WHITE PAPER

TIA 222 Codes and Dielectric Antenna Design

March, 2021

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Introduction

The following is an overview of how Dielectric applies the Telecommunications Industry Association (TIA) 222 Structural Standard for Antenna Supporting Structures and Antennas code to the design of top mounted pylon antennas. The TIA 222 code has changed over the last 30 years becoming more closely aligned with the data used and standard practices found in higher level structural codes such as the American Institute of Steel Construction (AISC), American Society of Civil Engineers (ASCE), and International Building Code (IBC). Some of these changes have made antenna designs more conservative. The Dielectric design approach has always been to follow the current code as written, maintain continuity with historical company design practices, and to leverage new design tools wherever possible. The effort to maintain continuity is largely centered on maintaining a consistent level of conservatism. Over the years this has prevented overly slender designs from being produced and has allowed safe and reliable methods to assess designs.

Loading, Assessment, and Design

It is Dielectric's responsibility to structurally evaluate the antenna mechanical design, and to generate an accurate set of loads for the tower Engineer of Record (EOR) to use to assess the tower or mounting structure. Antennas are checked per the designated code requirements and by limits set by Dielectric design requirements. The designated design code and the associated parameters are called out by EOR. A revision of the TIA 222 code is used in most cases. The Dielectric design requirements are based on antenna design experience. An antenna design must pass both these criteria to be submitted for proposal or released for production.

The current revision of the TIA 222 Code is H. This is referred to here as simply H Code. The previous revisions G, F, and C are referred to in the same manner. A rough comparison of the F, G, and H Codes is given in Table 1. C Code is not presented because it is essentially obsolete and is currently used only in extremely rare cases. Most of the antennas designed and built during the recent Re-pack period were designed to G Code. G Code was a significant departure from F Code in that it adopted the Load Resistance Factor Design (LRFD) approach. LRFD is based on reliability and requires a larger set of site specific parameters pertaining to the level of risk, location, and local topography to calculate the wind pressures, ice thicknesses, and allowable loads. G Code had a significant impact on antenna design. Wind and particularly ice loads generally went up. The basis for the basic wind speed was changed from fastest mile to 3 second gust measurements. Wind pressure was made a function of risk, location, and topography. The gust factor for tubular masts mounted on lattice structures changed from 1.25 to 1.35. The drag coefficient calculations were changed to better capture the relative effects of pairs of tubular appurtenances mounted on monopole structures. The result for top mount antennas was the sub critical (higher) drag coefficient was applied to the larger supporting mast while the lower transitional or super critical drag coefficient was applied to the smaller appurtenance. This had a significant effect on bottom of stack antennas and side mount antennas mounted on support poles. Ice thickness was made a function of a minimum ice thickness, risk, topography, and elevation. The thickness of the ice at the antenna increased dramatically. Ice thicknesses 1.5 inches are now common. This placed additional emphasis on evaluating the ice loading case when designing antenna mounts and antennas with many small members such as VHF/FM panels with back screens.

H Code is very similar to G Code with a few exceptions. H Code uses the ASCE 7-16 environmental loading tables for wind speed and ice thickness. The county based listing of wind speeds and ice thicknesses found in G Code is no longer given and has been replaced by contour maps for each of the risk categories. The maps are extremely hard to read so the user is directed to the on line ASCE-7 Hazard Tool. H Code uses ultimate wind speeds instead of Basic Wind Speed. The difference is ultimate wind speeds were calculated using much longer return periods. The return periods are now a function of the Risk Category. The higher the Risk Category, the longer the return period, and the higher the wind speed. Annex L of the H Code gives a conversion table to show the relationship of the H Code Ultimate wind speeds to the previous edition basic wind speeds which used a 50 year return period. It can be seen the G Code 3 second gust 50 year return period wind speed is related to the H Code ultimate wind speed by;

$$V_{H\ Code} = \sqrt{1.6 * I} * V_{G\ Code}$$

Where: I -the G Code Importance Factor.

The H Code ultimate wind speeds include the G Code 1.6 wind load factor. The wind pressure calculations do not impose a significant change in antenna design except in locations where the wind speed maps have changed, or the new factors are used. H Code includes two new factors in the wind pressure calculation. K_s is the Roof Top Speed-Up Factor and is used for building mounted structures. The K_s factor can be as high as 1.3. This would be significant for antennas mounted on tall buildings. K_e is Ground Elevation Factor and is used to account for the change in air density with altitude above sea level. K_e is less conservative. Lower air density means a lower resultant wind pressure for a given wind speed. Antennas mounted at extreme altitudes will see reductions in the wind pressure.

