COMPARATIVE STUDY ON ANALYSIS OF TELECOM TOWER USING INDIA AND AMERICAN STANDARDS

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Abstract: Self-supporting lattice tower are being effective structural system by considering simple, light weight, easy fabrication and installation for supporting telecom equipment at elevated heights. With increase in demand of lattice towers, a critical review on approach for analysis is highly essential to ensure reliable and safe structures. In this paper, a comparative study is taken up on methodologies followed in both national standards (India, America) for assessment of wind loads on bare tower, linear accessories, discrete accessories along with design resistance of members and connections for Two different configurations – Square angular tower, Triangular Hybrid Tower. From the detailed analysis, it is concluded that, American standard (ANSI/TIA-222H) is using Ultimate windspeed for calculation of wind loads based on risk category of structure along with strength reduction factors based on criticality of components compared to Indian Standards (IS 875(Part 3)-2015, IS 802) which resulted lesser wind load on structure i.e., 30% in Square Tower (Oblique wind direction) and 23% in Triangular Hybrid Tower using ANSI/TIA-222H. Also, no major difference observed for calculation of member capacity and connection. Therefore, it is concluded that Tower weights approximately reduces by 10-15% based on Tower configuration using ANSI/TIA-222H compared to Indian Standards

Keywords: *Analysis, Hot-rolled steel angles, Self-supporting lattice towers, Wind loads.*

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1. Introduction

Self-supporting lattice tower are being effective structural system by considering light weight, easy fabrication and installation and these are normally square or triangular in plan, made up of steel angle or hollow sections. Wind is predominant load for analysis of these slender structures, therefore in depth understanding on wind loads and buckling capacities of steel members are essential for structural analysis. In India, general wind loading standard is being referred for load calculations and member capacities are obtaining from specialized standards referring Transmission line towers. Using generic standards may lead to conservative approach, sometimes underestimating critical parameter which are affecting safety of structure. In this paper, an attempt is made to review current practice by comparing with American standards specially dealt on analysis of telecommunication towers and parametric study is undertaken with two different configurations – Square angular tower consists of Hot Rolled steel angle sections and Triangular Hybrid Tower comprises of Legs with Hollow steel sections and bracings are of steel angle sections. for comparative study on overall impact.

2. Wind and Influencing Parameters

Wind Means the motion of air in the atmosphere with respect to surface of the earth is fundamentally caused by variable solar heating of earth's atmosphere. The earth surface exerts on the moving air a horizontal drag force, whose effect is to retard the flow. This effect is diffused by turbulent mixing throughout a region referred as atmospheric boundary layer. The depth of boundary layer depending up on the wind intensity, roughness of terrain and angle of latitude. Within boundary layer, the wind speed increases with elevation its magnitude at the top of boundary layer is often referred to as a gradient speed. Therefore, parameter such as risk level of structure, terrain influences, topographical features, shape factor, direction factor and as well structural response to wind all are contributing wind effects on lattice towers.

2.1 Basic Wind Speed

Basic Wind speed is defined as the peak gust velocity averaged over a short time duration and corresponds to mean height above ground level in open terrain. Basic wind speed shall be extracted from respective country wind map, and duration of basic wind speed given in both codes i.e., IS 875 (Part 3), ANSI/TIA-222H observed as 3 second duration for a 50-year return period. In both codes, basic wind speed duration is remains same, however ultimate load factor based on higher return period (Predefined risk category of structure) is included in basic wind speed for obtaining ultimate wind speed in ANSI/TIA-222H with no extra load factors in analysis load combinations, whereas as per IS 875 (Part 3) – 2015, the nominal risk coefficient along with load factor of 1.5 is being considered in analysis load combination. Wind Speed against return period using two standards are listed below.

