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APPENDIX - C

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Proposed Associated Changes to Appendix F of General Order 95 to Incorporate Load and Resistance Factor Design Methodology into General Order

Appendix F
Typical Problems

The application of line construction requirements specified in this Order is exemplified in the following:

Part 1. Crossing Problem–A Class H and a Class C circuit Crossing over a major railroad, major Class C circuits and a highway.

Part 2. Dead End Problem–H and Class L circuits at a dead end.

Part 3. Angle Pole Problem–Guying a pole supporting Class H and Class L circuits at angles in lines.

The problems are computed on the assumptions of light loading conditions, with Grade "A" construction used for the power circuits and Grade "F" construction used for the communication circuits except in the crossing spans where Grade "B" is required. The construction details specified in these Typical Problems are made to conform to current good practice.

Part I

Crossing Problem

A diagram including dimensions is shown on page F–18. The data chosen for the crossing follow:

Data of Crossing

Circuits

Two 3–phase 60,000 Volt power circuits. One metallic private Class "C" telephone circuit

Configuration

Power conductors of each circuit are in vertical planes on opposite ends of the crossarm. Private telephone circuit is in a horizontal plane.

Conductors

Power circuits are six No. 00 AWG, bare, stranded, hard–drawn copper. Private telephone circuit is two No. 8 AWG, bare, solid, hard–drawn copper, except in the crossing span where it is two No. 6 AWG, bare, solid, hardrawn copper.

Insulators

Porcelain, pin type, meeting the requirements of Rule 49.5–A.

Ties

Annealed copper wire to comply with Rules 49.3–B and 49.3–C.

Pins

Power circuits–wrought iron pipe (extra strong), 1–1/2″ x 18–1/2″, to comply with Rules 49.3–B and 49.3C. Assumed bonded in accordance with the requirements of Rule 53.4.

Communication circuit - 1–1/2″ x 9″ locust

Crossarms

Power circuits–Douglas fir (dense), 4–3/4″ x 5–3/4″ x 12′, 1.9″ pin holes, 11/16″ hole for through bolt.

Communication circuit–Douglas fir (dense), 3–1/4″ x 4–1/4″ x 42″, l–l/2″ pin holes, 11/16″ hole for through bolt.

Crossarm Braces

Meeting the requirements of Rule 49.2–C.

Poles

Western red cedar, round, butt treated

Span Length

Crossing span, 200 feet.

Adjacent spans, 150 feet

Construction Requirements

1. Conductor Sags and Tensions

The conductors are assumed to be strung so that at normal conditions of 60°F and no wind the tension will be 35% of the ultimate tension of the conductors. From Chart No. 1, Page C–6, it will be seen that under these conditions the No. 00 AWG conductor, for a 200 foot span, will have a sag of 1.0 foot (0.99 when calculated), and the No. 6 AWG conductor will have a sag of 0.90 foot (0.89 when calculated). These sags may be calculated by means of the following approximation formula:

$$\text{Sag} = \frac{wd^2}{8T}$$

Where w = conductor loading, pounds per lineal foot
d = span length, feet
T = assumed allowable conductor tensions at 60_F and no wind

For No. 00 AWG conductor

$$Sag = \frac{0.4109 \times 200^2}{8 \times 2074} = 0.99 \text{ Foot}$$

For No 6 AWG conductor

$$Sag = \frac{0.0795 \times 200^2}{8 \times 448} = 0.89 \text{ Foot}$$

Maximum conductor load to be met with a safety factor of not less than 2 as specified in Rule 44.1 will occur at the conditions of 25°F and an 8 pound wind (Rule 43.2). Conductors which have been strung at the normal conditions stated above (60°F, no wind, and 35% ultimate tension) will have sags and tensions at the maximum loading conditions of 25°F and an 8 pound wind as indicated below. Maximum conductor sags will occur at the condition of maximum temperature, 130°F and also are shown in the following tabulation:

	#00 AWG		#6 AWG	
	Sag (Feet)	Tension (Pounds)	Sag (Feet)	Tension (Pounds)
Ultimate Conductor Tension (See Appendix B, Table 18)	-	5,925	-	1,280
35% Ultimate at 60°F, No Wind	0.99	2,074	0.89	448
25°F, 8 Lb Wind	0.95	2,605	1.18	570
130°F, No Wind	1.78	1,157	1.55	256

From the foregoing it will be seen that by stringing the conductors to 35% of ultimate tension at 60°F and no wind, the safety factor of the conductors at maximum loading (25°F, 8 lb wind) is somewhat greater than the minimum of 2 required by Rule 44.1

Lesser sags than those shown above may be used, provided conductor tension, at maximum loading condition specified in Rule 43, does not exceed 50% of the ultimate tension of the conductor. The rules, of course, do not prevent the use of greater sags than are calculated above.

2. *Conductor Clearance from Center Line of Pole*

Minimum clearances specified in Table 1, Case 8 and Rule 54.4–D2 and the clearances assumed for the purposed of this problem are as follows:

	Minimum	Used
60,000 Volt circuits	21.5″	5′ 6″
Communications circuit	15″	18″

3. *Conductor Separation*

Table 2, Case 12, Column H modified by Rule 54.4–Clc, permits a vertical separation of not less than 36 inches between the conductors of a 60,000 Volt circuit in vertical configuration. For this problem a separation of 5′6″ is used.

The minimum separation between the level of the lowest supply conductor and the communication circuit is 72 inches (Table 2, Case 8, Column H). For the problem, a separation of 96 inches between crossarm centers is used.

4. *Clearances of Conductors Above Crossarms*

The minimum clearance of a 60,000–volt conductor from the surface of a crossarm is required (by Table 1, Case 9, Column F) to be at least 1/4 of the pin spacing specified in Table 2, Case 15, Column H, which would be a minimum clearance of 9 inches. For this problem, an 18–1/2 inch pin is used which, with its insulator, places the conductor 14 inches above the crossarm.

5. *Conductor Clearances Above Highway, Pole Lines and Railroad Tracks*

The poles supporting the crossing span are 55 feet in length, set 7 feet (Rule 49.1C) in the ground. From dimensions of the pole framing diagram the distance of the private telephone circuit above ground is 28′ 4″. For this problem, a common elevation has been assumed for the ground line, the railroad tracks and the highway.

The sag of the communication conductors in the crossing span is approximately 11 inches at 60°F and 19 inches at 130° F. Since the allowable variation of 5% for temperature, applied to the ground clearance of 27′ 5″ (28′ 4″ - 11″), is 1′ 4″, which is greater than the difference between the sags at 60°F (11″) and at 130°F (19″), the clearances may be determined at 60°F for all conditions. In the diagram, Page F–18, the distances from supporting pole C to the various objects crossed over by the conductors are as follows:

Telephone pole line	37′	6″
Highway (center)	60′	0″
Telegraph pole line on RR r/w	97′	6″
Railroad Tracks (center)	138′	9″
Railroad Signal pole line	180′	0″

The total length of crossing span is 200 feet. Therefore, the clearance at 60°F of the private communications circuit above the telephone lead at point of crossing is obtained as follows:

Clearance point distance from Pole C is 37′ 6″.

At 37′ 6″, or 18.8% of the span, the sag is equivalent to 61% of the center sag (see Chart No. 9 on Page C–14), or 0.61 x 11 = 7″ sag.

Therefore, the clearance equals:

28′ 4″ - (7″ + 24′) = 3′ 9″ clearance.

The minimum required clearance as given in Table 2, Case 3, Column C is 2 feet. In a like manner the clearances, at 60°F, of the private communication circuit conductors at the other points of crossing are as follows:

Points of crossing	Clearances		Minimum by Rule	
Highway (center)	27′	7″	18′	0″
Telegraph pole line	3′	5″	2′	0″
Railroad Tracks (center)	27′	7″	25′	0″
Railroad Signal pole line	6′	0″	2′	0″

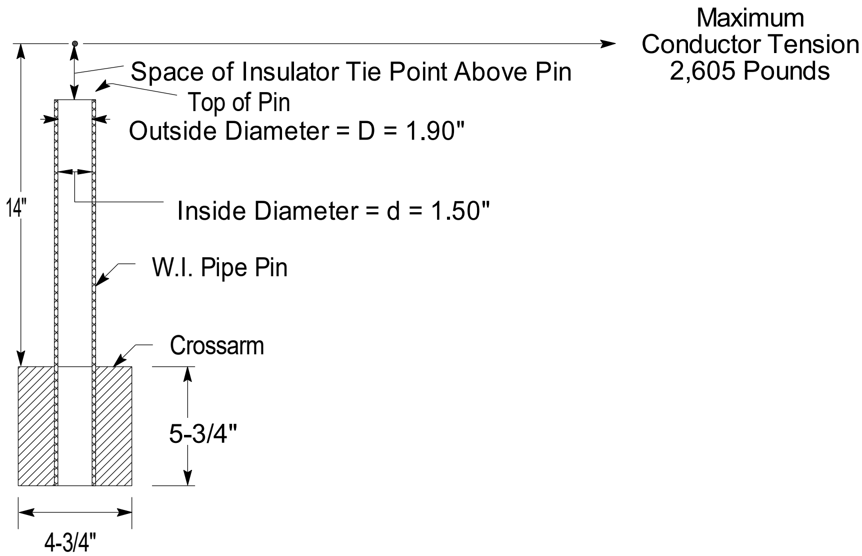
6. Insulators

In addition to the electrical requirements set forth in Rules 55 and 104, the insulators supporting the supply and communication conductors shall have safety factors (mechanical) of 3 and 2, respectively.

7. Pins, Ties and Conductor Fastenings

Ties used in connection with pin–type insulators shall conform to Rule 49.3. In this problem a No. 4 and No. 8 annealed copper wire are used for the No. 00 and No. 8 circuits involved.

Pins used in connection with pin–type insulators shall have sufficient strength to withstand the tension in the conductor. In the case under discussion wrought iron pipe–pins of the dimensions and construction indicated below are to be employed for the power conductors.



Bending moment (at crossarm) M = 2,605 x 14 = 36,470 pound–inches

$$\text{Section Modulus E} = \frac{11D^4 - d^4}{32D}$$

$$0.0982 \times \frac{1.90^4 - 1.50^4}{1.90} = .0412 \text{ inch}^3$$

$$\text{Fiber stress S} = \frac{M}{E} = \frac{36470}{0.412} = 88500 \text{ pounds per square inch}$$

Assuming that the ultimate fiber stress of wrought iron is 48,000 pounds per square inch, a single pin is not sufficient, as it provides a safety factor of 0.542,

$$\left(\frac{48000}{88500} = 0.542\right)$$

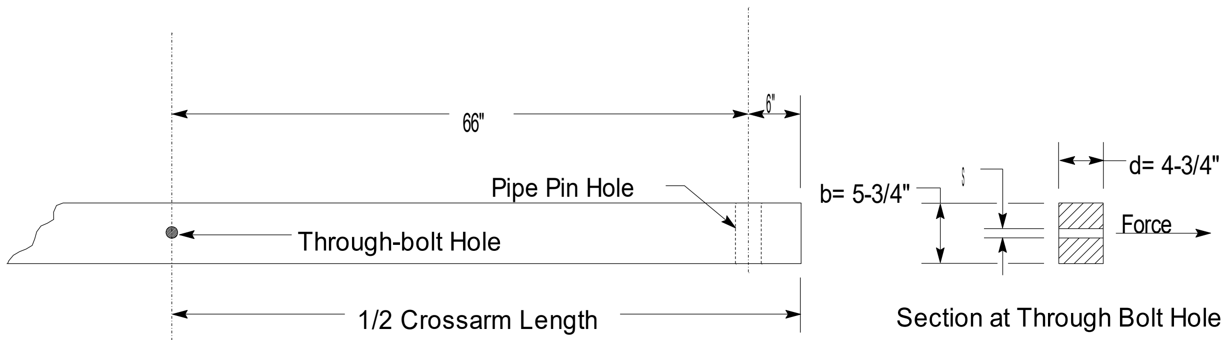
for an assumed tension of 2,605 pounds in the conductor at maximum loading. Since a safety factor of unity (Rule 47.3) is required, two pins are necessary and therefore double crossarms, pins and insulators are used on the poles supporting the crossing span.

Locust pins are to be used in this case for the private telephone conductors. Although a 1–1/2 inch locust pin would be sufficient to withstand the conductor tension of 570 pounds with a safety factor of at least unity, as required by Rule 47.2, care would be necessary to provide sufficient strength in the conductor fastenings. In this problem, the private telephone conductors are considered to be dead–ended at the ends of the crossing span.

8. Crossarms–Horizontal Loads

Power Circuits

The point of maximum bending moment will be at the crossarm through bolt attaching the arm to the pole, at which point the cross section of the arm is reduced by the amount of the bolt hole. Crossarms supporting the 60 kV wires are to be Douglas fir, dense, dimensions 4–3/4″ x 5–3/4″ x 12′, bored as illustrated below.



The section through the arm and the method of computing the fiber stress is shown below.

Long–time loading: Since longitudinal conductor loads are normally balanced, long–time horizontal loading of the power circuit crossarms need not be considered.

Single arm, Maximum loading, 25°F and an 8 lb wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

Section modulus = $\frac{bd^2}{6}$ where

b = 5.75″ – 0.69 = 5.06″

d = 4.75″

s = 11/16″ = 0.69″

Section modulus = $\frac{5.06 \times 4.75^2}{6}$ = 19.0 inches ^{3}

Fiber Stress = Bending moment divided by

Section modulus = $\frac{171930}{19.0}$ = 9050 lbs per square inch

As the allowable value for modulus of rupture in bending under maximum loading conditions is 6,300 lbs per sq. in. (see Table 5, Rule 48.1), a single crossarm of the size chosen provides a safety factor of only 0.70 for the assumed load at maximum loading conditions, whereas the provisions of Rule 47.3 require a safety factor of unity. Double arms will, therefore, be used in this problem to meet the strength requirements applicable to crossarms at end supports of crossings. Double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently.

Maximum loading, 25°F and an 8 lb wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

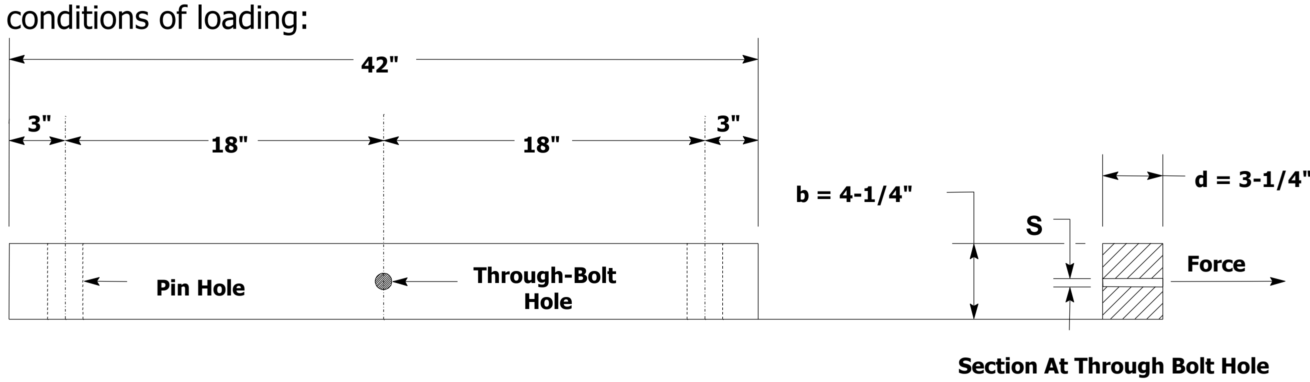
Single arm section modulus (same as previously calculated) = 19.0 inches^3
Double arm section modulus = 19.0 x 2 x 1.3 = 49.4 inches^3

$$\text{Fiber stress} = \frac{171930}{49.4} = 3840 \text{ lbs per square inch}$$

As the allowable modulus of rupture for short–time loading is 6,300 lbs per sq. in. then the double crossarms under these conditions will provide a safety factor of 1.91, which meets the unity safety factor required by Rule 47.3.

Private Communication Circuit

At the crossing span, double crossarms are used on account of dead–end construction due to change of conductor size. Current practice provides for this method of construction although a singlearm has sufficient strength as is found form the following calculations of modulus of rupture under the two limiting conditions of loading:



Long–time loading, 60°F and no wind

Bending moment = 448 x 18 = 8,064 pound–inches

$$\text{Section modulus} = \frac{bd^2}{6} = \frac{3.56 \times 3.25^2}{6} = 6.26 \text{ inches}^3$$

where d = 3.25″
s = 0.69″
b = 4.25″ – 0.69″ = 3.56″

$$\text{Fiber stress} = \frac{8064}{6.26} = 1290 \text{ pounds per square inch}$$

The allowable value for modulus of rupture in bending is 0.55 x 6,300 = 4,465 pounds per square inch and therefore with a single arm the factor of safety under conditions of long–time loading is 2.69.

Maximum Loading

Bending moment = 570 x 18 = 10,260 pound–inches
Section modulus = 6.26 inches^3 (as per calculations above)

$$\text{Fiber stress} = \frac{10260}{6.26} = 1640 \text{ pounds per square inch}$$

The allowable value for modulus of rupture in bending, under maximum loading conditions, is 6,300 pounds per sq. in., therefore a single arm provides a safety factor of 3.84 under these maximum loading conditions.

9. Crossarms - Vertical Loads

The vertical load on crossarms, where supports are approximately at the same elevation, is due to the vertical load of conductors in each adjacent span plus 200 pounds at the outer pin position. In the problem under consideration, the conductor supports on the crossing poles (C and D) are at the same elevation, and the supports at the adjacent poles (B and E) are 4.5 feet lower in elevation, which difference in elevation is greater than the normal sag. Then the conductor loading on a crossing span support would be one–half the weight of the conductor of the crossing span plus one–half the conductor weight of a hypothetical span, the curve of which passes through the points of support.

Half the length of the hypothetical span may be calculated as follows:

$$X = \frac{D}{2} + \frac{hT}{Dw}$$

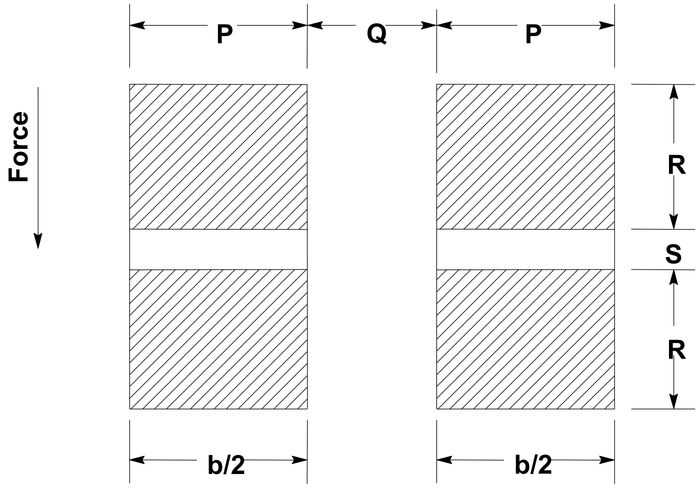
Where

X = 1/2 the hypothetical span in feet.
D = horizontal distance between supports in feet.
h = difference in elevation of supports in feet.
T = conductor tension in pounds.
w = weight of conductor in pounds per foot.

The total crossing support–load is calculated as follows:

$$0.411 \times \frac{200}{2} + 0.411\left(\frac{150}{2} + \frac{4.5 \times 2074}{150 \times 0.411}\right) + 200 = 334 \text{ pounds}$$

The bending moment is: 334 x 66 = 22,040 pound–inches



The method of calculating the unit fiber stress of the double crossarms acting as a simple beam is as follows:

$$\text{Section modulus} = \frac{b}{6} \times \frac{d^3 - d_1{}^3}{d} \text{ where}$$

b = P + P = 9.50″
d = R + S + R = 5.75″
d_1 = S = 0.69″

$$\text{Section modulus} = \frac{9.50}{6}\left(\frac{5.75^3 - 0.69^3}{5.75}\right) = \frac{9.50}{6} \times \frac{189.8}{5.75} = 52.3 \text{ inches}^3$$

$$\text{Fiber stress} = \frac{\text{Bending moment}}{\text{Section modulus}} = \frac{22040}{52.3} = 420 \text{ lbs per square inch}$$

Long–Time Loading

As the allowable modulus of rupture in bending is 0.55 x 6,300 lbs per sq. in. or 3,465 lbs per sq. in. (see Table 5), the double crossarms of the size chosen provide a safety factor of 8.2.

The fiber stress in the double crossarms of the private telephone circuit, similarly calculated, is found to be 196 lbs per sq. in. These arms obviously meet the strength requirements for vertical loads on crossarms.

Shear, compression and torsion stresses are not considered in this problem as they are negligible and likewise the effect of reduction of cross section due to bolt holes is not considered except for the through bolt holes.

10. Poles

The crossing poles are western red cedar and their dimensions are as follows:

Length	55 feet
Height above ground	48 feet
Circumference at top	28 inches
Diameter at top	8.9 inches
Circumference at ground line	49.0 inches
Diameter at ground line	15.6 inches

Distance from ground line to conductors supported is given as follows:

Top supply conductors	48′ 9″
Middle supply conductors	43′ 3″
Lower supply conductors	37′ 9″
Private telephone conductors	28′ 4″

Ground level at base of pole is considered to be at the same elevation as top of rail.

