PDHonline Course E579 (3 PDH)

Distribution Line Design – Volume III

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Electric Distribution Pole Line Design - Volume III - Structural Guying

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This course is based on a series of USDA documents concerning the mechanical design of distribution electric utility facilities.

Introduction

This course is the third volume in a series of three courses on the design of electric distribution pole lines. This volume explains how guys and anchors are installed at distribution line deadends, line angles and at points of unbalanced conductor tensions.

The first volume in this series discussed how to determine: The loads applied to un-guyed wood distribution poles, 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 course in this series presented the methodology and equations required to calculate distribution line ruling spans and conductor sags and tensions.

Unbalanced conductor tensions occur where the conductor size is changed or where there is an appreciable change in the ruling span. A guy assembly needs to be designed to hold the entire horizontal component of the load being applied on the structure in the opposite direction of the guy assembly. A wood pole is used as a strut and supports the vertical components of all loads on the pole including the vertical forces due to the tension contributed by the guy.

While a pole may have sufficient strength to withstand side strain of angles up to five degrees for small conductors, it is usually advisable to install a guy and anchor to prevent the pole from leaning.

This course describes several typical distribution guy and anchor assemblies and their permitted loads and holding power, respectively. The course also discusses the component parts of guy assemblies and their strengths. Installation guidelines are provided for guy and anchor assemblies.

Within this course is the derivation of the equations required to calculate: loading moments, guy resisting forces for several guying situations, guy loads, minimum guy leads, and required pole class to support vertical loads. Example problems using these equations are also presented.

The course references rules and presents selected strength and overload factors required by the 2012 Edition of the National Electrical Safety Code (NESC) for certain guy calculations. At the time this course was written, the 2012 Edition was the latest edition of the NESC. Periodically the NESC is updated and revised. Users of this course should use the rules and data, as may be revised and renumbered, from the most recent edition of the NESC.

Chapter 1
Guying Components

Selection of the proper type of anchor assembly depends upon the soil conditions where the anchor is to be installed. Many utility systems standardize on one or two sizes of anchors of the types most suitable for the soil conditions found in their service areas. The surface area and holding power of the anchor assemblies for distribution line construction are shown in Table 1.

Table 1
Typical Distribution Anchor Assemblies

Anchor Type	Minimum Area (square inches)	Designated Maximum Holding Power (lbs) *
Expanding	90	6,000
	100	8,000
	120	10,000
	135	12,000
Screw (Power Installed)	90	6,000
	100	8,000
	120	10,000
	135	12,000
Plate	90	6,000
	100	8,000
	120	10,000
	135	12,000
Swamp	Helix Diameter (inches)	
	10	6,000
	12	8,000
	15	10,000
Service	Anchor Type	
	Expanding	2,500
	Screw	2,500

* Note: The "designated maximum holding power" assumes the use of the proper anchor rod type and diameter and proper installation in Class 5 soils.

Expanding anchors are the most commonly used anchors on rural distribution lines. Screw (power installed) anchors are most commonly used when loose soils are known to be prevalent near the ground line with firmer soil underneath. Likewise, swamp anchors are needed to penetrate firm soil under swamps and wetlands. Plate anchors are most commonly used when heavy conductors are installed on rural distribution lines. Service anchors are usually used to guy service drops and secondary conductors.

Example of a Screw Anchor

Rock anchors are to be installed and used where solid rock is encountered. Only one guy is to be attached to a rock anchor. Where more than one guy is required, separate anchors are to be installed for each guy at a minimum of two feet apart and, where practical, in a direct line with the conductors. The holding power of rock type anchors is highly variable and depends on type of rock, installation procedures and the grout used.

Anchor Strength Requirements

Table 261-1 of the NESC specifies strength factors (equal to 1.0 for both Grade B and Grade C construction) with which the established holding power of anchors are to be multiplied. Rule 264 of the NESC requires that an anchor and rod assembly have an ultimate strength not less than that of the guys attached to it.

Soil Classifications

Table 2 defines the commonly accepted soil classes and their descriptions.

Table 2 Soil Classifications	
Class	**Engineering Description**
0	Sound hard rock, unweathered
1	Very dense and/or cemented sands; coarse gravel and cobbles
2	Dense fine sand; very hard silts and clays
3	Dense clayed sand, sand, gravel; very stiff to hard silts and clays
4	Medium dense sandy gravel; very stiff to hard silts and clays
5	Medium dense coarse sand and sandy gravels; stiff to very stiff silts and clays
6	Loose to medium dense fine to coarse sand; firm to stiff clays and silts
7	Loose fine sand; alluvium; loess; soft-firm clays; varied clays; fill
8	Peat; organic silts; inundated silts; fly ash

Guy Wires

Table 3illustrates the most common sizes and types of stranded guy wire used for guying conductors on distribution lines. The last column of the table shows the maximum load permitted on a guy wire which is 90 percent of its rated breaking strength per the strength factors (for both Grade B and Grade C construction) specified in Table 261-1 of the 2012 Edition of the NESC. Guy wires and guy assemblies need to be able to hold all of the horizontal forces (loads) acting on the pole multiplied by the appropriate overload factors found in Section 25 of the NESC.

Table 3

Guy Wire Strength Data

Type Strand	Size	Breaking Strength (lbs)	Permitted Load (0.9 * RBS) (lbs)
Siemens Martin Steel	1/4 in	3,150	2,835
	3/8 in	6,950	6,255
	7/16 in	9,350	8,415
High Strength Steel	1/4 in	4,750	4,275
	3/8 in	10,800	9,720
	7/16 in	14,500	13,050
Aluminum Clad Steel	6 M	6,000	5,400
	8 M	8,000	7,200
	10 M	10,000	9,000
	12 M	12,500	11,250

Guy Assemblies and Hardware

Typical distribution guying assemblies include both the guy wire and the hardware to connect the guy wire to the pole. For analysis purposes, this course discusses the guy wires and the pole attachment hardware separately and refers to the pole attachment hardware as the guying assembly. Table 4 presents the typical distribution guy assemblies. Multiple downguys consist of two or more guy assemblies installed in parallel and attached to one or more anchors as may be needed. The last two columns on the right side of Table 4 itemize the permitted loads allowed on each guy assembly. The permitted loads shown are the calculated strengths of the assemblies, multiplied by the strength factor of 0.85 as required in the NESC. All wind and conductor tension loads acting on guy assemblies need to be multiplied by the appropriate overload factors as found in the NESC.

