Installation Practices

Once the route and length of a transmission or distribution line has been decided upon and the correct conductor size and type selected to carry the system load safely and economically, there are still several mechanical considerations which will have an effect on installation practices and may influence the final choice of conductor.

Line Design Factors

The line designer must consider such factors as tower and pole locations and heights, span lengths, conductor tension and sags, ground clearances, etc. Technically, this means that he must have detailed knowledge of conductor sag-tension characteristics as a function of span length, temperature, and weight loading. Much of this information is supplied by wire and cable manufacturers in the form of tables and graphs that are to be used by the line designer.* Supplementing these, the line designer prepares other graphs, tables, templates, etc., that are related to a specific installation.

Thus, there are two distinct types of study: (1) That which is ordinarily performed by the engineers of the wire and cable manufacturers, and (2) that which is performed by the line-design engineer to utilize the manufacturer-supplied information to best advantage. Users of this handbook probably are more likely to work with manufacturer-supplied graphs and data for application to a specific installation than to work on the analysis of physical properties of conductors. Hence the first section of this chapter endeavors to show how the line designer uses manufacturer-supplied data. This will be followed by a brief outline of the work ordinarily done under manufacturer’s auspices. First, a few general statements that apply to both kinds of analysis are made.

The “tension limits” used as the basis for calculations in this chapter are stated as not exceeding a specified percentage of the rated strength of the conductor, and these strengths are calculated in accordance with current ASTM standards.

*If not otherwise identified, charts and graphs in this chapter were supplied by conductor manufacturers.

An overhead conductor suspended between insulator supports assumes the shape of a catenary curve provided the conductor is of uniform weight per ft. Usually it is convenient, without significant error, to regard the curve as a parabola. A family of such curves exists for a given conductor and span, Fig. 5-1. The mid-point sag depends on tension in the conductor; the greater the tension the less the sag. To distinguish between span length and conductor length, the latter is usually designated arc length.

Anything that increases are length after initial stringing increases the sag. Factors that may bring this about are (1) thermal expansion of the conductor because of increase of temperature above that during stringing, (2) increase of conductor apparent weight because of wind and/or ice load, (3) creep gradually lengthening the conductor wires as a result of tension being applied over a period of many years, (4) stressing of wires beyond their elastic limits.

![Diagram showing family of sag curves. The sag is less with increase of conductor tension.](image)

*For sags up to 6% of span, the error is about ½ %, and for a sag of 10% of span, the parabola results in a sag about 2% too small.
bare aluminum wire and cable

Though it might appear that sag-tension problems relating to these subjects could be solved in a simple manner, there are interrelated factors that must be taken into account. For example, ACSR has components that have differing stress-strain characteristics, differing coefficients of thermal expansion, and they normally undergo differing unit tensile stresses.

Thus, it is evident that proper selection of span length and sags for a given profile and conductor in order to minimize installation and operational costs requires a high order of engineering skill. However, for many applications, the required sag-tension analysis has been made by others, and the results are available in tables and graphs supplied by wire and cable manufacturers for all commercially offered conductors. Only a moderate amount of additional work is necessary to utilize them for specific applications.*

*Initial and Final Sag-Tension Charts for Variable-Length Spans

Two typical sag-tension charts are shown in Figs. 5-2 and 5-3. These charts apply to a 795 kmil 54/7 ACSR Condor with standard class A steel core wire and include both bare and heavy loading as defined by the National Electric Safety Code (NESC) and listed in Table 5-1. The curves of these graphs show sags and tensions for various temperatures for spans from 400 to 1600 ft. Fig. 5-2 shows initial sags and tensions based on one-hour creep. Fig. 5-3 shows final sag and tension values. In this example, the sag after 10 year creep exceeds the final sag after heavy loading. Thus, creep is the governing condition in determining the final sag and tensions.

Referring to the explanatory table accompanying Fig. 5-2, the sag-tension values are shown for bare conductor (no ice or wind) at six different temperatures, ** 1/2 in. ice at 32° F and heavy loading of 1/2 in. ice plus 4 lb/sq ft wind plus a constant. The resultant of the conductor weight plus ice and side wind load (which is at right-angle to the line) is increased by a constant K = 0.30 lb per ft. In the example, the cable weight alone is 1.024 lb per ft. The resultant NESC Heavy loading on the conductor is 2.432 lb per ft.

The upper set of curves of Fig. 5-2 shows conductor tension in lb vs span in ft; the lower set shows sag in ft vs span in ft. The rated strength of this conductor is 28,200 lb. With full ice and wind load, the allowable tension as shown below the explanatory table is 40% of 28,200 or 11,280 lb. This value has been selected as the maximum allowable tension and the No. 1 sag curve is drawn correspondingly. However, it should be noted that for spans below 720 ft, the tension as shown by curve 9 on the initial chart (Fig. 5-2) is less than 40 percent of the rated strength because, for spans shorter than this, the final tension limit of 25 percent of rated strength at 0°F is ruling. This can be noted from curve 15 of the final chart (Fig. 5-3) where the tension levels out at 7,100 lb for these shorter spans and does not exceed 25 percent of rated strength. In addition, the allowable initial tension on the unloaded or bare conductor, when installed, is 33.3 percent or 9400 lbs. Since curve 15 on the initial chart does not exceed 9000 lbs, this requirement is met.

Since the probable average span for an overhead conductor of this size is about 1000 ft, the strength margin for the conductor is even more favorable as seen by the reduced tensions above 720 ft.

**TABLE 5-1**

<table>
<thead>
<tr>
<th>Loading District</th>
<th>Description and Method of Obtaining Loaded Weight per foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Cond., plus 9 lb sq ft horiz. wind on projected area. To the resultant add K = 0.05 lb per ft. Applied at 30°F.</td>
</tr>
<tr>
<td>Medium</td>
<td>Cond., plus 1/4-in. ice, plus 4 lb/sq ft horiz. wind on projected area. To the resultant add K = 0.20 lb per ft. Applied at 15°F.</td>
</tr>
<tr>
<td>Heavy</td>
<td>Cond., plus 3/4-in. ice, plus 4 lb/sq ft horiz. wind on projected area. To the resultant add K = 0.30 lb per ft. Applied at 0°F.</td>
</tr>
</tbody>
</table>

Overhead conductor loadings of the three above classes are usually applicable to sections of the United States, according to the map below though heavier loadings are used if local conditions appear to require them.

*In addition, several computer programs have been developed to do these calculations and they are available to utility and computer engineers so they can do this work themselves.

**If the conductor is subject to electrical overloads, curves for the highest temperature likely to be encountered should be added.
TENSION LIMITS:

a. With ½" ice+4 lb wind=constant at 0°F, not to exceed 40% of Rated Strength.
b. Initial (when installed) with no ice or wind at 0°F not to exceed 33.3% of the Rated Strength.
c. Final (after maximum load or ten year creep) with no ice or wind at 0°F not to exceed 25% of the Rated Strength.

