Seismic And Wind-Induced Vibrations On High Mast Lighting Structures

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Abstract: This study is conceived the seismic and wind analysis of multi-sided high mast lighting structures (HMLS) of Steel and Aluminum of 20m, 30m, 40m and 50m heights. And also Fatigue design load factors like Galloping, Vortex shedding and Natural wind gust is also considered for the analysis from AASHTO 2001 Specifications. These loads are arrived at by adopting suitable importance factors. To understand the failure of HMLS under seismic and wind induced vibrations due to wind loads and earth quake loads. The ultimate focus is on the tip deflection of HMLS of different heights. The model has been analyzed using STAAD.ProV8i by adopting the finite element method. Analysis is done on Steel and Aluminum high mast lighting structures. Dynamic analysis such as Modal analysis, Response spectrum analysis and Time history analysis on HMLS is done. Primarily the modal analysis is performed and then the structures have been analyzed for wind loads with gust and without gust factor. Wind loads have been calculated based on three codes of reference namely IS-875 (Part 3)-1987 CODE, IBC-2009 CODE and AASHTO-2001 CODE. Gust factor has been taken from IS: 802 (Part 1 / Sec 1): 1995.

IndexTerms- Wind Analysis, modal analysis, Response Spectrum Analysis, Time History Analysis, and Analysis on Fatigue Design Loads like Galloping, Vertex Shedding and Natural Wind Gust.

1. INTRODUCTION

The modern High Mast Lighting Structure (HMLS) originated nearly at the beginning of the 20th century. Typically there is a functional utility on the tip of the structure such as a wind-force turbine, a radio wave transmitter, radar, or some lamps and lanterns. Up to today different configurations of tubular HMLS have been used widely in modern civil construction. The high mast lighting structures has the characters of light weight and high cost efficiency. Therefore it is widely used in the modern construction industry. It has a large the ratio of height (H) to least horizontal dimension (D) that makes it a particularly more slender and wind sensitive than any other structures. Therefore the purpose of this dissertation work is to find tip deflection of slender,tapered support structures of HMLS subjected to seismic and wind-inducedvibrations by wind loading excitation. This dissertation illustrates the wind analysis with gust and without gust factor including calculation procedures from three codes of reference namely AASHTO-2001 CODE, IBC-2009 CODE and IS-875 (Part 3)-1987 CODE. And also dynamic analysis such as Response spectrum analysis and Time history analysis on 20m, 30m, 40m and 50m heights ofSteel and Aluminum for all zones is done. Analysis on fatigue design loads like Galloping, Natural wind gust and Vortex shedding from the wind induced loads. The finite element program is used toanalyze the natural period and displacement of HMLS.

Galloping

Galloping, results in large amplitude, resonant oscillations in a plane normal to the direction of wind flow. It is usually limited to structures with nonsymmetrical cross-sections, such as sign and traffic signal structures with attachments to the horizontal cantilevered arm. The geometry and orientation of these attachments, as well as the wind direction, directly influence the susceptibility of cantilevered support structures to galloping. Structures without attachments to the cantilevered horizontal support are not susceptible to galloping induced wind load effects. Galloping is a typical effects over the instability of slender structures, having special cross-sectional shapes such as rectangular or nonsymmetrical cross-sections, (Wang, 1995).

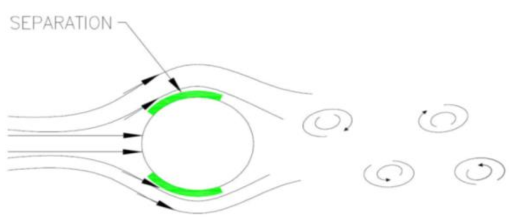

Fig -1: Disturbed airflow around a cylinder.

However, galloping is different from vortex shedding, which results in large-amplitude, resonant oscillation in a plane normal to the direction of wind flow. When the structural damping is equal to the aerodynamic damping, the critical wind velocity of galloping occurs.

