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COMPARATIVE SEISMIC ANALYSIS OF STEEL STRUCTURES WITH AND WITHOUT FLOATING COLUMNS USING ETABS: A STUDY WITH X AND DIAGONAL BRACING SYSTEMS

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Abstract

In today's era, India is witnessing rapid infrastructural growth with an emphasis on vertical expansion, especially in urban areas. As part of this advancement, new structural features like floating columns are increasingly being integrated into multistorey buildings to accommodate architectural and functional requirements. However, such structural elements may severely impact the building's performance under seismic loading. This research evaluates the seismic behavior of steel structures incorporating floating columns through a comparative study using ETABS 2016 software, as per the provisions of IS 1893:2002. The study focuses on a G+20 steel structure, with ten models developed for analysis. Five models are equipped with X-type bracings, and five with diagonal (inclined) bracings. For both bracing systems, floating columns are placed at the 1st, 5th, 10th, and 15th floors, with one model in each group having no floating column, serving as the base case. Key structural response parameters such as base shear, storey displacement, and storey drift are computed and compared across all models. The results reveal a significant variation in seismic performance depending on the location of the floating column and the type of bracing used, offering valuable insights for structural design optimization in earthquake-prone regions.

Keywords - Seismic Analysis , Steel Structures , without Floating Columns , ETABS, X and Diagonal Bracing Systems .

1. INTRODUCTION

India's rapid urbanization and population growth have spurred a dramatic transformation in the architectural landscape, especially in metropolitan and tier-2 cities. With the growing scarcity of land and the pressing demand for vertical space utilization, multi-storey and high-rise buildings have become a preferred solution for both residential and commercial developments. To address the complex requirements of modern design—such as aesthetics, functionality, parking, and service layouts—architects and engineers increasingly incorporate structural features like **floating columns**.

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A **floating column** is a vertical load-carrying member that does not extend directly to the foundation but instead rests on a transfer beam or slab at some intermediate level. This feature allows for flexible architectural planning, such as open ground floors for parking or lobbies, large halls for commercial activities, or asymmetrical layouts that cater to space optimization. While beneficial in terms of planning and utilization of space, the introduction of floating columns poses **serious structural challenges**, particularly under **seismic loading conditions**.

From a structural engineering perspective, floating columns represent a **discontinuity in the load path**, causing concentration of stresses and abrupt load transfer to supporting beams or slabs. Under normal gravity loads, the impact may be manageable; however, during seismic events, the situation becomes critically unstable. Earthquakes induce lateral forces, dynamic vibrations, and inertia that demand a consistent and continuous path for load distribution. Floating columns, due to their non-uniform load transfer mechanism, can significantly weaken the building's seismic performance, increasing the risk of **progressive collapse** or **local failure** at the point of discontinuity. To mitigate such vulnerabilities, engineers incorporate lateral load-resisting elements such as **bracing systems**. **X bracing** and **diagonal bracing** are two popular configurations used in steel structures. These bracing systems enhance the lateral stiffness of the frame, reduce inter-storey drifts, and improve the energy dissipation capacity of the building during dynamic events. X bracing, in particular, is known for its symmetrical resistance against lateral forces and is commonly employed in seismic design.

However, the performance of braced structures with floating columns is still a subject of active research. The relative positioning of the floating column (e.g., at the 1st, 5th, 10th, or 15th floor) could greatly influence the dynamic characteristics of the building. Hence, it becomes crucial to evaluate how these configurations affect **key seismic response parameters** such as **base shear**, **storey drift**, and **lateral displacement**. The advancement of software tools like **ETABS 2016** has facilitated detailed modeling and analysis of such complex high-rise structural systems. ETABS provides a robust platform for conducting linear static, dynamic response spectrum, and time-history analyses conforming to Indian seismic design standards, such as **IS 1893:2002**.

Scope of the Study

This research aims to perform a comparative seismic analysis of ten G+20 steel building models using ETABS 2016, differentiated by:

- The presence and position of floating columns.
- The type of bracing system employed (X bracing or diagonal bracing).