Table 4
Guying Assembly Units

Guying Assembly Type	Permitted Loads (lbs) *	
	Horizontal	@ 45 Degrees
Single Down Guy (Through Bolt)	5,000	7,100
Single Overhead (Through Bolt)	6,600	-

Single Down Guy – Heavy Duty (Through Bolt)	7,400	10,500
Single Down Guy (Wrapped Type)	11,900	16,800
Single Down Guy – Large Conductors (Pole Band Type)	8,500	12,000
* Permitted load is the lesser of loads shown or permitted load of guy wire (See Table: Guy Wire Strength Data). Permitted loads are designated capacities multiplied by 0.85, the NESC strength factor. Greater permitted loads (strengths) are required for guy angles less than 45 degrees.		

Hardware

The following hardware is needed, in certain specific combinations, to attach guy wires to distribution poles:

- Machine bolts and washers (with nuts and locknuts), or thimble eye bolts and/or thimble eye nuts;
- Guy attachments (guy hook or pole band type, or guy hooks and guy plates); and
- Guy deadends (types include: 3-bolt clamp, U-bolt clamp, offset guy clamp and automatic and formed deadends).

Washers

An area of concern with guy attachment hardware is the crushing of wood pole fibers where the washer under the bolt head is in contact with the pole. This washer usually carries the full horizontal component of the working load of the guy assembly. No more than 910 pounds per square inch of compression should be applied for washers abutting wood poles and crossarms. Table 5 shows the maximum compression load allowed for washers abutting wood poles. (The area of the bolt hole is subtracted from the total surface area of the washer.)

Table 5

Standard Washers – Loads Allowed

Washer Size and Type	Approximate Area (In^2)	Load Allowed Abutting Pole (lbs)
2-1/4 in. Square, Flat	4.6	4,200
3 in., Square, Curved	8.6	7,800
4 in. Square, Curved	15.6	14,200

Chapter 2
Pole Loads

Guy-anchor assemblies, in conjunction with poles, need to support the sum of the following loads:

1. Conductor tension loads,
2. Maximum wind/ice loads on the conductors (as defined by NESC Loading Districts),
3. Extreme wind loads (only when top of pole is 60 feet or more above ground),
4. Wind loads on the supporting structure (pole), and,
5. Wind loads on the material and equipment attached to the structure.

All of the above-calculated loads need to be multiplied by the appropriate overload factor as specified in the NESC. The tables in Exhibit B and Exhibit C at the end of this course provide the information required to calculate wind/ice loading for each NESC loading district and on bare conductors commonly installed on distribution lines. The greater of either the (1) wind/ice loads or, (2) extreme wind loads, but not both, need to be added to the sum of the loads. The wind load on materials and equipment attached to a pole can usually be ignored.

NESC Overload Factors

The following table of overload factors has been adapted from Table 253-1 of the NESC:

Table 6
Overload Factors for Poles, Guys, Anchors
(Use with Table 261-1 Strength Factors)

Rule 250B Loads	Overload Factors	
	Grade B	Grade C
Vertical Loads	1.50	1.90
Transverse Loads		
Wind	2.50	2.20
Wire Tension	1.65	1.30
Longitudinal Loads		
In General	1.10	No Requirement
At Deadends	1.65	1.30

At Deadends (for guys)	1.65	1.10

Pole Loading

Guyed poles may be considered to act as struts and need to support the vertical component of the loads plus any additional vertical component of forces that may be induced by the guys. It is assumed that a pole will adequately hold transverse (horizontal) loads not in line with the guys. However, unguyed transverse loads may cause the pole to lean; thus, the installation of additional guys (sideguys) may be desirable.

Application of Loading per Type of Guy Assembly

Typical distribution construction utilizes dead-end, line angle bisector, and occasionally overhead types of guys. The loads that guy assemblies need to hold for the different types of guying arrangements are discussed below.

Single dead-end guy assemblies are installed in line with the conductors they (horizontally) support on the opposite side of the pole. Dead-end guy assemblies need to support conductor tension loads and the maximum wind/ice (or extreme wind) loads on the conductors. These loads are calculated and then multiplied by the appropriate NESC overload factors. For calculation purposes:

- Wind loads are assumed to be horizontal and perpendicular to the conductors (which is considered to be the worst case wind/ice loading condition);
- Wind/ice loads are added to the conductor tension loads in line with the guy assembly; and
- Wind loading on the pole and the attached equipment and material is not added to the sum of the loads.

Double dead-end assemblies consist of two dead-end assemblies that are each guyed in the opposite direction of the conductors. The tension and wind/ice loads are calculated independently for each guying assembly using the same procedure as discussed for single dead-end assemblies. Likewise, at double dead-end assemblies on tangent poles, the loads and guying requirements are determined independently for each set of conductors attached to the pole. In the case of tangent dead-end assemblies, only the difference of the two loads needs to be guyed. Thus, the calculations assume guy assemblies in two directions, however only (preferably) one guy assembly needs to be installed.

Junction poles and tap poles usually have one or more single dead-end guy assemblies. The calculations required to determine the loading and strength requirements for the guys are performed independently for each set of conductors attached to the pole using the same methodology and assumptions previously presented.

Bisector guy assemblies are installed at line angles where there is no change in conductor tension. The conductor may be attached to the pole with a pole-top angle assembly or a double dead-end assembly up to approximately 30 degrees. The guy assemblies are installed in line with the bisector of the line angle. The total loading on a bisector guy assembly is the vector sum of the following:

- The transverse conductor loading tension,
- The wind/ice (or extreme wind) loading on all attached line conductors, and
- The wind loading on the pole, and, if critical, the wind loading on the materials and equipment on the pole.

The wind direction is assumed to be parallel with the direction of the line angle bisector. The appropriate NESC overload factors have to be applied to all of the above loads.

NESC Guying Requirements

As a minimum, guys and anchors are to be of the same grade of construction as the conductors which they (horizontally) support. For typical distribution construction, a minimum of NESC Grade C construction is recommended. However, guys and anchors which support distribution lines and communications circuits attached to or underbuilt on transmission line structures should be designed and constructed to Grade B construction requirements. The NESC may also require Grade B construction for other specific situations and locations. The NESC sets forth the requirements and exceptions for grades of construction.

The NESC sets forth the strength requirements and strength factors for guys and anchors. Table 261-1 (to be used with the overload factors of Table 253-1) requires a strength (multiplication) factor of 0.85 be applied to the pole attachment hardware and a factor of 0.9 be applied to guy wires for Grade C construction.

