Effect of Wind and Earthquake Loading on Telecommunication Tower

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Abstract: The telecommunication industry plays a great role in human societies and thus much more attention is now being paid to telecommunication towers than it was in the past. Telecommunication towers are tall structures usually designed for supporting parabolic antennas installed at a specific height. As telecommunication towers are the only means of enhancing both the coverage area and network reliability, more and more telecommunications towers are installed nowadays. The stability of towers post-earthquake or a cyclone is of great concern. Hence in the present study, a detailed analysis has been made on the behaviour of the telecommunication tower subjected to wind and seismic loads with varying the bracing system of towers. Gust factor method is used for wind load analysis. Conducted analytical study on effect of wind on telecommunication towers, for wind speed of 50m/s for four combination of bracing systems; Also studied the effect of earthquake loading on telecommunication towers using Modal analysis and Response Spectrum method, for seismic zones III, IV and V for all the four combination of bracing systems. The results of displacement at the top of the towers and stresses in the bottom leg of the towers are compared and the optimum bracing system is found.

Keywords: bracings, earthquake loading, telecommunication towers.

I. INTRODUCTION

Over the past 30 years, the growing demand for wireless and broadcast communication has spurred a dramatic increase in communication tower construction and maintenance. Many industries and communications demand towers for variety of purposes. Some of the applications of steel towers are Microwave transmission for communication, Radio transmission, Television transmission, Satellite reception, Air traffic controls, Flood light stands Meteorological measurements, Oil drilling masts, Overhead water tanks, Power transmission lines etc. Fastest growing telecommunication market has increased the demand of steel towers. Failure of such structures is a major concern.

Towers can be classified into three groups based on structural action. Free-standing towers – it is square in plan and is supported on ground or on tall buildings usually by four legs. Guyed towers – it is supported by guy wires which transmit the wind load to the ground and it is mostly suitable for large open spaces. Monopoles – it is self-supporting or free standing polygonal sectioned pole structures and are commonly used in cellular and personal communication service applications.

In this study, a comparative analysis is being carried out for towers with different bracing patterns for Wind zone with wind speed 50m/s and Earthquake zones III to V of India. Gust factor method is used for wind load analysis as per IS 875 (Part 3) - 1987; modal analysis and response spectrum analysis as per IS 1893-2002 is used for earthquake analysis.

II. LITERATURE REVIEW

G. Ghodrati Amiri et al (2004) conducted a study on seismic behaviour of four legged self-supporting telecommunication tower. They investigated the overall seismic response of 10 existing four legged self-supporting telecommunication towers in Iran under the effects of the design spectrum from the Iranian seismic code of practice and the normalized spectra of Manjil, Tabas and Naghan earthquakes. Detailed 3D full scale numerical simulations are done using Finite Element Method. For analysis purpose SAP 2000 is used. It is concluded that though lowest 3 modes of vibration are sufficient for Dynamic analysis, considering five modes would enhance the analysis precision.

NitinBhosale et al (2012) studied influence of host structure characteristics on response of roof top telecommunication tower. They compared the response of a four legged telecommunication tower located at roof top and ground at the same height from the ground. It is concluded that, the response in torsional mode were unaffected by the location of the roof top tower. Analytical results obtained for the same configuration situated at the ground level cannot be used for roof top tower. So by increasing the stiffness of the host structure in both direction the axial forces in the roof top towers were increased by minimal amount.

A. Jesumi et al (2013) investigated optimal bracing system for steel tower. The study has focused on identifying the economical bracing system for a given range of tower height. It is concluded that, Y-bracing is most economical system up to a height of 50m with respect to the joint displacement and weights.

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Vikaskumar Pandey et al (2013) studied influence of telecommunication tower on response of host structure. In this study, the seismic analysis of four legged angled section rooftop telecommunication tower has been studied under the effect of design spectrum from Indian seismic code of practice for Zone III along with wind analysis as per IS 875(part 3)1987.The analysis done in Etabs software. It concludes that, existing building is torsional irregular, the tower placed on the rigid side of host structure shows better performance compared to tower placed on the flexible side. The stresses in member of host structure increased 35%(max)by considering the effect of tower on roof of host structure.