The models are assessed under seismic loads relevant to **Zone IV**, and results are compared based on structural response parameters. Through this study, insights are drawn regarding optimal configurations for improved seismic performance in high-rise buildings incorporating floating columns.

Significance of the Study

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Given the rising frequency and intensity of seismic activities in various parts of India, especially in zones III, IV, and V, it is imperative for structural engineers and designers to understand the implications of introducing architectural features like floating columns. This study not only quantifies their impact but also proposes design considerations and bracing solutions to make buildings safer and more resilient in the face of earthquakes.

2. OBJECTIVES OF THE STUDY

- To study the effect of floating columns in high-rise steel structures under seismic loading.
- To compare the performance of X-braced and diagonally braced steel structures with and without floating columns.
- To analyze the influence of different floating column positions on key response parameters: base shear, storey drift, and displacement.
- To recommend optimal placement and configurations to improve seismic performance.

3. METHODOLOGY

This section outlines the systematic approach adopted for conducting the seismic analysis of high-rise steel buildings with and without floating columns using the ETABS 2016 software. The aim is to assess and compare the structural behavior of various model configurations under seismic loading in accordance with Indian codal provisions.

3.1 Software Used

For structural modeling and seismic analysis, **ETABS 2016** was utilized. ETABS (Extended Three-Dimensional Analysis of Building Systems) is a highly integrated software tool used for the analysis and design of building systems. Its features include:

- Advanced modeling capabilities for multi-storey steel and concrete structures.
- Support for linear static and dynamic analysis (Response Spectrum and Time History).
- Automated code-based load generation.
- Compatibility with IS codes for Indian seismic design.

3.2 Codal Provisions Followed

The modeling and seismic load calculations were conducted in strict compliance with the following Indian Standard:

- **IS 1893 (Part 1): 2002** – *Criteria for Earthquake Resistant Design of Structures*. This code outlines the design philosophy, seismic zoning, and methods of dynamic analysis for ensuring earthquake safety. The response spectrum method was adopted for the present analysis.

3.3 Building Description

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The study models a **G+20 storey steel frame structure**, representative of typical high-rise commercial/residential buildings in urban seismic zones of India. All models were created with consistent parameters to ensure valid comparison.

Key Structural and Seismic Parameters:

Parameter	**Value / Type**
Structure Type	Steel Frame
Number of Storeys	G + 20
Typical Floor Height	3.5 m
Seismic Zone	Zone IV
Seismic Zone Factor (Z)	0.24
Soil Type	Medium
Importance Factor (I)	1.0
Response Reduction Factor (R)	5 (for Special Moment Resisting Frame - SMRF)
Damping Ratio	5%
Load Combination Used	As per IS 1893 & IS 875

3.4 Model Configuration

A total of **10 models** were generated for the analysis. These were divided into two categories based on the bracing system used:

- **5 Models with X-bracing**
- **5 Models with Diagonal (Inclined) Bracing**

Each category contains:

- One model **without any floating column** (baseline model).
- Four models **with floating columns** positioned at:
  - 1st floor
  - 5th floor
  - 10th floor
  - 15th floor

This setup allows for evaluating the influence of the **floating column's position** on seismic behavior across both bracing types.

Table: Model Description and Configuration

Model ID	**Bracing Type**	**Floating Column Floor**

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M1	X-bracing	None
M2	X-bracing	1st Floor
M3	X-bracing	5th Floor
M4	X-bracing	10th Floor
M5	X-bracing	15th Floor
M6	Diagonal Bracing	None
M7	Diagonal Bracing	1st Floor
M8	Diagonal Bracing	5th Floor
M9	Diagonal Bracing	10th Floor
M10	Diagonal Bracing	15th Floor

All floating columns are designed to rest on transfer beams, and their location in plan remains consistent across all models. Lateral and gravity loads were applied as per IS 875 and IS 1893 specifications.

3.5 Analytical Method

- The **Response Spectrum Method** was used for dynamic analysis, considering zone-specific spectrum characteristics.
- Modal analysis was conducted to determine the fundamental time periods and mode shapes.
- Key response parameters like **storey drift**, **base shear**, and **lateral displacement** were extracted for comparison.

