Conversion of Concentrated Loads on Wood Crossarms to Loads Distributed at Each Pin Position

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ONE of the most important requisites in all fields of engineering endeavor is knowledge of the strength of materials. The development of testing machines and techniques to study the basic properties of metals, plastics and wood products to withstand breaking forces has been a distinctive achievement during the last half century. All materials, whether they be part of a bridge, a building, a shipping crate, a telephone pole or a crossarm on a telephone pole, break under an excessive stress. To have accurate knowledge of the strength of the millions of crossarms used to carry the regular load of wires, which are frequently subjected to the extra loads of wind and ice, is most important in electrical communication.

When strength tests of crossarms are made, the information most generally sought is how great a vertical load equally distributed at each insulator pin hole will the arms stand. In the past many crossarm tests have been made by the concentrated load method, where the arm is either supported at each end and loaded at the center, or supported at the center and loaded at the ends until failure occurs (Fig. 1, a and b). Some have been made by the distributed load method by placing, manually and simultaneously, 50-pound weights in wire baskets suspended from each pin hole, and continuing such load applications until the arm fails. The method is objectionable chiefly because, in many of the tests, the loading is inadvertently carried past the maximum loads the arms will support. This objection was overcome in recent tests made by the Bell Telephone Laboratories[1], where the loads were also distributed at each pin position. However, instead of subjecting the 10-pin test arms to sudden 500-pound load increments (viz. 50 pounds at each of the 10 pin holes), the loads were applied gradually by a hydraulic testing machine (Fig. 1, c). But, in spite of the advantages of this machine method of distributed load application, it is probable that, because of the less elaborate apparatus involved in simple beam tests, there will continue to be tests made by the concentrated load method.

Where tests have been made by the concentrated load method, the question arises how can the results be converted to a load-per-pin basis? A conversion is needed before a fair comparison can be made of all test results, and also to furnish the information generally most wanted, which is, as

[1]Bell System Monograph No. B-1563, Strength Tests of Wood Crossarms.

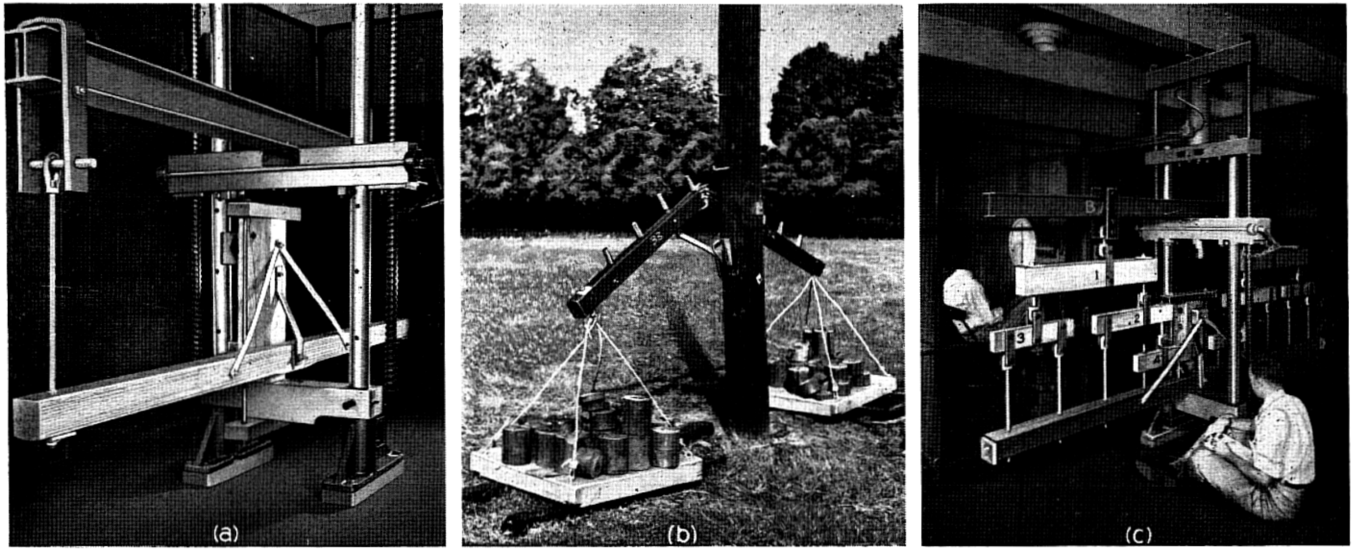

Fig. 1—Photographs of crossarm tests:
a—Arm supported at center in testing machine ready for application of load at end pin holes.
b—Arm supported at center on a pole. This roofed 10A arm was loaded manually at end pin holes and failed at a pole pin hole (critical) section.
c—Arm supported at center in testing machine ready for application of load at each pin position.

