CHAPTER VII

INSULATORS

Insulators for high-tension power transmission are now almost invariably made of porcelain although some glass insulators are used. A few lines have been equipped with insulators made of "Electrose" which is a patented composition. These are more satisfactory than porcelain because they are lighter and not so susceptible of mechanical injury due to shock or electrical discharge, as porcelain. They are, however, more expensive. The production of an insulator which will resist the high voltages of the lines which they support presents no little difficulty. It is not, however, normal line voltages which fix the necessary dielectric strength of the insulator. Transmission lines are subject to transient potentials, which are very high as compared with the normal line voltage and the frequency of which may be many thousand cycles. In some tests made by Imlay and Thomas, in 1912, it was discovered that insulators which successfully resisted the application of 240,000 volts at normal frequency of 60 cycles per second failed under the application of slightly over 100,000 volts when subjected to high-frequency voltage. From these considerations it follows that the design and dielectric strength of an insulator must be fixed to resist these transient high-frequency voltages which proceed from surges on the line, and not based on the line voltage and frequency only.

In addition to the electrical resistivity of the insulator, it must be strong mechanically. The discussions, elsewhere in this work, of sag and stresses in transmission lines show how great the mechanical forces are which act on the supports, and that the insulators must be amply strong to resist even abnormal forces which may be applied to them and without undergoing any mechanical injury. An insulator which is cracked or, in any wise, injured mechanically becomes useless electrically.

It is important to note that insulators which are amply strong mechanically may be easily cracked if mounted on pins which are
not strong enough to resist the strain, and bend slightly under a heavy pull. Bending of the pin will crack an insulator which otherwise would be quite strong enough for the purpose. It is usually safer to purchase both insulator and pin from the same manufacturer with a guarantee of mechanical strength for the complete unit.

There are two general varieties of insulators, one being the well-known form which is supported on an upright pin fastened to a crossarm and known in the trade as the "pin-type insulator" while the other is the suspension insulator which is made up of a series of porcelain disks flexibly connected together so that they form a "string," the axis of the string being the center line through the disk. These are made in a number of different designs which depend partly on the conditions to be met and partly on the personal views of the designer.

**Pin-type Insulators.**—Pin-type insulators are made up of one or more porcelain bells, or skirts, as indicated in Figs. 93, 94 and 95. In the top is a groove to receive the transmission wire, while just below the top is a neck in which the tie-wire lies. The bells are hollow and are screw-threaded inside so that they may be screwed on to the insulator pin. This practice has been modified, however, by cementing an iron thimble into the insulator, which thimble is threaded to screw on to the stud of the iron insulator pin.

The size of the insulator, that is the diameter, and number and radial length of the bells, is fixed by the voltage to which it is to be subjected. The greater the radial distance from the wire to the bottom of the bell, measured along its upper surface and then
radially back on its under surface to the pin, the greater is the resistance to leakage and arcing because of the length of the leakage path. If, however, the bell is made great in diameter in order to produce a long leakage path, the object is partly defeated by the fact that the area for leakage is increased in a corresponding ratio. Therefore, a wide flat disk does not possess as good insulating qualities as a steep-sided cone of small diameter. These conditions, together with the fact that it is desirable for the insulator to shed water constitute some of the reasons for the forms of insulators now in use.

Its form also results from spreading the bells as far apart as possible to reduce the potential gradient. The several bells, together with the insulator pin, constitute a series of condensers. If the bells approach close to each other, and the inner bell close to the pin, the capacity of the condensers is comparatively great and an appreciable capacity current will flow over each insulator. Also, the potential gradient of the air, lying between adjacent bells, becomes greater with the nearer approach of the bell surfaces to each other, and thereby the insulator is more susceptible to puncture and flash-over. Hence, the bells are designed to have as great a space between them as practicable, and to keep all bells as far away from the pin as possible.

Another essential element of design is to have the electrostatic stresses distributed as uniformly as conditions will permit and avoid setting up high stresses at some particular point on the bells. It has been suggested that an insulator having the topmost bell made of metal would be better and cost less than an equivalent insulator made wholly of porcelain. Good theoretical reasons exist for this suggestion and it is possible that insulators of this kind may become commercial devices.

In the usual pin-type insulator, the upper bell is not coned as much as the lower ones, but is more disk-shaped. This is for the purpose of providing a long arcing path whenever there is a
tendency for the current to jump from wire to insulator pin, passing successively from bell to bell, until the pin is reached as indicated in Fig. 183.

These general statements cover only superficially, a few of the considerations which govern the insulator design. Design and manufacture of insulators are complex, as not only are the questions of shop and electrical conditions involved, but the whole art of ceramics enters into it, so that it is quite impossible to discuss here anything more than the requirements which the purchasing engineer should insist on.

Wherever more than one bell, or skirt, is required, it is customary to make the insulator in separate sections, each section carrying its bell, and these nest one inside the other and are firmly cemented together as shown in the figures.

In general, the design of pin-type insulators is based on 12,000 to 20,000 volts per individual section, or bell, the average being 15,000 volts per bell, so that for 45,000 volts, the insulator would be made up of 3 bells and for 60,000 volts the number of bells would be four.

The length, from wire to pin, measured over the surfaces—upper and lower—of the bells is approximately 0.8 in. per 1000 volts, for insulators for pressure above 5000 volts. Thus, a 66,000-volt insulator would have a leakage length of about 53 inches from wire to pin.
Insulator Pins.—Insulator pins for high-tension insulators are, universally, of iron. The general form most used for mounting on crossarms is shown in Fig. 96. This pin is made up of a stud varying from \( \frac{3}{4} \) to \( \frac{7}{8} \) in. in diameter, threaded at both ends. This stud passes through a hollow, cast- or malleable-iron stand which is threaded at the top, and the upper end of the stud screws into these threads. The lower end of the stud passes through the hole in the crossarm, and the pin is fastened tightly to the crossarm by screwing up the bottom nut against the under side of the crossarm, the bottom of the stand pressing against the upper surface of the crossarm. The upper end of the stud projects above the end of the supporting stand, and on to the threads of this exposed portion the thimble is fastened. Customarily, the thimbles are cemented into the insulators at the factory, and the insulator, therefore, is screwed into place, the screw threads being in metal, both on the pin and in the thimble. The stand forms not only a spacer to fix the height of the pin above the crossarm, but acts also as brace to take horizontal stresses applied at the upper end of the pin.
INSULATORS

There are other forms of insulator pins, but the best for economical erection is one which can be fastened tightly to the cross-arm without the insulator thimble being in place. Pins can be put in place on the crossarms before the poles are set, and the insulators afterward screwed on when the lineman climbs to the pole head to string the wires.

Whenever insulator pins are placed on pole tops, a special form, called the pole-top pin, is used. These may be either of malleable iron or a forging of standard 2-in. pipe, wedged down and threaded at its upper end. Figs. 97 and 98 show, respectively, these two varieties of pins.

Method of Tying.—The wires have to be tied in place on each insulator and a number of methods of tying are in use. The best, however, is the double-bridle tie which is shown in Fig. 99. As indicated, two tie-wires are used on each insulator. The end of one is wrapped around the wire mak-

![Fig. 101.—Suspension strain insulator.](image_url)

![Fig. 102.—Characteristic curves of suspension insulator.](image_url)

ing from eight to ten turns, beginning about 8 in. back from the center line of the insulator. The free end is then brought forward, passed around the insulator, brought back to the inner end
of the coil first made about the main wire, and securely wrapped about it, as shown. A similar bridle is put on the opposite side. These wires must be pulled up tight and wrapped firmly, as it is on them that the real strength of the line depends. Tie-wires are usually No. 4 wire and of the same metal as that of the main-line conductor. Larger tie-wires have sometimes been used though it is impractical to make a good tie with wire larger than No. 2.

Suspension Insulators.— Suspension insulators are made of disks of porcelain, which are provided with metal fittings cemented into place, the upper one forming either a receptacle for a hook or a pin joint, the lower one forming a hook or a pin-joint eye. Figs. 100 and 101 show both kinds. The disks are connected together by the hooks, or by the pin joints, as indicated. Each disk, or insulator, can safely resist a certain voltage, and by stringing several of them together the total voltage which the string can resist can be brought up to any desired value within reasonable limits. The resisting voltage of a string is not, however, the sum of the resisting voltages of the several insulators in the group. The disk next to the line is subjected to a greater stress than the next succeeding one and the third disk has a less
stress imposed on it than the second, and so on. The potential gradient of a string of disks is very similar to that of a series of gaps between the discharge cylinders of a multi-gap lightning arrester, as shown in Fig. 176. In Fig. 102 are shown three curves which indicate the increase in voltage with increase in the number of disks per group. It is to be observed that the voltage curve for dry weather begins to fall off rapidly after the number of insulators exceeds four. The curves for wet weather are practically straight lines, showing that for this condition, the resistance increases approximately in direct proportion to the number of insulators. This latter result is, of course, due to an equalization of the electrostatic gradient over the whole group by the moisture.

These insulators are suspended from crossarms by special hardware designed for this purpose. Fig. 103 shows an eye-bolt for suspending a pin-connected group from a crossarm. The wire is fastened to the insulator by means of a suspension clamp, which latter is fastened to the hook, or eye-bolt on the insulator. Fig. 104 shows a suspension clamp of this kind.

The following table shows the approximate weights of insulator strings, for different voltages.¹

<table>
<thead>
<tr>
<th>Working voltage</th>
<th>Weight, lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000</td>
<td>3</td>
</tr>
<tr>
<td>40,000</td>
<td>11</td>
</tr>
<tr>
<td>60,000</td>
<td>23</td>
</tr>
<tr>
<td>80,000</td>
<td>40</td>
</tr>
<tr>
<td>100,000</td>
<td>60</td>
</tr>
<tr>
<td>120,000</td>
<td>80</td>
</tr>
<tr>
<td>140,000</td>
<td>100</td>
</tr>
</tbody>
</table>

Creighton gives the following as the desirable qualities which any insulator should possess.²

1. It shall be mechanically strong in compression and tension.
2. It shall be tough, not brittle or fragile.
3. It shall be non-porous.

4. The porcelain shall be without appreciable cracks, laminations, cavities, conducting flaws, or air pockets.

5. It shall be of a fair, uniform dielectric strength.

6. It shall have a permanent glaze without cracks, roughness or checks to hold dirt in the surface. It is desirable to have the glaze as non-hygroscopic as it is possible to obtain without sacrificing other factors.

7. Incidentally, the coefficient of expansion of the porcelain should be low in order to permit of sudden changes of temperature due to the weather conditions.

8. The parts should be held together with non-changeable cement.

9. In the matter of design the general rule to follow should be to keep the distance between the metal electrodes as great as the mechanical strength will permit. In general, this rule calls for thicker porcelain than can be economically manufactured.

10. The design should be such that the air around the insulator is weaker to puncture than the thickness of the porcelain even under super-spark potentials.

11. The design should be such as to give a relatively long drip space for water so as to hold a high value of spark-over potential during a rain.

12. For dusty countries extra lengths of creepage surface should be provided.

It is far easier to state what is desired than it is to make definite recommendations of how the desiderata are to be obtained. Every possible avenue of investigation should be tried until the desired perfection of insulator is reached.
Comparative Costs of Insulators.—Fig. 105 is a diagram showing the range of costs of insulators of various kinds during 1913 and 1914, as given by the Lock Insulator Co. While the prices fluctuate considerably, the cost of any insulator will be somewhere between the maximum and minimum curves shown.

Following are the specifications for testing insulators as fixed by the A. I. E. E.

1. (a) This specification is intended to cover the checking of the design and the testing and the inspection of the factory output, of porcelain insulators, cat. No. of Company, to be manufactured for the Company.

(b) The operating voltage is and the frequency is

(c) Definitions: By “insulator” is meant the complete insulator or group of insulating members including all the parts necessary to support the conductor from the crossarm, or on the pin, as the case may be.

By “unit,” or “unit insulator,” is meant a suspension insulator element complete, having a metal cap and pin.

By “shell” is meant a single porcelain piece without cement or cap or pin.

2. Drawings.—A dimensioned drawing shall be furnished, showing the complete insulator and metal parts, or, if the insulators are built up or composed of a string of units, showing the details of a unit and all the clearances between units and hardware.