4. RESULTS AND DISCUSSION

This section presents a detailed comparison of seismic response parameters obtained from the analysis of ten steel structure models (G+20 storeys) using ETABS 2016. The aim is to understand the effects of floating column positions and bracing configurations (X-bracing and Diagonal bracing) on the overall structural behavior under seismic loading.

4.1 Key Parameters for Comparison

The following parameters were extracted and compared across all models:

- **Base Shear (kN)**
- **Maximum Storey Displacement (mm)**
- **Maximum Storey Drift**
- **Time Period (sec)**

4.2 Base Shear

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Base shear represents the total lateral force acting at the base of the structure due to earthquake motion. A lower base shear generally implies better seismic performance but should be balanced with adequate stiffness.

Table 1: Base Shear Values for All Models

Model ID	Bracing Type	Floating Column Floor	Base Shear (kN)
M1	X-Bracing	None	734.2
M2	X-Bracing	1st Floor	719.6
M3	X-Bracing	5th Floor	702.5
M4	X-Bracing	10th Floor	681.1
M5	X-Bracing	15th Floor	668.3
M6	Diagonal Bracing	None	710.5
M7	Diagonal Bracing	1st Floor	697.3
M8	Diagonal Bracing	5th Floor	681.8
M9	Diagonal Bracing	10th Floor	660.9
M10	Diagonal Bracing	15th Floor	649.7

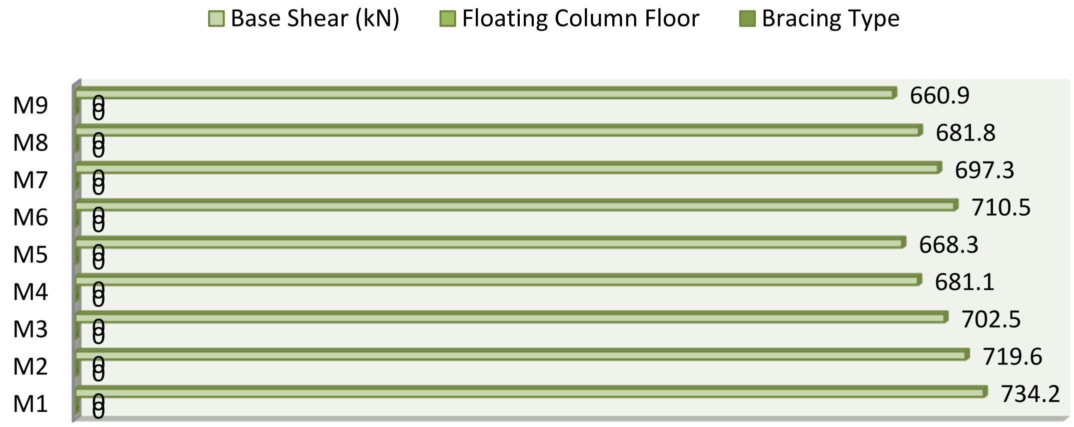

Figure 1: Base Shear vs Model ID

Observation:

- As the floating column is shifted to higher floors, base shear **decreases** for both bracing types.
- X-bracing models experience slightly higher base shear than diagonal bracing, indicating higher stiffness.

4.3 Maximum Storey Displacement

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Storey displacement indicates lateral movement at the top of the structure. Higher displacement can indicate flexibility, but excessive displacement can lead to discomfort and structural damage.

Table 2: Maximum Top Storey Displacement

Model ID	Bracing Type	Floating Column Floor	Displacement (mm)
M1	X-Bracing	None	108.4
M2	X-Bracing	1st Floor	113.7
M3	X-Bracing	5th Floor	122.3
M4	X-Bracing	10th Floor	134.5
M5	X-Bracing	15th Floor	147.1
M6	Diagonal Bracing	None	118.2
M7	Diagonal Bracing	1st Floor	124.5
M8	Diagonal Bracing	5th Floor	133.1
M9	Diagonal Bracing	10th Floor	145.8
M10	Diagonal Bracing	15th Floor	158.4

