Dynamic Analysis of Telecommunication Monopole under Wind Loads

By : Engr. Lum Peng Fatt M.I.E.M., P.Eng and
Engr. Jeyananda Chinniah Ahnantakrishnan M.I.E.M., P.Eng

INTRODUCTION

Telecommunication transmission structure has been traditionally using lattice space structure, similar to the electricity transmission towers. The aggressive growth of the telecommunications industry means an equal surge in the number of telecommunications structures on the urban and rural landscape. However, while "progress is inevitable, ugliness is not". Monopoles can be used where aesthetic concerns are of prime importance and also where usable space is limited. Monopoles can also be disguised to resemble trees or advertisement boarding, where ever-increasing ecological awareness concerns have to be taken into consideration, in order to protect our environment.

Recently, in an attempt to save land space and to shorten transmission commission lead time, steel monopoles are being used frequently.

Being a tall slender cantilever structure, it is naturally susceptible to wind excitation when subjected to wind-attributed loading.

Various wind load codes and design standard had been written to give guidelines on the derivation of wind loading.

This paper discusses the various approaches in deriving dynamic response from the static consideration of wind, as recommended in each Code.

STRUCTURE AND ANTENNA REQUIREMENTS

Two cantilever monopoles at 30m and 45m height were studied in detail. Table 1 lists the antenna loading for each pole whereas Table 2 shows the height at which platform is required.

The design wind speed specified was 120km/hr 3-sec gust. For the simplicity of comparison, no shielding of the pole from antenna and/or platform is considered. Terrain characteristics, topographic category and importance of structure were selected for urban areas and as far as possible, to be comparable among different Standards.

CODE REQUIREMENTS IN WIND LOAD DERIVATION

The traditional wind code used was CP3: Chapter V Part 2 (5). This was deemed not applicable when one looks at the natural frequencies of a monopole structure of the order of 0.6 ~ 0.9 Hz, which was thus excluded as per the comments given in the Wind Loading Handbook (6).

Furthermore, CP3 had been officially withdrawn on 15 October 2001, and replaced by BS6399:Part 2: 1997.

Wind Load to BS6399:Part2:1997

This Code placed a limit to its applicability to structures with dynamic augmentation factor, Cr, not exceeding 0.25 (Clause 1.6). If one assumes that a monopole structure as a single member welded steel unclad frame, then according to Table 1 and Figure 3 of this Code, the limiting height of applicability is only about 20m.

Nevertheless, as stated in Annex C of the Code, the wind loading onto the structure may still be derived using the provisions of the Code but the final response of deflection (and stresses) need to be amplified by a factor of (1+Cr), which according to the Code, would be less accurate and generally more conservative.

The dynamic augmentation factor, Cr for the two pole heights is shown in Table 3.

The Institution of Lighting Engineers (UK) in its Technical Report Number 7 (ILE-TR7) provides guidelines for the estimation of wind forces on high mast for lighting and CCTV applications.

In this report, the provisions in derivation of wind load according to BS6399:Part 2:1997 were followed and finally, to account for the dynamic nature of the high mast, a magnification factor called RESPONSE FACTOR Beta is applied.

The response factor is a function of the natural frequency of the structure, the mean hourly wind speed at 10m above ground level, and the logarithmic decrement of damping in the structural system. The response factor varies considerably according to the logarithmic decrement factor. The range given was from 0.1 to 0.4. The report recommended that the logarithmic decrement of damping to be used shall be assumed to be 0.1, unless evidence can be produce to justify the use of higher values. Harris (7) had indicated that the

Table 1: Antenna requirement

Diameter of parabolic	Distance measured upward from the bottom of tower (m)			
30m Monopole 1.8m	30m 1 no.	27m 1 no.	24m 1 no.	21m 1 no.
45m Monopole 1.8m	45m 1 no.	42m 3 1 no.	9m 1 no.	36m 1 no.