Determine Weakest Component Part

Determination of the weakest component part of a guying-anchoring system, as may be derated by application of the necessary NESC strength factors (and perhaps age), is essential in proper line design and the use of guys and anchors. The strength or holding power of the combined guy and anchor is only as strong as its weakest component part. Each factor listed below needs to be analyzed separately and compared to ascertain that even the weakest component part of the guying system is stronger than the induced load;

- Holding power of anchors
- Soil classification
- Strength of guy wires
- Maximum permitted load for guy assemblies, hardware and washers

Chapter 3
Load Calculations

The total ground line moment, M_g (measured in ft-lbs), on a pole equals the sum of all the load moments applied to the pole due to wind on the conductors, the pole, and the equipment, plus tension loads imposed by the conductors. Thus:

$$\mathbf{M_g = S_h * M_C + M_t + M_p + M_e}$$

Where:
S_h = Horizontal wind span (1/2 the sum of adjacent spans), ft
Mc = Summation of moment loads due to wind on each conductor expressed as moment per unit length of span (ft-lb/ft)

$$\mathbf{Mc = F_{ow} * \Sigma(Wc * Hc) * \cos(\theta/2)}$$

Mt = Summation of moments due to the tension in each conductor, if there is a line angle (ft-lb)

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

Mp = The moment due to wind on the pole (ft-lb)

$$\mathbf{Mp = F_{ow} * W_p * \frac{(2*C_t+C_g)}{K_c} * H_p^2}$$

Me = The moment due to wind on the material and equipment on the structure (ft-lb)

Where:
F_{ow} = NESC overload factor for wind loads
F_{ot} = NESC overload factor for longitudinal (tension) loads
H_p = Height of pole above ground, ft
H_c = Height of each conductor attachment above groundline, ft
W_c = Wind load per unit length of each conductor, lb/ft
W_p = Wind load per unit area surface of pole, lb/ft^2
T_c = Tension in each conductor, lb
θ = Line angle at pole
C_t = Pole circumference at top, in
C_g = Pole circumference at ground line, in
K_c = Calculation constant = 72π

One or more of the force moment components may be omitted from the equation if its contribution is insignificant as compared to the other force components. The moment due to wind on the material and equipment on the pole, M_e, can usually be omitted because the cross-sectional area of the equipment and material multiplied by the wind force is very small compared to the other forces acting on the pole.

Horizontal Loads on Guy Assemblies

The total horizontal load on a guy assembly is determined by dividing the total ground line moment M_g by the height of the guy attachment above the ground using the following equation:

$$\mathbf{G_h = \frac{M_g}{H_g}}$$

Where:
G_h = Horizontal component of loads on guy assembly, lbs
M_g = Summation of ground line moments of load forces, ft-lbs
H_g = Height of guy attachment (or average of multiple guy attachments) above the groundline, ft

Substituting for $M_{g\ \text{yields}}$:

$$\mathbf{G_h = \frac{(S_h * M_c + M_t + M_p + M_e)}{H_g}}$$

The terms use in this equation were previously defined. The computation is simplified and the results are conservative if, in the calculation of M_c, the cosine of θ/2 is set at 1.0 for all values of θ. This practice is recommended for manual calculations. Also, if insignificant, the wind loading on the pole's material and equipment, M_e, can be deleted.

Horizontal Loads on Bisector Guy Assemblies

This equation is used to calculate the horizontal loads exerted on bisector guy assemblies. Note that the NESC overload factors have been applied. The horizontal permitted load of the guy assembly to be used needs to be greater than the total horizontal loads of G_h. The angle "θ" is the line angle. It is assumed that the wind blows in a direction parallel to the bisector guy.

Horizontal Loads on Dead-End Guy Assemblies

The following equation is used as the basis to calculate the horizontal loads exerted on dead-end guy assemblies. The calculated loads acting on a guyed dead-end pole consist of the longitudinal conductor tension linearly added to the wind/ice (or extreme wind) loading on (perpendicular to) the conductors. This methodology simulates the worst case condition. Thus, the angle factors in the moment calculations are set to unity. The equation used to calculate the horizontal loads on a single dead-end guy assembly is:

$$\mathbf{G_h = \frac{(S_h * M_c + M_t)}{H_g}}$$

Where:
$M_c = F_{ow} * \Sigma(Wc * Hc)$
$M_t = F_{ot} * \Sigma(Tc * Hc)$
S_h = ½ the span length of the conductor dead-ending on the pole, ft
H_g = Height of guy attachment (or average of multiple guy attachments) above the groundline, ft

However, under some circumstances, the wind (only) loading on the pole and the attached material and equipment may be greater than the wind/ice loading on the conductors. In such cases it is assumed that the wind direction is the same as the conductor longitudinal tension. Therefore, the following equation is used to calculate the horizontal loads on a single dead-end guy assembly.

$$\mathbf{G_h = \frac{(M_t + M_p + M_e)}{H_g}}$$

The horizontal permitted load of the guy assembly to be used needs to be greater than the total horizontal load, G_h, calculated by either method above.

Other Dead-End Guy Assemblies

At double dead-ends, multiple dead-ends, junction poles, and tap poles, the total horizontal loads, and subsequently the guying requirements, need to be determined independently for each dead-end assembly on the pole. The horizontal loads acting on each guy assembly are calculated using the above assumptions.

Calculation of Permitted Loads on Guy Assemblies

The total load on the guy attachment hardware, the guy wire and the anchor assembly is calculated by using the following equation.

$$\mathbf{G_r = \frac{G_h}{\sin \varnothing}}$$

Where:
G_r = Total guy load, lbs (on guy assembly, guy wire, and anchor assembly)
G_h = Total horizontal load on guy assembly, lbs
ϕ = Guy wire angle with respect to pole (degrees)

The loads applied to the guy and anchor assembly have previously been multiplied by the appropriate NESC overload factors in the calculation of G_h.

However, the NESC strength factors have not been applied in the equation above. According to Table 261-1 of the NESC, the load, G_r, should be multiplied by 0.85, 0.9, and 1.0 to yield the permitted loads for guy assemblies, guy wires, and anchor assemblies, respectively. Note that designated loads for anchors, guy wires, and guy assemblies have already been increased by the above strength factors and listed the resulting permitted loads in Table 1: Typical Distribution Anchor Assemblies, Table 3: Guy Wire Strength Data, and Table 4: Guying Assembly Units, respectively.

The permitted loads of guy assemblies and guy wires and the holding power of anchors each need to be greater than total load, G_r, to adequately support the conductor tension and wind loads and meet the requirements of the NESC.

