Lesson: Pole Structural Loading

The purpose of this course is to review the methods used to calculate loads on wood utility poles and crossarm assemblies. Ground line moments as well as vertical loads are considered. After taking this course you will,

- Know how to calculate the wind load on a pole
- Know how to calculate the wind load on equipment
- Know how to calculate the wind and ice loads on conductors
- Understand the impact of vertical loads on poles
- Understand the impact of extreme wind on pole loading
- Know how to calculate crossarm and insulator loads

Introduction

Utility structures must be designed to support conductors, equipment, hardware, as well as the cables of other companies such as telephone and cable TV (CATV.)In addition to supporting these loads, the structures must be capable of withstanding the force of the wind blowing against the structure and all the equipment and conductors attached to the structure.

The typical loads on poles include wind pressure on the pole, wind pressure on the equipment attached to the pole, wind pressure on the conductors attached to the pole, and the tension in the conductors that is caused by angles in the pole line. The vertical loads on a pole and the soil stability must be considered in the design of a pole structure. Pole assemblies such as crossarms and insulator pins must be designed to withstand the vertical and longitudinal loads imposed due to conductors and other equipment.

The overriding design issue for a wood pole structure is the ultimate resisting force, or moments, imposed on the pole at the ground line. To properly design a wood pole structure, the moments at the ground line are calculated for all loads on the structure. NESC specified safety factors are included in the calculations to insure an adequate margin of safety.

I. National Electric Safety Code

The first place to begin in the study of pole structural loading is the NESC. The National Electric Safety Code (NESC) specifies what type of construction is appropriate for a given situation. The NESC has grades of construction that range from grade “N” (lowest) to grade “B” (highest).Most construction in use today on an electric distribution system is grade “C” except for certain situations such as railroad crossings and limited access highways, which must be grade B construction. The code says that Grade N is acceptable for distribution voltages in rural areas, but most utilities build to a minimum of Grade C construction.

When designing a pole structure, the NESC says that ice and wind must be considered based on the loading district where the utility is located. There are three loading districts and Figure 250-1 of the NESC explains the boundaries of each district. The three loading districts are defined as "Light", "Medium", and "Heavy". Chart 1 is from Table 250-1 of the NESC and it shows the ice and wind loads that must be considered based on the loading district.

Chart 1 **NESC Loading Districts** **Ice & Wind Loads** **(Adapted from NESC Table 250-1)**			
	Light	**Medium**	**Heavy**
Ice Radial inches	0.0"	0.25"	0.5"
Wind Lbs/sq. ft.	9	4	4
Temperature Degrees F	30	15	0

As you can see from chart 1, in the medium loading district a load of 0.25" of radial ice and a load of 4-lbs/sq ft. of wind must be considered. In the Light district, no ice need be considered, but a wind load of 9-lbs/sq ft. is required.

The NESC also specifies overload capacity factors for pole lines based on the grade of construction and the type of load applied. Chart 2, shown below, is from the NESC rule 253 and Table 253-1.This chart shows the overload capacity factors, or safety factors, that the NESC says should be considered in a pole design. Table 253-2 (not shown) is an alternative to Table 253-1 and does not require the application of the strength factors of Table 261-1A.This course uses Table 253-1 and the strength factors of Table 261-1A.

Chart 2 **Overload Capacity Factors** (Adapted from NESC Table 253-1)			
Condition	**Grade B**	**Grade C**	**Extreme Wind**
Vertical	1.50	1.90	1.00
Transverse Wind			
General	2.50	1.75	1.00
Crossings	2.50	2.20	1.00
Transverse Wire	1.65	1.65	1.00
Longitudinal			
General	1.10	N/a	1.00
Deadends	1.65	1.30	1.00

The factors in chart 2 are different depending on whether a transverse or longitudinal load is being considered and whether the construction is Grade B or Grade C. Remember that *transverse* loads are perpendicular (or nearly so) to the line and *longitudinal* loads are in-line with the pole line. From the chart, transverse wind loading for Grade C the overload capacity factor is 1.75.If a railroad crossing is involved the OCF is 2.20.Different factors are used depending on whether a transverse wire or transverse wind load is being considered.

Table 261-1A, a portion of which is shown in Chart 3, has strength factors that must be applied to the structures and hardware to derate the material for safety.

Chart 3 **Strength Factors** (Adapted from NESC Table 261-1A)		
Application	**Grade B**	**Grade C**
Rule 250B		
Wood Structures	0.65	0.85
Support Hardware	1.00	1.00
Rule 250C		
Wood Structures	0.75	0.75
Support Hardware	1.00	1.00
For Use with Table 253-1		

From Chart 3, we see that wood structures are derated 85% for Grade C construction, while the associated supporting hardware is not derated. Rule 250C applies to extreme wind conditions and is defined in Rule 250C of the NESC.

National Electric Safety Code Conclusion

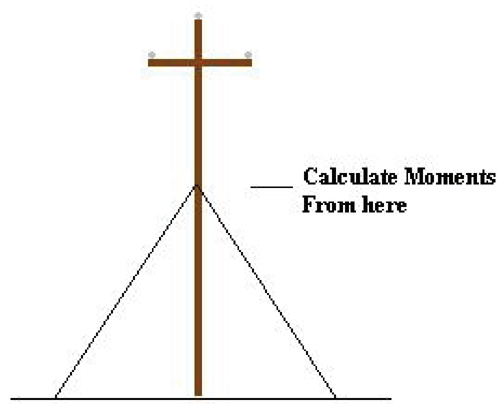
The National Electric Safety Code is the beginning point for determining safe pole loading. We have looked at several sections of the Code that explain how to apply safety factors and strength factors to wood. Once this information is understood, we can move on to calculating pole loads.

The next section shows numerous formulas for calculating the various loads that impact wood pole structures.

II. Pole Structures

The NESC says that an un-guyed wood pole must be able to withstand the vertical loads caused by the weight of equipment on the pole, plus the transverse wind loads on the pole, equipment, and conductors, and the transverse load caused by conductor tension due to un-guyed angle loads. When a wood pole is guyed, it is assumed that the guys satisfy all transverse or deadend loads and the pole only acts as a strut. In this case, the strut must support the vertical loads on the pole, including the downward component of the guy load.

Horizontal loads exist above a guy and the moments at the point of guy attachment should be checked. See the figure on the right. The calculations are the same as for the moments at the ground line of a pole except, the point of reference is the point of guy attachment and all moments are calculated from this point. For the resisting moments, the circumference at the ground line is replaced with the circumference at the point of guy attachment.



Loads are categorized at either longitudinal or transverse. Longitudinal loads are parallel to the direction of the line and transverse loads are perpendicular to the line. Whichever direction, longitudinal or transverse, that produces the largest load on the pole is known as the *direction of critical loading*. For unguyed poles, the direction of critical loading is transverse.

A. Pole Size

Poles sizes are based on the American National Standards Institute (ANSI) standard number ANSI 05.1-2002, “Specifications and Dimensions for Wood Poles. ”This standard defines dimensions and classifications for different species of wood.
ANSI determines classes so that similar class poles will have the same load carrying capability regardless of the wood species. For instance, all Class 5 poles will have approximately the same ground line resisting moments. However, the ground line circumference of the poles is different for different species to accommodate the load.
To determine the strength of a wood pole it is important to know the length, class, and species of the wood. Poles are designated by the length and then the class such as “45/5”.Where “45” is the length of the pole and “5” is the class.

Information about pole dimensions is necessary to calculate the moments at the ground line of the pole as a result of the wind load on the pole and the transverse pull on the pole. Chart 4 shows pole circumferences at the top of the pole and at the ground line of the pole for the most common size distribution poles.

