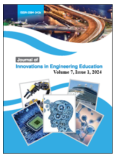

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Tribhuvan University

Structural performance optimization of Reinforced concrete buildings with rooftop Telecommunication towers: A location-based analysis

Bimal Ojha[a], Sabin Khatri [a], Prabin Pokharel[a], Rasique Jirel[a], Binaya Jamarkattel[a] and Abhinesh Khatri [b,*]

[a]*Department of Civil Engineering, Institute of Engineering, Thapathali Campus*
[b]*Department of Civil Engineering, Kantipur Engineering College*

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Abstract

This study evaluates the structural response of an RCC building in Parbat, Nepal, with a rooftop telecommunication tower positioned at various locations. In our case, a telecommunication tower is already located at a certain position in the building, and we are trying to evaluate the optimal position of telecommunication tower. The site lies in seismic Zone V as per IS 1893:2016 (Part 1), indicating very high seismic activity, and is subject to significant wind loads. This study examines the structural response of an RCC building with a rooftop telecommunication tower, using ETABS 18.1.1 and adhering to IS 1893:2016 (Part 1) seismic design standards. The analysis focuses on the impact of tower placement on critical structural parameters, such as base shear, nodal displacement, axial and shear forces, and bending and torsional moments. Through five tower placement scenarios, the study highlights significant findings: a 2.37% increase in base shear, up to 9.86% variation in axial forces, and a maximum 26.60% change in shear forces. By isolating tower location as a variable, this research provides detailed insights into how tower positioning affects building performance. A finite element analysis approach is used, ensuring accuracy by explicitly modeling RCC-steel tower interactions and bolted connection of telecommunication tower and RCC structure.

1. Introduction

Cities and human colonies are growing daily in today's environment, which is forcing our villages and agricultural fields to shrink. To avoid needless usage of land that is used for tall constructions is crucial. It lowers additional land use and expenses. In order to save land from needless construction, towers are now moved onto buildings [1]. The tower on building saves the extra land cost and if the analysis and modeling of the structure is accurate we can easily find out the safety of the structure against lateral loads and against sliding [2]. Buildings are used by tower companies for towers; they can be rented out or used permanently. Despite these advancements, substantial research gaps persist. There is a notable absence of comprehensive guidelines from regulatory bodies like the National Telecommunications Authority (NTA), and a lack of standardized protocols for optimizing tower placement [3].

Recent research has increasingly focused on the complexities of integrating telecommunication towers into building structures, particularly rooftop installations in high-risk seismic zones. The challenge lies in understanding the dynamic interactions between these towers and supporting structures [4]. Pioneering work by Assi and McClure (2007) highlighted the critical need for comprehensive seismic analysis of rooftop telecommunication towers [5]. Since steel telecommunication towers have a different seismic response to seismic loads than concrete structures, an investigation of the seismic loads on steel telecommunication towers is to be conducted [6]. Moreover the safety against seismic loads, and wind loads is more important while analyzing the

*Corresponding author:
khatriabhinesh@gmail.com (A.K.)

buildings with roof-top telecommunication tower [7]. This study primarily focuses on optimal location of roof-top communication tower over a reinforced concrete building located in high seismic zone.

The building taken into consideration is located in Parbat District, Nepal, situated in Seismic Zone V (as per IS: 1893:2016 part 1) [8]. The building under study is a G+3 story RCC structure. Material properties are specified for both the concrete (Grade M20, Fe415 grade steel reinforcement) and the steel tower (structural steel, ISA 200x200x25 sections). The building along with roof-top communication tower is modeled using ETABS 18.1.1. Load configurations are calculated based on IS 875, which include dead load, live load, seismic load, and wind load and a comprehensive load combination matrix is established. Several tower placement scenarios are explored, including central, corner (with four variations), and edge positioning configurations. A parametric analysis is conducted to examine base shear variations, nodal displacements, axial force distributions, shear force characteristics, bending moments, and torsional moments.

2. Objectives

This study aims to evaluate the structural response of a building with a rooftop telecommunication tower placed in various locations using ETABS. The specific objectives are:

- To analyze the building with a telecommunication tower at top using finite element analysis.
- To compare the response of building for various locations of telecommunication tower based on parameters like base shear, maximum nodal displacement, maximum axial, shear forces, bending moments and torsional moments in beams and columns.