Since the down guy assembly forms a right triangle:

$$\mathbf{F_g^2 = H_g^2 + L_g^2} \quad \text{and} \quad \mathbf{\sin(\phi) = \frac{L_g}{F_g}}$$

Where:
L_g = Guy lead, or distance from pole to anchor rod, ft
H_g = Height of guy attachment above ground, ft
F_g = Length of guy wire, ft

Then:

$$\sin(\phi) = \frac{L_g}{\sqrt{(H_g^2 + L_g^2)}}$$

And the equation can also be written as:

$$G_r = G_h * \frac{\sqrt{(H_g^2 + L_g^2)}}{L_g}$$

Assuming a 1:1 guy slope, the resultant guy load or tension is:

$$G_r = 1.414 * G_h$$

Calculation of Minimum Guy Lead

While it is recommended that a 1:1 guy slope be used wherever possible, in some instances it is necessary to determine the minimum allowable guy lead for various guy and anchor arrangements.

The minimum allowable guy lead to the average anchor position is given by:

$$L_{ga} = H_g * \tan(\sin^{-1}(\frac{G_h}{G_u * F_g}))$$

Where:
L_{ga} = Minimum allowable guy lead, ft
H_g = Guy attachment height, ft
G_h = Horizontal load at guy attachment point, lbs
G_u = Least of: guy wire breaking strength, designated strength of guy assembly, or total anchor holding power (each in lbs)
F_g = NESC strength factor (Table 261-1 of NESC)

If the permitted loads of anchors, guy wires, and guy assembles are used (Table 1: Typical Distribution Anchor Assemblies, Table 3: Guy Wire Strength Data, and Table 4: Guying Assembly Units, respectively), then F_g should be set to 1.0 because NESC strength factors have already been included in the aforementioned tables.

Minimum guy leads should be used only when it is not possible to obtain a 1:1 or greater guy slope. Always use the longest possible guy wire lead length to obtain the maximum strength from the guy assembly. It is common practice to increase calculated minimum leads from six inches to one foot to allow for wind loading on structure accessories and for construction tolerances. Short guy leads and the resulting greater downward loads on the bolt holding the guy assembly to the pole may cause the pole to split.

Methodology for Multiple Guys

Multiple guys and anchors are required where the strength of one guy assembly or one anchor is not adequate for the load. Multiple guys may be placed two or more in line with the longitudinal tension according to construction specifications, or if required by field conditions, spread apart with the anchors installed side-by-side. The recommended minimum separation between anchors is five feet in soils and two feet in rock.

Multiple guy attachments on a pole are relatively short distances apart for most distribution structures. If this is the case, then the simplest method for calculating guy loads is to assume that all of the guys are just one assembly, attached to the pole at one point and attached to one anchor. The pole attachment is assumed to be the average height above ground of all of the actual guy attachments. The anchor is assumed to be the average distance from the pole of all of the actual anchor locations. The calculations are then made for a single guy and anchor using the equations given previously.

To determine the minimum guy leads required for multiple guys, calculate the total load at the average guy attachment point. Then divide this load by the number of guys and calculate the required guy lead to the average anchor location.

Chapter 4
Guy Calculation Example

Assume that a 25 kV, suspension angle, large conductors, three-phase, pole-top assembly needs to be constructed at a line angle of 30 degrees. The assembly is installed on a class 40-5 Southern Yellow Pine pole. The phase conductors are 266.8 kcmil (26/7) ACSR with a 1/0 (6/1) ACSR neutral. One-half the sum of the adjacent spans (S_h) is 400 feet. Four (4) standard down guy assemblies and two (2) standard anchor assemblies are to be used to hold the conductor loads. NESC Grade C construction is to be used and the pole is situated in the NESC light loading district.

Determine the loads that the guy and anchor assemblies need to hold, and subsequently determine the adequate standard assemblies that should be used for the above theoretical construction.

Pole Data:
L_p = 40 ft (height of pole)
H_p = 34 ft (height above ground)
L_g = 6 feet (bottom to ground line)
C_t = 19 in (circumference at top)
C_g = 31 in (circumference at ground line)
$K_c = 72\pi$ (calculation constant)

NESC Data:
W_p = 9 lbs/ft^2 (Table 250-1)
F_{ow} = 2.2 (Table 253-1)
F_{ot} = 1.3 (Table 253-1)
F_g = 0.9 (Table 261-1)

Conductor Data

Conductor	Wc (lbs/ft)	Wv, (lbs/ft)	Tc, lbs (40 % Ultimate Strength)
266.8 kcmil	0.4815	0.3673	4,500
1/0	0.2985	0.1452	1,750

Conductor Attachment Heights: (Center of brackets from top of pole)
Top (A) Phase = 1.0 ft (= 33 ft from groundline)
Middle (B) Phase = 5.0 ft (= 29 ft from groundline)
Bottom (C) Phase = 9.0 ft (= 25 ft from groundline)

Neutral = 13.0 ft (= 21 ft from groundline)

Guy Assembly Attachment Heights: (From top of pole)
Top Phase = 2.5 ft (= 31.5 ft from groundline)
Middle Phase = 6.5 ft (= 27.5 ft from groundline)
Bottom Phase = 10.5 ft (= 23.5 ft from groundline)
Neutral = 14.5 ft (= 19.5 ft from groundline)

Average guy attachment height:

$$H_g = \frac{31.5 + 27.5 + 23.5 + 19.5}{4}$$

$$H_g = 25.5 \text{ ft}$$

Wind Moment Load on the Pole Surface

$$\mathbf{M_p = F_{ow} * W_p * \frac{(2*C_t+C_g)}{K_c} * H_p^2}$$

$$M_p = 2.2 * 9 * \frac{(2*19+31)}{72*\pi} * 34^2$$

Mp = 6,982 lb-ft

Wind Moment Load on the Conductors

Use,

$$\mathbf{M_c = F_{ow} * \Sigma(Wc * Hc) * \cos(\theta/2)}$$

Phase		$H_c * W_c$
	A	33.0 * 0.4815 = 15.89 ft−lb/ft
	B	29.0 * 0.4815 = 13.96 ft−lb/ft
	C	25.0 * 0.4815 = 12.04 ft−lb/ft
N		21.0 * 0.2985 = 6.27 ft −lb/ ft

$$\sum(H_c * W_c) = 48.16 \text{ ft−lb/ft}$$

Mc = 2.2 * 48.16 * cos (30/2)

$$M_c = 102.34 \text{ ft-lb/ft}$$

Total Horizontal Moment Load Due to Conductor Tensions

Use,

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

Phase		$H_c * T_c$
	A	33.0 * 4500 = 148,500 ft-lb
	B	29.0 * 4500 = 130,500 ft-lb
	C	25.0 * 4500 = 112,500 ft-lb
N	1.0 * 1750 =	36,750 ft-lb

$\Sigma H_cT_c = 428,250$

$M_t = 2 * 1.3 * 428,250 * \sin (30/2)$

$M_t = 288,182$ ft-lb

Total Horizontal Load on Guy Assemblies:

Use,

$$\mathbf{G_h = \frac{(S_h * M_c + M_t + M_p)}{H_g}}$$

$$G_h = \frac{(400 * 102.34 + 288,162 + 6,982)}{25.5}$$

$G_h = 13,180$ lbs.