<table>
<thead>
<tr>
<th>Sag</th>
<th>Tension</th>
<th>Ice</th>
<th>Wind</th>
<th>Temperature</th>
<th>NESC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve</td>
<td>Curve</td>
<td>inches</td>
<td>lb/sq/ft</td>
<td>°F</td>
<td>Constant</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>½</td>
<td>4</td>
<td>0</td>
<td>0.30</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>½</td>
<td>0</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>-20</td>
<td></td>
</tr>
</tbody>
</table>

Obvious relationships are shown by the curves. Thus, for a span of 1000 ft, the tension drops from 6800 lb* to 4950 lb when temperature increases from 0°F to 120°F (curves 15 and 11), and sag increases from 19 ft to 25 ft (curves 7 and 3) as shown in Fig. 5-2. Some charts also include sag and tension curves for estimated maximum temperatures greater than 120°F. Where higher operating temperatures are anticipated, the user should consult his conductor manufacturer.

Fig. 5-3 showing the final sags and tensions can be interpreted in the same manner as Fig. 5-2. It shows the effect of long time elongation from 10-year creep or heavy loading if it happens to permanently stretch the conductor.

*Because of uncertainties of reading values from a chart, such values in this book may differ slightly from computed values from which the graph was made.
to a greater degree than that resulting from creep. Thus, in this case, an initial sag of 22.4 ft at 60°F (Fig. 5-2 curve 5) increases to 25.5 ft. (Fig. 5-3 curve 5) and the tension (curve 13 in both figures) drops from 5700 lb to 5100 lb.

Initial Stringing Chart

Curves such as Figs. 5-2 and 5-3 provide basic information for use in the preliminary design of overhead lines and can be used directly for individual spans dead-ended at each end, but they cannot be used for a series of spans of different lengths because the tensions, if taken directly off Figs. 5-2 and 5-3, will be different for each span and in such a series of spans the line tensions must be equal so there will be no significant unbalanced longitudinal loads on structures, and so insulator strings will hang vertically.

The procedure for finding the initial sag and tension in a line, or section of line between dead-ends, having spans of differing lengths is based on taking the values off the initial sag-tension graph Fig. 5-2 for the ruling span as herein defined, and preparing an initial stringing sag chart such as is shown in Fig. 5-4. This chart shows the amount of sag for a span of any length that will result from a constant tension in all spans of the line. This tension will require adjustment so as to allow for the conductor temperature at the time of stringing. This adjustment is obtained from the temperature-tension line (curve 1) on Fig. 5-4. Thus, the initial stringing chart, as shown here, is for a new 795 kcmil 54/7 ACSR based on a ruling span of 1000 ft and 11,280 lbs maximum tension with NESC heavy loading. Curve 1 for tension and temperature is obtained by taking the tension values from Fig. 5-2 for a 1000 ft span at the various temperatures and plotting them as shown in Fig. 5-4. From Fig. 5-2, it can be noted that the tension at 0°F is 6800 lbs, at 60°F is 5700 lb and at 120°F is 4950 lb. These and intermediate values are used to determine curve 1 of Fig. 5-4. Thus, this curve gives the value of the stringing tension to be used for the particular temperature at which new conductor is installed in a section of line having this particular ruling span.

The Ruling Span

The first step in the preparation of a stringing chart Fig. 5-4, from the sag-tension chart Fig. 5-2, (or Fig.
5-3 for pre-stressed conductor) is to find the Ruling Span, which in effect is a weighted average taken from the various span lengths that occur in the line between dead ends. The formula for Ruling Span is

\[ \text{Ruling Span} = \left( \frac{S_1^2 + S_2^2 + S_3^2 + \ldots + S_n^2}{S_1 + S_2 + S_3 + \ldots + S_n} \right)^{\frac{1}{2}} \text{ ft} \]  

(Eq. 5-1)

in which the successive S-values are actual spans in ft. The ruling span is somewhat longer than the average span. A frequently used approximate rule is to make the ruling span equal to the average span plus two-thirds of the difference between the maximum span and the average span. This rule, however, obtains results that often vary considerably from what is obtained by applying Eq. 5-1, hence the use of Eq. 5-1 is preferred.

Example: A line having ten spans of 1000 ft, three spans of 800 ft, and two spans of 1200 ft, the Ruling Span by applying Eq. 5-1 is 1006 ft, and by applying the approximate rule it is 1129 ft. For this example a 1000 or 1006 ft ruling span should be used. If the ruling span calculated by the approximate rule were to be used, the actual final sags would be greater than the design final sags.

In order to establish the sag curves for the various temperatures shown in the stringing chart, the sags for the 1000-ft span of bare conductor (curves 3-8) are transferred from Fig. 5-2 to Fig. 5-4, that is, 18.8 ft for 0°F, 22.4 ft for 60°F, 25.8 ft for 120°F and similarly for the other temperatures. The method used for completing the curves and obtaining the sags for spans other than the 1000-ft ruling span is by using a parabola for the approximation of the sag values at various temperatures. In a parabola the sags are proportional to the square of
bare aluminum wire and cable

TABLE 5-2
Stringing Sags for Various Spans of Bare Unloaded 795 kcmil ACSR 54/7 Wt. 1.024 lb/ft, for Specified Constant Tension at Stated Temperatures, and Ruling Span of 1000 Ft

<table>
<thead>
<tr>
<th>Temperature Tension, lb</th>
<th>0°F Initial 6800</th>
<th>30°F Initial 6200</th>
<th>60°F Initial 5700</th>
<th>90°F Initial 5300</th>
<th>120°F Initial 4950</th>
<th>120°F Final 4400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span in Feet</td>
<td>Sag in Feet</td>
<td>Sag in Feet</td>
<td>Sag in Feet</td>
<td>Sag in Feet</td>
<td>Sag in Feet</td>
<td>Sag in Feet</td>
</tr>
<tr>
<td>400</td>
<td>3.0</td>
<td>3.3</td>
<td>3.6</td>
<td>3.9</td>
<td>4.1</td>
<td>4.7</td>
</tr>
<tr>
<td>500</td>
<td>4.7</td>
<td>5.2</td>
<td>5.6</td>
<td>6.1</td>
<td>6.5</td>
<td>7.3</td>
</tr>
<tr>
<td>600</td>
<td>6.8</td>
<td>7.4</td>
<td>8.1</td>
<td>8.7</td>
<td>9.3</td>
<td>10.5</td>
</tr>
<tr>
<td>700</td>
<td>9.2</td>
<td>10.1</td>
<td>11.0</td>
<td>11.8</td>
<td>12.7</td>
<td>14.3</td>
</tr>
<tr>
<td>800</td>
<td>12.0</td>
<td>13.2</td>
<td>14.3</td>
<td>15.5</td>
<td>16.5</td>
<td>18.7</td>
</tr>
<tr>
<td>1000</td>
<td>18.8</td>
<td>20.7</td>
<td>22.4</td>
<td>24.2</td>
<td>25.8</td>
<td>29.2</td>
</tr>
<tr>
<td>1200</td>
<td>27.0</td>
<td>29.8</td>
<td>32.2</td>
<td>34.8</td>
<td>37.2</td>
<td>42.0</td>
</tr>
<tr>
<td>1400</td>
<td>36.8</td>
<td>40.6</td>
<td>43.9</td>
<td>47.4</td>
<td>50.6</td>
<td>57.2</td>
</tr>
</tbody>
</table>

Note: For initial values this table is compiled from the 1000-ft values of Fig. 5-2. If the conductor has been prestressed, Fig. 5-3 is to be used as basis for sag values, as explained in text. Fig. 5-3 is also used as basis for final sag values in right-hand column.

the span, thus the sag at 60°F for a 500-ft span is 1/4 that of a 1000-ft span (i.e. 5.6 ft). This value is on curve 4 of Fig. 5-4 at 500 ft.

