Optimizing the Efficient Height Combination of Twin Towers under Earthquake Loading

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Abstract

The rapid urbanization of metropolitan areas has spurred the development of high-rise structures, including Twin Towers, to meet residential and commercial demands. This study investigates the seismic performance of Twin Tower structures with varying height combinations under earthquake loading in Seismic Zone III. Eleven distinct height combinations (labeled A to K) were modeled and analyzed using STAAD.Pro software via the Response Spectrum Method, adhering to IS 1893 (Part 1): 2016 guidelines. Key parameters such as maximum displacement, base shear, time period, mass participation factor, axial forces, shear forces, bending moments, and torsional moments were evaluated to identify the most efficient configuration. Results indicate that Height Combination B consistently outperforms other configurations across multiple criteria, demonstrating optimal seismic resilience and structural efficiency. This research provides valuable insights for designing seismically resistant Twin Tower structures while addressing urban challenges like parking and space utilization.

Keywords: Twin Towers, Seismic Zone III, Response Spectrum Analysis, STAAD.Pro, Earthquake Loading, Structural Efficiency

1. Introduction

High-rise buildings, particularly Twin Towers, have become a cornerstone of modern urban development, offering solutions to space constraints in densely populated cities. Twin Towers are characterized by two adjacent structures connected at various levels (e.g., ground, mid-height, or top) or via a common podium, designed to withstand lateral loads such as wind and earthquakes. In seismic regions like Zone III, as defined by IS 1893 (Part 1): 2016, ensuring structural stability under earthquake loading is critical. However, the absence of specific seismic design codes for Twin Towers poses a challenge, necessitating detailed analytical studies.

This research aims to optimize the height combination of Twin Towers to enhance their seismic performance. Using STAAD.Pro software, eleven height combinations (A to K) were analyzed to evaluate their behavior under earthquake forces. The study focuses on parameters such as displacement, base shear, and internal forces, providing a basis for identifying the most efficient and safe configuration.

2. Literature Review

Previous studies have explored the seismic behavior of high-rise structures, with a focus on lateral load-resisting systems like shear walls, bracings, and dampers. Petroski (1996) emphasized the challenges in designing tall buildings, highlighting material selection (concrete vs. steel) as a critical decision. Lu et al. (1997) investigated the seismic safety of high-rise buildings through model testing, underscoring the importance of material quality and structural dynamics. Chaurasiya and Jamle (2019) reviewed Twin Tower designs under seismic loading, noting their growing relevance but limited codal guidance.

Other researchers, such as Huang et al. (1998), proposed simplified methods for analyzing connected towers, treating connections as extensible beams to account for interaction effects. Smith and Willford (2000) introduced damped outrigger systems for tall buildings, improving seismic performance cost-effectively. However, few studies have systematically evaluated the impact of varying Twin Tower heights on seismic response, a gap this research addresses.

3. Methodology

3.1 Modeling Approach

Eleven Twin Tower models (A to K) with varying height combinations were developed in STAAD.Pro software. The Response Spectrum Method, as per IS 1893 (Part 1): 2016, was employed for seismic analysis in Zone III. This method assesses the contribution of multiple vibration modes to the structure’s seismic response, offering a robust approach for linear dynamic analysis.

3.2 Model Details

- **Building Type**: Commercial
- **Soil Type**: Medium
- **Seismic Zone**: III
- **Response Reduction Factor (SMRF)**: 4
- **Importance Factor**: 1.2
- **Damping Ratio**: 5%
- **Fundamental Time Period**: Tax = Taz = 0.692 s
- **Dimensions**: 45 m x 45 m plan, height = 51.58 m
- **Structural Elements**: Beams (750 mm x 650 mm), Columns (550 mm x 450 mm)
- **Material**: M30 concrete, Fe415 steel
- **Supports**: Fixed

3.3 Load Considerations

- **Dead Load (DL)**: Self-weight of the structure
- **Live Load (LL)**: As per IS 875 (Part II)
- **Earthquake Load (EQ)**: Defined in X and Z directions per IS 1893 (Part 1): 2016
- **Load Combinations**: Included 1.2(DL + LL + EQ), 1.5(DL + EQ), and 0.9DL + 1.5EQ, among others

3.4 Analysis Procedure

1. Model creation in STAAD.Pro using grid coordinates.
2. Assignment of member properties, supports, and loads.
3. Application of Response Spectrum Analysis.
4. Extraction of results for displacement, base shear, forces, and moments.

4. Results and Discussion

4.1 Maximum Displacement

- **X Direction**: Combination B exhibited the lowest displacement (122.788 mm), indicating superior stiffness compared to Combination J (161.825 mm).
- **Z Direction**: Combination A showed the least displacement (168.458 mm), while Combination J had the highest (244.738 mm). Combination B (178.957 mm) remained competitive.

4.2 Base Shear

- **X Direction**: Combination I recorded the lowest base shear (9804.96 kN), while Combination J had the highest (30472.28 kN). Combination B (16797.29 kN) balanced efficiency and capacity.
- **Z Direction**: Combination K had the lowest base shear (8015.43 kN), with Combination G peaking at 15221.03 kN. Combination B (13996.19 kN) performed well.

4.3 Time Period and Mass Participation

- **Time Period**: Ranged from 1.320 s (Combination K) to 1.381 s (Combination A) in X direction, and 0.646 s (Combination F) to 1.711 s (Combination H) in Z direction.
- **Mass Participation**: Combination A achieved the highest X-direction participation (44.974%), while Combination K led in Z-direction (15.267%). Combination B showed balanced participation (38.447% in X, 18.076% in Z).

4.4 Forces and Moments

- **Column Axial Force**: Combination A had the lowest (8502.388 kN), while Combination J peaked at 9927.641 kN. Combination B (8698.226 kN) was efficient.
- **Column Shear and Bending Moment**: Combination B consistently showed lower values (e.g., shear: 306.869 kN in Y, 397.620 kN in Z; moment: 783.494 kNm in Y, 695.994 kNm in Z) compared to higher combinations like J and K.

- **Beam Shear and Bending Moment**: Combination B exhibited optimal values (e.g., shear: 162.153 kN in X, 3.124 kN in Z; moment: 7.810 kNm in X, 264.028 kNm in Z).
- **Torsional Moment**: Combination B maintained low torsional moments (29.266 kNm in X, 28.428 kNm in Z), outperforming taller combinations like J (36.762 kNm in X, 35.148 kNm in Z).

4.5 Discussion

Combination B emerged as the most efficient height configuration, demonstrating minimal displacement, balanced base shear, and optimized force and moment distribution. Taller combinations (e.g., J, K) exhibited higher displacements and internal forces, reflecting reduced seismic efficiency due to increased flexibility and mass. Combination B's performance aligns with economic and safety considerations, making it a practical choice for Twin Tower designs in Zone III.

5. Conclusion

This study analyzed eleven Twin Tower height combinations under earthquake loading in Seismic Zone III, using STAAD.Pro and the Response Spectrum Method. Combination B proved to be the most efficient, excelling in displacement control, base shear management, and internal force optimization. This configuration satisfies safety and economic criteria, offering a robust solution for Twin Tower designs. Future research could explore asymmetrical towers, shock-absorbing systems, and additional seismic zones to further enhance design guidelines.

6. Future Scope

- Investigate Twin Towers with unequal heights.
- Assess performance across all seismic zones per IS 1893:2016.
- Develop simplified construction techniques for Twin Towers.
- Explore unsymmetrical designs due to site constraints.

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