NATURAL WIND GUST (BUFFETING)

Buffeting is the result of turbulence in the airstream upwind of the structure, which causes rapid changes in wind velocity. Buffeting or the effect of natural wind gusts is the along-wind response of the structure. Buffeting is characterized by behavior upwind of the structure and is associated with varying wind velocity. Buffeting is caused by velocity fluctuations that cause unsteady loading and is not self-induced. Loads due to natural wind gusts increases as the wind velocity increases. Wind, or the motion of air with respect to the earth, is caused by variable solar heating in the earth's atmosphere.It is due to the difference in pressures in areas that have differing temperatures. Natural wind gusts occur due to the fluctuations in the flow of wind. For structures with very low damping, the structural response to natural wind gusts is determined by the natural frequency of the structure. Since wind gusts are highly variable in velocity and direction, accumulation of fatigue loading cycles from wind gusts is less of a concern than those from a constant amplitude harmonic response such as that due to vortex shedding. Hence high-level lighting supports shall be designed to resist an equivalent static natural wind gust pressure range.

2. METHODOLOGY

- Detailed literature review is done on proposed work.
- The model generation and the FEM modeling of high mast lighting structures are analyzed using the finite element modeling (FEM) software.
- Geometrical model, dimensions and its element properties, supports and boundary conditions are adopted.
- Validating the previous work done and comparing the results.
- Modal analysis of all the models is carried out to know the natural frequency, modal mass participation factors and mode shapes.
- Calculation of wind loads for with gust and without gust factor based on three codes of reference namely IS-875 (Part 3)-1987, IBC-2009 and AASHTO-2001.
- Calculation of fatigue design load factors like Galloping, Natural wind gust and Vortex shedding from AASHTO-2001 Specifications.
    - Generation of response spectrum and time history for all zones as per IS 1893-2002 code.
    - Different models are created by varying the heights and material properties.
    - Wind analysis is carried out on all the models and finding the results.
    - Response spectrum analysis is carried out on all the models for all zones and finding the results.
    - Time history analysis is carried out on all the models for all zones and finding the results.
    - Applying the fatigue design individual loadings from galloping, natural wind gust and vortex shedding on all the models and finding the results.
    - Interpretation of results.

3. MATERIAL PROPERTIES

Table 3.1: Properties based on inbuilt properties for steel as per STAAD Pro software

Young's modulus of elasticity **E**	=	205000000 KN/m^2
Weight per unit volume **ρ**	=	78.33 KN/m^3
Poisson's ratio **μ**	=	0.3
Shear modulus **G**	=	76923077 KN/m^2

Table 3.2:Properties based on inbuilt properties for aluminum as per STAAD Pro software

Young's modulus of elasticity **E**	=	68948000 KN/m^2
Weight per unit volume **ρ**	=	27.13 KN/m^3
Poisson's ratio **μ**	=	0.3
Shear modulus **G**	=	25939850 KN/m^2

LOAD COMBINATIONS

1. **DL+LL**
2. **DL+LL+WL with Gust**
3. **DL+LL+WL without Gust**
4. **DL+LL+EQ**
5. **DL+LL+RS**
6. **DL+LL+TH**