The Initial Stringing Chart Fig. 5-4 is based on values obtained from the Initial Sag-Tension Chart, Fig. 5-2, because, as stated, the stringing of new conductor is assumed. However, conductor that has been removed from an old line or has been pre-stressed to final conditions should not be restrung to initial conditions. An approximate rule of thumb is to string old conductor half-way between initial and final sags because when conductor is removed from a line and reereited it relaxes. If strung to supposedly final sags, the actual final sags will be greater than planned.

Completion of Stringing Graph by Use of Parabola Formula

As previously noted, the sag values for the 1,000-foot ruling span for the stringing chart Fig. 5-4 have been transferred from Fig. 5-2 as points on the vertical line for the 1,000-foot span on Fig. 5-4. Note that these values are also listed in Table 5-2 on the horizontal line for the 1,000-foot span. It is now necessary to find the other mid-point sag values to complete Table 5-2 and Fig. 5-4 under a constant tension for all spans at a given temperature.

For this purpose, the parabola formula is satisfactory for calculating the sags; thus,

\[ D = \frac{W S^2}{8 H} \]  (Eq. 5-2)

in which

\[ D = \text{Sag, ft} \]
\[ W = \text{Weight of conductor, lb per ft} \]
\[ S = \text{Span length, ft} \]
\[ H = \text{Horizontal Tension, lb (a constant for each temperature)} \]

The above sag value should be corrected if the sag exceeds about 5% of span length (see Eq. 5-4, below).

From the above formula the following ratio is derived as a simple means of obtaining the required sags. Since the horizontal tensions in each span of the section of line between deadends are to be equal, \( H_1 = H_2 \) and therefore

\[ \frac{W S_1^2}{8 D_1} = \frac{W S_2^2}{8 D_2} \]

Since \( W \) and the constant 8 are common to both sides we have

\[ \frac{S_1^2}{D_1} = \frac{S_2^2}{D_2} \text{ or } D_2 = \frac{D_1 S_2^2}{S_1^2} \]  (Eq. 5-3)

Using this formula Table 5-2 and Fig. 5-4 can be completed. Thus, to complete the column for 60°F in Table 5-2 use sag for a tension of 5,700 lb. at 22.4 ft. and applying it to the ratio of the spans for the 400 ft. span the result is and so on up to spans for 1,400 ft. In

\[ D_2 = \frac{(22.4)(400)^2}{(1,000)^2} = 3.6 \text{ ft} \]
a similar manner Table 5-2 is completed for the other temperatures. These sag values are then transferred to the Initial Stringing Graph (Fig. 5-4) and the curves drawn for each temperature.

**Sag Correction for Long Spans**

If the sag exceeds about 5% of span length, an amount should be added to the sag read from Fig. 5-4, computed as follows:

\[ \text{Correction (ft)} = D^2 \times \frac{W}{6H} \]  

(Eq. 5-4)

in which \( D \) = Sag in feet obtained from Eq. 5-2, as previously described. Other values are as stated for Eq. 5-2.

This correction rarely is necessary (see footnote on page 5-1).

**Use of Stringing Charts**

A stringing chart such as Fig. 5-4, should be prepared and used for each line or section having different ruling spans and tensions between dead-ends.

Stringing charts are used to obtain the values used for the control of the tension and sag of the conductor. During the stringing operation, the conductor should be run through stringing sheaves which turn freely and are in good condition. As the conductor is brought up to initial sag it should be checked against the values taken from the chart, at different intervals, depending on the length of the section being sagged. Preferably this should be near each dead-end, in the middle, and in spans as close as possible to the ruling span. The sags should be checked even if the conductor is pulled, by means of a dynamometer, to the required tension. Normal sheave friction can result in uneven sag between spans. Sometimes the conductor will become caught in a stringing sheave, or the sheave does not move freely. In such cases some spans may be up to the required tension while others may not. The normal differences caused by sloping or offset contours are discussed on page 5-8.

When the conductor has mid-point sags according to the Initial Stringing Chart, in our example, the final maximum sag at 120°F (or estimated maximum conductor temperature if greater than 120°F) will not exceed the ten-year creep design sag. This sag is shown by curve 3 of Fig. 5-3 which indicates the unloaded condition at 120°F. Strung on this basis, the conductor ground clearance will not be less than that specified in the line design criteria.

For a more detailed treatment of stringing methods, equipment etc., reference should be made to the IEEE publication P-524 entitled “A Guide to the Installation of Overhead Transmission Line Conductors”.

**Stringing-Sag Tables**

Figs. 5-2 and 5-3 are typical of manufacturer supplied tension charts from which Stringing-Sag charts, such as 5-4, are made. Such stringing charts are used principally as an aid in line design of transmission and distribution lines where there is not much repetition. With the advent of computer programs it is much more common to use Stringing-Sag Tables instead of charts. These tables, for various ruling spans, are generally compiled by utilities for their own use. They avoid the need of reading from curves or interpolating from large-interval tables.

An extract from such a stringing sag table, Table 5-3 is from a book that contains 69 such tables for various ruling spans and for AWG sizes of ACSR in 6/1 and 7/1 strandings—with spans as short or as long as practicable for the specified ruling spans. Tables for NESC light, medium, and heavy loadings are included.

**The Sag-Span Parabola and Template**

For determining minimum clearance under a line over an irregular profile it is necessary to know the final sag at all points of the span. Only the mid-span initial sag is known from charts such as Fig. 5-4. These intermediate sag values are obtained graphically by plotting a parabolic curve between the point of maximum sag and the point of elevation of the support. The same parabola is used for inclined spans, as is described later in this chapter.

Depicted in Fig. 5-5 is the sag-span parabola* for the conductor and conditions described in the legend. The values are based on a constant tension of 4400 lb and mid-point sag of 29.2 ft for ruling span of 1000 ft, as noted from Fig. 5-3 for 120°F. A similar parabola for emergency-overload temperature is also advisable. The mid-point sags for other spans are obtained from the parabola (also listed in the right hand column of Table 5-2). The mid-point sag for the ruling span of 1000 ft most probably was obtained from a catenary curve, but the use of the parabola for intermediate values introduces no significant error. The mid-point sags shown by Fig. 5-5 for spans that differ from the 1000 ft ruling span vary from those for the same spans as shown on Fig. 5-3 because the latter figure is drawn to cover a range of “ruling spans” whereas Fig. 5-5 is based on only the 1,000-foot ruling span.