Table 2: Platforms to be provided

Ht of monopole	Distance measured upward from the bottom of Monopole (m)			
30m	29m	26m	23m	20m
45m	44m	41m	38m	35m

Table 3: Dynanic augmentation factor, Cr

Ht of monopole	Distance Augmentation Factor, Cr
30m	0.638
45m	0.880

Table 4: Dynamic factors for 30m and 45m monopole structures

Ht. of Monopole	Natural Frequency	Response Factor Beta	Dynamic Augmentation (1+Cr)	Ratio (1+Cr)/Beta
30m 45m	0.918 0.605	1.330 1.421	1.638 1.880	1.232 1.323

Table 5: Analysis results for base moments for 30m high monopole using different method of analysis

Method of Analysis	Moment at ULS	Ratio (as Compared with Lowest)	Ratio (Comparing Dynamic Analysis Results)
BS6399:Pt2/ILE-TR7	1636kNm	1.46	1.23
Dynamic analysis using Time-Histories Analysis	2091kNm	1.86	1.57
ANSI/TIA-2220G-2005	1330kNm	1.18	1.00
Equivalent Static Method BS8100:Pt1	1123kNm	1.00	-

Table 5: Analysis results for base moments for 30m high monopole using different method of analysis

Method of Analysis	Moment at ULS	Ratio (as Compared with Lowest)	Ratio (Comparing Dynamic Analysis Results)
BS6399:Pt2/ILE-TR7	1636kNm	1.46	1.23
Dynamic analysis using Time-Histories Analysis	2091kNm	1.86	1.57
ANSI/TIA-2220G-2005	1330kNm	1.18	1.00
Equivalent Static Method BS8100:Pt1	1123kNm	1.00	-

normal range of damping for lighting towers was 0.01 to 0.18. In view of these recommendations, therefore, a value of 0.1 was adopted in the present calculations.

BS8100:Part1:1986

This Code allows a quasi static or equivalent static method of analysis to be carried out on mast and tower structures using mean wind forces and a fluctuating component that accounts for the gustiness of wind. This code appeared to be more appropriate to the slender and dynamically sensitive pole structure, as it accounts directly for the gustiness of wind, just like the telecommunication mast and towers.

The Code imposed a limit for the applicability of the equivalent static method (clause 5.1) that the factor give therein must be less than 1.0. It was found that for the cantilever monopole structure, the factor was much more than 1.0 and hence some form of dynamic analysis, if not a spectral analysis, need to be carried out. Since there is no commonly available software to perform the spectral analysis, it was proposed to use time history analysis to simulate the dynamic response of the monopole.

Dutt (8) proposed a simplified sharp-edge gust with a variation of $V_{av}/4$ about V_{av}, and having a gradient of 200m.p.h. (89.4m/s) per second. V_{av} was the mean of 'five second gust'.

For the present study, the 3 sec gust wind speed was used in lieu of the proposed '5 sec gust' wind speed. Although, Dutt indicated that the proposed simplification worked well with natural frequencies between 1.7 Hz to 7 Hz, it was none the less adopted here as one of the method of computing dynamic response of the monopole structures, whose natural frequencies are lower than 1 Hz.

ANSI/TIA-222-G-2005

This Code uses the 3 sec gust as the design wind speed. Clause 3.6 of the Code states that in order to account for the dynamic effects of wind gusts, a series of wind load patterns are specified, which are similar to the patched loading defined in BS8100:Part4:1995-Code of Practice for Loading on Guyed Mast (9).

For monopole structures, there will only be one single load pattern, viz., full loads throughout, that need to be analysed. It must be pointed out that in order to comply with this Standard, Clause 3.5 concerning P-Delta effect appeared to be mandatory since the height to face width ratios is certainly greater than 10 for the two monopole structures considered here.

Nevertheless, it was found that for the present assumed antenna and platform loading, the second order or P-Delta effect was small.