Table 2.1: Wind Speed Against Return Period

Return Period (Years)	IS	222 H
50	47	47
5	33.4	-
25	42.3	-
100	50.3	-
300	-	55.5
700	-	59.2
1700	-	63.9
3000	-	66.3

2.2 Terrain and Height Multiplier

The wind speed varies with height due to ground friction and amount of friction varies with ground roughness and is characterized by terrain / exposure categories based on surrounding obstruction. Three categories are defined in ANSI/TIA-222H against four categories in IS 875 (Part 3). An average of 4%, 10% values are increased at 50-100m and 150-200m height respectively in ANSI/TIA-222H compared to IS 875 (Part 3) for open terrain with scattered obstruction having heights less than 10m.

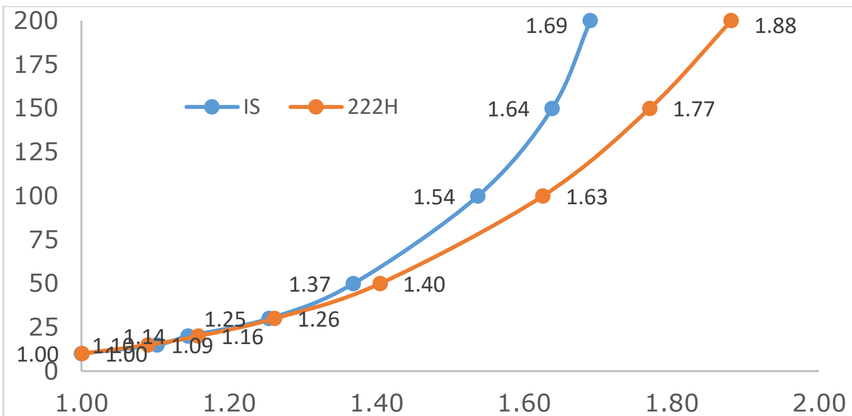

Fig. 2.1: Terrain Height Multiplier (Open Terrain)

2.3 Topography Influences

Topography influence that have some affects are – funnelling of winds (occurs when there is natural flow of air from an unrestricted area through restricted area, such as mountain pass), mountains (Flow over the crest of hill ridge when the wind is normal to edge is considerably less turbulent than the flow of upwind of hill and wind velocity is increased. The effect of topography is to accelerate wind near the summits of hills or crests or cliffs, escarpments or ridges and decelerate the wind in valleys or near the foot of cliffs, steep escarpment, or ridges. As per IS 875 (Part 3), detailed methodology is given for calculation of topographic factor based on up wind slop of hill / ridge with maximum factor of 1.36. In ANSI/TIA-222-H, four categories are defined based on structure location on hill and empirical formulae and rigorous calculations are given for topographic effects against each category without any maximum limits.

2.4 Force Coefficient

Force coefficient is the ratio of resulting force per unit area in the direction of wind to the applied wind pressure. It accounts for the effect of member characteristics (Shape, size, solidity, shielding and surface roughness) also it accounts for both wind ward and lee ward faces including shielding of leeward face by members in wind ward faces. Force coefficient is given for different type of tower configurations (Square / Equilateral triangular towers) and type of member such as Flat or tubular member based on frame solidity ratio (Ratio of Projected area of members and Total area of panel under considered). Reference to table 3.1, force coefficient is reduced by 9% and 4% for square and triangular tower respectively in ANSI/TIA-222G.

Table 2.2: Force Coefficient – Tower with Flat Sections

Solidity Ratio	Square		Triangular	
	IS	222H	IS	222H
0.1	3.80	3.45	3.1	2.96
0.2	3.30	2.98	2.7	2.60
0.3	2.80	2.59	2.3	2.30
0.4	2.30	2.28	1.9	2.06
0.5	2.10	2.05	1.5	1.90