previously stated, what load per pin will the arm support? There are more than twenty million crossarms in the pole lines of the Bell System and each year about a million arms are added. A complete understanding of every problem associated with this important item of outside plant material is manifestly worth while. This paper is intended to contribute to that end. It presents a solution of the problem of converting concentrated vertical loads to comparable loads distributed at each insulator pin position.

The location of the critical section in crossarms is a basic factor in a study of the problem. The critical section of a crossarm is the section at which the fiber stress is greatest when the arm is loaded. It is the section where the arm may be expected to break if overloaded. To determine its location, the bending moment at various sections along the arm is divided by the section modulus of the respective sections. The quotient in each instance is the fiber stress for each section investigated. The location showing the greatest fiber stress is the critical section. Since horizontal shear is not the controlling stress in crossarm failures under loads distributed at each pin hole, bending stresses only were considered in this analysis.

Because of the differences in arm shape and in the spacing of pin holes, the location of the critical section is not the same in all arms. It is estimated that at least three fourths of the arms in the Bell System are 10A and 10B crossarms.[2] Both are 10 feet long and 3.25″ x 4.25″ in cross section. In the 10A arm (Fig. 3), the space between the pin holes is 12 inches, except between the pole pin holes, where the space is 16 inches. In the 10B (Fig. 4) the pin hole spacing is 10 inches with a 32-inch space between the pole pins. Both types are bored for wood pins. Most of the arms now in the plant are "roofed", that is, the top surface of the arm, except the center foot of length, is rounded on a radius of about 4.25 inches. Under the current design, however, the top surface of Bell System arms is flat, except for the edges, which are beveled.

Previous studies of both roofed and beveled arms of various types have shown that the critical section of clear arms under vertical loads is either at the center or at the pole pin hole sections. This study is confined to those sections of clear 10A and 10B crossarms of nominal dimensions, both roofed and beveled. Moreover, it was assumed for the purpose of load analysis, that the crossarms are supported at the center only; since, under loads on each side of the pole, the standard crossarm braces provide no significant support when the loads are sufficient to break the arm.

Roofed 10A Arm

Let it be assumed that the breaking load concentrated in each end pin hole of a roofed 10A arm is 800 pounds. As shown in Calculation 1 in the

[2] 10A and 10B crossarms were formerly known as Type A and Type B crossarms, respectively.

appendix, the bending moment at the center of the arm from the assumed loads would be 44,800 pound-inches, and the fiber stress at the center would be 4600 psi. That calculation also shows that the bending moment at the pole pin holes would be 38,400 pound-inches, and the fiber stress at the pole pin holes 7515 psi. Since the stress at the pole pin holes is greater than that at the center, the critical section of a roofed 10A arm is at the pole pin holes when the arm is subjected to a breaking load at each end pin hole.

The information wanted, however, is what load at each of the ten pin positions would have produced the same moment and same fiber stress at the critical section? A *tentative* answer is found by dividing the 38,400 bending moment by the "total-per-pin" lever arm[3], 120″ (see Calculation 1) or 320 pounds. Checking to determine whether the location of the critical section changes under loads of 320 pounds at each pin position, Calculation 1 shows that the fiber stress at the pole pin holes and at the center would be 7515 psi and 5257 psi, respectively. Since the stress at the pole pin holes is greater, it is clear that the critical section is there also under equal loads at each pin position; and the 320-pound load per pin is comparable to the concentrated load of 800 pounds at each end of the arm.