Chart 4
Pole Dimensions
Southern Yellow Pine

Pole	Class	Circumference Top	Circumference Gnd		Pole	Class	Circumference Top	Circumference Gnd
30	5	19	27.5		50	2	25	42
	6	17	25			3	23	39
35	4	21	31.5			4	21	36.5
	5	19	29			5	19	34
	6	17	27		55	1	27	46.5
40	2	25	38.5			2	25	43.5
	3	23	36			3	23	40.5
	4	21	33.5		60	1	27	48
	5	19	31			2	25	45
	6	17	28.5			3	23	42
45	2	25	40.5		Note: For Diameter divide Circumference by 3.14.			
	3	23	37.5					
	4	21	35		Setting Depth: 10% of Pole Height plus 2.0'. 5.5' min. Depth.			
	5	19	32.5					
	6	17	30					

For some of the calculations we also need to know the amount of pole that is above the ground line. The note in chart 4 says the pole mounting depth for a pole is 10% of the pole height plus two feet, with a minimum setting depth of 5.5'.For instance, a 45 pole will be installed six and a half feet in the ground, leaving 38.5 feet of pole above ground level.

The ultimate fiber stress for a few of the common species of wood poles is shown in Chart 5.

Chart 5 Ultimate Fiber Stress Wood Products	
Species	**Fiber Stress (Fb)**
Southern Yellow Pine	8,000 psi
Douglas Fir	8,000 psi
Lodgepole Pine	6,600 psi
Western Larch	8,400 psi
Western Red Cedar	6,000 psi

As you can see in the chart, the ultimate fiber stress for a Southern Yellow Pine (SYP) wood pole is 8,000 psi. This information is used to determine the ability of the pole to withstand moments at the ground line of the pole.

B. Ultimate Resisting Moments

The strength of a pole is based on the ultimate fiber stress of the wood species and the diameter of the pole at the ground line. An NESC safety factor is also applied in the determination of the ultimate resisting moments of a wood pole.

The term, moments, is used to define the product of a load (in pounds) times a distance (from a reference point, in feet).Usually, moments are calculated using the ground line of the pole as the reference point.

The permissible moments at the ground-line for a wood pole is found by applying the following formula:

$$\mathbf{M_r = 0.000264 * Sf * F_b * C_{gnd}^3}$$

Where:
M_r = Ultimate Resisting Moments, Ft-lbs.
Sf = Safety Factor, NESC Table 261-1A, (see Chart 3.)
F_b = Fiber Stress, (see Chart 5.)
C_{gnd} = Circumference at the ground line, Inches.

The fiber stress, F_b, is from Chart 5, and is based on the type of wood under consideration. The circumference at the ground line for several typical size poles is found in Chart 4.

As an example, the ultimate resisting moment at the ground line for a 45/5 southern yellow pine wood pole in a Grade C application is:

$M_r = 0.000264 * 0.85 * 8{,}000 * (32.5)^3$
$M_r = 61{,}626$ ft-lbs

The strength factor in the above calculation is 0.85 and is from Chart 3 for Grade C, wood structures. From this example, the moments at the ground line on a 45-foot, class 5, Southern Yellow Pine, wood pole needs to be less than 61,626 ft-lbs, or the pole will need guying or other support to prevent overloading the pole.

C. Pole Diameter at Different Lengths

It is often necessary to know the diameter of a pole at a point other than at the ANSI prescribed ground line (e.g. A pole may be set deeper than normal, or the diameter may be needed at the mounting location of equipment.)The following formula is useful for determining pole diameters at locations other than the ground line:

$$\mathbf{Dia_x = [(H_{pole} - H_x) * (Dia_{gnd} - Dia_{top}) / (H_{pole} - H_{gnd})] + Dia_{top}}$$

Where:
Dia_x = Diameter of pole at distance, x, from bottom, inches.
H_{pole} = Length of the pole, ft.
H_x = Distance from the bottom of the pole to point “x”, ft.
Dia_{gnd} = Diameter of the pole at the six-foot point, inches.
Dia_{top}= Diameter of the pole at the top, inches.
H_{gnd} = Distance from bottom of pole to ground line (see Chart 4.)

For example, what is the diameter of a 45/5 SYP pole, 28 feet from the butt of the pole? From Chart 4, the circumference at the top of the pole is 19 inches and the circumference at the ground line (in this case, 6.5 feet from the butt) is 32.5 inches. First, we need to convert the circumferences to diameters. With a 19-inch circumference, the diameter is 19/3.14 or 6.05 inches. At the ground line, the diameter is 32.5/3.14 or 10.35 inches.

$$Dia_{28} = [(45 - 28) * (10.35 - 6.05) / (45-6.5)] + 6.05$$
$$Dia_{28} = 7.95 \text{ inches.}$$

This formula works for either circumference or diameter. Just be sure to keep the dimensions the same in the calculations.

D. Wind on Pole

One factor that must be considered in designing a pole structure is the impact of the wind pressure on the face of the pole. The NESC specifies how much wind should be considered based on the area of the country. Table 250-1 (See Chart 1) specifies the wind and ice loading for the various loading districts and grades of construction. The overload capacity factors are in Table 253-1 (Chart 2) of the NESC.

The formula to calculate the moments on a pole due to the wind on the pole is:

$$\mathbf{M_P = W * H_P{}^2 * [Dia_{Gnd} + 2 * Dia_{Top}] / 72 * OCF_w}$$

Where:
M_P = Moments on the pole, Ft-lbs.
W = Wind load, lbs/ft^2.
H_P = Height of pole above ground level, feet.
OCF_w = Overload Capacity Factor for Wind.(See Chart 2.)

Dia_{Top} = Diameter of the pole top, inches.
Dia_{Gnd} = Diameter of the pole at the ground line, inches.
For example, what is the bending moment on a 45-foot, class 5, pole in the medium-loading district with Grade C construction?

Since the pole is in the medium-loading district, the wind is 4 lbs/ft^2.From chart 4, a 45/5 pole has a pole top circumference of 19 inches, which is a diameter of 6.05 inches (19/3.14 = 6.05).The circumference of the pole at the ground line is 32.5 inches, which is a diameter of 10.35 inches. A 45/5 pole will be set 6.5 feet deep, so the height above the ground line is 38.5 feet. The overload factor is in Chart 2, for transverse wind load and is 1.75, if a road or railroad crossing is not involved. For crossing locations, the OCF is 2.20.The total moments due to the wind load is:

$$M_P = 4 * 38.5^2 *[10.35 + 2 * 6.05] / 72 * 1.75$$
$$M_P = 3{,}235 \text{ Ft-lbs.}$$

Therefore, the wind load on the pole creates a 3,235 ft-lb moment on the pole at the ground line.

E. Wind on Equipment
The wind on equipment that is attached to a pole is usually minor in comparison to the wind on the pole and the conductors. However, voltage regulators and three-phase transformer banks can produce large moments on poles. The wind on equipment is based on the surface area of the equipment exposed to the wind times the wind pressure for the NESC loading district in question, times the mounting height of the equipment. Just like the wind on the pole, the overload capacity factor is the transverse factor for wind.

$$M_e = W * H_L * Dia_{Load}/12 * L_{Load} * OCFw$$

Where:
M_e = Moments on Pole due to equipment, ft-lbs.
W = NESC Wind Pressure, lbs/ft^2.
H_L = Height of the load attachment on the pole, ft.
OCF_w = Overload Capacity Factor for Wind.(See Chart 2.)
Dia_{Load} = Diameter of the equipment, inches.
L_{Load} = Length of the equipment, ft.