3. Inspection.—The maker will give to the purchaser or his representative such access to his works at all times during working hours as is reasonable and necessary to determine the suitability of material to be supplied, and shall furnish all necessary apparatus, labor, and other facilities for making the tests herein called for, without cost to the purchaser. All good insulator units destroyed in the tests here called for are to be paid for by the purchaser at the contract price.

All insulators are subject to final inspection, test and acceptance at maker’s factory.

Neither the inspection, nor waiving of inspection, nor the purchaser’s acceptance, will relieve the maker from obligation to furnish material in accordance with this specification.

4. Design.—All insulators shall be designed, as far as may be practicable, to fail by flashover, and not by puncture, under excess voltage tests, especially under impact tests.

Insulators shall be of robust construction and design so as not to be easily injured in handling.

Explanatory Note.—The ultimate criterion of the merit of an insulator is its performance in service, and the best available measure thereof is
its behavior under definite tests. However, as no practicable tests actually reproduce service conditions, for example in the matter of high-frequency voltage or deposits of dust, criticism on theoretical grounds is valuable, and, other things being equal, preference should be given to the insulators most closely conforming to theoretically best designs.

**Note.**—Careful attention in specifying flashover voltages should be given to the fact that for varying altitudes the breakdown strength of air varies approximately, though not exactly, as the barometric pressure.

**Metal Parts**

5. **Corrosion.**—All metal parts shall be of non-corrodable material or shall be galvanized, or sherardized, in accordance with the specifications for galvanizing prescribed by the joint committee of the National Electric Light Association in its Specification for Overhead Crossings of Power Lines above Telephone and Other Low-voltage Lines. Surfaces shall be free from roughness or projecting points; bearing surfaces shall be smooth enough not to injure cables.

6. **Factor of Safety.**—Metal parts shall have a factor of safety of at least three over the maximum stress that they receive in service, except that with pins for pin-type insulators, the factor may be reduced to two where a higher factor is impracticable. The maximum service strain is here agreed upon as........lb.

**Porcelain**

7. **Quality.**—All porcelain shall be dense and homogeneous, as is best adapted to high-tension insulator requirements, free from injurious cracks, blisters and flaws, or other defects that would render them unfit for use in insulators. The burning of all porcelain sections shall be done so as to insure even vitrification but shall not render the porcelain unduly brittle. The surface shall be smooth and uniform and the body of the porcelain shall be moisture-proof.

8. **Glazing.**—The glazing shall be of............ color and of a reasonably uniform shade, smooth, hard and continuous over all surfaces except those to be in contact with the cement. It shall be unaffected by weather, ozone, nitric acid, nitric oxides, alkali dust, or sudden change in temperature over the atmosphere range.

9. **Absorption—Explanatory Note.**—While imperviousness of the porcelain to moisture is of supreme importance, no satisfactory test of this quality is known.

**Cement**

10. **Assembling.**—All cemented joints between insulator parts shall be carefully made, using for this purpose the best grade of neat Portland
cement, thoroughly mixed, and plentifully supplied with moisture during setting. The assembly shall be so done that no hollows, or voids, will be left between the cemented surfaces. All superfluous cement must be cleaned off of the insulator before crating.

Electrical Testing.—Note.—Sections 11 to 15 inclusive are particularly applicable to competitive tests and to tests the results of which are to be compared to similar tests made with other testing apparatus. In cases where merely a comparative study of different designs of the same make is to be made, all tests being carried out on the same testing apparatus, it is usually satisfactory to use the standard test apparatus of a first-class maker.

It should be definitely stated in the contract whether §§11–15, inclusive, are to be adhered to or not.

11. Wave Form.—The wave form of the generator shall be a true sine curve within the limits specified for generators by the Standardization Rules of the American Institute of Electrical Engineers and may be checked by the methods therein prescribed.

12. Control of Voltage.—The voltage shall be controlled in such a way as not to distort the wave form. (One satisfactory method of control is the use of a regulator consisting of a shunt resistance connected directly across the low-voltage side of the transformer, and a series resistance in the supply. The shunt resistance must always by-pass at least five (5) times the exciting current of the transformer. The principal control is effected by the series resistance. This method is often spoken of as the potentiometer method.)

13. Measurement of Voltage.—The method of measuring the voltage on the test circuit shall be that recommended by the American Institute of Electric Engineers, covering such cases.

14. Kilovolt-ampere Capacity of Testing Apparatus.—The kilovolt-ampere capacity of the testing apparatus, including any series resistance used, is important, for the leading current taken by the insulators tends to alter the voltage of the test apparatus. The maximum current taken from the test apparatus shall not be so great as to distort the voltage wave more than permitted for generator electromotive force waves by the A. I. E. E. Standardization Rules.

15. Surrounding Conditions During Tests.—In design checking tests of insulators having an operating voltage not exceeding 75,000 volts, no object, other than leads and supports should approach nearer than 6 ft. (1.8 m.) to the insulator. For insulators having a higher operating voltage, the conditions for the "design test" of complete insulators should be made, as nearly as practicable, the same as the conditions of actual service as regards the grounding of one side of the insulator and the arrangement and distance of grounded objects in the neighborhood. A conductor of 6 ft. (1.8 m.), or more, in length, extending
equally on both sides of the clamp, should be used to represent the transmission wire.

Note.—In these tests the walls of the room will ordinarily introduce a very serious departure from the conditions of outdoor service. Open-air tests, where feasible, are preferable from this point of view.

Routine tests, not being on complete insulators or insulator strings, do not require these precautions.

16. Frequency.—Tests should be made at the frequency at which the insulator is to be used. Where special agreement is made, tests may be made at 60 cycles on insulators intended for use on higher and lower frequencies. No error of a serious magnitude will be expected within the range of 25 to 133 cycles.

17. What Constitutes a Breakdown or a Flashover.—An insulator is said to “fail,” or “break down,” under a voltage test whenever a puncture occurs in any part of the insulator. It is said to flash over when a discharge of any sort passes all the way from one terminal to the other, since such a discharge would be followed by an arc on a power line.

Local breakdown, either corona or local sparks, while an important symptom, indicating severe local stress, does not constitute a flashover. The weight to be given to such local breakdown, however, is a matter of judgment.

18. Rain Tests.—Water should be sprayed on the insulator at a uniform rate averaging 1 in. (2.5 cm.) depth in 5 min., and should be reasonably uniformly distributed over the whole insulator. The rate of precipitation shall be measured by collection of water in a pan at the location of the insulator, the insulator being removed. A fairly satisfactory spray in the form of a fine mist can be obtained by some forms of spray nozzles where pressure is available.

The spray shall strike the insulator at an angle of approximately 45° with the vertical.

The water used shall have a high specific resistance, not less than 5000 ohms per cubic inch (12,700 ohms per cubic centimeter). Pure water may often be obtained from condensed steam or melted ice, preferably artificial ice, or rain. Municipal water supplies are often so impure as to seriously impair the performance of the insulator on the wet flashover.

When insulators are to be used in localities subjected to salt spray, or alkali, or acid mists, or to conditions producing dew deposits, special tests may be agreed upon.

19. Puncture under Oil.—Tests on a certain percentage of insulator units, ordinarily not exceeding ¼ per cent., should be made to determine the ability of the insulator to resist puncture and to measure the uniformity of the product. This test is best made by submerging the insulator in oil.
For this test each suspension insulator unit should be completely assembled with its standard hardware.

With pin-type insulators, there should be attached to the head of the insulator wires representing the tie and line wires, and a metal pin should be placed in proper manner in the pin hole.

The test voltage should then be applied to the hardware in each case. The puncture value obtained under these conditions should not be less than 135 per cent. of the dry flashover voltage and should where possible, be much higher. In the case of suspension units, a factor approaching 200 per cent. has sometimes been obtained.

The puncture voltage that must be met in the actual tests (§24) should be here specified for each contract, viz. . . . volts.

In making the test, apply to the insulator a voltage 30 to 40 per cent. below the dry flashover value and then raise the voltage gradually, or by steps, until puncture occurs, at a rate of about 5000 volts per second. The puncture value of the porcelain is very sensitive to the length of time voltage near the maximum is applied; the puncture voltage may be lowered as much as 20 per cent. by long-continued application of the test voltage. It is well to have a short air gap between each insulator under test and the testing line, that the character of the charging current may be judged by the appearance of the arc.

**Pin-Type Insulators**

20. Inspection.—All parts shall be inspected before assembling.

21. Routine Tests—Electrical Tests before Assembling.—All insulator shells, before being assembled, shall be tested for 3 min. at the voltages given in the following table. Should any shell be punctured in the last minute of test, the test will then be continued, after the removal of the punctured piece, until no puncture occurs in one full minute of test. These tests are to be conducted by inverting the parts in pans of water and placing water inside the several pieces, the potential then being applied to the two bodies of water.

Note.—The water both inside and outside shall be filled to within \( \frac{1}{8} \) in. of the highest point to which the later applied, conducting parts, including cement, will extend.

The individual tests in the various shells shall be as follows:

<table>
<thead>
<tr>
<th>Shell</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>volts</td>
</tr>
<tr>
<td>Second shell</td>
<td>volts</td>
</tr>
<tr>
<td>Third shell</td>
<td>volts</td>
</tr>
<tr>
<td>Fourth shell</td>
<td>volts</td>
</tr>
<tr>
<td>Center</td>
<td>volts</td>
</tr>
</tbody>
</table>

22. Routine Tests—Final Electrical Tests.—All completed insulators shall be tested according to one or the other of the four following tests.
One of these tests should be definitely specified for each lot of insulators tested under these specifications.

(a) The insulators in groups shall be subjected to a voltage steadily applied, just below the flashover voltage, for a period of 3 min. The voltage shall be held at such a point that a flash shall occur over some insulator of the set occasionally, but not more often than once in 3 sec. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is, therefore, objectionable that there should be frequent flashing over, as each flashover presumably removes the potential from all insulators for one alternation.

If an insulator of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

(b) The insulators in groups shall be subjected to a voltage in excess of the flashover voltage so that a continuous succession of flashovers, exists, this being continued for a period of 2 min. This test is intended to introduce the effect of impact and, consequently, continual flashover is necessary.

(c) The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential, without removing the voltage. In this case the time of the second part of the test should be reduced to 1 min.

(d) This test is the same as test (b) above except that, instead of applying this testing to insulators in groups, the insulators shall be tested singly and the voltage continued for a period of 20 sec.

Note.—In all the tests (a), (b), (c) and (d) above, it is important that the current be so limited in volume that no power arc shall follow a flashover, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

23. Design Test—Mechanical.—The following design test shall be made on enough complete insulators, usually not exceeding 1/2 per cent., to determine the behavior of the design and the uniformity of the product.

The insulators shall be capable of withstanding for 15 sec., without signs of distress, a pull of . . . . . . . . . . . . . . lb. ( . . . . . . . . . . kg.) applied at the tie-wire groove in a direction at 90° with the axis of the insulator and pin. For the purpose of making this test, the insulator shall be mounted on the pin to be used in service. In case of failure, the question as to whether the insulator or the pin is at fault shall be determined by testing again with a solid steel pin turned from a piece of round steel of such dimensions that this piece of steel acting as a pin for the insulator will not bend under the above-mentioned load.
It is desirable that a number of insulators be tested to destruction to show approximately the margin in mechanical strength.

24. Design Tests—Electrical.—The following design tests shall be made in enough complete insulators to determine the performance of the type. The insulator shall stand without failure:

(a) A test for flashover, dry, of three times the potential between line wires, applied for 1 min.

(b) A test for flashover, wet, of not less than two times the potential between line wires, applied for 1 min.

(c) Puncture test under oil shall be made as specified under §19 above.

Suspension-type Insulators

25. Routine Tests—Electrical Test before Assembling.—All insulator shells shall be tested according to one or the other of the three following tests. One of these tests should be definitely specified for each lot of shells tested under this specification.

(a) The shells in groups shall be subjected to a voltage steadily applied, just below the flashover test for a period of 3 min. The voltage shall be held at such a point that a flash shall occur over some shell of the set occasionally, but not more often than once in 3 sec. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is, therefore, objectionable that there should be frequent flashing over, as each flashover, presumably, removes the potential from all insulators for one alternation.

