APPENDIX E

CLEARANCE OF POLES, TOWERS AND STRUCTURES FROM RAILROAD TRACKS

Where poles, towers or other line structures are set in proximity to railroad tracks, the minimum side clearance from the face of a pole, tower or structure to the center line of the tangent railroad track shall be 8 feet 6 inches.

Clearance requirements above railroads are shown in General Order No. 6, in Rules 37, Table 1, 54.4-B, 56.4-B, 57.4-B, 58.2-B2, 74.4-B, 77.4-A, 84.4-B, 86.4-B, 87.4-B and 113.5.

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—Class 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 1

CROSSING PROBLEM

A diagram including dimensions is shown attached between pages 328 and 330. 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 6 No. OO AWG, bare, stranded, hard-drawn copper. Private telephone circuit is 2 No. 8 AWG, bare, solid, hard-drawn copper, except in the crossing span where it is 2 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), 1½"x18½", to comply with Rules 49.3-B and 49.3-C. Assumed bonded in accordance with the requirements of Rule 53.4.

Communication circuit—1½"x9" locust.

Crossarms

Power circuits—Douglas fir (dense), 4¾" x 5¾" x 12', 1.9" pin holes, 11/16" hole for through bolt.

Communication circuit—Douglas fir (dense), 3¼"x4¼"x42", 1½" 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 299, 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 feet, (0.99 when calculated) and the No. 6 AWG conductor will have a sag of 0.90 feet (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

$$\text{Sag} = \frac{.4109 \times (200)^2}{8 \times 2074} = 0.99 \text{ feet}$$

For No. 6 AWG conductor

$$\text{Sag} = \frac{.0795 \times (200)^2}{8 \times 448} = 0.89 \text{ feet}$$

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:

	No. 00 AWG		No. 6 AWG	
	Sag (feet)	Tension (pounds)	Sag (feet)	Tension (pounds)
Ultimate conductor tension (see App. B Table No. 18)	------	5925	------	1280
35% Ultimate at 60°F, no wind	0.99	2074	0.89	448
25°F, 8 lb. wind	0.95	2605	1.18	570
130°F, no wind	1.78	1157	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 purposes of this problem are as follows:

	Minimum	*Used*
60,000 volt circuits	21.5″	5′ 6″
Communication 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″ 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 ¼ 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 18½ 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 49.1-C) 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″), or 1′4″, 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, between Pages 328 and 330, 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 communication 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 span, the sag is equivalent to 61% of the center sag (see Chart No. 9 Page 279), or $0.61 \times 11 = 7$ inches 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.

19

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″

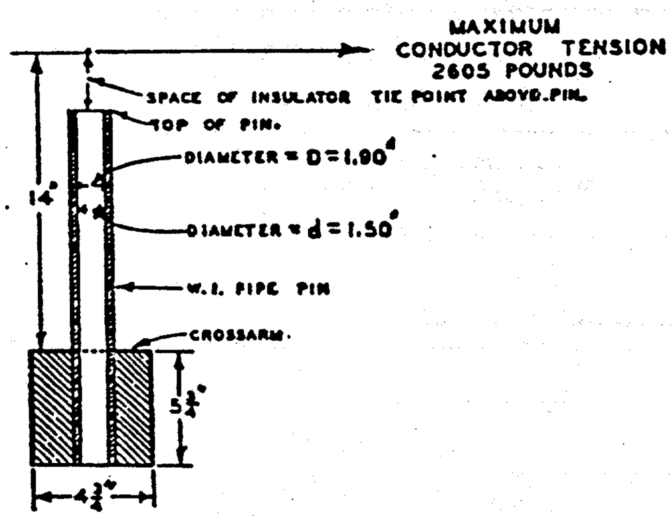
6. Insulators

In addition to the electrical requirements set forth in Rules 55, 104 and 114, 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) $M = 2605 \times 14 = 36{,}470$ pound-inches

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

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

Fiber stress $S = \frac{M}{E} = \frac{36{,}470}{0.412} = 88{,}500$ pounds per sq. in.