Jithesh Rajasekharan et al (2014) studied telecommunication towers subjected to seismic and wind loading. In this the displacement due to wind by Gust Factor Method and Seismic effect by modal analysis and response spectrum method at top of the tower for various bracing systems for 30m, 40m, and 50m towers were compared. It is concluded that the joint displacement stress increases as the height of the tower increases and suggested optimum design for various earthquake zones.

In the present study, a detailed analysis has been made on the behaviour of the telecommunication tower subjected to wind and seismic loads with varying the bracing system of towers. Gust factor method is used for wind load analysis. Conducted analytical study on effect of wind on telecommunication towers, for wind speed of 50m/s for four combination of bracing systems; Also studied the effect of earthquake loading on telecommunication towers using Modal analysis and Response Spectrum method, for seismic zones III, IV and V for all the four combination of bracing systems.

III. TOWER SPECIFICATIONS

The tower is a 4- legged square self-supporting lattice tower.The members are treated as truss members. (Only tension and compressive forces in it). The Steel Communication tower is designed for a height of 45 m. The towers are provided with 4-different types of bracings: K type, XBX-type, V-type, W-type, XX-type for lower portion and X-Bracing for upper portion of tower. STAAD Pro. V8i has been used for modelling, analysis of the towers. Details of towers, modelled are given in Table-I.

Table- I: Details of the tower

Details of the tower	Dimension in m
Height of Tower	45 m
Height of Slant portion	38 m
Height of Straight portion at the top of a tower	7 m
Base width	6.5 m
Top width	1.5 m

Angle section of size 110 x 110 x 15 mm is used upto 38 m and of size 70 x 70 x 10 mm is used above 38 m for all four bracing systems. Fig. 1 shows the elevation of the four different towers with different types of bracings.

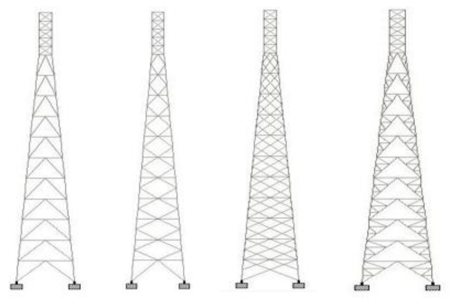

Fig.1. Elevation of towers with K-X, XB-X, W-X, V-X Bracings

IV. ANALYTICAL VERIFICATION

The various loads acting on the tower are self-weight of the lattice tower, load due to antenna, ladder load and platform loads are considered as shown in Table II The wind load is calculated by gust factor method (GFM) as per IS 875 (part 3)-1897. Seismic analysis is carried out by dynamic response spectrum method as per IS 1893- 2002.

Table- II: Antenna Loading for the Tower

Item	Quantity	Weight / antenna (kg)	Location from Base (45m)
CDMA	6	20	38
Microwave	1	45	34
Microwave	2	25	34

The additional loading effects due to wind turbulence and dynamic amplification in flexible structure is calculated using gust factor. The gust factor 'G' accounts for the dynamic effects of gust on tower. The values of these gust factors changes with wind speed, decreases with height and increases with increased terrain roughness.

The following design parameters are used for calculating the wind loads as per IS: 875 (Part 3) - 1987:

Basic Wind Speed: 50 m/s,
Risk coefficient k_1=1.08,
Terrain Category: 2, Class: B
Topography factor k_3=1.0

The basic wind speed given in the code is applicable to 10m height above mean ground level. It is based on peak Gust velocity averaged over a short interval of time about 3 seconds and corresponding to mean height above ground level in an open terrain. Solidity ratio for different panels are calculated in order to account for the open space in the tower lattice Solidity ratio = (Projected area of all the individual elements)/ (Area enclosed by the boundary of the frame normal to the wind direction).