Table 2.3: Force Coefficient – Flat Appurtenances

Aspect Ratio	IS	222 H
≤ 2.5	1.25	1.2
7	1.34	1.4
≥ 25	1.65	2.0

2.5 Structural Response to Wind

Wind force Is essentially dynamic in nature even through it is treated as steady force for simplicity in analysis. Due to turbulent nature of wind velocities, the wind loads acting on structure also highly fluctuating. The back-ground response made up of largely low-frequency contribution below the lowest natural frequency of vibration is the largest contributor for along wind loading. The resonant contribution becomes more significant, will eventually dominate as structure becomes taller in relation to their width and their natural frequencies becomes lower. The resonant response will be significant when the structure frequency is less than 1.0 Hz. When structure experiences resonant dynamic response, counteracting structural forces come in to play to balance wind forces are – inertia force proportional to mass of structure, damping or energy absorbing force, elastic or stiffness force proportional to deflection. As per IS 875 (Part 3), flexible slender structures (defined as first mode frequency is less than 1.0 Hz) shall be investigated to ascertain the importance of wind induced oscillations or excitations along wind and across wind directions. Static wind loading is recommended for rigid structure (first mode frequency is greater than 1.0 Hz), where maximum self-supporting lattice towers are fall in this category i.e., rigid structure by considering first mode frequency. As per ANSI/TIA-222H, a factor of 0.85 – 1.00 is recommended as gust effect factor which accounts for loading effects in the along-wind direction due to wind turbulence – structure interaction for self-supporting structure (Rigid structure) which shall be multiplied to ultimate design wind pressure obtained from ultimate wind speed of 3 second duration. While deciding frequency of structure, separate empirical formula is given in ANSI Code which can be reasonably estimate frequency of lattice towers compared to generic formula given in IS 875 (Part 3).

2.6 Design Wind Pressure

The design wind pressure at any height above mean ground level shall be calculated as per below against each standard.

As per IS 875 (Part 3) – 2015, design wind pressure is given by,

$$\rho_z = [0.6\ (V_b\ K_1\ K_2\ K_3\ K_4)^2]\ \text{x}\ K_d\ K_a\ K_c \qquad 2.1$$

As per ANSI/TIA-222H, design wind pressure is given by,

$$\rho_z = 0.613\ K_z\ K_{zt}\ K_d\ K_s\ K_e\ V^2 \qquad 2.2$$

Ultimate Design wind pressure (with Load factors, 1.5 for IS 875 & 1.0 for ANSI/TIA-222H) including force coefficient (Solidity ratio assumed as 0.2) using both standards are summarized in Fig. 4.1 and 4.2.

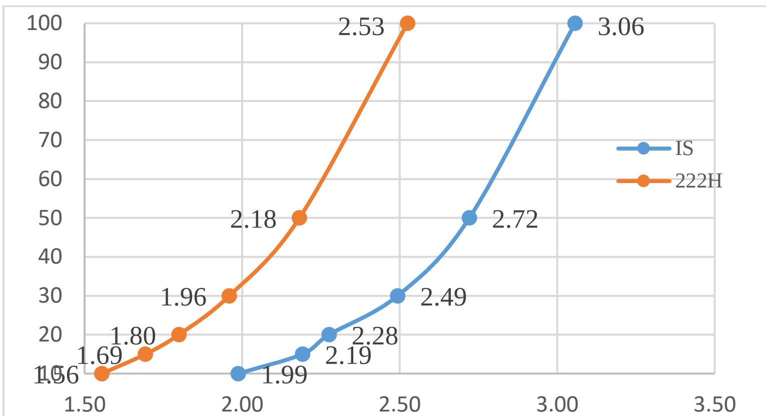

Fig. 2.2: Design Wind Pressure, kN/m^2 (Face Wind)

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Lattice structures are analysed almost exclusively as ideal elastic three-dimensional trusses made up of straight members and pin-connected at joints which produces - only joint displacements, tension and compression in the members. The flexural buckling strength of compression members is being derived from Euler's buckling theory and is mainly depends on slenderness ratio and vary based on members – concentric, eccentric. In both codes, the capacity calculation remains same except variation on strength reduction factors. Therefore, detailed methodology is not presented in this sec ... nection capacit

Fig. 4.1: Design Wind Pressure, kN/m^2 (Face Wind)

Fog. 4.2: Design Wind Pressure, kN/m^2 (Corner Wind)

4. Parametric Study

Two Different configuration (Square – Composed of Angle sections, Triangular – Legs with pipes and others with angular bracings) are considered for parametric study for a basic wind speed of 47m/s (3 second gust) with open terrain with well scattered obstruction of 1.5 – 10m. Basic Tower details are listed below along with tower elevation drawing.

