Distribution Line Design - Volume I: Poles and Crossarms

An Online Continuing Education Course for Engineers

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Distribution Line Design – Volume I: Poles and Crossarms

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Introduction

This course is the first in a series of three courses on the design of electric distribution pole lines. In this volume equations, data, and other information is provided to determine: The loads applied to un-guyed wood distribution poles 55 ft or less in total length, a pole's strength requirements to sustain applied loads, maximum horizontal spans based on pole strengths, crossarm vertical loads, and crossarm horizontal loads.

The second volume in this series addresses conductor sag and tension calculations and the application of NESC clearances to conductors. The third volume in the series explains the proper guying methods for distribution pole lines.

Sample solved problems are included to help understand and apply the presented equations. Tables of calculated ground line moments caused by wind on wood poles and tables of calculated permitted moments at the ground line of commonly used wood poles are included.

The presentation is limited to the horizontal loading of un-guyed wood distribution poles, 55 ft or less in total length, acting as simple cantilever beams or slender columns. Within the text of this course are references to typical distribution construction assemblies. Un-guyed poles, according to typical distribution construction standards, have a maximum line angle of 5 degrees. The loading effect of transformers and other heavy equipment on poles is not included.

This course references to rules and selected data contained specifically in the 2012 edition of the NESC. At the time this course was written, the 2012 edition was the latest edition of the NESC. Users of this course should use the rules and data—as may be periodically updated, revised, and renumbered—from the most recent edition of the NESC. The NESC is published by the Institute of Electrical and Electronics Engineers, Inc. (IEEE).

This course also references ANSI 05.1-2008, "Specifications and Dimensions for Wood Poles." This standard provides specifications for quality and dimensions of wood poles that are to be used in single-pole utility structures. ANSI 05.1-2008 designates the fiber stress and dimensions of natural wood poles and classifies poles by wood species, length, and class. Usually a pole's height and classification are abbreviated. For example, a pole identified as "35-6" indicates a 35-foot, (ANSI) Class 6 pole. Annex B of ANSI 05.1-2008 defines pole classes so that poles of various species and lengths will have approximately equal load-carrying capability. The minimum circumferences specified at 6 feet from the butt, have been calculated such that each species in a given class will not exceed the ground line stresses tabulated in Annex B, when a given horizontal load is applied two feet from the top of the pole. For example, all Class 6 poles are capable of holding a 1,500 pound load applied transversely two feet from the top of the pole. The ground line circumferences of different species of poles in the same class will deviate because of the differences in allowable fiber stress.

Chapter 1: Pole Loading

The NESC requires that wind and ice loads on conductors and poles be determined according to the location (Heavy, Medium, or Light loading district) of construction. Assumed ice and wind loads have to be increased if they are expected to be greater than the minimum requirements of the NESC. If any part of a pole or the conductors attached to it is 60 feet or more above the ground, then extreme wind loading or extreme ice with concurrent wind loading has to be considered. Extreme wind loading (Rule 250C) or extreme ice with concurrent wind (Rule 250D) has to be applied, using the formulas and data of the NESC, if it is greater than the otherwise calculated wind and ice loading based on loading districts. Loads applied to wood poles have to be multiplied by the appropriate load factors of NESC Table 253-1. Conductor tension data for the appropriate loading case can then be determined as outlined Volume II of this series.

All of the loads that can be expected to be applied to a pole have to be considered in order to determine the pole's strength requirements to sustain the loads. Loads are simultaneously applied to poles in both the horizontal and vertical directions. Poles need to have sufficient strength such that the following relationship is satisfied:

$$\frac{\boldsymbol{M_{applied}}}{\boldsymbol{S}} + \frac{\boldsymbol{P_{applied}}}{\boldsymbol{A}} =< MOR$$

Where,
$M_{applied}$ = Moments induced in the pole, in-lb
$P_{applied}$ = Vertical loads on the pole, lb
S = Section of modulus, in^3
A= Cross section area of pole, in^2
MOR= Modulus of rupture, $1b/in^2$

Usually the "P/A" portion of this equation is negligible in comparison with the "M/S" portion of the equation and, thus, is ignored in the distribution pole strength calculations.