Wind load on a structure on a strip area $A_e$at any height is given by

$$F_z= C_t A_e P_z G$$

Where,

F_z= along wind load on the structure at any height z corresponding to strip area
A_e = effective frontal area considered for the structure at height z
C_t = force coefficient for the building,
A_e = effective frontal area considered for the structure at height z
P_z= design pressure at height z due to hourly mean wind obtained as 0.6 V_z^2 (N/m^2),
G = Gust factor (peak load / mean load)

The load calculation is done for all four bracing systems and Table III gives the load calculation for K-X bracing.

Table- III: Wind load calculation

Panel no.	Height from Top	P_z	cf.Ae	Gust factor G	F_z
2	2.8	1199.49	8.67	2.621	27.28
4	5.6	1176.43	8.67	2.644	26.99
6	10.45	1142.25	4.97	2.837	16.11
8	17.35	1080.89	6.18	3.02	20.17
10	24.25	1007.91	7.07	3.27	23.32
12	31.15	909.51	7.86	3.48	24.89
14	38.05	785.39	8.62	3.92	26.54
16	45	785.39	9.39	4.12	30.39

V. NUMERICAL INVESTIGATION

Seismic analysis is a subset of structural analysis and is the calculation of the response of the building structure to earthquake. Seismic analysis is done in two methods: Equivalent static analysis method - simplest method of analyzing response of a building to earthquake ground motion other than unbalanced building and Dynamic analysis method - shall be performed to obtain the design seismic forces, and its distribution to different levels along the height of the building and to the various lateral loads resisting elements.

Analysis is done using Response Spectrum method (dynamic analysis) as per codal provision IS 1893 (part 1):2002. Response spectrum is a simply a plot of the peak or steady state response (displacement, acceleration or velocity)of a series of oscillators of varying natural frequency that are forced into motion by the same base vibration or shock.

A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different mode shapes will be associated with different frequencies. In this present study, we have analyzed the stability of the 45m lattice tower in Zone III, Zone IV, Zone V. Load is defined using Response Spectrum method in STAAD Pro. The inputs fed into the software are tabulated in Table IV.

Table- IV: STAAD inputs for Seismic Analysis

Parameters	Zone III	Zone IV	Zone V
Zone Factor	0.16	0.24	0.36
Importance factor	1.5	1.5	1.5
Response Reduction Factor	4	1	1
X`x`Soil Type	Medium	Medium	Medium
Damping Ratio	0.02	0.02	0.02

The structure is considered as a space truss and the wind load cases and seismic loading are considered separately. The design has been done using the limit state method. In case of seismic analysis, the behaviour of the structure is studied in seismic zone III, zone IV and zone V. In total four numbers of towers are analysed for each zone and the results are tabulated in Table V. The Frequency and time period for various bracings under study for all the seismic zones are tabulated in Table VI

Table- V: Seismic effect on Tower

Parameter	Zone	Bracing			
		K-X	XB-X	W	V
Displacement (mm)	III	22.386	21.009	32.425	25.28
	IV	19.731	31.553	48.443	37.68
	V	29.378	46.854	71.983	63.41
Base Shear (kN)	III	9.65	11	17.4	15.18
	IV	14.47	16.5	26.1	22.77
	V	21.54	24.56	38.86	38.45
Compressive Force (kN)	III	119.98	117.517	191.648	170.8
	IV	70.946	134.967	231.84	209.9
	V	70.946	163.577	290.76	267.0
Tensile Force (kN)	III	4.23	6.349	36.048	5.997
	IV	1.556	7.724	42.321	9.456
	V	1.556	23.241	75.236	56.85
Compressive Stress(N/mm^2)	III	44.915	46.899	97.995	73.59
	IV	28.445	57.904	119.447	86.87
	V	28.445	69.56	120.34	114.0
Tensile Stress(N/mm^2)	III	17.246	16.564	50.775	17.04
	IV	16.509	17.017	52.108	21.59
	V	16.509	17.709	56.0	41.67