Dimensions of adjacent poles B and E are:

Length	50 feet
Height above ground	43.5 feet
Circumference of top	28 .0 inches
Diameter of top	8.9 inches
Circumference at ground line	47.0 inches
Diameter at ground line	15.0 inches

11. Transverse Load on Crossing Poles C and D

The moment at the ground due to an 8 pound wind pressure on conductors is:

$$Mc = Ln\ P_h\left(\frac{S_1 + S_2}{2}\right) \text{ pound–feet}$$

Where:

L	=	Height of conductors above ground in feet
n	=	Number of wires
S_1 and S_2	=	Length of crossing and adjacent spans, respectively
P_h	=	Horizontal load per lineal foot due to an 8 pound wind pressure on projected area of wire
P_h	=	0.276 pounds per lineal foot for 00 AWG bare, stranded copper
	=	0.108 pounds per lineal foot for 6 AWG bare, solid copper
	=	0.085 pounds per lineal foot for 8 AWG bare, solid copper
M_{c0}	=	Moment due to pressure on top supply conductors
M_{c1}	=	Moment due to pressure on middle supply conductors
M_{c2}	=	Moment due to pressure on lower supply conductors
M_{c3}	=	Moment due to pressure on telephone conductors

$$M_{c0}=48.75 \times 2 \times 0.276 \times \left(\frac{150+200}{2}\right)=4710 \text{ lb-feet}$$

$$M_{c1}=43.25 \times 2 \times 0.276 \times \left(\frac{150+200}{2}\right)=4180 \text{ lb-feet}$$

$$M_{c2}=37.75 \times 2 \times 0.276 \times \left(\frac{150+200}{2}\right)=3650 \text{ lb-feet}$$

$$M_{c3}=28.33 \times 2 \times 0.108 \times \left(\frac{200}{2}\right)=610 \text{ lb-feet}$$

$$M_{c3}=28.33 \times 2 \times 0.085 \times \left(\frac{150}{2}\right)=360 \text{ lb-feet}$$

Total Moment due to Wind pressure on conductors = 13,510 lb-feet

The moment at the ground due to an 8 pound wind pressure on the pole is:

$$M_P=PH^2\left(\frac{D_1+2D_2}{72}\right) \text{ pound-feet}$$

Where:

M_p	=	Moment due to wind pressure on pole
P	=	Pressure in lbs per sq. ft. on projected area of pole (8 lbs/sq. ft.)
H	=	Height of pole above ground in feet (48′)
D_1	=	Diameter of pole at ground in inches (15.6″)
D_2	=	Diameter of pole at top in inches (8.9″)

$$M_P=\frac{8\ 48^2 \times 15.6 + 2 \times 8.9}{72} = 8550 \text{ lb-ft.}$$

Total moment = 13,510 + 8,550 = 22,060 lb–ft.

Moment of resistance of pole = $M=\frac{FI}{c}$

Where:

F = Fiber stress in pounds per sq. in.

I = Moment of inertia of section $= \frac{\pi D_1^{\ 4}}{64x12}$

c = Distance from neutral axis to outer fiber = $\frac{D_1}{2}$

$$M = \frac{\pi F D_1^{\ 3}}{384} = \frac{F D_1^{\ 3}}{122}$$

$$F = \frac{122M}{D_1^{\ 3}} = \frac{122 \text{ x } 22060}{15.6^3} = 710 \text{ lbs per square inch}$$

The allowable fiber stress for western red cedar poles to provide a factor of safety of 4 is 1,500 pounds per sq. in., hence the crossing poles are not required to be side guyed since they have a factor of safety of 8.5 for transverse load.

12. Side Guying

If side guying were required for the crossing poles C and D the method of computing the same would be as follows:

Side guys are designed to take the entire transverse load of the pole, the pole acting merely as a strut.

The transverse force acting on the poles will be due to wind pressure on poles C and D and the transverse wind pressure on the conductors supported. The length of conductor used in computing this transverse force will be equal to one–half the distance between the guyed poles C and D, plus one–half the length of the span adjacent to these poles.

The total wind pressure is computed as follows:

On Conductors

$$3 \text{ x } 2 \text{ x } 0.276 \text{ x } \frac{150 + 200}{2} = 289.8 \text{ pounds}$$

$$2 \text{ x } 0.108 \text{ x } \frac{200}{2} = 21.6 \text{ pounds}$$

$$2 \text{ x } 0.085 \text{ x } \frac{150}{2} = 12.8 \text{ pounds}$$

On Pole

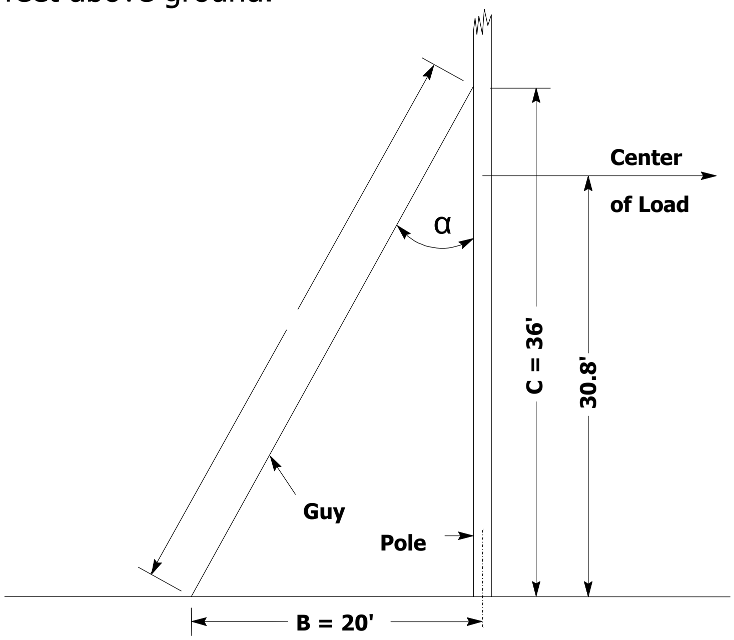
$$\frac{D_1 + D_2 \text{ HP}}{24} = \frac{15.6 + 8.91 \text{ 48 x 8}}{24} = 392.2 \text{ pounds}$$

Total Wind Pressure = 716.4 pounds

The total moment on the poles is the same as developed for “Transverse load on poles” which was 22,060 pound–feet.

$$\frac{22060}{716.4} = 30.8 \text{ feet above ground}$$

A side guy could not be attached at this center of load and provide the required clearances from the communication line; therefore, for construction purposes the guy is assumed attached just below the lowest supply crossarm at a distance of 36 feet above ground.



Let	M_t	=	Total moment on pole = 22,060 pound–feet
	C	=	Height of guy attachment above ground = 36 feet (assumed)
	B	=	Distance of guy anchor from base of pole = 20 feet
	T	=	Tension in guy wire in pounds
	A	=	Length of guy = $\sqrt{(20^2 + 36^2)} = 41.2\,feet$

$$\sqrt{20^2 + 36^2} = 41.2 \text{ feet}$$

$$T = \frac{M_2}{C \sin \alpha}$$

$$Sin\alpha = \frac{B}{A} where$$

1. $A = \sqrt{B^2 + C^2}$

$$Sin\alpha = \frac{20}{\sqrt{20^2 + 36^2}} = 0.485$$

$$T = \frac{22060}{36 \text{ x } 0.485} = 1260 \text{ pounds}$$

The specified safety factor for guys (Table 4, Rule 44.1) is 2 and, therefore, a guy having an ultimate strength of not less than 2,520 pounds is required. One 1/4 inch Siemens–Martin or a 5/16 inch common galvanized–steel strand would meet the requirements for transverse load.

13. Longitudinal Load on Crossing Poles C and D

Rule 47.3 provides that crossing structures shall withstand at all times with a safety factor of unity the unbalanced stress due to the combined pull toward the crossing of one–third of the total number of conductors supported, the pull in each such conductor being taken as the tension due to the specified loading.

Number of conductors involved $= \frac{8}{3} =$ 2-2/3 ;use3

Location of conductors resulting in maximum load - two on top arm and one on next arm below

Bending moment:

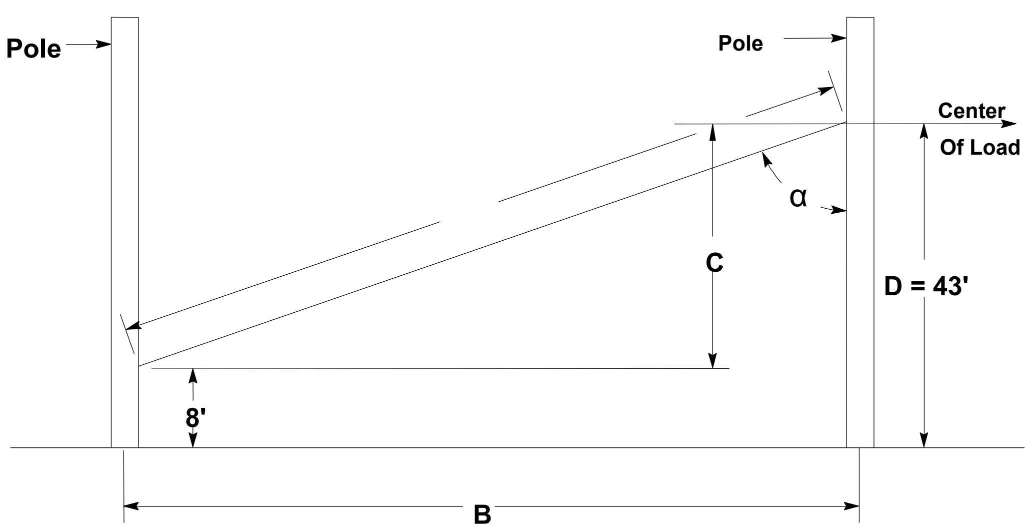
2 x 2,605 x 48.75 = 254,000 pound–feet

1 x 2,605 x 43.25 = <u>112,600</u> pound–feet

Total Moment = 366,600 pound–feet

Fiber stress $= \frac{122M}{D_1{}^3} = 122 \times \frac{366600}{15.6^3} = 11780$ lbs per square inch

The allowable value of modulus of rupture under this load is 6,000 lbs per square inch, hence poles C and D must be head guyed for longitudinal load.



The head guy should be attached approximately at the normal center of load, therefore:

The bending moment under full longitudinal load would be:

48.75 x 2 x 2,605	=	254,000 pound–feet
43.25 x 2 x 2,605	=	225,300 pound–feet
37.75 x 2 x 2,605	=	196,700 pound–feet
28.33 x 2 x 570	=	32,300 pound–feet
Total moment	=	708,300 pound–feet

The total longitudinal load would be:

3(2 x 2,605)	=	15,630 pounds
2 x 570	=	1,140 pounds
Total wire tensions	=	16,770 pounds

Therefore, the center of longitudinal load is:

$$D=\frac{\text{Longitudinal Bending Moment}}{\text{Longitudinal Load}}$$

$$=\frac{708300}{16770}=42.2 \text{ feet load center above ground}$$

Use 43 feet (to avoid contact with arm)

B = 150 feet

C = 43 - 8 = 35 feet *

$$A=\sqrt{B^2 + C^2}=\sqrt{(43)^2 + (150)^2}=156.0$$

$$Sin\alpha = \frac{B}{A} = \frac{150}{156.0} = 0.962$$

* Lower end of guy assumed 8 feet above ground on Poles A and E.

A guy attached at a point 43 feet above ground on pole C or D and at a point 8 feet above ground on pole B or E, respectively, would be required to withstand a load of:

$$\frac{366000}{43 \times 0.962}=8860 \text{ pounds}$$

In this case, a 9/16 inch common, 7/16 inch Siemens–Martin, or 3/8 inch high–strength guy strand would meet the requirements of Rule 47.5. The horizontal load transmitted to pole B or E by such a head guy would be:

8,860 x sin α = 8,860 x 0.962 = 8,520 pounds

The longitudinal moment on pole B and E would be:

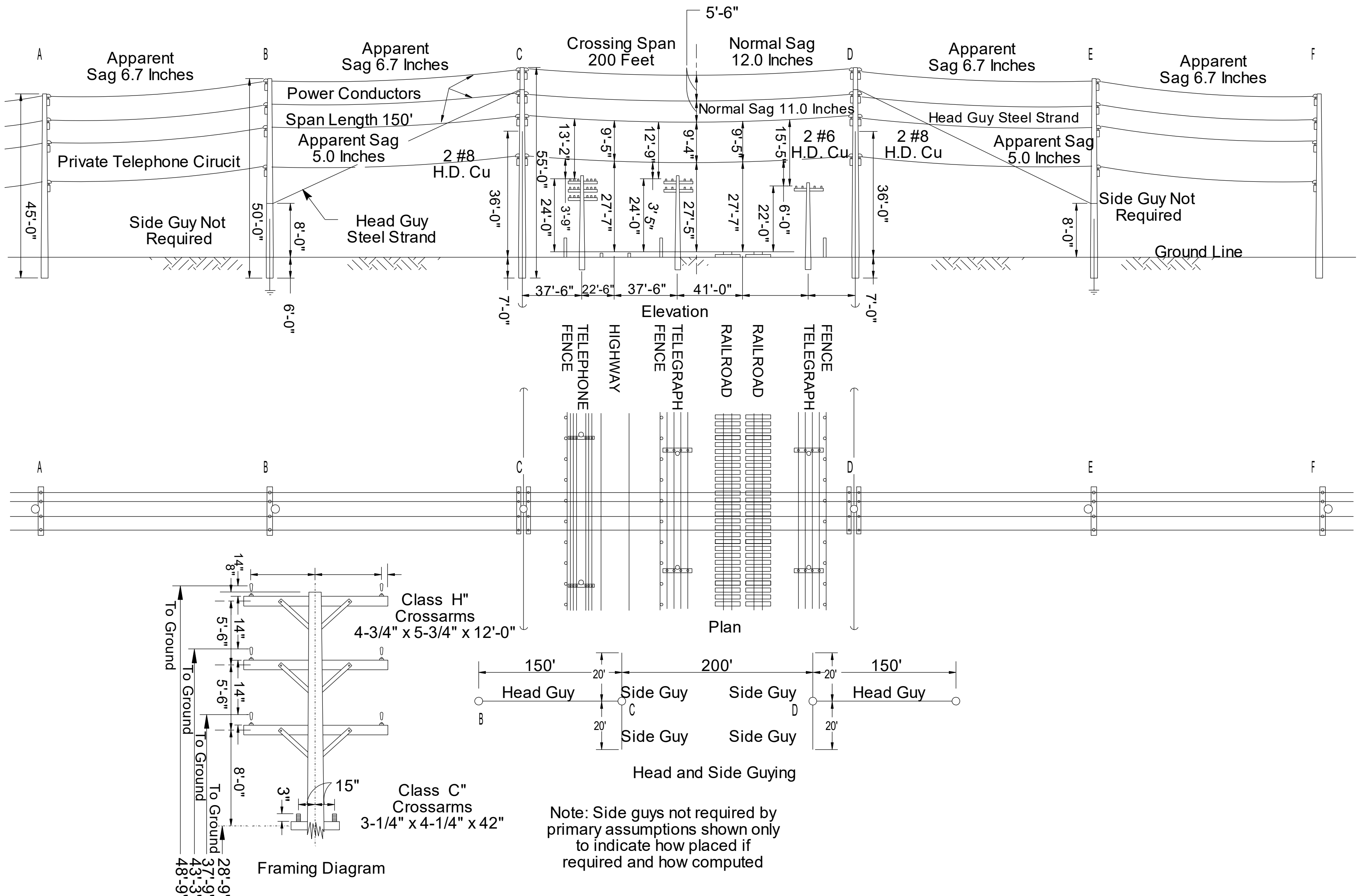
8,520 x 8 = 68,160 pound–feet

and the fiber stress developed in pole B or E by the tension of 9,070 pounds in the head guy would be:

$$F=\frac{122M}{D_1{}^3}=\frac{122 \text{ x } 68160}{15.0^3}=2460 \text{ pounds per square inch}$$

Poles B and E would, therefore, be adequate to hold the contemplated guy tension with a safety factor of unity as required by Rule 47.5.

Crossing of Class H" Supply Line Over Major Railroad and Major Communication Lines



Deadend Problem

It is the object of this problem to indicate the construction requirements for a typical deadend structure, since the longitudinal stresses imposed upon such a structure differ substantially from those on a pole on which the conductors supported are normally balanced. The deadend structure considered herein is assumed to support an 11,000 volt circuit, a 4,000 volt circuit and two secondary circuits. It is also assumed that the deadend pole takes Grade "A" construction by virtue of its location.

The deadend structure diagram and dimensions are shown on Page F–23. The primary data chosen for this structure are as follows:

Data For Deadend Structure

Supply Conductors
11 kV circuit 3 #0 AWG Stranded, hard–drawn copper
4 kV circuit 4 #2 AWG Stranded, hard–drawn copper
120/240 volt circuit 3 #4 AWG Solid, hard–drawn copper
120/240 volt circuit 3 #2 AWG Stranded, hard–drawn copper
Insulators - Strain Type (to conform to Rule 49.5).
Conductor fastenings (to meet the safety factor of Table 4, Rule 44.1)

Crossarms:

11 kV circuit Douglas fir 4–3/4″ x 5–3/4″ x 8′–0″
4 kV circuit Douglas fir 4–3/4″ x 4–3/4″ x 7′–8″
Secondary circuits Douglas fir 4–3/4″ x 4–3/4″ x 7′–0″
Crossarm braces (to conform to Rule 48.2 and 49.8)
Pole - western red cedar.
Pole dimensions: 55′ in length; 25″ top circumference; 50″ ground line circumference (ground line diameter 15.9″).

Construction Requirements

1. Conductor Tensions

It is assumed that the conductors are strung with the minimum sags specified in sag curves of Appendix C, hence the tension values at 60_F and no wind (normal tensions) are 35% of the ultimate tensions shown in Table 18. These tensions for each of the conductor sizes and corresponding tensions at maximum loading (25_F and wind of 8 pounds) are as follows, where span length is 250 feet:

	Tension–Pounds	
	35% of Ultimate	At Maximum Loading
#O AWG Stranded, hard–drawn copper	1,664	2,125
#2 AWG Stranded, hard–drawn copper	1,065	1,360
#4 AWG Solid, hard–drawn copper	690	890

2. Crossarms

Spacings assumed are shown on the pole framing diagram on Page F–23. Double crossarms of Douglas fir, dense, are employed for each of the four different circuits.

Computations of the fiber stresses imposed upon the various crossarms by the unbalanced wire loads of conductors in the physical configuration shown on the diagram are made in accordance with the method outlined in Part 1 to show these stresses under the conditions of long–time loading and maximum loading. Furthermore, double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently. The stresses computed in this manner are:

	Fiber Stress - lbs per Sq. In.	
	Long–Time Loading	Maximum Lading
Top crossarms	1,412	1,804
Second Crossarms	1,598	2,040
Third crossarms	932	1,202
Fourth crossarms	1,438	1,811

Since a factor of safety of 2 permits a maximum stress of modulus of rupture in bending of 1,732 lbs per square inch.

$\left(\frac{6300 \text{ x } 0.55}{2}\right)=1732$ under the conditions of long-time loading (60^{o} F and no Wind) and 3150 lbs per square inch $\left(\frac{6300}{2}\right)$ at maximum loading see Table 5, the crossarms chosen are satisfactory.

3. Pole (See Page F–23)

Rule 44 provides that poles supporting unbalanced longitudinal loads in Grade "A" construction shall have a safety factor of 4 against such loads. Rule 47 specifies that guys used to support unbalanced longitudinal loads shall have a safety factor of 2 for all grades of construction (Where guys are used they must take the entire load with the designated safety factor, the pole being considered merely as a strut).