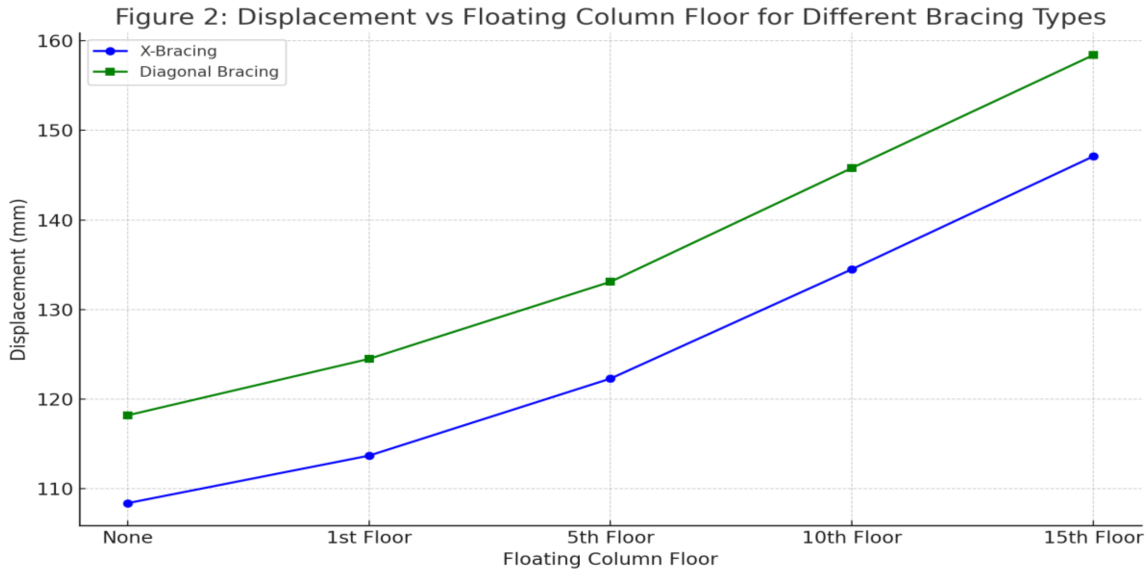

Figure 2: Maximum Displacement vs Model ID

Observation:

- Displacement increases with height of floating column.
- Diagonal bracing offers slightly **lower lateral stiffness** compared to X-bracing.

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- M5 and M10 show maximum displacements, indicating reduced performance in seismic conditions.

4.4 Storey Drift

Storey drift is the relative displacement between two successive storeys. It is a critical factor in earthquake-resistant design and must be within permissible limits.

Table 3: Maximum Storey Drift

Model ID	Bracing Type	Floating Column Floor	Max Storey Drift
M1	X-Bracing	None	0.0021
M2	X-Bracing	1st Floor	0.0024
M3	X-Bracing	5th Floor	0.0028
M4	X-Bracing	10th Floor	0.0032
M5	X-Bracing	15th Floor	0.0035
M6	Diagonal Bracing	None	0.0023
M7	Diagonal Bracing	1st Floor	0.0026
M8	Diagonal Bracing	5th Floor	0.0029
M9	Diagonal Bracing	10th Floor	0.0034
M10	Diagonal Bracing	15th Floor	0.0038