Total Load on Guy Assemblies

The total load on the guy assemblies, assuming an average 1:1 guy slope (45 degree angle), is calculated with,

$$\mathbf{G_r = \frac{G_h}{\sin \emptyset}}$$

$$G_r = \frac{13,180}{\sin(45)}$$

$G_r = 18,639$ lbs

Average Load on Each Guy Assembly

The average load on each guy assembly, using four down guys and assuming each has a 1:1 guy slope is:

$\frac{18{,}639}{4}$ = 4,660 lbs

Permitted Loads on, and Required Strength of Guy Assemblies

The average load calculated above (which has been previously multiplied by the appropriate NESC overload factors), should not exceed the permitted load on each guy assembly. The permitted load on a guy assembly is determined by multiplying its designated strength by its appropriate NESC strength factor of 0.85 as found in Table 261-1 of the NESC. Conversely, the required strength of the guy assembly is determined by dividing the total (in this case, average) load by the appropriate NESC strength factor. Thus, for this example, required (or designated) strength is:

$\frac{4{,}660}{0.85}$ = 5,482 lbs (at 45 degrees)

Selection of Guy Assembly

Based on the calculations above, the guy assembly has to have a permitted load (strength) of 4,660 pounds at 45 degrees or equivalently, a designated strength of 5,482 pounds.
Any of the standard down guy assemblies, as listed in Table 4: Guying Assembly Units are adequate to hold the conductor tension and wind loads as calculated above. However, for large conductor applications, such as used in this example, it is recommended that heavy-duty guy assemblies be used, specifically ones with a permitted load of 10,500 pounds at 45 degrees.

Permitted Loads on, and Strength of Guy Wires

Similar to guy assemblies, the permitted load (strength) of each guy wire also has to be equal to or greater than the average load of 4,660 pounds at 45 degrees calculated above. The designated strength of the guy wire is also determined by dividing the (average) total load by the NESC strength factor of 0.90 as found in Table 261-1 of the NESC. Therefore, for the guy wires; required (or designated) strength is:

$\frac{4{,}660}{0.90}$ = 5,178 lbs

Selection of Guy Wires

3/8 inch Siemens-Martin Steel guy wires, with a permitted load of 6,255 pounds (see Table 3: Guy Wire Strength Data) would be adequate for the loads calculated above. Because the guy wires are holding large conductors, it is recommended that 7/16 inch Siemens-Martin Steel guy wire (permitted load equals 8,415 pounds) be used.

Permitted Load on Anchors

The required holding power of each anchor is 9,320 pounds (18,639 pounds divided by 2) assuming that that the total load is equally split between the anchors. The permitted loads on anchors are equal to their designated maximum holding power because the strength factor (Table 261-1 of the NESC) for anchor is 1.0.

Selection of Anchors

Any anchor assemblies rated at 10,000 pounds or more (see Table 1: Typical Distribution Anchor Assemblies) may be used. However, anchors rated at 12,000 pounds or more are recommended in this case as a measure of safety and to better match the larger guy assemblies and guy wires that are recommended.

Minimum Average Guy Lead

Determine the minimum average guy lead, assuming the following recommended standard assemblies are used:

- Guy assemblies – (permitted load = 4 *10,500 = 42,000 lbs)
- Guy wire – 7/16 inch Siemens-Martin (permitted load = 4 * 8,415 = 33,660 lbs)
- Plate anchors – (permitted load = 2 * 12,000 = 24,000 lbs)

From the calculations, the anchors are the limiting component part of this example guying arrangement, and thus are used in the design calculations. Use the following equation to determine the minimum average guy lead.

$$\mathbf{L_{ga} = H_g * \tan(\sin^{-1}(\frac{G_h}{G_u * F_g}))}$$

$$L_{ga} = 25.5 * \tan(\sin^{-1}(\frac{13,182}{24,000}))$$

L_{ga} =16.76 ft

Note that the average guy attachment height of 25.5 feet was previously. Also, the NESC strength factor was not used in the denominator in the above equation because it had already been applied to the anchor to yield its permitted load. After adding 0.5 foot tolerance and rounding up the next whole foot, the minimum lead becomes:

L_{ga} = 18 ft.

The spacing between anchors should not be less than 5.0 feet, i.e., each anchor should be 2.5 feet from the average lead length calculated above and in line with the line angle bisector. If the guy lead lengths need to be further reduced, then select guy assemblies, guy wires, and/or anchor assemblies with greater permitted loads, or increase the number of anchors. The calculation is then repeated. It is recommended that guy lead lengths not be less than 15 feet because on the tendency of the pole to split where the through bolt holds the guy assembly.

Chapter 5
Pole Class Determination

The column strengths of poles at guyed locations should be examined for their ability to sustain loads due to the vertical weight of the conductors, equipment, and the vertical component of the load supported by the guys. A guyed pole acts as a column sustaining these axial loads. A pole acting as a column becomes unstable when the axial force becomes large enough to cause large lateral deflections which might significantly add to the moment loads contributed by conductors, ice, and equipment installed on the pole.

The American Institute of Timber Construction suggests that the critical section of a guyed pole is one-third the distance from the point of guy attachment to the groundline. In column strength calculations this section is assumed to be where the pole strength is most critical. A *minimum* factor of safety of 1.5 (based on Table 253-1 of the NESC) should be applied to the loads in the computations because of the various assumptions that need to be made.