3. Methodology

This study follows a systematic approach to evaluate the impact of telecommunication tower placement on the structural performance of reinforced concrete (RCC) buildings, specifically focusing on seismic load responses. The methodology is divided into the following key phases:

3.1. Preliminary investigations

3.1.1. Site characterization

- Location: Parbat District, Nepal
- Seismic Zone Classification: Zone V (High Seismic Risk)
- Environmental Conditions Assessment: Detailed evaluation of wind, temperature, and other environmental factors that influence the structure.

3.1.2. Building configuration

- G+3 story RCC structure is considered for modeling.
- Structural properties are defined as follows:
  1. Concrete Grade: M20 (Characteristic Compressive Strength: 20 MPa)
  2. Reinforcement: Fe415 grade steel
  3. Steel Tower Material: Structural steel (ISA 200x200x25 sections)

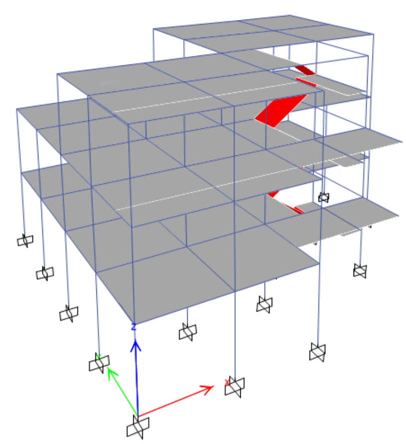

Figure 1: ETABS model of building

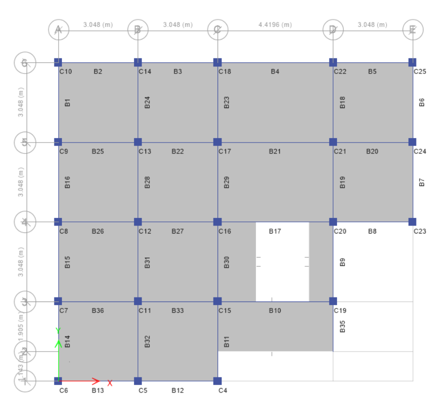

Figure 2: Floor plan of building

3.1.3. Modeling software

- ETABS 18.1.1 is used to conduct finite element analysis.

3.2. Analytical framework

3.2.1. Load Configuration

The following loads are applied based on relevant standards:

- Dead Load: Calculated using IS 875 Part 1 [9]
- Live Load: Determined according to IS 875 Part 2 [10]
- Seismic Load: Analyzed as per IS 1893:2016 [8]
- Wind Load: Calculated using IS 875 Part 3 [11]

3.2.2. Load combinations

- 1.5 Dead Load: Standard combination for general loading conditions.
- 1.5 Dead Load + 1.5 Live Load: Considered for the typical design scenario. Combined Seismic and Wind Load Interactions: The structural model also considers interactions between seismic, and wind loads under various scenarios.

These load combinations are incorporated into the model to simulate real-world forces that affect the structure.

3.3. Tower placement scenarios

Four distinct tower placement configurations are evaluated to assess their impact on the building's structural response:

- Central Placement: The telecommunication tower is placed centrally on the rooftop.
- Corner Placements: Two variations of tower placements at different corners of the rooftop.
- Edge Positioning: The tower is placed along the central edge of the building.

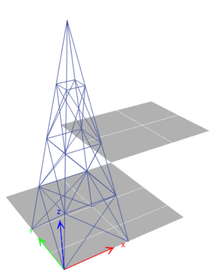

Figure 3: Tower at lower corner

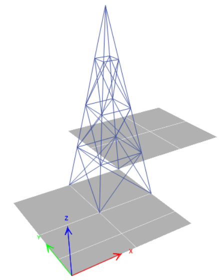

Figure 4: Tower at center

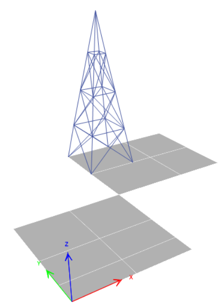

Figure 5: Tower at central edge

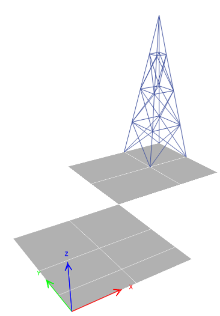

Figure 6: Tower at upper corner

3.4. Parametric analysis

The structural performance is analyzed by varying key parameters for each tower placement scenario. These include:

- Base Shear Variations: The force transmitted through the building's foundation during seismic events.
- Nodal Displacement: Shifts in the position of the building's structural nodes due to loads.
- Axial Force Distributions: The distribution of forces along the beams and columns.