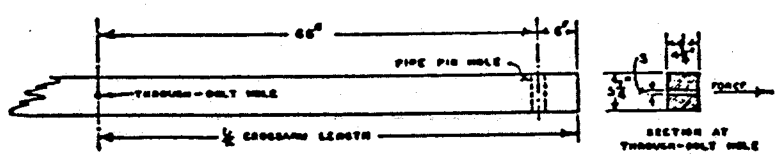
Assuming that the ultimate fiber stress of wrought iron is 48,000 pounds per square inch, a single pin is not sufficient, as it provides a safety factor of 0.542, $\left(\frac{48{,}000}{88{,}500} = 0.542\right)$, for an assumed tension of 2605 pounds in the conductor at maximum loading. Since a safety factor of unity (Rule 47.5) 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 1½-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 47.4, 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 cross arm 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 of Douglas fir, dense, dimensions 4¾" x 5¾" 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 $= 2605 \times 66 = 171{,}930$ pound-inches

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

$b = 5.75'' - 0.69 = 5.06''$

$d = 4.75''$

$s = \frac{11}{16}'' = 0.69''$

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

Fiber stress = Bending moment divided by

section modulus $= \frac{171{,}930}{19.0} = 9050$ lbs. per sq. in.

As the allowable value for modulus of rupture in bending under maximum loading conditions is 6300 lbs. per sq. in. (see Table 5, Page 63), 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 47.5 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 8 lb. wind

Bending moment $= 2605 \times 66 = 171{,}930$ pound-inches

Single arm section modulus (same as previously calculated) $= 19.0$ inches^3

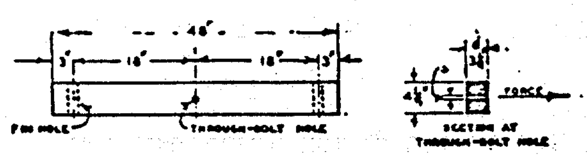
Double arm section modulus $= 19.0 \times 2 \times 1.3 = 49.4$ inches^3

Fiber stress $= \dfrac{171{,}930}{49.4} = 3480$ lbs. per sq. in.

As the allowable modulus of rupture for short-time loading is 6300 lbs. per sq. in. then the double crossarms under these conditions will provide a safety factor of 1.81, which meets the unity safety factor required by Rule 47.5.

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 $= 448 \times 18 = 8064$ pound-inches

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

where $d = 3.25''$
$s = 0.69''$
$b = 4.25'' - 0.69 = 3.56''$

$$\text{Fiber stress} = \frac{8064}{6.26} = 1290 \text{ pounds per sq. in.}$$

The allowable value for modulus of rupture in bending is $0.55 \times 6300 = 3465$ pounds per sq. in. and therefore with a single arm the factor of safety under conditions of long-time loading is 2.69.

Maximum loading

Bending moment = 570 × 18 = 10,260 pound-inches
Section modulus = 6.26 inches³ (as per calculations above)

$$\text{Fiber stress} = \frac{10{,}260}{6.26} = 1640 \text{ pounds per sq. in.}$$

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:

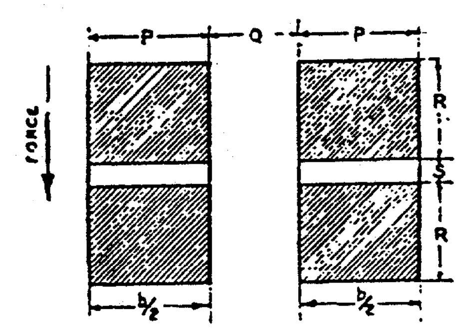
$$X = \frac{D}{2} + \frac{hT}{Dw}$$

Where X = ½ 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 × 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:

$$\text{Section modulus} = \frac{b}{6} \times \frac{(d^2 - d_1^2)}{d}, \text{ where}$$