COMPARISON OF DIFFERENT CODES/STANDARD

While the British Standards set out a clear criterion for determining whether the structure is dynamically sensitive by the limiting Cr factor in BS6399:Part 2 or Equivalent Static limit factor in BS8100:Part1, the final method adopted for dynamic analysis rests with the designer.

It is the authors' opinion that the American Standard TIA-222-G-2005 appeared to be silent in this aspect, although it has a pole gust factor of 1.10 (clause 2.6.7.3) and a higher load factor (for strength analysis) of 1.6, which is higher than 1.44 for BS8100:Part 1 or 1.4 for ILE-TR7/BS6399LPart 2.

Incidentally, it was felt that the use of wind velocity factor of 1.2 in BS8100, which results in a load factor of 1.44, is more rationale than the simple factor of 1.4 as proposed in ILE-TR7 and as such in the present analyses, a velocity factor of 1.2 was adopted for both BS8100 and BS6399/ILE-TR7 methods of analysis.

RESULTS OF ANALYSIS

The computed natural frequencies and response factors Beta according to the recommendations of ILE-TR7 for the two monopoles are listed in Table 4. A comparison with the dynamic augmentation according to BS6399:Part2:1997 is also presented.

From the table, it can be seen that a direct magnification of static moments by (1+Cr) is conservative as per the comments in Annex C of BS6399:Part 2:1997.

Figures 1 to 6 shows the typical structural model of the monopole in finite element, loading and moment distribution along the height of the pole and mode shapes of deflection.

The results of analysis for the 30m and 45m monopole structures are present in Table 5 and 6 respectively. The results for equivalent static analysis from BS8100:Part1 is also included for comparison.

From the above results, the following can be noted:

(i) Equivalent static method BS8100:Part1 under estimate the base moment.

(ii) Time history analysis using the arbitrary velocity variation of +/-V_{av}/4 appeared to be over-conservative.

(iii) Although ANSI/TIA-222-G-2005 results were lower than that computed using BS6399:Part2:1997 with magnification Beta factor, the overall results appeared to be within practical limits and could be considered similar, in view of the wide ranging assumptions in deriving various factors and wind resistance of the pole and antenna.