Using the values given above for tensions at maximum loading, the following moments due to dead ending the conductors are obtained:

3 x 2,125 x 47.3	=	301,500 pound–feet
4 x 1,360 x 38.3	=	208,400 pound–feet
3 x 890 x 30.3	=	80,900 pound–feet
3 x 1,360 x 25.3	=	103,200 pound–feet
Total Moments	=	694,000 pound–feet

The total deadend stress, using the tension values for maximum loading given above, will be:

3 x 2,125	=	6,380 pounds
4 x 1,360	=	5,440 pounds
3 x 890	=	2,670 pounds
3 x 1,360	=	4,080 pounds
Total	=	18,570 pounds

Center of load = $\frac{694000}{18570}$=37.4 feet above ground

The tension of a single guy with a lead to height ratio of 1 to 1 (assumed) and a safety factor of 2 would be:

$$T = \frac{\text{safety factor X total load}}{\cos\Theta} = \frac{2x18570}{\cos\Theta} = 52500\,pounds$$

A stranded guy attached at the center of load could be used provided the allowable fiber stress of the pole is not exceeded. The stress due to guying at this point would be as follows:

The center of load (37.4′ above ground) would be
9.9 ft. (118.8″) below the top conductors (11 kV) and
0.9 ft. (10.8″) below the second crossarm (4 kV)

The fiber stress in the pole at the center of load due to the tension in the conductors above the center of load is computed as follows:

Bending moment	3 x 2,125 x 118.8	=	757,400 pound–inches
	1,360 x 10.8	=	8,800 pound–inches
Total moment		=	16,200 pound–inches

The section modulus of a solid circular section is $E = \frac{\pi \ d^3}{32} = 0.0982d^3$

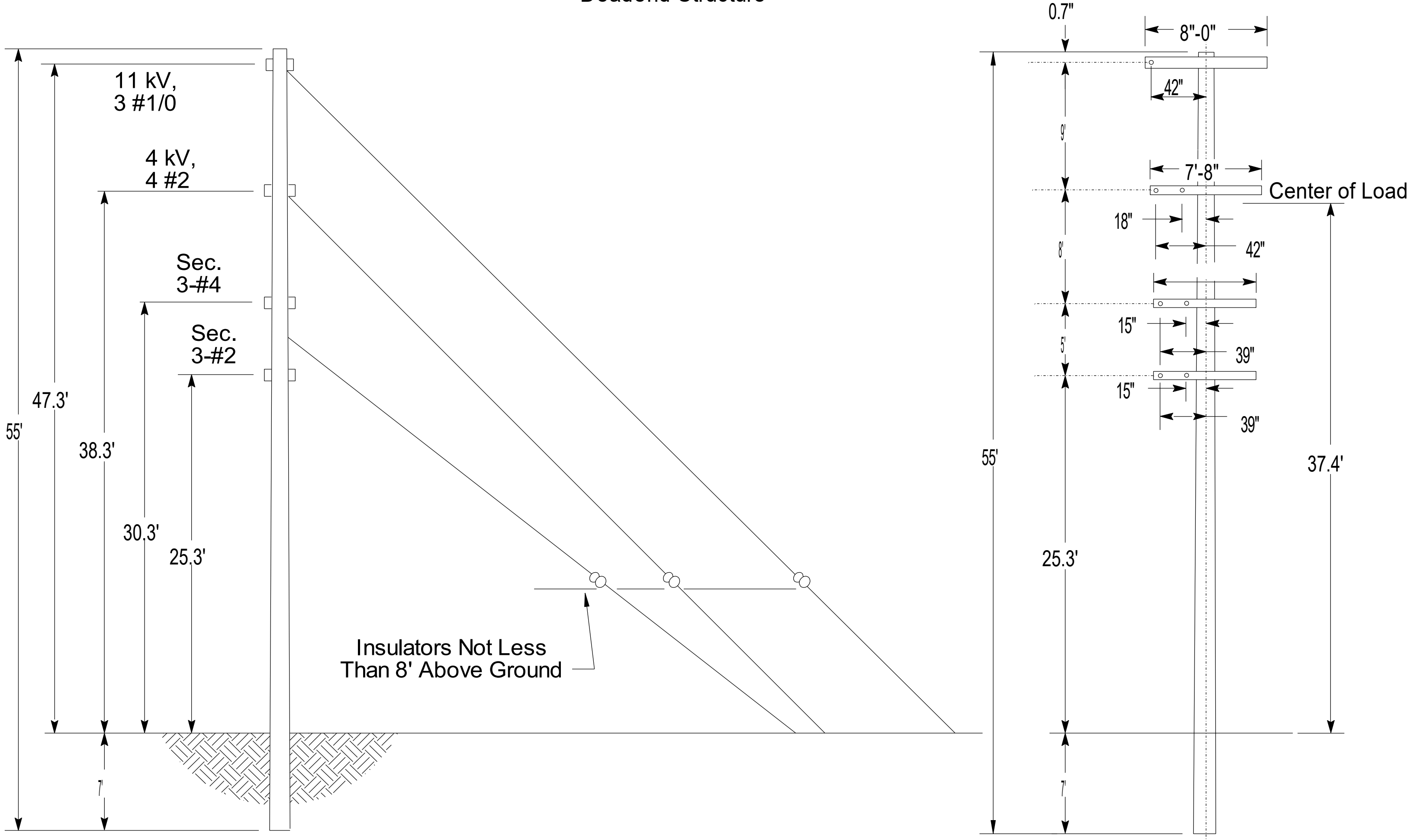
The diameter of the pole at the center of load is d = 9.7inches

Then, E = 0.0982 x $(9.7)^3$ = 89.6″ ^{3}

$$\text{Fiber stress} = \frac{\text{Bending Moment}}{\text{Section modulus}} = \frac{816200}{89.6} = 9110 \text{ lbs per sq in}$$

Since a pole in Grade "A" construction must have a safety factor of 4, the allowable value of fiber stress would be 5,600/4 = 1,400 pounds per square inch; therefore, the pole cannot be guyed by a single guy but can be guyed as illustrated on Page F–23.

Deadend Structure



Part 3
Angle Pole Problem – Methods Of Providing Proper Strength For Unbalanced Conductor Loads At Angle Poles

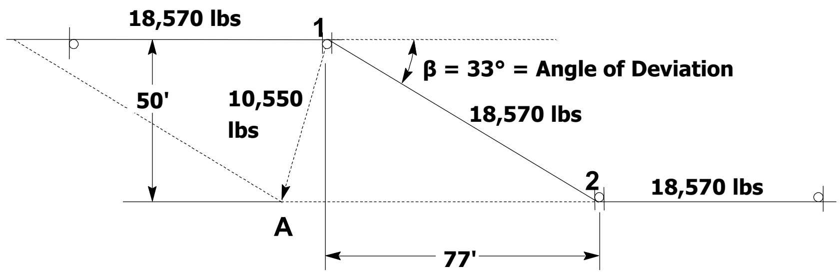
To maintain poles in proper position at angles and corners, it is generally necessary to use guys or some other form of pole bracing. Unless the line is dead–ended, the pull of the conductors is taken as being the same throughout the line.

The degree of unbalanced pull at an angle or corner pole is dependent upon the angle in the line at that point; that is, the greater the angle in the line, the greater is the magnitude of unbalance. Rule 47 specifies that when the longitudinal loads in a structure are not normally balanced, the members stressed shall be of such strength as to withstand the total unbalanced load with factors of safety equal to those of Table 4. As it is assumed that the line considered in this problem is Grade "A" construction, the pole would be required to provide a safety factor of 4 against unbalanced loads; where guys are used to take the unbalanced loads they must provide a safety factor of 2.

It is assumed that the line discussed in the foregoing deadend problem crosses from one side of a street to the opposite side, that the longitudinal distance along the street between the two poles concerned is 77 feet, and that the angle of deviation is 33° (see sketch). This would result in an unbalanced force being exerted in the direction of A of

$$18570x2Sin\frac{\beta}{2} = 18570x2x0.2840 = 10550 pounds$$

Methods of Guying Angle Poles



Force Diagram

Assuming the pole height and framing as shown in Part 2, the top circumference of pole to be 25", the ground circumference to be 50" and the center of load to be 37.4 feet above ground line (as determined in Part 2), the fiber stress on the pole at the ground line is as follows:

Bending moment, M = 37.4 x 10,550 = 394,400 pound–feet

Fiber stress = $\frac{122M}{d^3}$

where circumference = 50″ and d = 15.9″

Fiber stress = $\frac{122 \times 349400}{15.9^3}$ = 11970 lbs square inch

As a safety factor of 4 is required, the allowable working stress is $\frac{5600}{4}$ or 1,400 lbs per square inch, and therefore the use of guys is necessary.

A single guy attached at the center of load could be used provided the modulus of rupture with a safety factor of 4 is not exceeded. The stress due to guying at this point is as follows:

Bending moments

$$Toparm = 3x2125x118.8x2\sin\frac{\beta}{2} = 430200\,pound-inches$$

$$Secondarm = 4x1370x10.8x2\sin\frac{\beta}{2} = 33400\,pound-inches$$

Total moment=463600 pound-inches

Section modulus, E

The section modulus (E) at 37.4 feet above ground is 89.6 inches cubed, which is the value computed in Problem 2

Fiber stress:

The fiber stress is

F=$\frac{M}{E}$=$\frac{463600}{89.6}$=5170 pounds per square inch

Since this stress exceeds the allowable stress of 1,400 lbs per sq. in. for the pole, it is necessary to place guys at more than one point on the pole, and therefore, they are attached at positions similar to the guys shown in the diagram on Page F–23.

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Appendix F
Typical Problems

The application of line construction requirements specified in this Order is exemplified in the following:

Part 1. Crossing Problem–A Class H and a Class C circuit Crossing over a major railroad, major Class C circuits and a highway.

Part 2. Dead ~~E~~end Problem–H and Class L circuits at a dead end.

Part 3. Angle Pole Problem–Guying a pole supporting Class H and Class L circuits at angles in lines.

The problems are computed on the assumptions of light loading conditions, with Grade "A" construction used for the power circuits and Grade "F" construction used for the communication circuits except in the crossing spans where Grade "B" is required. The construction details specified in these Typical Problems are made to conform to current good practice.

This edition of GO 95 replaces the use of "safety factors" with "load factors" (Table 4-1) and "strength factors" (Table 4-2). The ratios of the load factors in Table 4-1 to the strength factors in Table 4-2 correspond to equivalent minimum safety factors as indicated in Rule 44. In some cases, there are slight differences due to rounding the results of the calculations. The equivalent minimum safety factors are provided in Table F-1 (Table 4) which matches the minimum safety factors in Table 4 from previous editions of GO 95. Table F-1 (Table 4), previously referred to as Table 4, is referenced in Appendix F for historical purposes, and so other General Orders which incorporate Table 4 may continue to reference Table 4.

Table F-1 (Table 4) Minimum Safety Factors

Line Element	Grades of Construction		
	Grade "A"	Grade "B"	Grade "C"
Conductors, splices and conductor fastenings (other than tie wires)	2	2	2
Pins	2	2	2
Pole line hardware	2	2	2
Line Insulators (mechanical)	3	2	2
Guy insulators (mechanical)			
Interlocking	2	2	2
Noninterlocking glass fiber	3	2 (a)	2 (b)
Guys	2	2	2
Messengers and span wires	2	2	2
Foundations against uplift	1.5	1.5	1.5
Foundations against depression	3	2	2
Poles, Towers and Structures			
Wood	4	3	2
Metal (including elements of foundations)	1.5 (c)	1.25 (c)	1.25 (c)
Reinforced concrete	4	3	3
Prestressed or post-tensioned concrete	1.8	1.5	1.5
Other engineered materials	1.5	1.25	1.25
Crossarms			
Wood	2	2	2
Metal (c)	1.5 (c)	1.25 (c)	1.25 (c)
Prestressed Concrete	1.8	1.5	1.5
Other engineered materials	1.5	1.25	1.25

(a) Insulators are to be replaced before safety factors have been reduced (due to deterioration or changes in construction, arrangement, or other conditions subsequent to installation) to less than 95 percent of the safety factor specified in Rule 44.1.

(b) Insulators are to be replaced before safety factors have been reduced (due to deterioration or changes in construction, arrangement, or other conditions subsequent to installation) to less than 75 percent of the safety factor specified in Rule 44.1.

(c) For aluminum members subject to tension caused by one or more estimated loads and where the critical load combination for the tension member would not endanger adjacent compression members, the safety factor on ultimate tension shall be 2 for Grade "A" and 1.67 for Grades "B" and "C" construction.

Crossing Problem

A diagram including dimensions is shown ~~on page F–18~~ at the end of Part 1. The data chosen for the crossing follow:

Data of Crossing

Circuits

Two 3–phase 60,000 Volt power circuits. One metallic private Class "C" telephone circuit.

Configuration

Power conductors of each circuit are in vertical planes on opposite ends of the crossarm. Private telephone circuit is in a horizontal plane.

Conductors

Power circuits are six No. 00 AWG, bare, stranded, hard–drawn copper. Private telephone circuit is two No. 8 AWG, bare, solid, hard–drawn copper, except in the crossing span where it is two No. 6 AWG, bare, solid, hard drawn copper.

Insulators

Porcelain, pin type, meeting the requirements of Rule 49.5–A.

Ties

Annealed copper wire to comply with Rules 49.3–B and 49.3–C.

Pins

Power circuits–wrought iron pipe (extra strong), 1–1/2″ x 18–1/2″, to comply with Rules 49.3–B and 49.3C. Assumed bonded in accordance with the requirements of Rule 53.4.

Communication circuit - 1–1/2″ x 9″ locust.

Crossarms

Power circuits–Douglas fir (dense), 4–3/4″ x 5–3/4″ x 12′, 1.9″ pin holes, 11/16″ hole for through bolt.

Communication circuit–Douglas fir (dense), 3–1/4″ x 4–1/4″ x 42″, l–l/2″ pin holes, 11/16″ hole for through bolt.

Crossarm Braces

Meeting the requirements of Rule 49.2–C.

Poles

Western red cedar, round, butt treated.

Span Length

Crossing span, 200 feet.

Adjacent spans, 150 feet.

Construction Requirements

1. Conductor Sags and Tensions

The conductors are assumed to be strung so that at normal conditions of 60°F and no wind the tension will be 35% of the ultimate tension of the conductors. From Chart No. 1, Page C–6, it will be seen that under these conditions the No. 00 AWG conductor, for a 200 foot span, will have a sag of 1.0 foot (0.99 when calculated), and the No. 6 AWG conductor will have a sag of 0.90 foot (0.89 when calculated). These sags may be calculated by means of the following approximation formula:

$$\text{Sag} = \frac{wd^2}{8T}$$

Where w = conductor loading, pounds per lineal foot
d = span length, feet
T = assumed allowable conductor tensions at 60°~~–~~F and no wind

For No. 00 AWG conductor

$$Sag=\frac{0.4109 \times 200^2}{8 \times 2074} = 0.99 \text{ Foot}$$

For No 6 AWG conductor

$$Sag=\frac{0.0795 \times 200^2}{8 \times 448} = 0.89 \text{ Foot}$$

Maximum conductor load to be met with ~~a safety factor of not less than 2~~ load and strength factors applied as specified in Rule 44.1 will occur at the conditions of 25°F and an 8 pounds per square foot (psf) wind (Rule 43.2). Conductors which have been strung at the normal conditions stated above (60°F, no wind, and 35% ultimate tension) will have sags and tensions at the maximum loading conditions of 25°F and an 8 ~~pound~~ psf wind as indicated below. Maximum conductor sags will occur at the condition of maximum temperature, 130°F and also are shown in the following tabulation:

	#00 AWG (Power)		#6 AWG (Comm)	
	Sag (Feet)	Tension (Pounds)	Sag (Feet)	Tension (Pounds)
Ultimate Conductor Tension (See Appendix B, Table 18)	-	5,925	-	1,280
35% Ultimate at 60°F, No Wind	0.99	2,074	0.89	448
25°F, 8 ~~Lb~~ psf Wind	0.95	2,605	1.18	570
130°F, No Wind	1.78	1,157	1.55	256

~~From the foregoing it will be seen that by stringing the conductors to 35% of ultimate tension at 60°F and no wind, the safety factor of the conductors at maximum loading (25°F, 8 lb wind) is somewhat greater than the minimum of 2 required by Rule 44.1~~
The tension in the supply conductors (2,605 lbs) at maximum loading (25°F, 8 psf wind), multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the conductors (5,925 lbs) multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

2,605 lbs x 1.5 ≤ 5,925 lbs x 0.75

or

2,605 lbs ≤ 5,925 lbs /(1.5/0.75) = 5,925 lbs /2.0 = 2,962 lbs

The tension in the communication conductors (570 lbs) at maximum loading (25°F, 8 psf wind), multiplied by the load factor of 1.25 (Table 4-1), for Grade B construction, must not exceed the strength of the conductors (1,280 lbs) multiplied by the strength factor of 0.625 (Table 4-2), or it is required that

570 lbs x 1.25 ≤ 1,280 lbs x 0.625

or

570 lbs ≤ 1,280 lbs /(1.25/0.625) = 1,280 lbs /2.0 = 640 lbs

Hence, the tensions at maximum loading for both types of circuits are within the required limits.

Lesser sags than those shown above may be used, provided conductor tension, at maximum loading condition specified in Rule 43, does not exceed 50% of the ultimate tension of the conductor. The rules, of course, do not prevent the use of greater sags than are calculated above.

2. Conductor Clearance from Center Line of Pole

Minimum clearances specified in Table 1, Case 8 and Rule 54.4–D2 and the clearances assumed for the purposed of this problem are as follows:

	Minimum	Used
60,000 Volt circuits	21.5″	5′ 6″
Communications circuit	15″	18″

3. Conductor Separation

Table 2, Case 12, Column H modified by Rule 54.4–~~Clc~~ C1c, permits a vertical separation of not less than 36 inches between the conductors of a 60,000 Volt circuit in vertical configuration. For this problem a separation of 5′6″ is used.

The minimum separation between the level of the lowest supply conductor and the communication circuit is 72 inches (Table 2, Case 8, Column H). For the problem, a separation of 96 inches between crossarm centers is used.

4. Clearances of Conductors Above Crossarms

The minimum clearance of a 60,000–volt conductor from the surface of a crossarm is required (by Table 1, Case 9, Column F) to be at least 1/4 of the pin spacing specified in Table 2, Case 15, Column H, which would be a minimum clearance of 9 inches. For this problem, an 18–1/2 inch pin is used which, with its insulator, places the conductor 14 inches above the crossarm.

5. Conductor Clearances Above Highway, Pole Lines and Railroad Tracks

The poles supporting the crossing span are 55 feet in length, set 7 feet (Rule 49.1C) in the ground. From dimensions of the pole framing diagram the distance of the private telephone circuit above ground is 28′ 4″. For this problem, a common elevation has been assumed for the ground line, the railroad tracks and the highway.

The sag of the communication conductors in the crossing span is approximately 11 inches at 60°F and 19 inches at 130° F. Since the allowable variation of 5% for temperature, applied to the ground clearance of 27′ 5″ (28′ 4″ - 11″), is 1′ 4″, which is greater than the difference between the sags at 60°F (11″) and at 130°F (19″), the clearances may be determined at 60°F for all conditions. In the crossing diagram, ~~Page F–18~~ at the end of Part 1, the distances from supporting pole C to the various objects crossed over by the conductors are as follows:

Telephone pole line	37′	6″
Highway (center)	60′	0″
Telegraph pole line on RR r/w	97′	6″

Railroad Tracks (center)	138′	9″
Railroad Signal pole line	180′	0″

The total length of crossing span is 200 feet. Therefore, the clearance at 60°F of the private communications circuit above the telephone lead at point of crossing is obtained as follows:

Clearance point distance from Pole C is 37′ 6″.

At 37′ 6″, or 18.8% of the span, the sag is equivalent to 61% of the center sag (see Chart No. 9 on Page C–14), or 0.61 x 11 = 7″ sag.

Therefore, the clearance equals:

28′ 4″ - (7″ + 24′) = 3′ 9″ clearance.

The minimum required clearance as given in Table 2, Case 3, Column C is 2 feet.
In a like manner the clearances, at 60°F, of the private communication circuit conductors at the other points of crossing are as follows:

Points of crossing	Clearances		Minimum by Rule	
Highway (center)	27′	7″	18′	0″
Telegraph pole line	3′	5″	2′	0″
Railroad Tracks (center)	27′	7″	25′	0″
Railroad Signal pole line	6′	0″	2′	0″

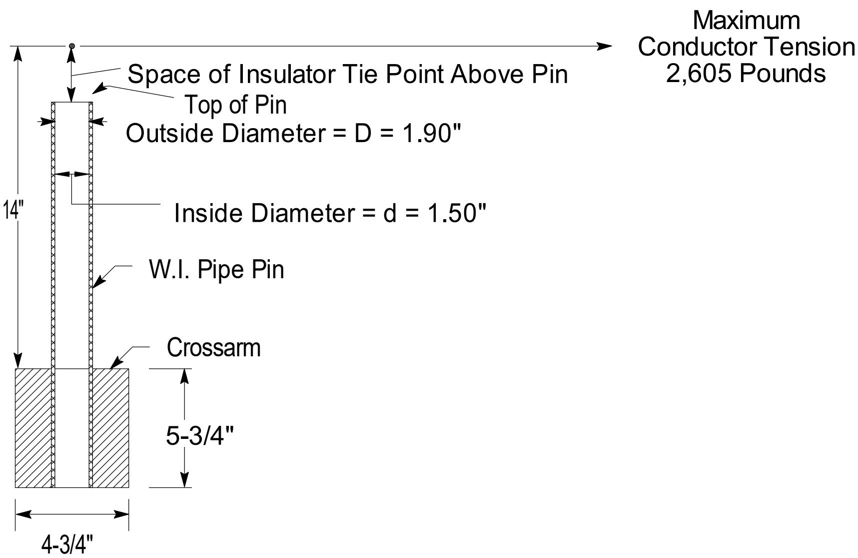
6. Insulators

In addition to the electrical requirements set forth in Rules 55 and 104, the insulators supporting the supply and communication conductors shall have safety factors (mechanical) of 3 and 2, respectively.

7. Pins, Ties and Conductor Fastenings

Ties used in connection with pin–type insulators shall conform to Rule 49.3. In this problem a No. 4 and No. 8 annealed copper wire are used for the No. 00 and No. 8 circuits involved.

Pins used in connection with pin–type insulators shall have sufficient strength to withstand the tension in the conductor. In the case under discussion wrought iron pipe–pins of the dimensions and construction indicated below are to be employed for the power conductors.