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

$$\text{Section modulus} = \frac{9.50}{6}\left(\frac{(5.75)^2 - (0.69)^2}{5.75}\right) = \frac{9.50}{6} \times \frac{189.8}{5.75} = 52.3 \text{ inches}^3$$

$$\text{Fiber stress} = \frac{\text{Bending moment}}{\text{Section modulus}} = \frac{22{,}040}{52.3} = 420 \text{ pounds per sq. in.}$$

Long-time loading

As the allowable modulus of rupture in bending is 0.55 × 6300 lbs. per sq. in. or 3465 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	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	inches
Diameter of top	8.9	inches
Circumference at ground line	47	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 the conductors, is:

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

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_b = 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

$$M_{c0} = 48.75 \times 2 \times .276 \times \left(\frac{150 + 200}{2}\right) = 4710 \text{ lb.-ft.}$$

$$M_{c1} = 43.25 \times 2 \times .276 \times \left(\frac{150 + 200}{2}\right) = 4180 \text{ lb.-ft.}$$

$$M_{c2} = 37.75 \times 2 \times .276 \times \left(\frac{150 + 200}{2}\right) = 3650 \text{ lb.-ft.}$$

$$M_{c3} = 28.33 \times 2 \times .108 \times \left(\frac{200}{2}\right) = 610 \text{ lb.-ft.}$$

$$M_{c3} = 28.33 \times 2 \times .085 \times \left(\frac{150}{2}\right) = 360 \text{ lb.-ft.}$$

Total moment due to wind pressure on conductors 13,510 lb.-ft.

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″)

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

$$\text{Total moment} = 13{,}510 + 8{,}550 = 22{,}060 \text{ lb.-ft.}$$

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

Where

F = Fiber stress in pounds per sq. in.
I = Moment of inertia of section $= \dfrac{\pi D_1^4}{64 \times 12}$
c = Distance from neutral axis to outer fiber $= \dfrac{D_1}{2}$

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

$$F = \frac{122\ M}{D_1^3} = \frac{122 \times 22.060}{(15.6)^3} = 710 \text{ lbs. per sq. in.}$$

The allowable fiber stress for western red cedar poles to provide a factor of safety of 4 is 1400 pounds per sq. in., hence the crossing poles are not required to be side guyed since they have a factor of safety of 7.9 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

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

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

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

On Pole

$$\frac{(D_1 + D_2)\,H\,P}{24}$$

$$\frac{(15.6 + 8.91)\,48 \times 8}{24} = \underline{392.2} \text{ pounds}$$

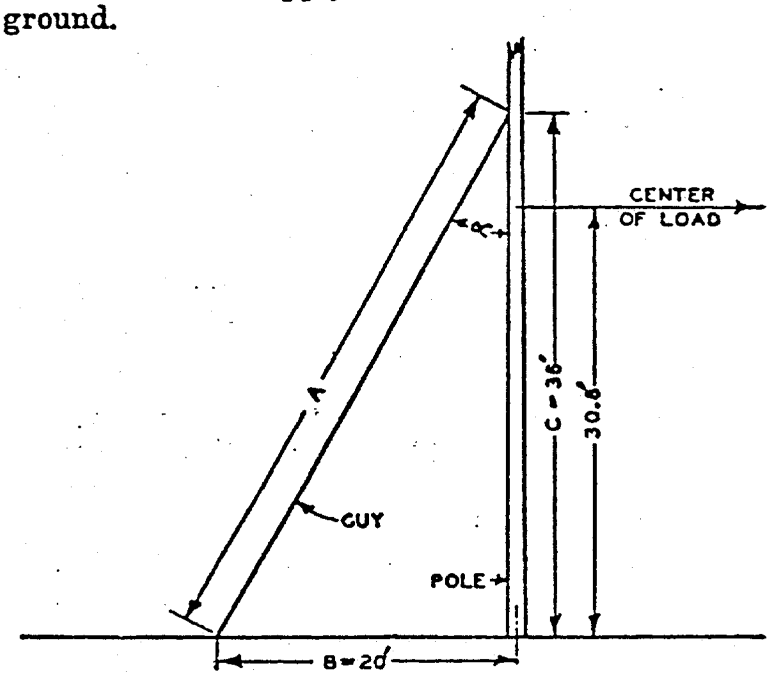
$$\text{Total Wind Pressure} = 716.4 \text{ pounds}$$