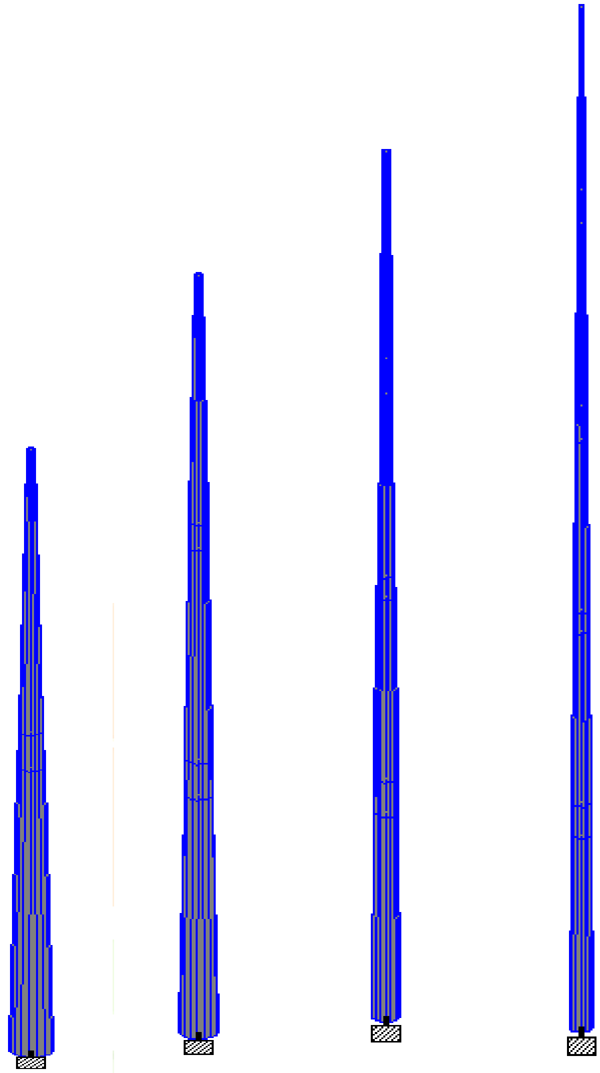

Fig-2:(a): 20m height (b): 30m height (c): 40m height (d): 50m height.

4. MODAL ANALYSIS

Modal analysis procedure is used for knowing the dynamic characteristics of a high mast lighting structure. The mode shapes assumed by the structure and the frequencies at which vibrations occur naturally are determined analytically based on the various properties as stiffness, damping and mass of the system. The results obtained from the modal analysis, especially the modal periods, are the governing parameters used in response spectrum analysis and non-linear time history analysis. These procedures give a realistic evaluation of the seismic demand and the structural response of a structure through the simulation of ground motion. These resonance effects can lead to an unanticipated or premature failure. The natural frequencies and mode shapes of a structure are the primary parameters that affect the response of a structure under dynamic loading. The free vibration problem is solved to extract these values. Since no external forcing function is involved the natural frequencies and mode shapes are direct functions of the stiffness and mass distribution in the structure. Results of the frequency and mode shape calculations may vary significantly depending upon the mass modeling.

The first-three mode shapes of the 50m high mast lighting structure shown in Figure 7.3(a-c).

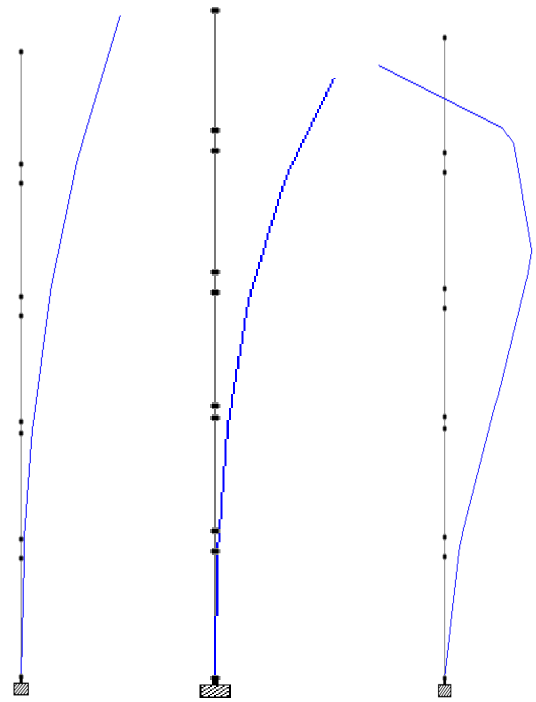

Fig-3: (a) Tn =3.012 (sec) (b) Tn = 3.012 (sec) (c)Tn =0.815 (sec)