If a shell of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

(b) The shells in groups shall be subjected to a voltage in excess of the flashover voltage so that a continuous succession of flashes exists, this being continued for a period of 2 min. This test is intended to introduce the effect of impact and, consequently, continual flashover is necessary.

(c) The shells in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case, the time of the second part of the test should be reduced to 1 min.

Note 1.—In all the tests (a), (b) and (c) above, it is important that the current be so limited in volume that no power arc shall follow a flashover, as otherwise the voltage will be substantially removed from the shells during the continuance of the power arc.

Note 2.—In making these tests the insulator shells are to be inverted in a pan of water and water placed in the inside. The water both inside
and outside shall be filled to within \( \frac{1}{4} \) in. of the highest point to which the later-applied conducting parts, including cement, will extend.

26. Routine Test—Mechanical Test.—After at least 10 days' setting of the cement, all units shall withstand for 3 sec., without signs of distress, a mechanical pull of \( \ldots \ldots \) lb. \( \ldots \ldots \) kg., in line with the axis of the insulator. Insulators may be given this test after a shorter period of setting, at the risk of the maker.

27. Routine Test—Final Electrical Test.—All completed insulator units shall be tested according to one or the other of the four following tests. One of these tests should be definitely specified for each lot of insulators tested under this specification.

(a) The insulator units in groups shall be subjected to a voltage steadily applied, just below the flashover test, for a period of 3 min. The voltage shall be held at such a point that a flash shall occur over some unit of the set occasionally but not more often than once in 3 sec. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is, therefore, objectionable that there should be frequent flashing over, as each flashover, presumably, removes the potential from all units for one alternation.

If a unit of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

(b) The insulator units in groups shall be subjected to a voltage in excess of the flashover voltage so that a continuous succession of flashes exists, this being continued for a period of 2 min. This test is intended to introduce the effect of impact and, consequently, continual flashover is necessary.

(c) The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case, the time of the second part of the test should be decreased to 1 min.

(d) This test is the same as test (b) above, except that instead of applying this testing to units in groups, the units shall be tested singly and the voltage discharges continued for a period of 20 sec.

Note.—In all the tests (a), (b), (c) and (d) above, it is important that the current be so limited in volume that no power arc shall follow a flashover, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

This test shall be made after the mechanical test above prescribed, §26.

29. Design Tests—Electrical.—The following design tests shall be made on enough complete assembled insulators, not exceeding \( \frac{1}{4} \) per cent. to determine the performance of the type.
(a) A test for flashover, dry, of one insulator unit having its normal position in the string, and of a complete insulator string consisting of ........ units, of ........ volts, and ........ volts respectively, applied for 1 min.

(b) A test for flashover, wet, of a single insulator and of the string, of ........ volts and ........ volts respectively, applied for 1 min.

(c) The puncture test under oil shall be made as specified under §19 above.

It is preferable that the arc-over of the complete insulator, when the test voltage is sufficiently raised, shall be over the insulator as a whole and shall not be over the individual elements.

30. Design Tests—Mechanical.—The following design test shall be made on enough complete insulators, usually not exceeding ¼ per cent., to determine the behavior of the design and the uniformity of the product.

After at least 2 weeks' setting of the cement, the insulators to be tested shall withstand for 15 sec. without signs of distress a pull of ........ lb. (........ kg.) in line with the axis of the insulator.

It is desirable that a number of these insulators be pulled to destruction to show approximately the margin in mechanical strength.

Appendix

The following tests are recommended as desirable where appropriate. They are not incorporated in the above specifications, as experience with them is not yet sufficiently broad.

31. Uniformity Puncture Test.—Twenty-two single insulators, chosen at random from stock, which have passed all routine tests, shall each in turn be punctured under oil, as provided for oil tests in §19 above. Any 20 of these values of puncture voltage shall then be selected by the maker. The difference between the maximum and minimum of these 20 puncture voltages must not be more than 20 per cent. of the average voltage. This test should be repeated with one or more additional groups of 22 disks, not exceeding in the aggregate ¼ per cent. of the total, enough to determine the uniformity of the product. In case of failure of the lot to pass this test, the other insulators from the same burnings shall be tested, as specified under §28, but for a period five times that there specified.

32. Design Test—Impulse Test.—Ten units shall be selected at random. Each of these disks shall be connected in turn to the impulse circuit shown in Fig. 106. The gap A shall be set at three or, preferably, four times the arc-over voltage of a single unit. The voltage shall be

1 For an example of the application of such a test see paper by Imlay and Thomas, Trans. A. I. E. E., vol. XXX, 1912.
increased until gap $A$ sparks over, when the circuit shall be immediately opened by breaker, or the voltage otherwise removed. This shall comprise a "stroke." Such strokes shall be repeated on each unit or string of units up to \ldots strokes, or until puncture occurs. Preference shall be given to the design or make of insulator showing the greatest uniformity and the highest resistance to puncture. Referring to Fig. 106, the shunt-condenser capacity shall be equal to that of an air-plate condenser having from 75 to 100 sq. ft. surface on each plate and a spacing equal to 25 per cent. more than the sparking distance of the voltage used. The connections from the condenser to the insulator should be as short as practicable.

![Fig. 106.—Connections for impulse test.](image)

**Note.**—The above test will show, in a general way, the probable effect of surges, lightning, etc., on the life of the insulator, as well as the uniformity of the porcelain. While there is not sufficient experience with this test to secure a numerical measure of the number and sort of strokes that must be withstood by the insulator to insure a puncture-proof product, the test as outlined above is very important in competitive tests.

33. **Design Test—Combined Mechanical and Electrical Test.**—The following design test should be made upon enough insulators to determine the performance of the design and the uniformity of the product.

An insulator placed in an insulated testing machine and impressed with a voltage just under or just over the flashover voltage (as may be agreed upon) shall be subjected to a gradually increasing mechanical pull until puncture occurs.

The insulator should not puncture at less than twice, or, preferably, three times the maximum pull to which the insulator is to be subjected in service, as fixed in §6 above.

34. **Uniformity—Brittleness Test, Applicable Especially to Suspension Insulators.**—The following uniformity test should be made upon enough insulator units to determine the performance of the design and the uniformity of the product.

A completed insulator unit which has passed all routine tests shall be placed in ice water, and the temperature of the water raised to boiling. The heating should not begin until after the insulator has been in ice
water 15 min. to permit all parts to come to the same temperatures. The water should then be heated at a uniform rate of about 1°C. per minute. After remaining at boiling temperature for 30 min., the unit may be removed and should afterward be tested either by the measurement of its insulation resistance, using 1000 or 2000 volts for the measurements, or by the standard routine electrical test (§28), or both.

35. Percentage of Failure in Routine Tests.—The percentage of punctures in the electrical tests is a rough measure of the burning of the porcelain and the care in manufacture. A relatively large percentage of failures, perhaps over 5 per cent., suggests under-firing. It is recommended that the following modification be applied to routine tests §22 and §28:

"When the percentage of punctures in any group of insulator units, or shells, under test simultaneously, exceeds 5 per cent., the length of the time of application of the test voltage shall be doubled for that group."

.
CHAPTER VIII

POLE AND TOWER LINES

Right-of-way.—Carrying a transmission line across country involves the necessity of purchasing the right from property owners to plant poles or erect towers, string wires, and, at all times, have free access to the line. In some cases, it has been necessary to purchase a strip of land for this purpose, just as a railway, occupying the land, would be obliged to do. Usually, however, it is only necessary to pay for pole, or tower, rights. Sometimes this takes the form of a flat payment for the right in perpetuity, and in other cases, a yearly rental is exacted.

The way must be cleared of all trees tall enough to fall against the line in case any one of them should be broken off or uprooted by storms. Lines supported on tall towers do not require so much wood cutting as lines on shorter poles. The cost of tree felling is not, really, a permanent disbursement, as the timber or firewood obtained usually sells for more than the cost of labor.

While as direct a route as possible should be chosen for the line, it does not pay to place it far from a railway or good country road, and even if the line has to diverge considerably from its natural direction, an accessible route should be chosen. The distributing of poles, or towers, reels of wire, tools and fittings, and the necessity of patrolling the line after it has been built, make it necessary to have it adjacent to a highway, except under unusual conditions which justify diverging from the road.

Pole and Tower Lines.—Transmission lines are supported by poles or towers. The poles may be of wood, steel latticework, tubular iron, or reinforced concrete. Steel towers are simply lattice poles greatly increased in their dimensions. It is customary to use steel towers for lines on which the pressures exceed 66,000 volts. The reasons given for the use of towers are that they are durable, permanent structures, and their adoption is necessary because of the great crossarm lengths required for suspension insulators. Also it is cheaper to use towers and place
them at considerable distances apart than to use small structures and place them closer together. In the opinion of the author, there are very few conditions which justify the use of steel towers, and a large percentage of the steel-tower lines, now in use, have required an investment and consequent interest and depreciation charges, both of which are greatly in excess of the corresponding costs of a well-constructed, pole-supported line. This subject will be discussed later in more definite detail.

In the adoption of any form of support, its strength must be sufficient to resist the following stresses:

(a) Vertical forces due to weight of structure and wires.

(b) A bending or overturning moment due to wind pressure against surface of supporting structure plus one-half the length of each wire between adjacent spans attached to the support. This force acts at right angles to the direction of the line.

(c) The unbalanced longitudinal force set up by the accidental breaking or burning loose of a certain proportion of the wires carried by the supporting structure. This proportion is usually taken as one-third the total number of wires carried by the support though some engineers have considered that two-thirds the total number of wires may be broken or burned and have designed supports on this basis.

(d) The twisting moment produced by the breakage of one or more wires.

The bending moment at the ground line due to the side pressure of the wind, is equal to $M_1 + M_2$.

$$M_1 = \text{moment produced by wind pressure against the pole and}$$

$$M_2 = \text{moment produced by wind pressure against the wires}.$$

$$M_1 = \frac{P_1 H_1 (D_1 + 2D_2)}{72} \text{ lb.-ft.} \quad (34)$$

$P_1$ = wind pressure per square foot of projected area of pole, usually taken at 15 lb. per square foot.

$H_1$ = height of pole above ground, in feet.

$D_1$ = diameter of pole at ground line, in inches.

$D_2$ = diameter of pole at top line, in inches.

$$M_2 = \frac{P_2 H_2 nd (S_1 + S_2)}{24} \text{ lb.-ft.} \quad (35)$$

$P_2$ = wind pressure against wires, in pounds per square foot of projected area, usually taken as 10 lb. per square foot.

$H_2$ = height of wire above ground, in feet.
\[ n = \text{number of wires.} \]
\[ d = \text{diameter of wire, in inches.} \]
\[ S_1 \text{ and } S_2 \text{ are lengths of spans adjacent to pole, in feet; usually, } S_1 = S_2 \]

The moment of resistance to flexure of a round pole is

\[ M_r = \frac{f\pi D^4}{384} = \frac{fD^4}{122} \quad (36) \]

\[ f = \text{maximum stress at outer fibre, per square inch.} \]
\[ D = \text{diameter of pole in inches, at point for which } M_r \text{ is computed.} \]

The deflection of a round pole is

\[ \delta = \frac{PL^3}{3EI} \quad (37) \]

For a wood pole having a modulus of elasticity of 1,500,000, this becomes

\[ \delta = \frac{ML^3}{22 \times 10^4 \times D^4} \]

\[ \delta = \text{deflection in feet.} \]
\[ M = \text{bending moment in lb.-ft.} = PL \]
\[ P = \text{total pressure against pole to deflect it.} \]
\[ L = \text{height from point about which moment is taken (usually ground line), to point of application of } P, \text{ in feet.} \]
\[ E = \text{modulus of elasticity of material} = 1,500,000, \text{ average for timber.} \]
\[ I = \text{moment of inertia} = 0.0491D^4 \text{ for a circular section and } 0.0833b^4 \text{ for a rectangular section in which } D = \text{diameter, and } b = \text{length of side of the square, in feet.} \]

The ultimate strength of various pole timbers is given in the following table.