The 120°F mid-point sag for the 1000-ft ruling span from Fig. 5-3 is used as the basis for Fig. 5-5, because from Fig. 5-3 it is seen that the sag of a bare conductor at 120°F is greater than that of a conductor carrying full ice load. The maximum possible sag for clearance investigations usually occurs when the conductor is at high temperature because of an emergency-load, depending on user’s standard for emergency temperature of bare conductors.

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* Such parabolas are easily prepared. See Page 5-11.
bare aluminum wire and cable

TABLE 5-3
Stringing-Sag Values for 1/0 ACSR (6/1), for Ruling Span of 550 ft for NESC Heavy Loading for Various Temperatures, and Maximum Tension 60% of Rated Strength

<table>
<thead>
<tr>
<th>Span Length feet</th>
<th>Initial sag, inches, for various temperatures (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
</tr>
<tr>
<td>230</td>
<td>12</td>
</tr>
<tr>
<td>520</td>
<td>61</td>
</tr>
<tr>
<td>540</td>
<td>63</td>
</tr>
<tr>
<td>550</td>
<td>65</td>
</tr>
<tr>
<td>560</td>
<td>68</td>
</tr>
<tr>
<td>570</td>
<td>70</td>
</tr>
<tr>
<td>700</td>
<td>106</td>
</tr>
</tbody>
</table>

thence continuing for span intervals of 10 ft to 700 ft

If a parabola is used very much, it is convenient to cut its outline in a plastic sheet as a template marked with its vertical axis.

Sag When Supports Are at Different Elevations

The parabola template of Fig. 5-5 also may be used to find the low point of a conductor suspended between supports that are not at the same elevation. Thus, Fig. 5-6 denotes the application of the Fig. 5-5 template to an 800-ft span which has one support 25 ft above the other. Points A and B are located to the same scale as that of the parabola. The template is then shifted until both points A and B fall on the parabola outline and the parabola axis is vertical. The outline is then drawn as the curve AFDB, in which F is low point, and D is a tangent under C, at the mid-point of the span.

It can be shown that the mid-point sag CD is equal to that of a horizontal span equal in length to the inclined span (in this case 18.7 ft). However, it is point F that is required in order to determine adequate clearance, and this is found graphically as illustrated in Fig. 5-6. Point F also may be found in terms of the mid-point sag on a horizontal span of the same length provided the difference in elevation is not greater than four times the mid-point sag, as follows:

\[ AH = CD \left(1 - \frac{GB}{4(CD)}\right)^2 \]  \hspace{1cm} (Eq. 5-5)

or in this case \[ AH = 18.7 \left(1 - \frac{25}{4(18.7)}\right)^2 = 8.3 \text{ Ft.} \]

BJ = AH + Diff. in elevation = 33.3 Ft.

Horiz. distance HF = \[ \frac{\text{Span}}{2} \left(1 - \frac{\text{Elev. Diff.}}{4 \times 18.7}\right) = 265 \text{ Ft.} \]

Formulas are also available for use when the difference of elevation is greater than four times the mid-point sag and also for critical work where a catenary curve is used instead of a parabola. A graphic method of drawing the parabola is described on Page 5-11.

The Uplift Condition (Negative Sag)

Transmission lines, in hilly and mountainous terrain, sometimes have steep inclines in some of the spans, and if the towers are not properly spaced a condition can exist similar to that depicted in Fig. 5-7. In cases such as this, the maximum sag is obtained in the usual manner from the applicable 120°F (or whatever maximum temperature the utility uses for this purpose) parabola template. This step will show the normal maximum sag between each support. However, if the temperature drops to the lowest likely to be encountered in the unloaded condition (with no ice load to increase the sag), the conductor may shorten sufficiently, because of thermal contraction, so that the force on the support at tower C is upward instead of downward. Such a condition is to be avoided and there should be a considerable downward force at the conductor support to prevent collapse of the suspension insulators or a pullout at the insulator caps. Under these conditions it is also possible that side winds will cause the suspension insulator to swing beyond a safe
angle (usually 45° per NESC).

In order to predict and evaluate the possibility of such an occurrence, a parabola template similar to Fig. 5-5 is prepared based on the ruling span, but done for the lowest temperature likely to be encountered in the unloaded condition. In some areas this temperature may be well below 0°F. The template is based on Fig. 5-2 for initial stringing because this represents the period of minimum sag before load offsets or appreciable creep occurs. Thus, a template might be prepared for a 1,000-foot ruling span for -20°F, with a mid-point sag of 18.8 feet and a tension of 7,300 lbs. (from curve 16 of Fig. 5-2). The resulting parabola, Fig. 5-8, is "flatter" than that of Fig. 5-5 because both the aluminum and the steel are carrying their full share of the load. When this curve is applied to a line layout similar to that shown in Fig. 5-7, it will indicate a condition of uplift at support C. This condition is usually corrected by altering the tower spacing, by increasing the height of the towers where this occurs, or by installing dead-ends where the slope from the tower is large. Usually both the maximum sag and uplift curves are drawn on the same template.
Unbalanced Forces at Support Points

In a series of spans between dead-ends, adjacent spans may differ in length, or their supports may be at different elevations. In addition, sleet may drop from one span and not from an adjacent one. These conditions cause an unbalance of longitudinal forces at the insulator support. This unbalance will cause a suspension insulator to swing from vertical positions, or a cantilever load will be applied to a cap-and-pin insulator. If the unbalance is greater than what is regarded as good practice, as often is the case in hilly country, dead-end connections at individual spans are used to avoid these forces on the insulators.

Note: For more information on this subject, reference should be made to the IEEE paper 64-146 "Limitations on Stringing and Sagging Conductors."

Preparation of Sag-Tension Charts

The sag-tension charts Figs. 5-2 and 5-3, that are the basis of line design, usually are prepared by wire and cable manufacturers. Differing methods are used for such work—principally those originated by P. H. Thomas, J. S. Martin, and H. H. Rodee, or a combination of them. References should be consulted for full explanation of these methods.* All require considerable mathematical or graphical analysis, particularly for composite conductors. The steel and aluminum components of ACSR, for example, differ as to stress-strain properties, coefficient of thermal expansion, and allowable stress, hence ACSR analysis is not a simple process.

Space does not permit a full discussion of these methods, but a brief outline of the Rodee Graphic Method is included, that applies to a non-composite AAC conductor, along with a worked-out example.

The Catenary Curve and Preliminary Sag-Tension Graph

The sag curves of Fig. 5-1 are catenaries if the conductor is of uniform weight per ft. Though such a curve can be approximated by a parabola, it is customary to obtain mid-point sags for sag-tension graphs Figs. 5-2 and 5-3, by the catenary formula, and to use the parabola for finding mid-point sags at constant stress as depicted in Fig. 5-4.

All catenary curves can be defined from the values in Table 5-4. Those in the two-left-hand columns apply to any catenary, regardless of material, weight per ft or length. Thus, for a 500-ft span in which the conductor arc length increases by 0.30%, or to 501.5 ft, the mid-point sag is 3.3576% of 500 ft, or 16.8 ft, or if it is a 1000-ft span, the sag is 33.6 ft. Mid-point sag values for any arc-length elongation are similarly found for the range of applicable sag percents. They are plotted as curve D on the Preliminary Sag-Tension Graph, Fig. 5-11, for the specified 500-ft span. This same Curve D is on all similar graphs for 500-ft spans, regardless of the kind or weight of the conductor.

