Bracing	12.3	713.0	113.1	13.9	760.6	122.8
Single Bracing	7.2	709.6	55.4	7.0	756.9	53.8
Cross-Bracing	6.3	788.5	39.2	5.4	841.1	38.7
V- Bracing	7.3	787.4	52.3	7.6	839.9	58.5
Chevron Bracing	7.2	787.1	50.9	7.6	839.6	58.1

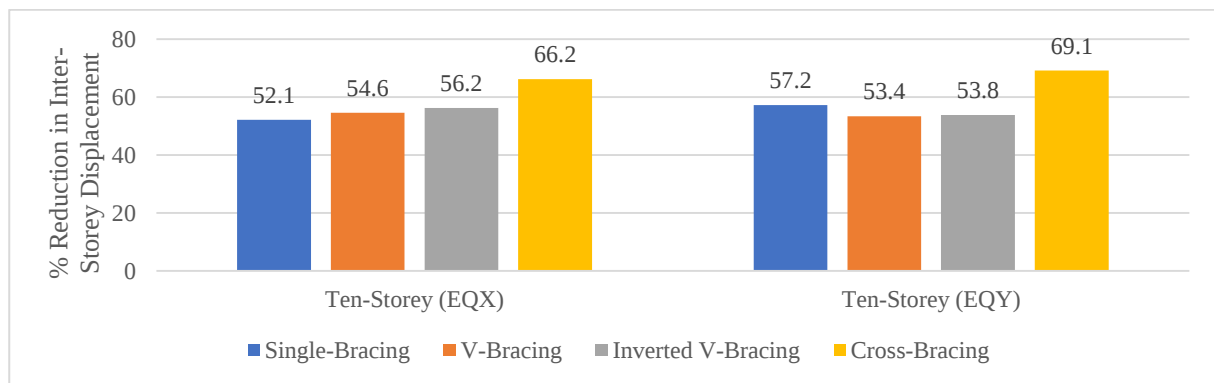


Chart-5: Percentage Reduction of Maximum Storey Displacement Across Various Bracing Systems in a ten-storey Steel Structure in EQX and EQY Forces

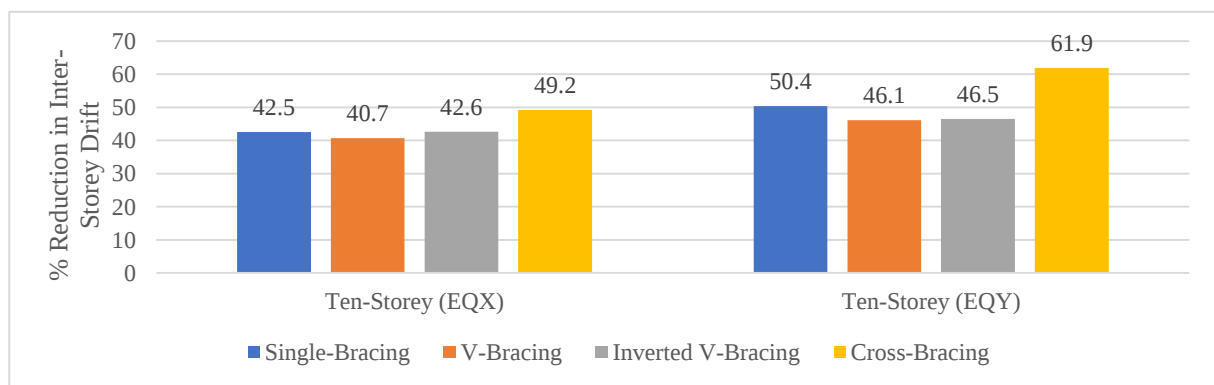


Chart-6: Percentage Reduction of Maximum Inter-Storey Drift Across Various Bracing Systems in a ten-storey Steel Structure in EQX and EQY Forces

Table-5: Comparison of Seismic Parameters of a Fifteen-storey Steel Structure with Various Bracing Systems

	Fifteen-storey Steel structure					
	Earthquake in X-Direction			Earthquake in Y-Direction		
Type of Bracing System	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)	Maximum Inter-Storey Drift (mm)	Base Shear (kN)	Maximum Storey Displacement (mm)
Without Bracing	11.9	699.2	157.7	14.2	742.6	178.8
Single Bracing	7.5	772.9	92.0	7.0	820.9	88.0
Cross-Bracing	4.7	773.2	58.3	7.3	821.3	60.0
V- Bracing	6.2	772.2	78.2	6.9	820.2	88.3
Chevron Bracing	6.1	771.9	75.9	6.9	819.8	86.6