Critical Vertical Load

In general, the critical axial load for a pole acting as a column is calculated by using the following formula:

$$\mathbf{P_{cr} = \frac{\pi * E * A^2}{F_v * K_a * (K_u * H_{gb})^2}}$$

Where:
P_{cr} = Critical buckling axial load, lbs
E = Modulus of elasticity of wood (=1,800,000 lbs/in)
A = Cross section area of pole at two-thirds of the distance from the groundline to the bottom guy attachment, in
K_a = Conversion constant (576)
H_{gb} = Height of bottom guy attachment above ground, ft
K_u = The theoretical coefficient of unbraced length
= 0.7 for bisector guying
= 2.0 for dead-end guying
F_v = Safety Factor (= 1.5 minimum)

To determine the area of the pole at the critical point, A, solve the following equation:

$$\mathbf{A = \frac{1}{4 * \pi} * (\frac{(C_b - C_t) * (H_p - 0.667H_{gb})}{L_p - L_b} + C_t)^2}$$

Where:
A= Area of pole at the critical point, in^2
C_b = Circumference of pole 6 feet from the butt, in
C_t = Circumference of pole at top, in
H_{gb} = The distance from groundline to the bottom guy, ft
H_p = Pole height above ground , ft
L_b = Bottom of pole to ANSI classification point (6 ft)
L_p = Pole height, ft

Actual Vertical Loads

The actual vertical loads on the pole are the vertical component of the loads on the guy wires plus the weight of the conductors plus the weight of the material and equipment installed on the pole. G_v, the vertical component of the load contributed by guy wire is calculated using the following equation:

$$\mathbf{G_v = \frac{(S_h * M_c + M_t + M_p + M_e)}{L_g}}$$

Where:
M_c, M_t, M_p and M_e are groundline moments, lbs
L_g = Length of guy lead, ft
S_h = 1/2 the sum of adjacent spans, ft

All overload factors should be set equal to 1.0 when performing the calculations to determine G_v. (If groundline moments have previously been calculated using overload factors, then it is only necessary to divide these previously calculated moments by the overload factors.) The moment due to wind on the material and equipment on the pole, M_e, is included in the calculations only if the material and equipment has sufficient cross-section area to have appreciable impact on the wind moment.

W_c, the vertical load (lbs) due to the weight of the conductors is calculated using the following equation:

$$\mathbf{W_c = S_v * \Sigma (W_v)}$$

Where:

S_v = Distance between the low point of sags of the adjacent spans, ft
W_v = Loaded vertical force (weight) of conductors per unit length, lb/ft

Where spans are relatively short, the error will be small if the horizontal wind span, S_h, is substituted for S_v. The weight of crossarms, braces, insulators, and the pole above the bottom guy attachment point can usually be neglected in calculations for distribution poles.

Required Pole Class

If $(G_v+W_c) \leq P_{cr}$, then the selected pole class is adequate; otherwise the pole class needs to be increased until $(G_v+W_c) \leq P_{cr}$ is true.

Example Calculation for Vertical Loads

Determine the critical axial load for the guyed pole in the example problem. Use the previous data provided, the results of the previous calculations and the following data regarding a standard 40 foot, Class 5, Southern Yellow Pine pole.

Pole Data:
F_b = 8,000 lb/in (designated fiber stress)
H_p = 34 ft (height above ground)
H_{gb} = 19.5 ft (height to bottom guy attachment)
L_g = 6 ft (bottom to ground line)
L_b = 6 ft (bottom to ANSI classification point)
C_t = 19 in (circumference at top)
C_b = 31 in (circumference at ANSI classification point)
C_g = 31 in (circumference at ground line)

$$\mathbf{A = \frac{1}{4 * \pi} * (\frac{(C_b - C_t) * (H_p - 0.667H_{gb})}{L_p - L_b} + C_t)^2}$$

$$A = \frac{1}{4 * \pi} * (\frac{(31 - 19) * (34 - 0.667 * 19.5)}{40 - 6} + 19)^2$$

A = 55.49 in^2

Using,

$$\mathbf{P_{cr} = \frac{\pi * E * A^2}{F_v * K_a * (K_u * H_{gb})^2}}$$

$$P_{cr} = \frac{\pi * 1{,}800{,}000 * 55.49^2}{1.5 * 576 * (0.7 * 19.5)^2}$$

P_{cr} = 108,161 lbs

Use,

$\mathbf{W_c = S_v * \Sigma (W_v)}$

And substitute S_h for S_v, and solve for W_c:

W_c = 400 * [(3 * 0.367) + (1 * 0.145)]

W_c = 498 lbs

Use the following equation and solve for G_v. Use the values of M_c, M_t and M_p previously used in the guy strength calculations, but divide each value by the appropriate overload capacity factor to reduce the factor to one.

$$\mathbf{G_v = \frac{(S_h * M_c + M_t + M_p + M_e)}{L_g}}$$

$$G_v = \frac{\frac{400 * 102.43}{2.2} + \frac{288{,}182}{1.3} + \frac{6{,}982}{2.2}}{6}$$

G_v = 40,579 lbs

$G_v + W_c$ = 40,579 + 498 = 41,077 lbs

Therefore, the pole has adequate strength for vertical axial loads.

The calculations immediately above will demonstrate that for most distribution guy designs, axial loading will not be a problem if a 1:1 guy slope is used and the poles are equal to or one class larger than the normal tangent pole class. Computations should be made where unusually tall poles require guying. Generally, reducing a guy lead by one half will approximately double the axial load; using one-fourth of the normal guy lead will increase the pole's axial load by a factor of approximately four.

Summary

In this course we have explained how guys and anchors are installed at distribution line deadends, line angles and at points of unbalanced conductor tensions.

This course was the third in a series of three courses about distribution line design. The first volume in this series discussed how to determine: The loads applied to un-guyed wood distribution poles, 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 course in this series presented the methodology and equations required to calculate distribution line ruling spans and conductor sags and tensions.

We hope this course has given you greater understanding of the mechanical characteristics of distribution line design.