For example, a 100-amp voltage regulator is mounted at 28 feet on a pole in the Medium loading district with Grade C construction. The diameter of the regulator is 24 inches and it is 5 feet tall. What are the moments on the pole due to the voltage regulator?
In the Medium loading district the wind (per Chart 1) is four lbs/ft. The moments are,

$$M_e = 4 * 28 * 24/12 * 5 * 1.75$$
$$M_e = 1{,}960 \text{ ft-lbs.}$$

In this example, the equipment load is only slightly less than the moments due to the wind on a 45/5 pole.

F. Wind on Conductors

The most significant factor in determining pole strength is the impact of wind on the conductors attached to the pole. Wind pressure on the conductors, especially when the conductors are loaded with ice is a significant load on a pole structure.

The diameter of the conductor must be known to calculate the effects of ice and wind load on conductors. Chart 6 has the rated breaking strength and cable diameters for several popular sizes of distribution conductors.

Chart 6 Conductor Tensions					
Size	Code	Dia	Weight	Stranding	Breaking Strength
#4 ACSR	Swanate	0.257	0.067	7/1	2,360
#2 ACSR	Sparrow	0.316	0.092	6/1	2,850
1/0 ACSR	Raven	0.398	0.145	6/1	4,380
4/0 ACSR	Penguin	0.563	0.291	6/1	8,350
266 ACSR	Partridge	0.642	0.366	26/7	11,300
336 ACSR	Merlin	0.684	0.365	18/1	8,860
397 ACSR	Ibis	0.783	0.546	26/7	16,300
636 ACSR	Grosbeak	0.990	0.874	26/7	25,200
795 ACSR	Drake	1.108	1.093	26/7	31,500
266 AAC	Daisy	0.586	0.250	7	4,830
336 AAC	Tulip	0.666	0.316	19	6,159
556 AAC	Mistletoe	0.858	0.521	37	9,940
795 AAC	Arbutus	1.026	0.745	37	13,900

With the conductor diameter known, ice and wind load effects can be calculated. The following formula shows how to calculate the conductor load in pounds per foot based on ice and wind.

$$\mathbf{C_L = W * (Dia_C + 2 * Ice) / 12}$$

Where:
C_L = Transverse load due to ice and wind load, lbs/ft.
Dia_C = Conductor Diameter, inches.
W = Wind load, lbs/ft^2.(Chart 1.)
Ice = Radial ice load, inches.(Chart 1.)

For instance, what is the transverse conductor load in the medium-loading district, which is 4 pounds of wind and 0.25-inches of radial ice, on a 336 ACSR, “Merlin” conductor? From Chart 6, the diameter of Merlin is 0.684, so the equation becomes:

$C_L = 4 * (0.684 + 2 * 0.25) / 12$
$C_{L\ Medium} = 0.395$ lbs/ft.

The conductor load, due to NESC ice and wind is 0.395 lbs/ft.

This same process applies to all cables attached to the pole such as telephone and CATV cables. The chart shown below (Chart 7) has the diameters of several common sizes of telephone and CATV cables.

Chart 7 **Typical Telephone And Catv Cables**		
Cable Type	**Cable Diameter**	**Design Tension**
Telephone		
3/8" Messenger, 1.00" Cable	1.50"	4,100
3/8" Messenger, 2.00" Cable	2.50"	4,100
3/8 Messenger, 2.50" Cable	3.00"	4,100
Catv		
¼" Messenger, 0.500" Cable	0.85"	2,300
¼" Messenger, 0.750" Cable	1.10"	2,300
Note: 0.10" has been added for lashing tape		

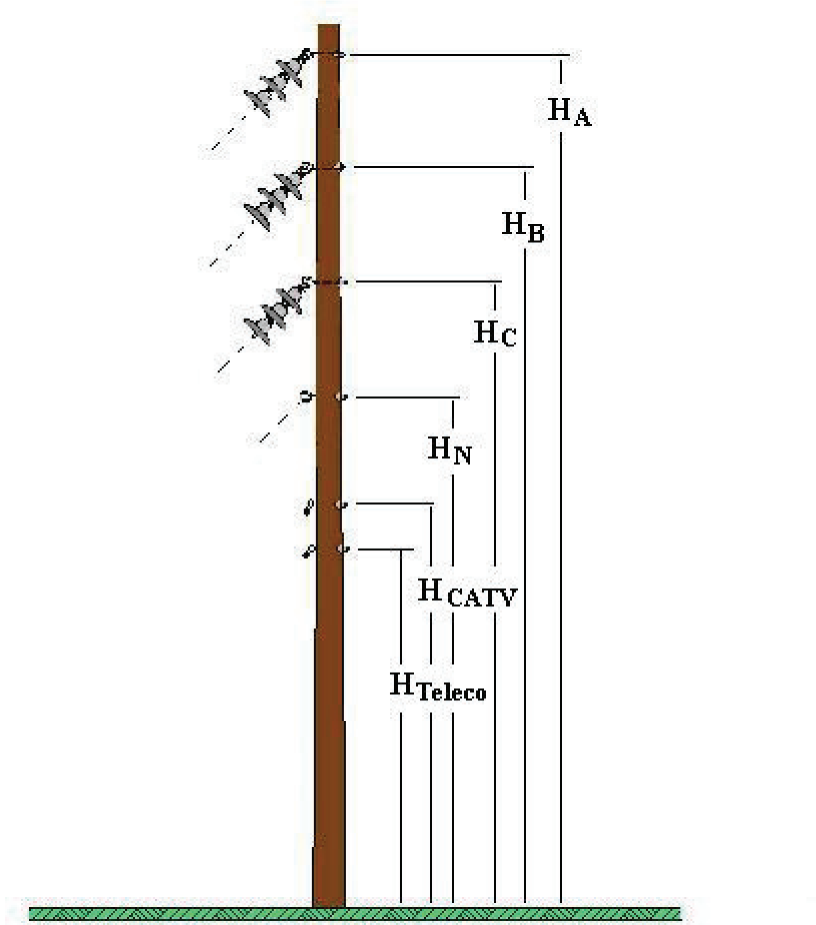
In Chart 7, the cable diameter in the second column includes the "messenger" cable, the communications cable, and the lashing tape.

Once the conductor load due to ice and wind is known, the moments on the pole due to the conductor load is found by multiplying the conductor load by the height of the conductor attachment and the appropriate safety factor. This value is the moments per foot of conductor and is expressed in foot-pounds per foot of conductor. Finally, this value is multiplied by the wind span to determine the moments on the pole. The moments due to wind on conductors is:

$$\mathbf{M_c = C_L * H_c * OCF_w}$$

Where:
M_c = Moments of pole due to conductors, ft-lbs/ft.
C_L =Wind load, lbs/ft.
H_c = Height of the conductor attachment, ft.
OCF_w = Overload Capacity Factor for Wind.(See Chart 2.)

The drawing below shows a typical installation where the phase conductors are arranged vertically on the pole with the neutral conductor, a CATV cable, and a telephone cable below the phase conductors.



To illustrate the calculation of the moments on a pole due to the wind on the conductors consider the following example. A vertical, three phase structure (like the one pictured above), has 336 ACSR, Merlin, phase conductors, a 1/0 ACSR, Raven, neutral, a ¾" CATV cable, and a 2.00" telephone cable. The pole is a 45/5 SYP pole and the attachments are at 38, 34, 30 feet, respectively for the phase conductors and 26 feet for the neutral conductor. The CATV cable is mounted at 22 feet above the ground and the telephone cable is at 20 feet. If the pole is in the medium-loading district, with Grade C construction, what is the total moment on the pole due to wind on the conductors? First, the conductor loading due to ice and wind must be found. The following table summarizes the results of the conductor loading calculations.