Table 4.1: Basic Tower Details

#	Description	Case 1	Case 2
a	Tower Configuration	Square	Triangular
b	Legs	Steel Angles	Steel – CHS
c	Bracings	Steel Angles	Steel Angles
d	Bottom Face Width	7.35 m	9.15 m
e	Top Face Width	1.80 m	2.00 m
f	Vertical Portion	15 m	10 m

Table 4.2: Wind Influence Parameters

#	Description	IS	ANSI
a	Basic Wind Speed (3Sec.)	47 m/s	47 m/s
b	Risk Coefficient	1.00	1.26
c	Topography factor	1.00	1
d	Ultimate Wind Speed	47 m/s	59.2 m/s
e	Basic Design wind Pressure (kg/m^2)	135.153	158.38
f	Load factor	1.5	1.0
g	Ultimate Design Wind Pressure (kg/m^2)	202.73	158.38

Table 4.3: Antenna Details

Antenna Type		Square / Triangular
GSM Antenna	Size (m)	2.58 x 0.262 x 0.116
	Quantity (Nos)	12
MW Antenna	Size (m)	1.2m Dia.
	Quantity (Nos)	3

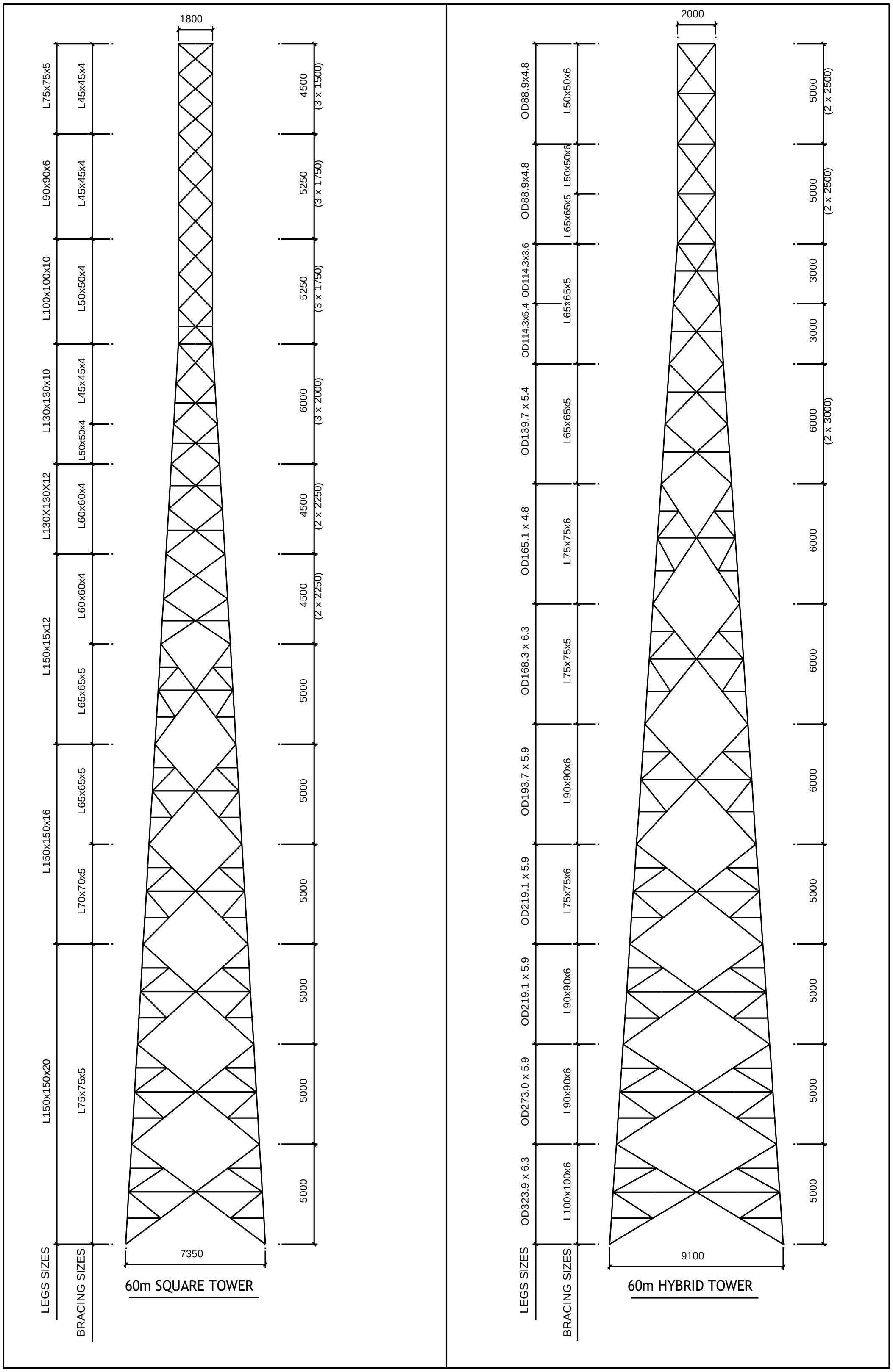

Fig. 4.1: Tower Elevation Drawing – Both Options

4.1 Wind Load

Section wise wind loads are calculated on tower body for two different configurations considered in the parametric study and results are tabulated as below.