If a similar investigation were made of a roofed 10B arm and of a beveled 10A arm, it would be found that the pole pin hole section is the critical section of these arms; and that the load per pin comparable to concentrated loads at the arm ends would, like the roofed 10A arm, be equal to the bending moment at the pole pin hole section due to the concentrated load divided by the total per pin lever arm to that section. Figure 1b shows a roofed 10A arm that broke under test at a pole pin hole (critical) section from concentrated loads at the ends of the arm.

Beveled 10B Arm

For the investigation of this arm, let a breaking load of 1000 pounds at each end pin hole be assumed. Incidentally, it should be noted that so far as this analysis is concerned, the magnitude of the assumed concentrated loads is of no importance. However, since both computations and tests show the 10B arm to be stronger than the 10A, it seemed appropriate to assume a larger concentrated load for the 10B arm.

As shown in Calculation 2 of the appendix, the bending moment at the center due to the 1000-pound load would be 56,000 pound-inches and the fiber stress 5882 psi, while at the pole pin holes the bending moment would be 40,000 pound-inches and the fiber stress 6885 psi. Here again, under concentrated loads at each end pin hole, the critical section is at the pole pin holes.

[3]By total-per-pin lever arm is meant the summation of the distances from each pin position to the section concerned—in this instance to the pole pin hole section.

Calculating the load for each of the 10 pin positions in the same manner as for the roofed 10A arm, we have, tentatively, a load per pin of 400 pounds. However, in checking to determine whether the location of the critical section changes under loads of 400 pounds at each pin position, we obtain results quite different from those in Calculation 1; for Calculation 2 indicates a fiber stress of 6885 psi at the pole pin holes, but a higher stress (7563 psi) at the center, which shows that the location of the critical section does change. Moreover, this change would occur whether the loads were 400 pounds per pin or 4 pounds per pin. But let us now consider the 400-pound load.

If a concentrated load of 1000 pounds results in a fiber stress at the pole pin hole section of 6885 psi and causes failure, that stress is the *maximum* ultimate fiber stress for the arm. It is, therefore, not reasonable to suppose that the same arm would have endured a higher stress (7563 psi) at the center if it had been loaded at each pin position. If 6885 psi is the maximum stress for the arm, the maximum moment it would endure at its center would be 65,500 pound-inches (viz. 6885 multiplied by 9.52, the section modulus of the center section). The maximum load per pin would be 364 pounds (viz. 65,500 divided by 180, the total-per-pin lever arm to the center); and this load of 364 pounds, not 400 pounds, distributed at the 10 pin positions is comparable to the 1000-pound concentrated load. Thus, while the critical section of a beveled 10B arm is at the pole pin holes when the load is concentrated at the arm ends, it shifts to the center when the load is distributed at each pin position; and, moreover, the load is less than the load per pin tentatively computed.

A graphic illustration of this shift of the critical section is shown in Fig. 2. Graph 1 in this figure is the graph of the resisting moments of a clear, straight-grained beveled 10B arm, 3.25″ x 4.25″ in cross-section, and having an assumed ultimate fiber strength in bending of 6000 psi. Each point in the graph is equal to the section modulus of the section under consideration multiplied by 6000 psi. Graph 2, which is the graph of a concentrated load at the end pin position, was drawn from the zero moment under the end pin to the point of greatest moment possible without intersecting resisting moment Graph 1. Since the point of coincidence between Graphs 1 and 2 is the pole pin hole section, that section is the critical section for a concentrated load at the end pin. The magnitude of this concentrated load is equal to the resisting moment at the pole pin hole, 34,860 pound-inches (viz. 5.81 inches^3 x 6000 psi) divided by the 40″ lever arm, or 871.5 pounds. The load per pin, *tentatively figured*, would be 34,860 pound-inches divided by 100 inches or 348.6 pounds. Graph 3 is the graph of a load (P) of 348.6 pounds at each pin hole. Under such loading, however, the bending moment at the center of the crossarm would be 62,748 pound-inches (viz. 348.6 x 180), which exceeds the 57,120 pound-inches resisting moment at the center (viz. 9.52 inches^3 x 6000 psi). This means that the