Calculation of Conductor Loading			
Item	**Type**	**Dia**	C_L
A Phase Conductor	336 ACSR, Merlin	0.684	0.395
B Phase Conductor	336 ACSR, Merlin	0.684	0.395
C Phase Conductor	336 ACSR, Merlin	0.684	0.395
Neutral Conductor	1/0 ACSR, Raven	0.398	0.299
CATV Cable	0.750" Cable	1.100	0.533
Telephone Cable	2.00" Cable	2.500	1.000

Now, the moments on the pole are calculated using the information from the table above, the cable mounting heights, and the appropriate safety factor. The following chart summarizes the calculation of the moments on the pole due to wind on the conductors. The overload capacity factor for this application is 1.75, which is the overload capacity factor for wind load in a transverse, non-crossing environment.(See Chart 2.)

Moments Due to Wind on Conductors					
Item	**Type**	C_L	H_C	OCF_W	M_C
A Phase Conductor	336 ACSR, Merlin	0.395	38'	1.75	26.25
B Phase Conductor	336 ACSR, Merlin	0.395	34'	1.75	23.48
C Phase Conductor	336 ACSR, Merlin	0.395	30'	1.75	20.72
Neutral Conductor	1/0 ACSR, Raven	0.299	26'	1.75	13.62
CATV Cable	0.750" Cable	0.533	22'	1.75	13.26
Telephone Cable	2.00" Cable	1.000	20'	1.75	17.50
				Sum of loads =	114.82

By summing the moments for each of the cables, we have the load due to wind on conductors, which is 114.82 ft-lbs/ft of conductor. To determine the total moments on the pole we must know the wind span on the pole.

G. Tension in Conductors

Anytime there is an angle on the pole, the tension in the conductors creates a pulling force that must be accounted for in the load on the pole. The rated breaking strength of the conductor is found in Chart 6 and this value times the percent design tension equals the design tension. The NESC safety factor is the transverse *wire* value shown in Chart 2.

The design tensions times the mounting height create a moment on the pole as follows:

$$\mathbf{M_t = 2 * DT * OCF_T * Sin\ (Angle\ /\ 2) * H_c}$$

Where:

M_t = Moments as a result of the angle on the conductors, ft-lbs.
DT = Design Tension, Breaking Strength times percentage design tension, lbs.
OCF_T = Overload Capacity Factor for Transverse Wire. (Chart 2.)
Angle = Angle of the pole line, degrees.
H_c = Height of the conductor attachment, ft.

For example, what is the conductor tension for a 336 ACSR, Merlin conductor with a slight 0.5-degree angle, Grade C construction, and a 50% design tension?

For 336 ACSR, Merlin, the rated breaking strength is 8,860 lbs and times the design tension multiplier becomes 8,860 * 0.50 = 4,430 lbs. The overload capacity factor for conductors in tension is found in Chart 2.For this example, the overload capacity factor for wire is 1.65.With a 38-foot mounting height, the moment is:

$M_t = 2 * 4{,}430 * 1.65 * \text{Sin}(0.5/2) * 38$
$M_t = 2{,}424$ lbs.

Continuing with the previous example, a chart can be built for the tension in all conductors based on various mounting heights of the cables.

Moments Due to Angle on Conductors

Item	Type	DT	H_C	OCF_T	M_C
A Phase Conductor	336 ACSR, Merlin	4,430	38'	1.65	2,424
B Phase Conductor	336 ACSR, Merlin	4,430	34'	1.65	2,169
C Phase Conductor	336 ACSR, Merlin	4,430	30'	1.65	1,913
Neutral Conductor	1/0 ACSR, Raven	2,190	26'	1.65	820
CATV Cable	0.750" Cable	1,150	22'	1.65	364
Telephone Cable	2.00" Cable	2,050	20'	1.65	590
				Sum of loads =	8,280

The total moments due to the 0.5-degree angle on the conductors is 8,280 ft-lbs. As you can see, this small angle resulted in a large load on the pole. Just about any angle on a pole needs to guyed to reduce the ground line stress in the pole.

H. Moments on Pole

The total moments on a pole result from the pressure of wind on the conductors attached to the pole, wind blowing on the pole, wind blowing against equipment mounted on the pole, and the transverse load caused by an angle in the conductors. There a few other items that contribute to the overturning moments on a pole, but they are generally insignificant. Moreover, the wind on equipment is usually a minor item compared to the wind on conductors and is often ignored in distribution electric systems. Mathematically, the overturning moments on a pole is:

$$\mathbf{M_{Gnd} = \sum (M_c * WS) + M_p + M_e + M_t}$$

Where:
M_{Gnd} = Sum of all moments applied to the pole at the ground line, ft-lbs.
M_c = Sum of the moments due to wind on the conductors, ft-lbs/ft.
WS = Wind Span on the pole, ft.
M_p = Moments due to wind on the pole, ft-lbs.
M_e = Moments due to wind on equipment on the pole, ft-lbs.
M_t = Moments due to transverse load due to conductor tension in an angle, ft-lbs.

The Wind Span is the sum of the forward and back spans divided by two. If the spans are 300 and 350 feet, respectively, then the Wind Span is (300+350)/2 = 325 feet. From our previous examples the total load on the pole is,

$$M_{Gnd} = (114.82 * 325) + 3{,}235 + 1{,}960 + 8{,}280$$
$$M_{Gnd} = 50{,}792 \text{ ft-lbs.}$$

The total ground line moments are 50,792 ft-lbs and the ultimate resisting strength of a 45/5 SYP is 61,626 ft-lbs, so the pole is adequate for this load.

I. Maximum Wind Span
When designing a distribution electric line it is often easier to determine the maximum allowable straight-line span based on the resisting moments of the pole and the anticipated loads on the pole. By rearranging the formula in the previous example (and dropping the angle and equipment loads) yields a formula for the maximum allowable wind span for a straight-line. The formula is:

$$\mathbf{WS_{max} = (M_r - M_p) / M_c}$$

Where:
WS_{max} = Maximum allowable wind span, ft.
M_r = Ultimate resisting moments of the pole, ft-lbs.
M_p = Wind pressure on the pole, ft-lbs.
M_c = Moments due to wind on conductors, ft-lbs.
For example, what is the maximum allowable wind span for a 45/5 SYP with the loads from the previous examples? From the previous examples, the resisting moments of a 45/5 SYP is 61,626 ft-lbs. The wind on the pole is 3,235 ft-lbs and the wind on the conductors (including the telephone and CATV cables) is 114.82 ft-lbs/ft.

$$WS_{max} = (61{,}626 - 3{,}235) / 114.82$$
$$WS_{max} = 509 \text{ feet.}$$

Any angles or equipment loads will need to be evaluated separately, but for a straight-line pole with the conditions mentioned above, the structures can support span lengths up to 509 feet.

J. Extreme Wind Loading
The National Electric Safety Code (NESC) requires that structures able to withstand three second gusts of high wind speeds. Any structure, without conductors must be able

to withstand the extreme wind values, and structures that are 60 and taller must be able to withstand the extreme wind including the extreme wind on the conductors.
This “Extreme Wind” is covered in Rule 250C of the NESC. Figure 250-2 in the NESC has the extreme winds for use in the extreme wind calculations. From Figure 250-2 (Not shown in this course) the extreme winds for most parts of the country are 90 mph, but can vary up to 150 mph along the Atlantic coast regions. The extreme wind is used like the NESC wind in other calculations, except that *no ice is considered* with extreme wind. The extreme wind factor is based on the wind speed from Figure 250-2, a factor known as the velocity pressure exposure coefficient (Kz), a gust response factor (Grf), an importance factor (I), and a shape factor (Cd).The formula for extreme wind is:

$$\mathbf{W_{Extreme} = 0.00256 * V^2 * k_z * G_{rf} * I * C_d}$$

Where:
$W_{Extreme}$ = Extreme Wind Loading, lbs/ft^2.
V = Wind Velocity, MPH.
K_z = Velocity Pressure Exposure Coefficient.
G_{rf} = Gust Response Factor.
I = Importance Factor.
C_d = Shape Factor.

