Influence of host structure characteristics on response of rooftop telecommunication towers

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ABSTRACT

The increasing trend of mobile communications has seen exponential growth in the last three years. Increased competitions among mobile operators also have contributed to the installation of many towers to enhance both coverage area and network reliability. The tower locations as specified in terms of latitudes and longitudes with the height of mounted antenna dictated by functional requirements of the network. The availability of land which satisfies ideal installation conditions in urban areas is extremely limited giving no alternative but to adopt rooftop towers (with marginal adjustment in position but not in height). In the present study, the seismic response of 4-legged telecommunication tower has been studied under the effect of design spectrum from the Indian seismic code of practice for Zone-IV. The analysis has been performed on ground tower and tower located on the roof of host structure by varying positions of tower with increasing the stiffness of host structure in the both direction (X and Y). Their dynamic analyses are performed by SAP2000 program. The axial forces of the tower members are considered as the main parameter. The comparison has been made between rooftop tower and ground tower members at the same height from the ground.

Keywords: Rooftop Tower, Response spectrum analysis, Host Structure, Telecommunication Tower.

1. Introduction

Telecommunication towers are tall structure usually designed for supporting parabolic antennas which are normally used for microwave transmission for communication, also used for sending radio, television signals to remote places and they are installed at a specific height. These towers are self-supporting structures and categorized as three-legged and four-legged space trussed structures. The self-supporting towers are normally square or triangular in plan and are supported on ground or on buildings. They act as cantilever trusses and are designed to carry wind and seismic loads. These towers even though demand more steel but cover less base area, due to which they are suitable in many situations. The availability of land which satisfies ideal installation conditions in urban areas is extremely limited giving no alternative but to adopt rooftop towers (with marginal adjustment in position but not in height). The various bracing patterns are available but the most common brace patterns are the chevron and the x-bracing. Most of the researches mainly done on 3-
legged self-supporting towers and very limited attention have been paid to the dynamic behavior of 4-legged self-supporting telecommunication towers.

McClure G, Georgi L and Assi R, 2004, presented the seismic response of two self-supporting telecommunication lattice towers of height 30m and 40m, mounted on the rooftop of two medium-rise buildings: Burnside Hall, which is located on McGill Campus, and 2020 University, which is located nearby in downtown Montreal. The time history analyses were used to explore the correlation between the building accelerations and maximum seismic base shear as well as the base overturning moment of towers mounted on building rooftops. Konno and Kimura, 1973, presented the effects of earthquake loads on lattice telecommunication towers atop buildings and obtained the mode shapes, the natural frequencies, and the damping properties of such structures. Simulation of a stick model of the tower using lumped masses and a viscous damping ratio of 1% was used in their studies and observed that in some of the members, the forces due to earthquake were greater than those due to wind. Amiri and Boostan, 2002, carried out the dynamic analysis of 10 existing self-supporting telecommunication towers varying height from 18 to 67m scaled using spectra of Tabas, Naghan and Manjil earthquake with respect to Iranian 2800 seismic code, which are among major earthquakes in Iran and comparison was made between the results of wind and seismic loading. It was observed that the values obtained from wind load exceed from earthquake load. Mikus studied in 1994, the seismic response of six 3-legged self-supporting telecommunication towers with heights varying from 20 to 90 meters without considering the antennas and other accessories. It was concluded that modal superposition with the lowest four modes of vibration would ascertain sufficient precision. In the present study, two 4-legged telecommunication towers with square transversal cross-sections are considered for dynamic analysis; one is supported on the rooftop of single storey building and other on stiff ground. Different types of bracings, such as XBX bracing, have been adopted in each tower. The cross-section of the tower members is made-up of single equal-legged angles.