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

Therefore, the center of load would be:

$$\frac{22{,}060}{716.4} = 30.8 \text{ feet above ground}$$

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 (assumed)
T = Tension in guy wire in pounds
A = Length of guy = $\sqrt{20^2 + 36^2}$ = 41.2 feet

$$T = \frac{M_t}{C \operatorname{Sin} \alpha}$$

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

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

$$\operatorname{Sin} \alpha = \frac{20}{\sqrt{20^2 + 36^2}} = .485$$

$$T = \frac{22{,}060}{36 \times .485} = 1260 \text{ pounds}$$

The specified safety factor for guys (Table 4) is 2 and, therefore, a guy having an ultimate strength of not less than 2520 pounds is required. One ¼-inch Siemens-Martin or a $\frac{5}{16}$-inch common galvanized-steel strand would meet the requirements for transverse load.

13. Longitudinal Load on Crossing Poles C and D

Rule 47.5 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 $= \frac{8}{3} = 2\frac{2}{3}$; use 3

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

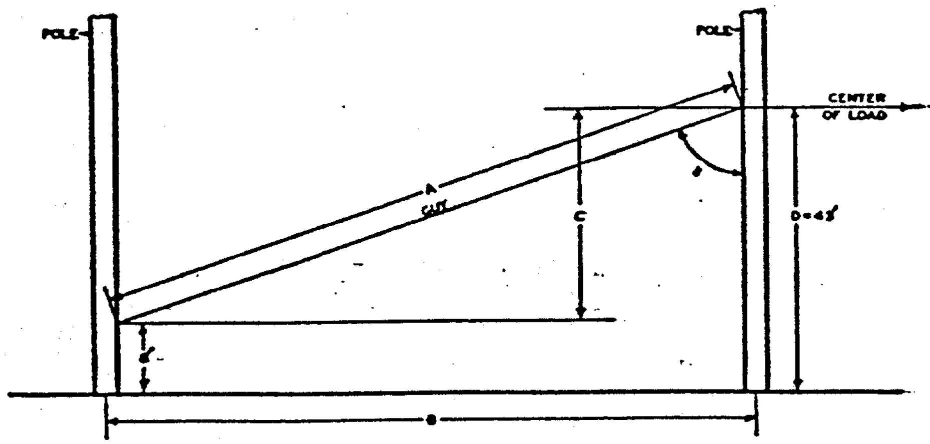
Bending moment:

$2 \times 2605 \times 48.75 = 254{,}000$ pound-feet
$1 \times 2605 \times 43.25 = 112{,}600$ pound-feet

Total moment = 366,600

$$\text{Fiber stress} = \frac{122\,M}{D^3_1} = 122 \times \frac{366{,}600}{15.6^3} = 11{,}780 \text{ pounds}$$
per sq. in.

The allowable value of modulus of rupture under this load is 5600 lbs. per square inch, hence poles C and D must be head guyed for the 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:

$$48.75 \times 2 \times 2605 = 254{,}000 \text{ pound-feet}$$
$$43.25 \times 2 \times 2605 = 225{,}300 \text{ pound-feet}$$
$$37.75 \times 2 \times 2605 = 196{,}700 \text{ pound-feet}$$
$$28.33 \times 2 \times 570 = 32{,}300 \text{ pound-feet}$$

$$\text{Total moment} = 708{,}300 \text{ pound-feet}$$

The total longitudinal load would be:

$$3\ (2 \times 2{,}605) = 15{,}630 \text{ pounds}$$
$$2 \times 570 = 1{,}140 \text{ pounds}$$

$$\text{Total wire tensions} = 16{,}770 \text{ pounds}$$

Therefore the center of longitudinal load is:

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

$$= \frac{708{,}300}{16{,}770} = 42.2 \text{ ft. (load center above ground)}$$

use 43 feet (to avoid contact with arm)

$$B = 150 \text{ ft.}$$

$$C = 43 - 8 = 35 \text{ ft.}^*$$

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

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

* 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:

$$\frac{366{,}600}{43 \times 0.962} = 8{,}860 \text{ pounds}$$

In this case, a $\frac{9}{16}$-inch common, $\frac{7}{16}$-inch Siemens-Martin, or $\frac{3}{8}$-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:

$$8{,}860 \times \sin \alpha = 8{,}860 \times .962 = 8{,}520 \text{ pounds}$$

The longitudinal moment on pole B or E would be:

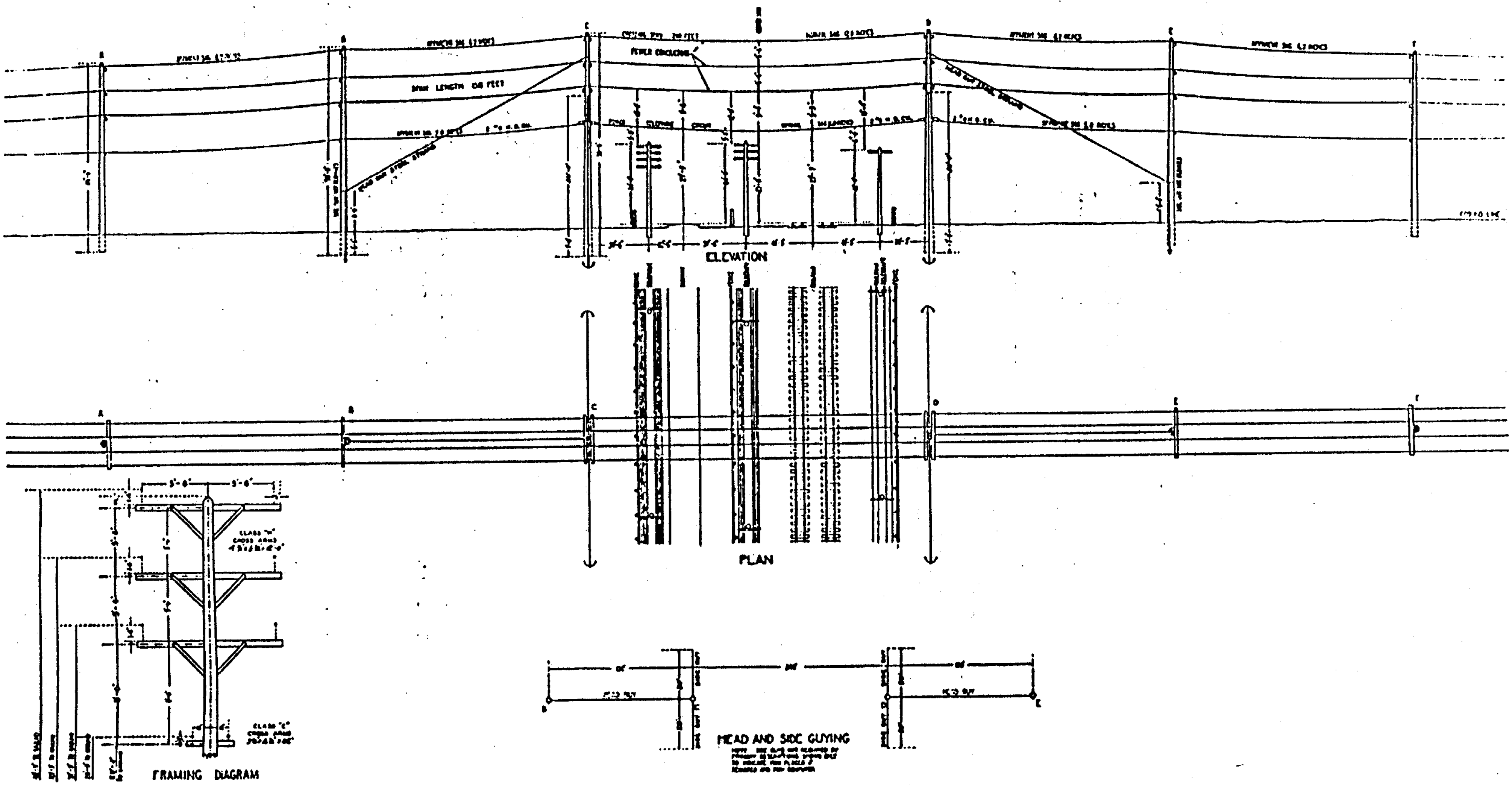
$$8{,}520 \times 8 = 68{,}160 \text{ pound-feet}$$