The values in the three right-hand columns of Table 5-4 enable calculation of tension (lb) or tensile stress (psi) in the conductor for any arc-elongation percent for any weight of conductor and span. Thus, using symbols of Table 5-4, the tensile stress (psi) in the conductor is as follows:

\[ \text{Stress (psi)} = \frac{P}{E} = \left( \frac{P}{W} \right) \times \frac{W}{E} \] (Eq. 5-6)

or, substituting: \( P/W \) from table as \( \frac{1}{2} \) of 3745 = 1873, for 500-ft span

\( W = \) Weight of conductor = 0.3725 lb per ft
\( E = \) Conductor Area 0.3122 sq in.

\[ \text{Stress (psi)} = 1873 \times \frac{0.3725}{0.3122} = 2235 \text{ psi} \]

The value 2235 psi is the point on Curve B for 0.30% arc elongation and similarly the other values for Curve B are obtained. The designation B for the curve signifies Bare-unloaded.

If it be assumed that the conductor is to carry ice and wind load corresponding to the NESC Heavy Loading the conductor weight is 1.587 lb/ft, and the stress is increased proportionately to 9520 psi, which becomes a point on curve H for the 30% arc elongation. Similarly curves B, L, M, and H are completed. The L and M signify Light and Medium NESC loadings, per Table 5-1.

The completion of the Preliminary Sag-Tension Graph before it can be used for preparation of graphs such as Figs. 5-2 and 5-3 requires the additions of index points as indicated on Fig. 5-11 to show the stress limits that cannot be exceeded. Thus, for a conductor with a rated strength of 6880 lb and 0.3122 sq in. area, the breaking stress is 22,000 psi. If 50% of this amount is allowable as maximum stress at 0°F under Heavy loading, 33.1/3% thereof as initial stress at 0°F when installed, and 25% at 0°F without ice or wind load after 10-year creep, then the corresponding stress limits are marked by index points on Fig. 5-11 curve H (11,000 psi) and on curve B (7330 and 5500 psi). No index points are added to curves L and M because it is assumed that the design in this instance is for Heavy loading, so only values for bare unloaded conductor and for Heavy loaded conductor are required.

Method of Drawing the Parabola

Referring to Fig. 5-9 the horizontal and vertical scales may be as desired. Given half-span distance O-4 and mid-point sag distance equal to D-4, a parabola fitted to points O and D is obtained by: (1) Divide lines O-4 and 4-D into the same number of equal parts; (2) Draw lines...
TABLE 5-4
Catenary Constants for Horizontal Spans
Listing Percent Change in Sag and Tension-Factors for Conductor Weighing 1-lb per ft for Various Percents of Elongation of Arc Length in a 1000-ft Span

<table>
<thead>
<tr>
<th>% Increase</th>
<th>% Sag of Over Span</th>
<th>1000-Foot Span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over Span Length</td>
<td>W</td>
</tr>
<tr>
<td>L (S-1)</td>
<td>100</td>
<td>T</td>
</tr>
<tr>
<td>0.01</td>
<td>0.6124</td>
<td>20419</td>
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<tr>
<td>0.015</td>
<td>0.7500</td>
<td>16675</td>
</tr>
<tr>
<td>0.02</td>
<td>0.8661</td>
<td>14443</td>
</tr>
<tr>
<td>0.025</td>
<td>0.9683</td>
<td>12920</td>
</tr>
<tr>
<td>0.03</td>
<td>1.0608</td>
<td>11796</td>
</tr>
<tr>
<td>0.04</td>
<td>1.2249</td>
<td>10219</td>
</tr>
<tr>
<td>0.05</td>
<td>1.3695</td>
<td>9143</td>
</tr>
<tr>
<td>0.075</td>
<td>1.6775</td>
<td>7471</td>
</tr>
<tr>
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<td>1.9372</td>
<td>6476</td>
</tr>
<tr>
<td>0.15</td>
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<td>5295</td>
</tr>
<tr>
<td>0.20</td>
<td>2.7406</td>
<td>4593</td>
</tr>
<tr>
<td>0.25</td>
<td>3.0645</td>
<td>4115</td>
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<tr>
<td>0.30</td>
<td>3.5766</td>
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<tr>
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<td>0.45</td>
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<td>4.3377</td>
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<tr>
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<td>2800</td>
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<tr>
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<td>4.7534</td>
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</tr>
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<td>9.1526</td>
<td>1472</td>
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<td>9.3615</td>
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<td>9.7688</td>
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</tr>
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<td>2.60</td>
<td>9.9636</td>
<td>1370</td>
</tr>
<tr>
<td>2.70</td>
<td>10.1569</td>
<td>1349</td>
</tr>
<tr>
<td>2.80</td>
<td>10.3468</td>
<td>1326</td>
</tr>
</tbody>
</table>

SYMBOLS USED IN TABLE 5-4

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Arc length of cable, ft</td>
</tr>
<tr>
<td>S</td>
<td>Horizontal Span, Ft</td>
</tr>
<tr>
<td>D</td>
<td>Mid-point Sag, ft</td>
</tr>
<tr>
<td>W</td>
<td>Weight of conductor, lb per ft</td>
</tr>
<tr>
<td>T</td>
<td>Tension at Support, lb</td>
</tr>
<tr>
<td>H</td>
<td>Tension at Midpoint, lb</td>
</tr>
<tr>
<td>P</td>
<td>Average Tension, (T + H)/2, lb</td>
</tr>
</tbody>
</table>

Though the T/W, H/W, and P/W values are for a 1000-ft span, they are suitable also for other spans; thus, for 100 ft span, divide table values by 10; for a 2000-ft span, multiply table values by 2.

A-O, B-O, etc. Their intersection with the ordinates above points I, 2, etc., are points on the parabola. The vertical distances from the base line to the curve are proportional to the square of the distances of the ordinates from point O.

The Stress-Strain Graph

As has been stated, a sagging conductor comes to rest when the external force required to sustain its weight produces an arc-elongation percent in the conductor that equals the elongation-percent in the conductor that would be obtained by applying the same force to the conductor in a testing machine. It is customary to use stress (psi) instead of force (lb) when applying this principle to sag-tension analysis.

The relation of stress in the conductor (psi) and the resulting elongation (strain), herein expressed as percent of conductor length, is shown by a stress-strain graph, Fig. 5-10, which is typical for all-aluminum stranded conductor of 1350-H19 wires regardless of size, though there are slight variations depending on stranding. The curve of 6201 alloy is similar, except that they are extended to higher stress values (because of their greater strengths). For ACSR, a different graph is used for each temperature because of differing thermal-expansion rates of aluminum and steel. Fig. 5-16 shows typical curves for composite conductors of various kinds, but each curve applies only to one stranding for that kind of conductor.