By using vector algebra, all horizontal loads applied to a pole can be calculated in two component directions: *longitudinal* (parallel to the direction of the line) and *transverse* (perpendicular to the line). Usually there is only one direction of loading that dictates the minimum class of pole required to sustain all of the loads expected to be applied. This direction is called the *direction of critical loading*. Computations for pole strength requirements only need be made for the direction of critical loading when that direction is known. The direction of critical loading for un-guyed poles is in the transverse direction.

Chapter 2: Horizontal Moments on a Pole

An applied moment is the multiplication product of an applied load or force times the distance from its centroid to the ground line of the pole. The unit of measure for moments is foot-pounds (ft-lb). The sum of all of the applied moments, multiplied by the appropriate NESC load factors, has to be determined before a pole of sufficient strength (i.e., class) can be selected. The total of all the ground line moments induced in a pole (M_g) is expressed as follows:

$$\boldsymbol{M}_{g} = \boldsymbol{S}_{h} * \boldsymbol{M}_{wc} + \boldsymbol{M}_{wp} + \boldsymbol{M}_{we} + \boldsymbol{M}_{tc} + \boldsymbol{M}_{vo} + \boldsymbol{M}_{p-\delta}$$

Where:
S_h = Horizontal wind span (= the sum of 1/2 the lengths of the adjacent spans), ft

M_{wc} = Summation of moment loads due to wind on each conductor expressed as moment per unit length of conductor (ft-lb/ft)

$$\mathbf{M_{wc} = F_{ow} * \{\Sigma(W_c * H_c)\} * \cos(\theta/2)}$$

M_{wp} = The moment due to wind on the pole (ft-lb)

$$M_{wp} = \mathbf{F_{ow}} * \mathbf{W_p} * \frac{\mathbf{2 * C_t + C_g}}{\mathbf{K_c}} * \mathbf{H_p^2}$$

Note: M_{wp} is calculated for several commonly used poles and tabulated in Appendix B.

M_{we} = The moment due to wind on the material and equipment attached to the pole (ft-lb)

M_{tc} = Summation of moments due to the tension of the conductors (ft-lb)

$$\mathbf{M_{tc} = 2 * F_{ot} * \{\Sigma(Tc * Hc)\} * \sin(\theta/2)}$$

Mvo = The moment due to unbalanced vertical loads, ft-lb
Mp-δ = The moment due to pole deflection, ft-lb

Where:
F_{ow} = NESC (Table 253-1) load factor for wind loads
F_{ot} = NESC (Table 253-1) load factor for longitudinal (tension) loads
H_p = Height of pole above ground, ft
Hc = Height of each conductor attachment above ground line, ft
Wc = Wind load per unit length of each conductor, 1b/ft
Wp = Wind load per unit area surface of-pole, lb/ft^2
Tc = Tension in each conductor, lb
θ = Line angle at pole, degrees
Ct = Pole circumference at top, in
Cg = Pole circumference at ground line, in
Kc = Calculation constant = 72π

The following force moment terms can usually be omitted for the following reasons:

- M_{we} can usually be ignored because the transverse moment due to wind on pins, insulators, and the ends of crossarms is typically less than 500 ft-lbs. However, M_{we}

should be considered for attached transformers or other equipment. Throughout this course it is assumed that no equipment is attached to the pole. If equipment is attached to the pole, the designer must take the equipment into account in these calculations.

- M_{tc} is zero on tangent poles where the line angle $\theta = 0$ because the sine of $(\theta/2) = 0$ and thus $M_{tc} = 2 * F_{ot} * \{\Sigma(T_c H_c)\} * \sin(\theta/2) = 0$. The nearly equal and opposite longitudinal conductor tensions essentially cancel each other.