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

$$F = \frac{122M}{D^3_1} = \frac{122 \times 68{,}160}{(15.0)^3} = 2{,}460 \text{ pounds per square inch}$$

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



PART 2

DEAD-END PROBLEM

It is the object of this problem to indicate the construction requirements for a typical dead-end 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 dead-end structure considered herein is assumed to support a 11,000-volt circuit, a 4,000-volt circuit and two secondary circuits. It is also assumed that the dead-end pole takes Grade "A" construction by virtue of its location.

The dead-end structure diagram and dimensions are shown on page 333. The primary data chosen for this structure are as follows:

DATA OF DEAD-END STRUCTURE

Supply Conductors.

11 kv circuit--------3 No. 0 AWG Stranded, hard-drawn copper
4 kv circuit--------4 No. 2 AWG Stranded, hard-drawn copper
120/240 volt circuit--3 No. 4 AWG Solid, hard-drawn copper
120/240 volt circuit--3 No. 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).

Crossarms.

11 kv circuit---------Douglas fir 4¾" x 5¾" x 8' 0"
4 kv circuit---------Douglas fir 4¾" x 4¾" x 7' 8"
Secondary circuits----Douglas fir 4¾" x 4¾" 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 per cent 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*
No. 0 AWG stranded, hard-drawn copper	1664	2125
No. 2 AWG stranded, hard-drawn copper	1065	1360
No. 4 AWG solid, hard-drawn copper	690	890

2. Crossarms

Spacings assumed are shown on the pole framing diagram on page 333. 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 I 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 loading*
Top crossarms	1412	1804
Second crossarms	1598	2040
Third crossarms	932	1202
Fourth crossarms	1438	1811

Since a factor of safety of 2 permits a maximum stress of modulus of rupture in bending of 1732 lbs. per sq. in. $\left(\frac{6300 \times 0.55}{2}\right) = 1732$ under the conditions of long-time loading (60° F. and no wind) and 3150 lbs. per sq. in. $\left(\frac{6300}{2}\right)$ at maximum loading (see Table 5), the crossarms chosen are satisfactory.

3. Pole (See page 333)

Rule 44 provides that poles supporting unbalanced longitudinal loads in Grade "A" construction shall have a safety factor of 4 against such loads. Rule 47.3 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:

$$3 \times 2125 \times 47.3 = 301{,}500 \text{ pound-feet}$$
$$4 \times 1360 \times 38.3 = 208{,}400 \text{ pound-feet}$$
$$3 \times 890 \times 30.3 = 80{,}900 \text{ pound feet}$$
$$3 \times 1360 \times 25.3 = 103{,}200 \text{ pound feet}$$

$$\text{Total moments} = 694{,}000 \text{ pound-feet}$$

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

$$3 \times 2125 = 6{,}380 \text{ pounds}$$
$$4 \times 1360 = 5{,}440 \text{ pounds}$$
$$3 \times 890 = 2{,}670 \text{ pounds}$$
$$3 \times 1360 = 4{,}080 \text{ pounds}$$
$$\text{Total} = 18{,}570 \text{ pounds}$$

$$\text{Center of load} = \frac{694{,}000}{18{,}570} = 37.4 \text{ feet above ground}$$