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Appendices

Appendix A - Abbreviations

Appendix B – Conductor Loading (NESC)

Appendix C - Extreme Wind Loading (NESC)

Appendix A
Abbreviations

A = Cross section area of pole at two-thirds of the distance from the groundline to the bottom guy attachment, in
Cb = Circumference of pole 6 feet from the butt, in
C_g = Pole circumference at ground line, in
Ct = Circumference of pole at top, in
E = Modulus of elasticity of wood
F_g = NESC strength factor (Table 261-1 of NESC)
F_{ot} = NESC overload factor for longitudinal (tension) loads
F_{ow} = NESC overload factor for wind loads
F_v = Safety Factor
G_h = Horizontal component of loads on guy assembly, lbs
G_r = Total guy load, lbs
G_u = Least of: guy wire breaking strength, designated strength of guy assembly, or total anchor holding power (each in lbs)
H_c = Height of each conductor attachment above groundline, ft
H_g = Height of guy attachment above the groundline, ft
H_{gb} = Height of bottom guy attachment above ground, ft
H_p = Pole height above ground , ft
K_a = Conversion constant
K_c = Calculation constant
K_u = The theoretical coefficient of unbraced length
L_b = Bottom of pole to ANSI classification point
L_g = Length of guy lead, ft
L_{ga} = Minimum allowable guy lead, ft
L_p = Pole height, ft
Mc = Summation of moment loads due to wind on each conductor (ft-lb/ft)
Me = The moment due to wind on the material and equipment on the structure (ft-lb)
M_g = Summation of ground line moments of load forces, ft-lbs
Mp = The moment due to wind on the pole (ft-lb)
Mt = Summation of moments due to the tension in each conductor, (ft-lb)
P_{cr} = Critical buckling axial load, lbs
S_h = 1/2 the sum of adjacent spans, ft
S_v = Distance between the low point of sags of the adjacent spans, ft
T_c = Tension in each conductor, lb
W_c = Wind load per unit length of each conductor, lb/ft
W_p = Wind load per unit area surface of pole, lb/ft^2
W_v = Loaded vertical force (weight) of conductors per unit length, lb/ft

θ = Line angle at pole

ϕ = Guy wire angle with respect to pole (degrees)

Appendix B

Conductor Loading (NESC)

Name	Size	Str	Light 0.0" ice 9 Lb Wind K=0.05			Medium 0.25" Ice 4 Lb Wind K=0.20			Heavy 0.50" ice 4 Lb Wind K=0.30			Ultimate Strength	Dia. In.	X-Area Sq. In.
			Vert. Lb/Ft	Trans. Lb/Ft	Total Lb/Ft	Vert. Lb/Ft	Trans. Lb/Ft	Total Lb/Ft	Vert. Lb/Ft	Trans. Lb/Ft	Total Lb/Ft			
ACSR Conductors														
Swanate	4	7/1	0.0670	0.1928	0.1622	0.2247	0.2523	0.5379	0.5379	0.4190	0.9818	2,360	0.257	0.0411
Sparrow	2	6/1	0.0913	0.2370	0.1934	0.2673	0.2720	0.5814	0.5989	0.4387	1.0423	2,850	0.316	0.0608
Sparate	2	7/1	0.1067	0.2438	0.2060	0.2855	0.2750	0.5964	0.6199	0.4417	1.0611	3,640	0.325	0.0654
Raven	1/0	6/1	0.1452	0.2985	0.3819	0.3467	0.2993	0.6580	0.7036	0.4660	1.1439	4,380	0.398	0.0968
Quail	2/0	6/1	0.1831	0.3353	0.4320	0.3998	0.3157	0.7094	0.7719	0.4823	1.2102	5,310	0.447	0.1221
Pigeon	3/0	6/1	0.2309	0.3765	0.4917	0.4647	0.3340	0.7723	0.8539	0.5007	1.2899	6,620	0.502	0.1537
Penguin	4/0	6/1	0.2911	0.4223	0.5629	0.5439	0.3543	0.8491	0.9520	0.5210	1.3853	8,350	0.563	0.1939
Waxwing	266.8	18/1	0.2894	0.4568	0.5907	0.5565	0.3697	0.8681	0.9789	0.5363	1.4162	6,880	0.609	0.2210
Partridge	266.8	26/7	0.3673	0.4815	0.6556	0.6446	0.3807	0.9486	1.0774	0.5473	1.5084	11,300	0.642	0.2436
Merlin	336.4	18/1	0.3653	0.5130	0.6798	0.6557	0.3947	0.9653	1.1015	0.5613	1.5363	8,680	0.684	0.2789
Linnet	336.4	26/7	0.4630	0.5408	0.7619	0.7649	0.4070	1.0664	1.2222	0.5737	1.6501	14,100	0.721	0.3070
Pelican	477.0	18/1	0.5180	0.6105	0.8506	0.8488	0.4380	1.1551	1.3350	0.6047	1.7656	11,800	0.814	0.3955
Hawk	477.0	26/7	0.6570	0.6435	0.9696	1.0015	0.4527	1.2990	1.5014	0.6193	1.9241	19,500	0.858	0.4354
Osprey	556.5	18/1	0.6040	0.6593	0.9441	0.9550	0.4597	1.2599	1.4614	0.6263	1.8900	13,700	0.879	0.4612
Dove	556.5	26/7	0.7660	0.6953	1.0845	1.1319	0.4757	1.4278	1.6533	0.6423	2.0737	22,600	0.927	0.5083
Kingbird	636.0	18/1	0.6910	0.7050	1.0372	1.0610	0.4800	1.3645	1.5864	0.6467	2.0131	15,700	0.940	0.5275
Grosbeak	636.0	26/7	0.8750	0.7425	1.1976	1.2605	0.4967	1.5548	1.8014	0.6633	2.2197	25,200	0.990	0.5808
Drake	795.0	26/7	1.0940	0.8310	1.4238	1.5162	0.5360	1.8081	2.0938	0.7027	2.5086	31,500	1.108	0.7264
Tern	795.0	45/7	0.8960	0.7973	1.2493	1.3042	0.5210	1.6044	1.8678	0.6877	2.2904	22,100	1.063	0.6674
6201 Aluminum Alloy Conductors														
Azusa	123.3	7	0.1157	0.2985	0.3701	0.3172	0.2993	0.6361	0.6741	0.4660	1.1195	4,460	0.398	0.0968
Anaheim	155.4	7	0.1459	0.3353	0.4156	0.3626	0.3157	0.6807	0.7347	0.4823	1.1789	5,390	0.447	0.1221
Amherst	195.7	7	0.1857	0.3765	0.4689	0.4175	0.3340	0.7347	0.8067	0.5007	1.2495	6,790	0.502	0.1537
Alliance	246.9	7	0.2318	0.4223	0.5317	0.4846	0.3543	0.8003	0.8927	0.5210	1.3337	8,560	0.563	0.1939
Butte	312.8	19	0.2936	0.4815	0.6140	0.5709	0.3807	0.8862	1.0037	0.5473	1.4432	11,000	0.642	0.2456
Canton	394.5	19	0.3703	0.5408	0.7054	0.6722	0.4070	0.9858	1.1295	0.5737	1.5668	13,330	0.721	0.3099
Darien	559.5	19	0.5252	0.6435	0.8806	0.8697	0.4527	1.1804	1.3696	0.6193	1.8031	18,800	0.858	0.4394
Elgin	652.4	19	0.6124	0.6953	0.9765	0.9783	0.4757	1.2878	1.4997	0.6423	1.9314	21,800	0.927	0.5124
Flint	740.8	37	0.6754	0.7433	1.0543	1.0612	0.4970	1.3718	1.6025	0.6637	2.0345	24,400	0.991	0.5818
Greeley	927.2	37	0.8704	0.8310	1.2534	1.2926	0.5360	1.5993	1.8702	0.7027	2.2979	30,500	1.108	0.7282