Table- VI: Modes shapes of the tower

Types of Zones	Types of bracings	Mode shapes		
		Modes	Frequency (HZ)	Period (secs)
III, IV,V	K-X	1	2.121	0.471
		2	2.122	0.471
		3	6.857	0.146
		4	7.400	0.135
		5	7.405	0.135
		6	8.045	0.124
III,IV,V	XB-X	1	1.968	0.501
		2	1.998	0.501
		3	7.383	0.135
		4	7.383	0.135
		5	8.212	0.122
		6	10.592	0.094

III,IV,V	W-X	1	1.794	0.557
		2	1.794	0.557
		3	7.091	0.141
		4	7.095	0.141
		5	9.518	0.105
		6	9.640	0.104
III,IV,V	V-X	1	1.869	0.535
		2	1.869	0.535
		3	6.481	0.154
		4	6.481	0.154
		5	6.791	0.147
		6	8.415	0.119

In case of wind analysis, the stability of the various towers subjected to 50 m/s basic wind speed is analysed and the results are tabulated in Table VII.

Table- VII: Wind load effect on Tower

Bracings	K-X	XB-X	W-X	V-X
Displacement (mm)	776.06	1083.7	783.76	751.987
Tensile stress(N/mm^2)	494	869	590	646
Compressive Stress(N/mm^2)	495	866	589	645
Tensile Force(kN)	1463	2133	1606	1506.65
Compressive Force(kN)	1463.17	2125	1604.89	1506.60

VI. RESULTS AND DISCUSSION

For Seismic analysis, displacement at top of towers, base shear, member forces and stress values obtained for various bracing are plotted in form of the graph for comparision.

A. Displacement at Top of the Tower - Seismic

Fig.2. shows the displaced shape of the tower with K-X bracing in zone III, zone IV and zone V.

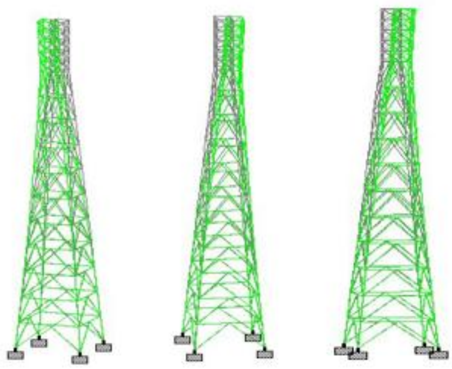

Fig. 2. Displaced tower of K-X bracing in Zone III, Zone IV, Zone V

Fig.3. shows the comparative displacement values of all the bracings at various seismic zones are presented.

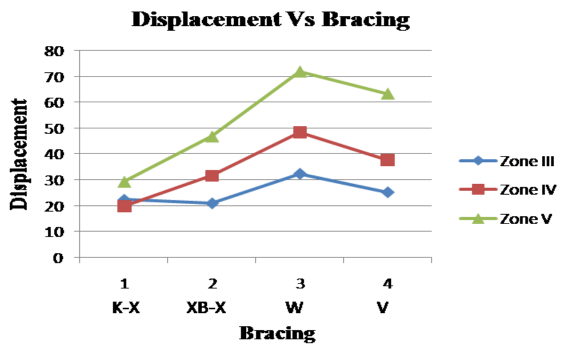

Fig. 3 Displacement vs bracing

It can be observed that, for seismic Zone III, the displacement for XB-X is found to be less, compared to all other bracings. The deflection at the top is 6.15%, 16.89% and 35.20% more for K-X bracings, V-X bracings and W-X bracing respectively compared to XB-X bracing. Whereas in zone IV and zone V the displacement for K-X bracing is less compared to rest of the bracings. There is an increase in displacement at top of tower by 37.47%, 50% and 59% for XB-X, V-X and W-X bracing with respect to K-X bracing.

B. Base shear - Seismic

The base shear obtained from the Response Spectrum Analysis for various bracing system at different seismic zone is given in Fig.4.