Bending moment (at crossarm) M = 2,605 x 14 = 36,470 pound–inches

$\cancel{\text{Section Modulus E} = \frac{11D^4 - d^4}{32D}}$

Section Modulus E = $\frac{\pi(D^4 - d^4)}{32D}$ =

$\cancel{0.0982 \times \frac{1.90^4 - 1.50^4}{1.90} = .0412 \text{ inch}^3}$

$\cancel{\text{Fiber stress S} = \frac{M}{E} = \frac{36470}{0.412} = 88500 \text{ pounds per square inch}}$

~~Assuming that the ultimate fiber stress of wrought iron is 48,000 pounds per square inch, a single pin is not sufficient, as it provides a safety factor of 0.542,~~

$\cancel{\left(\frac{48000}{88500} = 0.542\right)}$

$$0.0982 \times \frac{(1.90^4 - 1.50^4)}{1.90} = 0.412 \text{ in}^3$$

$$\text{Stress S} = \frac{M}{E} = \frac{36470}{0.412} = 88500 \text{ psi}$$

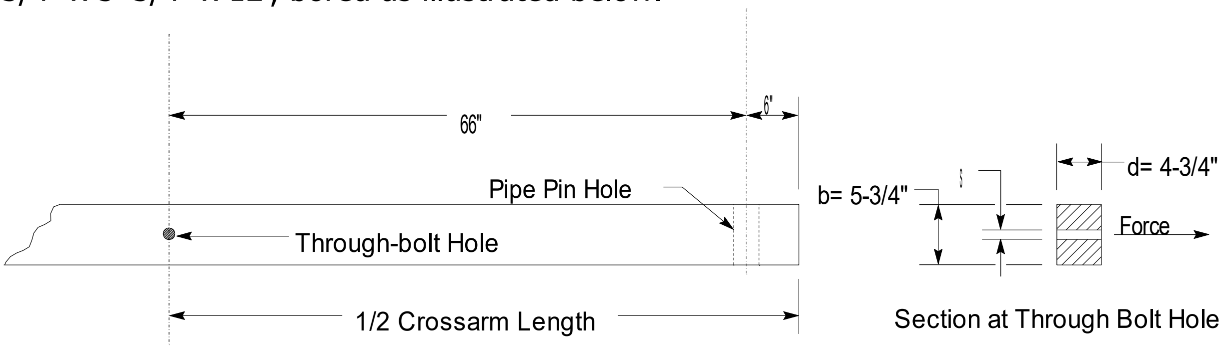
~~for an assumed tension of 2,605 pounds in the conductor at maximum loading.~~
Since ~~a safety factor of unity (Rule 47.3)~~ the stress in the pin (88,500 psi) at maximum loading must not exceed the strength of the pin (48,000 psi) is required by Rule 47.3, two pins are necessary and therefore double crossarms, pins and insulators are used on the poles supporting the crossing span.

Locust pins are to be used in this case for the private telephone conductors. Although a 1–1/2 inch locust pin would be sufficient to withstand the conductor tension of 570 pounds with a safety factor of at least unity, as required by Rule 47.2, care would be necessary to provide sufficient strength in the conductor fastenings. In this problem, the private telephone conductors are considered to be dead–ended at the ends of the crossing span.

8. Crossarms–Horizontal Loads

Power Circuits

The point of maximum bending moment will be at the crossarm through bolt attaching the arm to the pole, at which point the cross section of the arm is reduced by the amount of the bolt hole. Crossarms supporting the 60 kV wires are to be Douglas fir, dense, dimensions 4–3/4″ x 5–3/4″ x 12′, bored as illustrated below.



The section through the arm and the method of computing the fiber stress is shown below. Note: for simplicity this example only assesses weak axis bending stress on the crossarm, there may be other load effects that should be assessed.

Long–time loading: Since longitudinal conductor loads are normally balanced, long–time horizontal loading of the power circuit crossarms need not be considered.

Single arm, Maximum loading, 25°F and an 8 ~~lb~~ psf wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

$$\text{Section modulus} = \frac{bd^2}{6} \text{ where}$$

b = 5.75″ – 0.69 = 5.06″
d = 4.75″
s = 11/16″ = 0.69″

$$\cancel{\text{Section modulus} = \frac{5.06 \times 4.75^2}{6} = 19.0 \text{ inches}^3}$$

$$\text{Section modulus} = \frac{5.06 \times 4.75^2}{6} = 19.0 \text{ in}^3$$

Fiber Stress = Bending moment divided by

$$\cancel{\text{Section modulus} = \frac{171930}{19.0} = 9050 \text{ lbs per square inch}}$$

$$\text{Section modulus} = \frac{171930}{19.0} = 9050 \text{ psi}$$

As the ~~allowable~~ value for ~~modulus of rupture~~ designated fiber strength in bending under maximum loading conditions is ~~6,300 lbs per sq. in.~~ 7,800 psi (see ~~Table 5, Rule 48.1~~ ANSI O5.3 2008), a single crossarm of the size chosen provides a ~~safety factor~~ strength of only ~~0.70 for~~ 0.86 of the assumed load effects at maximum loading conditions, whereas the provisions of Rule 47.3 ~~require a safety factor of unity~~ do not allow a strength less than the effects of the load. Double arms will, therefore, be used in this problem to meet the strength requirements applicable to crossarms at end supports of crossings. Double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently.

Maximum loading, 25°F and an 8 ~~lb~~ psf wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

Single arm section modulus (same as previously calculated) = 19.0 inches^3
Double arm section modulus = 19.0 x 2 x 1.3 = 49.4 inches^3

~~Fiber stress =~~ $\cancel{\frac{171930}{49.4}}$ ~~= 3840 lbs per square inch~~

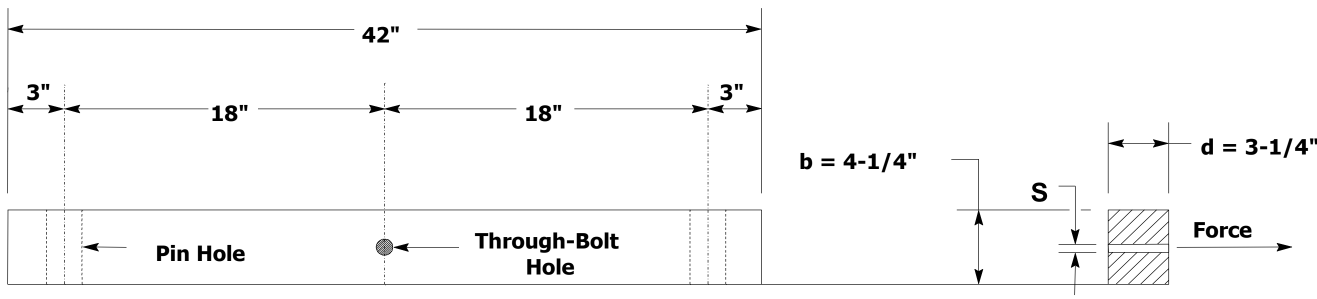
~~As the allowable modulus of rupture for short–time loading is 6,300 lbs per sq. in. then the double crossarms under these conditions will provide a safety factor of 1.91, which meets the unity safety factor required by Rule 47.3.~~

Fiber stress = $\frac{171930}{49.4}$ = 3840 psi

Hence the fiber stress in the double crossarm (3,840 psi) at maximum loading (25°F, 8 psf wind) does not exceed the designated fiber strength of the crossarm (7,800 psi), as required by Rule 47.3.

Private Communication Circuit

At the crossing span, double crossarms are used on account of dead–end construction due to change of conductor size. Current practice provides for this method of construction although a single arm has sufficient strength as is found ~~form~~ from the following calculations of modulus of rupture under the two limiting conditions of loading:



Section At Through Bolt Hole

Long–time loading, 60°F and no wind

Bending moment = 448 x 18 = 8,064 pound–inches

$\cancel{\text{Section modulus} = \frac{bd^2}{6} = \frac{3.56 \times 3.25^2}{6} = 6.26 \text{ inches}^3}$

$\text{Section modulus} = \frac{bd^2}{6} = \frac{3.56 \times 3.25^2}{6} = 6.26 \text{ in}^3$

where d = 3.25″
s = 0.69″
b = 4.25″ – 0.69″ = 3.56″

$$\text{Fiber stress} = \frac{8064}{6.26} = 1290 \text{ pounds per square inch}$$

The ~~allowable~~ value for ~~modulus of rupture~~ designated fiber strength for long-time loading in bending ~~is 0.55 x 6,300 = 4,465 pounds per square inch and therefore with a single arm the factor of safety under conditions of long–time loading is 2.69~~ (Rule 48.1: ANSI O5.3 2008) is 0.55 x 7,800 = 4,290 psi.

Hence, the fiber stress in the single crossarm (1,290 psi) at maximum loading (25°F, 8 psf wind) does not exceed the long-time strength of the crossarm (4,290 psi), as required by Rule 47.3.

Maximum Loading

Bending moment = 570 x 18 = 10,260 pound–inches
Section modulus = 6.26 inches^3 (as per calculations above)

$$\cancel{\text{Fiber stress} = \frac{10260}{6.26} = 1640 \text{ pounds per square inch}}$$

$$\text{Fiber stress} = \frac{10260}{6.26} = 1640 \text{ psi}$$

The ~~allowable~~ value for ~~modulus of rupture~~ designated fiber strength in bending, under maximum loading conditions, is ~~6,300 pounds per sq. in~~ 7,800 psi (ANSI O5.3 2008).~~, therefore a single arm provides a safety factor of 3.84 under these maximum loading conditions.~~

Hence, the fiber stress in the single crossarm (1,640 psi) at maximum loading (25°F, 8 psf wind) does not exceed the designated fiber strength of the crossarm (7,800 psi), as required by Rule 47.3.

9. Crossarms - Vertical Loads

Power Circuits

The vertical load on crossarms, where supports are approximately at the same elevation, is due to the vertical load of conductors in each adjacent span plus ~~200~~ 300 pounds at the outer pin position. In the problem under consideration, the conductor supports on the crossing poles (C and D) are at the same elevation, and the supports at the adjacent poles (B and E) are 4.5 feet lower in elevation, which difference in elevation is greater than the normal sag. Then the conductor loading on a crossing span support would be one–half the weight of the conductor of the crossing span plus one–half the conductor weight of a hypothetical span, the curve of which passes through the points of support.

Half the length of the hypothetical span may be calculated as follows:

$$X = \frac{D}{2} + \frac{hT}{Dw}$$

Where

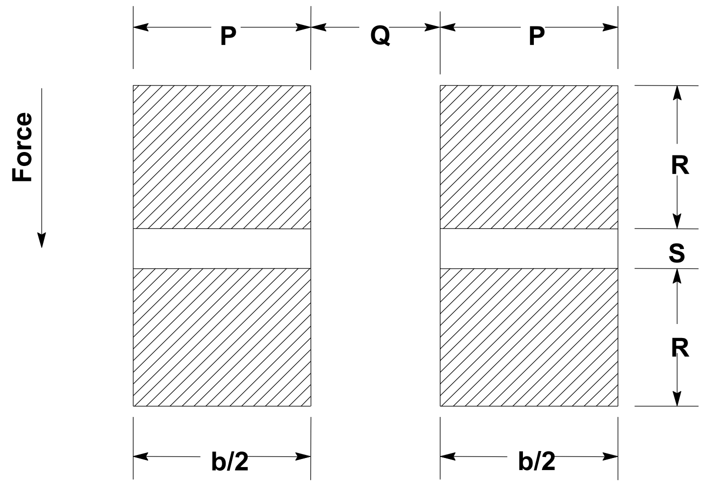
X = 1/2 the hypothetical span in feet.
D = horizontal distance between supports in feet.
h = difference in elevation of supports in feet.
T = conductor tension in pounds.
w = weight of conductor in pounds per foot.

The total crossing support–load is calculated as follows:

$$\cancel{0.411 \text{ x } \frac{200}{2} + 0.411\left(\frac{150}{2} + \frac{4.5 \text{ x } 2074}{150 \text{ x } 0.411}\right) + 200 = 334 \text{ pounds}}$$

$$0.411 \text{ x } \frac{200}{2} + 0.411\left(\frac{150}{2} + \frac{4.5 \text{ x } 2074}{150 \text{ x } 0.411}\right) + 300 = 434 \text{ pounds}$$

The bending moment is: ~~334 x 66 = 22,040~~ 434 x 66 = 28,640 pound–inches



The method of calculating the unit fiber stress of the double crossarms acting as a simple beam is as follows:

$$\text{Section modulus} = \frac{b}{6} \times \frac{d^3 - d_1{}^3}{d} \quad \text{where}$$

$b = P + P = 9.50''$
$d = R + S + R = 5.75''$
$d_1 = S = 0.69''$

~~Section modulus=~~ ~~$\frac{9.50}{6}\left(\frac{5.75^3 - 0.69^3}{5.75}\right) = \frac{9.50}{6} \times \frac{189.8}{5.75} = 52.3$ inches^3~~

~~Fiber stress=~~ ~~$\frac{\text{Bending moment}}{\text{Section modulus}} = \frac{22040}{52.3} = 420$ lbs per square inch~~

Section modulus= $\frac{9.50}{6}\left(\frac{5.75^3 - 0.69^3}{5.75}\right) = \frac{9.50}{6} \times \frac{189.8}{5.75} = 52.3\ \text{in}^3$

Fiber stress= $\frac{\text{Bending moment}}{\text{Section modulus}} = \frac{28640}{52.3} = 550$ psi

Long–Time Loading

~~As the allowable modulus of rupture in bending is 0.55 x 6,300 lbs per sq. in. or 3,465 lbs per sq. in. (see Table 5), the double crossarms of the size chosen provide a safety factor of 8.2.~~

The designated fiber strength for long-time loading in bending (Rule 48.1: ANSI O5.3 2008) is 0.55 x 7,800 psi or 4,290 psi. The effects of the load (550 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the long-time strength of the crossarm (4,290 psi) multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

$$550 \text{ psi} \times 1.5 \leq 4{,}290 \text{ psi} \times 0.75$$

or

$550 \text{ psi} \le 4{,}290 \text{ psi}/(1.5/0.75) = 4{,}290 \text{ psi}/2.0 = 2{,}145 \text{ psi}$

Hence, the crossarms are more than adequate.

The fiber stress in the double crossarms of the private telephone circuit, similarly calculated, is found to be ~~196 lbs per sq. in. These arms obviously meet the strength requirements for vertical loads on crossarms~~ less than the required strength.

Shear, compression and torsion stresses are not considered in this problem as they are negligible and likewise the effect of reduction of cross section due to bolt holes is not considered except for the through bolt holes.

10. Poles

The crossing poles are western red cedar and their dimensions are as follows:

Length	55 feet
Height above ground	48 feet
Circumference at top	28 inches
Diameter at top	8.9 inches
Circumference at ground line	49.0 inches
Diameter at ground line	15.6 inches

Distance from ground line to conductors supported is given as follows:

Top supply conductors	48′ 9″
Middle supply conductors	43′ 3″
Lower supply conductors	37′ 9″
Private telephone conductors	28′ 4″

Ground level at base of pole is considered to be at the same elevation as top of rail.

Dimensions of adjacent poles B and E are:

Length	50 feet
Height above ground	43.5 feet
Circumference of top	28 .0 inches
Diameter of top	8.9 inches
Circumference at ground line	47.0 inches
Diameter at ground line	15.0 inches

11. Transverse Load on Crossing Poles C and D

The moment at the ground due to an 8 ~~pound~~ psf wind pressure on conductors is:

$$Mc = Ln\ P_h\left(\frac{S_1 + S_2}{2}\right) \text{ pound–feet}$$

Where:

L	=	Height of conductors above ground in feet
n	=	Number of wires
S_1 and S_2	=	Length of crossing and adjacent spans, respectively
P_h	=	Horizontal load per lineal foot due to an 8 ~~pound~~ psf wind pressure on projected area of wire
P_h	=	0.276 pounds per lineal foot for 00 AWG bare, stranded copper
	=	0.108 pounds per lineal foot for 6 AWG bare, solid copper
	=	0.085 pounds per lineal foot for 8 AWG bare, solid copper
M_{c0}	=	Moment due to pressure on top supply conductors
M_{c1}	=	Moment due to pressure on middle supply conductors
M_{c2}	=	Moment due to pressure on lower supply conductors
M_{c3}	=	Moment due to pressure on telephone conductors

$$M_{C0}=48.75 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=4710 \text{ lb-feet}$$

$$M_{C1}=43.25 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=4180 \text{ lb-feet}$$

$$M_{C2}=37.75 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=3650 \text{ lb-feet}$$

$$M_{C3}=28.33 \text{ x } 2 \text{ x } 0.108 \text{ x } \left(\frac{200}{2}\right)=610 \text{ lb-feet}$$

$$M_{C3}=28.33 \text{ x } 2 \text{ x } 0.085 \text{ x } \left(\frac{150}{2}\right)=360 \text{ lb-feet}$$

Total Moment due to Wind pressure on conductors = 13,510 lb-feet

The moment at the ground due to an 8 ~~pound~~ psf wind pressure on the pole is:

$$M_P=PH^2\left(\frac{D_1+2D_2}{72}\right) \text{ pound-feet}$$

Where:

M_p	=	Moment due to wind pressure on pole
P	=	Pressure in lbs per sq. ft. on projected area of pole (8 ~~lbs/sq. ft~~psf.)
H	=	Height of pole above ground in feet (48′)
D_1	=	Diameter of pole at ground in inches (15.6″)
D_2	=	Diameter of pole at top in inches (8.9″)

$$\cancel{M_P=\frac{8\ 48^2 \text{ x } 15.6+2 \text{ x } 8.9}{72}=8550 \text{ lb-ft.}}$$

$$M_P=\frac{8 \text{ x } 48^2 \text{ x } (15.6+2 \text{ x } 8.9)}{72}=8550 \text{ lb-ft.}$$

Total moment = 13,510 + 8,550 = 22,060 lb–ft.

Moment of resistance of pole = $M=\frac{FI}{c}$

Where:

F = Fiber stress in pounds ~~per sq. in.~~psi

I = Moment of inertia of section $= \frac{\pi D_1^4}{64x12}$

c = Distance from neutral axis to outer fiber $= \frac{D_1}{2}$

$$M = \frac{\pi F D_1^3}{384} = \frac{F D_1^3}{122}$$

$$\cancel{F = \frac{122M}{D_1^3} = \frac{122 \times 22060}{15.6^3} = 710 \text{ lbs per square inch}}$$

$$F = \frac{122M}{D_1^3} = \frac{122 \times 22060}{15.6^3} = 710 \text{ psi}$$

~~The allowable fiber stress for western red cedar poles to provide a factor of safety of 4 is 1,500 pounds per sq. in., hence the crossing poles are not required to be side guyed since they have a factor of safety of 8.5 for transverse load.~~

The effects of the load (710 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

$$710 \text{ psi} \times 1.5 \leq 6{,}000 \text{ psi} \times 0.375$$

or

$$710 \text{ psi} \leq 6{,}000 \text{ psi} /(1.5/0.375) = 6{,}000 \text{ psi}/4.0 = 1{,}500 \text{ psi}$$

Hence the crossing poles are not required to be side guyed.

12. Side Guying

If side guying were required for the crossing poles C and D the method of computing the same would be as follows:

Side guys are designed to take the entire transverse load of the pole, the pole acting merely as a strut.

The transverse force acting on the poles will be due to wind pressure on poles C and D and the transverse wind pressure on the conductors supported. The length of conductor used in computing this transverse force will be equal to one–half the distance between the guyed poles C and D, plus one–half the length of the span adjacent to these poles.

The total wind pressure is computed as follows:

On Conductors

$$3 \times 2 \times 0.276 \times \frac{150 + 200}{2} = 289.8 \text{ pounds}$$

$$2 \times 0.108 \times \frac{200}{2} = 21.6 \text{ pounds}$$

$$2 \times 0.085 \times \frac{150}{2} = 12.8 \text{ pounds}$$

On Pole

$$\cancel{\frac{D_1 + D_2 HP}{24} = \frac{15.6 + 8.91\ 48 \times 8}{24} = 392.2 \text{ pounds}}$$

Total Wind Pressure = 716.4 pounds

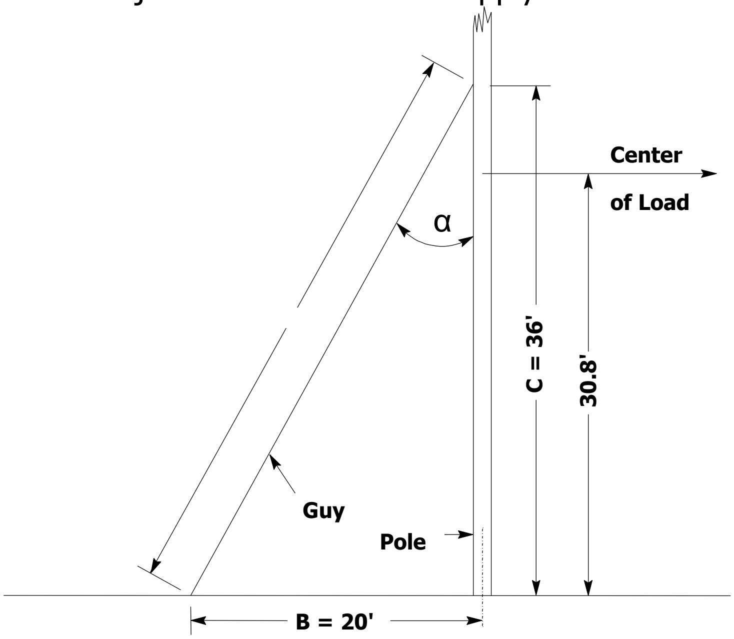
$$\frac{(D_1 + D_2)\, H \times P}{24} = \frac{(15.6 + 8.91)\ 48 \times 8}{24} = 392.2 \text{ pounds}$$

Total Wind Pressure = 716.4 pounds

The total moment on the poles is the same as developed for "Transverse load on poles" which was 22,060 pound–feet.

$$\frac{22060}{716.4} = 30.8 \text{ feet above ground}$$

A side guy could not be attached at this center of load and provide the required clearances from the communication line; therefore, for construction purposes the guy is assumed attached just below the lowest supply crossarm at a distance of 36 feet above ground.