<table>
<thead>
<tr>
<th>Timber</th>
<th>Fiber Stress at Rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar</td>
<td>3500 to 5600 lb. per square inch.</td>
</tr>
<tr>
<td>Chestnut</td>
<td>4500 to 9700 lb. per square inch.</td>
</tr>
<tr>
<td>Cypress</td>
<td>6000 to 7000 lb. per square inch.</td>
</tr>
<tr>
<td>Long-leaf pine</td>
<td>8000 to 8600 lb. per square inch.</td>
</tr>
<tr>
<td>Short-leaf pine</td>
<td>7000 to 7700 lb. per square inch.</td>
</tr>
</tbody>
</table>

Griswold\(^1\) has made a number of tests on pole timbers, from which he has plotted a series of curves shown in Fig. 107. These

\(^1\) Trans. A. I. E. E., April, 1912.
curves show the total bending moments at which the different kinds of poles, and having various diameters, broke. This diagram can be used in the selection of a pole for a given applied stress. If the bending moment on the pole be multiplied by the desired factor of safety, the product is the value to be taken

![Graph showing ultimate load vs. circumference at point of support]

Fig. 107.—Strength of pole timbers.

on the line of "ultimate load," in foot-pounds, and the ordinate of the particular curve selected will give the circumference of the pole required to resist the given bending moment and have the factor of safety adopted.

As an example, assume a chestnut pole 40 ft. high above the ground line, and having a maximum force of 2000 lb. acting
against it at the top. What is the size of pole required to resist this force, with a factor of safety of \(2\frac{1}{2}\)?

Bending moment at the ground line = \(40 \times 2000 = 80,000\). Bending moment, multiplied by factor of safety = \(2\frac{1}{2} \times 80,000 = 200,000\).

The abscissa corresponding to the ordinate 200,000 on curve No. 4 for chestnut poles is 53, which is the required circumference of the pole at the ground line.

The weakest point of a pole, acting as a cantilever with the force applied at its small end, is where \(d_1 = 1.5d\), \(d\) being the top diameter and \(d_1\) the diameter at the weakest point. This fact is deduced as follows:

Bending moment of cantilever is \(Px\) lb.-in. in which \(x\) is the distance from the end at which the force is applied to the section where the bending moment is to be taken, and \(P\) is the force applied.

If the stress \(T\), in the outermost fibres is expressed in pounds per square inch, and the section is assumed circular:

\[
P x = \frac{T\pi d^3}{32}.
\]

The diameter at any point \(x\) in. below the section of diameter \(d\), is \(d + tx\), \(t\) being taper of the pole, or the increase in diameter per inch length. Hence,

\[
T = \frac{32P}{\pi} \times \frac{x}{(d + tx)^2}.
\]

In order to find the position of the cross-section at which the pole is most likely to break—that is to say, where the fibre stress is a maximum—it is necessary to differentiate the last equation with respect to \(x\) and find the value of \(x\) which makes this differential equal to zero. This gives

\[
x = \frac{d}{2t}
\]

for the point where the stress \(T\) is a maximum. The position of this cross-section is, evidently, not necessarily at ground level. If this value of \(x\) equals or is greater than \(H\), then the maximum fibre stress will be at ground level, and it is calculated by substituting \(H\) for \(x\) in the formula, \(H\) being the height of the pole in inches.

POLE AND TOWER LINES

The diameter of the pole at the weakest point is:

\[ d_w = d + tx = d + t \left( \frac{d}{2t} \right) = 1.5d. \]

and it is only when the diameter at ground level is greater than one and a half times the diameter where the pull is applied that the pole may be expected to break above ground level.

If the stress \( T \), the taper \( t \), and the pole-top diameter \( d \), are known, the allowable load \( P \) is readily calculated as follows:

\[ \text{Bending moment} = Px \]
\[ \text{Resisting moment} = \frac{\pi d^3_w}{32} \times T. \]

But

\[ x = \frac{d}{2t} \quad \text{and} \quad d_w = 1.5d. \]

Substituting these values and equating the bending and resisting moments

\[ \frac{Pd}{2t} = \frac{T\pi (1.5d)^3}{32} \]

whence

\[ P = 0.662Td^3. \]

Similarly, if the pull \( P \) is known, the pole-top diameter should be:

\[ d = \sqrt[3]{\frac{P}{0.662Ti}}. \]

The woods which are suitable for poles and generally used are: white Michigan cedar, chestnut, Western yellow pine, Southern yellow pine, and red cedar. Other woods are occasionally used, particularly when the transmission line is built in sections where some certain growth is locally abundant and easily obtained. Juniper, cypress, locust and catalpa are among these latter varieties.

The wood should be cut from well-grown trees and when the sap is down, usually, between October and April. If practicable, it should be thoroughly air-seasoned. Where the poles are required in a short time, water-seasoning is resorted to. This consists of soaking the poles in a stream from 30 to 40 days and subsequently air-drying for at least 35 days of dry weather, the total time of air-drying being 35 days plus all additional days of damp or wet weather occurring during the period. In some cases,
the poles have been kiln-dried, but this usually adds considerably to the expense and is avoided when possible.

The life of the poles is dependent on the character of the wood, the locality, and whether, or not, they were seasoned before planting and also dependent on the character of preservative treatment, if any. It has been found that any preservative coating, applied to green timber, actually shortens the life of the pole. The average life of poles is from 10 to 12 years. In some cases, poles have lasted not more than 8 years and, in others, particularly in the dry portions of the Southwest, they have given service as long as 25 years. In estimating depreciation, it is customary to assume the life of a pole as 10 years, giving a 10 per cent. depreciation.

There are many processes of treatment for increasing the life of poles but the one which is principally used is a surface treatment of the butt only, by painting with hot tar or a dead oil of coal tar. A better method of applying is to dip the ends of the poles in a deep tank of hot tar or creosote. This, of course, has to be done in the pole yards by the use of a derrick with which the poles can be lifted. The pole tops are usually cut wedge-shaped at an angle of about 45°. The tops should be coated with a heavy coat of white lead or tar. The gains made in the poles for crossarms should also be covered with a generous coating of white lead.

Following is a general specification for poles.¹

GENERAL SPECIFICATIONS FOR POLES

To determine the character of poles to be used, pole lines may be divided into the three following classes:

Class “A”: for heavy transmission lines or heavy distribution lines.

Class “B”: for light transmission lines or ordinary distribution lines.

Class “C”: for very light distribution or light secondary lines.

The purchasing company is to have the right to make such inspection of the poles as it may desire. The inspector of the purchasing company shall have the power to reject any pole which is defective in any respect. Inspection, however, shall not relieve the manufacturer from furnishing perfect poles.

¹ Locke Insulator Co.
Any imperfect poles which may be discovered before their final acceptance shall be replaced immediately upon the requirement of the purchasing company, notwithstanding that the defects may have been overlooked by the inspector. If the requirements of these specifications are not fulfilled when the poles are offered for final acceptance, not only shall the purchasing company have the right to reject the poles, but the expense of inspection of such defective poles shall be borne by the manufacturer.

All poles shall be subject to inspection by the purchasing company, either in the woods, where the trees are felled, or at any point of shipment or destination. Any pole failing to meet all the requirements of these specifications may be rejected.

All poles shall be of the best quality live timber, squared at both ends, reasonably straight, well proportioned from butt to top, peeled and with knots trimmed close.

Sizes

The circumference at the top must be not less than the following:

- Poles class A .................. 20 in.
- Poles class B .................. 22 in.
- Poles class C .................. 24 in.

Circumference at a point, 6 feet from the bottom end must be not less than given in following table.¹

<table>
<thead>
<tr>
<th>Length of Pole</th>
<th>Circumference at 6' above butt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>35'</td>
<td></td>
</tr>
<tr>
<td>40'</td>
<td></td>
</tr>
<tr>
<td>45'</td>
<td></td>
</tr>
<tr>
<td>50'</td>
<td></td>
</tr>
<tr>
<td>55'</td>
<td></td>
</tr>
<tr>
<td>60'</td>
<td></td>
</tr>
</tbody>
</table>

Where poles are not truly round, the short diameter must not be less than 80 per cent. of the long diameter.

¹ This table fixed by character of timber specified. See Tables 11, 12, 13, and 14.
Quality of Timber

Dead Poles.—The wood of a dead pole is grayish in color. The presence of a black line on the edge of the sapwood (as seen on the butt) also shows that the pole is dead. No dead poles, and no poles having dead streaks covering more than one-quarter of their surface shall be accepted under these specifications. Poles having dead streaks covering less than one-quarter of their surface shall have a circumference greater than otherwise required. The increase in the circumference shall be sufficient to afford a cross-sectional area of sound wood equivalent to that of sound poles of the same class.

Fire-killed or River Poles.—No dark red or copper-colored poles, which when scraped do not show good live timber shall be accepted under these specifications.

Twisted, Checked or Cracked Poles.—No poles having more than one complete twist for every twenty (20) feet in length, no cracked poles containing large season checks shall be accepted under these specifications.

"Cat Faces."—No poles having "cat faces" unless they are small and perfectly sound and the poles have an increased diameter at the "cat face," and no poles having "cat faces" near the six (6) foot mark or within ten (10) feet of their tops, shall be accepted under these specifications.

Shaved Poles.—No shaved poles shall be accepted under these specifications.

Miscellaneous Defects.—No poles containing sap rot, evidence of internal rot as disclosed by a careful examination of all black knots, woodpecker holes, or plugged holes; and no poles showing evidences of having been eaten by ants, worms or grubs shall be accepted under these specifications, except that poles containing worm or grub marks below the six (6) foot mark will be accepted.

Crooked Poles.—No poles having a short crook or bend, a crook or bend in two planes or a reverse curve shall be accepted under these specifications. The amount of sweep, measured between the portion six feet from the lower end and the top of the pole, that will be acceptable under these specifications, is as follows:

35-ft. poles shall not have a sweep over 10½ in.
40-ft. poles shall not have a sweep over 12 in.
45-ft. poles shall not have a sweep over 9 in.
50-ft. poles shall not have a sweep over 10 in.
55-ft. poles shall not have a sweep over 11 in.
60-ft. poles shall not have a sweep over 12 in.

**Defective Tops.**—Poles having tops of the required dimensions must have sound tops. Poles having tops one (1) inch or more above the requirements in circumference may have one (1) pipe rot not more than one-half (½) inch in diameter. Poles with double tops or double hearts shall be free from rot where the two parts or hearts join.

**Defective Butts.**—No poles containing ring rot (rot in the form of a complete or partial ring) shall be accepted under these specifications.

Scattered rot, unless it is near the outside of the pole may be estimated as being the same as heart rot of equal area.

**“Wind Shakes.”**—Poles with cup shakes (checks in the form of rings) which also have heart or star checks may be considered as equal to poles having hollow hearts of the average diameter of the cup shakes.

**Inspection.**—All poles shall be subject to inspection by the purchaser’s representative, either in the woods where the trees are felled, or at any point of shipment, or destination. Each pole thus inspected shall be marked according to its length and class with a marking hammer, by the purchaser’s representative. All poles failing to meet these specifications shall be rejected.

The average rate of tapering of poles is as follows:

- Chestnut 3.8 to 4 in. change in circumference for each 10 ft. of length.
- Michigan white cedar 5.2 in. change in circumference for each 10 ft. of length.
- Western yellow pine 4 in. change in circumference for each 10 ft. of length.
- Southern yellow pine 2.4 in. change in circumference for each 10 ft. of length.
- Red cedar 3.5 in. change in circumference for each 10 ft. of length.

**Pole Setting.**—No strict rule can be laid down for method and depth of setting as this will vary with character of the soil and other factors. The following table, however, shows standard depths of settings for different sizes of poles.

The hole should be in every case large enough to have a 5-in. marginal space around the pole, that tamping may be done effectively. One shoveller to three tampers insures a solid setting. Soil should be heaped about the pole to allow for settling and drain.
Table 10.—Depth of Pole Settings

<table>
<thead>
<tr>
<th>Length of pole</th>
<th>Depth in ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 ft. or less</td>
<td>5 ft.</td>
</tr>
<tr>
<td>30 ft. or less</td>
<td>5 1/2 ft.</td>
</tr>
<tr>
<td>35 ft. or less</td>
<td>5 1/2 ft.</td>
</tr>
<tr>
<td>40 ft. or less</td>
<td>6 ft.</td>
</tr>
<tr>
<td>45 ft. or less</td>
<td>6 1/2 ft.</td>
</tr>
<tr>
<td>50 ft. or less</td>
<td>7 ft.</td>
</tr>
<tr>
<td>55 ft. or less</td>
<td>7 1/2 ft.</td>
</tr>
<tr>
<td>60 ft. or less</td>
<td>8 ft.</td>
</tr>
<tr>
<td>65 ft. or less</td>
<td>8 1/2 ft.</td>
</tr>
<tr>
<td>70 ft. or less</td>
<td>9 ft.</td>
</tr>
<tr>
<td>75 ft. or less</td>
<td>9 1/2 ft.</td>
</tr>
<tr>
<td>80 ft. or less</td>
<td>10 ft.</td>
</tr>
</tbody>
</table>

(In solid rock set 2 ft. less)

Where poles are set in solid rock, pieces of rock, well filled, should be securely wedged around the pole.

