



Standard Test Methods of Static Tests of Wood Poles¹

This standard is issued under the fixed designation D 1036; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

One of the important factors involved in the design and economical use of poles for the support of aerial communication and power lines is the value of the maximum fiber stress for the different species of timber used for poles. In order to gain information on this characteristic, mechanical tests on pole size specimens have been made by numerous investigators. These tests have been made in various manners, such as the use of a testing machine, holding the pole butt horizontally in a crib and applying the load at the tip, setting poles in the earth and applying the load at the tip, etc. The amount of seasoning the test poles have received and the type of preservative treatment applied to the poles are additional variables. The result is that it is difficult, if not impossible, to obtain sufficient information pertaining to the various tests to permit accurate comparisons.

It is the purpose of these test methods to cover testing procedures in sufficient detail so that the results of tests made in accordance with the test methods defined will be comparable. It is, of course, not intended that using other test methods that may be better adapted to a particular investigation should be discouraged. However, experience gained from tests of several hundred poles has indicated the test methods specified are entirely practicable.

The data forms presented have been found to be convenient for recording the test data and for making the calculations necessary for the proper analysis of the test results.

1. Scope

1.1 These test methods cover determination of the bending strength and stiffness of wood poles. Knowledge of these properties is used in providing for reliable and economical design with poles of different species, size, or grade.

1.2 Two test methods are included: the cantilever test method, and the machine test method.

1.3 Provision is also made for extracting small clear specimens from the butt section and determining static bending and compression parallel to grain strength values in accordance with Methods D 143.

1.4 The procedures specified in these test methods apply to tests of either treated or untreated material.

1.5 The values stated in inch-pound units are to be regarded as the standard. SI values are given in parentheses and are provided for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appro-*

priate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 143 Methods of Testing Small Clear Specimens of Timber²

D 198 Test Methods of Static Tests of Timbers in Structural Sizes²

2.2 ANSI Standard:

O5.1 Specifications and Dimensions for Wood Poles³

3. Summary of Test Methods

3.1 Major Tests:

3.1.1 In the cantilever test method the pole is supported securely from butt to ground line in a horizontal position, and a load is applied near the pole tip by means of a pulling line.

3.1.2 In the machine test method, the pole is supported near the butt and tip, and a load is applied at the ground line by the moving head of a mechanical testing machine.

3.1.3 Determinations of age, rate of growth, moisture, and density are also made.

¹ These test methods are under the jurisdiction of ASTM Committee D-7 on Wood and are the direct responsibility of Subcommittee D07.04 on Pole and Pile Products.

Current edition approved Oct. 10, 1999. Published April 2000. Originally published as D 1036 – 49 T. Last previous edition D 1036 – 98.

² *Annual Book of ASTM Standards*, Vol 04.10.

³ Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

3.2 *Minor Tests:*

3.2.1 Small clear specimens are taken from the butt section of the tested poles for the determination of strength values such as static bending, compression parallel to grain, toughness, compression perpendicular to grain, and hardness. The overall objectives of the program will determine which of these tests are desired.

4. Significance and Use

4.1 Tests of wood poles are made to determine:

4.1.1 Data for use in establishing allowable stresses,

4.1.2 Data upon which to base economical pole line design,

4.1.3 Data on the strength properties of different species in pole sizes,

4.1.4 Data as to the influence of defects on the strength properties of poles,

4.1.5 Data as to the effect of preservatives and preservative treatments on the strength properties of poles, and

4.1.6 Data for correlating the strength properties of full-size poles with those of small clear specimens of the same species.

4.2 Treating procedures to which poles have been subjected may introduce variables that prohibit direct comparisons between different groups of data. Complete information on the treating techniques shall form a part of the test records.

COLLECTION OF MATERIAL

5. Identification

5.1 The material for test shall be selected by one qualified to identify the species.

6. Number of Major Specimens

6.1 For each species under investigation it is desirable that a minimum of 50 specimens be selected for test. The poles shall be carefully chosen as representative of the commercial product being supplied.

NOTE 1—Tests may be conducted to study the effect of some particular characteristic and in such cases the selection of test specimens shall be made in such a manner as to ensure that the range of the characteristic under study has been adequately sampled.

7. Field Notes

7.1 Field notes fully describing the material shall be carefully made by the collector. These notes shall, so far as possible, supply data outlined as follows and shall be incorporated into the test records:

FIELD NOTES

Project No.
 Locality cut
 County
 Slope ... Elevation
 Undergrowth
 Crown
 Soil
 Shipment No.
 Species
 Date cut
 Seedling or sprout
 How and when transported from woods
 Age of tree in years
 Treatment
 Seasoning
 Preservative retention

Age in service (if pole had been in service)

Age of pole since treatment

Source of pole (supplier, region and climate), if pole had been in service

Classification standard

Condition of pole (decay, woodpecker holes, splits), if pole had been in service

8. Field Marking

8.1 Each specimen shall be legibly marked on the butt with its length, class, and source of supply, in accordance with the requirements of ANSI O5.1 using such symbols as may apply to each specimen.

CONDITIONING AND MEASURING OF SPECIMENS FOR TESTING

9. Conditioning

9.1 Two basic procedures for conditioning and moisture content are provided as follows:

9.1.1 *Test Method A*, providing for air seasoning and butt soaking of poles prior to test.

9.1.2 *Test Method B*, providing for tests of poles in the full-length green condition.

NOTE 2—Test Method A, providing for butt soaking of poles after seasoning, has been used as a preconditioning test method when it is desired to provide tests simulating, as nearly as possible, actual field use under certain climatic conditions.

Test Method B, providing for tests of poles in the green condition, has been used where the stability of moisture-strength relationships thus established is particularly desired for comparison between species, grades, and testing procedures, and for establishing relationship of strength between full-size poles and that of small clear specimens taken from the pole material.

10. Alternative Conditioning Requirements

10.1 *Test Method A*—All poles tested shall be air-seasoned on skids at least 2 ft (600 mm) above the ground. Prior to testing, the butt sections (from the groundline to the butt) shall be soaked in water in order to bring the moisture content of this section equal to or above the fiber saturation point. Butt soaking shall be conducted in a manner to prevent decay and with the poles in a vertical position. Moisture determinations of the butt section shall be made by means of increment borings. The determinations shall be made by using the portions of the borings nearest the pole surface with a length of boring equal to one-half the pole radius.

NOTE 3—For the purposes of these test methods, poles will be considered air-seasoned when two successive determinations made one week apart indicate the moisture content of the pole to have reached a practically constant value at or below 22 %.

10.2 *Test Method B*—All poles to be tested shall be selected in the green condition and shall be tested before any seasoning has taken place. If there is any delay in testing which would result in seasoning, this shall be prevented by proper storage, preferably by full-length immersion in water. If other methods of maintaining the green condition are employed, care shall be exercised to prevent the development of stain or decay. Special moisture determinations of the test sections are not required prior to test (Section 25).

11. Initial Measurements

11.1 Before placing a pole in the testing apparatus, a record shall be made of the following items:

- 11.1.1 Weight,
- 11.1.2 Length to the nearest 1 in. (25 mm),
- 11.1.3 Class,
- 11.1.4 Circumference at butt, at tip, and at the ground line to the nearest 1/16 in. (1.5 mm),
- 11.1.5 Diameter of each knot over 1/2 in. (13 mm) in diameter and its location on the surface of the pole relative to the butt and to the longitudinal center line of the face of the pole, and
- 11.1.6 Any possible strength reducing defects observed other than knots, such as sweep, crook, checks, shakes, spiral grain, insect damage, etc.

STATIC BENDING TESTS OF POLES
Cantilever Test Method

12. Apparatus

12.1 A schematic drawing of the testing apparatus and field layout for conducting the tests is shown in Fig. 1. For convenience of reference, the principal features of the layout are denoted on the drawing by capital letters. The pole to be tested shall be held securely from the butt to the ground line in the crib A. The crib shall be built in such a manner that there will be no significant movement of the pole butt during the test. The design of the crib and holding devices shall be such that all vertical and rotational motion of the pole shall be prevented.

12.2 A support B shall be provided at a point about three quarters of the distance from the ground line to the point of load application to minimize vertical movement at that point and reduce the stress from the weight of the pole. This support shall be such that any friction associated with the deflection of the pole under load shall not be a significant portion of the measured load on the pole.

12.3 As a pole is placed in the testing apparatus, it shall be rotated to align the pole so as to minimize out-of-plane shear stresses due to torque. The pole shall be shifted longitudinally until its ground line coincides with the front face of the crib, and then it shall be secured firmly in place (see 12.1). A wooden saddle C, Fig. 1, with a concave surface on the pole side and rounded edges, shall be placed against the pole to prevent injury to the ground-line section. This saddle shall be made of wood at least as soft as the pole under test and shall have dimensions as shown in Fig. 2.