The importance factor is 1.0 for utilities and the shape factor for round structures is 1.0, so these terms are ignored in the extreme wind calculations for wood poles and wire. The velocity pressure exposure coefficient, Kz, is different for poles and wires. For poles:

$$K_{zpole} = 2.01 * (0.67 * H_p / 900)^{0.21}$$

And, for wires it is:

$$K_{zwire} = 2.01 * (H_c / 900)^{0.21}$$

The formula for the gust response factor is shown below. The gust response factor has two additional terms E_s and B_s that are based on the height of the pole for the pole calculation. For the wire calculation, E_w and B_w are based on the height of the conductor and the wind span.

$$\mathbf{G_{rf} = [1 + (2.7 * E_s * B_s^{0.5})] / 2.05}$$

Where:
$E_s = 0.346 * [33 / (0.67 * H_p)]^{0.143}$
$B_s = 1 / [1+ (0.325 * H_p / 220)]$
H_p = Height of the pole, ft.
For conductors substitute E_w for E_s and B_w for B_s.
$E_w = 0.346 * (33 / H_c)^{0.143}$
$B_w = 1 / (1+ 0.8 * WS / 220)$
H_c = Height of the Conductor, ft.
WS = Wind Span, ft.

For example, consider a 45/5 SYP in the Atlanta, Georgia region. What is the extreme wind for this pole? For the Atlanta, Georgia region, the extreme wind is 90 mph.

To solve the extreme wind calculations, work backwards starting with E_s, B_s, G_{rf}, K_z, and finally $W_{extreme}$. For a 45-foot pole, the height above the ground is 38.5 feet.

$E_s = 0.346 * [33 / (0.67 * 38.5)]^{0.143}$
$E_s = 0.358$
$B_s = 1 / [1+ (0.325 * 38.5 / 220)]$
$B_s = 0.946$
$G_{rf} = [1 + (2.7 * E_s * B_s^{0.5})] / 2.05$
$G_{rf} = [1 + (2.7 * 0.358*0.946^{0.5})]/ 2.05$
$G_{rf} = 0.948$
$K_{zpole} = 2.01 * (0.67 * 38.5/ 900)^{0.21}$
$K_{zpole} = 0.953$
$W_{Extreme} = 0.00256 * 90^2 * 0.953 * 0.948 * 1 * 1$
$W_{Extreme} = 18.73$ lbs/ft.

Once the extreme wind is known it can be applied to the formula for the moment due to wind on the pole. The moments on the pole are based on the wind on the pole, height of the pole above ground level, ground line pole diameter, the pole top diameter. The overload capacity factor for extreme wind is 1.00.

$M_P = 18.73 * 38.5^2 *[10.35 + 2 * 6.05] / 72 * 1.00$
$M_P = 8{,}656$ Ft-lbs.

Under the Medium loading district, the wind load on a pole creates 3,235 ft-lbs of stress in the pole at the ground line. However, in this case, with extreme wind, the stress on the ground line of the pole is 8,656 ft-lbs, or almost three times more than the normal wind load.

K. Pole Stability
Even if a pole can withstand a certain load, the soil may not generate sufficient resistance to prevent the pole from overturning. In this case, the prudent approach is to guy the pole. Occasionally it is impractical to guy a structure and the structure is dependent on the holding capacity of the soil. The following empirical formula will help estimate the holding capacity of the soil for a given setting depth:

$$\mathbf{M_{r\ soil} = [S_e * D^{3.75} / (H_{pole} - 0.0662 * D)] * (H_{pole} - D)}$$

Where:
$M_{r\ soil}$= Resisting moments of the soil, ft-lbs.
S_e = Soil Stability.
D = Setting depth of the pole, ft.
H_{pole} = Total Length of pole, ft.

The term, S_e, was derived based on experiments in different types of soils. There is not an exact definition of soil stability for this application, but engineers assume a value of 35 for poor soils, 70 for normal soils, and 140 for extremely good soils. The engineer is free to choose any value between 35 and 140 that fits his definition of the soil condition. As an example, what is the soil withstand capability for a 45 pole that is set 6.5 feet in the ground in average soil?

$M_{r\ soil} = [70 * 6.5^{3.75} / (45 - 0.0662 * 6.5)] * (45 - 6.5)$

$M_{r\ soil}$ = 67,600 ft-lbs.

The ultimate resisting moment of a 45/5 wood pole is 61,626 ft-lbs, so the soil has adequate strength for this application. What if the construction crew is only able to set the pole 6 feet deep in average soil before hitting rock?

$M_{r\ soil} = [70 * 6.0^{3.75} / (45 – 0.0662 * 6.0)] * (45 – 6.0)$
$M_{r\ soil}$ = 50,686 ft-lbs.

The resisting moments of the soil is dramatically compromised by just setting the pole one-half foot shallow. Therefore, it is critical that appropriate pole setting depths be achieved.

L. Eccentric Loading
An Extremely heavy load on a pole can cause unacceptable bending in the pole. Usually the conductor loads will help support the structure, but it is a good idea to consider the pole as a strut with one end fixed (in the ground) and the other end free to move. Under this scenario, the pole top deflection can be calculated as:

$$\Delta_p = e * \{[1 - \cos(H_{load} * \beta) + \beta * (H_p – H_{load}) * \sin(H_{load} * \beta)] / \text{Cos}\ (H_{load} * \beta)\} *100$$

Where:
Δp = Pole deflection with an eccentric load, in percent deflection.
e = Eccentricity, Distance from the center of the load to the center of the pole, inches.
H_{load} = Height of the load from the base (above the ground line) of the pole, inches.
H_p = Height of the pole above ground, inches.
β = A factor that accounts for the modulus of elasticity and moment of inertia of the load.

Note: This formula is only valid for loads that are reasonably close to the top of the pole! This formula accounts for the deflection due to the eccentricity of the load and is not appropriate for pole deflections due to tensions on the pole.

Be careful to note the units for the length of the pole and the height of the load attachment are in inches instead of in feet. In the factor-b calculation, the modulus of elasticity and the moment of inertia are required. The modulus of elasticity is a measure of stiffness of a material and the moment of inertia is a measure of resistance to rotation based on the geometry and size of a material.

$$\beta = \text{Sqrt}(\ \text{Load} / (E * I)$$

Where:
Sqrt = Square root function.
Load = Weight of additional load on pole, lbs.
E = Modulus of Elasticity, lbs/in^2.
I = Moment of Inertia, in^4.

The moment of inertia, I, is:

$$I = 0.0491 * Dia_{load} * Dia_{Gnd}^3$$

Where:
I = Moment of Inertia, in^4.
Dia_{load} = Diameter of the pole at the load, inches.
Dia_{Gnd} = Diameter of the pole at the ground line, inches.

Consider a 45/5 SYP with a 500-pound transformer that is attached at 28.5 feet above the ground.What is the percent deflection of the pole as a result of the transformer?(The transformer is offset 20 inches and the diameter of the pole at the transformer is 7.87 inches.)

First, the Moment of Inertia is found.
$I = 0.0491 * 7.87 * 10.35^3$
$I = 428\ in^4$.