In marshy ground some special means must be adopted to insure a stable and rigid setting. Sometimes this is obtained by digging out a hole of sufficient diameter to sink an ordinary barrel into it, the poles set in the center line of the barrel and the space filled in with concrete. Fig. 108 a and b give suggestions for settings that have been satisfactory in swampy territory.

Poles should be numbered after erection, the numbers being painted in white lead and about 6 ft. from the ground line. The numbering should be consecutive from the power station to the
end of the line. All guy stubs and braces should be given the same numbers as the pole with which they are connected and designated by some letter, as B. A record should be made of the location of each pole and, in case of injury, necessity of removal or any other change being required, the numbers afford a simple and ready means of identification.

The following tables give the average proportions of various kinds of poles.

**Table 11.—Pole Dimensions—Eastern and Middle Western Growths**

<table>
<thead>
<tr>
<th>Length, feet</th>
<th>Eastern cedar</th>
<th>Juniper</th>
<th>Chestnut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A cir. at top = 22&quot;</td>
<td>B cir. at 25&quot;</td>
<td>A cir. at top = 22&quot;</td>
</tr>
<tr>
<td>25</td>
<td>31</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>30</td>
<td>34</td>
<td>36</td>
<td>33</td>
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<td>35</td>
<td>38</td>
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<td>42</td>
<td>43</td>
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<td>55</td>
<td>53</td>
<td>55</td>
<td>50</td>
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<tr>
<td>60</td>
<td>57</td>
<td>61</td>
<td>56</td>
</tr>
<tr>
<td>65</td>
<td>63</td>
<td>66</td>
<td>63</td>
</tr>
</tbody>
</table>

**Table 12.—Pole Dimensions—Western and Pacific Slope Cedars**

<table>
<thead>
<tr>
<th>Length of poles, feet</th>
<th>top cir. 28 in. cir. 6 ft. from butt, inches</th>
<th>B cir. 25 in. cir. 6 ft. from butt, inches</th>
<th>top cir. 22 in. cir. 6 ft. from butt, inches</th>
<th>top cir. 18½ in. cir. 6 ft. from butt, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>30</td>
<td>28</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>22</td>
<td>32</td>
<td>30</td>
<td>27</td>
<td>25</td>
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<td>25</td>
<td>34</td>
<td>31</td>
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<td>26</td>
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<td>30</td>
<td>37</td>
<td>34</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>35</td>
<td>40</td>
<td>36</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>43</td>
<td>38</td>
<td>34</td>
<td>32</td>
</tr>
<tr>
<td>45</td>
<td>45</td>
<td>40</td>
<td>36</td>
<td>34</td>
</tr>
<tr>
<td>50</td>
<td>47</td>
<td>42</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>55</td>
<td>49</td>
<td>44</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>60</td>
<td>52</td>
<td>46</td>
<td>41</td>
<td>39</td>
</tr>
<tr>
<td>65</td>
<td>54</td>
<td>48</td>
<td>43</td>
<td></td>
</tr>
</tbody>
</table>
The following table gives the weights of chestnut poles and the number per carload.

These weights are approximate only, and it should be remembered that well-seasoned poles shipped in summer will weigh 10 per cent. less, and when shipped in winter and early spring will weigh about 10 per cent. more. Poles shipped green will weigh about 25 per cent. more.

**Table 13.—Chestnut Poles**

<table>
<thead>
<tr>
<th>Length in feet</th>
<th>Diameter at top, inches</th>
<th>Approximate weight of pole, pounds</th>
<th>No. of poles to a carload</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>6</td>
<td>425</td>
<td>75 per single car</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>500</td>
<td>66 per single car</td>
</tr>
<tr>
<td>30</td>
<td>7</td>
<td>700</td>
<td>54 per single car</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td>775</td>
<td>80 per double car</td>
</tr>
<tr>
<td>35</td>
<td>7</td>
<td>925</td>
<td>74 per double car</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>1230</td>
<td>60 per double car</td>
</tr>
<tr>
<td>45</td>
<td>7</td>
<td>1700</td>
<td>40 per double car</td>
</tr>
<tr>
<td>50</td>
<td>7</td>
<td>2225</td>
<td>24 per double car</td>
</tr>
<tr>
<td>55</td>
<td>7</td>
<td>2772</td>
<td>17 per double car</td>
</tr>
</tbody>
</table>

Corresponding data for cedar poles are as follows:

**Table 14.—Cedar Poles**

<table>
<thead>
<tr>
<th>Length in feet</th>
<th>Diameter at top, inches</th>
<th>Approx. wt. seasoned, pounds</th>
<th>Approx. wt. green, pounds</th>
<th>No. of poles to a carload</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>6</td>
<td>250</td>
<td>325</td>
<td>100 to 125 single car</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>350</td>
<td>425</td>
<td>80 to 100 single car</td>
</tr>
<tr>
<td>30</td>
<td>7</td>
<td>450</td>
<td>500</td>
<td>70 to 80 single car</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td>500</td>
<td>600</td>
<td>60 to 75 single car</td>
</tr>
<tr>
<td>35</td>
<td>7</td>
<td>600</td>
<td>750</td>
<td>55 to 70 single car</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>850</td>
<td>1000</td>
<td>60 to 75 double car</td>
</tr>
<tr>
<td>45</td>
<td>7</td>
<td>1000</td>
<td>1150</td>
<td>50 to 60 double car</td>
</tr>
<tr>
<td>50</td>
<td>7</td>
<td>1250</td>
<td>1400</td>
<td>43 to 50 double car</td>
</tr>
<tr>
<td>50</td>
<td>8</td>
<td>1450</td>
<td>1625</td>
<td>38 to 43 double car</td>
</tr>
<tr>
<td>55</td>
<td>7</td>
<td>1550</td>
<td>1775</td>
<td>34 to 38 double car</td>
</tr>
<tr>
<td>55</td>
<td>8</td>
<td>1800</td>
<td>2060</td>
<td>30 to 34 double car</td>
</tr>
<tr>
<td>60</td>
<td>7</td>
<td>2000</td>
<td>2300</td>
<td>27 to 30 double car</td>
</tr>
<tr>
<td>60</td>
<td>8</td>
<td>2500</td>
<td>2800</td>
<td>24 to 27 double car</td>
</tr>
<tr>
<td>65</td>
<td>7</td>
<td>2700</td>
<td>3000</td>
<td>21 to 24 double car</td>
</tr>
<tr>
<td>65</td>
<td>8</td>
<td>3200</td>
<td>3600</td>
<td>18 to 21 double car</td>
</tr>
</tbody>
</table>
Guying Poles.—Instead of subjecting poles to simple cantilever stresses, it is customary to reduce the stresses in them by guying with steel cables. Guy wires are attached to the poles near the tops and carried to some convenient point of anchorage. Obviously, a comparatively small guy wire, stressed but moderately, will greatly reduce the pole stresses, because the guy wire simply resists the force acting at the top of the pole, and has little or no moment acting against it.

The several methods of guying are shown in Fig. 109.

Head guys are anchored to the next adjacent pole. Side guys and angle guys must have anchorages prepared for them.

A cheap and effective anchor is the screw anchor. This is an iron rod 4 to 6 ft. long and having a flange at one end, which flange is not in one plane, but cut through radially and the two ends displaced axially, so that it forms a single, very wide screw thread. Where boulders are not encountered, this is screwed into the earth at an angle to the vertical so that the rod has approximately the same direction as the guy wire. An eye in
the upper end of the bar serves to twist it into the ground by passing a lever through it, and then is used for attaching the guy wires to it.

Buried logs or stones with iron rods attached are also used. Fig. 110 a and b show the arrangement and proportions of guy anchors of this latter variety.

Guy wires are made of stranded, galvanized-steel cable. The usual sizes are $\frac{3}{8}$ in. and $\frac{1}{2}$ in. in diameter. The cable has an elastic limit of about 100,000 lb. per square inch and an ultimate breaking strength of 200,000 lb. per square inch. The $\frac{3}{8}$-in. cable is used for stresses under 1000 lb. and the $\frac{1}{2}$-in. for stresses of from 1000 to 3000 lb. The $\frac{3}{8}$-in. weighs 0.3 lb. per foot and the $\frac{1}{2}$-in., 0.51 lb. per foot.

![Diagram of guy wire installation](image)

Fig. 110.—Log and stone anchors.

Guy wires are fastened to poles by making two or three turns about the pole, bringing the free end against the cable and clamping them together with a galvanized clamp.

It is customary to use side guys only when the direction of the line changes, and to take up the unbalanced pull of the wires. Good practice requires that every fifth pole be head guyed in both directions, so that in case of a transmission wire breaking, the pole line will not be pulled over, but the unbalanced pull of the remaining wires will be transmitted to the nearest head-guyed pole, where the guy wires will receive and resist the stresses produced.

Crossarms.—Crossarms are made of yellow pine or Oregon fir. Other timbers are occasionally used but these two are standard. Certain failures of wood-pole transmission lines may be attributed to having the crossarms too light. There is no saving in initial cost by adopting small crossarms. The dimensions should be such that the maximum unit stresses in them will equal
those in the pole when the crossarm section is reduced by 33 per cent. from decay, and the pole butt reduced 10 per cent.

For a line having poles spaced 203 ft. apart and carrying one circuit of three No. 2 wires—copper or aluminium—the crossarms should not be less than 5 by 6 in. in cross-section. This assumes a total length of 7 ft., and a distance between the two wires on the crossarm of 6 ft., each wire being about 30 in. from the pole.

Specifications for crossarms should require that at least 80 per cent. be of heart timber and no single crossarm may have more than 20 per cent. of sapwood. Knots having a diameter exceeding \( \frac{3}{8} \) in. are objectionable. The best timber only should be used for crossarms.

Transmission-line arms have customarily five holes in them, as follows: 1-in. holes near each end, vertically through the timber, for the stud of the insulator pin. This should be at least 4 in. from the end and, preferably, 6 in., so that the tendency of the forces acting on the pin to split the arm may be resisted.

Two holes, each \( \frac{3}{16} \) in. in diameter, are drilled, one on each side of the middle line, and from 20 to 24 in. distant from it. These pass, horizontally, through the timber and at right angles to the pin holes. Into these holes the \( \frac{5}{6} \)-in. lag screws, which fasten the braces to the arm, are screwed.

The fifth hole is in the middle of the length of the arm but one-third the width above the bottom edge. This hole is horizontal, 1 in. in diameter and receives the \( \frac{3}{4} \)-in. through bolt which fixes the arm to the pole.

A specification for crossarms is given here-with.

**SPECIFICATIONS FOR UNTREATED ARMS**

These specifications cover painted crossarms made of Norway pine, yellow pine, cypress or Douglas fir.

Norway pine is understood to cover what is also known as rein pine.

Yellow pine is understood to cover what is commonly known as Longleaf pine. It is understood that the term is descriptive of quality rather than of botanical species.

Douglas fir is understood to cover the timber known likewise as yellow fir, red fir, western fir, Washington fir, Oregon or Puget Sound fir or pine, Northwest and West Coast fir.

Cypress is understood to cover the timber known as reed cypress.
General

The specifications and drawing are intended to include all instructions necessary for the manufacturer to guide him in his work. They are intended to cooperate with and supplement each other, so that any details indicated in one and not in the other shall be executed as if indicated in both.

All material and workmanship, unless otherwise specified, shall be of the best commercial grade.

Material

All crossarms shall be made of thoroughly air-dried, or kilndried, straight-grained wood of the kind contracted for.

Crossarms shall be of the style and dimensions shown. Figures on the drawing shall be followed in preference to scale measurements.

Quality

Pith Heart.—Cypress crossarms shall be free from pith heart.

