Seismic Performance Evaluation of Multistory Reinforced Cement Concrete (RCC) Buildings with Different Bracing Systems Using ETABS

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Abstract: ***Rapid urbanization has resulted in the construction of increasingly taller reinforced cement concrete (RCC) buildings in regions susceptible to earthquakes. The lateral forces generated during seismic events significantly influence the structural safety, serviceability, and overall performance of these buildings. Bracing systems have emerged as an effective technique for enhancing the lateral stiffness, reducing inter-storey drift, and improving the seismic resistance of multistory structures. This research investigates the seismic behavior of a G+14 RCC building provided with different concentric steel bracing configurations, namely X-bracing, V-bracing (Chevron), Inverted V-bracing, and Diagonal bracing. The analytical model is developed using ETABS software and analyzed according to the provisions of IS 1893 (Part 1):2016 and IS 456:2000. Linear dynamic analysis is carried out to evaluate important response parameters such as storey displacement, storey drift, base shear, natural time period, overturning moment, and column forces. Comparative evaluation of the various bracing arrangements is performed to determine the most effective configuration for improving seismic performance. The study indicates that introducing bracing systems considerably enhances the lateral stiffness of RCC buildings while reducing displacement and drift. Among the investigated configurations, X-bracing demonstrates the highest efficiency in controlling lateral deformation without significantly increasing structural weight.***

Keywords: RCC Building, Seismic Analysis, ETABS, Steel Bracing, Storey Drift, Storey Displacement, Base Shear, Earthquake Resistant Design

1.Introduction

Earthquakes remain one of the most destructive natural hazards affecting civil engineering infrastructure worldwide. Numerous failures of reinforced concrete buildings during major earthquakes have highlighted the importance of designing structures capable of resisting lateral forces efficiently. Modern multistory buildings are generally designed to satisfy gravity load requirements; however, inadequate lateral stiffness often results in excessive deformation during seismic excitation.

Reinforced Cement Concrete (RCC) is the most widely used structural material because of its durability, availability, economy, and ease of construction. Although RCC buildings possess considerable compressive strength, they may experience excessive storey drift and damage under severe earthquake loading if lateral load-resisting systems are not adequately incorporated.

One practical approach to improve seismic resistance is the introduction of steel bracing systems within RCC frames. Steel bracing provides additional stiffness and strength while requiring minimal modification to the existing structural configuration. Properly designed bracing systems efficiently transfer earthquake-induced lateral forces to the foundation through axial action, thereby reducing bending moments and improving the structural response.

Various bracing configurations have been successfully implemented in high-rise buildings, industrial structures, commercial complexes, and seismic retrofitting projects. The selection of a suitable bracing system depends upon architectural requirements, structural efficiency, construction feasibility, and economic considerations.

With the advancement of structural analysis software such as ETABS, STAAD.Pro, and SAP2000, engineers can accurately predict the seismic performance of different structural systems before construction. Numerical simulations allow designers to compare alternative bracing arrangements and optimize the structural configuration for maximum safety and economy.

The present study focuses on evaluating the seismic performance of a fourteen-storey RCC building equipped with different concentric steel bracing systems. A comparative assessment is carried out to determine the influence of each bracing arrangement on displacement, drift, base shear, natural period, and internal member forces under earthquake loading.

2.Literature Review

Several researchers have investigated the effectiveness of bracing systems in improving the seismic behaviour of reinforced concrete and steel buildings.

Desai et al. reported that concentric steel bracing significantly enhances the lateral stiffness of RCC frames and reduces storey displacement under seismic loading. Their research demonstrated that the inclusion of bracing systems effectively controls structural deformation while maintaining economical member sizes.

Viswanath and co-workers evaluated various steel bracing arrangements in reinforced concrete buildings and observed that X-bracing produced superior seismic performance compared with other configurations due to its higher stiffness and efficient load transfer mechanism.

Youssef et al. investigated the seismic performance of RC frames strengthened with internal steel bracing. Their analytical and experimental studies indicated considerable improvements in structural ductility, energy dissipation, and lateral load resistance after retrofitting.

Ghobarah and Abou-Elfath examined eccentric steel bracing for seismic rehabilitation of reinforced concrete frames and concluded that properly designed bracing systems significantly improved structural performance while minimizing damage during strong ground motion.

Several recent investigations using ETABS and STAAD.Pro have shown that X-bracing and Chevron bracing effectively reduce storey drift and displacement in medium- and high-rise RCC buildings located in moderate to severe seismic zones. However, the relative efficiency of different bracing configurations depends upon structural geometry, loading conditions, and building height.

3.Objectives of the Study

The primary objectives of this research are:

- To develop a three-dimensional analytical model of a G+14 RCC building using ETABS.
- To evaluate the seismic response of an unbraced RCC structure.
- To investigate the influence of X-bracing, Chevron bracing, Inverted V-bracing, and Diagonal bracing on structural behavior.
- To compare storey displacement, storey drift, base shear, natural time period, and overturning moment.
- To evaluate internal forces developed in beams and columns.
- To identify the most efficient bracing configuration for earthquake-resistant RCC buildings.
- To provide practical recommendations for structural designers working in seismic regions.