13. Load

13.1 The load shall be applied at a point 2 ft (600 mm) from the tip of the pole by a power winch, or other means of sufficient capacity and capable of pulling at a constant rate of speed. The pulling line shall be kept level between the winch position and the point where load is applied to the pole. The load shall be applied continuously until the pole fails, and at such a rate of speed as to cause a deflection at the point of load of N in./min (mm/min), as determined by the equation:

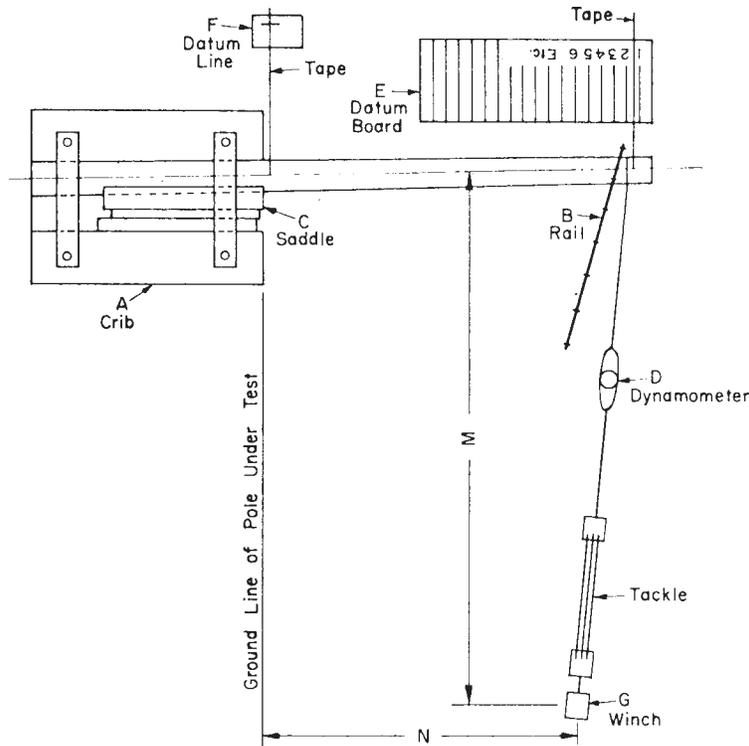
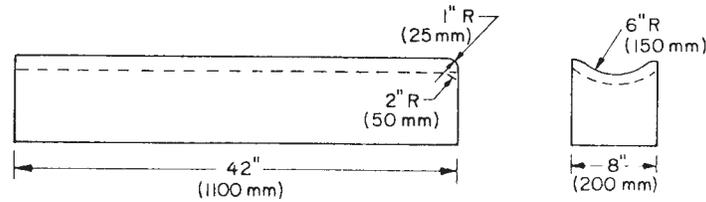
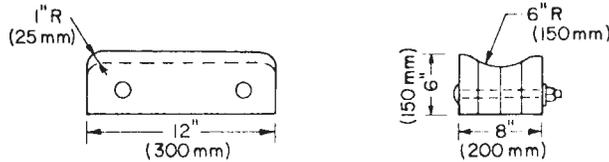


FIG. 1 Schematic Layout of Field Mechanical Tests of Wooden Poles



(a) Wooden Saddle, Solid or Laminated as Shown for Cradle.



(a) Wooden Saddle, Solid or Laminated as Shown for Cradle.

FIG. 2 Saddle and Cradle

$$N = 2\pi ZL^2/3C_t \quad (1)$$

where:

- N = rate of deflection, in./min (mm/min),
- Z = rate of fiber strain, in./in.·min (mm/mm·min) = 0.0010, the value specified in Test Methods D 198,
- L = lever arm, in. (mm), and
- C_t = circumference at point of load application, in. (mm).

14. Pulling Line

14.1 The pulling line shall be secured around the pole at the load point. The load measuring device shall be placed in series with the pulling line and the line to the winch with a free-running swivel on each side of it.

15. Winch Positions

15.1 If the winch G , Fig. 1, is set far enough away from the pole to make the angle between the initial and final positions of the pulling line small, the error in assuming that the pull is always perpendicular to the original direction of the pole axis will be negligible. The winch shall be located at the positions given in Table 1.

16. Load Measurement

16.1 Load shall be measured by a suitable measuring device placed in series in the pulling line. The recommended method

TABLE 1 Winch Positions

| Pole Length, ft (m) | Distance M from Pole Axis, ft (m) ^A | Distance N from Ground Line, ft (m) ^A |
|---------------------|--|--|
| 20 (6.1) | 100 (30.5) | 13.5 (4.1) |
| 22 (6.7) | 110 (33.5) | 15.5 (4.7) |
| 25 (7.6) | 125 (38.1) | 17.5 (5.3) |
| 30 (9.1) | 150 (45.7) | 22.0 (6.7) |
| 35 (10.7) | 175 (53.3) | 26.5 (8.1) |
| 40 (12.2) | 200 (61.0) | 31.0 (9.4) |
| 45 (13.7) | 225 (68.6) | 35.5 (10.8) |
| 50 (15.2) | 250 (76.2) | 40.0 (12.2) |
| 55 (16.8) | 275 (83.8) | 44.5 (13.6) |
| 60 (18.3) | 300 (91.4) | 49.0 (14.9) |

^ASee Fig. 1 for location of distances M and N .

is a calibrated metal tension bar fitted with calibrated electric-type strain gages, suitably wrapped or housed for protection against shock when the pole breaks. This method permits remote reading of loads and minimizes the possibility of personal injury during test. Alternatively, where electric-type strain gaging equipment is not available, load may be measured by a dynamometer of suitable capacity, graduated in 50-lb (200-N) divisions. Calibration of the dynamometer shall be checked at frequent intervals during the tests. The load-measuring device shall be supported on a sled or cradle moving on a suitable platform or level space. The sled or cradle and the surface on which it moves shall be such that the force required to pull it shall not add materially to the measured load on the pole.

17. Deflections

17.1 The deflection of the pole at the point of load shall be measured at such intervals of load as to provide not less than 15 simultaneous readings of load and deflection. A greater number of readings (25 to 40) is preferred. The measurement of the deflection of the load point shall be made in a direction perpendicular to the unloaded position of the pole axis. A measurement of the movement of the load point toward the butt resulting from the deflection shall also be made at each increment of load.

NOTE 4—These measurements may be facilitated if a piece of plywood (datum board), E , Fig. 1, is ruled with lines perpendicular to the unloaded axis of the pole and spaced 1 in. (25 mm) apart. The edge of the plywood board away from the pole may be used as the datum line from which the deflection is measured. Then as the pole is deflected under load, the tape by which the deflection is measured is kept parallel to the ruled lines and its motion toward the butt may be measured by noting the line to which the tape is parallel when the deflection is measured.

17.2 A second datum line shall be established at F , Fig. 1, from which movement of the ground line shall be measured.

17.3 Alternatively, the deflection of the pole may be measured with respect to a wire tightly stretched along the upper surface of the pole between the load point and a point 1 ft (300 mm) from the butt. The movement of the wire relative to the

position of the pole at the ground line can be observed by means of a suitable horizontal scale attached to the upper surface of the pole.

TABLE 2 Sample Data Sheet 1

Pole Strength Tests

Test Pole No. 26

| Observed Dynamometer Reading, lb | †* | | s [⚡] , in. | g [⚡] , in. | Remarks |
|--|---------------------------|--------|----------------------|----------------------|---------------------------|
| | Feet | Inches | | | |
| 0 | 10 | 8 3/4 | 5 | 0 | |
| 200 | 11 | 1/2 | 5 5/8 | 0 | |
| 400 | 11 | 3 7/8 | 6 1/4 | 1/16- | |
| 600 | 11 | 9 1/4 | 6 1/4 | 1/16+ | |
| 800 | 12 | 1 | 6 3/8 | 1/8 | |
| 1000 | 12 | 6 | 6 5/8 | 3/16 | Start time |
| 1200 | 12 | 10 3/8 | 6 3/4 | 3/16 | |
| 1400 | 13 | 4 1/8 | 7 1/8 | 1/4 | |
| 1600 | 13 | 11 1/2 | 7 3/8 | 5/16 | 3 m 4 s |
| 1800 | 14 | 8 3/8 | 7 1/2 | 3/8 | |
| 2000 | (14.95 = Lat. (g = Lat.)) | | | | 1840 Max. |
| 2200 | | | 10.0 | | short break at knot whorl |
| 2400 | | | (9.8 min) | | |
| 2600 | | | | | |
| 2800 | | | | | |
| 3000 | | | | | |
| 3200 | | | | | |
| 3400 | | | | | |
| 3600 | | | | | |
| 3800 | | | | | |
| 4000 | | | | | Total s = 5 |

*GL (Ground Line) = Point of support.
 † = Perpendicular distance from tip datum to load point.
 s = Distance load point moves toward butt.
 g = Distance pole moves at ground line.