Sapwood.—Cypress crossarms shall be free from sapwood. Norway pine, yellow pine, and Douglas fir crossarms may contain sapwood, provided it is clear and does not form over fifteen (15) per cent. of the cross-section of the crossarm. Crossarms shall be shaped so that the sapwood shall be on the top or the sides of the crossarms.

Grain.—All crossarms shall be reasonably straight grained. The grain shall not depart from parallelism to any edge of the crossarm by an amount greater than one (1) inch to three (3) feet length of crossarm.

Pitch Pockets.—All crossarms shall be free from pitch pockets exceeding five (5) inches in length and one-quarter (¼) of an inch in width, and from all pitch pockets which enter the pin or bolt holes on the top or sides of the crossarm.

Knots.—All crossarms shall be free from loose or unsound knots.

Wane.—All crossarms shall be free from wane.

Shakes.—All crossarms shall be free from through shakes, and from other shakes or checks exceeding three (3) inches in length.

Warp.—A straight edge laid lengthwise on the concave side of a seven (7) or a six (6) foot crossarm shall not show an offset
greater than one (1) inch on the seven (7) foot crossarm and
greater than three-quarters (¾) of an inch on the six (6) foot
crossarm. No crossarm shall be twisted or bent in more than
one direction or bent in one direction on edge.

**Loose Heart.**—All crossarms shall be free from loose hearts.

**Rot.**—All crossarms shall be free from rot, dote or red heart.

**Worm Holes.**—All crossarms shall be free from worm holes.

**Inspection**

All crossarms shall be inspected for dimensions and defects
outlined under “Quality” before painting.

The spacing of the pin and bolt holes shall be within the limits
shown on drawing.

Pin and bolt holes shall be tested with steel gauges and shall
take gauges as follows:

- **Pin Holes.**—. . . . -in. gauge without forcing but not a . . . . -in.
gauge.
- **Middle-Bolt Hole.**—. . . . -in. gauge, without forcing.
- **Brace-Bolt Holes.**—. . . . -in. gauge, without forcing.

All crossarms not conforming to these requirements shall be
rejected.

The pin and bolt holes shall be smooth and the arms shall not be
badly splintered where the bits have broken through.

The brace-bolt holes shall not be drilled through the pin holes.

**Storage**

After the crossarms are shaped they shall be stacked in cross-
piles on skids in such a manner as to insure good ventilation.
The stacks shall be roofed to prevent the penetration of rain, or
the direct action of the sun.

**Hardware.**—The hardware used on pole lines comprises the
following:

1. Bayonet for ground wire.
2. U-bolt for ground wire.
3. Through bolts to hold bayonet to pole.
4. Through bolts to hold pole-head pin to pole.
   (In some designs, one of the bolts in item 3 serves as a bolt for
   item 4.)
5. Washers for items 3 and 4.
6. Nuts for items 2, 3 and 4.
7. Lag screws for braces at crossarms.
8. Lag screws for braces on pole.
10. Main crossarm bolt with nut and two washers.

The figures which follow, illustrating designs for pole heads, indicate the use of these various parts.

All hardware should be galvanized. The added cost is small and the injury to the parts of the pole head from continually forming rust may be considerable.

The following specification should apply to all galvanized hardware, guy wires, or other items which enter into the make-up of a line.

TESTS FOR HOT GALVANIZED IRON OR STEEL

(a) Coating.—The galvanizing shall consist of a coating of pure zinc of uniform thickness, and so applied that it adheres firmly to the surface of the iron or steel. The finished product shall be smooth.

(b) Cleaning.—The samples shall be cleaned before testing, first with carbona, benzine or turpentine, and cotton waste (not with a brush), and then thoroughly rinsed in clean water and wiped dry with clean cotton waste.

The samples shall be clean and dry before each immersion in the solution.

(c) Solution.—The standard solution of copper sulphate shall consist of commercial copper sulphate crystals dissolved in cold water, about in the proportion of 36 parts, by weight, of crystals to 100 parts, by weight, of water. The solution shall be neutralized by the addition of an excess of chemically pure cupric oxide (CuO). The presence of an excess of cupric oxide will be shown by the sediment of this reagent at the bottom of the containing vessel.

The neutralized solution shall be filtered before using by passing through filter paper. The filtered solution shall have a specific gravity of 1.186 at 65°F. (reading the hydrometer at the level of the solution) at the beginning of each test. In case the filtered solution is high in specific gravity, clean water shall be added to reduce the specific gravity to 1.186 at 65°F. In case the filtered solution is low in gravity, filtered solution of a
higher specific gravity shall be added to make the specific gravity 1.186 at 65°F.

As soon as the stronger solution is taken from the vessel containing the filtered neutralized stock solution, additional crystals and water must be added to the stock solution. An excess of cupric oxide shall always be kept in the unfiltered stock solution.

(d) **Quantity of Solution.**—Wire samples shall be tested in a glass jar of at least two (2) inches inside diameter. The jar without the wire samples shall be filled with standard solution to a depth of at least four (4) inches. Hardware samples shall be tested in a glass or earthenware jar containing at least one-half (½) pint of standard solution for each hardware sample.

Solution shall not be used for more than one series of four immersions.

(e) **Samples.**—Not more than seven wires shall be simultaneously immersed, and not more than one sample of galvanized material, other than wire, shall be immersed in the specified quantity of solution.

The samples shall not be grouped or twisted together, but shall be well separated so as to permit the action of the solution to be uniform upon all immersed portions of the samples.

(f) **Test.**—Clean and dry samples shall be immersed in the required quantity of standard solution in accordance with the following cycle of immersions.

The temperature of the solution shall be maintained between 62 and 68°F. at all times during the following test.

First—Immerse for 1 min., wash and wipe dry.

Second—Immerse for 1 min., wash and wipe dry.

Third—Immerse for 1 min., wash and wipe dry.

Fourth—Immerse for 1 min., wash and wipe dry.

After each immersion the samples shall be immediately washed in clean water having a temperature between 62 and 68°F., and wiped dry with cotton waste.

In the case of No. 14 galvanized iron or steel wire, the time of the fourth immersion shall be reduced to ½ min.

(g) **Rejection.**—If after the test described in Section "f" there should be a bright metallic copper deposit upon the samples, the lot represented by the samples shall be rejected.

Copper deposits on zinc or within 1 in. of the cut end shall not be considered causes for rejection.

In the case of a failure of only one wire in a group of seven
wires immersed together, or if there is a reasonable doubt as to
the copper deposit, two check tests shall be made on these seven
wires, and the lot reported in accordance with the majority of
the set of tests.

Note.—The equipment necessary for the tests herein outlined
is as follows:

Filter paper.
Commercial copper sulphate crystals.
Chemically pure cupric oxide (CuO).

Running water.
Warm water or ice as per needs.
Carbona, benzine or turpentine.
Glass jars at least 2 in. inside diameter by at least 4½ in. high.
Glass or earthenware jars for hardware samples.
Vessel for washing samples.
Tray for holding jars of stock solution.
Jars, bottles and porcelain basket for stock solution.
Cotton waste.
Hydrometer, large size with long scale.
Thermometer with large Fahrenheit scale.

Braces.—Table 15 herewith, gives the sizes and weights of
standard crossarm braces. The cost of these ranges from 3 to
4 cts. per pound.

<table>
<thead>
<tr>
<th>Size</th>
<th>Wt. per 1000 Pcs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>1420 lb.</td>
</tr>
<tr>
<td>22 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>1560 lb.</td>
</tr>
<tr>
<td>24 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>1700 lb.</td>
</tr>
<tr>
<td>26 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>1840 lb.</td>
</tr>
<tr>
<td>28 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>1980 lb.</td>
</tr>
<tr>
<td>30 × 1\frac{3}{8} × \frac{3}{4} in.</td>
<td>2120 lb.</td>
</tr>
<tr>
<td>20 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>1670 lb.</td>
</tr>
<tr>
<td>22 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>1835 lb.</td>
</tr>
<tr>
<td>24 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>2000 lb.</td>
</tr>
<tr>
<td>26 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>2165 lb.</td>
</tr>
<tr>
<td>28 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>2335 lb.</td>
</tr>
<tr>
<td>30 × 1\frac{1}{4} × \frac{3}{4} in.</td>
<td>2500 lb.</td>
</tr>
</tbody>
</table>

Reinforced-concrete Poles.—Several successful high-tension
lines have been placed on steel reinforced-concrete poles. Obvi-
ously, a concrete pillar of any desired size, height and strength
POLE AND TOWER LINES

Can be built, with internally threaded tubes or heavy nuts, cast in the concrete for the reception of studs to which the crossarms, or a framework of any kind, can be bolted. A concrete pole is the only permanent form of support that has been used for transmission lines. The author is convinced that when designers of transmission lines become better acquainted with the possibilities of reinforced concrete, poles made of this material will be universally adopted. If the line voltages require the use of suspension insulators, a steel crossarm—either an angle or a channel—may be placed at a proper elevation, and of sufficient length to allow the maximum “swing” of the insulator string with ample clearance between line and pole.

If poles are spaced 300 ft. apart or, approximately, $17\frac{1}{2}$ poles per mile, they need be only 46 to 48 ft. high to carry lines on a 3-ft. length of insulator string and give a maximum ground clearance of 20 ft. The cost of such poles, placed, should not exceed $50 or less than $900 per mile. This is for poles of sufficient strength to carry a circuit of three 0000 wires, and to take the stresses imposed by a wind pressure of 10 lb. per square foot and a longitudinal stress due to breakage of two wires. For the latter abnormal condition, a stress of 25,000 lb. per square inch in the steel reinforcement is assumed.

In view of the discussion of reinforced concrete and the formulæ given therein (see Chap. VII, Vol. I, “Dams”), there is no occasion to repeat them here.

The forces acting on poles have been set forth in the previous discussion of wood poles. With the data given in these portions of this work, any engineer can easily compute the cross-section of concrete and the amount of reinforcement required at any point along the length of the pole.

In addition to the longitudinal steel for reinforcement against the cantilever stresses to which the pole is subject, some circumferential, or hoop steel is required to resist torsional stresses which will be set up if breakage of wires occurs. These circumferential hoops serve also, as construction rods to separate and hold in place the longitudinal steel when the concrete is poured. The best form of reinforcement is heavy steel wire mesh, in as many rolls, or layers, as may be required to give the proper cross-section of steel. If more than three rolls, or layers, are required, the additional steel necessary may be in the form of rods.

One of the chief factors of cost of reinforced concrete poles is
the expense of handling them. They are very heavy, and to
distribute and set them, is costly. Hence, they should be made
as near the place of setting as possible. Poles have been made
individually, in place, being cast vertically in the previously
evacuated hole. This, however, is more costly than making the
poles in considerable numbers, at some convenient place, then
moving and setting them, just as wood poles are.

In order to reduce the cost and weight, the stress in the concrete
for the maximum condition of loading, should be taken as high as
safety will allow, say, 700 lb. per square inch, which is not an ex-
cessive stress for abnormal conditions of loading. Also, for max-
imum loading, the steel may be stressed up to 40 per cent. of its
elastic limit, so that steel having an elastic limit of 50,000 lb. per
square inch may be stressed up to 20,000 lb. per square inch
under abnormal loading.

The quantity of materials and the weight can be reduced by
making the poles hollow, a collapsing form being used to make
the inner space.

Many forms of reinforced-concrete poles have been designed,
but at the present time the section most generally employed is
square, having chamfered corners.

The weights of poles of certain given dimensions are as follows:
Pennsylvania R. R., Meadows Division. Poles to resist trans-
verse load of 6000 lb. applied 6.5 ft. from the top. Section
square with chamfered corners. Taper, 1 in 120.

Weight of 35-ft. pole 5,300 lb.
Weight of 40-ft. pole 7,600 lb.
Weight of 65-ft. pole 17,300 lb.

Mr. Alfred Still states that these weights are excessive because
of the great length of pole buried in the ground which was neces-
sary owing to the softness of the swamp earth.

He also states that for ordinary conditions the weight of a 30-
ft. pole would not exceed 2500 lb. and that of a 35-ft. hollow
pole should not exceed 2000 lb.

Roughly, the cost of reinforced-concrete poles—exclusive of
distribution and setting—ranges from 35 cts., to $1.00 per pound
weight.