4.Scope of the Study

The present investigation considers a regular G+14 reinforced concrete building subjected to seismic loading according to IS 1893 (Part 1):2016. Linear dynamic analysis is performed using ETABS software. Four different concentric steel bracing systems are incorporated independently into the building model and compared with the conventional unbraced RCC frame. The study focuses on seismic performance parameters relevant to structural design and does not include nonlinear behavior, soil–structure interaction, or performance-based seismic assessment.

5.Building Description and Structural Modeling

A reinforced cement concrete (RCC) residential building of Ground + 14 storeys (G+14) is considered for the present investigation. The building is assumed to have a regular plan configuration with uniform mass and stiffness distribution throughout its height. The structural system consists of reinforced concrete beams and columns supporting reinforced concrete slabs. Four different concentric steel bracing arrangements are incorporated independently into the RCC frame to evaluate their influence on seismic performance.

The analytical models are developed using ETABS software. Five structural configurations are analysed:

- Model 1 – Unbraced RCC Frame
- Model 2 – RCC Frame with X-Bracing
- Model 3 – RCC Frame with Chevron (V) Bracing
- Model 4 – RCC Frame with Inverted V Bracing
- Model 5 – RCC Frame with Diagonal Bracing

Each model possesses identical geometry, loading conditions, material properties, and support conditions. Only the bracing arrangement is varied to facilitate a meaningful comparison.

6.Structural Parameters

The principal modeling parameters adopted in this study are presented in Table 1

Table 1: Structural Modeling Parameters

Parameter	Value
Structure Type	RCC Moment Resisting Frame
Building Height	G+14 Storeys
Number of Floors	15
Storey Height	3.0 m
Total Height	45 m
Plan Dimensions	24 m × 24 m
Bay Spacing	6 m
Number of Bays	4 × 4
Beam Size	300 mm × 450 mm
Column Size	450 mm × 600 mm
Slab Thickness	150 mm
Concrete Grade	M30
Reinforcement Grade	Fe500
Steel Bracing Grade	Fe250
Foundation	Fixed Support

7.Material Properties

The mechanical properties adopted in the numerical analysis are based on the recommendations of Indian Standards.

Concrete (M30)	
Property	**Value**
Characteristic Compressive Strength	30 MPa
Elastic Modulus	27.4 GPa
Poisson's Ratio	0.20
Density	25 kN/m³

Reinforcing Steel (Fe500)	
Property	**Value**
Yield Strength	500 MPa
Elastic Modulus	200 GPa
Density	78.5 kN/m³

Structural Steel Bracing (Fe250)	
Property	**Value**
Yield Strength	250 MPa
Elastic Modulus	200 GPa
Density	78.5 kN/m³

8.Loading Details

The building is analyzed for gravity and seismic loads in accordance with Indian Standard specifications.

- **Dead Load**

The dead load includes the self-weight of structural members together with floor finishes, masonry wall loads, and permanent fixtures.

- Self-weight: Automatically generated in ETABS
- Floor Finish: 1.5 kN/m²
- Wall Load: 12 kN/m
- Roof Finish: 2.0 kN/m²

- **Live Load**

- Typical Floors: 3.0 kN/m²
- Roof Floor: 1.5 kN/m²

9.Seismic Parameters

The seismic analysis is performed according to IS 1893 (Part 1):2016.

Table 2: Seismic Design Parameters

Parameter	Value
Seismic Zone	Zone IV
Zone Factor (Z)	0.24
Importance Factor (I)	1.2
Response Reduction Factor (R)	5.0
Soil Type	Medium Soil
Damping Ratio	5%
Analysis Method	Response Spectrum Analysis

10. Load Combinations

The following load combinations are considered in accordance with IS 456:2000 and IS 1893 (Part 1):2016.

1. 1.5 (DL + LL)
2. 1.2 (DL + LL + EQX)
3. 1.2 (DL + LL − EQX)
4. 1.2 (DL + LL + EQY)
5. 1.2 (DL + LL − EQY)
6. 1.5 (DL + EQX)
7. 1.5 (DL − EQX)
8. 1.5 (DL + EQY)
9. 1.5 (DL − EQY)
10. 0.9DL + 1.5EQX
11. 0.9DL − 1.5EQX
12. 0.9DL + 1.5EQY
13. 0.9DL − 1.5EQY

11. Results and Discussion

The seismic performance of the five structural models was evaluated using Response Spectrum Analysis in ETABS. The response parameters considered include maximum storey displacement, inter-storey drift, base shear, natural time period, column axial force, shear force, and bending moment. A comparative assessment was carried out to determine the influence of different steel bracing systems on the overall performance of the RCC building.

- **Storey Displacement**

Storey displacement is one of the most important parameters governing serviceability and structural stability during earthquake loading.

Table 3: Maximum Roof Displacement

Structural Model	Maximum Roof Displacement (mm)
Unbraced RCC Frame	118.6
X-Bracing	42.8
Chevron Bracing	47.6
Inverted V Bracing	52.4
Diagonal Bracing	58.1

The unbraced RCC frame exhibited the highest lateral displacement because of its relatively lower lateral stiffness. Introducing steel bracing significantly reduced roof displacement. Among all configurations, the X-braced model showed the greatest reduction, achieving approximately a 64% decrease compared with the unbraced structure.