- Shear Force Characteristics: Analysis of forces acting in perpendicular directions to structural elements.
- Bending Moment Analysis: The moment that causes bending in beams due to loads.
- Torsional Moment Evaluations: Rotational forces on the structure caused by eccentric loads.

3.5. Validation methodology

The results obtained through finite element analysis are validated through:

- Manual calculations to check for consistency with simulation results.
- Comparison with existing literature on similar structural studies.

4. Results

For the analysis, five cases were evaluated. For the five cases, following load combinations were used as per IS code (IS 456, Table 18) [12]:

1. 1.5DL
2. 1.5DL+1.5LL
3. 1.2DL+1.2LL±1.2WL
4. 1.5DL±1.5WL
5. 0.9DL±1.5WL
6. 1.2DL±1.2EL+1.2LL
7. 1.5DL±1.5EL
8. 0.9DL±1.5EL

The first case assessed the building without a tower, while the remaining four cases assessed different tower locations on the rooftop, as outlined below:
The above cases were analyzed by applying all the load combinations as per IS code (defined above) for the following parameters. For all the parameters, the case with the lowest value was defined as the optimum case for the particular parameter.

5. Discussion

The key findings from the analysis are as follows:

1. Base Shear: The addition of the telecommunication tower increased base shear by 2.37% in all cases when compared to the building without telecommunication tower. This increase is because of the additional seismic load due to the telecommunication tower.

Table 1: Base shear in X and Y direction

Case No.	Max Base Shear (kN)		Optimum Case
	X-Direction	Y-Direction	
0	525.3685	525.3685	All have same base shear
1	537.8044	537.8044	
2	537.8044	537.8044	
3	537.8044	537.8044	
4	537.8044	537.8044	

Remarks: With tower on top of the building, there was a 2.37% increase in base shear.

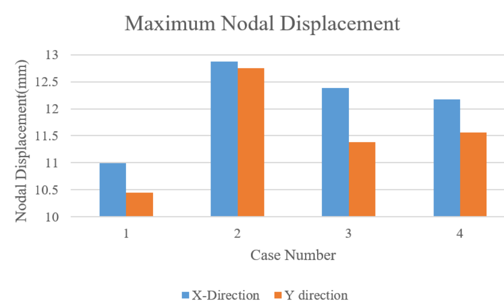

Figure 7: Maximum Nodal displacement

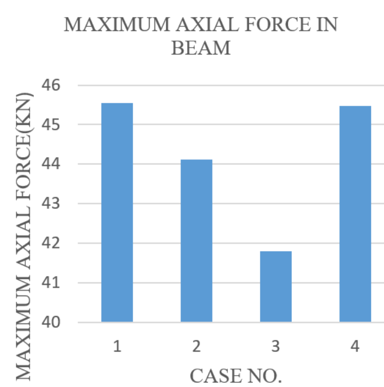

Figure 8: Maximum Axial force in beam

2. Nodal Displacement: The maximum nodal displacements in X and Y direction varied with tower location. The optimum case for nodal displacement was Case 1.
3. Axial Forces: The axial force in the beam increased by up to 9.86% (Case 1) and in column by up to 14.32% (Case 2) with the tower on top of the building. Case 3 showed the minimum axial force in the beam, and Case 4 showed the minimum axial force in the column.

Table 2: Maximum nodal displacement in X and Y direction

Case No.	Max Nodal Displacement(mm)		Optimum Case
	X-Direction	Y-Direction	
0	10.553	10.532	X-direction-Case 1, Y-Direction-Case 1
1	10.996	10.443	
2	12.877	12.753	
3	12.383	11.377	
4	12.178	11.563	
Remarks: With tower on top of the building, the maximum nodal displacement is minimum in case I.			