Referring to Fig. 5-10 for AAC new conductor, curve 2 shows elongation percents that are obtained as stress gradually is increased to 70% of rated strength (sometimes called the “working limit”). During this increase the stress is held for one-half hour at 30% of rating, after which load is slowly withdrawn. It is then slowly reapplied until stress is 50% of rating, at which it
is held for one hour, followed by reduction as before. A final slow load application is made until 70% of rating at which point the final reading is not taken until after one hour. The values for curve 2 reflect the delay at 30%, 50%, and 70% of rated strength. By this process the conductor attains a high degree of compactness and stabilized length.

Line 3 shows the stress-elongation relationship while stress is decreased from the 70% point, or is subsequently increased again to that point. Line 3 is practically straight. Subsequent increase or decrease of stress causes elongations that are represented by this line or one parallel to it. The distance between the bottom of curve 2 and that of line 3 represents the permanent increase of elongation, caused by the settling of the cable strands and reduction of spaces between them, and also perhaps by a slight permanent set of the aluminum.

Line 4 represents conditions after 10-year creep at average temperature of 60°F, but no single application of an increasing stress produces such a line. The line is the locus of points each of which is a point on curve 2 from which a horizontal line extends to represent the elongation percent after 10-year 60°F creep at the indicated stress. Also line 5 represents the condition when stress is reduced after 10 years of 60°F creep at 4000 psi. An increase of load shortly thereafter will likewise show elongation percents indicated by line 5.

It is customary to place temperature indexes on the abscissa of such graphs as Fig. 5-10 to adapt the graph for use when the conductor is at various temperatures. The use of these temperature indexes is explained in the description of the application of the graph. Index-points for temperatures above 120°F are not normally shown on the stress-strain graph, though they may be added if required.

The stress-strain graphs for composite conductors, Fig. 5-16 show a sharp knee toward the bottom of curve 3 because the permanent elongation of the 1350-H19 part of the conductor is greater than that of the reinforcing component due to their different elastic limits. At stresses below the knee, the reinforcing wires carry the full load. The slope of the part of curve 3 below the knee is less than what is above the knee because the cross-sectional area of the reinforcing wires is small.

Because the 1350-H19 wires of steel-reinforced composite conductors creep more at a given temperature than do the reinforcing wires, the stress at which the curve 3 changes in slope increases during the 10-year creep period.
Initial and Final Sag and Tension of a Designated Conductor, Span and NESC Loading for Various Temperatures

Given the applicable preliminary sag-tension graph, Fig. 5-11 and the stress-strain graph, Fig. 5-10, we can determine the sag-tension values at which the arch-elongation in percent of the conductor under sag, as shown in Fig. 5-11, equals the percent of elongation of the tested conductor under the same tension and temperature. Another requirement is that the stresses under the various conditions will not exceed the values indexed on Fig. 5-11 as \( \text{a)} \), \( \text{b)} \), and \( \text{c)} \), as previously defined when describing Fig. 5-11. Essentially, the process is one of graphic comparison.

The temperature selected for the first comparison is the lowest likely to be encountered for the specified loading (in this case the Heavy loading). For average conditions, \( 0^\circ\text{F} \) ordinarily may be taken. An infrequent below-zero temperature rarely occurs with full ice-and-wind load, and if it should, the margin of safety is ample; also, after long-time creep, the stress is likely to be below what it is initially. If the temperature, however, will be below \( 0^\circ\text{F} \) for long periods, this lower value should be assumed for the first comparison.
Fig. 5-12. First-trial check of tension limits.

Conductor: 397.5 kcmil 19-strand aluminum, Canna, Span: 500 ft

The comparison is made graphically by superposing a transparent-paper stress-strain graph, Fig. 5-10, (with its grid, ordinate, and abscissa values removed) over the preliminary sag-tension graph, Fig. 5-11, so their abscissas coincide and so the initial line 2 of Fig. 5-10 intersects the 11,000 psi index mark on line H. It is then apparent that neither tension limit b or c will be exceeded. Therefore, tension a is the governing condition. The superposed graphs then appear as Fig. 5-12.

The sag under heavy loading (14.5 ft) is found vertically above a on curve D. The initial tension at 0°F without ice and wind (3,630 psi) is found at the intersection of curve 2 with curve B, and the corresponding sag (10.3 ft) is on curve D.

The final stress-strain curve 3a after heavy loading and holding for one hour is drawn from point a parallel to curve 3, and the final tension after heavy loading (3,140 psi) is found where it intersects curve B. The corresponding sag (11.5 ft) is found on curve D.

The next operation is to determine whether the final sag after 10-year creep at 60°F will exceed the final sag after heavy loading. Before moving the stress-strain graph from
its present position, the location of 0°F on its temperature scale is marked on the first-trial check of tension limits (Fig. 5-12) as reference point R.

The stress-strain graph is then moved to the right until 60°F on the temperature scale coincides with reference point R, Fig. 5-13. The initial tension at 60°F (2,910 psi) is found at the intersection of curve 2 with curve B, and the corresponding sag (12.85 ft) is on curve D.

The final tension at 60°F after heavy loading is found at the intersection of curve 3b with curve B. It will be observed that curve 4, which shows the elongation of the conductor after creep for 10 years, intersects curve B at 2,570 psi. The corresponding sag (14.45 ft) is found on curve D. Since this sag exceeds the final sag after heavy loading at 0°F creep is the governing condition.

A new final stress-strain curve 3b is now drawn parallel to curve 3 through the point on curve 4 where it intersects curve B. The final sag and tension at 0°F must now be corrected, using the revised stress-strain curve.

For this purpose the stress-strain graph is moved to its former position so that 0°F on the temperature scale coincides with reference point R, Fig. 5-14. The corrected final
tension (3,100 psi) is found where curve $3_b$ intersects curve $B$. The corresponding sag (12.0 ft) is on curve $D$.

The final sag after 10-years at 60°F after *Heavy* loading (14.7 ft) is found where the ordinate at intersection of curve $3_a$ and curve $H$ intersects curve $D$; the corresponding tension is 10,840 psi. These values are not indexed on the curves. The sag and tension values thus far found are entered in Table 5-5 as the initial and final sags and tensions for 0°F, both unloaded and for *Heavy* loading. Sags and tensions for other temperatures are similarly found and entered in Table 5-5. Thus, for 120°F the stress-strain graph is shifted until the 120°F point is moved to reference mark $R$ to produce Fig. 5-15, from which the initial tension (2,470 psi) is found at the intersection of curve 2 with curve $B$, and the corresponding sag (15.15 ft) is on curve $D$. Final tension (2,270 psi) is found at the intersection of curve $3_b$ with curve $B$ and the corresponding sag (16.5 ft) is on curve $D$. 

---

Fig. 5-14. Final trial for 0°F after adjustment for 10-year creep correction. Values for 0°F unloaded, and 0°F with heavy load are entered from this graph on Table 5-5.