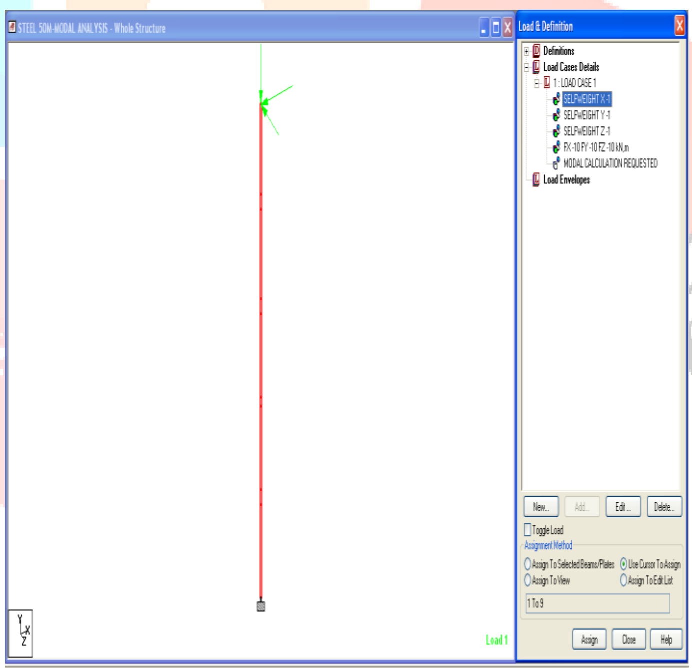

Fig-4:Load case details considered for modal analysis

5. RESULTS ANDDISCUSSIONS

Modal Analysis:

Table 5.1: Modal frequencies versus mode Nos of 50 meter steel and aluminum HMLS.

MODE NUMBERS	FREQUENCY (Hz)	
	STEEL	ALUMINUM
1	0.649	0.441
2	0.649	0.441
3	2.044	1.861
4	2.044	1.861
5	5.171	5.027
6	5.171	5.027
7	10.519	10.355

8	10.519	10.355
9	21.412	21.101
10	21.412	21.101
11	30.364	23.068
12	52.103	50.645
13	52.103	51.343
14	59.640	51.343
15	92.521	91.181

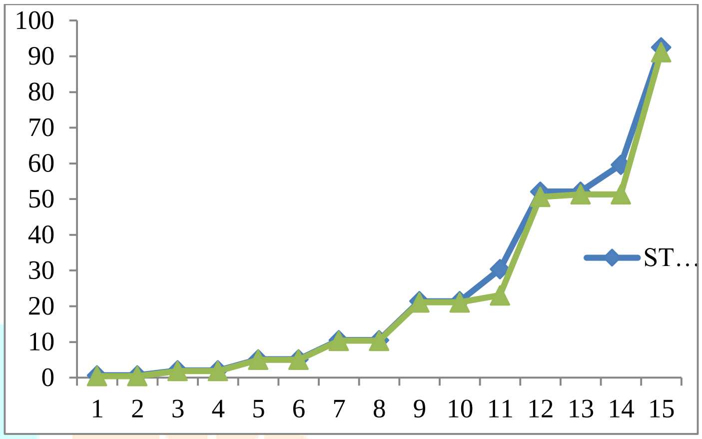

Fig-5: 50m steel & aluminum HMLS mode Nos v/s Frequency.

Wind Analysis:

Codal comparison for tip deflections of steel HMLS forwith gust case

STEEL HMLS FOR WITH GUST CASE				
	20M	**30M**	**40M**	**50M**
CODES	Deflections(mm)			
IS-875(Part-3)	241	345	412	560
IBC-2009	99	263	294	405
AASHTO-2001	252	278	312	429

Table 5.2: Tip deflections of 20m, 30m, 40m & 50m steel HMLS for with gust case.