H and G Code use a LRFD. LRFD is based on reliability and compares factored load cases against factored structural resistances. The previous revision, F Code, used the Allowable Stress Design (ASD) approach which compares unfactored load cases to structural resistances with a factor of safety applied. LRFD uses fully plastic section bending as the assessment criterion for bending failure whereas ASD used a maximum allowed stress level based on a percentage of the material yield strength. Top mounted antennas are essentially steel mast structures and although there is compression due to weight and shear loads from the wind, the primary loading is bending. H Code includes a section requiring openings in tubular structures be reinforced to essentially put back all the area of cutout material. This would allow the section to be assessed in compression without accounting for the cutout. This requirement is difficult to meet for most slotted antenna designs, as reinforcements adversely affect antenna performance. Top mount pylon antennas are tubular masts with layers of circumferentially arrayed 1 to 2 inch wide longitudinal slots, starting 1 to 5 feet above the base flange and continue up to 1 foot below the top of the antenna. The slots are the radiating feature on the antenna, and any changes to the pipe outer surface around the slots will affect the electrical performance. Antennas by necessity must be assessed using reduced slotted cross section properties with their associated stress concentrations. Antenna mast slotted cross sections meet the definition of a non-compact section given in section F-2 of the AISC Manual of Steel Construction. Fully plastic bending gives the maximum allowable bending moment, M_n as;

$$M_n = F_y Z$$

Where: Fy -the material yield strength

Z -the plastic section modulus (in^3)

The maximum allowable stress, F_b for F Code (AISC ASD Manual) is based on the onset of yielding;

$$F_b = 0.6F_y$$

Or in terms of maximum applied moment

$$M_b = 0.6F_y S$$

Where: S -the elastic section modulus (in^3)

The plastic section modulus is approximately 1.5 times greater than the elastic section modulus. This has been confirmed by calculation and from measurements of CAD drawings of slotted cross sections. The maximum allowable bending moment derived from the plastic section modulus must be divided by the 1.6 load factor in here order to fairly compare the two criteria. Then, assuming the same importance factor, gust factor, and wind pressure is used;

$$M_n' = \frac{F_y Z}{1.6} \approx \frac{1.5F_y S}{1.6} \approx 0.94F_y S$$

The maximum allowable bending moment from plastic bending will always be approximately 1.5 times greater than the maximum allowable bending moment based on the onset of yielding. Plastic bending is an assessment criterion that is checked on all Dielectric designs, but it is never the limiting factor. This by itself would allow longer smaller diameter pipes than have been historically used and possibly cause excessive deflection and vibration problems.

Dielectric still uses the maximum allowable stress criteria at the slots. The slots are treated as stress concentrations and the stresses are calculated using the slotted section properties. Finite Element Analysis (FEA) of slotted pipes in bending has shown the stress concentration factor to be on the order of 1.16 at the start of the radius at the ends of the slots. The maximum stress assessment criteria for slotted and un-slotted for F, G, and H Code are given below;

F Code

$$\frac{(1.16)\sigma_{F\ Code}}{(0.9)\frac{2}{3}F_Y} \leq 1 \qquad \text{Slotted}$$

$$\frac{\sigma_{G\ Code}}{(0.9)\frac{2}{3}F_Y} \leq 1 \qquad \text{Un-Slotted}$$

G Code

$$\frac{(1.6)(1.16)\sigma_{G\ Code}}{(0.9)F_Y} \leq 1 \qquad \text{Slotted}$$

$$\frac{(1.6)\sigma_{G\ Code}}{(0.9)F_Y} \leq 1 \qquad \text{Un-Slotted}$$

H Code

$$\frac{(1.16)\sigma_{H\ Code}}{(0.9)S_Y} \leq 1 \qquad \text{Slotted}$$

$$\frac{\sigma_{H\ Code}}{(0.9)F_Y} \leq 1 \qquad \text{Un-Slotted}$$

G and H Code limit the deflection of top mounted mast structures to 1.5% of the mast height under service loading conditions. The deflection is measured from the top to the bottom of the mast. Service loading is defined as a basic wind speed of 60 mph without load factors applied. Calculations show antenna masts designed to this requirement will still fail the above maximum allowable stress criterion unless higher yield strength material ($S_Y \approx$ 50 ksi) is used. Dielectric uses either ASTM A53, ASTM A106 Grade B, ASTM Grade C, or Dual Certified ASTM A519 1025 seamless pipe materials. These are all prequalified materials. Flanges are made from ASTM A350 LF2 forgings or ASTM A516 Grade 70 material with special Charpy requirements for toughness (15 ft-lbs @ -20^{o}F). The maximum yield strength pipe material used by Dielectric is 40 ksi.