Table 4.5: Section Wise Wind Load Comparison – Square Tower

Section Ht. (m)	Cum. Ht (m)	Exposed Area (m^2)	Solidity Ratio (Φ)	Cf - Angles		Design Wind Pressure (KPa)		**Ultimate Wind Load (kN) (0 Deg.)**		**Ultimate Wind Load (kN) (45 Deg.)**	
				IS	**222H**	**IS**	**222H**	**IS**	**222H**	**IS**	**222H**
4.5	60.0	1.42	0.17	3.43	3.09	1.8	2.25	13.4	9.82	16.0	11.12
5.25	55.5	1.62	0.17	3.44	3.10	1.8	2.21	15.3	11.12	18.3	12.56
5.25	50.2	1.88	0.20	3.30	2.98	1.8	2.16	16.7	12.12	20.0	13.94
6	45.0	2.71	0.21	3.25	2.94	1.7	2.10	23.1	16.75	27.7	19.37
4.5	39.0	2.31	0.18	3.39	3.06	1.7	2.05	20.0	14.42	24.0	16.39
4.5	34.5	2.54	0.17	3.47	3.13	1.6	1.99	22.1	15.75	26.5	17.73
5	30.0	3.03	0.15	3.53	3.19	1.6	1.93	26.0	18.60	31.3	20.74
5	25.0	3.17	0.14	3.61	3.26	1.5	1.85	26.6	19.05	31.9	21.03
5	20.0	3.44	0.13	3.64	3.29	1.4	1.75	27.9	19.81	33.5	21.77
5	15.0	3.78	0.13	3.65	3.30	1.3	1.63	28.7	20.33	34.5	22.32
5	10.0	3.98	0.12	3.68	3.33	1.3	1.47	29.1	19.43	34.9	21.23
5	5.00	4.26	0.12	3.69	3.34	1.3	1.32	31.3	18.83	37.5	20.54