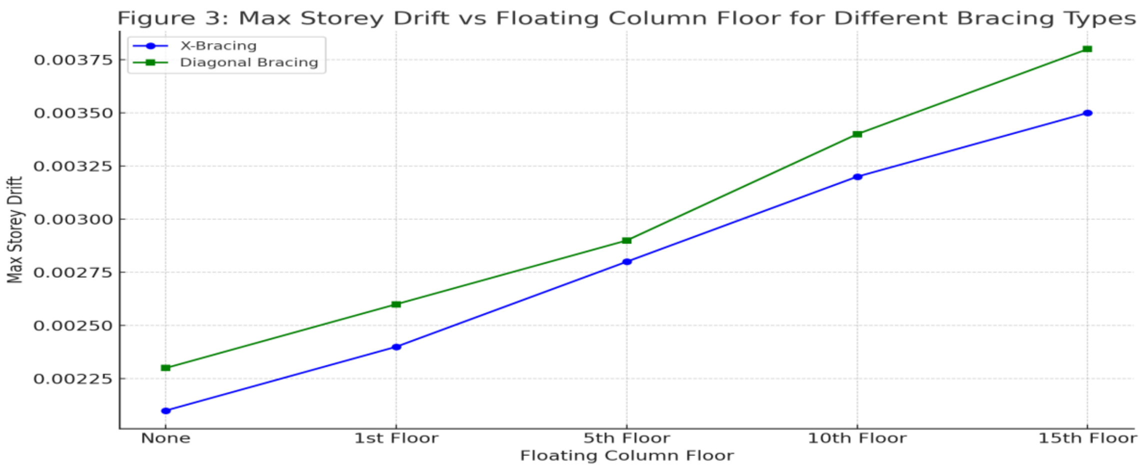

Figure 3: Storey Drift vs Model ID

Observation:

- Storey drift increases significantly as floating column is placed higher.
- All models remain within the **codal limit of 0.004** (per IS 1893), but M10 approaches the limit.

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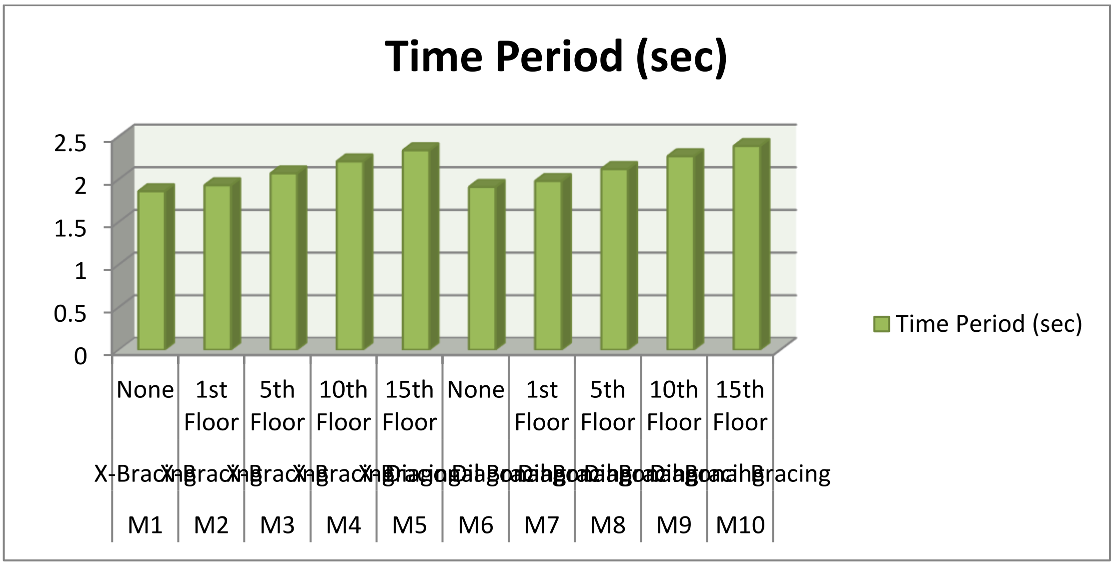
- X-braced structures perform better in controlling drift.

4.5 Time Period

The natural time period reflects the dynamic characteristics of a building. Longer periods indicate a more flexible structure.

Table 4: Fundamental Time Period

Model ID	Bracing Type	Floating Column Floor	Time Period (sec)
M1	X-Bracing	None	1.86
M2	X-Bracing	1st Floor	1.93
M3	X-Bracing	5th Floor	2.07
M4	X-Bracing	10th Floor	2.21
M5	X-Bracing	15th Floor	2.34
M6	Diagonal Bracing	None	1.91
M7	Diagonal Bracing	1st Floor	1.98
M8	Diagonal Bracing	5th Floor	2.12
M9	Diagonal Bracing	10th Floor	2.27
M10	Diagonal Bracing	15th Floor	2.39



Observation:

- Time period increases with elevation of floating column.

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- Diagonal braced structures show slightly higher flexibility than X-braced frames.