Wind driven vibration issues are difficult to predict. It does not always happen when it is predicted to occur. It can be caused by periodic unsteady airflow, shedding vortices, tower driven excitations, or a combination of these factors. There is no methodology in the current TIA Codes to assess potential antenna vibration issues. H Code does give a section on Small Wind Turbines (SWT) that provides a fatigue analysis method based around calculating constant amplitude stresses using SWT loads and comparing with crack initiation threshold stress levels for common structural detail and load combinations. Unfortunately, the loads are specific to SWT's and are not useful for anything else. The Canadian code for Antennas, Towers, and Antenna Supporting Structures, CSA-S37-18, annex N gives procedures for wind gust and vortex shedding assessment. CSA-S37-18 uses a 10 year return wind pressure (q_{10}) to check a structure's ability to withstand repeated wind gusts. It is not clear what the basis for selecting a 10 year return period as representative value to calculate an effective alternating wind gust pressure. This means there is a 10% yearly chance of exceeding this wind speed. This most likely tied to a reliability target. The analysis method proposed in CSA-S37-18 applies the unfactored q_{10} pressure to the antenna with the appropriate drag coefficients and a gust factor of 1. The resulting stresses are compared with the fatigue crack initiation threshold stresses associated with common design features (stress concentrations) such as fillet welds, and geometric discontinuities. This is like the H Code method for assessing the stresses on SWT's. Dielectric does not use this method at the present time but is considering it as a possible additional check. The basis for the selection of the 10 year return period would have to be fully understood and consultations with recognized experts in this field would be necessary before this could be implemented as a design criterion.

The CSA-S37-18 approach for assessing vortex shedding is like the method currently used by Dielectic. The critical wind speeds for vortex shedding to occur are calculated using a Strouhal number of 0.2, the first mode natural frequency of the antenna mast, and the outside diameter of the antenna. Slotted pylon antenna outside diameters are usually the diameter of the antenna radome. This is typically less than 30 inches. Natural frequencies are normally less than 1.5 Hz. This result is that critical wind speeds are usually less than 15 mph and sub critical Reynolds numbers. The approach in this case is to apply a uniform pressure to the top 3rd of the antenna perpendicular to the wind direction and calculate the maximum stresses. The uniform pressure is calculated using the equations found in would be equal to the following;

$$q_{vortex} = \frac{1}{2}\rho D_{radome} V_{critical}^2 C_L \sin(2\pi f t)$$

$$C_L = 0.707$$

This can be done using either a simplified beam model with known stress concentration factors, or with an ANSYS FEA model using the ANSYS fatigue tool for more complicated designs with unknown stress concentrations.

Summary

The TIA Design codes and antenna designs will most likely continue to change in the coming years. Dielectric will keep pace with changes and apply new tools and additional design limits to continue building antennas that meet the code requirements and provide continuity with historical company practices. Dielectric has had good experience with maximum stress as a conservative limit and will continue to use this limit as a supplement to the code requirements. It is anticipated that new requirements in future releases of the TIA code may be enacted to address the risk of fatigue in non-typical structures such as antennas. Dielectric currently checks for vortex shedding and is working on a wind gust based fatigue criteria like that found in CSA-S37-18 and other references. This combination of designing to code requirements and applying additional Dielectric developed criteria has resulted in excellent field experience with the installed base of antennas. It is expected that by continuing to examine the structural limits of existing and new antennas designs it will ensure compliance with future code changes. Dielectric is confident that, by continuing to examine the structural limits of existing and new antennas designs, it will ensure compliance with future code changes and extend its performance record in the field.

Table 1 F, G, and H Code Comparison

		F Code	G Code	H Code
Load Cases	Dry	$D+W_o$	$1.2D+1.6W_o$	$1.2D+W_o$
	with Ice	$D+D_i+.75*W_o$	$1.2D+D_i+W_i$	$1.2D+D_i+W_i$
	Service	70 mph at antenna	$D+W_{60\ mph}$	$D+W_{60\ mph}$
Parameters Specified by the Engineer of Record (EOR) for the main supporting structure.	Wind Speed	Basic Wind Speed, Fastest Mile, 33 ft (10 m) above ground level, 50 year reoccurrence interval (0.02 probability)	Basic Wind Speed, 3 second gust, 33 ft (10 m) above ground level, 50 year reoccurrence interval (0.02 probability)	Ultimate Wind Speed, 3 second gust, 33 ft (10 m) above ground level, reoccurrence interval based on the structure risk category
	Wind Speed with Ice	75% of the dry wind pressure is used	Tabularized	ASCE-7 Hazard Tool
	Minimum Ice Thickness	Thickness at Antenna Elevation given by EOR	Tabularized Minimum Value, Thickness at Elevation from formula	ASCE-7 Hazard Tool
	Structural Class/Risk Category	N/A	I,II, or III	I, II, III, or IV
	Exposure Category	N/A	B, C, or D	B, C, or D
	Topographic Category	N/A	1, 2, 3, 4, or 5	1, 2, 3, 4, or 5
Wind Speed with Ice		75% of Dry Wind Pressure	Tabularized	ASCE-7 Hazard Tool