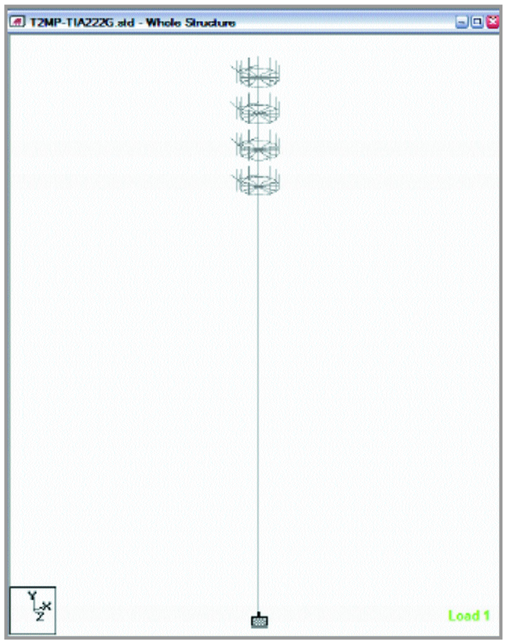

Figure 1: Finite element of monopole structure with platform

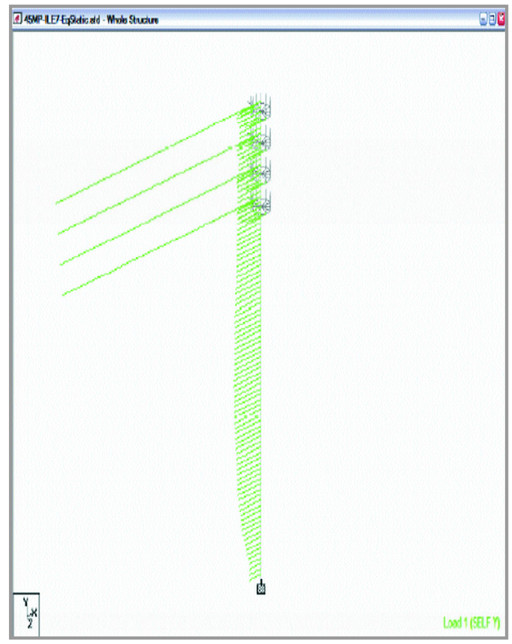

Figure 2: Loading application onto pole structure

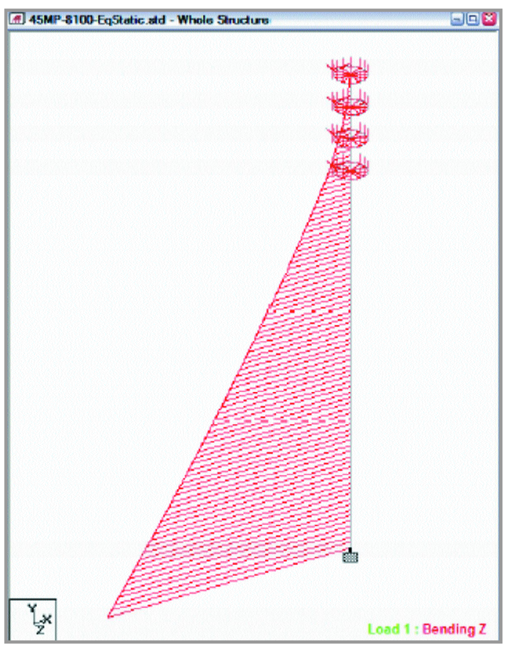

Figure 3: Distribution of moment with pole height

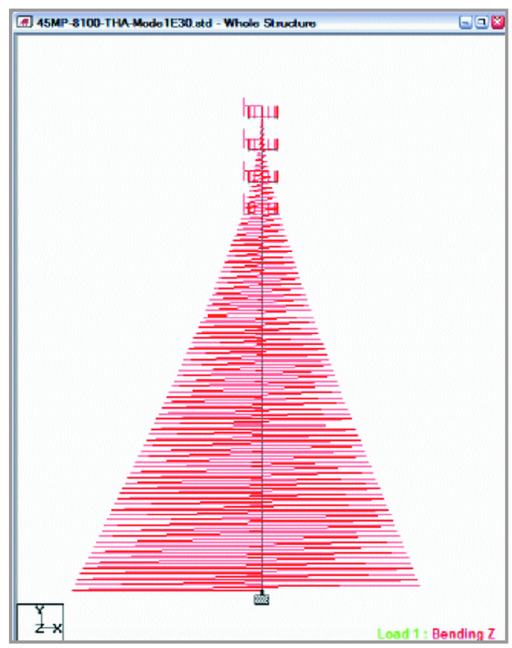

Figure 4: Dynamic moment response of pole

CONCLUSION

Dynamic response of two cantilever monopole structures of height 30m and 45m had been computed according to various methods and recommendation by the British and American Standards. Despite the fact that each Standard define its own manner in accounting for wind pressure computations for structural elements and appurtenances, the resulting base bending moments appeared to be fairly similar to each other, with the American Standard ANSI/TIA-222-G-2005 being lower by about 20% as compared to the British Standard BS6399:Part2:1997/ILE-TR7 recommendations.