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NOTE 1—This data sheet is an example using inch-pound units. If the metric equivalents were being used the quantities would be measured as follows:
 circumferences—mm
 lengths—m, s—mm
 dynamometer readings—N g—mm
 t—m

18. Procedure

18.1 Before any load is applied to the pole, take zero readings for the following and enter in the appropriate columns of Table 2 (Data Sheet 1):

18.1.1 On the tape which measures the deflection of the load point to the edge of the datum board, t ,

18.1.2 On the datum board the line to which the tape of 18.1.1 is parallel, s ,

18.1.3 On the tape for measuring ground line movement, g , and

18.1.4 On the horizontal scale at the ground line of the pole when the wire is used.

18.2 At this time also make the following measurements and record them in the appropriate place in Table 2 (Data Sheet 1):

18.2.1 Actual distance from butt of test pole to ground line (that is, point of support),

18.2.2 The distance from ground line to point of load,

18.2.3 Circumference at ground line and at point of load,

18.2.4 Species of timber,

18.2.5 Source of pole,

18.2.6 Preservative treatment if any, and

18.2.7 Test number.

18.3 Make the circumference measurements to the nearest 0.1 in. (2 mm).

18.4 The difference between the zero and any subsequent t readings measures the movement of the point of load in a direction perpendicular to the unloaded position of the pole axis. Similarly, the difference between the zero and subsequent s readings measures the movement of the point of load toward the pole butt in a direction parallel to the unloaded position of the pole axis. The data relative to the ground line movement, g readings, will be needed only for correction of the deflection readings and for a calculation of the modulus of elasticity if this characteristic is desired.

18.5 Apply the load continuously and at a uniform rate until the pole fails. At each increment in the load, as indicated by the load measuring device, make simultaneous readings of t , s , and g and record them in Table 2 (Data Sheet 1) until failure occurs in the pole. Record the maximum load shown by the load measuring device. After failure estimate the break location and measure and record the distance from this location to the point of load.

19. Test Results

19.1 *Load Correction*—Record the corrected load reading in the appropriate column of Table 3 (Data Sheet 2). Determine these corrected readings from calibration curves of the load measuring device.

19.2 *Lever Arm Correction*—The difference between the t and s readings and the zero readings made during each test are, respectively, measures of the movement of the point of load in a direction perpendicular to and parallel to the unloaded position of the pole axis. Deduct the difference between the zero and final s readings from the distance from point of load to ground line and from the distance from point of load to point

of break, to obtain the true lever arm for the calculation of the fiber stress at the ground line and at the breaking point, respectively.

19.3 *Load-Deflection Curve*—Plot a load-deflection curve for each pole tested.

19.4 *Calculations*—Calculate the maximum fiber stress at the ground line as follows:

$$F = 32\pi^2 P(L - \Delta_L)/C^3 \quad (2)$$

where:

F = maximum fiber stress at ground line, psi (MPa),

P = load at failure (corrected), lbf (N),

L = distance from ground line to point of load, in. (mm),

Δ_L = longitudinal deflection of the load point at the maximum load, in. (mm), and

C = circumference at ground line, in. (cm).

If the maximum fiber stress at break is desired, calculate it as follows:

$$F_b = 32\pi^2 P(a - \Delta_a)/C_a^3 \quad (3)$$

where:

F_b = maximum fiber stress, psi (MPa),

P = load at failure (corrected), lbf (N),

a' = distance from break to point of load, in. (mm),

$\Delta_{a'}$ = longitudinal deflection of break point at maximum load, a lever arm correction for stress at point of break, accounting for the lever arm shortening between the point of break and point of load, in. (mm), calculated as:

$$\Delta_{a'} = \Delta_L [1 - (b/L)^3] \quad (4)$$

where:

L = distance from ground line to point of load, in. (mm),

b = distance from ground line to point of break, in. (mm), and

Δ_L = longitudinal deflection of the load point at the maximum load, a lever arm correction for maximum ground line stress, accounting for the lever arm shortening between ground line and point of load, in. (mm), and

C_a = circumference at point of break, in. (mm).

The modulus of elasticity may be calculated as follows:

$$E = \frac{4L^3 P}{3\pi \Delta A^3 B} \quad (5)$$

TABLE 3 Sample Data Sheet 2

Pole Strength Tests

Test Pole No. 26

| Dynamometer | | Corrected** Deflection, in | Section | Circumference, in. | $F = \frac{K L P}{C^3}$ and $F_b = \frac{K L' P}{C_1^3}$ | | | | | | | | | | | | | | | | |
|----------------------|------------------------|----------------------------|---------------|--------------------|--|----------|--------|---------------------|-----|------------|---|--|-----|----------------|--|---------------------|-----|------------|---|--|-----|
| Observed Reading, lb | Corrected* Reading, lb | | | | | | | | | | | | | | | | | | | | |
| 0 | | | Butt | 27.1 | where: $K = 32\pi^2 = 315.82734$, L and L' = Lever arms in inches, P = maximum load in pounds, and C and C ₁ = circumferences at ground line and at break, respectively, in inches. | | | | | | | | | | | | | | | | |
| 200 | 190 | | 2' | 27.0 | | | | | | | | | | | | | | | | | |
| 400 | 350 | | 4' | 26.8 | | | | | | | | | | | | | | | | | |
| 600 | 550 | | 6' | 27.1 | | | | | | | | | | | | | | | | | |
| 800 | 780 | | 8' | 25.5 | | | | | | | | | | | | | | | | | |
| 1000 | 980 | | 10' | 24.9 | | | | | | | | | | | | | | | | | |
| 1200 | 1170 | | 12' | 24.5 | | | | | | | | | | | | | | | | | |
| 1400 | 1370 | | 14' | 23.7 | | | | | | | | | | | | | | | | | |
| 1600 | 1560 | | 16' | 23.1 | | | | | | | | | | | | | | | | | |
| 1800 | 1790 | | 18' | 22.8 | | | | | | | | | | | | | | | | | |
| 2000 | | | 20' | 21.8 | <table border="1"> <thead> <tr> <th>Distance</th> <th>Inches</th> </tr> </thead> <tbody> <tr> <td>Load Point to GL***</td> <td>270</td> </tr> <tr> <td>Total s***</td> <td>5</td> </tr> <tr> <td></td> <td>265</td> </tr> <tr> <td colspan="2">L = \swarrow</td> </tr> <tr> <td>Load Point to Break</td> <td>199</td> </tr> <tr> <td>Total s***</td> <td>5</td> </tr> <tr> <td></td> <td>194</td> </tr> </tbody> </table> | Distance | Inches | Load Point to GL*** | 270 | Total s*** | 5 | | 265 | L = \swarrow | | Load Point to Break | 199 | Total s*** | 5 | | 194 |
| Distance | Inches | | | | | | | | | | | | | | | | | | | | |
| Load Point to GL*** | 270 | | | | | | | | | | | | | | | | | | | | |
| Total s*** | 5 | | | | | | | | | | | | | | | | | | | | |
| | 265 | | | | | | | | | | | | | | | | | | | | |
| L = \swarrow | | | | | | | | | | | | | | | | | | | | | |
| Load Point to Break | 199 | | | | | | | | | | | | | | | | | | | | |
| Total s*** | 5 | | | | | | | | | | | | | | | | | | | | |
| | 194 | | | | | | | | | | | | | | | | | | | | |
| 2200 | | | 22' | 21.4 | | | | | | | | | | | | | | | | | |
| 2400 | | | 24' | 20.8 | | | | | | | | | | | | | | | | | |
| 2600 | | | 26' | 20.1 | | | | | | | | | | | | | | | | | |
| 2800 | | | 28' | 19.3 | | | | | | | | | | | | | | | | | |
| 3000 | | | 30' | 18.7 | | | | | | | | | | | | | | | | | |
| 3200 | | | GL | 26.9 | | | | | | | | | | | | | | | | | |
| 3400 | | | 11'5/4" Break | 24.6 | | | | | | | | | | | | | | | | | |
| 3600 | | | | | P = 1835 lb. $C^3 = 19465.109$ $C_1^3 = 14886.936$ (MR): 7890 psi. Maximum fiber stress at break section (MB): 7550 psi. | | | | | | | | | | | | | | | | |
| 3800 | | | | | | | | | | | | | | | | | | | | | |
| 4000 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |

* Corrections based on calibration curves.
 ** Corrected deflection = Difference between the t values of Table 2 (Data Sheet 1) for any load and zero load, minus a correction for movement at point of support.
 *** See Table 2 (Data Sheet 1).

See Table II (Data Sheet I)

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NOTE 1—This data sheet is an example using inch-pound units. It could also be used with metric equivalents where N would be substituted for lb and cm for ft.

where:

- E = modulus of elasticity, psi (MPa),
- L = length from ground line to tip support of wire, in. (mm),
- P = applied load at tip end, lbf, (N),
- Δ = observed deflection at the load point,
- A = radius of pole at ground line, in. (mm), and
- B = radius of pole at point where load is applied, in. (mm).