Next, the value of factor- β is found. The Modulus of Elasticity for Southern Yellow Pine is 1.58 x 106 lbs/in^2.
β = Sqrt(500 / (1.58*106 * 428)
β = 0.00086.
Once we have the Moment of Inertia and β, the deflection can be calculated. The height of the load is 28.5 feet, which is 342 inches. Likewise, the pole height is 38.5 feet, which is 462 inches. The deflection is:

Δp = 20 * {[1 - Cos(342 * 0.00086)
+ 0.00086 * (462 - 342) * Sin(342 * 0.00086)] / Cos(342 * 0.00086)}* 100
Δp = 1.08%

From this example, a 500-pound load 10 feet from the top of a 45-foot pole, that is offset from the pole center, will cause a 1.08% deflection in the pole at the top of the pole.

Pole Structures Conclusion

In this section, we looked at how to calculated the loads on an un-guyed wood pole. Methods to calculate the wind on a pole, wind on conductors, wind on equipment, and the effect of transverse tensions of conductors on poles were reviewed. Using this information, the safe loading of a pole was determined.

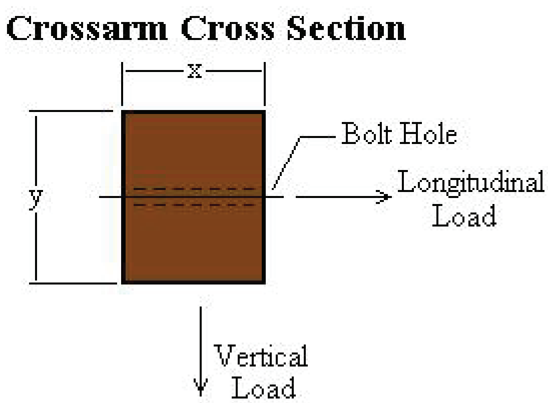
In addition to pole loading, we must also consider the impact of wind and conductor loads on the crossarms and insulators on a pole. The next section covers crossarm and insulator loads.

III. Crossarms

Crossarms are designed to withstand the load of conductors, equipment, and ice. The NESC says that lower crossarms must also be able to support the weight of lineman. Both the horizontal and vertical loads on a crossarm are considered. Longitudinal, or horizontal, unbalances are caused by changes in conductor sizes or tensions, or conductor deadends. Vertical loads are conductor loads due to the weight of the conductor including ice, if any, and the weight of a lineman on the crossarm.

A. Crossarm Capacities

Moments on a crossarm are based on the fiber stress of the wood, the moment of inertia based on the shape of the crossarm, and the section modulus of the crossarm. The moment of inertia for a wood crossarm is different in the vertical direction than in the horizontal direction. The following drawing illustrates the moment of inertia calculation for a wood crossarm.



For a horizontal, or longitudinal, load, the moment of inertia is:

$$\mathbf{I_x = (y * x^3\,) / 12 - (y_h * x^3\,) / 12}$$

Where:
I_x = Moment of Inertia in the "x" direction, in^4.
x = Horizontal dimension of the crossarm, inches.
y = Vertical dimension of the crossarm, inches.
y_h = Diameter of the bolt hole, inches.

The term, "$– (y_h * x^3\,) /12$" accounts for the loss of strength in the crossarm due to the bolt hole in the center of the crossarm.

For a vertical load, the moment of inertia is:

$$\mathbf{I_y = (x * y^3\,) /12 - (y * y_h^3\,)/12}$$

Notice that in the "y" direction, the moment of inertia for the bolt hole is slightly different than in the "x" direction.

The section modulus is based on the moment of inertia, which is a physical property of a material that relates the bending moment in the material to its maximum bending stress. The section modulus in the longitudinal direction is:

$SM_x = 2 * I_x / x$, in^3

In the vertical direction, the section modulus is:

$SM_y = 2 * I_y / y$, in^3

Once the moment of inertia and the section modulus are known, the resisting moments of the crossarm are found as:

$MR = F_b * SM / 12$

Where:
MR = Resisting Moment for a wood crossarm in the specified direction, ft-lbs.
F_b = Fiber stress of a wood crossarm.
SM = Section Modulus in the specified direction, in^3.

Consider this example. What is the resisting moment for a 3.5"w x 4.5"h, wood crossarm, with an 11/16" bolt hole in the center of the crossarm?

First, we find the moment of inertia in both the "x" and the "y" direction.(The 11/16" hole is 0.6875".)

$I_x = (4.5 * 3.5^3) / 12 – (0.6875 * 3.5^3) /12$
$I_x = 13.62\ in^4$
$I_y = (3.5 * 4.5^3) /12 – (4.5 * 0.6875^3)/12$
$I_y = 26.46\ in^4$

Next, the section modulus is found for both the "x" direction, and the "y" direction.

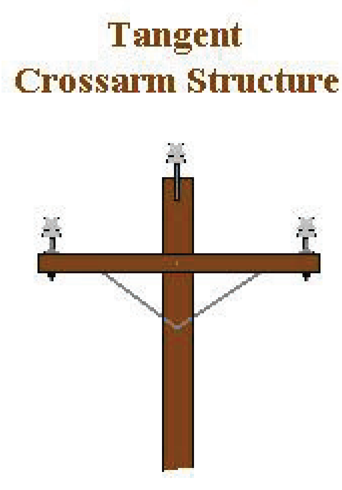
$SM_x = 2 * 13.62 / 3.5$
$SM_x = 7.783\ in^3$
$SM_y = 2 * 26.46 / 4.5$
$SM_y = 11.760\ in^3$

Finally, the resisting moments are calculated from the section modulus.

$MR_x = 7,800 * 7.783 /12$
$MR_x = 5,062$ ft-lbs.
$MR_y = 7,800 * 11.760 / 12$
$MR_y = 7,644$ ft-lbs.

A strength factor from Table 261-1A of the NESC (Chart 3) must be applied to the resisting moment based on whether Grade B or Grade C construction is involved.

B. Vertical Loads
The vertical moments on the crossarm consist, primarily, of the weight of the conductor with ice, if appropriate. The NESC says that another factor to include in the vertical load is the weight of a lineman standing or sitting on the crossarm. The Code does not specify how much weight to consider for the lineman, or where the lineman is situated on the crossarm (close to the pole, or at the end of the crossarm.)Many utilities consider the lineman weight to be 225 pounds at two feet from the pole or 450 ft-lbs. An overload capacity factor for vertical loads is included in the calculation of vertical loading.



The illustration on the right shows a typical utility structure with a crossarm. Notice the crossarm brace. The effect of the crossarm brace is not considered in these calculations, but it will provide an additional safety factor.
A new term, W_tS, is introduced here, which is known as the "weight span" of the conductors. This differs from wind span

in that it is not necessarily one-half of the distance between adjacent spans, but is the distance from the low point of sag in the front span to the low point of sag in the back span. If a pole line is on a steep hill, the weight on the crossarm may be much further down the span than mid-span. For the purposes of this course, weight span and wind span are considered the same.

The vertical loading on a crossarm is:

$$\mathbf{M_V = (W_tS * W_c * L_{phase} * OCF_v) + 450 * OCF_v}$$

Where:
M_V = Vertical moments on the crossarm, ft-lbs.
W_tS = Weight Span, lbs.
W_c = Weight of the conductor with ice, lbs/ft.
L_{phase} = Distance from the pole attach point to the phase conductor, ft.
OCF_v = Overload Capacity Factor, Vertical. (See Chart 2.)

In this equation, the conductor weight includes the conductor weight from Chart 6.If the loading district includes ice (medium and heavy loading districts), then the weight of the ice on the conductor must also be considered. The total conductor weight with ice is found by:

$$\mathbf{W_c = 0.396 * [(3.14*(dia_c + 2 * Ice)^2 / 4) – (3.14 * Dia_c^2 / 4)] + Cond_{wt}}$$

Where:
W_c = Weight of Conductor, with Ice, lbs/ft.
dia_c = Diameter of the conductor, in.
Ice = Ice thickness, in.
$Cond_{wt}$ = Conductor weight, lbs/ft.