Let M_t = Total moment on pole = 22,060 pound–feet
C = Height of guy attachment above ground = 36 feet (assumed)
B = Distance of guy anchor from base of pole = 20 feet
T = Tension in guy wire in pounds
A = Length of guy = $\sqrt{(20^2 + 36^2)} = 41.2\, feet$

$\sqrt{20^2 + 36^2} = 41.2$ feet

$$T = \frac{M_2}{C \sin \alpha}$$

$$Sin\alpha = \frac{B}{A} where$$

2. $A = \sqrt{B^2 + C^2}$

$$Sin\alpha = \frac{20}{\sqrt{20^2 + 36^2}} = 0.485$$

$$T=\frac{22060}{36 \times 0.485}=1260 \text{ pounds}$$

~~The specified safety factor for guys (Table 4, Rule 44.1) is 2 and, therefore, a guy having an ultimate strength of not less than 2,520 pounds is required. One 1/4 inch Siemens–Martin or a 5/16 inch common galvanized–steel strand would meet the requirements for transverse load.~~ The effects of the load (1,260 lbs) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the guy multiplied by the strength factor of 0.75 (Table 4-2). For example, for a 5/16 common galvanized steel strand for which Table 24 indicates the strength is 3,200 lbs, it is required that

$$1{,}260 \text{ lbs} \times 1.5 \le 3{,}200 \text{ lbs} \times 0.75$$

or

$$1{,}260 \text{ lbs} \le 3{,}200 \text{ lbs} /(1.5/0.75) = 3{,}200 \text{ lbs} /2.0 = 1{,}600 \text{ lbs}$$

Hence, one 5/16 inch common galvanized–steel strand would meet the requirements for transverse load. One 1/4 inch Siemens–Martin (3,150 lbs, Table 24) would also meet the requirements.

13. Longitudinal Load on Crossing Poles C and D

Rule 47.3 provides that the strength of the crossing structures shall withstand at all times ~~with a safety factor of unity~~ the unbalanced stress due to the combined pull toward the crossing of one–third of the total number of conductors supported, the pull in each such conductor being taken as the tension due to the specified loading.

~~Number of conductors involved $= \frac{8}{3} =$ 2-2/3 ;use3~~

Number of conductors involved $= \frac{8}{3} =$ 2-2/3 ;use 3

Location of conductors resulting in maximum load - two on top arm and one on next arm below

Bending moment:

2 x 2,605 x 48.75 = 254,000 pound–feet

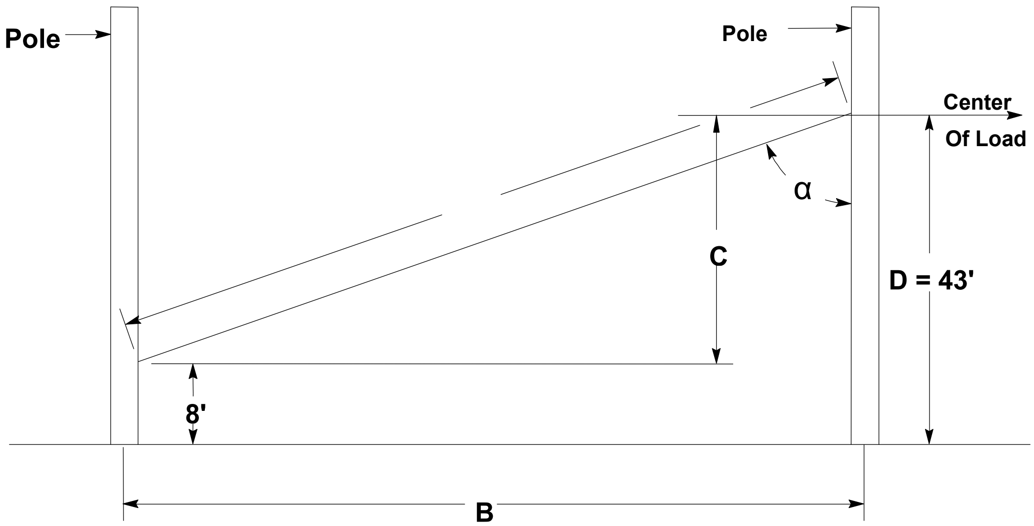
1 x 2,605 x 43.25 = 112,600 pound–feet

Total Moment = 366,600 pound–feet

~~Fiber stress~~ $\cancel{= \frac{122M}{D_1^3} = 122 \times \frac{366600}{15.6^3}}$ ~~=11780 lbs per square inch~~

Fiber stress $= \frac{122M}{D_1^3} = 122 \times \frac{366600}{15.6^3} =$ 11780 psi

The ~~allowable value of modulus of rupture~~ fiber stress is greater than the designated fiber strength under this load is 6,000 ~~lbs per square inch~~ psi, hence poles C and D must be head guyed for longitudinal load.



The head guy should be attached approximately at the normal center of load, therefore:

The bending moment under full longitudinal load would be:

48.75 x 2 x 2,605	=	254,000 pound–feet
43.25 x 2 x 2,605	=	225,300 pound–feet
37.75 x 2 x 2,605	=	196,700 pound–feet
28.33 x 2 x 570	=	32,300 pound–feet
Total moment	=	708,300 pound–feet

The total longitudinal load would be:

3(2 x 2,605)	=	15,630 pounds
2 x 570	=	1,140 pounds
Total wire tensions	=	16,770 pounds

Therefore, the center of longitudinal load is:

$$D=\frac{\text{Longitudinal Bending Moment}}{\text{Longitudinal Load}}$$

$$=\frac{708300}{16770}=42.2 \text{ feet load center above ground}$$

Use 43 feet (to avoid contact with arm)

B = 150 feet

C = 43 - 8 = 35 feet *

$$A=\sqrt{B^2 + C^2}=\sqrt{(43)^2 + (150)^2}=156.0$$

$$Sin\alpha = \frac{B}{A} = \frac{150}{156.0} = 0.962$$

* Lower end of guy assumed 8 feet above ground on Poles A and E.

A guy attached at a point 43 feet above ground on pole C or D and at a point 8 feet above ground on pole B or E, respectively, would be required to withstand a load of:

$$\frac{366000}{43 \text{ x } 0.962}=8860 \text{ pounds}$$

In this case, a 9/16 inch common, 7/16 inch Siemens–Martin, or 3/8 inch high–strength guy strand would meet the requirements of Rule ~~47.5~~47.3. The horizontal load transmitted to pole B or E by such a head guy would be:

8,860 x sin α = 8,860 x 0.962 = 8,520 pounds

The longitudinal moment on pole B and E would be:

8,520 x 8 = 68,160 pound–feet

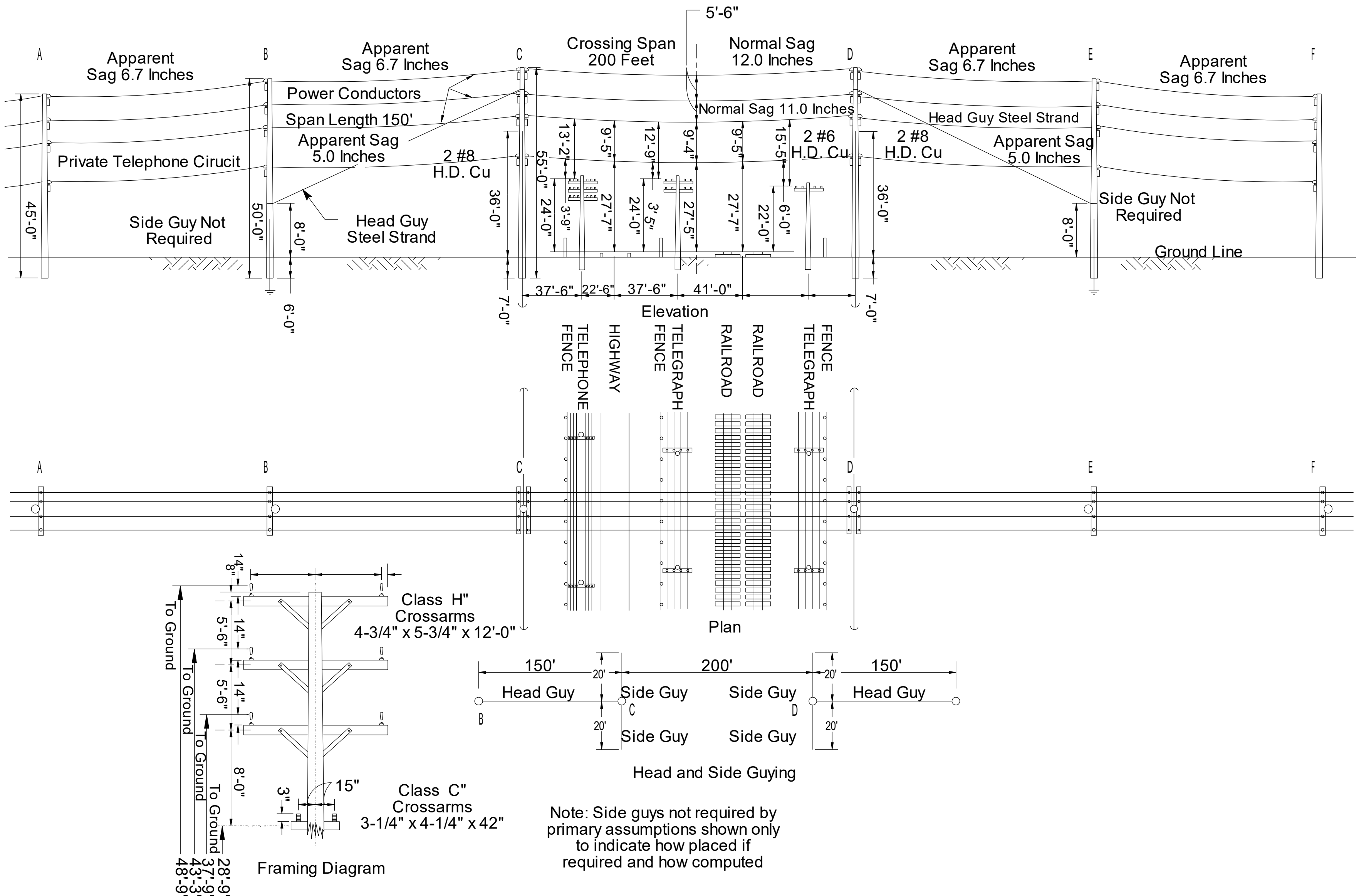
and the fiber stress developed in pole B or E by the tension of ~~9,070~~ 8,520 pounds in the head guy would be:

~~$F=\frac{122M}{D_1^3}=\frac{122 \times 68160}{15.0^3}$=2460 pounds per square inch~~

$F=\frac{122M}{D_1^3}=\frac{122 \times 68160}{15.0^3}$=2460 psi

Poles B and E would, therefore, be adequate to hold the contemplated guy tension ~~with a safety factor of unity~~ since the effects of the loads do not exceed the strength as required by Rule ~~47.5~~47.3.

Crossing of Class H" Supply Line Over Major Railroad and Major Communication Lines



Part 2

Deadend Problem

It is the object of this problem to indicate the construction requirements for a typical deadend structure, since the longitudinal stresses imposed upon such a structure differ substantially from those on a pole on which the conductors supported are normally balanced. The deadend structure considered herein is assumed to support an 11,000 volt circuit, a 4,000 volt circuit and two secondary circuits. It is also assumed that the deadend pole takes Grade "A" construction by virtue of its location.

The deadend structure diagram and dimensions are shown ~~on Page F-23~~at the end of Part 2. The primary data chosen for this structure are as follows:

Data For Deadend Structure

Supply Conductors

11 kV circuit	3 #0 AWG Stranded, hard–drawn copper
4 kV circuit	4 #2 AWG Stranded, hard–drawn copper
120/240 volt circuit	3 #4 AWG Solid, hard–drawn copper
120/240 volt circuit	3 #2 AWG Stranded, hard–drawn copper

Insulators - Strain Type (to conform to Rule 49.5).
Conductor fastenings (to meet the safety factor of Table 4, Rule 44.1)

Crossarms:

11 kV circuit	Douglas fir 4–3/4" x 5–3/4" x 8'–0"
4 kV circuit	Douglas fir 4–3/4" x 4–3/4" x 7'–8"
Secondary circuits	Douglas fir 4–3/4" x 4–3/4" x 7'–0"

Crossarm braces (to conform to Rule 48.2 and 49.8)
Pole - western red cedar.
Pole dimensions: 55' in length; 25" top circumference; 50" ground line circumference (ground line diameter 15.9").

Construction Requirements

1. Conductor Tensions

It is assumed that the conductors are strung with the minimum sags specified in sag curves of Appendix C, hence the tension values at ~~60 F~~ 60ºF and no wind (normal tensions) are 35% of the ultimate tensions shown in Table 18. These tensions for each of the conductor sizes and corresponding tensions at maximum loading (~~25 F~~ 25ºF and wind of 8 ~~pounds~~psf) are as follows, where span length is 250 feet:

	Tension–Pounds	
	35% of Ultimate	At Maximum Loading
#O AWG Stranded, hard–drawn copper	1,664	2,125
#2 AWG Stranded, hard–drawn copper	1,065	1,360
#4 AWG Solid, hard–drawn copper	690	890

2. Crossarms

Spacings assumed are shown on the pole framing diagram ~~on Page F–23~~ at the end of Part 2. Double crossarms of Douglas fir, dense, are employed for each of the four different circuits.

Computations of the fiber stresses imposed upon the various crossarms by the unbalanced wire loads of conductors in the physical configuration shown on the diagram are made in accordance with the method outlined in Part 1 to show these stresses under the conditions of long–time loading and maximum loading. Furthermore, double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently. The stresses computed in this manner are:

	Fiber Stress - ~~lbs per Sq. In.~~ psi	
	Long–Time Loading	Maximum Loading
Top crossarms	1,412	1,804
Second ~~C~~crossarms	1,598	2,040
Third crossarms	932	1,202
Fourth crossarms	1,438	1,811

~~Since a factor of safety of 2 permits a maximum stress of modulus of rupture in bending of 1,732 lbs per square inch.~~

$$\cancel{\left(\frac{6300 \times 0.55}{2}\right) = 1732}$$ ~~under the conditions of long-time loading (60° F and no Wind) and 3150 lbs per square inch~~ $\cancel{\left(\frac{6300}{2}\right)}$ ~~at maximum loading see Table 5, the crossarms chosen are satisfactory.~~

The second crossarm is subject to the greatest loading, for which effects of the load (1,598 psi long-time and 2,040 psi maximum) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the crossarm (Rule 48.1: ANSI O5.3 2008: 7,800 psi maximum or 0.55 x 7,800 psi = 4,290 psi long-time) multiplied by the strength factor of 0.75 (Table 4-2); or it is required that

1,598 psi x 1.5 ≤ 4,290 psi x 0.75

or

1,598 psi ≤ 4,290 psi /(1.5/0.75) = 4,290 psi/2.0 = 2,145 psi

and

2,040 psi x 1.5 ≤ 7,800 psi x 0.75

or

2,040 psi ≤ 7,800 psi /(1.5/0.75) = 7,800 psi/2.0 = 3,900 psi

Hence, all the crossarms chosen are satisfactory.

3. Pole (See ~~Page F–23~~Diagram at End of Part 2)

~~Rule 44 provides that poles supporting unbalanced longitudinal loads in Grade "A" construction shall have a safety factor of 4 against such loads.~~ Rule 47 specifies that guys may be used to support unbalanced longitudinal loads ~~shall have a safety factor of 2 for all grades of construction~~ with the load and strength factors provided in Rule 44. (Where guys are used they must take the entire load with the ~~designated safety~~ load factors (Table 4-1) and strength factors (Table 4-2) applied and~~,~~ the pole being considered merely as a strut).

Using the values given above for tensions at maximum loading, the following moments due to dead ending the conductors are obtained:

3 x 2,125 x 47.3	=	301,500 pound–feet
4 x 1,360 x 38.3	=	208,400 pound–feet
3 x 890 x 30.3	=	80,900 pound–feet
3 x 1,360 x 25.3	=	103,200 pound–feet
Total Moments	=	694,000 pound–feet

The total deadend ~~stress~~ load, using the tension values for maximum loading given above, will be:

3 x 2,125	=	6,380 pounds
4 x 1,360	=	5,440 pounds
3 x 890	=	2,670 pounds
3 x 1,360	=	4,080 pounds
Total	=	18,570 pounds

$$\text{Center of load} = \frac{694000}{18570} = 37.4 \text{ feet above ground}$$

The tension (T) of a single guy with a lead to height ratio of 1 to 1 (assumed), or a 45º angle, and a safety factor of 2 would be:

$$\boxed{\cancel{T = \frac{\text{safety factor X total load}}{\cos \Theta} = \frac{2 \times 18570}{\cos \Theta} = 52500 \text{ pounds}}}$$

T = total load/COS(45º) = 18,570 lbs/0.707 = 26,265 lbs

The effects of the load (26,265 lbs) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the guy multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

26,265 lbs x 1.5 ≤ strength x 0.75

or

strength ≥ 26,265 lbs x 1.5/0.75 = 26,265 lbs x 2.0 = 52,530 lbs

A stranded guy attached at the center of load could be used provided the allowable fiber stress of the pole is not exceeded. The stress due to guying at this point would be as follows:

The center of load (37.4' above ground) would be

9.9 ft. (118.8″) below the top conductors (11 kV) and
0.9 ft. (10.8″) below the second crossarm (4 kV)

The fiber stress in the pole at the center of load due to the tension in the conductors above the center of load is computed as follows:

Bending moment	3 x 2,125 x 118.8	=	757,400 pound–inches
	1,360 x 10.8	=	8,800 pound–inches
Total moment		=	16,200 pound–inches

The section modulus of a solid circular section is $E = \frac{\pi\ d^3}{32} = 0.0982 d^3$

The diameter of the pole at the center of load is d = 9.7 inches

Then, E = 0.0982 x $(9.7)^3$ = 89.6~~" ^{3}~~ in^3

~~Fiber stress =~~ $\cancel{\frac{\text{Bending Moment}}{\text{Section modulus}} = \frac{816200}{89.6}}$ ~~=9110 lbs per sq in~~

Fiber stress = $\frac{\text{Bending Moment}}{\text{Section modulus}} = \frac{816200}{89.6}$ =9110 psi

~~Since a pole in Grade "A" construction must have a safety factor of 4, the allowable value of fiber stress would be 5,600/4 = 1,400 pounds per square inch; therefore, the pole cannot be guyed by a single guy but can be guyed as illustrated on Page F-23.~~

The effects of the load (9,110 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

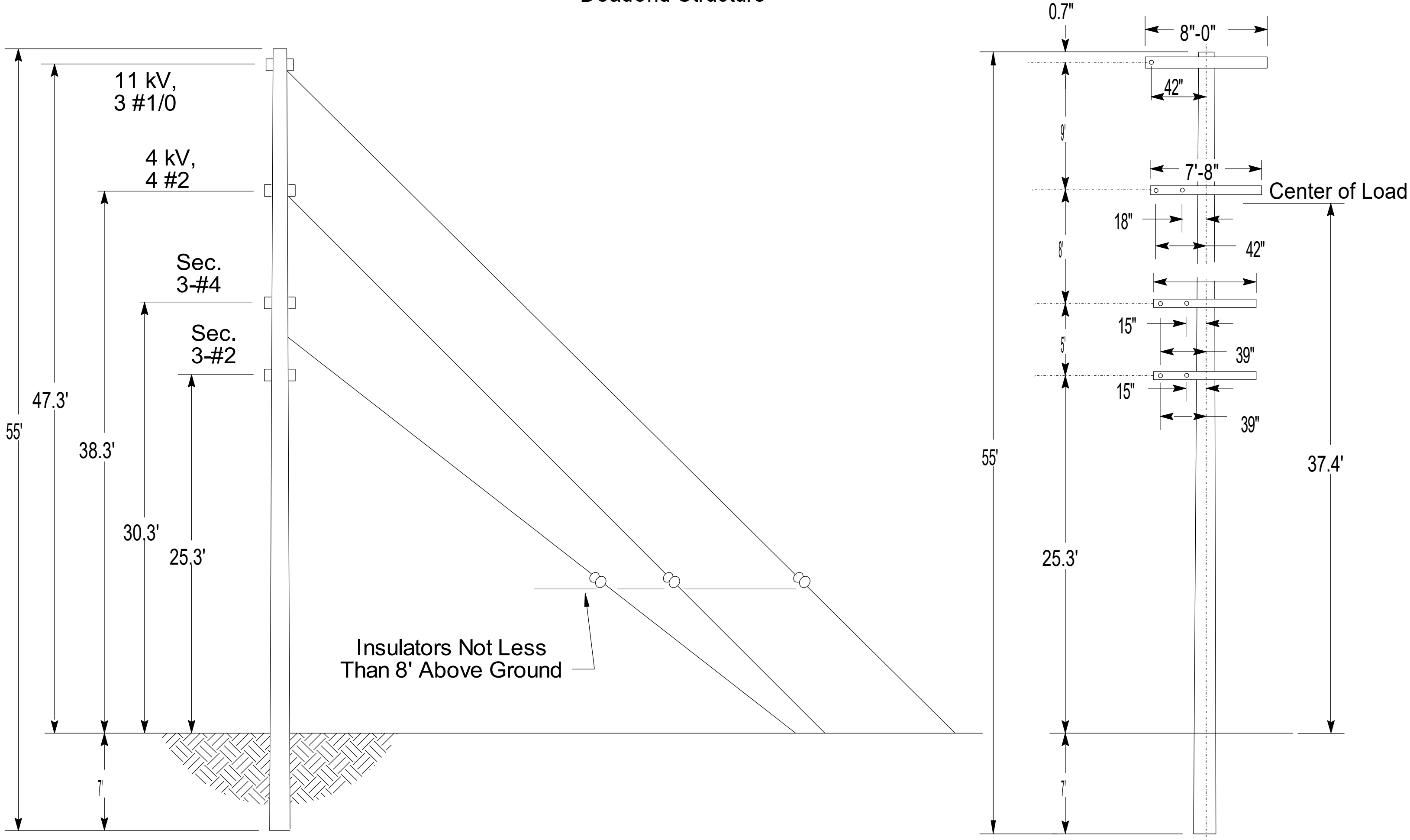
9,110 psi x 1.5 ≤ 6,000 psi x 0.375

or

9,110 psi ≤ 6,000 psi /(1.5/0.375) = 6,000 psi/4.0 = 1,500 psi

which condition is not satisfied. Hence, the pole cannot be guyed by a single guy but can be guyed as illustrated in the diagram of the deadend structure.