NOTE 5—If a crib consisting of vertical poles is used, the modulus of elasticity shall be calculated from the wire deflection at ground line, using the formula in 23.3.

NOTE 6—Since shear deformation makes a negligible contribution to the deflection of the pole in test, the modulus of elasticity calculated by the formula will correspond more nearly to the true (compression) modulus of elasticity of the wood than to the apparent (bending) modulus in the standard test of a small clear specimen.

Machine Test Method

20. Apparatus

20.1 The poles shall be tested in a hydraulic or mechanical testing machine with the load applied by the movable head of the testing machine at the ground line of the pole.

20.2 When the poles are short enough to permit supporting the tip end on an extension of the weighing platform, the load may be observed by means of the weighing system of the machine. The extension wing of the testing machine shall be secured in such a manner that it will be capable of carrying the loads applied to it. An arrangement of such a testing apparatus is shown schematically in Fig. 3(a). Alternatively, and for longer poles, one or both ends of the pole may be supported independently of the testing machine with provision for observing the load by means of a properly calibrated weighing device, such as a hydraulic weighing cell, at either or both ends or at the load point. Such an arrangement is shown in Fig. 3(b).

20.3 The pole shall rest at each end in cradles (Fig. 2) supported in rocker bearings free to rotate about a horizontal axis as the pole deflects. The cradle and rocker bearing at each end shall rest on rollers to accommodate longitudinal movement of the pole during test. The wood used for the cradles shall be no harder than that of the poles being tested.

20.4 The axis of rotation of the rocker bearings shall be 1 ft (300 mm) from the butt and 2 ft (600 mm) from the tip end of the pole, respectively. The poles shall be placed in the cradles with the grained side up.

21. Deflection

21.1 Deflection of the pole under test shall be measured at the ground line.

NOTE 7—The deflection may be measured by stringing a fine wire taut between nails driven into the neutral axis of the pole directly over the end supports, and crossing a scale secured to the pole at the ground line.

22. Procedure

22.1 Apply the load continuously until the pole fails and at such a rate of speed as to cause a deflection at the point of load of *N* in./min (mm/min), as determined by the equation:

$$N = 2\pi abZ/3C_1 \tag{6}$$

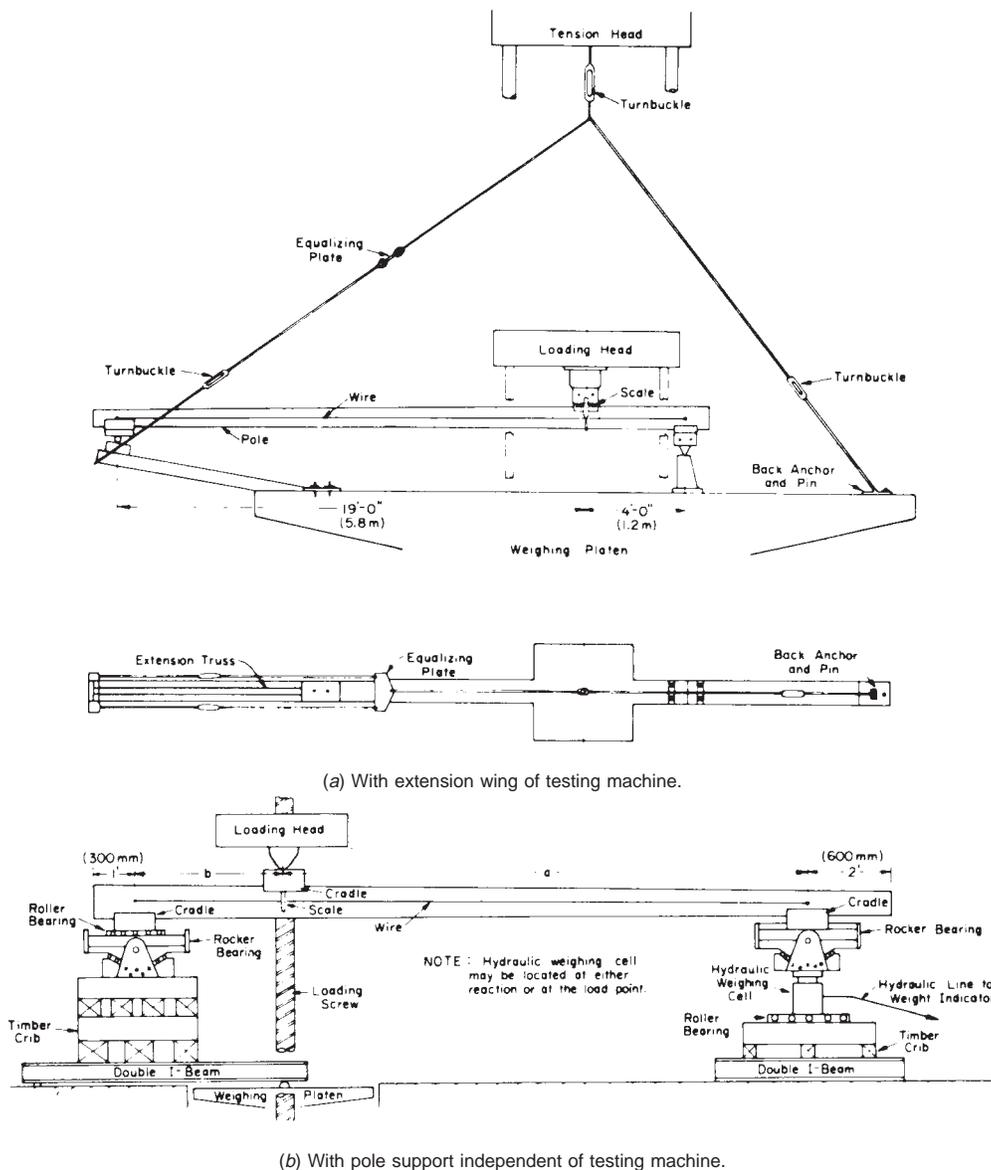


FIG. 3 Schematic Diagram of Set-up for Testing Wooden Poles in Transverse Bending

where:

- N = rate of deflection, in./min (mm/min),
- Z = rate of fiber strain, in./in.·min (mm/mm·min), = 0.0010, which is the value specified in Test Methods D 198,
- a = distance from tip bearing to point of load, in. (mm),
- b = distance from butt bearing to point of load, in. (mm), and
- C_l = circumference at point of load, in. (mm).

22.2 Take deflection readings at such increments of load as to provide not less than 15 simultaneous readings of load and deflection. A greater number of readings (25 to 40) is preferred.

22.3 Note each failure as it occurs and mark its location on a sketch of the pole.

23. Report and Calculation

23.1 Figs. 4 and 5 indicate two forms in which the test data may be recorded.

23.2 Calculations—If the weight of the section of pole from the load point to the tip end has been determined, the maximum fiber stress at ground line may be calculated as follows:

$$T = Pb/L \tag{7}$$

U.S. DEPARTMENT OF AGRICULTURE

TREATED SPECIES DOUGLASS FIR FOREST SERVICE WORKED BY L. H.