2. Modeling of Telecommunication Tower

The towers have been idealized as space frame and were modeled using frame element in SAP 2000 software. The descriptions of the towers are listed in Table 1 and Table 2. The connections for both towers assumed to be rigid. The structure idealization and member section details of 15m rooftop tower (R tower) and 18m ground tower (G tower) shown in Figure 1 and 2 respectively.

| Table 1: Details of rooftop tower (R Tower) |
|---------------------------------------------|
| Height of tower                             | 15m |
| Height of straight portion at top of the tower | 12m |
| Height of slant portion                      | 3m  |
| Effective base width                        | 1.8m|
| Effective top width                         | 1m  |
| No. of 3 m high panels                      | 4nos.|
| No. of 1.5 m high panels                    | 2nos.|

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Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

Figure 1: Structure idealization & member section details of 15m antenna tower, (Rooftop Tower)

Table 2: Details of ground tower (G Tower)

| Description                                      | Value  |
|--------------------------------------------------|--------|
| Height of tower                                 | 18m    |
| Height of straight portion at top of the tower   | 15m    |
| Height of slant portion                         | 3m     |
| Effective base width                            | 1.8m   |
| Effective top width                             | 1m     |
| No. of 3 m high panels                          | 5nos.  |
| No. of 1.5 m high panels                        | 2nos.  |
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

The combined modeling of building and tower has been adopted for rooftop tower considering various selected positions of tower at the top of roof as shown in Figure 3 and 4. The members of the building are modeled as space frame (3D) having six degrees of freedom at each node with rigid diaphragm action. The preliminary data required for analysis of building are assumed given in Table 3.

Table 3: Building Description (Preliminary Data)

|   |   |
|---|---|
| 1. Number of Storey’s | Single Storey |
| 2. Infill Wall | External: 200 mm thick, Internal: 150 mm thick |
| 3. Slab Thickness | 200 mm |
| 4. Beam Size | 350 mm X 400 mm |
| 5. Column Size | 450 mm X 450 mm |
| 6. Floor Height | 3 m |

Material Properties

**Concrete:** M30 grade, Compressive strength of concrete, $f_{ck} = 30 \text{ N/mm}^2$
Modulus of Elasticity of concrete, $E_c = 5000 \sqrt{f_{ck}} \text{ N/mm}^2 = 27386.12 \text{ N/mm}^2$

**Steel:** Fe 415 grade, Yield stress, $f_y = 415 \text{ N/mm}^2$
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

Figure 3: Various selected positions of the rooftop (15m) tower mounted on single storey building.

Figure 4: Typical model of rooftop (15m) tower mounted on single storey building
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

3. Loading Details of Tower

Gravity load acting on both the towers composed of its own weight and the weight of antennas along with other appurtenances attached to it. The loading details of antennas on towers are given in Table 4. The weight of the platform at top assumed to be 0.82 Kn/m² (Dayaratnam, 2008). Normally weight of the ladder and cage assembly is 10% of the total weight of the tower.

| SR. NO. | ITEMS  | NO. | DIA (WXDXH) m | WEIGHT / ANTENNA (KG) | LOCATION HEIGHT FROM BASE (15m TOWER) | LOCATION HEIGHT FROM BASE (18m TOWER) |
|---------|--------|-----|---------------|-----------------------|---------------------------------------|---------------------------------------|
| 1       | CDMA   | 6   | 0.26 X 2.5    | 20                    | 14                                    | 17                                    |
| 2       | Microwave | 1   | 1.2           | 77                    | 12                                    | 15                                    |
| 3       | Microwave | 1   | 0.6           | 45                    | 12                                    | 15                                    |
| 4       | Microwave | 2   | 0.3           | 25                    | 12                                    | 15                                    |

4. Dynamic Analysis

The dynamic analysis (Response Spectrum Analysis) has been carried out on antenna towers’ using codal response spectra given by Seismic code (IS 1893: Part 1, 2002) shown in Figure 5. The analysis has been performed by assuming fixed base at the base of the building on rock site (hard soil).