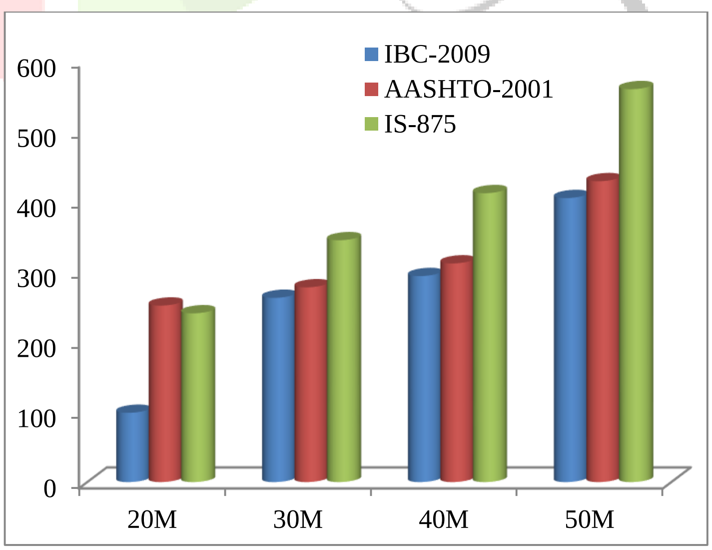

Fig-5: Tip deflections of 20m, 30m, 40m & 50m steel HMLS for with gust caseHeight v/s Deflection.

Codal comparison for tip deflections of Aluminum HMLS forwith gust case

Table 5.3: Tip deflections of 20m, 30m, 40m & 50m aluminum HMLS for with gust case.

STEEL HMLS FOR WITH GUST CASE				
	20M	**30M**	**40M**	**50M**
CODES	Deflections(mm)			
IS-875(Part-3)	716	1026	1225	1665
IBC-2009	295	782	877	1205
AASHTO-2001	749	828	926	1275

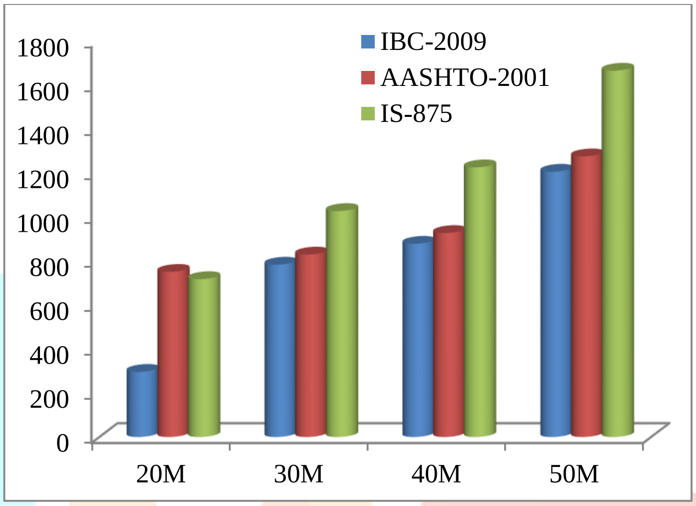

Fig-6: Tip deflections of 20m, 30m, 40m & 50m aluminum HMLS for with gust caseHeight v/s Deflection.

Response spectrum:

Table5.4: Tip deflections of 20m, 30m, 40m & 50m steel HMLS.

STEEL HMLS FOR RESPONSE SPECTRUM				
	20M	**30M**	**40M**	**50M**
Zones	Deflections(mm)			
II	25	47	44	72
III	40	76	71	115
IV	60	114	107	172
V	91	170	160	258

Table5.5: Tip deflections of 20m, 30m, 40m & 50m aluminum HMLS.