SHIP NO. _____ FOREST PRODUCTS LABORATORY CARDS WORKED BY _____

PROJECT NO. 50-3-161 POLE NO. F-120 CHECKED BY _____

TABULATION SHEET DATE SEPT. 13, 1956

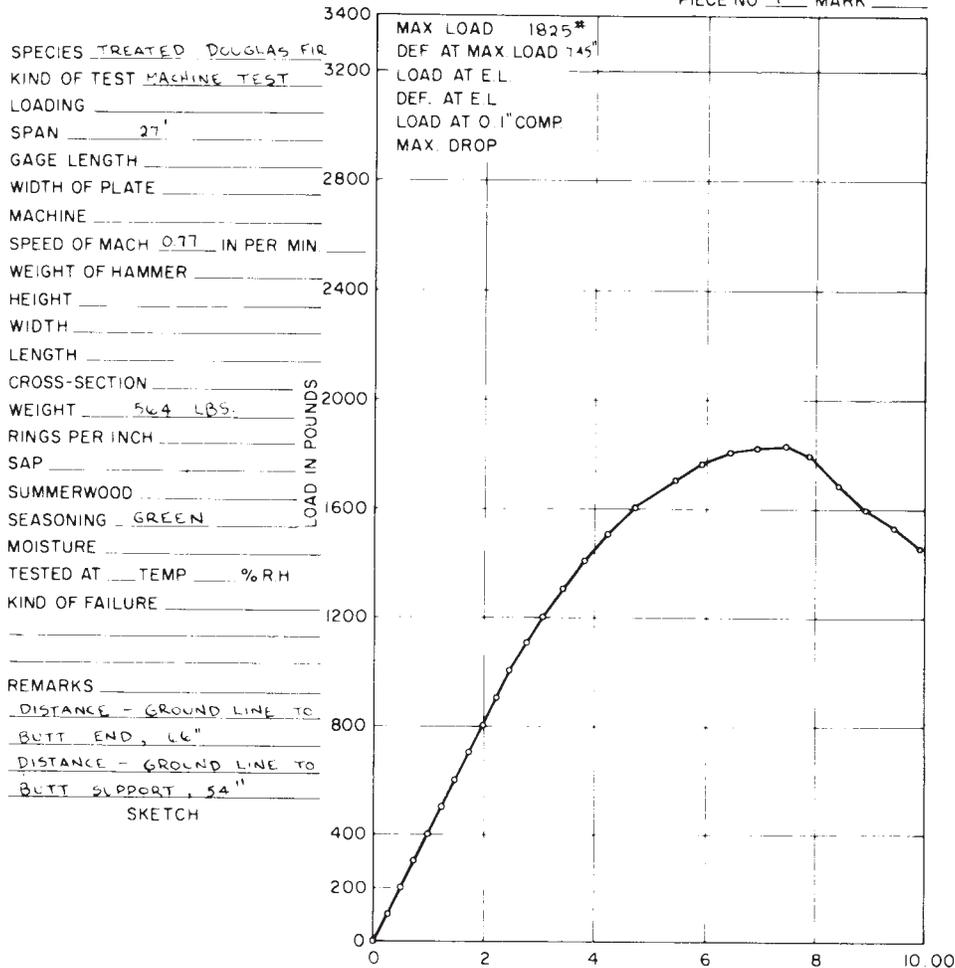
| LOAD | DEFLECTIONS | | | | | NOTES |
|----------|----------------|------------|------------|------------|--|-----------------------------|
| | AT GROUND LINE | | AT MIDSPAN | | | |
| | READING | DIFFERENCE | READING | DIFFERENCE | | |
| (1) | (2) | (3) | (4) | (5) | | |
| lbs. | IN. | IN. | IN. | IN. | | |
| 0 | 23.55 | 0.00 | 13.15 | | | |
| 100 | .80 | .25 | 13.60 | | | |
| 200 | 24.05 | .50 | 14.00 | | | |
| 300 | .29 | .74 | 14.40 | | | |
| 400 | .54 | .99 | 14.85 | | | |
| 500 | .79 | 1.24 | 15.25 | | | |
| 600 | 25.02 | 1.47 | 15.65 | | | |
| 700 | .29 | 1.74 | 16.10 | | | |
| 800 | .54 | 1.99 | 16.50 | | | |
| 900 | .79 | 2.24 | 16.92 | | | |
| 1000 | 26.04 | 2.49 | 17.32 | | | |
| 1100 | .34 | 2.79 | 16.80 | | | |
| 1200 | .64 | 3.09 | 17.30 | | | |
| 1300 | 27.00 | 3.45 | 18.80 | | | |
| 1400 | .38 | 3.83 | 19.40 | | | |
| 1500 | .79 | 4.24 | 20.05 | | | |
| 1600 | 28.32 | 4.77 | 20.82 | | | |
| 1700 | 29.00 | 5.45 | 21.80 | | | |
| 1755 | .50 | 5.95 | 22.50 | | | |
| 1795 | 30.00 | 6.45 | 23.15 | | | |
| 1815 | .50 | 6.95 | 23.80 | | | |
| MAX-1825 | 31.00 | 7.45 | 24.35 | 11.20 | | COMPRESSION NEAR LOAD AT 6' |
| 1780 | .50 | 7.95 | 24.85 | | | CREAKING |
| 1680 | 32.00 | 8.45 | 24.95 | | | CREAKING |
| 1585 | .50 | 8.95 | 25.05 | | | CREAKING AND SPLITTING |
| 1525 | 33.00 | 9.45 | 25.25 | | | CREAKING |
| 1445 | .50 | 9.95 | 25.45 | | | CREAKING |
| 1380 | .75 | 10.20 | 25.20 | | | CREAKING |
| 1220 | .85 | 10.30 | 25.15 | | | FAILED |
| 1130 | 34.25 | 10.70 | 25.15 | | | |

NOTE 1—This figure is an example of data recorded using inch-pound units. The same arrangement could be used with the metric equivalents with load in newtons and deflections in millimetres.

FIG. 4 Tabulation of Data Observed in Machine Test

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

FILE NO. STR 6-4-B MEASURED _____
 COST CHARGE 50-3-161 TESTED L.H. RS. SD
 LABORATORY NO. 424762A STATION MADISON DATE 9-13-26 SHIP NO. _____ POLE NO. 120
 PIECE NO. F MARK _____



NOTE 1—Metric equivalents may be substituted for the inch-pound units.
FIG. 5 Load-Deflection Curve and Related Data in Machine Test

$$F = \frac{\left(T + t - \frac{w}{2}\right)a}{0.0982d^3}$$

where:

- T = tip reaction at maximum load due to superimposed load, lbf (N),
- P = maximum superimposed load on pole, lbf (N),
- b = distance from load point to butt support, in. (mm),
- L = distance between the tip and butt supports, in. (mm),
- F = maximum fiber stress at ground line, psi (MPa),
- a = distance from load point to tip support, in. (mm),
- t = tip reaction due to dead weight of pole, lbf (N),
- d = diameter of pole at load point, in. (mm), and
- w = weight of section of pole from the load point to the tip end, lbf (N).

NOTE 8—The equation assumes that the center of gravity of the section of the pole above the ground line acts at a distance of $a/2$ from the load point. If so desired, the center of gravity can be determined by balancing the section on a narrow fulcrum and the equation altered accordingly for each pole. Experience has indicated that the error involved in using the distance $a/2$ when calculating bending stress is usually negligible, except in long and large poles.

23.3 Annex A2 provides an equation for calculating an effective modulus of elasticity for a tapered round timber tested following procedures recommended in this section.

NOTE 9—Since shear deformation makes a negligible contribution to the deflection of the pole in test, the modulus of elasticity calculated by the formula will correspond more nearly to the true (compression) modulus of elasticity of the wood than to the apparent (bending) modulus in the standard test of a small clear specimen.

PROCEDURE AFTER TESTING

24. Photographs

24.1 Take a photograph or make a sketch of each pole failure as a portion of the permanent record of the tests.

25. Age, Rate of Growth, and Moisture Determination

25.1 Cut two disks, each 1 in. (25 mm) in thickness, from the pole approximately 1 ft (300 mm) from the ground line toward the butt. Determine the age, sapwood thickness, and number of rings per inch (average ring width in millimetres) from one disk.

25.2 Reserve the other disk for moisture and specific gravity determinations. Split the disk along radii into six approximately equal sectors. If any of the sectors contain knots, split these off and discard all knotty portions.

25.3 Select three alternative (nonadjacent) knot-free sectors for the determination of the moisture content, and if desired, the retention of preservative. Retain the other three sectors for the determination of specific gravity (see 25.4). Split the sapwood off each of the moisture sectors and remove all splinters and sawdust from the sapwood and heartwood pieces remaining. Immediately obtain the weights of the sapwood and heartwood pieces. Store the specimens of sapwood and heartwood in suitably labeled containers until tests for moisture content (and preservative retention) can be made. Make moisture determinations of untreated specimens and tests for the moisture content and preservative retention of treated specimens by standard methods.

25.4 Determine the volume of the specific gravity sectors by displacement as soon as possible after the sectors are cut. Oven dry the sectors and determine the specific gravity as follows:

$$\text{Specific gravity} = \frac{\text{oven dry weight, g}}{\text{volume, cm}^3} \quad (8)$$

26. Specimens for Minor Tests

26.1 Cut minor specimens from the end of the butt section nearest the disks mentioned in Section 25 or from a section cut from the butt of the pole prior to the major test. Determine the number and types of specimens to be taken for minor tests in accordance with the overall objectives of the test program (3.2). As a minimum, however, take five 2 by 2 by 40-in. (50 by 50 by 1000-mm) test samples to furnish five static bending and five compression-parallel-to-grain specimens. When poles are of such small size as to preclude the use of test specimens 2 by 2 in. (50 by 50 mm) in cross section, specimens 1 by 1 in. (25 by 25 mm) in cross section may be used in accordance with Methods D 143. All specimens shall be clear and free of defects. When the minimum number of specimens mentioned above is taken, they shall be from as near the surface of the butt as possible and shall not have surface defects or imperfections. Each specimen shall be marked to show its position relative to the compression side of the pole and shall also bear the number of the pole from which it was taken as well as its own number.

NOTE 10—If 40-in. (1000-mm) specimens cannot be obtained from the butt section, 30-in. (760-mm) specimens shall be obtained and five additional specimens each 2 by 2 by 10 in. (50 by 50 by 250 mm) shall be taken for tests of compression parallel to grain.

26.2 Handle all minor test specimens in such a manner as to keep the moisture content above fiber saturation until tested.

27. Procedure for Minor Tests

27.1 The procedure for conducting the minor tests, including a determination of moisture content and specific gravity, shall conform to that prescribed in Methods D 143.