Deadend Structure



Part 3
Angle Pole Problem – Methods ~~O~~of Providing Proper Strength ~~F~~for Unbalanced Conductor Loads ~~A~~at Angle Poles

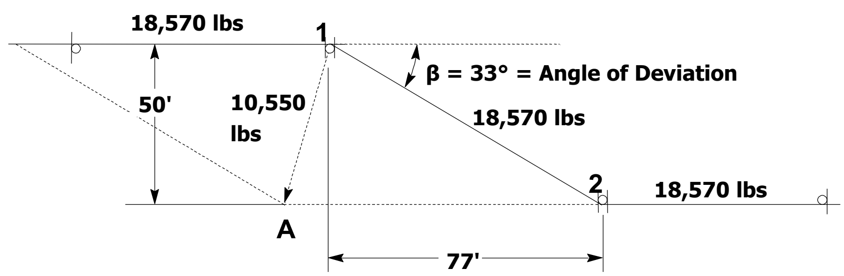
To maintain poles in proper position at angles and corners, it is generally necessary to use guys or some other form of pole bracing. Unless the line is dead–ended, the pull of the conductors is taken as being the same throughout the line.

The degree of unbalanced pull at an angle or corner pole is dependent upon the angle in the line at that point; that is, the greater the angle in the line, the greater is the magnitude of unbalance. Rule 47 specifies that ~~when the longitudinal loads in a structure are not normally balanced,~~ where there is a change in the direction of conductors and messengers, transverse load shall be calculated as the resultant of all tensions under the assumed loading conditions. ~~t~~The members stressed shall be of such strength, using guys if necessary, as to withstand the total unbalanced load with load and strength factors ~~of safety~~ equal to those of ~~Table 4~~ Rule 44.. ~~As it~~ It is assumed that the line considered in this problem is Grade "A" construction. ~~, the pole would be required to provide a safety factor of 4 against unbalanced loads; where guys are used to take the unbalanced loads they must provide a safety factor of 2.~~

It is assumed that the line discussed in the foregoing deadend problem crosses from one side of a street to the opposite side, that the longitudinal distance along the street between the two poles concerned is 77 feet, and that the angle of deviation is 33° (see sketch). This would result in an unbalanced force being exerted in the direction of A of

$$18570x2Sin\frac{\beta}{2} = 18570x2x0.2840 = 10550\,pounds$$

Methods of Guying Angle Poles



Force Diagram

Assuming the pole height and framing as shown in Part 2, the top circumference of pole to be 25", the ground circumference to be 50" and the center of load to be 37.4 feet above ground line (as determined in Part 2), the fiber stress on the pole at the ground line is as follows:

Bending moment, M = 37.4 x 10,550 = 394,400 pound–feet

$$\text{Fiber stress} = \frac{122M}{d^3}$$

where circumference = 50” and d = 15.9”

~~Fiber stress =~~ $\cancel{\frac{122 \times 349400}{15.9^3}}$ ~~= 11970 lbs square inch~~

~~As a safety factor of 4 is required, the allowable working stress is~~ $\cancel{\frac{5600}{4}}$ ~~or 1,400 lbs per square inch, and therefore the use of guys is necessary.~~

$$\text{Fiber stress} = \frac{122 \times 349400}{15.9^3} = 11970 \text{ psi}$$

The effects of the load (11,970 psi) multiplied by the load factor of 1.5 (Table 4-1), for the assumed Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

$$11{,}970 \text{ psi} \times 1.5 \leq 6{,}000 \text{ psi} \times 0.375$$

or

$$11{,}970 \text{ psi} \leq 6{,}000 \text{ psi} /(1.5/0.375) = 6{,}000 \text{ psi}/4.0 = 1{,}500 \text{ psi}$$

which condition is not satisfied. Hence, even without the additional horizontal load due to wind loading (Rule 43), it is clear the pole must be guyed to support the transverse loading.

A single guy attached at the center of load could be used provided the ~~modulus of rupture with a safety factor of 4 is not exceeded~~ effects of the load at the point of guying do not exceed the required strength of the pole. The stress due to guying at this point is as follows:

Bending moments

$$Toparm = 3x2125x118.8x2\sin\frac{\beta}{2} = 430200\,pound - inches$$

$$Secondarm = 4x1370x10.8x2\sin\frac{\beta}{2} = 33400\,pound - inches$$

Total moment=463600 pound-inches

Section modulus, E

The section modulus (E) at 37.4 feet above ground is 89.6 ~~inches cubed~~ in^3, which is the value computed in ~~Problem 2~~ the example in Part 2.

Fiber stress:

The fiber stress is

~~$F=\frac{M}{E}=\frac{463600}{89.6}=5170$ pounds per square inch~~

~~Since this stress exceeds the allowable stress of 1,400 lbs per sq. in. for the pole,~~

$F=\frac{M}{E}=\frac{463600}{89.6}=5170$ psi

The effects of the load (11,970 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

$5{,}170 \text{ psi} \times 1.5 \leq 6{,}000 \text{ psi} \times 0.375$

or

$5{,}170 \text{ psi} \leq 6{,}000 \text{ psi} /(1.5/0.375) = 6{,}000 \text{ psi}/4.0 = 1{,}500 \text{ psi}$

which condition is not satisfied. Hence, it is necessary to place guys at more than one point on the pole, and therefore, they are attached at positions similar to the guys shown in the diagram ~~on Page F-23~~ at the end of Part 2.

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Appendix F
Typical Problems

The application of line construction requirements specified in this Order is exemplified in the following:

Part 1. Crossing Problem–A Class H and a Class C circuit Crossing over a major railroad, major Class C circuits and a highway.

Part 2. Deadend Problem–H and Class L circuits at a dead end.

Part 3. Angle Pole Problem–Guying a pole supporting Class H and Class L circuits at angles in lines.

The problems are computed on the assumptions of light loading conditions (Rule 43.2), with Grade "A" construction used for the power circuits and Grade "C" construction used for the communication circuits except in the crossing spans where Grade "B" is required. The construction details specified in these Typical Problems are made to conform to current good practice.

This edition of GO 95 replaces the use of "safety factors" with "load factors" (Table 4-1) and "strength factors" (Table 4-2). The ratios of the load factors in Table 4-1 to the strength factors in Table 4-2 correspond to equivalent minimum safety factors as indicated in Rule 44. In some cases, there are slight differences due to rounding the results of the calculations. The equivalent minimum safety factors are provided in Table F-1 (Table 4) which matches the minimum safety factors in Table 4 from previous editions of GO 95. Table F-1 (Table 4), previously referred to as Table 4, is referenced in Appendix F for historical purposes, and so other General Orders which incorporate Table 4 may continue to reference Table 4.

Table F-1 (Table 4) Minimum Safety Factors

Line Element	Grades of Construction		
	Grade "A"	Grade "B"	Grade "C"
Conductors, splices and conductor fastenings (other than tie wires)	2	2	2
Pins	2	2	2
Pole line hardware	2	2	2
Line Insulators (mechanical)	3	2	2
Guy insulators (mechanical)			
Interlocking	2	2	2
Noninterlocking glass fiber	3	2 (a)	2 (b)
Guys	2	2	2
Messengers and span wires	2	2	2
Foundations against uplift	1.5	1.5	1.5
Foundations against depression	3	2	2
Poles, Towers and Structures			
Wood	4	3	2
Metal (including elements of foundations)	1.5 (c)	1.25 (c)	1.25 (c)
Reinforced concrete	4	3	3
Prestressed or post-tensioned concrete	1.8	1.5	1.5
Other engineered materials	1.5	1.25	1.25
Crossarms			
Wood	2	2	2
Metal (c)	1.5 (c)	1.25 (c)	1.25 (c)
Prestressed Concrete	1.8	1.5	1.5
Other engineered materials	1.5	1.25	1.25

(d) Insulators are to be replaced before safety factors have been reduced (due to deterioration or changes in construction, arrangement, or other conditions subsequent to installation) to less than 95 percent of the safety factor specified in Rule 44.1.

(e) Insulators are to be replaced before safety factors have been reduced (due to deterioration or changes in construction, arrangement, or other conditions subsequent to installation) to less than 75 percent of the safety factor specified in Rule 44.1.

(f) For aluminum members subject to tension caused by one or more estimated loads and where the critical load combination for the tension member would not endanger adjacent compression members, the safety factor on ultimate tension shall be 2 for Grade “A” and 1.67 for Grades “B” and “C” construction.

Crossing Problem

A diagram including dimensions is shown at the end of Part 1. The data chosen for the crossing follow:

Data of Crossing

Circuits

Two 3–phase 60,000 Volt power circuits. One metallic private Class "C" telephone circuit.

Configuration

Power conductors of each circuit are in vertical planes on opposite ends of the crossarm. Private telephone circuit is in a horizontal plane.

Conductors

Power circuits are six No. 00 AWG, bare, stranded, hard–drawn copper. Private telephone circuit is two No. 8 AWG, bare, solid, hard–drawn copper, except in the crossing span where it is two No. 6 AWG, bare, solid, hard-drawn copper.

Insulators

Porcelain, pin type, meeting the requirements of Rule 49.5–A.

Ties

Annealed copper wire to comply with Rules 49.3–B and 49.3–C.

Pins

Power circuits–wrought iron pipe (extra strong), 1–1/2″ x 18–1/2″, to comply with Rules 49.3–B and 49.3C. Assumed bonded in accordance with the requirements of Rule 53.4.

Communication circuit - 1–1/2″ x 9″ locust.

Crossarms

Power circuits–Douglas fir (dense), 4–3/4″ x 5–3/4″ x 12′, 1.9″ pin holes, 11/16″ hole for through bolt.

Communication circuit–Douglas fir (dense), 3–1/4″ x 4–1/4″ x 42″, l–l/2″ pin holes, 11/16″ hole for through bolt.

Crossarm Braces

Meeting the requirements of Rule 49.2–C.

Poles

Western red cedar, round, butt treated.

Span Length

Crossing span, 200 feet.

Adjacent spans, 150 feet.

Construction Requirements

1. Conductor Sags and Tensions

The conductors are assumed to be strung so that at normal conditions of 60°F and no wind the tension will be 35% of the ultimate tension of the conductors. From Chart No. 1, Page C–6, it will be seen that under these conditions the No. 00 AWG conductor, for a 200 foot span, will have a sag of 1.0 foot (0.99 when calculated), and the No. 6 AWG conductor will have a sag of 0.90 foot (0.89 when calculated). These sags may be calculated by means of the following approximation formula:

$$\text{Sag}=\frac{wd^2}{8T}$$

Where w = conductor loading, pounds per lineal foot
d = span length, feet
T = assumed allowable conductor tensions at 60°F and no wind

For No. 00 AWG conductor

$$Sag=\frac{0.4109 \times 200^2}{8 \times 2074} = 0.99 \text{ Foot}$$

For No 6 AWG conductor

$$Sag=\frac{0.0795 \times 200^2}{8 \times 448} = 0.89 \text{ Foot}$$

Maximum conductor load to be met with load and strength factors applied as specified in Rule 44.1 will occur at the conditions of 25°F and an 8 pounds per square foot (psf) wind (Rule 43.2). Conductors which have been strung at the normal conditions stated above (60°F, no wind, and 35% ultimate tension) will have sags and tensions at the maximum loading conditions of 25°F and an 8 psf wind as indicated below. Maximum conductor sags will occur at the condition of maximum temperature, 130°F and also are shown in the following tabulation:

	#00 AWG (Power)		#6 AWG (Comm)	
	Sag (Feet)	Tension (Pounds)	Sag (Feet)	Tension (Pounds)
Ultimate Conductor Tension (See Appendix B, Table 18)	-	5,925	-	1,280
35% Ultimate at 60°F, No Wind	0.99	2,074	0.89	448
25°F, 8 psf Wind	0.95	2,605	1.18	570
130°F, No Wind	1.78	1,157	1.55	256

The tension in the supply conductors (2,605 lbs) at maximum loading (25°F, 8 psf wind), multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the conductors (5,925 lbs) multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

$$2{,}605 \text{ lbs} \times 1.5 \leq 5{,}925 \text{ lbs} \times 0.75$$

or

$$2{,}605 \text{ lbs} \leq 5{,}925 \text{ lbs} /(1.5/0.75) = 5{,}925 \text{ lbs} /2.0 = 2{,}962 \text{ lbs}$$

The tension in the communication conductors (570 lbs) at maximum loading (25°F, 8 psf wind), multiplied by the load factor of 1.25 (Table 4-1), for Grade B construction, must not exceed the strength of the conductors (1,280 lbs) multiplied by the strength factor of 0.625 (Table 4-2), or it is required that and

$$570 \text{ lbs} \times 1.25 \leq 1{,}280 \text{ lbs} \times 0.625$$

or

$$570 \text{ lbs} \leq 1{,}280 \text{ lbs} /(1.25/0.625) = 1{,}280 \text{ lbs} /2.0 = 640 \text{ lbs}$$

Hence, the tensions at maximum loading for both types of circuits are within the required limits.

Lesser sags than those shown above may be used, provided conductor tension, at maximum loading condition specified in Rule 43does not exceed 50% of the ultimate tension of the conductor. The rules, of course, do not prevent the use of greater sags than are calculated above.

2. Conductor Clearance from Center Line of Pole

Minimum clearances specified in Table 1, Case 8 and Rule 54.4–D2 and the clearances assumed for the purposed of this problem are as follows:

	Minimum	Used
60,000 Volt circuits	21.5″	5′ 6″
Communications circuit	15″	18″

3. Conductor Separation

Table 2, Case 12, Column H modified by Rule 54.4–C1c, permits a vertical separation of not less than 36 inches between the conductors of a 60,000 Volt circuit in vertical configuration. For this problem a separation of 5′6″ is used.

The minimum separation between the level of the lowest supply conductor and the communication circuit is 72 inches (Table 2, Case 8, Column H). For the problem, a separation of 96 inches between crossarm centers is used.

4. Clearances of Conductors Above Crossarms

The minimum clearance of a 60,000–volt conductor from the surface of a crossarm is required (by Table 1, Case 9, Column F) to be at least 1/4 of the pin spacing specified in Table 2, Case 15, Column H, which would be a minimum clearance of 9 inches. For this problem, an 18–1/2 inch pin is used which, with its insulator, places the conductor 14 inches above the crossarm.

5. Conductor Clearances Above Highway, Pole Lines and Railroad Tracks

The poles supporting the crossing span are 55 feet in length, set 7 feet (Rule 49.1C) in the ground. From dimensions of the pole framing diagram the distance of the private telephone circuit above ground is 28′ 4″. For this problem, a common elevation has been assumed for the ground line, the railroad tracks and the highway.

The sag of the communication conductors in the crossing span is approximately 11 inches at 60°F and 19 inches at 130° F. Since the allowable variation of 5% for temperature, applied to the ground clearance of 27′ 5″ (28′ 4″ - 11″), is 1′ 4″, which is greater than the difference between the sags at 60°F (11″) and at 130°F (19″), the clearances may be determined at 60°F for all conditions. In the crossing diagram, at the end of Part 1, the distances from supporting pole C to the various objects crossed over by the conductors are as follows:

Telephone pole line	37′	6″
Highway (center)	60′	0″
Telegraph pole line on RR r/w	97′	6″
Railroad Tracks (center)	138′	9″
Railroad Signal pole line	180′	0″

The total length of crossing span is 200 feet. Therefore, the clearance at 60°F of the private communications circuit above the telephone lead at point of crossing is obtained as follows:

Clearance point distance from Pole C is 37′ 6″.

At 37′ 6″, or 18.8% of the span, the sag is equivalent to 61% of the center sag (see Chart No. 9 on Page C–14), or 0.61 x 11 = 7″ sag.

Therefore, the clearance equals:

28′ 4″ - (7″ + 24′) = 3′ 9″ clearance.

The minimum required clearance as given in Table 2, Case 3, Column C is 2 feet. In a like manner the clearances, at 60°F, of the private communication circuit conductors at the other points of crossing are as follows:

Points of crossing	Clearances		Minimum by Rule	
Highway (center)	27′	7″	18′	0″
Telegraph pole line	3′	5″	2′	0″
Railroad Tracks (center)	27′	7″	25′	0″
Railroad Signal pole line	6′	0″	2′	0″

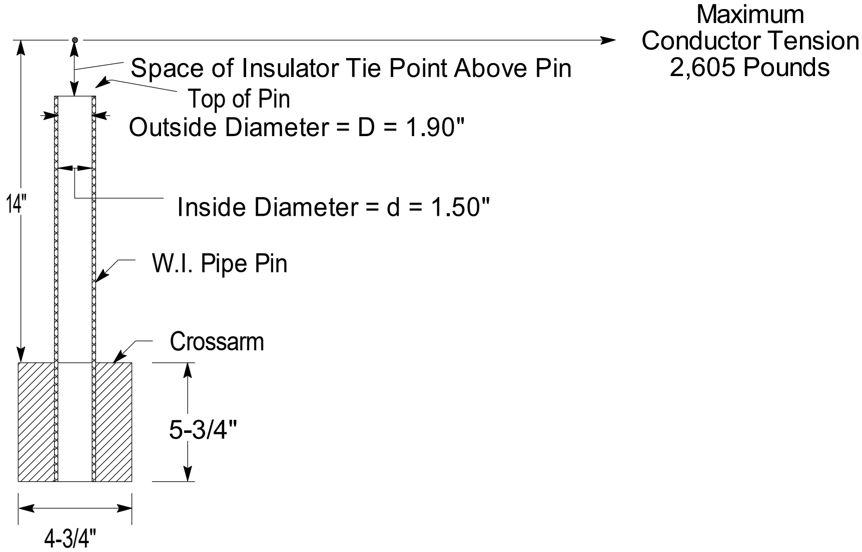
6. Insulators

In addition to the electrical requirements set forth in Rules 55 and 104, the insulators supporting the supply and communication conductors shall have safety factors (mechanical) of 3 and 2, respectively.

7. Pins, Ties and Conductor Fastenings

Ties used in connection with pin–type insulators shall conform to Rule 49.3. In this problem a No. 4 and No. 8 annealed copper wire are used for the No. 00 and No. 8 circuits involved.

Pins used in connection with pin–type insulators shall have sufficient strength to withstand the tension in the conductor. In the case under discussion wrought iron pipe–pins of the dimensions and construction indicated below are to be employed for the power conductors.