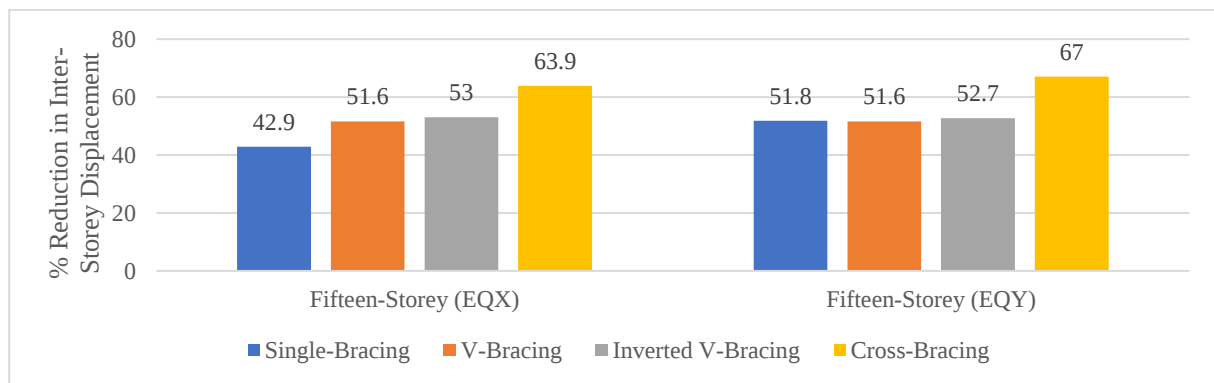


Chart-7: Percentage Reduction of Maximum Storey Displacement Across Various Bracing Systems in a fifteen-storey Steel Structure in EQX and EQY Forces

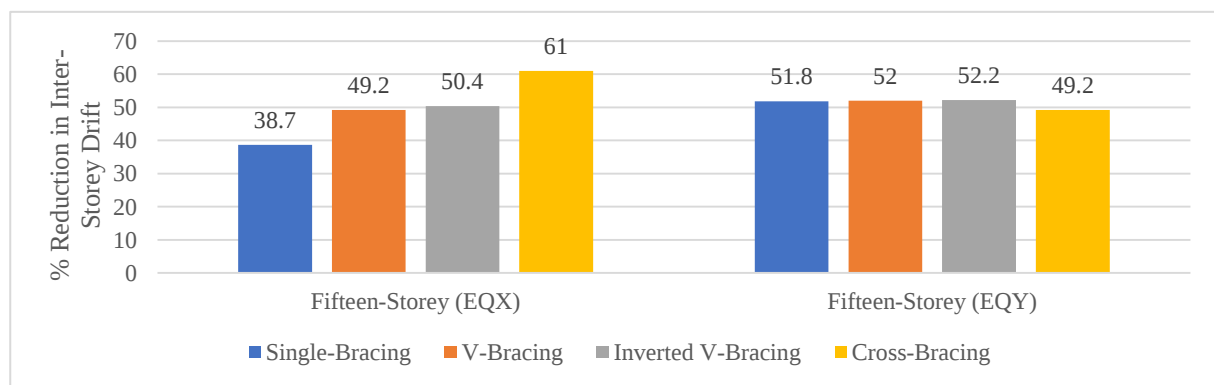


Chart-8: Percentage Reduction of Maximum Inter-Storey Drift Across Various Bracing Systems in a fifteen-storey Steel Structure in EQX and EQY forces

A key observation is that RCC structures, owing to their inherent stiffness, exhibit lower absolute displacements and drifts compared to their steel structures. For instance, the unbraced fifteen-storey RCC structure has a roof displacement of 87 mm, whereas the steel structure has 179 mm. This highlights that steel structures rely more on bracing for stability. When bracing is introduced, particularly Cross-bracing, both structures show substantial reductions. The percentage reduction in displacement is more in steel frames (60–65%) than in RCC (30–40%), reflecting the fact that flexible frames gain more from stiffening. Chevron bracing and V-bracing are emerging as a reliable alternative, delivering reductions nearly comparable to Cross-bracing, while single bracing consistently underperforms in the structures. Inter-storey drift follows the same trend, with bracing ensuring compliance with the codal limit of $0.004h$ (≈ 12.8 mm for ten-storey and ≈ 19.2 mm for fifteen-storey). Another important feature is that the base shear increases with bracing across all models. In conclusion, Cross-bracing is universally the most effective, Chevron bracing and V-bracing are moderately effective, and single-bracing systems provide only marginal benefits. The comparison confirms that bracing selection plays a decisive role in ensuring seismic resilience, especially in high-rise structures where the unbraced performance is unsatisfactory.

6. CONCLUSIONS

Based on the results of the analyses of the RCC and Steel structures the following are the conclusions:

- For a ten-storeyed RCC structure, the roof and inter-storey displacements are reduced by 33.5% and 36% in a cross-braced structure when compared to an unbraced structure.
- For a fifteen-storey Steel structure, the roof displacement is reduced by 63% in a cross-braced structure when compared to an unbraced structure.
- The analysed RCC and Steel structures with the Chevron bracing system indicate approximately 15% to 25% and 40% to 60% reduction in inter-storey drift compared to an unbraced structure.
- Single bracing system results in approximately 10 to 20% and 35 to 50% reduction of inter-storey drift for an RCC and steel structures, respectively.

- Braced RCC structures exhibited reduced roof displacement, but the reduction is moderate, whereas unbraced steel structures exhibit more roof displacement, but the reduction is more in the case of braced structures
- For both RCC and Steel structures, a cross-braced system can be considered as an effective solution in severe seismic regions.

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