TABULATION OF RESULTS

28. Tabulation of Results

28.1 A table shall be prepared, listing the following information for each pole:

- 28.1.1 Pole number,
- 28.1.2 Species,
- 28.1.3 Treatment,
- 28.1.4 Seasoning condition,
- 28.1.5 Preservative retention (if known),
- 28.1.6 Age in service (if pole had been in service),
- 28.1.7 Age of pole since treatment,
- 28.1.8 Source of pole (supplier, region and climate, if pole had been in service),
- 28.1.9 Classification standard,
- 28.1.10 Condition of pole (decay, woodpecker holes, splits) if pole had been in service,
- 28.1.11 Average moisture content of butt section of pole,
- 28.1.12 Moisture content of heartwood at ground line,
- 28.1.13 Moisture content of sapwood at ground line,
- 28.1.14 Specific gravity of pole, volume as tested, weight oven-dry,
- 28.1.15 Rate of growth, rings per inch (average ring width in millimetres),
- 28.1.16 Age of tree, years,
- 28.1.17 Sapwood, percent of total cross-section,
- 28.1.18 Sapwood, depth in inches (millimetres),
- 28.1.19 Weight of pole, pounds (kilograms),
- 28.1.20 Temperature of pole at time of test,
- 28.1.21 Circumference of pole at ground line, inches (millimetres),
- 28.1.22 Circumference of pole at break, inches (millimetres),
- 28.1.23 Circumference of pole at butt, inches (millimetres),
- 28.1.24 Circumference of pole at tip, inches (millimetres),
- 28.1.25 Maximum load, pounds-force (newtons),
- 28.1.26 Maximum fiber stress at ground line, pounds-force per square inch (megapascals),
- 28.1.27 Maximum fiber stress at break, pounds per square inch (megapascals), if calculated, and
- 28.1.28 Modulus of elasticity, if calculated, pounds-force per square inch (megapascals).

29. Precision and Bias

29.1 A statement of precision and bias for this test method has not yet been developed.

30. Keywords

30.1 bending; cantilever; fiber stress; moisture content; poles

ANNEXES
(Mandatory Information)
A1. APPARATUS DESIGN AND EXAMPLES OF OBTAINING DATA

A1.1 Since these test methods cover, in general, the kinds of data to be collected in a series of tests, and specific directions as to how these data should be taken are not given, it is thought the following information on apparatus design and descriptions of how certain data were obtained in successful tests might be helpful.

A1.2 Fig. A1.1 shows a field layout which has been used, with crib *A*, test pole, supporting rail *E*, pulling tackle *G*, and winch *H*. The sketch indicates winch positions for three lengths of poles. Details of parts of the testing apparatus are also included. Points *B* and *C* are reference points for measuring the movement of the ground line and the load point of the test pole, respectively. The sand plank barrier at *D* is a safety device to protect against failure of the tackle or pulling line. The screens *F* are to protect the person reading the dynamometer from possible breaks in the pulling line.

A1.3 Fig. A1.2 shows details of a concrete testing crib and crib fittings that have proven adequate for conducting pole tests.

A1.4 A convenient and satisfactory method of making the readings of the various data required is to have the person reading the load on the dynamometer blow a whistle for each 200-lbf (1000-N) increment of load. The person reading the deflection then reads the tape for deflection and the location of the tape, and the tape for the movement of the pole at the ground line is then read. If one person is designated as the recorder, he may make his record easily if a sequence is established for the readings to be shouted out after each whistle.

A1.5 The following is a method for recording knots and defects that has also proved convenient:

A1.5.1 The pole to be measured is laid out on skids.

A1.5.2 Before measuring, the pole is rolled so that its face (that is, its grain side) is up.

A1.5.3 The zero end of a steel tape is secured to the butt surface of the pole in such a manner that the zero mark coincides with the uppermost point of the butt surface.

A1.5.4 The tape is then stretched taut along the longitudinal center line of the face of the pole and secured to the top surface of the pole.

A1.5.5 At the midpoint, the tape is secured to the pole to prevent sag when the pole is subsequently rolled for knot measurement.

A1.5.6 At intervals of 2 ft (600 mm), beginning at the extreme butt, circumferences are measured and recorded. The pole is then rolled through an angle of 90° and secured.

A1.5.7 Using the tape as a reference line, the diameter of each knot more than ½ in. (13 mm) in diameter, its distance from the butt, and its distance circumferentially from the tape are measured and recorded.

A1.5.8 A record is made of any strength reducing defects other than knots that may be present. Fig. A1.4 shows a form that will assist in making those records.

A1.6 The “Working Plan for Grading Hardwood Logs” dated Jan. 1, 1947, and issued by the Forest Products Laboratory at Madison, WI, contains directions for noting defects, etc., on a form for logs. These directions and form could be easily adapted for use in pole tests.

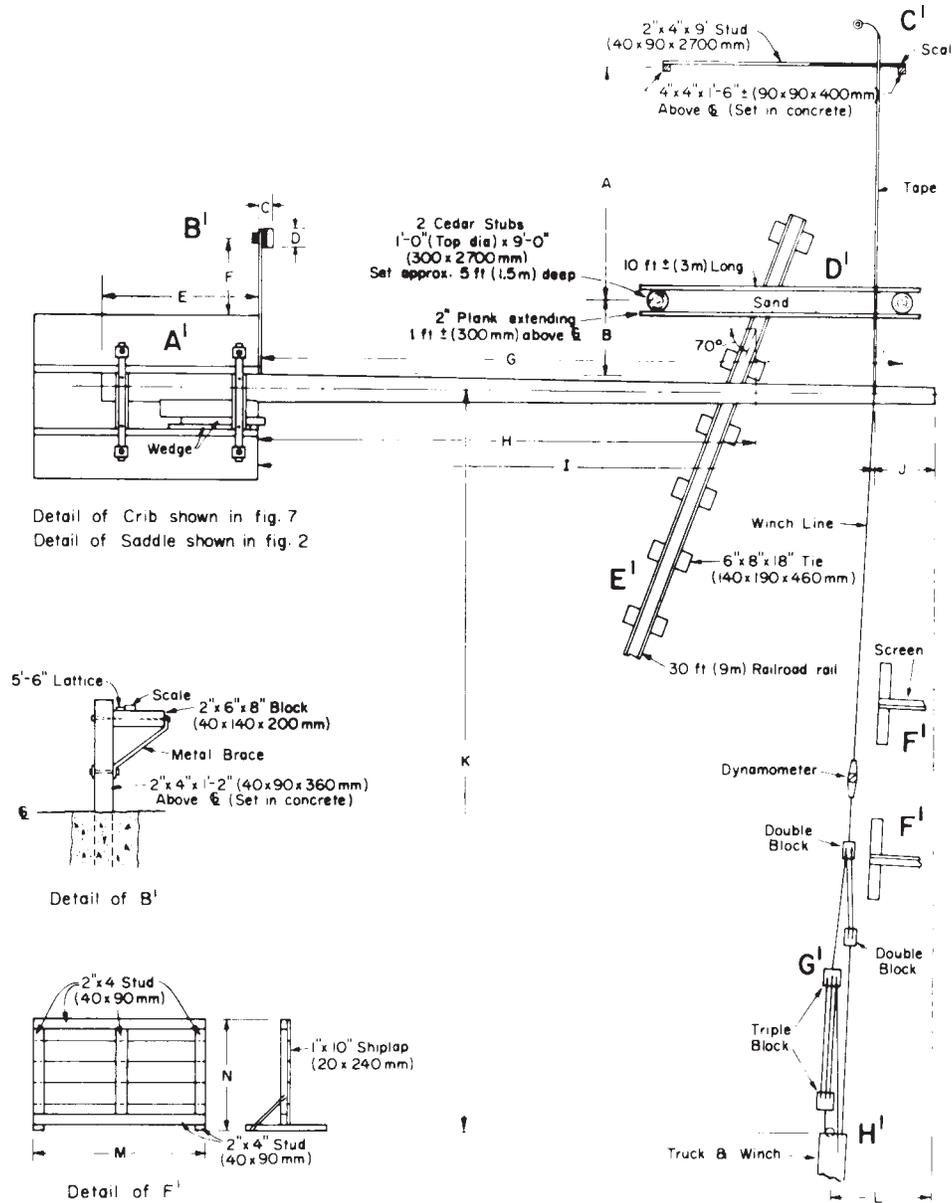


FIG. A1.1 A Field Layout Which has Been Used for Pole Strength Tests

| Dimension | Inch-Pound Units | Metric Equivalent | Dimension | Inch-Pound Units | Metric Equivalent |
|-----------|------------------|-------------------|-----------|------------------|-------------------|
| A | 8 ft 4 in. | 2.5 m | H | 17 ft 9 in. | 5.4 m |
| B | 2 ft 9 in. | 840 mm | I | 22 ft 6 in. | 6.9 m |
| C | 6 in. | 150 mm | J | 2 ft | 600 mm |
| D | 8 in. | 200 mm | K | 150 ft | 45.7 m |
| E | 5 ft 6 in. | 1.7 m | L | 2 ft 6 in. | 760 mm |
| F | 2 ft 10 in. | 860 mm | M | 6 ft | 1.8 m |
| G | 23 ft 6 in. | 7.2 m | N | 4 ft | 1.2 m |