Figure 5: Codal (IS 1893: 2002) Response spectra for hard soil (Type I)

The structures analyzed for earthquake loading using response spectrum as per IS 1893:2002 in zone IV with PGA 0.24g, importance factor (I) = 1 (importance factor depending upon the functional use of the structures, characterized by post-earthquake functional needs and economic importance) and response reduction factor (R) = 5 (depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations). In case of rooftop tower case (R₁, R₂, R₃, R₄ & R₅), the input acceleration for...
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

analysis should be at roof of the structure (Building) on which it is supported, so floor spectra of building is required, but due to combined modeling of building and tower, the design spectrum have been used in the analysis for whole structure.

5. Results and Discussion

In the present study modal analysis was carried out with the help of SAP 2000 software and first few modes were considered in the analysis whose cumulative sum of modal mass participation ratio was up to 90%. The modal analysis helps in determination of natural frequencies and the corresponding mode shape of the structure, which essentially depends on distribution of stiffness and mass within the structure. In the analysis natural frequencies obtained are shown in Table 5. The mode shapes of the rooftop tower and ground tower are shown in Figure 6.

| Modes       | G1 | R1 | R2 | R3 | R4 | R5 |
|-------------|----|----|----|----|----|----|
| Sway 1      | 2.815 | 3.998 | 4.01 | 4.006 | 3.937 | 4.013 |
| Torsion 1   | 13.988 | 7.952 | 7.487 | 7.446 | 7.417 | 7.041 |
| Sway 2      | 2.817 | 4.002 | 4.014 | 4.009 | 3.939 | 4.014 |
| Torsion 2   | 16.846 | 16.646 | 16.65 | 16.637 | 16.398 | 16.634 |
| Sway 3      | 18.317 | 6.751 | 6.607 | 6.626 | 6.622 | 6.485 |
| Torsion 3   | 25.664 | 16.973 | 16.988 | 16.973 | 16.679 | 16.973 |

First Sway Mode (R2) \( f = 4.01 \) Hz
Second Sway Mode (R2) \( f = 4.014 \) Hz
First Torsion Mode (R2) \( f = 7.487 \) Hz
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

Figure 6: Mode shapes of rooftop tower (R2) and Ground tower (G1)

The particular members of tower at same height from ground were selected as shown in Figure 7 and member forces for different cases were found and comparison between them have been made.

Figure 7: Selected Members Naming of Roof Top Tower and Ground Tower at same Heights (X Z Plane)
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

By increasing the stiffness of host structure (Building) there should be increase of forces in the tower members but in the present study due to single storey building there was minimal amount of effect seen on the response of rooftop towers (R Tower). Also due to symmetry of host structure both in longitudinal and transverse direction, the response of rooftop tower was found same in both directions. The axial forces of selected members were tabulated in Table 6 for leg, diagonal and horizontal members. Figure 8 to 10 shows the comparison plot of axial forces for leg, diagonal and horizontal members.

Table 6: Axial Forces (KN) in Leg, Diagonal and Horizontal Bracings of Towers at same Height from the Ground Level

| Member     | Members | R1  | R2  | R3  | R4  | R5  | G1  |
|------------|---------|-----|-----|-----|-----|-----|-----|
| LEG        | B       | 0.015 | 0.015 | 0.015 | 0.018 | 0.016 | 0.005 |
|            | D       | 2.846 | 2.902 | 2.921 | 2.977 | 2.98 | 0.793 |
|            | G       | 4.284 | 4.363 | 4.389 | 4.46 | 4.484 | 1.178 |
|            | I       | 3.293 | 3.375 | 3.376 | 3.423 | 3.447 | 1.517 |
|            | A       | 0.025 | 0.025 | 0.025 | 0.026 | 0.026 | 0.008 |
|            | C       | 0.364 | 0.365 | 0.371 | 0.367 | 0.379 | 0.097 |
|            | F       | 0.35  | 0.351 | 0.356 | 0.353 | 0.363 | 0.105 |
|            | E       | 0.175 | 0.178 | 0.179 | 0.181 | 0.182 | 0.07  |
|            | H       | 0.481 | 0.489 | 0.492 | 0.498 | 0.502 | 0.104 |

Figure 8: (a), (b), (c) and (d) Comparison of Axial forces in leg members of Roof towers and Ground tower
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

Figure 9: (a), (b), (c) Comparison of Axial forces in diagonal members of Roof towers and Ground tower

Figure 10: (a), (b) Comparison of Axial forces in horizontal members of Roof towers and Ground tower

5.1 Conclusions

1. The design of rooftop towers cannot be based on analytical results obtained for a similar configuration situated at ground level. As seen, the axial forces in rooftop towers are increased approximately by two to three times (max.) with respect to ground tower.