Conductor: 397.5 kcmil 19-strand aluminum. Canna, Span: 500 ft
In a similar manner, the values for other temperatures are obtained to complete Table 5-5. The load values in pounds $P$ are obtained by multiplying the tensile stress values in psi by the conductor area (0.3122 sq in). The values from Table 5-5 are then transferred to Initial and Final Sag- and Tension Graphs (similar to Figs. 5-2 and 5-3) at the 500-ft span ordinate. Completion of a similar series of values for other spans and for Light, Medium and Heavy loading provides everything necessary to complete the sag-tension graphs that customarily wire and cable manufacturers supply to customers as a basis for their work as described in the early portion of this chapter. The manufacturers also supply a wide variety of graphs, such as Figs. 5-10, 5-11, 5-16 and data for templates for various sizes of conductors and conditions.

**Sag-Tension Graphs for Composite Conductors**

The graphic method used for the preceding work similarly can be employed for obtaining sag-tension graphs for ACSR and ACAR, but with considerable difference in details because the reinforcing wires have different physical properties from those of the 1350-H19 wires (Fig. 5-16). Thus, for ACSR the components differ as to elastic modulus, temperature coefficient of expansion, elastic
limit, rate of long-time creep, and allowable unit stress. In ACAR the creep rates and temperature coefficients are not significantly different, but because of differences of elastic limit the elastic moduli differ greatly in the upper range of stress. The allowable unit stress in the two kinds of wire also differs.

For example, finding sag-tension data for ACSR at a specified temperature requires the use of three stress-strain graphs, one for the entire conductor, and one for each of the components (aluminum and steel). The graph for
The complete conductor (Fig. 5-16) is made by test in the usual manner. A similar graph for the steel core is made by test. The stress-strain graph for the aluminum is then obtained by subtracting the values for the steel from the values for the entire conductor. All three graphs, however, are plotted on the same sheet (Fig. 5-17). The effect of ratio of steel area to aluminum area is taken into account when preparing the graphs. The process is thus more complicated than what is used for AAC and AAAC, but the basic principle is the same.

Similarly for ACAR, stress-strain graphs are made for the entire conductor, and also for the reinforcing alloy wires. The graph for the 1350-H19 wires is obtained by difference.

The preliminary sag-tension graph (such as Fig. 5-11) is used unchanged for composite-conductor analysis; it is only the superposed stress-strain curves that differ.

Because of the necessary space required for an adequate explanation of the details of preparing sag-tension graphs for composite conductors, a description of the method is not included herein, but readily available references provide full information.

![Fig. 5-17. Stress-Strain Curves.](image)

Typical Stress-Strain-Creep Curves for a 4/0 ACSR conductor
Overhead Conductor Accessories and Fittings

Wire and cable accessories for aluminum overhead lines are similar to those used for copper lines, but it is essential that they be designed for aluminum because of differences of physical properties of aluminum and copper. Fittings used at terminals, or where overhead lines connect to insulated cables, underground lines, or bus structures often are of combination types that embody design features described in Chapter 11 for insulated cables and Chapter 13 for bus conductors, to which reference should be made for details.

Customarily, the fittings and accessories for overhead lines are classified as follows:

**Joints and Connectors**

Joints carry full current and withstand at least 95 percent of the rated strength of the conductors. Connectors carry full current, and limited tension. Joints for line conductors are made by compression of the conductor ends within a long sleeve or tube. Connectors also may be of the compression type, or may be bolted or welded. Connectors also are designated according to use, such as for terminal, tee, parallel or tee tap, etc. See Figs. 5-18 and 5-19.

Sometimes the term connector also is applied to a small assembly of connectors, cables and terminals for a designated use. Thus, a jumper connector may refer to a short length of cable to which connectors are attached at each end, used to “jump” across the insulation-support structure where adjacent conductor spans are dead-ends, or the term may refer to a connector fitting used in such an assembly (see Fig. 5-19A).

**Dead-Ends:** hold the mechanical tension and provide anchorage to a strain insulator at end of a span.

**Suspension Clamps:** support the conductor at tangent or light angle structures usually through suspension insulators.

**Armor Rods:** surround and reinforce cable near points of support.

**Flat Armor Wire:** used for wrapping around conductors to protect them from chafing, and sometimes is used instead of armor rods in short spans.

**Tie Wires:** attach the cable mechanically to the top of pin-type insulators.

**Vibration Dampers:** reduce resonant vibration. These are described in Chapter 6.

---

![Fig. 5-18. Tubular Aluminum Compression Joints.](image)

A joint is sufficiently strong to develop a tensile strength equal to at least 95 percent of the strength of the conductors it joins. Sometimes filler plugs are omitted in joints used in distribution circuits; in such cases the filler compound must be injected into the ends of each sleeve before inserting the conductor.

**A—For ACSR.** The aluminum sleeve is placed over one cable and run back. The aluminum wires are then cut away to provide room for the steel sleeve which is then inserted, cables joined, and steel sleeve compressed. The aluminum sleeve is then positioned, filler compound injected, and filler plug driven in place, after which the aluminum sleeve is compressed.

**B—For ACSR with extra large core.** Installation is similar to A except that the filler sleeve is inserted in one end before injecting compound.

**C—For all-aluminum conductors.** Compression sleeves for high-strength-alloy conductors should be sufficiently large to match the increased tensile strength of the conductors, as compared with those of EC grade.
Connectors are used for joining comparatively short lengths where full conductivity is required, but where the cable tension is comparatively low. The same connector is used for ACSR as for all-aluminum conductors because the added strength of the steel core is not required.

A—For Jumpers. Used on short lengths of all-aluminum conductors that join adjacent dead-ended conductors.

B—For Tee Taps. In the closed-run type, the long sleeve is placed on the conductor from its end, or it may serve as a joint between conductors of the run. In the open-run type the long sleeve is split longitudinally so it may be placed sideways over an already-installed run conductor.

C—For Flat-Pad End Terminals. The compression sleeve is welded or forged to a flat-bar pad drilled according to NEMA standard. The direction of take-off may be straight or at an angle.

D—For Flat-Pad Side Terminals—The compression sleeve is usually of the open-run type, so the tap may be made from an installed conductor.

E—For Cable Repair (Repair Sleeve)—The repair sleeve is applied to strengthen a cable where strands have broken or local damage is suspected. It is of the split type.
**Bolted Clamp Connectors**

Bolted aluminum clamp connectors are used extensively in bus structures, and also for connecting or supporting bare aluminum cables at terminals or connecting them to other cables. Bolted fittings are available in a wide variety of types. They are easy to install and offer little handicap to future circuit re-arrangement, if required. Aluminum bolts (2024-T4) of the heavy series type or equivalent U-bolts are widely used, and the bodies may be of cast, forged or extruded aluminum.

Although the usual clamp-bolt connection of an ACSR or stranded aluminum cable will not withstand the full tensile strength of the cable, it is possible to achieve such strength by employing the snubbing principle. Thus, by looping the cable around a semi-circular grooved body of a snubber-type dead-end fitting, and providing a hump in the clamp between the two clamp bolts, the holding power of the fitting is increased a great deal.

The use of additional clamp-bolt assemblies in series is another way of increasing holding power.

**Welded Connections**

Welding as a means of joining components of an aluminum connector fitting is recognized standard procedure but direct welding of stranded aluminum line cables is presently limited to welding cable strands to the body of an aluminum terminal fitting, which in turn may be either bolted or welded to a matching flat pad or other fitting. The advantages of welding cables to terminal pads are most evident for the sizes of cables for which compression or bolted fittings are bulky and comparatively costly. So far as possible, welding of stranded cable to terminal pads should be a shop operation instead of being done in the field.