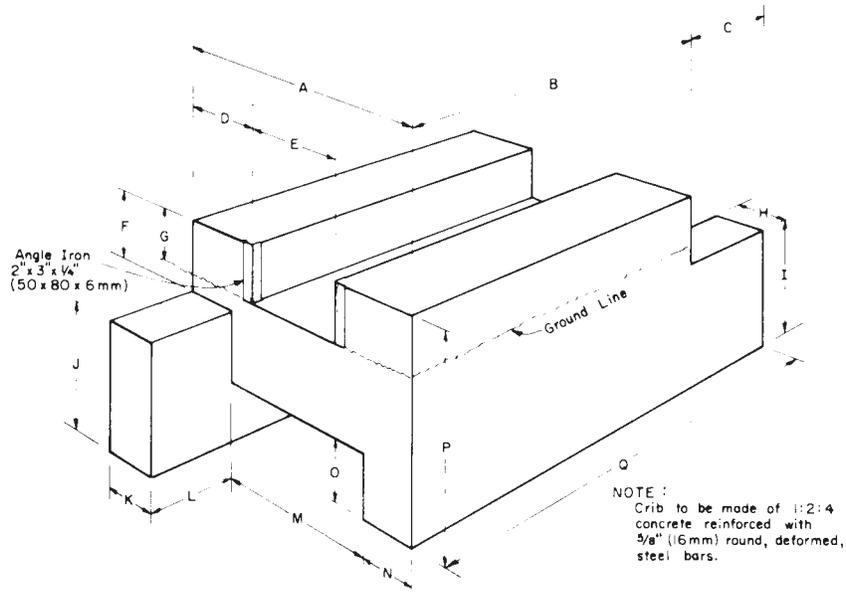
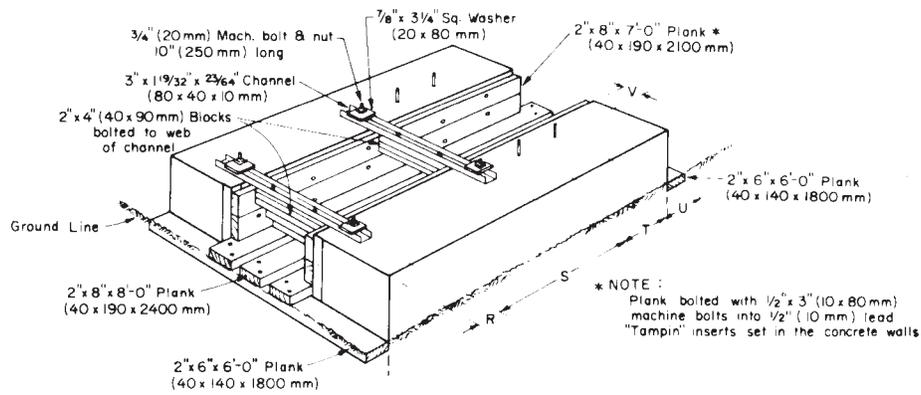


FIG. A1.2 Concrete Testing Crib



| Dimension | Inch-Pound Units | Metric Equivalents | Dimensions | Inch-Pound Units | Metric Equivalents |
|-----------|------------------|--------------------|------------|------------------|--------------------|
| A | 6 ft | 1.8 m | L | 2 ft | 610 mm |
| B | 7 ft | 2.1 m | M | 3 ft 6 in. | 1070 mm |
| C | 2 ft | 610 mm | N | 1 ft 3 in. | 380 mm |
| D | 1 ft 11 in. | 580 mm | O | 1 ft 6 in. | 460 mm |
| E | 2 ft 2 in. | 660 mm | P | 5 ft | 1.5 m |
| F | 1 ft 10 in. | 560 mm | Q | 9 ft | 2.7 m |
| G | 1 ft 6 in. | 460 mm | R | 5 in. | 130 mm |
| H | 1 ft 3 in. | 380 mm | S | 3 ft 1 in. | 940 mm |
| I | 3 ft 2 in. | 970 mm | T | 1 ft | 300 mm |
| J | 3 ft 2 in. | 970 mm | U | 1 ft | 300 mm |
| K | 1 ft 3 in. | 380 mm | V | 5 in. | 130 mm |

FIG. A1.3 Wood Plank and Steel Fittings for Crib

PLANT: *Spartanburg-Chester* KIND OF TIMBER: *Lo. Pine* CLASS-LENGTH: *6-30*
 ENGINEER: *A. H. H. and R. C. E.* DATE: *4-12-39*

| Height (ft) | BUTT OF POLE | | | | | | | | | | | | SUM OF DIAMETERS | CIRCUM-FERENCE | REMARKS 289 | | | |
|-------------|--------------|-----|-----|-----|-----|----|----|----|----|----|-----|-----|------------------|----------------|-------------|------|------|-------------------------|
| | 28" | 24" | 20" | 16" | 12" | 8" | 4" | 0" | 4" | 8" | 12" | 16" | | | | 20" | 24" | 28" |
| 1' | | | | | | | | | | | | | | | | 27.1 | 27.1 | <i>Test Pole No. 26</i> |
| 2' | | | | | | | | | | | | | | | | | 27.0 | |
| 3' | | | | | | | | | | | | | | | | | | |
| 4' | | | | | | | | | | | | | | | | | 26.8 | <i>Suspended Butt</i> |
| 5' | | | | | | | | | | | | | | | | | | |
| 6' | | | | | | | | | | | | | | | | | 27.1 | |
| 7' | | | | | | | | | | | | | | | | | | |
| 8' | | | | | | | | | | | | | | | | | 25.5 | |
| 9' | | | | | | | | | | | | | | | | | | |
| 10' | | | | | | | | | | | | | | | | | 24.9 | |
| 11' | | | | | | | | | | | | | | | | | | |
| 12' | | | | | | | | | | | | | | | | | 4.7 | 24.5 |
| 13' | | | | | | | | | | | | | | | | | | |
| 14' | | | | | | | | | | | | | | | | | | 23.7 |
| 15' | | | | | | | | | | | | | | | | | | |
| 16' | | | | | | | | | | | | | | | | | | 23.1 |
| 17' | | | | | | | | | | | | | | | | | | |
| 18' | | | | | | | | | | | | | | | | | | 22.8 |
| 19' | | | | | | | | | | | | | | | | | | |
| 20' | | | | | | | | | | | | | | | | | | 21.8 |
| 21' | | | | | | | | | | | | | | | | | | |
| 22' | | | | | | | | | | | | | | | | | 5.2 | 21.4 |
| 23' | | | | | | | | | | | | | | | | | | |
| 24' | | | | | | | | | | | | | | | | | | 20.8 |
| 25' | | | | | | | | | | | | | | | | | | |
| 26' | | | | | | | | | | | | | | | | | | 20.1 |
| 27' | | | | | | | | | | | | | | | | | 4.7 | |
| 28' | | | | | | | | | | | | | | | | | | 19.3 |
| 29' | | | | | | | | | | | | | | | | | | |
| 30' | | | | | | | | | | | | | | | | | | 18.7 |
| 31' | | | | | | | | | | | | | | | | | | |
| 32' | | | | | | | | | | | | | | | | | | |
| 33' | | | | | | | | | | | | | | | | | | |
| 34' | | | | | | | | | | | | | | | | | | |
| 35' | | | | | | | | | | | | | | | | | | |
| 36' | | | | | | | | | | | | | | | | | | |
| 37' | | | | | | | | | | | | | | | | | | |
| 38' | | | | | | | | | | | | | | | | | | |
| 39' | | | | | | | | | | | | | | | | | | |
| 40' | | | | | | | | | | | | | | | | | | |

TOP OF POLE

↙ = BREAK POINT

○ = MAX SINGLE AND MAX GROUP OF KNOTS

NOTE 1—This form is an example for use with inch-pound units. A similar form could be used with metric equivalents, with the grid layed out in terms of millimetres.

FIG. A1.4 Sample Form for Recording Defects

A2. CALCULATION OF MOE BASED ON DEFLECTION AT GROUND LINE

A2.1 The derivation of MOE presented in this annex is based on the moment-area method applied to a beam of varying section properties with the load applied at a point located a distance of 10 % of the pole length plus 2 ft from the butt end.