- M_{vo} is usually small and can be ignored. Standard crossarm assemblies are symmetrical (looking in the longitudinal direction). Thus, the moments induced in the pole by conductor weights supported by crossarms cancel one another. The remaining conductors are attached directly to the pole. Therefore, the moment induced in the pole due to offset conductor weights is negligible. (Vertical conductor weights alone seldom dictate the required pole class.) Non-balanced pole loads—such as narrow profile assemblies—will affect the pole class and must be taken into account in these calculations.

- $M_{p\text{-}\delta}$ are small ground line moments. Transverse loads cause an un-guyed pole to deflect a small distance. Vertical loads on the pole times this deflection distance cause additional moments to be induced in the pole. These additional moments are small compared to the other moments.

After applying these assumptions and omissions the equation can be simplified to:

$$\mathbf{M_g = S_h * M_{wc} + M_{wp} + M_{tc}}$$

Example Problem: Calculate the Total Horizontal Moment

Given the following information and data, calculate the moment (M_g) at the ground line of a 35-foot un-guyed pole adjacent to a highway crossing span that supports a 3-phase, crossarm assembly. The horizontal wind span (S_h) is 300 feet. The line angle (ϑ) is 2 degrees.

Given pole data:
Pole: Southern Yellow Pine (SYP); 35-foot (set 6 foot deep); Class 5
C_t = 19 in
C_g = 29 in

H_p = 29 ft

<u>Given conductor data</u>:
NESC Heavy Loading District (0F, ½" ice, 4 lb/ft^2 wind)

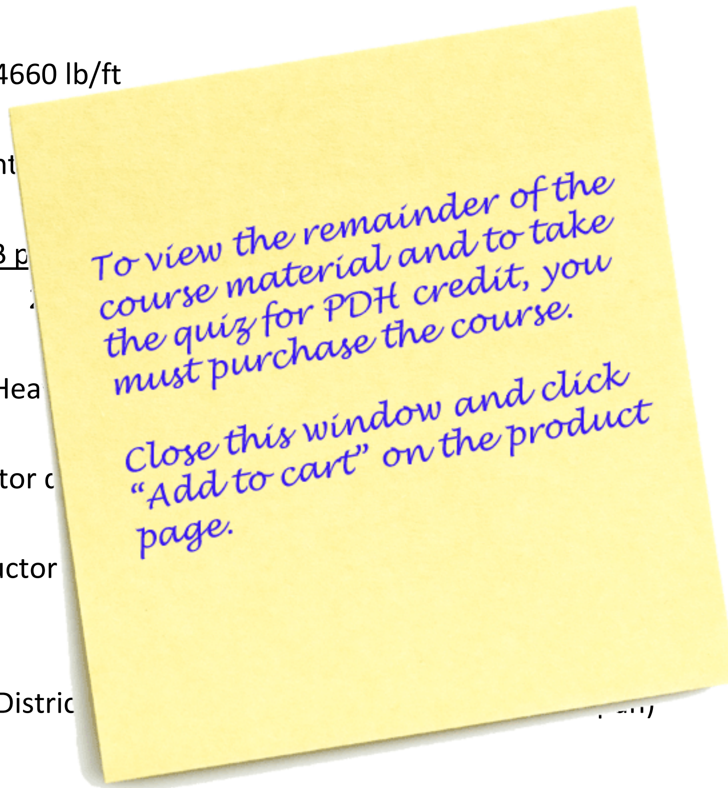
Three Primary Conductors: 266.8 18/1 kcmil ACSR ("Waxwing")

W_c = 0.5363 lb/ft

One Neutral Conductor: 1/0 6/1 ACSR ("Raven")

W_c = 0.4660 lb/ft

Conductor attachment



	A phase	B p
H_c =	28.25	2

The Design Tension, Hea

Phase conductor c

Neutral conductor

<u>Given NESC data</u>:
NESC Heavy Loading Distric

F_{ow} = 2.20
F_{ot} = 1.30
W_p = 4 lb/ft^2

<u>The summation of moments</u> per unit length of conductor (M_{wc}) due to wind on each conductor can be tabulated as follows:

Phase	$W_c H_c$
A	0.5363 * 28.25 = 15.15
B	0.5363 * 29.87 = 16.02
C	0.5363 * 28.25 = 15.15