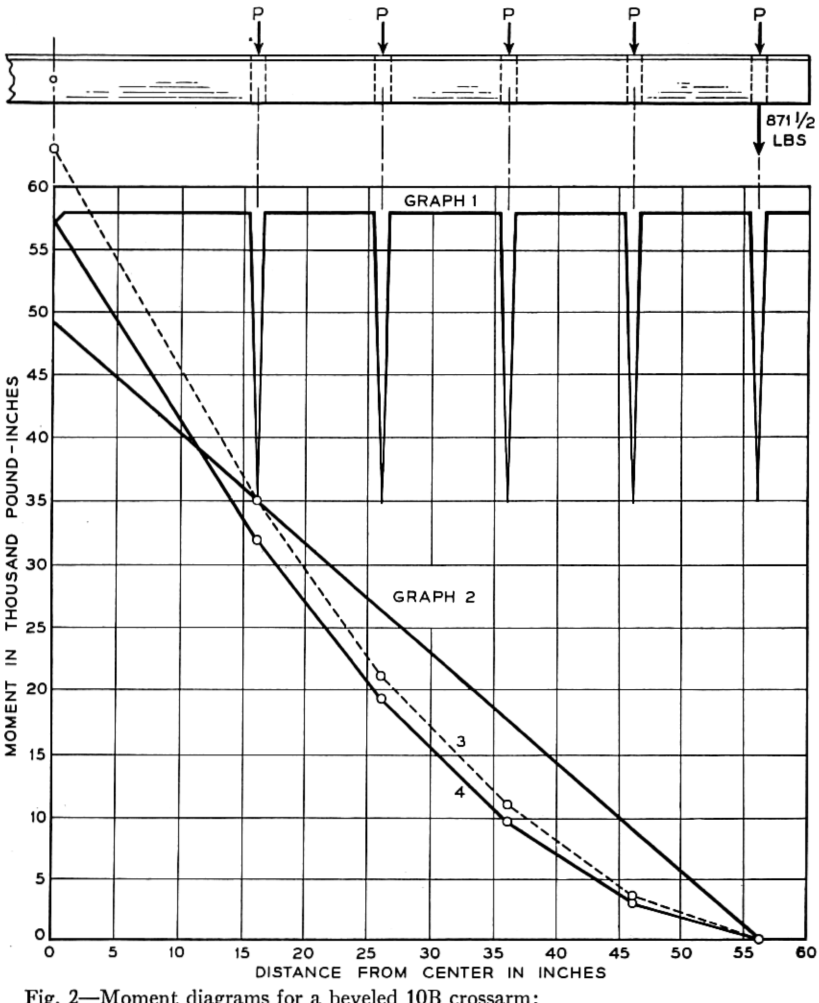

Fig. 2—Moment diagrams for a beveled 10B crossarm:
Graph 1—Resisting moments of a clear, straight grained, 3.25″ x 4.25″ arm. Fiber stress assumed to be 6000 psi;
Graph 2—Bending moments from a concentrated load of 871.5 pounds at end pin hole;
Graph 3—Bending moments from a load of 348.6 pounds at each pin hole; and
Graph 4—Bending moments from a load of 317.3 pounds at each pin hole.

arm would fail under such loading; and that the critical section of the arm under loads distributed at each pin hole is not at the pole pin holes but at the center of the arm. The maximum load per pin that the arm would endure is the resisting moment at the center divided by the total-per-pin lever arm, or 57,120 pound-inches divided by 180 inches or 317.3 pounds. Graph 4 is the bending moment graph of this 317.3-pound maximum load per pin.

Summary

Let W = Concentrated load,
P = Load per pin,
Mp = Bending moment at pole pin hole section,
fc = Fiber stress at center section,
fp = Fiber stress at pole pin hole section,
Sc = Section modulus of center section, and
Sp = Section modulus of pole pin hole section.

Using this notation, the results of the analyses may be summarized as follows:

For 10A arms both roofed and beveled:

$$Mp = 48W \quad \text{(for concentrated loads), and}$$

$$Mp = 120P \quad \text{(for pin loads). Therefore,}$$

$$P = \frac{48W}{120} = 0.4W$$

For 10B arms-roofed:

$$Mp = 40W \quad \text{(for concentrated loads), and}$$

$$Mp = 100P \quad \text{(for pin loads). Therefore,}$$

$$P = \frac{40W}{100} = 0.4W$$

For the beveled 10B arm, however, where the critical section is at the center, the value P = 0.4W does not apply. The value of P would be such as to produce the same fiber stress at the center section as the fiber stress resulting from the concentrated load (W) at the pole pin hole section. Thus

$$fc = \frac{180P}{Sc} \quad \text{and}$$

$$fp = \frac{40W}{Sp}$$

Equating these, we have

$$\frac{180P}{Sc} = \frac{40W}{Sp} \quad \text{and}$$

$$P = \frac{40W}{Sp} \times \frac{Sc}{180} = \frac{2ScW}{9Sp} = \frac{2 \times 9.52W}{9 \times 5.81} = 0.364W$$

Therefore, under the conditions assumed, and only under such conditions, we may say that the loads per pin (P) comparable to the assumed concentrated loads (W) would be

$$P = 0.4W \text{ for } \begin{cases} \text{10A arms—roofed} \\ \text{10A arms—beveled} \\ \text{10B arms—roofed} \end{cases}$$

and

$$P = 0.364W \text{ for 10B arms—beveled}$$

While these results are restricted to the four arm types listed, the same principles followed in arriving at these results may be applied to other types and sizes of arms, and to other conditions of loading. Whether the conversion of single concentrated loads to loads per pin is performed by the method illustrated in Calculations 1 and 2 of the appendix, or is done by a moment diagram, as in Fig. 2, the procedure recommended is as follows:

Step 1. Determine the critical section under the concentrated load.

Step 2. Divide the bending moment at the critical section by the total-per-pin lever arm to the critical section to determine the load per pin.

Step 3. Check the fiber stress (under such loads per pin) at various sections to see whether the *location* of the critical section differs under load per pin.

Step 4. If it does differ, proceed as shown for the beveled 10B arm (viz., the comparable load per pin is equal to the resisting moment of the *critical section* divided by the total-per-pin lever arm to the critical section). If it does not differ, the load per pin as determined in Step 2 is the comparable load per pin sought.

Conclusions

(1) The location of the critical section under loads distributed at each pin position must be determined before undertaking the conversion of concentrated loads to distributed loads.

(2) The location of the critical section of a crossarm under a given condition of loading may or may not be the same under a different condition of loading.

(3) The load per pin comparable with a given concentrated load is equal to the resisting moment of the *critical* section divided by the total-per-pin lever arm to the critical section.

(4) While the results shown are confined to the conversion of concentrated vertical loads to distributed loads for 10A and 10B arms only, the principles of the study may be applied to other types and sizes of arms and to other conditions of loading.

APPENDIX

Calculation 1. Bending Moments and Fiber Stresses in a Roofed 10A Crossarm—(See Figure 3)

Notation:

W = 800 pounds concentrated load
P = Load per pin
Mc = Bending moment at arm center
Mp = Bending moment at pole pin hole
fc = Fiber stress at center
fp = Fiber stress at pole pin hole
Sc = Section modulus of center section[4]
Sp = Section modulus of pole pin hole section[4]

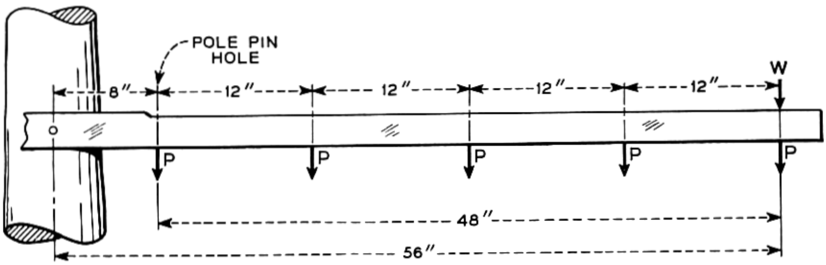

Fig. 3—Loading diagram for a roofed 10A crossarm.

Concentrated Load:

$Mc = W \times 56 = 800 \times 56 = 44{,}800$ pound-inches
$Mp = W \times 48 = 800 \times 48 = 38{,}400$ pound-inches
$fc = Mc \div Sc = 44{,}800 \div 9.74 = 4600$ psi
$fp = Mp \div Sp = 38{,}400 \div 5.11 = 7515$ psi

Load per Pin:

$Mc = 56P + 44P + 32P + 20P + 8P = 160P$
$Mp = 48P + 36P + 24P + 12P = 120P$

(Note: The total-per-pin lever arms are 160″ to center and 120″ to the pole pin hole).