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

$$T = \frac{\text{safety factor} \times \text{total load}}{\cos \theta} = \frac{2 \times 18{,}570}{\cos \theta} = 52{,}500 \text{ pounds}$$

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 inches) below the top conductors (11 kv) and
0.9 ft. (10.8 inches) 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:

$$\text{Bending moment } 3 \times 2125 \times 118.8 = 757{,}400 \text{ pound-inches}$$
$$4 \times 1360 \times 10.8 = 58{,}800 \text{ pound-inches}$$
$$\text{Total moment} = 816{,}200 \text{ pound-inches}$$

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

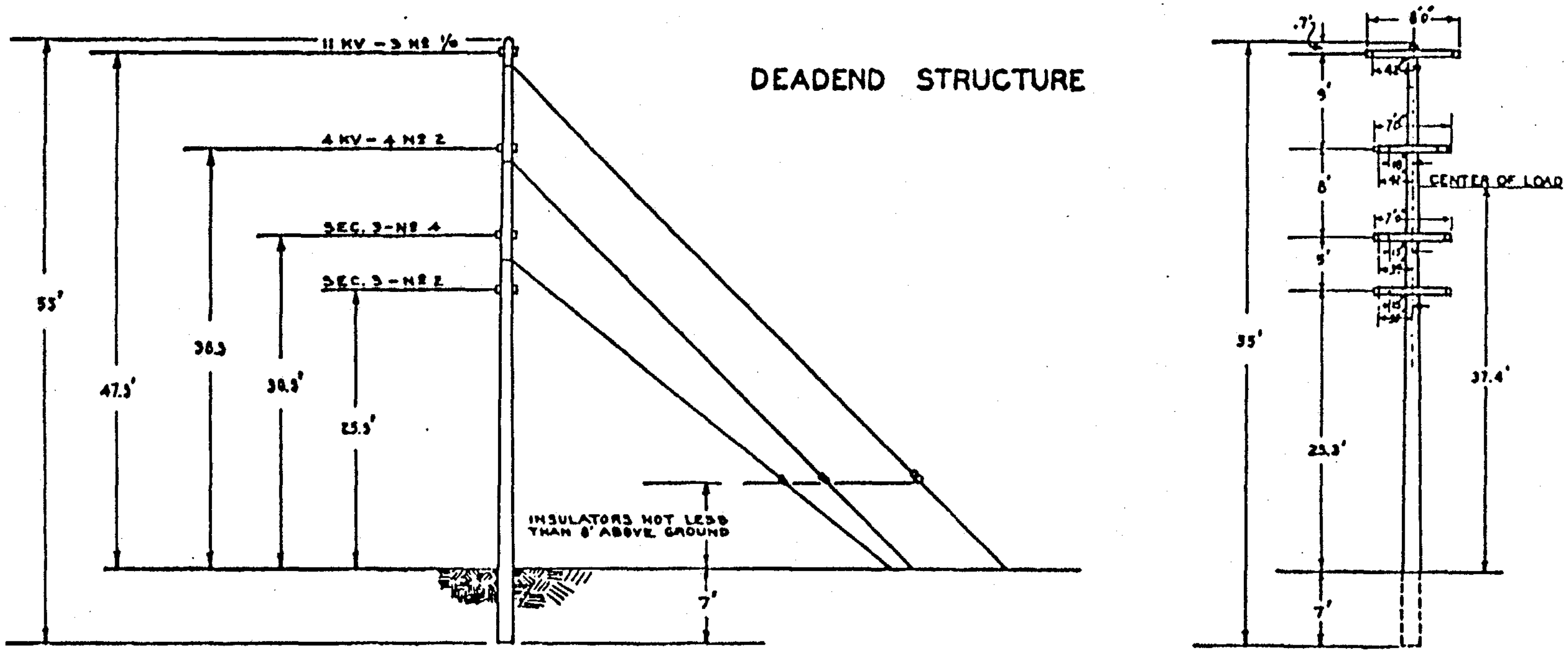
$$d = 9.7 \text{ inches}$$

Then

$$E = 0.0982 \times (9.7)^3 = 89.6 \text{ in.}^3$$

$$\text{Fiber stress} = \frac{\text{Bending moment}}{\text{Section modulus}} = \frac{816{,}200}{89.6} = 9110 \text{ lbs. per sq. in.}$$

Since a pole in Grade "A" construction must have a safety factor of 4, the allowable value of fiber stress would be $\frac{5600}{4} = 1400$ pounds per sq. in.; therefore the pole can not be guyed by a single guy but can be guyed as illustrated on page 333


DEADEND STRUCTURE
11 KV - 3 No 1/0
4 KV - 4 No 2
SEC. 3 - No 4
SEC. 3 - No 2
53'
47.3'
38.3
30.3'
25.3'
INSULATORS NOT LESS
THAN 8' ABOVE GROUND
7'
8'0"
.7'
9'
7'0"
CENTER OF LOAD
8'
5'
35'
37.4'
25.3'
7'

PART 3

METHODS OF PROVIDING PROPER STRENGTH FOR UNBALANCED CONDUCTOR LOADS AT ANGLE POLES

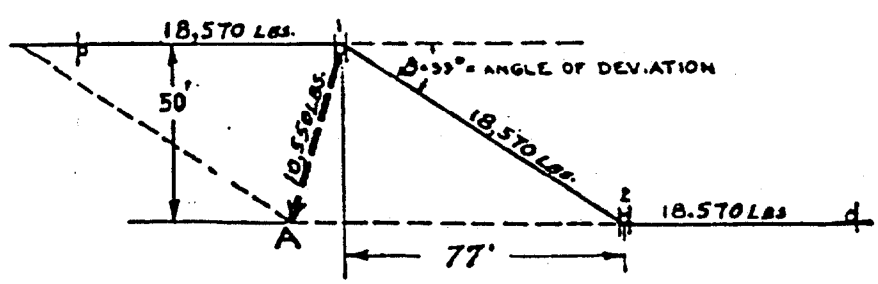
To maintain poles in proper position at angles and corners, it is generally necessary to use guys or some other form of pole bracing. Unless the line is dead-ended, the pull of the conductors is taken as being the same throughout the line.