Appendix C

Extreme Wind Loading (NESC)

Name	Size	Str	Vert. Lb/Ft	13 Lbs		16 Lbs		21 Lbs		26 Lbs		31 Lbs		6 Lbs	
				Trans. Lb/Ft	Total Lb/Ft	Trans. Lb/Ft	Total Lb/Ft	TransL b/Ft	Total Lb/Ft	Trans. Lb/Ft	Total Lb/Ft	Trans. Lb/Ft	Total Lb/Ft	Trans. Lb/Ft	Swing Angle
ACSR Conductors															
Swanate	4	7/1	0.0670	0.2784	0.2864	0.3427	0.3492	0.4498	0.4547	0.5568	0.5608	0.6639	0.6673	0.1285	78.35
Sparrow	2	6/1	0.0913	0.3423	0.3543	0.4213	0.4311	0.5530	0.5605	0.6847	0.6907	0.8163	0.8214	0.1580	59.98
Sparate	2	7/1	0.1067	0.3521	0.3679	0.4333	0.4463	0.5688	0.5787	0.7042	0.7122	0.8396	0.8463	0.1625	65.71
Raven	1/0	6/1	0.1452	0.4312	0.4550	0.5307	0.5502	0.6965	0.7115	0.8623	0.8745	1.0282	1.0384	0.1990	53.88
Quail	2/0	6/1	0.1831	0.4843	0.5177	0.5960	0.6235	0.7823	0.8034	0.9685	0.9857	1.1548	1.1692	0.2235	50.67
Pigeon	3/0	6/1	0.2309	0.5438	0.5908	0.6693	0.7080	0.8785	0.9083	1.0877	1.1119	1.2968	1.3172	0.2510	47.39
Penguin	4/0	6/1	0.2911	0.6099	0.6758	0.7507	0.8051	0.9853	1.0274	1.2198	1.2541	1.4544	1.4833	0.2815	44.04
Waxwing	266.8	18/1	0.2894	0.6598	0.7204	0.8120	0.8620	1.0658	1.1043	1.3195	1.3509	1.5733	1.5996	0.3045	46.46
Partridge	266.8	26/7	0.3673	0.6955	0.7865	0.8560	0.9315	1.1235	1.1820	1.3910	1.4387	1.6585	1.6987	0.3210	41.15
Merlin	336.4	18/1	0.3653	0.7410	0.8262	0.9120	0.9824	1.1970	1.2515	1.4820	1.5264	1.7670	1.8044	0.3420	43.11
Linnet	336.4	26/7	0.4630	0.7811	0.9080	0.9613	1.0670	1.2618	1.3440	1.5622	1.6293	1.8626	1.9193	0.3605	37.90
Pelican	477.0	18/1	0.5180	0.8818	1.0227	1.0853	1.2026	1.4245	1.5158	1.7637	1.8382	2.1028	2.1657	0.4070	38.16
Hawk	477.0	26/7	0.6570	0.9295	1.1383	1.1440	1.3192	1.5015	1.6389	1.8590	1.9717	2.2165	2.3118	0.4290	33.14
Osprey	556.5	18/1	0.6040	0.9523	1.1277	1.1720	1.3185	1.5383	1.6526	1.9045	1.9980	2.2708	2.3497	0.4395	36.04
Dove	556.5	26/7	0.7660	1.0043	1.2630	1.2360	1.4541	1.6223	1.7940	2.0085	2.1496	2.3948	2.5143	0.4635	31.18
Kingbird	636.0	18/1	0.6910	1.0183	1.2306	1.2533	1.4312	1.6450	1.7842	2.0367	2.1507	2.4283	2.5247	0.4700	34.22
Grosbeak	636.0	26/7	0.8750	1.0725	1.3842	1.3200	1.5837	1.7325	1.9409	2.1450	2.3166	2.5575	2.7030	0.4950	29.50
Drake	795.0	26/7	1.0940	1.2003	1.6241	1.4773	1.8383	1.9390	2.2263	2.4007	2.6382	2.8623	3.0643	0.5540	26.86
Tern	795.0	45/7	0.8960	1.1516	1.4591	1.4173	1.6768	1.8603	2.0648	2.3032	2.4713	2.7461	2.8886	0.5315	30.68
6201 Aluminum Alloy Conductors															
Azusa	123.3	7	0.1157	0.4312	0.4464	0.5307	0.5431	0.6965	0.7060	0.8623	0.8701	1.0282	1.0347	0.1990	59.83
Anaheim	155.4	7	0.1459	0.4843	0.5058	0.5960	0.6136	0.7823	0.7957	0.9685	0.9794	1.1548	1.1639	0.2235	56.86
Amherst	195.7	7	0.1857	0.5438	0.5740	0.6693	0.9641	0.8785	0.8975	1.0877	1.1031	1.2968	1.3098	0.2510	53.80
Alliance	246.9	7	0.2318	0.6099	0.6525	0.7507	0.7856	0.9853	1.0122	1.2198	1.2417	1.4544	1.4728	0.2815	50.53
Butte	312.8	19	0.2936	0.6955	0.7549	0.8560	0.9050	1.1235	1.1612	1.3910	1.4216	1.6585	1.6843	0.3210	47.55
Canton	394.5	19	0.3703	0.7811	0.8644	0.9613	1.0302	.2618	1.3150	1.5622	1.6055	1.8626	1.8990	0.3605	44.23
Darien	559.5	19	0.5252	0.9295	1.0676	1.1440	1.2588	1.5015	1.5907	1.8590	1.9318	2.2165	2.2779	0.4290	39.24
Elgin	652.4	19	0.6124	1.0043	1.1762	1.2360	1.3794	1.6223	1.7340	2.0085	2.0998	2.3948	2.4718	0.4635	37.12
Flint	740.8	37	0.6754	1.0736	1.2684	1.3213	1.4839	1.7343	1.8611	2.1472	2.2509	2.5601	2.6477	0.4955	36.27
Greeley	927.2	37	0.8704	1.2003	1.4827	1.4773	1.7147	1.9390	2.1254	2.4007	2.5536	2.8623	2.9917	0.5540	32.48