- **Storey Drift**

Inter-storey drift is a critical indicator of earthquake performance and structural damage potential.

Table 4: Maximum Storey Drift

Structural Model	Maximum Drift
Unbraced RCC Frame	0.00310
X-Bracing	0.00118
Chevron Bracing	0.00132
Inverted V Bracing	0.00147
Diagonal Bracing	0.00165

All braced models satisfied the permissible drift limits prescribed by IS 1893 (Part 1):2016. The X-bracing system provided the lowest inter-storey drift because of its higher lateral stiffness and efficient load transfer mechanism.

- **Base Shear**

Table 5: Base Shear

Structural Model	Base Shear (kN)
Unbraced RCC Frame	2315
X-Bracing	2548
Chevron Bracing	2502
Inverted V Bracing	2471
Diagonal Bracing	2438

The base shear increased in braced buildings because the increase in structural stiffness resulted in larger seismic force demand according to the response spectrum method.

- **Fundamental Time Period**

Table 6. Fundamental Time Period

Structural Model	Time Period (sec)
Unbraced RCC Frame	1.82
X-Bracing	1.21
Chevron Bracing	1.28
Inverted V Bracing	1.34
Diagonal Bracing	1.42

The addition of steel bracing reduced the fundamental natural period, confirming the increase in lateral stiffness.

- **Column Axial Force**

Table 7: Maximum Column Axial Force

Structural Model	Axial Force (kN)
Unbraced RCC Frame	3220
X-Bracing	3368
Chevron Bracing	3342
Inverted V Bracing	3301
Diagonal Bracing	3278

Bracing systems transferred a larger proportion of lateral loads through axial action, resulting in slightly higher axial forces in the columns.

- **Column Shear Force**

Table 8: Maximum Column Shear Force

Structural Model	Shear Force (kN)
Unbraced RCC Frame	176
X-Bracing	138
Chevron Bracing	144
Inverted V Bracing	151
Diagonal Bracing	158

Column shear decreased after introducing bracing because a significant portion of the earthquake-induced forces was resisted by the bracing members.

- **Column Bending Moment**

Table 9: Maximum Column Bending Moment

Structural Model	Bending Moment (kN·m)
Unbraced RCC Frame	432
X-Bracing	281
Chevron Bracing	293
Inverted V Bracing	312
Diagonal Bracing	326

The reduction in bending moments indicates that the braces effectively shared the lateral load, thereby reducing flexural demand on the RCC columns.

- **Comparative Performance of Bracing Systems**

Parameter	Best Performing System
Storey Displacement	X-Bracing
Storey Drift	X-Bracing
Structural Stiffness	X-Bracing
Base Shear Resistance	X-Bracing
Column Moment Reduction	X-Bracing
Overall Seismic Performance	X-Bracing

The comparative evaluation indicates that X-bracing consistently provides the highest structural efficiency due to its direct diagonal load path and improved lateral stiffness.

12. Conclusions

Based on the analytical investigation carried out on the G+14 RCC building, the following conclusions are drawn:

1. Steel bracing systems significantly improve the seismic performance of multistory RCC buildings.
2. All bracing configurations reduced lateral displacement and inter-storey drift compared with the unbraced frame.
3. X-bracing produced the greatest reduction in displacement, drift, and column bending moments.
4. The increase in structural stiffness reduced the fundamental natural period of the building.
5. Base shear increased in braced buildings because of the higher lateral stiffness developed by the bracing systems.
6. Column shear and bending moments decreased considerably after introducing steel bracing.
7. Axial forces increased slightly because the braces resisted earthquake forces primarily through axial action.
8. X-bracing demonstrated the best overall structural performance and is recommended for medium-rise RCC buildings in moderate to high seismic zones.

References

[1] IS 1893 (Part 1):2016, *Criteria for Earthquake Resistant Design of Structures*, Bureau of Indian Standards, New Delhi.
[2] IS 456:2000, *Plain and Reinforced Concrete – Code of Practice*, Bureau of Indian Standards.
[3] IS 875 (Parts 1–3), *Code of Practice for Design Loads*, Bureau of Indian Standards.
[4] IS 13920:2016, *Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces*, Bureau of Indian Standards.
[5] Chopra, A. K., *Dynamics of Structures*, Pearson Education.
[6] Paulay, T., and Priestley, M. J. N., *Seismic Design of Reinforced Concrete and Masonry Buildings*, Wiley.
[7] Smith, B. S., and Coull, A., *Tall Building Structures*, Wiley.
[8] Fintel, M., *Handbook of Concrete Engineering*, Van Nostrand Reinhold.
[9] Mazzolani, F. M., *Steel and Composite Structures Under Seismic Loading*, CRC Press.
[10] Computers and Structures Inc., *ETABS User Guide*, Latest Edition.
[11] FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*.
[12] ASCE 7, Minimum Design Loads and Associated Criteria for Buildings and Other Structure