Since under W load f is maximum at pole pin hole, the P load that would result in same f is $P = 38{,}400 \div 120 = 320$ pounds. Thus

$fp = 120P \div Sp = (120 \times 320) \div 5.11 = 7515$ psi
$fc = 160P \div Sc = (160 \times 320) \div 9.74 = 5257$ psi

Conclusion:

Under both W loads and P loads, the critical section is the pole pin hole section.

[4] $Sc = 9.74$ and $Sp = 5.11$ for clear roofed 3.25″ x 4.25″ crossarms. (See Pages 27 and 28 of *Bell Sys. Tech. Jour.*, Jan. 1945).

Calculation 2. Bending Moments and Fiber Stresses in a Beveled 10B Crossarm—(See Figure 4)

Notation:

W = 1000 pounds concentrated load
P = Load per pin
Mc = Bending moment at arm center
Mp = Bending moment at pole pin hole
fc = Fiber stress at center
fp = Fiber stress at pole pin hole
Sc = Section modulus of center section[5]
Sp = Section modulus of pole pin hole section[5]

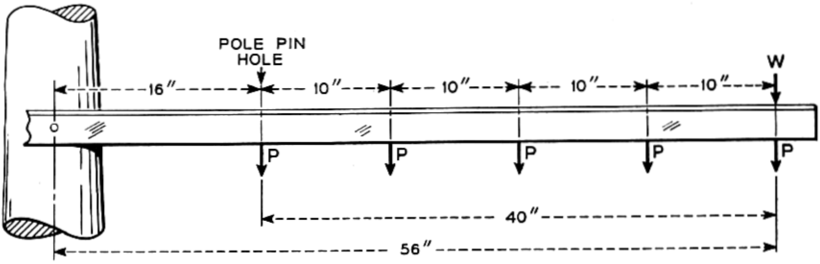

Fig. 4—Loading diagram for a beveled 10B crossarm.

Concentrated Load:

$$Mc = W \times 56 = 1000 \times 56 = 56{,}000 \text{ pound-inches}$$
$$Mp = W \times 40 = 1000 \times 40 = 40{,}000 \text{ pound-inches}$$
$$fc = Mc \div Sc = 56{,}000 \div 9.52 = 5882 \text{ psi}$$
$$fp = Mp \div Sp = 40{,}000 \div 5.81 = 6885 \text{ psi}$$

Load per Pin:

$$Mc = 56P + 46P + 36P + 26P + 16P = 180P$$
$$Mp = 40P + 30P + 20P + 10P = 100P$$
$$P = 40{,}000 \div 100 = 400 \text{ pounds}$$
$$fp = \frac{100P}{Sp} = \frac{100 \times 400}{5.81} = 6885 \text{ psi}$$
$$fc = \frac{180}{Sc} = \frac{180 \times 400}{9.52} = 7563 \text{ psi}$$

Conclusion:

Critical section shifts under P loads, and arm will not support 400 pounds per pin.

[5] Sc = 9.52 and Sp = 5.81 for clear beveled 3.25″ x 4.25″ crossarms. (See Calculation 3 of this appendix.)