Table 4.6: Section Wise Wind Load Comparison – Triangular Tower

Section Ht. (m)	Cum. Ht	Exposed Area (m^2)		Solidity Ratio	Cf - Pipes		Cf - Angles		Design Wind		**Ultimate Wind Load**	
		Pipe	Angle		**IS**	**222**	**IS**	**222**	**IS**	**222**	**IS**	**222H**
5	60	0.89	0.79	0.17	1.6	1.47	2.8	2.71	1.8	2.25	10.1	7.73
5	55	0.89	0.88	0.18	1.6	1.46	2.7	2.68	1.8	2.20	10.6	8.04
3	50	0.69	0.67	0.20	1.6	1.32	2.6	2.58	1.8	2.17	7.85	5.73
3	47	0.69	0.64	0.17	1.6	1.35	2.8	2.71	1.7	2.14	7.82	5.69
6	44	1.68	1.45	0.16	0.9	1.23	2.8	2.74	1.7	2.09	15.1	12.66
6	38	1.99	1.87	0.16	0.9	1.16	2.8	2.75	1.7	2.03	18.6	15.10
6	32	2.02	2.11	0.14	0.9	1.16	2.9	2.82	1.6	1.95	19.9	16.14
6	26	2.33	2.69	0.14	0.9	1.16	2.9	2.80	1.5	1.85	23.5	18.99
5	20	2.20	2.55	0.14	0.9	1.16	2.9	2.80	1.4	1.75	21.2	16.94
5	15	2.20	3.02	0.14	0.9	1.16	2.9	2.80	1.3	1.63	22.8	17.97
5	10	2.74	3.45	0.15	0.9	1.16	2.8	2.76	1.3	1.47	25.0	18.61
5	5	3.25	3.96	0.16	0.9	1.16	2.8	2.72	1.3	1.32	28.7	19.18

Table 4.7: Antenna Wind Load Comparison

Antenna	Description	IS	222H
GSM Antenna	Area (m^2)	0.68	0.68
	Elevation (m)	57.75	57.75
	Force Coefficient	1.389	1.495
	Antenna - Qty	12	12
	Total EPA (m^2)	11.27	12.13
	Ultimate Wind Load	**31.27**	**27.54**
MW Antenna (With Radome)	Diameter (m)	1.2	1.2
	Elevation (m)	57.75	57.75
	Force Coefficient	1.2	0.863
	EPA / Antenna	1.36	0.98
	Antenna - Qty	3	3
	Total EPA (m^2)	4.07	2.93
	Ultimate Wind Load	**11.29**	**6.65**

4.2 Analysis

Three-dimensional space truss analysis is carried out using STAAD-Pro V8 software by applying wind loads on different panels on complete tower. Wind forces due to tower body are distributed to the all sectional points at an elevation equally with fact that the force coefficient has accounted for both wind ward and leeward tower faces including shielding effects. And Wind forces due to linear, discrete accessories are distributed based on their location with respect tower centre of axis. Two wind directions are assumed – face wind (parallel to the frame) and corner wind in the analysis based on tower configuration considered for parametric study.