Note: Only use this formula to find W_c with ice. If ice is not present, $W_c = Cond_{wt}$.
For instance, what is the iced-weight of a 1/0 ACSR, Raven conductor in the medium loading district?

From Chart 1, the ice load in the medium loading district is 0.25”.From Chart 6, the diameter and weight of the conductor are 0.684” 0.145" and 0.642 0.398" lbs/ft respectively.

$W_c = 0.396 * [(3.14*(0.398 + 2 * 0.25)^2 / 4) – (3.14 * 0.398^2 / 4)] + 0.145$
$W_c = 0.346$ lbs/ft.

Consider a three phase, 1/0 ACSR, Raven, line with 400 foot spans, and an 3.5”x4.5”x8-foot crossarm, with one conductor at each end of the crossarm, 6-inches from the end of the arm. What is the vertical load on the crossarm in the medium loading district and with Grade C construction?

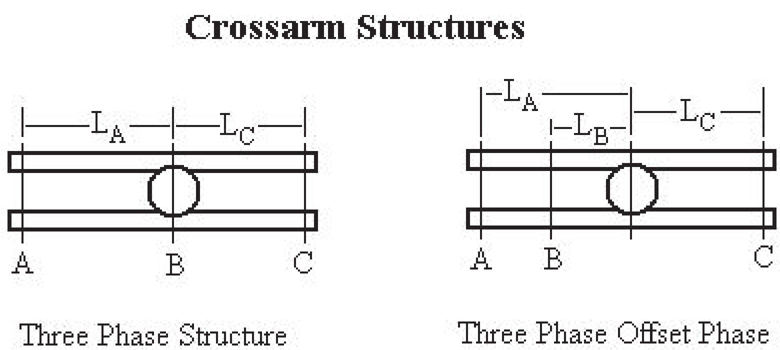
The weight span is (400+400)/2, or 400 feet.The distance to the phase is 3.5-feet, and the overload capacity factor for vertical, Grade C construction is 1.90.The conductor weight with ice is 0.346 lbs/ft.

Therefore the vertical load is:

M_V = (400 * 0.346 * 3.5 * 1.90) + 450 * 1.90
M_V = 1,775 ft-lbs.

The resisting moment for this arm in a Grade C application is:
MR_y = 7,644 * 0.85
MR_y = 6,497 ft-lbs.

The crossarm has adequate strength for the vertical loading. In this example, one phase was at each end of the arm and the third phase was assumed to be connected at the pole. Another case is where two of the phases are on one side of the arm. See the illustration below. In this case, the moments for each phase, L_A and L_B, are calculated, based on their respective distance to the pole and summed together to obtain the total vertical moments.



C. Longitudinal Loads
There are two applications to consider with longitudinal loads, one is tangent structures where the load on one side of the crossarm may be different than the other side, which creates an unbalanced load, and the other is a deadend structure, where the crossarm must withstand the full tension load of the conductors. Longitudinal loads are the conductor design tension times the distance to the attach point and the overload factor.

1.Deadends
In a deadend application, the load is simply the design tension times the distance times an overload factor.

$$\mathbf{M_L = DT * L_{phase} * OCF_L}$$

Where:
M_L = Longitudinal Load, ft-lbs.
DT = Design Tension of the conductor, lbs.
L_{phase} = Distance to the attach point on the pole to the phase, ft.
OCF_L = Overload Capacity Factor, Longitudinal loads. (See Chart 2.)

For example, consider a 1/0 ACSR, Raven, conductor on a three phase line in a Grade C application, with a 3.5”x4.5”x8’ crossarm with the outer phases located at 6-inches from the end. What is the longitudinal loading?

From Chart 6, 1/0 ACSR, Raven conductor has a breaking strength of 4,380 lbs. With a 50% design tension, the load is 2,190 pounds. The distance to the phase is 3.5-feet, and the overload capacity factor is 1.30 for Grade C, Deadend, longitudinal loads (see Chart 2).

Therefore, the longitudinal moments are:

M_L = 2,190 * 3.5 * 1.3
M_L = 9,965 ft-lbs.

A 3.5”x4.5”x8’ crossarm in Grade C construction has a rating of:
MR_x = 5,062 * 0.85
MR_x = 4,302 lbs.

Since the crossarm can only withstand 4,302 pounds and the deadend load is 9,965 pounds, one crossarm is not sufficient. In fact, three arms are required to adequately support this load, since 3 * 4,302 = 12,906 pounds, which is greater than the load of 9,965 pounds.

It is normal utility practice to use two or three crossarms for deadend structures. After three crossarms, most utilities will install a steel angle for additional strength.

2.Tangents
The longitudinal loads on a tangent structure are caused by the differences in tension between the phases on each side of the pole. The formula is the same as for a deadend application, except that the differences in tensions between the two sides of the crossarm are used.

For example, assume that a double deadend structure has 1/0 ACSR, Raven on one side and 336 ACSR, Merlin, on the other side. The construction is Grade C, and the conductors are at 50% design tension on a 3.5”x4.5”x8’ crossarm, with the phases mounted 6 inches from the end of the arm (3.5’ from the pole attach point).What is the longitudinal load?

The design tension for the 1/0 ACSR, Raven is 2,190 pounds. The 336 ACSR, Merlin, has a breaking strength of 8,860 pounds for a design tension of 4,430 pounds. The NESC does not require an overload capacity factor for this application. The longitudinal load is:
M_L = (4,430 – 2,190) * 3.5’
M_L = 7,840 ft-lbs.

Since each crossarm in Grade C construction can withstand 4,302 pounds, two crossarms can adequately support this load. Two arms are 2 * 4,302 = 8,604 ft-lbs.

3.Combined Loads
Actually, vertical loads are present in the longitudinal case as well as the effect of the longitudinal loads on the vertical case. To ensure a safe installation, it is a good idea to make sure the combined vertical and longitudinal loads do not exceed the capability of the crossarm.To do this, divide the vertical load by the capability of the crossarm and the longitudinal load by the longitudinal capability of the crossarm and sum the two values. If the sum is less than or equal to one, the crossarm has adequate strength for the load. For example, consider the previous vertical and deadend examples where the vertical load is 1,777 ft-lbs and the longitudinal load is 9,965 ft-lbs. The vertical withstand of the

arm is 6,495 ft-lbs and the longitudinal withstand is 4,302 ft-lbs. Since three crossarms are necessary for the longitudinal case, the computation is:

Combined Load = 1,775 / (3 * 6,495) + 9,965 / (3 * 4,302)
Combined Load = 0.09 + 0.77 = 0.86.

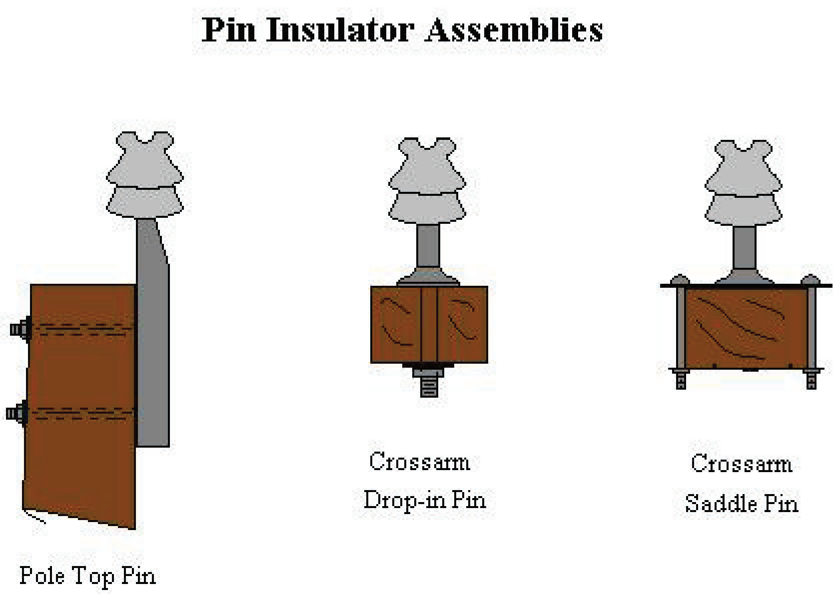
Since the combined load is less than 1.00, the crossarm should be adequate for the loading application.