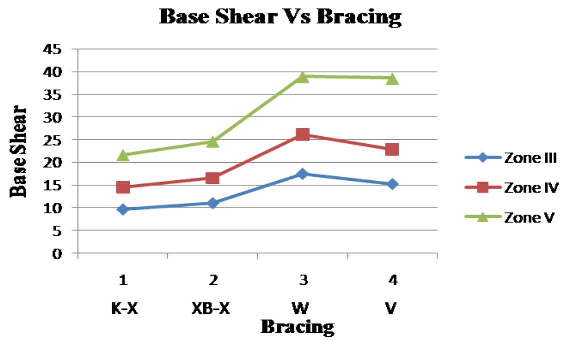

Fig. 4 Base shear vs bracing

The graph shows the base shear pattern for 4 different bracings with respect to different zones of earthquake. It can be observed from the graph that K-X bracing have the minimum base shear values. The Base shear increases by 12.3%, 36%, and 44.5%. For XB-X,V-X,W-X Bracing respectively in all three seismic zones.

C. Member forces - Seismic

The comparative maximum compressive force and maximum tensile force developed in the tower for various bracings and at different zones are presented in Fig.5. and Fig.6. respectively.

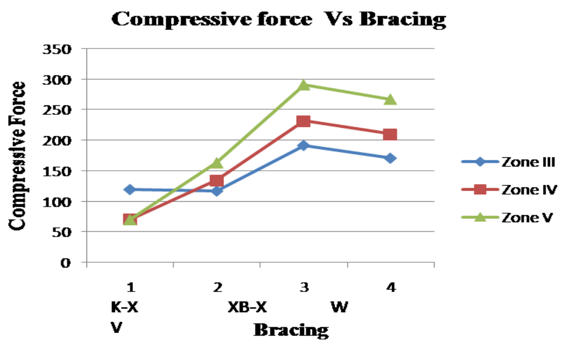

Fig. 5. Compressive force vs bracing

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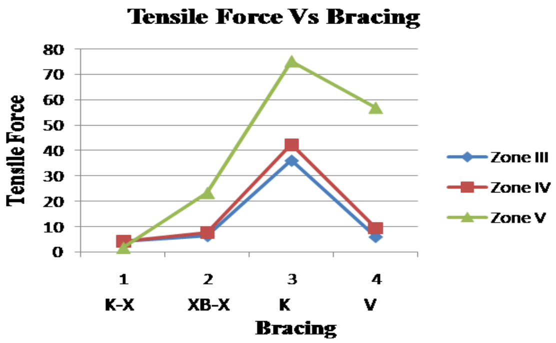

Fig. 6. Tensile force vs bracing

It can be observed that the member forces in leg members are maximum, in all the seismic zones. In all the Seismic zones K-X bracing is found to have less member force compared to other bracing system. The compressive force in leg member of the tower in zone III for XB-X, W-X, V-X, bracing increases by 2.056%, 38.68%, 31.23% respectively when compared with K-X bracing. Likewise, the compressive force in K-X bracing in zone IV decreases by 47.43%, 69.39%, 66.2% for XB-X, W-X, V-X bracings respectively and the compressive force in K-X bracing in zone V is less by 56.62%, 75.51%, 73.44% for XB-X, W-X, V-X bracings respectively. The tensile force in leg member of the tower in zone III for XB-X, W-X, V-X, bracing increases by 30.37%, 88.26%, 29.46% respectively when compared with K-X bracing. Likewise, the tensile force in K-X bracing in zone IV decreases by 79.85%, 96.32%, 83.54% for XB-X, W-X, V-X bracings respectively and the tensile force in K-X bracing in zone V isless by 93.3%, 97.93%, 97.26% for XB-X, W-X, V-X bracings respectively

D. Axial stresses - Seismic

The comparative maximum compressive stress and maximum tensile stress developed in the tower for various bracings and at different zones are presented in Fig.7. and Fig.8. respectively.