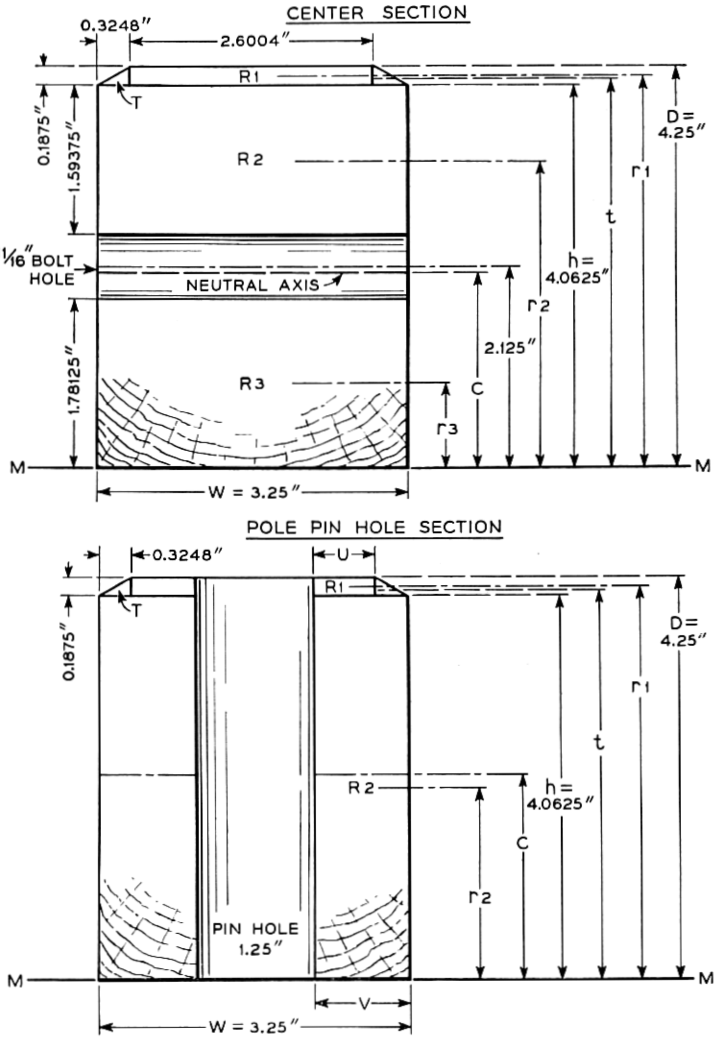

Fig. 5—Beveled crossarm sections showing significance of the notation used in Calculation 3 of this appendix.

Calculation 3. Section Modulus—Clear Beveled Sections
(The notation used in this calculation is shown in Fig. 5)

		Center Section	*Pole Pin Hole Section*
Section width (W)	Inches	3.25	3.25
Section depth (D)	Inches	4.25	4.25
$V = (W - 1.25'') \div 2$	Inches		1.00
$U = V - .3248''$	Inches		.6752
Areas:			
T	Sq. Ins.	($2T$) .0609	.0304
$R1$	Sq. Ins.	.4876	.1266
$R2$	Sq. Ins.	5.1797	4.0625
$R3$	Sq. Ins.	5.7891	—
Total 1	Sq. Ins.	11.5173	4.2145
$t = h + (.1875'' \div 3)$	Inches	4.1250	4.1250
$r1 = h + (.1875'' \div 2)$	Inches	4.1563	4.1563
$r2 = h - (1.59375'' \div 2)$	Inches	3.2656	($\frac{1}{2}h$) 2.0313
$r3 = 1.78125'' \div 2$	Inches	.8906	—
Moments about MM:			
Tt	Ins.^{3}	($2Tt$) .2512	.1254
$R1r1$	Ins.^{3}	2.0266	.5262
$R2r2$	Ins.^{3}	16.9148	8.2522
$R3r3$	Ins.^{3}	5.1558	—
Total 2	Ins.^{3}	24.3484	8.9038
c = Total 2 ÷ Total 1	Inches	2.1141	2.1127
$dt = t - c$	Inches	2.0109	2.0123
$dr1 = r1 - c$	Inches	2.0422	2.0436
$dr2 = r2 - c$	Inches	1.1515	($c - r2$) .0812
$dr3 = c - r3$	Inches	1.2151	—
Moments of Inertia:			
IT	Ins.^{4}	($2IT$) .0001	.00006
$IR1$	Ins.^{4}	.0014	.0003
$IR2$	Ins.^{4}	1.0964	5.5873
$IR3$	Ins.^{4}	1.5307	—
$T(dt)^2$	Ins.^{4}	[$2T(dt)^2$] .2463	.0612
$R1(dr1)^2$	Ins.^{4}	2.0336	.5287
$R2(dr2)^2$	Ins.^{4}	6.8680	.0268
$R3(dr3)^2$	Ins.^{4}	8.5474	—
I	Ins.^{4}	20.3239	6.2044
$y = D - c$	Inches	2.1359	2.1373
Section Modulus:			
$S = I \div y$	Ins.^{3}	9.52	($\frac{1}{2}S$) 2.9029
			S = 5.81