IV. Pin & Post Insulators

Pin and post-type insulators are used to support conductors on tangent structures and small angle structures. For anything other than very small angles, suspension insulators in a vertical configuration should be used.

The limitations on the structure to withstand pin loads is based on the ability of the insulator to withstand to side forces on the pin insulator itself, the capability of the wood arm to withstand splitting due to the torque of the pin on the crossarm, and the capability of the steel pin that supports the insulator to withstand the moments on the pin at the crossarm (or poletop.)

The drawing below illustrates a few of the common pin configurations. The drawing shows a pole top pin, a crossarm drop-in pin, and a crossarm saddle pin. The drop-in pin can be rated higher if a square washer is placed under the pin to increase the bearing pressure on the crossarm.



The pin insulator assemblies generally have the capacities shown in Chart 8.

Chart 8 Strength of Pin Assemblies	
Pin Assembly	**Rating**
Pole Top Pin	500 lbs
Drop-in Pin	500 lbs
Drop-in Pin With square washer	750 lbs
Saddle Pin	1,000 lbs
Note: In most cases, adding two pins will double the capacity, if anti-split bolts are Installed in the pole or crossarm.	

These ratings are approximate, and are based on operating experience from many utilities in the United States.

The angle on an insulator is determined by the wind span, conductor loading including ice and wind, the design tension of the conductor, plus the appropriate overload capacity factors. The formula to calculate the load on a pin for a given angle is”

Pin_{Load} = [Sin(Angle/2) * (2 * DT * OCF_t)] + WS * C_L * OCF_w

Where:
Pin_{Load} = Pin Load due to the angle on the pole, lbs.
Angle = Line angle, degrees.
WS = Wind Span, feet.
C_L = Conductor wind and ice load, lbs/ft^2.
OCF_w = Overload Capacity Factor, Wind.(See Chart 2.)
DT = Design Tension of the conductor, lbs.
OCF_t = Overload Capacity Factor, Transverse.(See Chart 2.)

As an example, consider a three phase, 336 ACSR, Merlin, Conductor with a 5-degree angle in the medium loading district with Grade C construction and a 50% design tension. Assume the conductor load is 0.395 lbs/ft and the wind span is 325 feet. What is the Pin Load?

The breaking strength of 336 ACSR, Merlin is 8,860 pounds, so the design tension is 4,430 pounds.The overload capacity factor for the transverse wire load is 1.65 and for the transverse wind load, 1.75.
Pin_{Load} = [Sin(5/2) * (2 * 4,430 * 1.65)] + 325 * 0.395 * 1.75
Pin_{Load} = 862 lbs.

In this example, two pole top pins along with saddle pins on the crossarms is sufficient. If the angle had been 7 degrees, or more, the pole top pins would not be adequate, and the center phase would need to be dropped down onto the crossarm and double saddle pins used.

Pole Assemblies Conclusion

A safe structure can be designed by carefully considering the force moments on poles and pole structures that are created by the loads on structures. The NESC must be consulted to be sure that the appropriate loads and safety factors are considered. Safely designing a structure requires knowledge of the loading districts, NESC safety factors, conductor tensions, weights, and diameters, as well as the capacities of the structures themselves

Glossary

For reference, a glossary of terms used in the course are listed below.

Angle = Line angle, degrees.
B_s = Pole factor used in the gust response factor calculation.
B_w = Wire factor used in the gust response factor calculation.
C_d = Shape Factor. Cd = 1 for round structures.
C_{gnd} = Circumference at the ground line, Inches.
C_L = Transverse load due to ice and wind load, lbs/ft.
$Cond_{wt}$ = Conductor weight, lbs/ft.
D = Setting depth of the pole, ft. (The is the same as H_{gnd}.)
Dia_C = Conductor Diameter, inches.
Dia_{Gnd} = Diameter of the pole at the ground line, inches.
Dia_{Eqp} = Diameter of the equipment, inches.
Dia_{load} = Diameter of the pole at the load, inches.
Dia_{top}= Diameter of the pole at the top, inches.
Dia_x = Diameter of pole at distance, x, from bottom, inches.
DT = Design Tension, Breaking Strength times percentage design tension, lbs.
e = Eccentricity, Distance from the center of a load to the center of the pole, inches.
E = Modulus of Elasticity, lbs/in^2.
E_s = Pole factor used in the gust response factor calculation.
E_w = Wire factor used in the gust response factor calculation.
F_b = Fiber stress of a wood crossarm, lbs/in^2.
F_b = Fiber Stress, (see Chart 5.)
G_{rf} = Gust Response Factor.
H_c = Height of the conductor attachment, ft.
H_{gnd} = Distance from bottom of pole to ground line (see Chart 4).
H_{load} = Height of the load from the butt of the pole, inches.
H_P = Height of pole above ground level, feet.
H_{pole} = Total Length of pole, ft.
H_x = Distance from the bottom of the pole to point x, ft.
I = Importance Factor.
I = Moment of Inertia, in^4
Ice = Radial ice load, inches.
I_x = Moment of Inertia in the “x” direction, in^4.
K_z = Velocity Pressure Exposure Coefficient.
L_{Load} = Length of the equipment, ft.
Load = Weight of additional load on pole, lbs.
L_{phase} = Distance from the pole attach point to the phase conductor, ft.
M_c = Moments due to wind on conductors, ft-lbs.
M_e = Moments due to wind on equipment on the pole, ft-lbs.
M_{Gnd} = Sum of all moments applied to the pole at the ground line, ft-lbs.

M_L = Longitudinal Load, Ft-lbs
M_p = Moments due to wind on the pole, ft-lbs.
MR = Resisting Moment for a wood crossarm in the specified direction, ft-lbs.
M_r = Ultimate resisting moments of the pole, ft-lbs.
$M_{r\ soil}$= Maximum load at two feet from top, lbs.
M_t = Moments due to transverse load due to conductor tension in an angle, ft-lbs.
M_V = Vertical moments on the crossarm, ft-lbs.
OCF_L = Overload Capacity Factor – Longitudinal, (See Chart 2)
OCF_t = Overload Capacity Factor – Transverse, (See Chart 2)
OCF_v = Overload Capacity Factor, Vertical. (See Chart 2)
OCF_w = Overload Capacity Factor – Wind, (See Chart 2)
Pin_{Load} = Pin Load due to the angle on the pole, lbs.
S_e = Soil Stability.
Sf = Safety Factor, NESC Table 261-1A, (see Chart 3.)
SM = Section Modulus in the specified direction, in^3.
V = Wind Velocity, MPH.
W = Wind load, lbs/ft^2.
W_c = Weight of Conductor, with Ice, lbs/ft.
$W_{Extreme}$ = Extreme Wind Loading, lbs/ft^2.
WS = Wind Span, ft.
WS_{max} = Maximum allowable wind span, ft.
W_tS = Weight Span, lbs.
x = Horizontal dimension of the crossarm, inches.
y = Vertical dimension of the crossarm, inches.
y_h = Diameter of the bolt hole, inches.
D_p = Pole deflection with an eccentric load, in percent deflection.
b = A factor that accounts for the modulus and moment of inertia of the load.