Bending moment (at crossarm) M = 2,605 x 14 = 36,470 pound–inches

$$\text{Section Modulus } E = \frac{\pi(D^4 - d^4)}{32D} =$$

$$0.0982 \times \frac{(1.90^4 - 1.50^4)}{1.90} = 0.412 \text{ in}^3$$

$$\text{Stress } S = \frac{M}{E} = \frac{36470}{0.412} = 88500 \text{ psi}$$

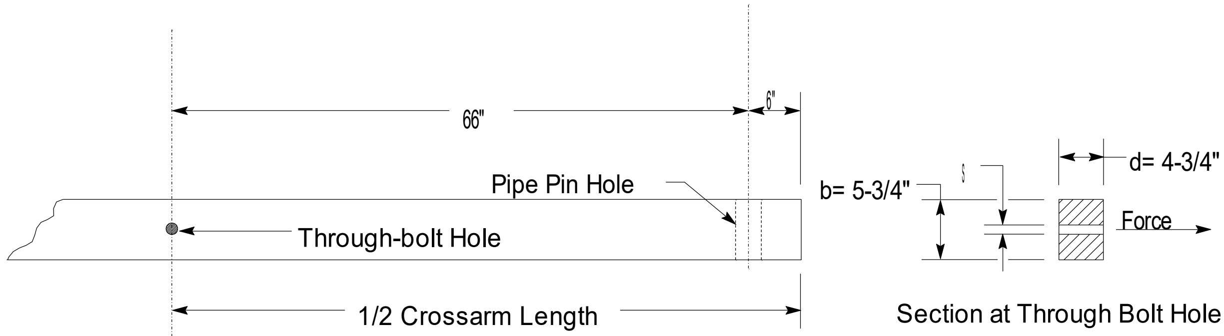
Since the stress in the pin (88,500 psi) at maximum loading must not exceed the strength of the pin (48,000 psi), is required by Rule 47.3, two pins are necessary and therefore double crossarms, pins and insulators are used on the poles supporting the crossing span.

Locust pins are to be used in this case for the private telephone conductors. Although a 1–1/2 inch locust pin would be sufficient to withstand the conductor tension of 570 pounds, as required by Rule 47.2, care would be necessary to provide sufficient strength in the conductor fastenings. In this problem, the private telephone conductors are considered to be dead–ended at the ends of the crossing span.

8. Crossarms–Horizontal Loads

Power Circuits

The point of maximum bending moment will be at the crossarm through bolt attaching the arm to the pole, at which point the cross section of the arm is reduced by the amount of the bolt hole. Crossarms supporting the 60 kV wires are to be Douglas fir, dense, dimensions 4–3/4″ x 5–3/4″ x 12′, bored as illustrated below.



The section through the arm and the method of computing the fiber stress is shown below. Note: for simplicity this example only assesses weak axis bending stress on the crossarm, there may be other load effects that should be assessed.

Long–time loading: Since longitudinal conductor loads are normally balanced, long–time horizontal loading of the power circuit crossarms need not be considered.

Single arm, Maximum loading, 25°F and an 8 psf wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

Section modulus = $\frac{bd^2}{6}$ where

b = 5.75″ – 0.69 = 5.06″
d = 4.75″
s = 11/16″ = 0.69″

Section modulus = $\frac{5.06 \times 4.75^2}{6}$ = 19.0 in^3

Fiber Stress = Bending moment divided by

Section modulus = $\frac{171930}{19.0}$ = 9050 psi

As the value for designated fiber strength in bending under maximum loading conditions is 7,800 psi (see ANSI O5.3 2008), a single crossarm of the size chosen provides a strength of only 0.86 of the assumed load effects at maximum loading conditions, whereas the provisions of Rule 47.3 do not allow a strength less than the effects of the load . Double arms will, therefore, be used in this problem to meet the strength requirements applicable to crossarms at end supports of crossings. Double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently.

Maximum loading, 25°F and an 8 psf wind

Bending moment = 2,605 x 66 = 171,930 pound–inches

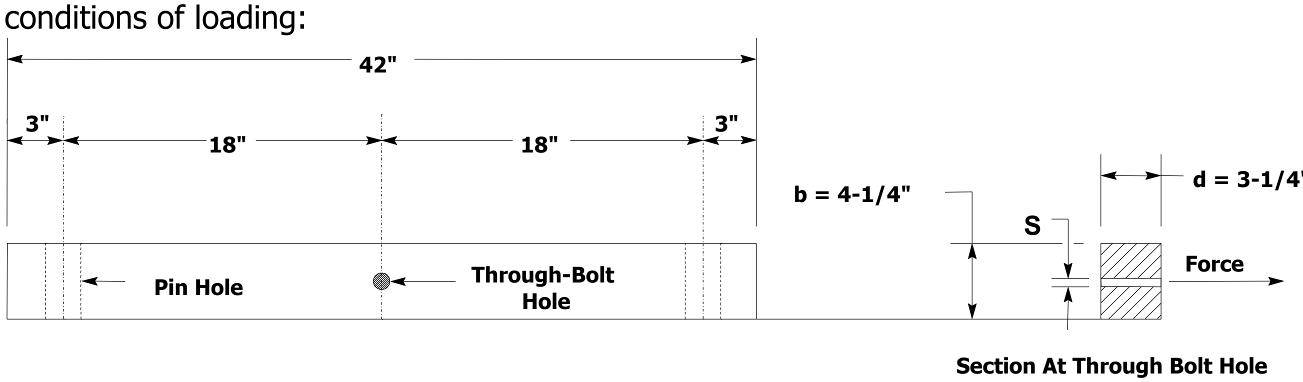
Single arm section modulus (same as previously calculated) = 19.0 in^3
Double arm section modulus = 19.0 x 2 x 1.3 = 49.4 in^3

$$\text{Fiber stress} = \frac{171930}{49.4} = 3840 \text{ psi}$$

Hence the fiber stress in the double crossarm (3,840 psi) at maximum loading (25°F, 8 psf wind) does not exceed the designated fiber strength of the crossarm (7,800 psi), as required by Rule 47.3.

Private Communication Circuit

At the crossing span, double crossarms are used on account of dead–end construction due to change of conductor size. Current practice provides for this method of construction although a single arm has sufficient strength as is found from the following calculations of modulus of rupture under the two limiting conditions of loading:



Long–time loading, 60°F and no wind

Bending moment = 448 x 18 = 8,064 pound–inches

$$\text{Section modulus} = \frac{bd^2}{6} = \frac{3.56 \times 3.25^2}{6} = 6.26 \text{ in}^3$$

where d = 3.25”

$s = 0.69''$
$b = 4.25'' - 0.69'' = 3.56''$

$$\text{Fiber stress} = \frac{8064}{6.26} = 1290 \text{ pounds per square inch (psi)}$$

The value for designated fiber strength for long-time loading in bending (Rule 48.1: ANSI O5.3 2008) is 0.55 x 7,800 = 4,290 psi.
Hence, the fiber stress in the single crossarm (1,290 psi) at maximum loading (25°F, 8 psf wind) does not exceed the long-time strength of the crossarm (4,290 psi), as required by Rule 47.3.

Maximum Loading

Bending moment = 570 x 18 = 10,260 pound–inches
Section modulus = 6.26 inches^3 (as per calculations above)

$$\text{Fiber stress} = \frac{10260}{6.26} = 1640 \text{ psi}$$

The value for designated fiber strength in bending, under maximum loading conditions, is 7,800 psi (ANSI O5.3 2008).

Hence, the fiber stress in the single crossarm (1,640 psi) at maximum loading (25°F, 8 psf wind) does not exceed the designated fiber strength of the crossarm (7,800 psi), as required by Rule 47.3.

9. Crossarms - Vertical Loads

Power Circuits

The vertical load on crossarms, where supports are approximately at the same elevation, is due to the vertical load of conductors in each adjacent span plus 300 pounds at the outer pin position. In the problem under consideration, the conductor supports on the crossing poles (C and D) are at the same elevation, and the supports at the adjacent poles (B and E) are 4.5 feet lower in elevation, which difference in elevation is greater than the normal sag. Then the conductor loading on a crossing span support would be one–half the weight of the conductor of the crossing span plus one–half the conductor weight of a hypothetical span, the curve of which passes through the points of support.

Half the length of the hypothetical span may be calculated as follows:

$$X = \frac{D}{2} + \frac{hT}{Dw}$$

Where

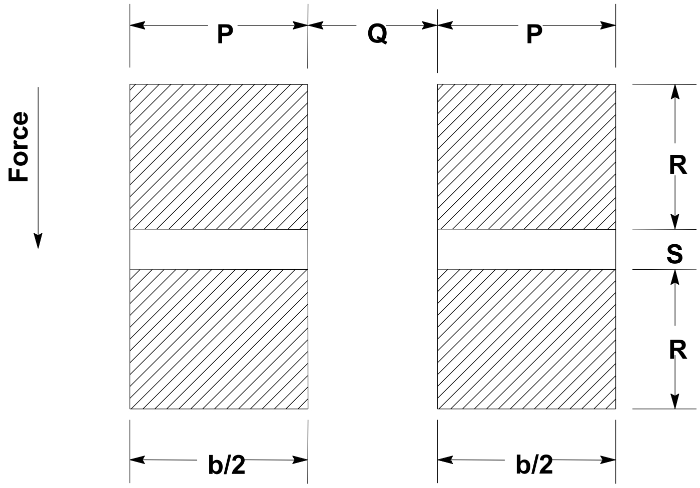
X = 1/2 the hypothetical span in feet.
D = horizontal distance between supports in feet.
h = difference in elevation of supports in feet.

T = conductor tension in pounds.
w = weight of conductor in pounds per foot.

The total crossing support–load is calculated as follows:

$$0.411 \text{ x } \frac{200}{2} + 0.411 \left(\frac{150}{2} + \frac{4.5 \text{ x } 2074}{150 \text{ x } 0.411}\right) + 300 = 434 \text{ pounds}$$

The bending moment is: 434 x 66 = 28,640 pound–inches



The method of calculating the unit fiber stress of the double crossarms acting as a simple beam is as follows:

$$\text{Section modulus} = \frac{b}{6} \times \frac{d^3 - d_1^3}{d} \text{ where}$$

$b = P + P = 9.50''$
$d = R + S + R = 5.75''$
$d_1 = S = 0.69''$

$$\text{Section modulus} = \frac{9.50}{6}\left(\frac{5.75^3 - 0.69^3}{5.75}\right) = \frac{9.50}{6} \times \frac{189.8}{5.75} = 52.3 \text{ in}^3$$

$$\text{Fiber stress} = \frac{\text{Bending moment}}{\text{Section modulus}} = \frac{28640}{52.3} = 550 \text{ psi}$$

Long–Time Loading

The designated fiber strength for long-time loading in bending (Rule 48.1: ANSI O5.3 2008) is 0.55 x 7,800 psi or 4,290 psi. The effects of the load (550 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the long-time strength of the crossarm (4,290 psi) multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

$$550 \text{ psi} \times 1.5 \leq 4{,}290 \text{ psi} \times 0.75$$

or

$$550 \text{ psi} \leq 4{,}290 \text{ psi}/(1.5/0.75) = 4{,}290 \text{ psi}/2.0 = 2{,}145 \text{ psi}$$

Hence, the crossarms are more than adequate.

The fiber stress in the double crossarms of the private telephone circuit, similarly calculated, is found to be less than the required strength.

Shear, compression and torsion stresses are not considered in this problem as they are negligible and likewise the effect of reduction of cross section due to bolt holes is not considered except for the through bolt holes.

10. Poles

The crossing poles are western red cedar and their dimensions are as follows:

Length	55 feet
Height above ground	48 feet
Circumference at top	28 inches
Diameter at top	8.9 inches
Circumference at ground line	49.0 inches
Diameter at ground line	15.6 inches

Distance from ground line to conductors supported is given as follows:

Top supply conductors	48′ 9″
Middle supply conductors	43′ 3″
Lower supply conductors	37′ 9″
Private telephone conductors	28′ 4″

Ground level at base of pole is considered to be at the same elevation as top of rail.

Dimensions of adjacent poles B and E are:

Length	50 feet
Height above ground	43.5 feet
Circumference of top	28 .0 inches
Diameter of top	8.9 inches
Circumference at ground line	47.0 inches
Diameter at ground line	15.0 inches

11. Transverse Load on Crossing Poles C and D

The moment at the ground due to an 8 psf wind pressure on conductors is:

$$Mc = Ln\ P_h\left(\frac{S_1 + S_2}{2}\right) \text{ pound–feet}$$

Where:

L	=	Height of conductors above ground in feet
n	=	Number of wires
S_1 and S_2	=	Length of crossing and adjacent spans, respectively
P_h	=	Horizontal load per lineal foot due to an 8 psf wind pressure on projected area of wire
P_h	=	0.276 pounds per lineal foot for 00 AWG bare, stranded copper
	=	0.108 pounds per lineal foot for 6 AWG bare, solid copper
	=	0.085 pounds per lineal foot for 8 AWG bare, solid copper
M_{c0}	=	Moment due to pressure on top supply conductors
M_{c1}	=	Moment due to pressure on middle supply conductors
M_{c2}	=	Moment due to pressure on lower supply conductors
M_{c3}	=	Moment due to pressure on telephone conductors

$$M_{c0}=48.75 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=4710 \text{ lb-feet}$$

$$M_{c1}=43.25 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=4180 \text{ lb-feet}$$

$$M_{c2}=37.75 \text{ x } 2 \text{ x } 0.276 \text{ x } \left(\frac{150+200}{2}\right)=3650 \text{ lb-feet}$$

$$AM_{c3}=28.33 \text{ x } 2 \text{ x } 0.108 \text{ x } \left(\frac{200}{E2}\right)=610 \text{ lb-feeEt}$$

$$M_{c3}=28.33 \text{ x } 2 \text{ x } 0.085 \text{ x } \left(\frac{150}{2}\right)=360 \text{ lb-feet}$$

Total Moment due to Wind pressure on conductors = 13,510 lb-feet

The moment at the ground due to an 8 psf wind pressure on the pole is:

$$M_P=PH^2\left(\frac{D_1+2D_2}{72}\right) \text{ pound-feet}$$

Where:

M_p	=	Moment due to wind pressure on pole
P	=	Pressure in psf. on projected area of pole (8 psf)
H	=	Height of pole above ground in feet (48′)
D_1	=	Diameter of pole at ground in inches (15.6″)
D_2	=	Diameter of pole at top in inches (8.9″)

$$M_P=\frac{8 \text{ x } 48^2 \text{ x } (15.6+2 \text{ x } 8.9)}{72} = 8550 \text{ lb-ft.}$$

Total moment = 13,510 + 8,550 = 22,060 lb–ft.

$$\text{Moment of resistance of pole} = M=\frac{FI}{c}$$

Where:

F = Fiber stress in psi

I = Moment of inertia of section $= \frac{\pi D_1{}^4}{64x12}$

c = Distance from neutral axis to outer fiber = $\frac{D_1}{2}$

$$M = \frac{\pi F D_1{}^3}{384} = \frac{F D_1{}^3}{122}$$

$$F = \frac{122M}{D_1{}^3} = \frac{122 \text{ x } 22060}{15.6^3} = 710 \text{ psi}$$

The effects of the load (710 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

710 psi x 1.5 ≤ 6,000 psi x 0.375

or

710 psi ≤ 6,000 psi /(1.5/0.375) = 6,000 psi/4.0 = 1,500 psi

Hence the crossing poles are not required to be side guyed.

12. Side Guying

If side guying were required for the crossing poles C and D the method of computing the same would be as follows:

Side guys are designed to take the entire transverse load of the pole, the pole acting merely as a strut.

The transverse force acting on the poles will be due to wind pressure on poles C and D and the transverse wind pressure on the conductors supported. The length of conductor used in computing this transverse force will be equal to one–half the distance between the guyed poles C and D, plus one–half the length of the span adjacent to these poles.

The total wind pressure is computed as follows:

On Conductors

$$3 \text{ x } 2 \text{ x } 0.276 \text{ x } \frac{150+200}{2} = 289.8 \text{ pounds}$$

$$2 \text{ x } 0.108 \text{ x } \frac{200}{2} = 21.6 \text{ pounds}$$

$$2 \text{ x } 0.085 \text{ x } \frac{150}{2} = 12.8 \text{ pounds}$$

On Pole

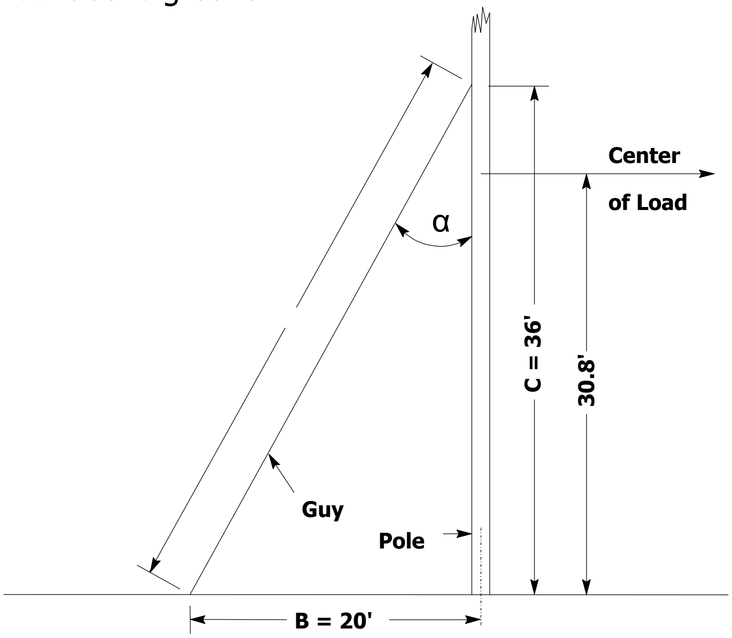
$$\frac{(D_1 + D_2)\ H \times P}{24} = \frac{(15.6 + 8.91)\ 48 \times 8}{24} = 392.2 \text{ pounds}$$

Total Wind Pressure = 716.4 pounds

The total moment on the poles is the same as developed for "Transverse load on poles" which was 22,060 pound–feet.

$$\frac{22060}{716.4} = 30.8 \text{ feet above ground}$$

A side guy could not be attached at this center of load and provide the required clearances from the communication line; therefore, for construction purposes the guy is assumed attached just below the lowest supply crossarm at a distance of 36 feet above ground.



Let	M_t	=	Total moment on pole = 22,060 pound–feet
	C	=	Height of guy attachment above ground = 36 feet (assumed)
	B	=	Distance of guy anchor from base of pole = 20 feet
	T	=	Tension in guy wire in pounds
	A	=	Length of guy = $\sqrt{(20^2 + 36^2)} = 41.2\, feet$

$\sqrt{20^2 + 36^2} = 41.2$ feet

$$T = \frac{M_2}{C \sin \alpha}$$

$$Sin\alpha = \frac{B}{A}\, where$$

3. $A = \sqrt{B^2 + C^2}$

$$Sin\alpha = \frac{20}{\sqrt{20^2 + 36^2}} = 0.485$$

$$T = \frac{22060}{36 \times 0.485} = 1260 \text{ pounds}$$

The effects of the load (1,260 lbs) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the guy multiplied by the strength factor of 0.75 (Table 4-2). For example, for a 5/16 common galvanized steel strand for which Table 24 indicates the strength is 3,200 lbs, it is required that

$$1{,}260 \text{ lbs} \times 1.5 \leq 3{,}200 \text{ lbs} \times 0.75$$

or

$$1{,}260 \text{ lbs} \leq 3{,}200 \text{ lbs} /(1.5/0.75) = 3{,}200 \text{ lbs} /2.0 = 1{,}600 \text{ lbs}$$

Hence, one 5/16 inch common galvanized–steel strand would meet the requirements for transverse load. One 1/4 inch Siemens–Martin (3,150 lbs, Table 24) would also meet the requirements.

13. Longitudinal Load on Crossing Poles C and D

Rule 47.3 provides that the strength of the crossing structures shall withstand at all times the unbalanced stress due to the combined pull toward the crossing of one–third of the total number of conductors supported, the pull in each such conductor being taken as the tension due to the specified loading.

Number of conductors involved $= \frac{8}{3} =$ 2-2/3 ;use 3

Location of conductors resulting in maximum load - two on top arm and one on next arm below

Bending moment:

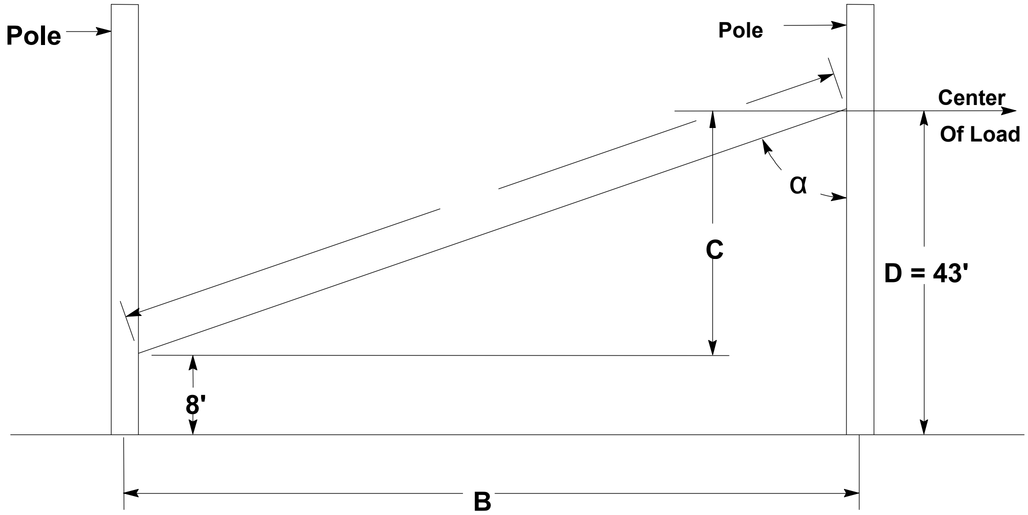
2 x 2,605 x 48.75 = 254,000 pound–feet

1 x 2,605 x 43.25 = <u>112,600</u> pound–feet

Total Moment = 366,600 pound–feet

$$\text{Fiber stress} = \frac{122M}{{D_1}^3} = 122 \times \frac{366600}{15.6^3} = 11780 \text{ psi}$$

The fiber stress is greater than the designated fiber strength of 6,000 psi, hence, poles C and D must be head guyed for longitudinal load.