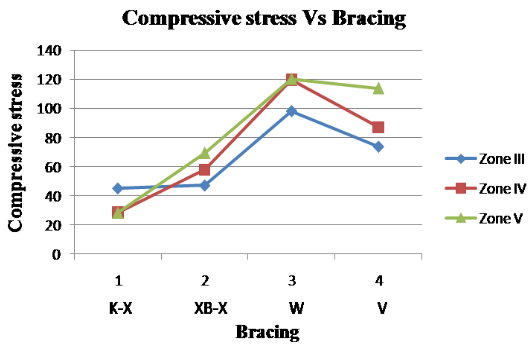

Fig. 7. Compressive stress vs bracing

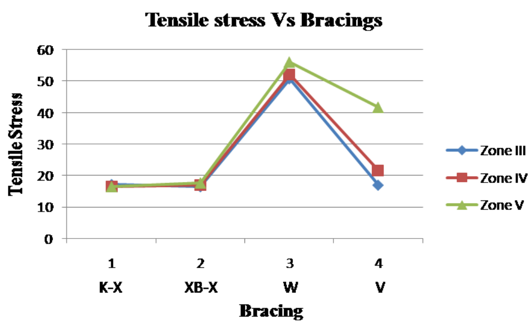

Fig. 8. Tensile stress vs bracing

The Compressive stress of X-B bracing of the tower located in zone III is less than that of XB-X, W-X, V-X bracings by 4.23%, 54.17%, 38.97% respectively. Similarly, the compressive stress of K-X bracing located in zone IV and zone V is decreased by considerable percentage in case of XB-X, W-X, V-X bracing. The tensile stress of X-B bracing of the tower located in zone III is less than that of B-X, W-X, V-X bracings by 4.11%, 66%, 66.44% respectively. Similarly, the tensile stress of K-X bracing located in zone IV and zone V is decreased by considerable percentage in case of XB-X, W-X, V-X bracing.

For Wind load analysis, displacement at top of towers, stresses and member forcevalues obtained for various bracing are plotted in form of the graph.The displaced shape of the tower is shown in Fig.9.

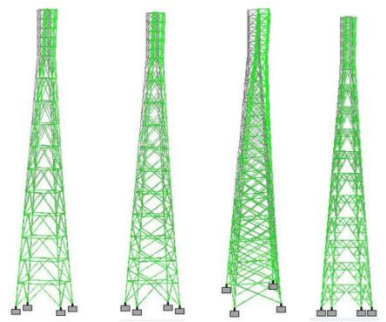

Fig. 9. Displacement due to wind load in K-X, XB-X, W-X, V-X Bracings

E. Displacement at Top of Tower –Wind load

The displacement obtained from the wind load analysis is shown in the Fig.10.

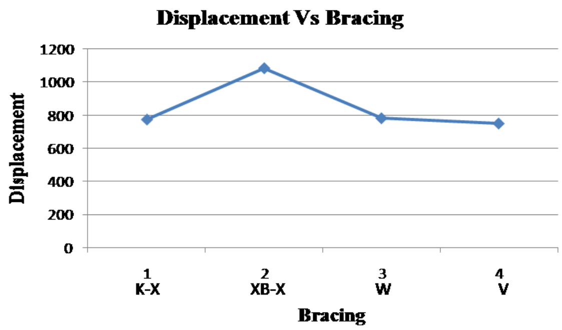

Fig.10. Displacement vs bracing

It can be observed that maximum displacement occurs at the top node of the tower at 45m from the ground level. The displacement in the K-X bracing is 39.64% and 1.2% lesser than that of XB-X bracing and W-X bracing respectively but it is 3.2% higher than V-X bracing.

F. Axial stresses – Wind load

The variation of tensile and compressive stresses for the various bracing systems considered are presented in Fig.11. and Fig.12. respectively. The stress in K-X bracing is decreases by 51.56%, 16.27%, 23.53% than XB-X, W-X, V-X bracing respectively.