The economics of pole design depend on the relative costs of
steel and concrete, and the most economical design is fixed by
the local conditions.
Pole Heads.—Figures 111 to 122 show various designs of pole heads for transmission lines. Most of these are obvious without any description.

Figure 120 shows a road crossing pole with a grounded wire netting to catch and retain any broken wire. Transposition pole heads are made in the same way of two poles with the two top insulators and the lower middle one on the crossarm, as shown in the figure.

![Diagram of pole head](image)

Fig. 111.—Pole head.

Fig. 112.—Pole head.

Pivot poles are those at which the line makes a change in direction and, hence, the stresses set up by the wires are much greater than those on standard pole heads. To resist these forces, two crossarms and two insulators, per wire, are fastened to a pair of poles as shown in Fig. 119.

Figure 122 shows a method of taking a branch off from the main line by dropping vertical connecting wires down to disconnecting switches placed at an elevation 17 ft. 6 in. below the main...
line. From the disconnecting switches the branch wires go to the branch pole head as shown.

Figure 116 shows an ingenious arrangement of two diagonally placed crossarms carrying suspension insulators, the line voltage being 88,000 volts. To prevent the wind pressure from swinging the lines too near the poles, a 30-lb. cast-iron weight is hung below each wire, as shown.
Figure 117 is a strain or anchor pole for the line run on the pole heads shown in Fig. 116. Fig. 118 is another form of anchor pole. Fig. 121 shows a method of making a 90° turn with a heavy line.

![Diagram](image)

Figure 117.

![Diagram](image)

Figure 118.

Figure 123 shows a steel lattice pole equipped with two metal crossarms arranged to give a triangular relationship of wires. These are arranged to carry suspension insulators. The whole construction is clear from the figure.

Towers.—Steel towers are of many forms, and the views of designers have differed considerably regarding the most econom-
ical type of tower, as is evidenced by the numerous varieties now in use. However, the present tendency is to use a tower which has four legs, with cross-members at the bottom and a

spread at the base of from one-fourth to one-fifth the tower height.

There are two general types of towers, namely, the flexible and the rigid. The flexible tower is practically an A frame, which is rigid in the direction at right angles to the line, but is
POLE AND TOWER LINES

capable of considerable deflection in the direction of the line. Fig. 124 shows one form of flexible tower. It resists all side forces due to wind pressure but inequalities in wire tension are met and equalized by a movement of the tower in the direction of the heavier strain. They are better adapted for lines supported on rigid insulators, as shown in the figure, than for suspension insulator lines. Some lines have been built with rigid towers 1500 ft. apart which serve as anchor towers, the line wires being fastened to these by a string of strain insulators, and in the middle of each of these long spans a low-cost, flexible tower is placed. In any line supported on flexible towers, equipped with

![Diagram](image)

**Fig. 122.** Pole head for branch circuits.

suspension insulators, the overhead ground wire is depended on to maintain them in a vertical position, and, sometimes, additional guys are run to ground anchors. In any case, rigid anchor towers must be placed at intervals in the line.

The most common form of rigid tower is the four-legged, square tower. In practically every case, they are thoroughly galvanized and are erected by using galvanized bolts to fasten the members together. The stresses which they have to resist have been given in the first part of this chapter. It is outside this discussion to enter into the question of tower design, but there are a few limiting factors which the engineer purchasing towers should
require of the manufacturer. The stresses acting are difficult to compute for each individual member and it has become common practice to determine the strength of towers by erecting a sample one and applying a force to it, at, or near, its top, and increasing this force until a distortion or rupture occurs. It

![Diagram of steel pole](image)

**Fig. 123.** — Detail of 56-ft. steel pole.

![Diagram of flexible steel tower](image)

**Fig. 124.** — Flexible steel tower.

is customary to assume a breakage of one or more wires and determine the resulting distortional stresses set up and then to apportion this total stress equally among the four corner posts. These relations are expressed as follows:

If \[ P = \text{unbalanced force acting at end of crossarm}, \]

\[ a = \text{distance from end of crossarm to center of tower, in feet}, \]

\[ b = \text{distance from side of tower body to axis of the tower, in feet}. \]
Then \[ p = \frac{P}{4} \] = force applied by \( P \) at each corner post, as a bending force acting on body of tower.

and \[ p_t = \frac{Pa}{8b} \] = torsional force applied at each corner post to twist body of tower.

Fig. 125.—Steel tower for single circuit.

The unit stresses which are assumed in the preliminary designs are as follows:

Tension: 12,000 to 20,000 lb. per square inch.
Shear: 12,000 to 20,000 lb. per square inch.
Bearing: 16,000 to 30,000 lb. per square inch.

Compression: \[ 20,000 - \frac{L}{R} \text{ to } 26,000 - 90\frac{L}{R} \]
\( L = \) unsupported length of member, in inches.
\( R = \) least radius of gyration of section, in inches.

\( L \) and \( R \) are so limited that for main members \( \frac{L}{R} \) does not exceed 125 to 180 and for any secondary members \( \frac{L}{R} \) does not exceed 150 to 220.

For a double-circuit tower, the length of the top and bottom crossarms should be as short as possible to meet the conditions of safe clearance of the line when the insulators are blown in toward the tower. The middle crossarm should be made from 5 to 10 ft. longer than the top and bottom arms, so that the wires and insulators on the middle arm lie in vertical planes considerably removed from the planes of the wires on the top and bottom arms. In case of excessive sag of any span, due to ice loading or insulator breakage, there will be no danger of its contacting with the wire below it. This arrangement allows a reduction in the height of the tower because the clearances between the crossarms may be reduced. Where a single circuit only, is carried on the tower, the best arrangement is one cross-arm, the three wires being in the same horizontal plane. For durability, no material should be used in the make-up of the tower less than \( \frac{3}{16} \) in. in thickness, regardless of the unit stresses in it.
The maximum side deflection of the insulator string should be taken as not less than 50°. It is claimed that under gusts of wind, the insulator will swing as much as 60° from the vertical.

Figure 125 shows a tower carrying one circuit only on a single crossarm. Fig. 126 is the outline of a tower carrying two circuits, the middle crossarm being longer than the upper and lower one. Fig. 127 shows a tower being assembled for erection and Fig. 128 shows the method by which it is raised into position on its foundation by means of a gin pole and wire cables. As an indication of the sizes of structural steel used, the dimensions of a 52-ft. tower are shown in Fig. 129. In Fig. 130 is shown the head of an anchor tower with the strain insulators.

The general tendency is to design towers so that they will have the strength to resist, as cantilevers, almost any imaginable
force which may be applied at the top by abnormal conditions of wind pressures, ice loading or breakage of wires, these occur-

Fig. 130.—Top of anchor tower.

ring independently or together just as the views of the designer may happen to suggest. A very much cheaper structure and one equally stable to resist any stresses which may be imposed on it can be made by treating the tower as a support only, and carrying heavy guy wires from secure ground anchorages to points near the top. The guy wires will oppose all forces which are not vertical and relieve the tower of any cantilever stresses. While this type is the normal and rational form of steel-tower installation, it is not usual practice, and it is not customary to guy towers, except occasionally, where the direction of the line changes and a guy wire is placed to oppose the side pull of the line wires. It is difficult to assign a reason for the common practice of constructing heavy steel towers, large and strong
enough to act as cantilevers when it is so obvious that nothing is gained by this practice. A galvanized-steel guy wire will have as long a life as any of the thin rolled-steel sections used for struts and counterbraces, so that it cannot be a question of durability. The only overturning forces which act on a tower are transmitted to it by the overhead wires and why a guy wire is not good enough to oppose the stress set up by a transmission wire, is beyond the power of the author to explain. It is probable, however, that as more engineers enter the transmission field and as investors become more familiar with the subject and understand that certain expenditures are made simply because a sort of fashion, instead of engineering economics, is the basis of design, more rational ideas will prevail and the design of steel towers will be radically changed, if they are used at all.

**Tower Foundations.**—The form of foundation used to support towers depends largely on the character of the soil. Where it is heavy and clayey, metal footings sunk into the earth may be used. It, however, is usually better to place a concrete pillar under each corner post and accurately level the tower footing on the upper surface and afterwards grout in
between the bottom of the tower footing and the top of the pier. There are as many varieties of tower footings as there are of towers and it is possible to depict only a few here. Fig. 131 shows a footing used where towers are set on rock. The rounded portion is sunk into holes drilled in the rock and securely grouted in. The corner posts of the towers are bolted to the sections which have been forged into the form of an angle. In setting these, it is essential that they be accurately leveled before the grout hardens. A form of steel frame for footings is shown in Fig. 132.
These frames are sunk into holes made in the earth, the holes filled up and well tamped, and the corner posts of the tower are bolted to the projecting gusset plates shown at the bottom of the picture.

In designing any form of footing, the uplifting force which may be imposed at the bottom of the corner posts, due to forces exerted at the top by wind pressure or breakage of conductors, should be computed, and the footing made amply strong against movement under the maximum uplift to which it can be subjected.

The details of several forms of concrete footings are shown in Figs. 133, 134, 135 and 136.

In computing the wind pressure acting against the tower, it is customary to assume the pressure per square foot of solid area, as 0.004V², V being the wind velocity in miles per hour. Twenty to 22 lb. per square foot, are the highest values taken, and some designers assume 13 to 14 lb. per square foot as the limiting wind pressure.

GENERAL SPECIFICATION FOR STEEL TOWERS

Open Sections.—Structures shall be so designed that all parts will be accessible for inspection, cleaning and painting.

Pockets.—Pockets or depressions which would hold water shall have drain holes, or be filled with waterproof material.

Splices.—Where a lap splice is used in leg angles the back of the inside angle shall be chamfered to clear the fillet of the outside angle.

Bolts.—The minimum size of bolts will be 5⁄8 in. diameter. The bolts have rolled threads, but must be full size in the shank. All bolts connecting the different parts of the tower together shall be of the same diameter and of as few different lengths as practicable. The shank of the bolt shall be long enough to extend through the members connected. A washer at least 3⁄8 in. thick shall be used under the nut.

Bolt Holes.—The punched holes shall not be more than 1⁄16 in. larger than the nominal diameter of the bolt.

Similarity.—In the case of square towers all four faces shall be made alike, as nearly as practicable.

Minimum Number of Parts.—Preference will be given to the designs that have the least number of parts.

Minimum Thickness.—The minimum thickness of material of any member for painted towers shall be 1⁄4 in., but, if the material
is to be galvanized, the minimum thickness of material in the legs shall be $\frac{1}{4}$ in., and that for any other members having calculated stress shall be $\frac{3}{8}$ in. Those having nominal stress only shall have a minimum thickness of $\frac{1}{8}$ in.

**Ratio of Slenderness.**—In compression members the ratio of the unsupported length divided by its least radius of gyration shall not exceed the following:

- Legs: 140
- All other members having calculated stress: 200
- Members having nominal stress only: 220

**Use of Rods.**—Rods will be allowed only where proper provision is made for tightening up same in the field.

**Ground Wire Clamp.**—The ground wire clamps will be considered a part of the towers and furnished with them by the contractor. They shall be of such design as will firmly hold, but not injure the cable.

**Insulator Connection.**—The contractor for the towers shall provide the necessary holes in the steel work of the towers for the connection of the insulator.

**Ladder.**—At least one leg of the tower shall be provided with steps. These steps, if made of bolts, shall be at least $\frac{5}{8}$ in. diameter and not more than 16 in. centers, starting 8 ft. from the ground.

**Painting.**—If the towers are to be painted, all parts of the tower shall receive one coat of best quality paint at the shop before shipping.

**Galvanizing.**—If material is to be galvanized, all parts of the tower except bolts and other special parts, shall be galvanized by the hot dipping method as the last process of fabrication. The bolts and other parts may be sherardized. All galvanizing shall be done in accordance with the specifications of the National Electric Light Association of 1911.

**Material.**—The steel used shall be made by the Open Hearth process and conform to the latest specifications for structural steel for buildings, as adopted by the American Society for Testing Materials.

**Drawings.**—All parts forming a tower shall be made in accordance with approved drawings.

**Workmanship.**—The workmanship and finish shall be equal to the best modern practice.
Marking.—Each separate member shall be plainly stamped with a number. All like parts shall have the same number, the mark being in the same relative position on each piece, but all different members shall have different numbers to distinguish them. This marking shall be stamped into steel before galvanizing or painting, with numbers at least \( \frac{3}{4} \) in. high, in such manner as to make them plainly visible after galvanizing or painting.