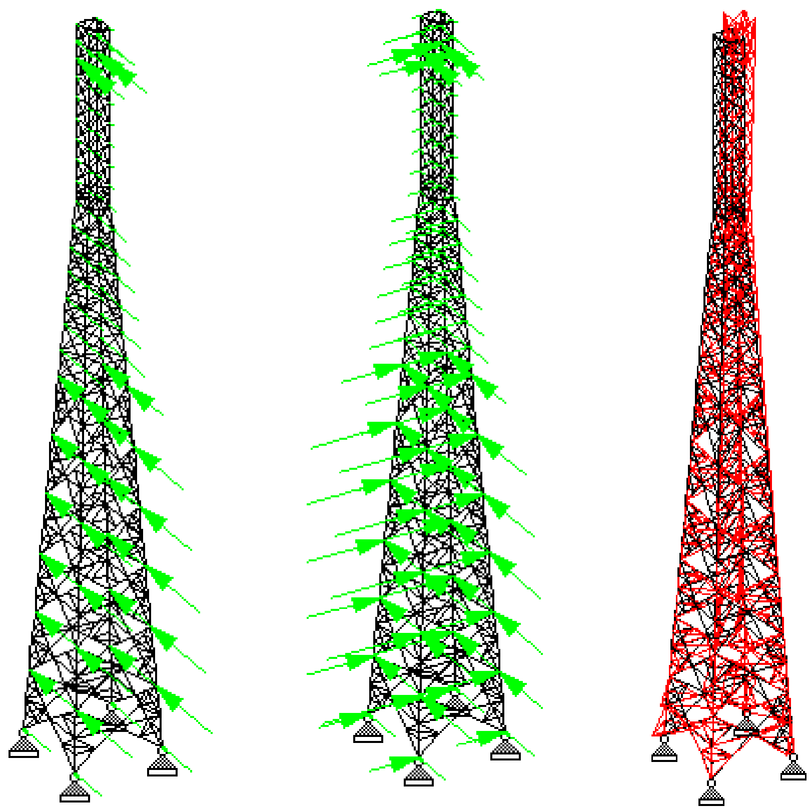

Fig. 4.2: Analysis Model of Square Tower – a) Face Wind, b) Diagonal Wind, c) Deflected Profile

4.3 Design Resistance

Member design resistance are calculated based on two national standards against each section for two different configuration and are tabulated below.

Table 4.8: Section Wise Main leg member capacity Comparison – Square Tower

Sec. No.	Section Ht. (m)	Cum. Ht	Section Properties (mm)					Properties		Eff.L (mm)	Member Capacity (kN)	
		(m)	Type	Width	Depth	Thk.	Fy (Mpa)	Ag (mm^2)	R (mm)		**IS**	**222 H**
See-12	4.50	60.00	L	75	75	5	250	725	14.9	1500	121	123
Sec-11	5.25	55.50	L	90	90	6	250	1044	17.9	1750	178	182
Sec-10	5.25	50.25	L	100	100	10	250	1900	19.7	1750	386	386
Sec-9	6.00	45.00	L	130	130	10	250	2500	25.7	2010	562	562
Sec-8	4.50	39.00	L	130	130	12	250	2976	25.6	1190	694	694
Sec-7	4.50	34.50	L	150	150	12	250	3456	29.6	2260	763	763
Sec-6	5.00	30.00	L	150	150	12	250	3456	29.6	1360	806	806
Sec-5	5.00	25.00	L	150	150	16	250	4544	29.4	1340	1061	1061
Sec-4	5.00	20.00	L	150	150	16	250	4544	29.4	1330	1062	1062
Sec-3	5.00	15.00	L	150	150	20	240	5600	29.3	1320	1261	1261
Sec-2	5.00	10.00	L	150	150	20	240	5600	29.3	1320	1261	1261
Sec-1	5.00	5.00	L	150	150	20	240	5600	29.3	1310	1262	1262

Table 4.9: Section Wise Bracing member capacity Comparison – Square Tower

Sec. No.	Section Ht. (m)	Cum. Ht (m)	Section Properties (mm)					Properties		Eff. Le. (mm)	Member Capacity (kN)	
			Type	Width	Depth	Thk.	Fy (mpa)	Ag (mm^2)	R (mm)		IS	222H
See-12	4.50	60.00	L	45	45	4	250	344	8.9	1170	41	41
Sec-11	5.25	55.50	L	45	45	4	250	344	8.9	1260	36	37
Sec-10	5.25	50.25	L	50	50	4	250	384	9.9	1260	48	48
Sec-9	6.00	45.00	L	45	45	4	250	344	8.9	1480	28	28
Sec-8	4.50	39.00	L	60	60	4	250	464	11.9	1840	41	41
Sec-7	4.50	34.50	L	60	60	4	250	464	11.9	2060	34	34
Sec-6	5.00	30.00	L	65	65	5	250	625	20.2	3450	49	49
Sec-5	5.00	25.00	L	65	65	5	250	625	20.2	3630	45	45
Sec-4	5.00	20.00	L	70	70	5	250	675	21.8	3820	51	51
Sec-3	5.00	15.00	L	75	75	5	250	725	23.4	4040	56	56
Sec-2	5.00	10.00	L	75	75	5	250	725	23.4	3880	60	60
Sec-1	5.00	5.00	L	75	75	5	250	725	14.9	2260	69	69