Table 3: Maximum Axial Force in Beam and Column

Case No.	Max Axial Force (KN)						Optimum Case	
	Beam			Column				
	Force (kN)	Storey	Label	Force (kN)	Storey	Label	Beam	Column
0	41.4538	1	B10	562.1814	1	C21	Case 3	Case 4
1	45.5416	1	B10	603.4081	1	C15		
2	44.1106	3	B29	642.6358	1	C21		
3	41.7909	2	B17	588.3941	1	C21		
4	45.4745	1	B10	566.3138	1	C15		
Remarks:	With the tower on top of the building, the axial force increased by up to 9.86% in the beam (Case 1) and up to 14.32% in the column (Case 2).							

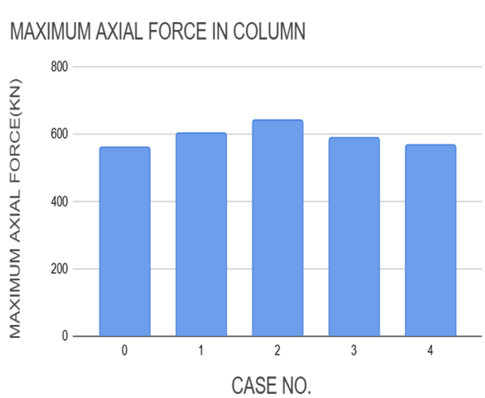

Figure 9: Maximum Axial force in Column

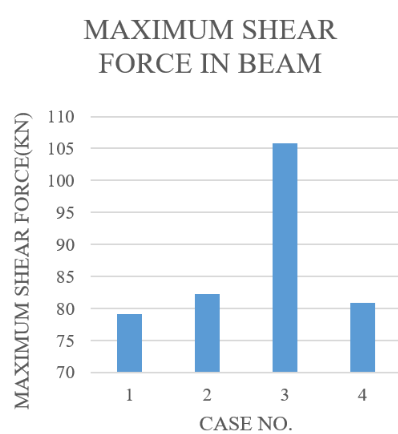

Figure 10: Maximum shear force in Beam

4. Shear Forces: The shear force in beams increased by up to 26.60% (Case 1) and in columns by up to 5.97% (Case 1). Case 1 showed minimum shear force in beam and Case 3 showed the minimum shear force in column.

5. Bending Moments: The bending moment in beams increased by up to 17.26% (Case 3) and in columns by up to 7.70% (Case 4). Case 2 showed minimum bending moment in beam and Case 3 showed minimum bending moment in column.

6. Torsional Moments: The torsional moment in beams increased by up to 3.69% (Case 4) and in columns by up to 5.73% (Case 3). Case 3 showed minimum torsional moment in beam and Case 1 showed minimum torsional moment in column.

The parameter increases due to the telecommunication tower because the tower adds additional mass and height to the building, which in turn increases the overall seismic and wind load. This additional load increases the forces and moments that the structure must resist during an earthquake. Specifically, the presence of the tower changes the dynamic characteristics of the building, leading to higher base shear, nodal displacement, axial and shear forces, and bending and torsional mo-

Table 4: Maximum shear force in Beam and Column

Case No.	Max Axial Force (KN)						Optimum Case	
	Beam			Column				
	Force (kN)	Storey	Label	Force (kN)	Storey	Label	Beam	Column
0	77.6576	1	B10	72.0496	1	C19	Case 1	Case 3
1	79.0952	1	B10	76.35	1	C19		
2	82.2815	1	B10	71.576	1	C19		
3	105.8023	3	B21	71.4741	1	C19		
4	80.9339	1	B10	77.1582	1	C19		
Remarks:	With the tower on top of the building, the shear force increased by up to 26.60% in beam (case 3) and up to 5.97% in column (Case 1).							

Table 5: Maximum bending moment in beams and columns

Case No.	Max Bending Moment (KN-m)						Optimum Case	
	Beam			Column				
	Moment	Storey	Label	Moment	Storey	Label	Beam	Column
0	58.7229	1	B10	66.3833	1	C19	Case 2	Case 3
1	61.385	1	B10	70.2645	1	C19		
2	58.0279	1	B17	65.8339	1	C19		
3	68.8613	3	B21	65.7372	1	C19		
4	62.7541	1	B10	71.4932	1	C19		
Remarks:	With the tower on top of the building, the bending moment increased by up to 17.26% in beam (case 3) and up to 7.70% in column (Case 4).							