ALUMINUM HMLS FOR RESPONSE SPETRUM				
	20M	**30M**	**40M**	**50M**
Zones	Deflections(mm)			
II	73	116	96	123
III	116	185	154	197
IV	174	278	230	296
V	262	417	346	443

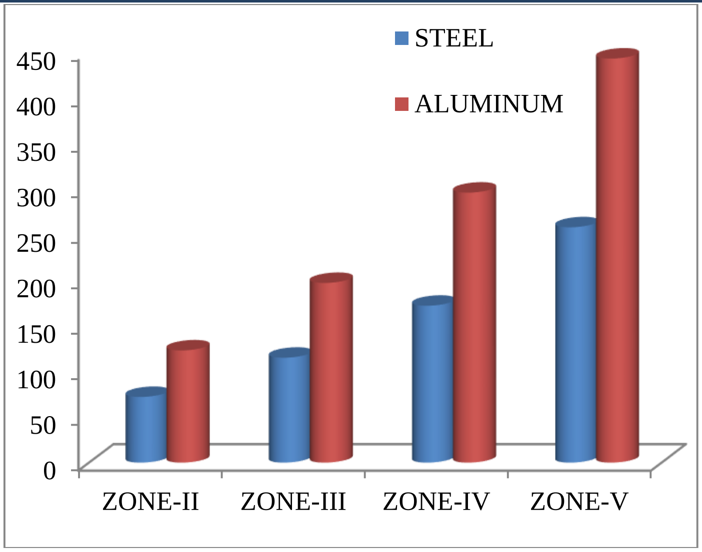

Fig-6: Tip deflections of 50m steel& aluminum HMLS for response spectrumzonesv/s Deflection.

Time History Analysis:

Table 5.5: Tip deflections of 20m, 30m, 40m & 50m steel HMLS.

STEEL HMLS FOR TIME HISTORY				
Zones	20M	30M	40M	50M
	Deflections(mm)			
II	21	22	26	35
III	34	35	41	57
IV	51	53	62	85
V	76	80	93	128

Table5.6: Tip deflections of 20m, 30m, 40m & 50m aluminum HMLS.

ALUMINUM HMLS FOR TIME HISTORY				
Zones	20M	30M	40M	50M
	Deflections(mm)			
II	21	21	23	26
III	34	34	36	42
IV	51	51	54	63
V	76	75	82	95

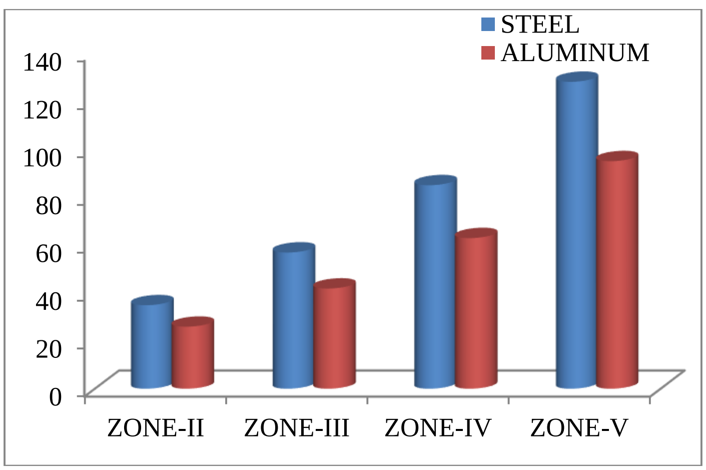

Fig-7: Tip deflections of 50m steel& aluminum HMLS for time history zones v/s Deflection.

Fatigue analysis: Galloping& Vortex Shedding

Table5.7: Tip deflections of 20m, 30m, 40m & 50m steel & aluminum HMLS for galloping.