2. By increasing the stiffness of the host structure in both the directions (X and Y), the axial forces (tensile & compression) in rooftop towers were increased by minimal amount of 5%.

3. It can be concluded that the response in torsional modes were unaffected by the locations of the rooftop tower.
4. The axial forces in leg members under the effect of seismic load attain the highest value. Nevertheless, it has been observed that the forces in diagonal members are greater as compared to the horizontal members.

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6. References

1. Amiri G., Barkhordari M.A., Massah S. R., Vafaei M.R., (2007), “Earthquake Amplification Factors for Self-supporting 4-legged Telecommunication Towers”, World Applied Sciences Journal, 6(2), pp 635-643.

2. Amiri G., Massah S.R., (2007), “Seismic response of 4-legged self-supporting telecommunication towers”, International Journal of Engineering Transactions B: Applications, 20(2), pp 107-126.

3. Amiri G., Barkhordari M.A., Massah S.R., (2004), “Seismic Behaviour of 4-Legged Self-Supporting Telecommunication Tower”, 13th World Conference on Earthquake Engineering, Canada, Paper No. 215.

4. Amiri G., Boostan A., (2002), “Dynamic response of antenna-supporting structures”, 4th Structural Specialty Conference of the Canadian Society for Civil Engineering, pp.1-9.

5. Amiri G., Azad A., (2002), “Seismic sensitivity of self-supporting telecommunication masts”, 12th European Conference on Earthquake Engineering, London, Paper Reference 198.

6. Agarwal Pankaj, Shrikhande Manish., (2009), “Earthquake Resistant Design of Structure”, PHI Publication.

7. Bharat Sanchar Nigam Limited (Civil Wing), A Government of India, (2004), “Manual on communication steel tower”.

8. Dayaratnam P., (2008), “Design of Steel Structures”, Wheeler Publisher, pp 671-709.

9. Galvez C, McClure G., (1995), "A simplified method for a seismic design of self-supporting lattice telecommunication towers”. Proceedings of the 7th Canadian Conference on Earthquake Engineering, Montreal, Canada, pp 541-548.

10. H.Siddhesha, 2010, “Wind analysis of Microwave Towers”, International Journal of Applied Engineering Research, Dindigul, 1(3), pp 574-584.

11. IS:1893-2002 (Part 1) “Criteria for earthquake resistant design of structures”
Influence of host structure characteristics on response of rooftop telecommunication towers
Nitin Bhosale, Prabhat Kumar, A.D Pandey

12. Khedr A., McClure G., (2000), “A simplified method for seismic analysis of lattice telecommunication towers”, Canadian Journal of Civil Engineering, 27(3), pp 533-542.

13. Khedr M.A, McClure G., (1999), “Earthquake amplification factors for self-supporting telecommunication towers”, Canadian Journal of Civil Engineering, 26(2), pp 208-215.

14. Konno T, Kimura E., (1973), “Earthquake effects on steel tower structures atop buildings”. Proceedings of the 5th World Conference on Earthquake Engineering, Rome, Italy, 1, pp 184-193.

15. McClure G., Georgi L., Assi R, 2004, “Seismic considerations for telecommunication towers mounted on building rooftop”, 13th World Conference on Earthquake Engineering, Vancouver, Canada, Paper No. 1988.

16. Mikus, J., (1994), “Seismic analysis of self-supporting telecommunication towers, M. Eng. Project Report G94-10. Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada.

17. Punmia B.C., Jain A.K., (1998), “Comprehensive Design of Steel Structures”, Firewall Media Publisher, pp 681-709.