The use of simplified wind velocity profiles based on Vav +/- Vav/4 produce the largest base moment at the lowest mode of natural frequency, which was as much as 50% higher than estimation by Code method. ■

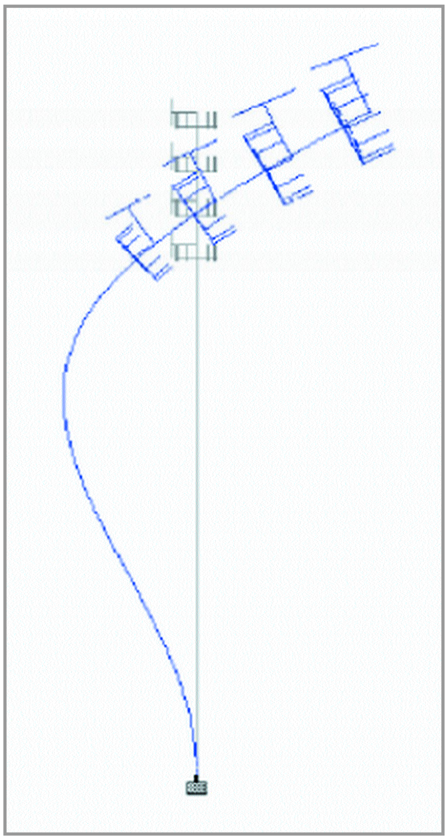

Figure 6: Second mode of deflection of pole under time-history loading

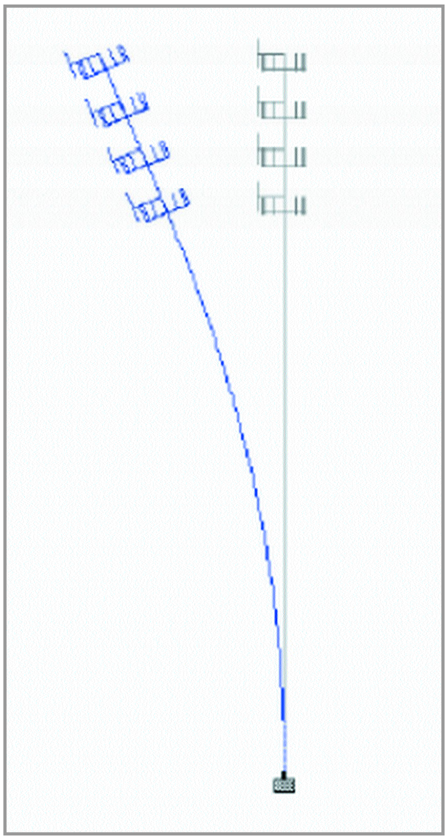

Figure 5: First mode of deflection of pole under time-history loading

REFERENCES

[1] BS6399:Part 2 : 1997 British Standard for Loading for Buildings, Part 2: Code of practice for wind loads

[2] HIGH MAST FOR LIGHTING AND CCTV
The Institution of Lighting Engineers (UK), Technical Report Number 7 Specification for design, manufacture, assembly, erection, painting, testing and maintenance. (2000 Edition, Amended and reprinted 2003)

[3] ANSI/TIA-222-G-2005
TIA STANDARD, Structural Standard for Antenna Supporting Structures and Antennas, Effective January 1, 2006, Telecommunications Industry Association (TIA) August 2005

[4] BS8100:Part 1 : 1986
British Standard for Lattice Towers and Masts, Part 1: Code of practice for loading
(Superseded and replaced with BS6399:Part 2:1997)

[5] CP3: Chapter V Part 2:1972
Code of Basic Data for the design of buildings, Chapter V. Loading, Part 2. Wind loads
(Superseded and replaced with BS6399:Part 2:1997)

[6] Wind loading handbook
C.W. Newberry and K.J. Eaton, Building Research Establishment (1974)

[7] Harris, R I
On the spectrum and auto-correlation function of gustiness in high winds.
Electrical Research Association TR 5273

[8] Dutt, A J
An Approach to the Simplification of the Dynamic Characteristics of Wind Loading on Tall Buildings.
Proceeding, Conference on Tall Buildings, Kuala Lumpur, Dec 1974

[9] BS8100:Part 4 : 1995
British Standard for Lattice Towers and Masts, Part 4: Code of practice for loading of guyed masts