STEEL& ALUMINUMHMLS FOR GALLOPING				
MATERIALS	20M	30M	40M	50M
	Deflections(mm)			
STEEL	161	328	325	415
ALUMINUM	480	975	966	1235

Table 5.8: Tip deflections of 20m, 30m, 40m & 50m steel & aluminum HMLS for vortex shedding

STEEL & ALUMINUM HMLS FOR GALLOPING				
MATERIALS	20M	30M	40M	50M
	Deflections(mm)			
STEEL	197	240	277	273
ALUMINUM	230	280	345	374

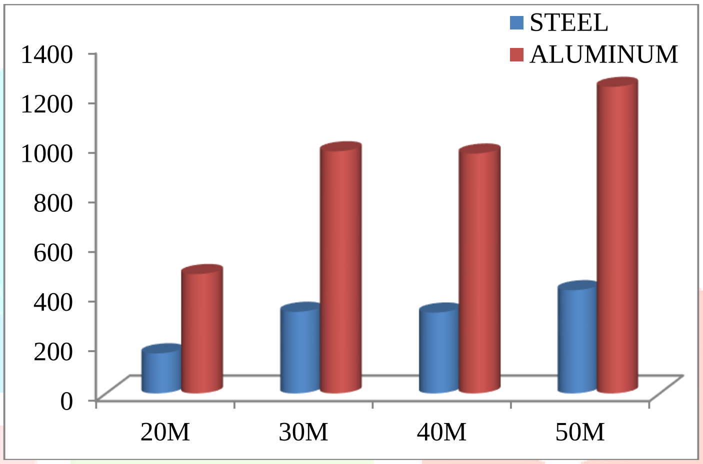

Fig-8: Tip deflections of 20m, 30m, 40m & 50m steel &aluminum HMLS for galloping caseHeight v/s Deflection.

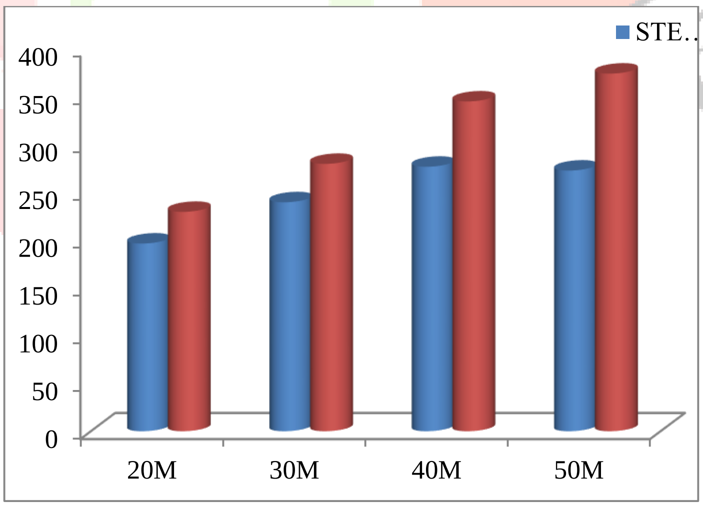

Fig-9: Tip deflections of 20m, 30m, 40m & 50m steel & aluminum HMLS for vortex shedding caseHeight v/s Deflection.

6. CONCLUSIONS

This study is conceived so as to focus on the wind analysis and dynamic analysis of high mast structures and to arrive at the cause for the most plausible collapse of high mast lighting structures by adopting different wind cause like Galloping, Vertex shedding and Natural wind gust. Materials like Steel, Aluminum and Fiber reinforced polymers have been considered. The study is carried out for 20m, 30m, 40m and 50m height of HMLSes, focusing on the tip displacement under each case. Codes like AASHTO-2001 CODE, IBC-2009 CODE and IS-875 (Part 3)-1987 CODE, has been used for wind load calculations. Based on analytical studies following conclusions may be drawn.

1. The tip displacement for HMLSes is highest as per IS 875 Code and for IBC 2009 and AASHTO Code.

2. Fatigue design should be given more importance so as to prevent collapse of HMLSes and to increase the service life of the same. Hence it found that FRP pole section has to be increased to withstand Fatigue loads like Galloping, Vertex shedding and Natural wind gust.

3. The HMLSes are more susceptible to Natural wind gust than Galloping loads.

7. REFERENCES

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