The head guy should be attached approximately at the normal center of load, therefore:

The bending moment under full longitudinal load would be:

48.75 x 2 x 2,605	=	254,000 pound–feet
43.25 x 2 x 2,605	=	225,300 pound–feet
37.75 x 2 x 2,605	=	196,700 pound–feet
28.33 x 2 x 570	=	32,300 pound–feet
Total moment	=	708,300 pound–feet

The total longitudinal load would be:

3(2 x 2,605)	=	15,630 pounds
2 x 570	=	1,140 pounds
Total wire tensions	=	16,770 pounds

Therefore, the center of longitudinal load is:

$$D=\frac{\text{Longitudinal Bending Moment}}{\text{Longitudinal Load}}$$

$$=\frac{708300}{16770}=42.2 \text{ feet load center above ground}$$

Use 43 feet (to avoid contact with arm)
B = 150 feet
C = 43 - 8 = 35 feet *

$$A=\sqrt{B^2 + C^2}=\sqrt{(43)^2 + (150)^2}=156.0$$

$$Sin\alpha = \frac{B}{A} = \frac{150}{156.0} = 0.962$$

* Lower end of guy assumed 8 feet above ground on Poles A and E.

A guy attached at a point 43 feet above ground on pole C or D and at a point 8 feet above ground on pole B or E, respectively, would be required to withstand a load of:

$$\frac{366000}{43 \times 0.962}=8860 \text{ pounds}$$

In this case, a 9/16 inch common, 7/16 inch Siemens–Martin, or 3/8 inch high–strength guy strand would meet the requirements of Rule 47.3. The horizontal load transmitted to pole B or E by such a head guy would be:

8,860 x sin α = 8,860 x 0.962 = 8,520 pounds

The longitudinal moment on pole B and E would be:

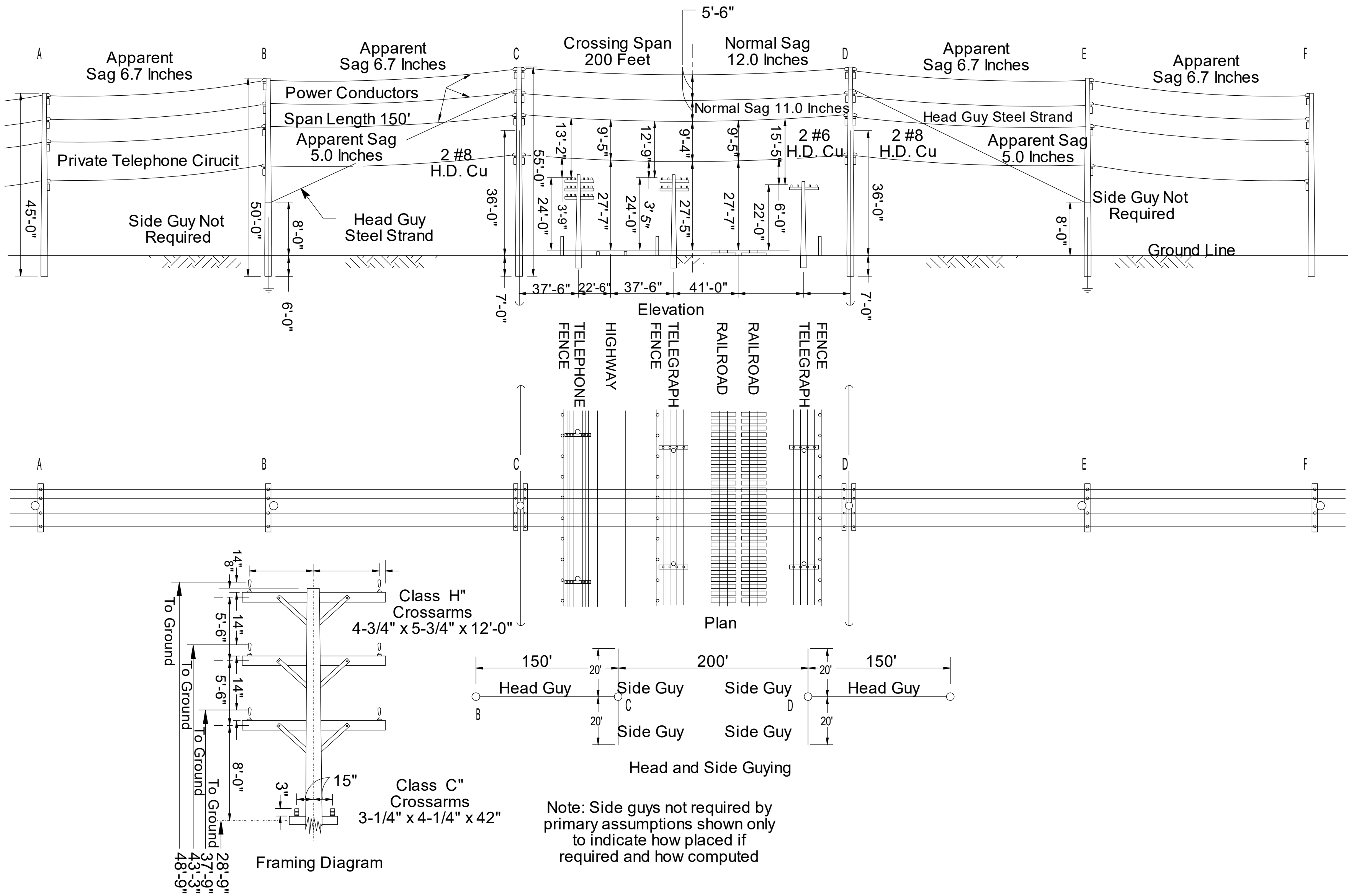
8,520 x 8 = 68,160 pound–feet

and the fiber stress developed in pole B or E by the tension of 8,520 pounds in the head guy would be:

$$F=\frac{122M}{D_1{}^3}=\frac{122 \times 68160}{15.0^3}=2460 \text{ psi}$$

Poles B and E would, therefore, be adequate to hold the contemplated guy tension since the effects of the loads do not exceed the strength-as required by Rule 47.3.

Crossing of Class H" Supply Line Over Major Railroad and Major Communication Lines



January 2020

Deadend Problem

It is the object of this problem to indicate the construction requirements for a typical deadend structure, since the longitudinal stresses imposed upon such a structure differ substantially from those on a pole on which the conductors supported are normally balanced. The deadend structure considered herein is assumed to support an 11,000 volt circuit, a 4,000 volt circuit and two secondary circuits. It is also assumed that the deadend pole takes Grade A construction by virtue of its location.

The deadend structure diagram and dimensions are shown at the end of Part 2. The primary data chosen for this structure are as follows:

Data For Deadend Structure

Supply Conductors

11 kV circuit	3 #0 AWG Stranded, hard–drawn copper
4 kV circuit	4 #2 AWG Stranded, hard–drawn copper
120/240 volt circuit	3 #4 AWG Solid, hard–drawn copper
120/240 volt circuit	3 #2 AWG Stranded, hard–drawn copper

Insulators - Strain Type (to conform to Rule 49.5).
Conductor fastenings (to meet the safety factor of Table 4, Rule 44.1)

Crossarms:

11 kV circuit	Douglas fir 4–3/4″ x 5–3/4″ x 8′–0″
4 kV circuit	Douglas fir 4–3/4″ x 4–3/4″ x 7′–8″
Secondary circuits	Douglas fir 4–3/4″ x 4–3/4″ x 7′–0″

Crossarm braces (to conform to Rule 48.2 and 49.8)
Pole - western red cedar.
Pole dimensions: 55′ in length; 25″ top circumference; 50″ ground line circumference (ground line diameter 15.9″).

Construction Requirements

1. Conductor Tensions

It is assumed that the conductors are strung with the minimum sags specified in sag curves of Appendix C, hence the tension values at 60ºF and no wind (normal tensions) are 35% of the ultimate tensions shown in Table 18. These tensions for each of the conductor sizes and corresponding tensions at maximum loading (25ºF and wind of 8 psf) are as follows, where span length is 250 feet:

	Tension–Pounds	
	35% of Ultimate	At Maximum Loading
#O AWG Stranded, hard–drawn copper	1,664	2,125
#2 AWG Stranded, hard–drawn copper	1,065	1,360
#4 AWG Solid, hard–drawn copper	690	890

2. Crossarms

Spacings assumed are shown on the pole framing diagram at the end of Part 2. Double crossarms of Douglas fir, dense, are employed for each of the four different circuits.

Computations of the fiber stresses imposed upon the various crossarms by the unbalanced wire loads of conductors in the physical configuration shown on the diagram are made in accordance with the method outlined in Part 1 to show these stresses under the conditions of long–time loading and maximum loading. Furthermore, double crossarm construction of this type with separation maintained by space bolts is assumed to have a horizontal strength equivalent to 130% of the sum of the strengths of two single crossarms acting independently. The stresses computed in this manner are:

	Fiber Stress (psi)	
	Long–Time Loading	Maximum Loading
Top crossarms	1,412	1,804
Second crossarms	1,598	2,040
Third crossarms	932	1,202
Fourth crossarms	1,438	1,811

The second crossarm is subject to the greatest loading, for which effects of the load (1,598 psi long-time and 2,040 psi maximum) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the crossarm (Rule 48.1: ANSI O5.3 2008: 7,800 psi maximum or 0.55 x 7,800 psi = 4,290 psi long-time) multiplied by the strength factor of 0.75 (Table 4-2); or it is required that

$$1{,}598 \text{ psi} \times 1.5 \leq 4{,}290 \text{ psi} \times 0.75$$

or

$$1{,}598 \text{ psi} \leq 4{,}290 \text{ psi} /(1.5/0.75) = 4{,}290 \text{ psi}/2.0 = 2{,}145 \text{ psi}$$

and

$$2{,}040 \text{ psi} \times 1.5 \leq 7{,}800 \text{ psi} \times 0.75$$

or

$2,040 \text{ psi} \leq 7,800 \text{ psi} /(1.5/0.75) = 7,800 \text{ psi}/2.0 = 3,900 \text{ psi}$

Hence, all the crossarms chosen are satisfactory.

3. Pole (See Diagram at End of Part 2)

Rule 47 specifies that guys may be used to support unbalanced longitudinal loads with the load and strength factors provided in Rule 44. (Where guys are used they must take the entire load with the load factors (Table 4-1) and strength factors (Table 4-2) applied and the pole being considered merely as a strut).

Using the values given above for tensions at maximum loading, the following moments due to dead ending the conductors are obtained:

3 x 2,125 x 47.3	=	301,500 pound–feet
4 x 1,360 x 38.3	=	208,400 pound–feet
3 x 890 x 30.3	=	80,900 pound–feet
3 x 1,360 x 25.3	=	103,200 pound–feet
Total Moments	=	694,000 pound–feet

The total deadend load, using the tension values for maximum loading given above, will be:

3 x 2,125	=	6,380 pounds
4 x 1,360	=	5,440 pounds
3 x 890	=	2,670 pounds
3 x 1,360	=	4,080 pounds
Total	=	18,570 pounds

Center of load = $\frac{694000}{18570}$=37.4 feet above ground

The tension (T) of a single guy with a lead to height ratio of 1 to 1 (assumed), or a 45º angle, and a safety factor of 2 would be:

T = total load/COS(45º) = 18,570 lbs/0.707 = 26,265 lbs

The effects of the load (26,265 lbs) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the guy multiplied by the strength factor of 0.75 (Table 4-2), or it is required that

26,265 lbs x 1.5 ≤ strength x 0.75

or

strength ≥ 26,265 lbs x 1.5/0.75 = 26,265 lbs x 2.0 = 52,530 lbs

A stranded guy attached at the center of load could be used provided the allowable fiber stress of the pole is not exceeded. The stress due to guying at this point would be as follows:

The center of load (37.4′ above ground) would be
9.9 ft. (118.8″) below the top conductors (11 kV) and

0.9 ft. (10.8”) below the second crossarm (4 kV)

The fiber stress in the pole at the center of load due to the tension in the conductors above the center of load is computed as follows:

Bending moment	3 x 2,125 x 118.8	=	757,400 pound–inches
	1,360 x 10.8	=	8,800 pound–inches
Total moment		=	16,200 pound–inches

The section modulus of a solid circular section is $E = \dfrac{\pi \ d^3}{32} = 0.0982 d^3$

The diameter of the pole at the center of load is d = 9.7 inches

Then, E = 0.0982 x $(9.7)^3$ = 89.6 in^3

$$\text{Fiber stress} = \frac{\text{Bending Moment}}{\text{Section modulus}} = \frac{816200}{89.6} = 9110 \text{ psi}$$

The effects of the load (9,110 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

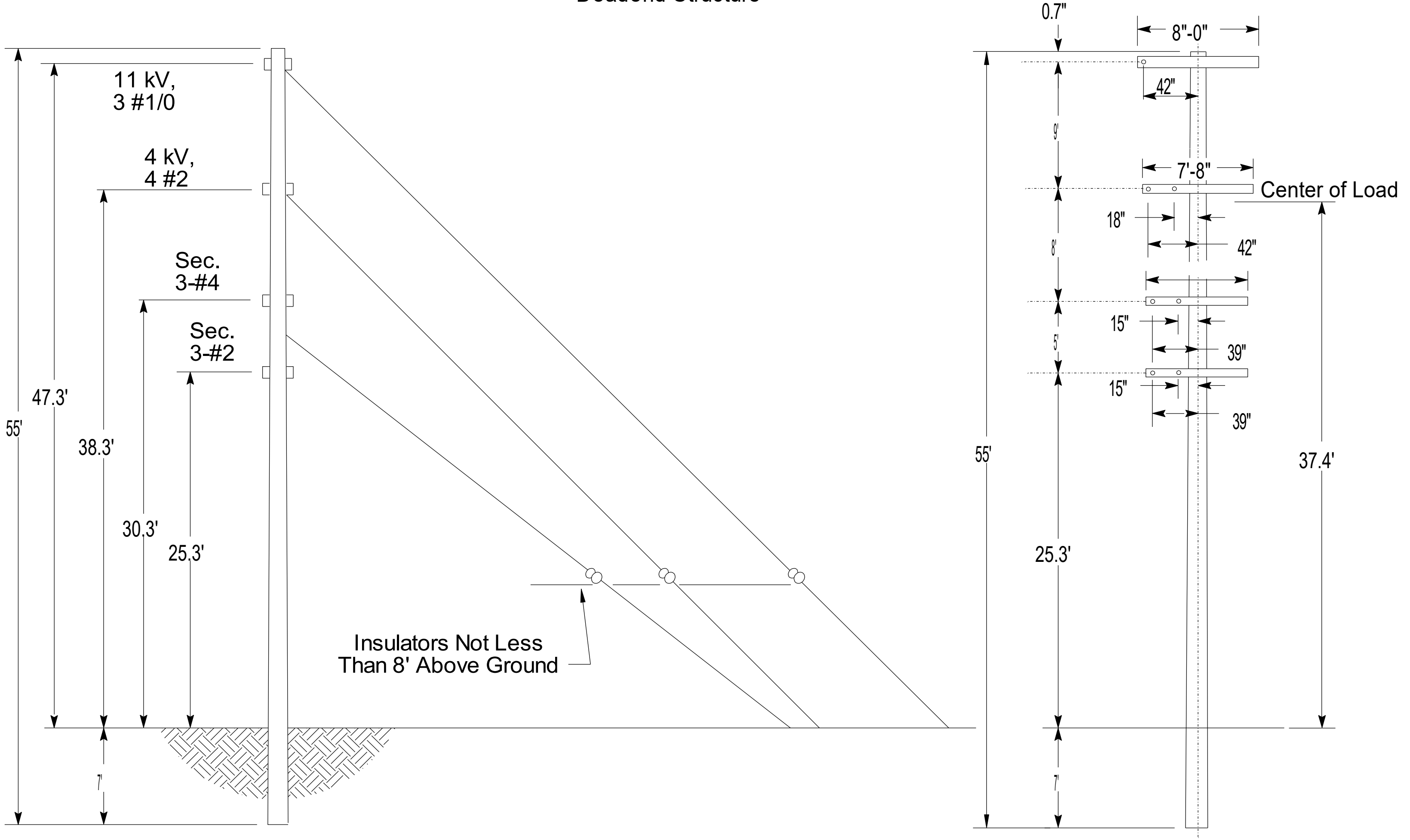
9,110 psi x 1.5 ≤ 6,000 psi x 0.375

or

9,110 psi ≤ 6,000 psi /(1.5/0.375) = 6,000 psi/4.0 = 1,500 psi

which condition is not satisfied. Hence, the pole cannot be guyed by a single guy but can be guyed as illustrated in the diagram of the deadend structure.

Deadend Structure



Part 3
Angle Pole Problem – Methods of Providing Proper Strength for Unbalanced Conductor Loads at Angle Poles

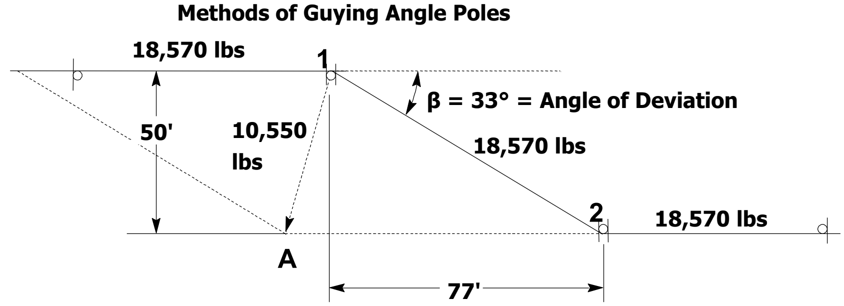
To maintain poles in proper position at angles and corners, it is generally necessary to use guys or some other form of pole bracing. Unless the line is dead–ended, the pull of the conductors is taken as being the same throughout the line.

The degree of unbalanced pull at an angle or corner pole is dependent upon the angle in the line at that point; that is, the greater the angle in the line, the greater is the magnitude of unbalance. Rule 45 specifies that where there is a change in the direction of conductors and messengers, transverse load shall be calculated as the resultant of all tensions under the assumed loading conditions. The members stressed shall be of such strength, using guys if necessary, as to withstand the total unbalanced load with load and strength factors equal to those of Rule 44. It is assumed that the line considered in this problem is Grade "A" construction.

It is assumed that the line discussed in the foregoing deadend problem crosses from one side of a street to the opposite side, that the longitudinal distance along the street between the two poles concerned is 77 feet, and that the angle of deviation is 33° (see sketch). This would result in an unbalanced force being exerted in the direction of A of

$$18570x2Sin\frac{\beta}{2}=18570x2x0.2840=10550pounds$$

Methods of Guying Angle Poles



Force Diagram

Assuming the pole height and framing as shown in Part 2, the top circumference of pole to be 25", the ground circumference to be 50" and the center of load to be 37.4 feet above ground line (as determined in Part 2), the fiber stress on the pole at the ground line is as follows:

Bending moment, M = 37.4 x 10,550 = 394,400 pound–feet

$$\text{Fiber stress} = \frac{122M}{d^3}$$

where circumference = 50″ and d = 15.9″

$$\text{Fiber stress} = \frac{122 \times 349400}{15.9^3} = 11970 \text{ psi}$$

The effects of the load (11,970 psi) multiplied by the load factor of 1.5 (Table 4-1), for the assumed Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

11,970 psi x 1.5 ≤ 6,000 psi x 0.375

or

11,970 psi ≤ 6,000 psi /(1.5/0.375) = 6,000 psi/4.0 = 1,500 psi

which condition is not satisfied. Hence, even without the additional horizontal load due to wind loading (Rule 43), it is clear the pole must be guyed to support the transverse loading.

A single guy attached at the center of load could be used provided the <u>effects of the load at the point of guying do not exceed the required strength of the pole</u>. The stress due to guying at this point is as follows:

Bending moments

$$Toparm = 3x2125x118.8x2\sin\frac{\beta}{2} = 430200 pound - inches$$

$$Secondarm = 4x1370x10.8x2\sin\frac{\beta}{2} = 33400 pound - inches$$

Total moment=463600 pound-incheEs

Section modulus, E

The section modulus (E) at 37.4 feet above ground is 89.6 in^3, which is the value computed in the example in Part 2.

Fiber stress:

The fiber stress is

$$F=\frac{M}{E}=\frac{463600}{89.6}=5170 \text{ psi}$$

The effects of the load (11,970 psi) multiplied by the load factor of 1.5 (Table 4-1), for Grade A construction, must not exceed the strength of the pole (6,000 psi, Table 5) multiplied by the strength factor of 0.375 (Table 4-2), or it is required that

$$5{,}170 \text{ psi} \times 1.5 \leq 6{,}000 \text{ psi} \times 0.375$$

or

$$5{,}170 \text{ psi} \leq 6{,}000 \text{ psi} /(1.5/0.375) = 6{,}000 \text{ psi}/4.0 = 1{,}500 \text{ psi}$$

which condition is not satisfied. Hence, it is necessary to place guys at more than one point on the pole, and therefore, they are attached at positions similar to the guys shown in the diagram at the end of Part 2.

END APPENDIX C