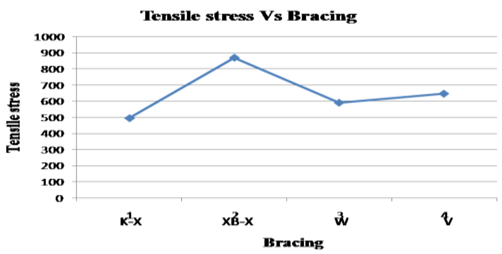

Fig. 11 Tensile stress vs bracing

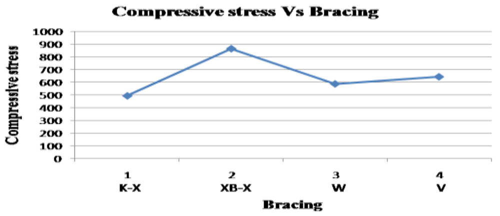

Fig. 12 Compressive stress vs bracing

G. Member forces – Wind load

The magnitude of force in members both tensile and compressive in nature are same. From the Fig. 13.and Fig.14.We infer that the forces in the K-X bracing decreases by 41.36%, 8.9%, 2.89% than XB-X, W-X, V-X bracings respectively.

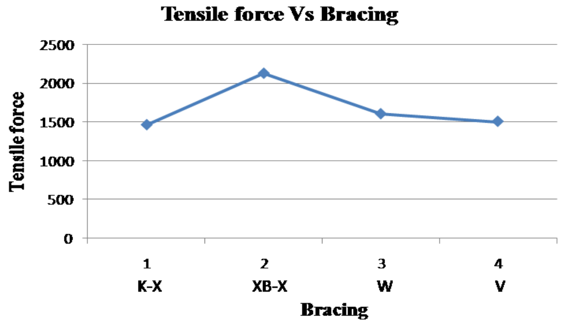

Fig. 13 Tensile force vs bracing

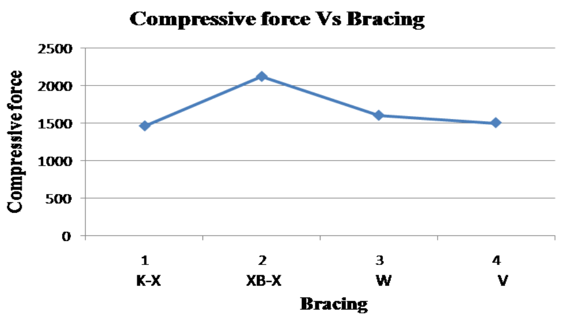

Fig. 14. Compressive force vs bracing

VII. CONCLUSION

The effect of Wind and Earthquake on Telecommunication tower with four different types of bracings are studied. The following conclusions can be drawn based on the analysis of results.

1) From the wind analysis, it can be observed that the increase in joint displacement of K-X bracing and W-bracing are almost same and it is 3.2% and 23.38% less compared to V-X bracing and KB-X bracing respectively.
2) The member force in K-X bracing is found to be minimum and the force increase by 41%, 8.9%, and 2.89% for KB-X, W-X, and V-X bracing respectively compared to K-X bracing.
3) The stress in towers with K-X bracing is found to be less by 51%, 16% and 23.5% for KB-X, W-X and V-X bracing respectively.
4) In the response spectrum analysis, the joint displacement at tower located in seismic zone III is found to be less for tower with XB-X bracing. The displacements in K-X, W-X and V-X is 6.15%, 35.20% and 16.89% more than XB-X bracing system. Also taking member forces and stress into account, XB-X bracing proves to be optimum compared to other bracing system.
5) In seismic zone IV and zone V, the joint displacement of K-X bracing is 37%,59%and 47% less compared to XB-X,W-X and V-X respectively. Also stresses developed in towers with K-X bracing is less compared to towers with other bracing systems.

From the analysis it is clearly seen that the wind effects are critical for tower design and it is suggested to adopt K-X bracing system.

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