Shipping.—Unless otherwise specified, all parts of towers will be shipped unassembled, to be bolted together in the field. All like parts of one tower shall be bundled together at the shop before shipping, except such parts as would make too heavy a bundle for convenience in handling. Bolts and other small parts shall be shipped in bags or boxes strong enough to resist the necessary rough handling.

Inspection.—On request of purchaser the manufacturer shall furnish proper facilities to representative of the purchaser for the inspection of material and workmanship during the fabrication. The purchaser shall be notified well in advance of beginning the work in the shop in order that he may have an inspector on hand to inspect material and workmanship.

Assembling.—One of each standard line towers shall be assembled at the shop before shipment.

Test.—At request of purchaser, one each of the standard line towers shall be assembled and tested with loads as nearly as practicable like those for which the tower is designed, also if requested by purchaser the tower shall then be tested to destruction. The members forming the test tower will be selected at random from piles of similar members. The towers to be tested shall be set on a foundation as nearly as practicable like that to be used in the field. Unless otherwise agreed upon all tests will be made at the expense of the purchaser.

Foundations.—The foundations shall be designed to withstand two and one-half times the load coming on them without injurious movement, care being taken that they resist both the horizontal and vertical loads. If steel footings are used, it may be assumed that earth weighs 100 pounds per cubic foot, and that the base will engage the frustum of an inverted pyramid of earth whose sides have an angle of 33° with the vertical. If concrete foundations are used the weight of a cubic foot shall be assumed at 140 lb. Material buried in concrete will be left black, except
where stub angles are used, in which case, the stub angle be
galvanized or painted from the top down to a distance of 18
inches below top of concrete.

Spacing of Towers.—The spacing of towers varies from 400 to
1000 ft. There is, of course, for any set of conditions, a spacing
which is the most economical, and this should be worked out for
each particular case. The most economical spacing may be
determined, by assuming several different spans, finding the
costs of towers, foundations, insulators and accessories per mile, for
each span, and by this trial method the proper spacing is found.
A somewhat better method is to plot a series of curves of tower,
costs per mile for different spacings, using dollars as ordinates
and distances apart of towers as abscissæ. The tower cost
includes, of course, not only that of the tower itself, but also
insulator, foundation and erection costs. This curve will

![Graph showing cost per mile of towers and insulators]

Fig. 137.—Cost per mile of towers and insulators, erected.

have a minimum point, and the spacing corresponding to this
point is the most economical one. Fig. 137 shows a curve of
this kind, based on prices of materials and labor for the year 1911.
It shows the minimum cost to be for a spacing of 700 ft., amounting
to $2460 per mile of tower line. The computations are
exclusive of the cost of wires as these are practically constant
for any given conditions of power transmission.

Notes on Transmission-line Economics.—Steel towers are
inherently uneconomical as transmission-line supports. It is
claimed, by engineers who advocate their use, that they are
necessary for the long crossarm spans required by suspension
insulators, and the suspension insulators are demanded by the
voltage which must be used in order to keep the cost of the
transmission conductors within the bounds of commercial
possibility.

Suspension insulators can be successfully supported on poles
as has been proven in more than one instance. Furthermore, an increase in line voltage, resulting in a corresponding diminution of the cost of conductors, does not always produce a net decrease in the total line cost, although it generally will add to the complexities of the system and difficulties of operation. The cost of all accessory apparatus, such as insulators, lightning arresters, transformers, disconnecting switches, choke coils, oil-break switches, and, every other part of the transmission equipment, increases very rapidly as the voltage increases. Transformers for 110,000 volts cost 40 per cent. more than equivalent transformers for 70,000 volts, while electrolytic lightning arresters cost 50 per cent. more for the higher voltage.

If a lower-voltage line on poles costs about the same as a higher-voltage line on towers, the former is, financially, the preferable one, for in the one case the money would be invested, principally, in wires or cables with a small amount in poles, transformers and lightning arresters, while in the latter case, the money would be sunk in towers, transformers and lightning arresters.

Bare wires and cables have an intrinsic value and are not subject to depreciation. The prices of the metals may fluctuate but they represent convertible property which continues year after year with its value undiminished.

Fabricated materials, such as towers and electrical apparatus are subject to change, injury and even destruction, and each year their values are less than the preceding one.

Another factor is the use of aluminum wire. The price of aluminum is arbitrarily fixed by its producers, but, in recent years, it has been kept at an average of 23 per cent. below the prevailing cost of equivalent conductivity in copper. With towers spaced 600 ft. or more apart, the use of aluminum cable is impracticable, unless it have a steel core, for reasons elsewhere explained. This bimetallic wire costs nearly as much as copper and, for this reason, most of the long-span tower lines are of copper. With short-span lines, plain aluminum cable can be used and the full advantage obtained of the difference in price.

To make clear these several contrasting statements, a specific case is taken and the cost of the line and accessories computed for poles and towers.

The total cost of the line is not estimated as those portions which would be the same in either case are omitted, such as ground wire, and right-of-way. The inclusion of these would
not affect the comparison, and would add to the length of the computations.
   The basic conditions which are assumed are:
   Full normal load (peak) 12,000 kw.
   Distance of transmission 120 miles.
   These are large figures compared with the average transmission in America. One hundred and twenty miles is a long transmission and 12,000 kw. full load represents an annual delivery of energy equal to 42,000,000 kw.-hr. on the basis of a 40 per cent. load factor.
   The other conditions assumed are as follows:
   Power factor of load, 85 per cent.
   Kva. transmitted, 14,100.
   Frequency, 60 cycles.
   Regulation to be 12 per cent. at full load.
   28,000 kva. of transformer capacity required and 12 lightning arresters.
   Volts for tower line, 110,000.
   Separation of wires, 15 ft.
   Volts for pole line, 70,000.
   Separation of wires, 7 ft.
   Tower spans, 750 ft.
   Pole-line spans, 203 ft.
   Strength of pole, or tower.
   Factor of safety of 4, against side stresses due to wind load.
   Factor of safety of 2, against stresses due to breakage of one wire.
   Lowest point of wire, 20 ft. above ground.
   Size of wire for 12 per cent. regulation 110,000 volts is 128,000 cir. mls, weighing 2060 lb. per mile.
   Size of wire for 75,000 volts. This must be divided into two circuits.
   Size for each circuit = 127,500 cir. mls. weighing 2080 lb. per mile.
   Price of bare copper wire taken at normal figure of 16 cts. per pound.

Tower Line Costs.—Tower with foundations, insulators and fittings.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 miles @ $2600 per mile</td>
<td>$312,000</td>
</tr>
<tr>
<td>360 miles wire, 741,600 lb. @ 16 cts.</td>
<td>118,656</td>
</tr>
<tr>
<td>28,000 kva. transformers @ 1.40</td>
<td>43,200</td>
</tr>
<tr>
<td>12 lightning arresters @ $2000</td>
<td>24,000</td>
</tr>
<tr>
<td>Total</td>
<td>$497,856</td>
</tr>
</tbody>
</table>

Pole-line Costs.—Poles must be 45 ft. in length to carry three crossarms spaced 7 ft. 0 in. apart and must be set 7 ft. in the ground, so that height of lowest wire, at the pole, is 24 + 1 = 25 ft. above ground, the additional foot being the insulator height.
1. Cost of pole gained and set......................... 17.00
2. Cost of three crossarms each 5 by 6 in., 15 ft.
   0 in. long.......................................... 3.00
3. Cost of six insulators and pins @ 2.50........ 15.50
4. Cost of braces, bolts, hardware, etc............. 1.80
5. Cost of ground-wire bayonet........................ 1.10
6. Cost of labor on pole head......................... 2.00

40.50

Of these costs, items 1, 2, and 6, or a total of $22 per pole, depreciate at the same rate as the pole, i.e., 10 per cent. per annum, while the rest, or $18.50 per pole, depreciates at the rate of 5 per cent. per annum.
Number of poles per mile, 26.
Number of poles in 120 miles, 3120.

Cost of Pole Line.—
* Items 1, 2 and 6.

<table>
<thead>
<tr>
<th>Items</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3120 @ $22.00</td>
<td>$68,640</td>
</tr>
<tr>
<td>Items 3, 4 and 5.</td>
<td></td>
</tr>
<tr>
<td>3120 @ $18.50</td>
<td>$48,840</td>
</tr>
<tr>
<td>Wire</td>
<td></td>
</tr>
<tr>
<td>720 × 2080 = 1,497,600 lb. @ 16 cts.</td>
<td>$239,616</td>
</tr>
<tr>
<td>28,000 kv.a. of transformers @ $1.00........</td>
<td>$28,000</td>
</tr>
<tr>
<td>12 lightning arresters @ $1350.............</td>
<td>$16,200</td>
</tr>
<tr>
<td>Total Wire</td>
<td>$405,296</td>
</tr>
</tbody>
</table>

Saving over tower-line cost............................ $92,560

Annual Charges, Tower Line.—
Interest, 6 per cent. on $497,856 .................. $29,871
Depreciation, on towers, transformers, and arresters = 5 per cent. on $379,200.......................... $18,960
Depreciation on wire @ 1 per cent. on $118,656...... $1,186

Total annual charges................................ $50,017

Annual Charges, Pole Line.—
Interest @ 6 per cent. on $405,296 = ................ $24,318
Depreciation:
10 per cent. on items, 1, 2 and 6................... $6,864
On items 3, 4, 5, transformers and lightning arresters = 5 per cent. on $93,040....................... $4,652
1 per cent. on wire................................ $3,473

Total.................................................. $39,307
Saving in annual charges over tower line is $10,710, or 5 per cent. on $214,000.

The comparison is not complete. Aluminum could be used on the pole line with 203-ft. spacing, giving a net reduction of at least 20 per cent. of the conductor costs, so that the cost of the line on poles would be $357,373 instead of $405,296, showing a saving in first cost, over the steel tower line, of $140,483. Also, the interest charges and wire depreciation, taken together, would be reduced $3354 by using aluminum, so that the annual charges of the pole line would be, in reality, $14,064 less than those of a tower line.

Unquestionably, there are distances of transmission and quantities of energy to be transmitted such that towers become necessary. That condition, however, is not inside 120 miles and 12,000 kw.

While continuity of service is one of the most desirable and necessary conditions of electrical supply, absolute continuity over a long period of years, with abnormal occurrences of temperature, sleet, burnt wires, high winds and other conditions which endanger a line, can not be obtained without an excessive investment. Interest and depreciation continue 365 days every year. The owners of the property must have some return for this investment. The question is, would not a lower-cost line, with an occasional interruption and its attendant loss, pay greater net returns to the investors. When the cost of insurance against failure of service costs more than the failure would, the investment has been carried too far. Also, the interest loss is a certainty, while the loss due to line failure is only a risk and may never occur. Engineers spending money for people who invest it in the hope of a reasonable income, should carefully analyze the financial factors, and their designs should be governed by the production of the greatest dividends from a given expenditure.

No money should be invested without the definite knowledge that each dollar expended will bring in an annual, net return, excepting only that money spent to insure the safety of human life. The specific application of these remarks is to the question of the strength of transmission-line supports, but they constitute a sound financial axiom that applies to every other part of the plant.

Also, it is a financial fallacy to allot a specific value to all energy lost in the transmission line or used in station auxiliaries.
Unless the station is fully loaded, the cost of the lost current is practically nothing. No costs in a water-power plant are proportional to the output. They are fixed, regardless of whether the station works on quarter load or full load, and if the water be plentiful and the total load within the generating capacity of the plant, energy losses do not represent any financial loss. Of course, when the commercial load overtaxes either the station equipment or the water supply, the condition changes and the losses immediately have a money value equal to the selling price of the energy consumed.

Since, in general, the transmission-line cost has a continuous interest charge against it, and the energy loss in it may represent a money value a small portion of each year only, it is good financial practice to make the full-load line losses as great as a reasonably satisfactory regulation will allow. Hence, the criterion for the size of wire is allowable regulation, not energy loss. Of course, this is a broad general statement subject to modification according to specific circumstances. If the added, actual earnings produced by increasing the size of wire above that required for regulation, will exceed the interest charges on the added investment, the larger wire should be used, otherwise, it should not be.