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 47.3 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 dead-end 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 (β) is 33 degrees. (See sketch.) This would result in an unbalanced force being exerted in the direction of A of

$$18{,}570 \times 2 \sin\frac{\beta}{2} = 18{,}570 \times 2 \times .2840 = 10{,}550 \text{ pounds}$$

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 inches, the ground circumference to be 50 inches 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, $M = 37.4 \times 10{,}550 = 394{,}400$ pound-feet

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

where circumference = 50 inches and d = 15.9 inches

$$\text{Fiber stress} = \frac{122 \times 394{,}400}{(15.9)^3} = 11{,}970 \text{ lbs. per sq. in.}$$

As a safety factor of 4 is required, the allowable working stress is $\frac{5600}{4}$ or 1400 lbs. per sq. in., 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

Top arm: $3 \times 2125 \times 118.8 \times 2 \sin\frac{\beta}{2} = 430{,}200$ pound-inches

Second arm: $4 \times 1370 \times 10.8 \times 2 \sin\frac{\beta}{2} = \underline{33{,}400}$ pound-inches

Total moment = 463,600 pound-inches

Section modulus, E

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

Fiber stress

The fiber stress is

$$F = \frac{M}{E} = \frac{463{,}600}{89.6} = 5{,}170 \text{ pounds per sq. in.}$$

Since this stress exceeds the allowable stress of 1400 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 333.