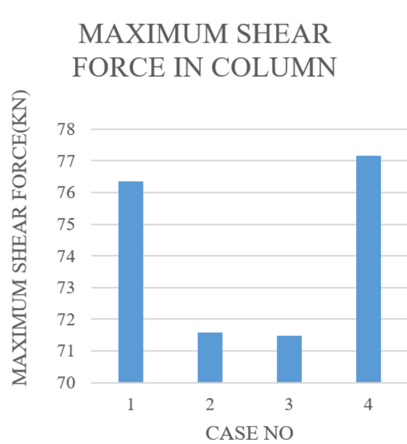

Figure 11: Maximum shear force in Column

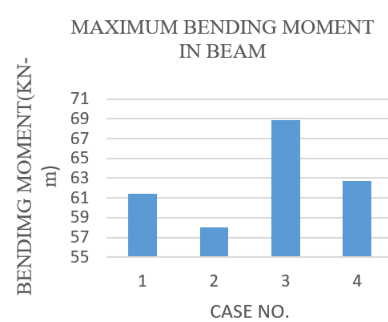

Figure 12: Maximum bending moment in Beam

ments in the structural elements.

6. Conclusion and Recommendation

This study analyzed the structural performance of an RCC building in Seismic Zone V, focusing on the impact of a rooftop telecommunication tower positioned at various locations. The findings reveal that the placement of the tower significantly influences structural parameters, including base shear, nodal displacement, axial forces, shear forces, bending moments, and torsional moments. Among the key observations, it was found that placing the tower at the center of the building minimized nodal displacements in both the X and Y directions. Similarly, placing the tower at the center of the longer edge generally resulted in reduced base shear, axial forces, shear forces, bending moments, and torsional moments. The study also underscores the impact of additional loads introduced by the telecommunication tower, which increased all structural forces and moments due to the added seismic mass and altered dynamic characteristics of the building. These findings highlight the critical importance of analyzing tower placement during the

Table 6: Maximum torsional moment in beams and columns

Case No.	Max Torsional Moment (KN-m)						Optimum Case	
	Beam			Column				
	Moment	Storey	Label	Moment	Storey	Label	Beam	Column
0	7.1446	2	B35	1.8947	1	C20		
1	7.2777	1	B35	1.8151	1	C20		
2	7.2373	2	B35	2.2907	1	C20	Case 2	Case 3
3	7.2317	2	B35	2.0032	1	C20		
4	7.4084	1	B35	1.8772	2	C20		
Remarks:	With the tower on top of the building, the torsional moment increased by up to 3.69% in beam (case 3) and up to 5.73% in column (Case 4).							

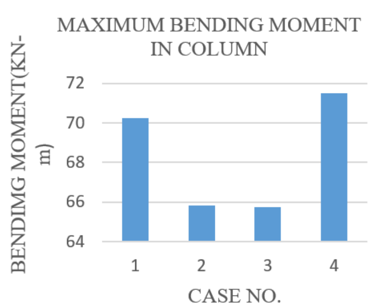

Figure 13: Maximum bending moment in Column

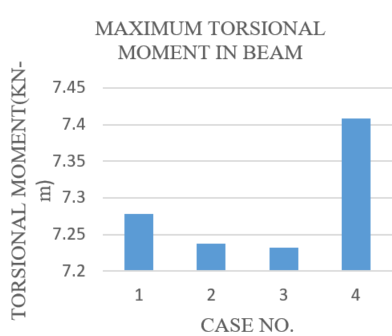

Figure 14: Maximum torsional moment in Beam

design phase to ensure the structural safety of buildings, especially in high seismic zones. Centralized or edge-central placement configurations are recommended for optimizing structural performance.

This research contributes valuable insights for structural optimization and resilience in similar configurations. Future studies could focus on experimental validation and incorporate additional dynamic factors, such as soil-structure interaction and fatigue analysis, to build upon the findings.

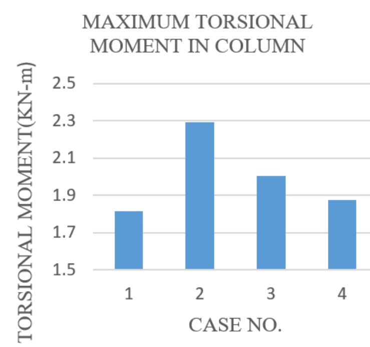

Figure 15: Maximum torsional moment in Column

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