Table 4.10: Section Wise Main leg member capacity Comparison – Triangular Tower

Section Properties							Eff. Len. (mm)	Member Capacity (kN)	
No.	Type	Dia. (m)	Thk. (mm)	Fy (mpa)	A_g (mm^2)	R (mm)		**IS**	**222H**
See-12	OD	0.089	4.85	240	1281	29.80	2500	215	208
Sec-11	OD	0.089	4.85	240	1281	29.80	2500	215	208
Sec-10	OD	0.114	3.65	240	1269	39.10	1660	261	270
Sec-9	OD	0.114	5.40	240	1847	38.50	1630	381	392
Sec-8	OD	0.140	5.40	240	2278	47.50	1610	485	500
Sec-7	OD	0.165	4.85	240	2442	56.70	1660	529	544
Sec-6	OD	0.168	6.30	240	3206	57.30	1640	696	716
Sec-5	OD	0.194	5.90	240	3481	66.40	1620	767	786
Sec-4	OD	0.219	5.90	240	3952	75.40	1320	893	906
Sec-3	OD	0.219	5.90	240	3952	75.40	1310	893	906
Sec-2	OD	0.273	5.90	240	4951	94.50	1310	1133	1141
Sec-1	OD	0.324	6.30	240	6286	112.30	1300	1450	1453

Table 4.11: Section Wise Bracing member capacity Comparison – Triangular Tower

Sec. No.	Section Ht. (m)	Cum. Ht	Section Properties (mm)							Eff. Len. (mm)	Member Capacity (kN)	
		(m)	Type	Width	Depth	Thk.	Fy (mpa)	A_g (mm^2)	R (mm)		**IS**	**222H**
See-12	5	60	L	50	50	6	250	564	9.8	1600	42	42
Sec-11	5	55	L	50	50	6	250	564	9.8	1600	61	61
Sec-10	3	50	L	65	65	5	250	625	12.9	2050	55	55
Sec-9	3	47	L	65	65	5	250	625	12.9	2160	51	51
Sec-8	6	44	L	65	65	5	250	625	12.9	2300	43	44
Sec-7	6	38	L	75	75	6	250	864	23.3	4030	66	67
Sec-6	6	32	L	75	75	5	250	725	23.4	4240	52	51
Sec-5	6	26	L	90	90	6	250	1044	28.1	4500	91	90
Sec-4	5	20	L	75	75	6	250	864	23.3	4380	58	58
Sec-3	5	15	L	90	90	6	250	1044	28.1	4670	86	86
Sec-2	5	10	L	90	90	6	250	1044	28.1	4960	77	78
Sec-1	5	5	L	100	100	6	250	1164	31.3	5260	94	93

5. Conclusion

Following conclusions are drawn from the detailed analysis carried out on parametric study specifications using two different standards.

- Estimation of Wind Loads are reduced in ANSI/TIA-222H – 33% in Square angular tower, 23% in Triangular Hybrid tower for critical wind direction. The Major Factors contributing in reduction of wind loads are.,
  - Gust effect factor of 0.85 for self-supporting structures are mainly contributing on estimation of lesser wind load in American standard compared to IS 875 (Part 3).
  - For Square towers, wind direction factor for corner wind is estimated using panel solidity ratio compared to standard value of 1.2 of IS 875 (Part 3)
  - Force coefficient is lesser in ANSI/TIA-222H – 10% in square tower, 5% in triangular Tower
  - Force Coefficient for different MW Antenna given in ANSI Standard which lead to accurate estimation of wind load rather than generic using Indian standards
- No Major variation observed in calculation of member / connection capacity due to both standards are referring specialized code for calculation of capacities.

It is further noticed that, Tower weights approximately reduces by 10-15% based on tower configuration using ANSI/TIA-222H compared to general Indian wind loading standard (IS 875, Part 3). Therefore, specialized wind loading guidelines shall be given in Indian standard for accurate and reliable estimation of wind loads on lattice towers.

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