A2.2 Assumptions—The derivation is intended to compute deflection of a tapered pole relative to its dead load deflection: weight of the pole is not included. It assumes a linear taper (s-in./in.) and no variation in MOE along the length. An

empirical equation of the distance from the tip reaction to the point of maximum deflection is used to simplify the derivation. This equation was derived using a simulation routine that comprised a range of pole lengths (40 to 80 ft), pole tapers (0.001 to 0.05 in./in.) and tip diameters (6 to 12 in.).

A2.3 Outline of Basic Approach Used in the Derivation:

A2.3.1 Estimate the point of maximum deflection:

(1) First moment of area under M/EI about butt end reaction divided by span will give the deflection angle at the tip.

(2) The point where the area under the M/EI , beginning at tip, equals the angle found in Step 1 is the point of maximum deflection.

(3) First moment of area between tip reaction and point of maximum deflection about an axis through the tip reaction gives the maximum deflection.

(4) First moment of area under M/EI between the load point and point of maximum deflection about an axis through the load point gives maximum deflection relative to load point deflection.

A2.3.3 List of Parameters:

- d_b = butt diameter (in.).
- d_t = tip diameter (in.).
- d_p = diameter at load point (in.).
- L = test span (in.).
- b = butt reaction to load.
- a = distance from tip to load point (in.).
- A = distance from tip to point of maximum deflection (in.).
- s = taper (in./in.).
- E = bending MOE.

A2.3.2 Solve resulting deflection equation for E .

$$\delta = \int_0^L \frac{P \cdot a \cdot 20.37}{L \cdot E} \cdot \frac{x^2}{[d_t + s \cdot (L - x)]^4} dx - \int_b^L \frac{20.37 \cdot P}{E} \cdot \frac{x - b}{[d_t + s \cdot (L - x)]^4} \cdot x dx$$

$$\theta = \frac{\delta}{L}$$

$$\theta = \frac{3.395 \cdot P \cdot a \cdot b}{L \cdot E} \cdot \left[\frac{d_t \cdot (L + b) + s \cdot L \cdot a}{d_b \cdot d_p^2 \cdot d_t^2} \right]$$

$$\Delta_\theta = \int_0^A \frac{20.37 \cdot P \cdot b}{L \cdot E} \cdot \frac{x}{(d_t + s \cdot x)^4} dx = \text{Curvature}$$

$$\Delta_\theta = (-3.395 \cdot d_t - 10.185 \cdot s \cdot A) \cdot P \cdot \frac{b}{[s^2 \cdot [(d_t + s \cdot A)^3 \cdot (L \cdot E)]]} + \frac{3.395}{d_t^2} \cdot P \cdot \frac{b}{[s^2 \cdot (L \cdot E)]}$$

$$\Delta_\theta = \frac{3.395 \cdot P \cdot b \cdot A^2}{L \cdot E \cdot d_t^2} \cdot \frac{(3 \cdot d_t + s \cdot A)}{[(d_t + s \cdot A)^3]}$$

A is the point where $\theta = \Delta_\theta$

$$A^2 \cdot \frac{3 \cdot d_t + s \cdot A}{(d_t + s \cdot A)^3} = a \cdot \left[\frac{d_t \cdot (L + b) + s \cdot L \cdot a}{d_b \cdot d_p^2} \right]$$

$$A^2 \cdot (3 \cdot d_t + s \cdot A) - K \cdot (d_t + s \cdot A)^3 = 0$$

Solve for A , the distance from the tip to the point of maximum deflection:

$$A = \frac{\left[\frac{-1 \cdot d_t^3}{s^3 \cdot (1 - K \cdot s^2)} + \sqrt{K} \cdot \frac{d_t^3}{s^2 \cdot (-1 + K \cdot s^2)^{\left(\frac{3}{2}\right)}} \right]^{\left(\frac{2}{3}\right)} \cdot \left[\frac{-d_t^2}{(1 - K \cdot s^2) \cdot s^2} \right]}{\left[\frac{-1 \cdot d_t^3}{s^3 \cdot (1 - K \cdot s^2)} + \sqrt{K} \cdot \frac{d_t^3}{s^2 \cdot (-1 + K \cdot s^2)^{\left(\frac{3}{2}\right)}} \right]^{\left(\frac{1}{3}\right)} \cdot \left[\frac{-1 \cdot d_t^3}{(1 - K \cdot s^2) \cdot s^3} + \sqrt{K} \cdot \frac{d_t^3}{s^2 \cdot (-1 + K \cdot s^2)^{\left(\frac{3}{2}\right)}} \right]^{\left(\frac{1}{3}\right)}} - \frac{d_t}{s}$$

As this is primarily a function of span length (L), taper (s) and tip diameter (d_t), values that can be measured only to a limited accuracy, the following empirical expression was derived for pole lengths extending from 40 to 70 ft with tapers ranging from 0.001 in./in. to 0.05 in./in. and tip diameters ranging from 6 to 12 in.

$$A = L \cdot \left(-0.0104 \cdot \frac{1}{12} \cdot s^{0.5} \cdot L - 1.6 \cdot s + 0.0077 \cdot d_t + 0.5 \right)$$

where L is the pole length in inches, s is the taper (%), and d_t is the tip diameter in inches.

Estimate the maximum deflection:

$$\delta_A = \int_0^A \frac{20.37 \cdot P \cdot b}{L \cdot E} \cdot \frac{x^2}{(d_i + s \cdot x)^4} dx$$

$$\delta_A = (-6.79 \cdot d_i^2 - 20.37 \cdot s^2 \cdot A^2 - 20.37 \cdot d_i \cdot s \cdot A) \cdot P \cdot \frac{b}{[s^3 \cdot (d_i + s \cdot A)^3 \cdot (L \cdot E)]} + \frac{6.79}{d_i} \cdot P \cdot \frac{b}{[s^3 \cdot (L \cdot E)]}$$

$$\delta_A = 6.79 \cdot P \cdot b \cdot \frac{A^3}{[(d_i + s \cdot A)^3 \cdot [L \cdot (E \cdot d_i)]]}$$

Estimate deflection at the load point:

$$\delta_p = \int_{(L-a)}^{(L-A)} \frac{20.37 \cdot P \cdot (L-a)}{L \cdot E} \cdot \frac{(a-x) \cdot (x-L+a)}{[d_i + s \cdot (L-x)]^4} dx \quad \text{displacement relative to maximum}$$

$$\delta_p = 3.395 \cdot P \cdot (-1 \cdot L + a) \cdot \frac{[[A^3 \cdot (4 \cdot s \cdot a - s \cdot L + 2 \cdot d_i) + 3 \cdot A^2 \cdot (2 \cdot s \cdot a^2 + L \cdot d_i)] - 3 \cdot A \cdot a \cdot [2 \cdot d_i \cdot (L-a) + s \cdot L \cdot a] + a^2 \cdot [2 \cdot s \cdot a \cdot (a-L) + d_i \cdot (4 \cdot a - 3 \cdot L)]]}{[(d_i + s \cdot A)^3 \cdot [L \cdot [E \cdot (d_i + s \cdot a)^2]]]}$$

$$\Delta_p = \delta_A - \delta_p$$

$$\Delta_p = 6.79 \cdot P \cdot (L-a) \cdot \frac{A^3}{[(d_i + s \cdot A)^3 \cdot [L \cdot (E \cdot d_i)]]}$$

$$+ \left[3.395 \cdot P \cdot (-1 \cdot L + a) \cdot \frac{(-6 \cdot s \cdot A^2 \cdot a^2 + 4 \cdot s \cdot a \cdot A^3 - 1 \cdot s \cdot L \cdot A^3 + 2 \cdot d_i \cdot A^3 + 6 \cdot L \cdot A \cdot d_i \cdot a - 6 \cdot d_i \cdot A \cdot a^2 + 3 \cdot s \cdot L \cdot A \cdot a^2 - 3 \cdot a^2 \cdot L \cdot d_i + 2 \cdot s \cdot a^4 + 4 \cdot a^3 \cdot d_i - 2 \cdot s \cdot a^3 \cdot L - 3 \cdot L \cdot d_i \cdot A^2)}{[(d_i + s \cdot A)^3 \cdot [L \cdot [E \cdot (d_i + s \cdot a)^2]]]} \right]$$

Solving for E gives:

$$E = \frac{3.395 \cdot P \cdot (L-a)}{L \cdot \Delta_p \cdot [d_i \cdot (d_i + s \cdot A)^3 \cdot (d_i + s \cdot a)^2]} \cdot K$$

$$K = A^3 \cdot [s \cdot (2 \cdot s \cdot a^2 + d_i \cdot L)] + A^2 \cdot [3 \cdot d_i \cdot (2 \cdot s \cdot a^2 + L \cdot d_i)] + A \cdot [6 \cdot d_i^2 \cdot (a^2 - L) - 3 \cdot d_i \cdot s \cdot L \cdot a^2] + C$$

$$C = d_i \cdot a^2 \cdot [d_i \cdot (3 \cdot L - 4 \cdot a) + 2 \cdot s \cdot a \cdot (1 - a)]$$

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