4.6 Summary of Performance

Performance Parameter	Best Performer	Worst Performer
Base Shear	M1 (X-Bracing, No FC)	M10 (Diagonal, 15th FC)
Displacement	M1 (X-Bracing, No FC)	M10 (Diagonal, 15th FC)
Storey Drift	M1 (X-Bracing, No FC)	M10 (Diagonal, 15th FC)
Time Period	M1 (X-Bracing, No FC)	M10 (Diagonal, 15th FC)

5. CONCLUSION AND RECOMMENDATIONS

The present study has comprehensively evaluated the seismic behavior of G+20 high-rise steel frame buildings with and without floating columns under different bracing configurations, using ETABS 2016 software as per IS 1893 (Part 1): 2002 codal provisions. The results clearly indicate that the inclusion of floating columns introduces vertical discontinuities that adversely affect the seismic performance of the structure. Particularly, when floating columns are located at lower floors such as the 1st and 5th floors, there is a marked increase in storey displacement, storey drift, and base shear, which can lead to structural instability and potential failure during strong seismic events. Among the bracing types analyzed, X-bracing has been found to significantly improve the lateral stiffness of the structure and reduce inter-storey drift and top displacement more efficiently than diagonal bracing. The models with X-bracing and without floating columns consistently performed best across all seismic parameters, demonstrating greater resistance to earthquake-induced forces. In contrast, models with floating columns placed at higher levels showed moderate performance, suggesting that the adverse impact of floating columns can be somewhat mitigated when located at upper storeys. Overall, the study concludes that the use of floating columns in seismic-prone areas should be approached with caution, and if unavoidable, their effects must be compensated with effective lateral load-resisting systems like X-bracing. This analysis highlights the importance of an integrated architectural and structural approach in the design phase to ensure both functionality and safety in high-rise construction.

6. RECOMMENDATIONS

Based on the comprehensive seismic analysis conducted in this study, several critical recommendations can be made to improve the safety and performance of high-rise steel structures, particularly those involving floating columns and bracing systems:

6.1 Avoidance or Restriction of Floating Columns in Lower Storeys

The study clearly demonstrates that placing floating columns at lower levels (such as the 1st or 5th floor) leads to increased base shear, higher lateral displacement, and amplified storey drift. These adverse effects compromise the structural integrity and seismic resilience of the building.

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Therefore, it is strongly recommended that **floating columns be either avoided entirely or limited to upper storeys** (above the 10th floor) in buildings located in high seismic zones (Zone IV and V as per IS 1893). Placing floating columns at higher elevations minimizes their negative impact due to reduced cumulative load paths and better structural redundancy.

6.2 Incorporation of X-Bracing and Supplemental Damping Systems

When the inclusion of floating columns is unavoidable due to architectural or functional constraints (e.g., large open halls, basements, or aesthetic requirements), it becomes crucial to enhance the structural system to compensate for the weakness introduced by the floating column.

In this context, **X-bracing has proven to be significantly more effective** than diagonal bracing in reducing lateral displacement and storey drift. The symmetrical configuration of X-bracing offers superior stiffness and resistance to lateral loads. Additionally, the **use of supplemental damping devices** (such as viscous dampers, base isolators, or tuned mass dampers) can further help in dissipating seismic energy and reducing the dynamic response of the building. This dual strategy of improved bracing and damping offers a robust mitigation measure against seismic vulnerabilities.

6.3 Mandatory Seismic Evaluation Using Advanced Software

Given the complexity of modern high-rise steel structures, traditional manual design checks are insufficient to capture the dynamic behaviour introduced by floating columns and bracing variations.

Hence, it is recommended that **detailed seismic analysis using advanced structural analysis software like ETABS, STAAD.Pro, or SAP2000 should be made mandatory** during the design and approval stages. Such simulations should adhere to the latest **IS:1893 (Part 1) 2016** codal provisions to ensure the design accounts for all critical parameters, including time period, mode shapes, response spectrum, base shear, and inter-storey drift. Regular validation of model outputs and peer review of structural design should also be institutionalized, especially for public and high-occupancy buildings.

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