For example, a transmission line required hundreds of jumper cables to span the support towers where dead-ends are located. Both ends of the jumper cable were shop welded to a flat-pad bolt-type terminal, Fig. 5-22; by placing the pad fitting in a vertical clamp jig following suitable preparation of the cable wires. After preheating, weld metal was puddled in by gravity, then allowed to cool, after which the weld was completed to provide contact between the ends of all wires of the cable and the terminal pad.

**Dead-Ends and Dead-End Clamps**

Dead-end fittings hold the cable against span tension and provide attachment to the strain insulator. Continuation of the cable beyond a dead-end may be provided by a jumper cable with end connections suitable for attaching to the dead-end. In the snubber dead-end, Figs. 5-21A1 and A2, the line may be looped downward, across, and continued through the opposite dead end to the next span, or may be run downward to a terminal. Other compression-type and bolted-type dead-ends and dead-end clamps are also shown in Fig. 5-21.

For city distribution where design tensions are relatively low straight-line dead-end clamp fittings are much used. The cable is not looped around an insulator or thimble but is gripping in a horizontal body by U-bolts and pressure bar. Figs. 5-21A3, -4, and -5. None of the bolted dead-end fittings differ for ASCR or all-aluminum conductors, hence are mostly used for cables of moderate size.

Tubular aluminum compression dead ends for ACSR, all-aluminum and Alumoweld conductors are shown in Fig. 5-24.

**Suspension Clamps**

Suspension clamps support the cable at the bottom of insulator strings. Normally the clamp has two U-bolts and a pressure bar that clamps the cable. The ends are bell-mouthed to avoid sharp bends, Fig. 5-20.

**Tie Wires**

Aluminum tie wire for attaching cables to pin-type insulators comes in rolls, and is available as regular strength wire in Nos. 6, 4, and 2 AWG sizes and as Strong Aluminum Alloy Tie Wire in No. 6 AWG. The latter is used where maximum holding power is required. The greater ductility of the regular strength wire somewhat speeds completion of a tie, and it is also used under hot-line conditions. Added protection of the conductor at insulator supports usually is provided by armor rods, and the tie wires not only tie the rod-and conductor assembly to the insulator, but also bind the armor rods to the conductor.

The method of application of tie wires for attaching a cable to a pin-type insulator is depicted in Fig. 5-26.

**Armor Rods**

These are generally used on overhead lines to protect the strands from fatigue-effects of vibration near points of support. They consist of an assembly of aluminum rods, each somewhat larger in diameter than the conductor-strand diameter, arranged around the conductor to form a complete protective shield, Fig. 5-25. The rods are spirally twisted so they lie approximately parallel to the conductor strands.
bare aluminum wire and cable

Fig. 5-21. Clamp-bolt connections.

Clamp-bolt connections are widely used, particularly for distribution circuits or where there is likelihood of future changes. Though single clamp connections usually are suitable for full conductivity, special construction is required if the full tensile strength of the cable is to be withstood. The use of multiple connections as well as employing the snubbing principle enables bolted connections to aluminum stranded cable to meet all usual requirements as to strength.

A—Snubbing-Type Dead-End (A1 and A2). The clevis is attached to the strain insulator. The line cable is looped around the fitting and clamped below by the double-U-bolt pressure joint. The lump between the bolts also aids holding power. In many cases, no separate jumper connector is necessary; the line conductor is merely looped down through the clamp fitting, run across to the adjacent dead-end and run upward and continued in the adjacent span.

Types A3, A4, and A5 are straight-line dead-end clamps for limited tensions. Type A6 is an aluminum thimble much used for connecting a looped-around cable to a clevis pin. Applying bolted clamps to the two cable ends completes the dead-end connection.

B—Miscellaneous Clamp-Bolt Connections. B-1 and B-2 are parallel-line clamps for making taps. B-3 is a typical tee tap in which the branch connection is bolted. B-4 is similar, except the branch is a compression fitting. B-5 is a terminal-pad bolted connection.
Straight and helically formed armor rods are available. Each formed rod is essentially an open helix with a pitch length somewhat less than that of the "lay" of the outer strands of the cable.

**Aluminum-to-Copper Connections**

Connecting aluminum cable to copper bushing studs and switch pads is often necessary, and this form of connection for the high current ratings has received extensive study to assure long-time reliability under normal and short-circuit conditions.

For connecting large aluminum conductors (500 kcmil and up) to heavy equipment having copper terminal studs and or pads, large compression-type lugs, preferably with two holes, should be used. In making such a connection (Figure 5-23) with other than aluminum bolts, Belleville spring washers and heavy flat washers in consecutive arrangement as shown in Figure 11-11 must be used. If aluminum bolts and nuts are used only the heavy washer, bearing on the aluminum lug, is necessary.

![Welded connection between stranded aluminum cable and terminal pad for transmission-line jumper cables.](image1)

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**Fig. 5-22.** Welded connection between stranded aluminum cable and terminal pad for transmission-line jumper cables.

![Diagram of large aluminum conductors connected to equipment studs or terminal pads made of copper.](image2)

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**Fig. 5-23.** Method for connecting large aluminum conductors to equipment studs or terminal pads made of copper. If bolts are made of aluminum it is not necessary to provide the Belleville spring washer.
bare aluminum wire and cable

Fig. 5-24. Tubular Aluminum Compression Dead Ends.

A—For ACSR. The assembly comprises an inner steel dead end body and an outer aluminum dead end body. The conductor is run through the aluminum body, and the aluminum wires are cut away to expose steel strands for insertion in the sleeve of the steel body. After compression of the steel sleeve, the aluminum body is positioned so that after compression the aluminum body is clamped to the aluminum wires and also to the ridges around the steel body. The flange of the aluminum body extends outward for bolting the terminal pad of a jumper connector. The attachment to the strain insulator may be of eye or clevis type, and the tongue extension to the jumper may be single- or two-way.

B—For all-aluminum conductors. The steel eye or clevis dead end has a comparatively short shank which is ribbed to transfer the tensile stress from the aluminum compression sleeve to which is welded the flange and terminal pad for the jumper.

C—For Alumoweld conductors. The steel body includes steel sleeve which is first compressed on the entire conductor, after which the aluminum body is compressed over the ridges of the steel body and the conductor. An aluminum filler sleeve is placed between the conductor and the aluminum body.
Fig. 5-25. Formed armor rods.

Fig. 5-26. Arrangement of tie wires for attaching a cable to pin-type insulator.

The looping arrangements are shown schematically, and the plan views show actual configurations for single and double insulators, both for side tie and across-top tie. The conductor is shown protected by armor rods. Though the sketches show the conductor as ACSR, the same arrangement is used for all-aluminum conductors. Field assembly starts at points marked B and continues outwardly. Make ties as snug and tight as possible, twisting by hand except for the final two turns which should be made with pliers. For side ties be sure that the insulator has a large enough groove to hold three turns of the tie wire selected for use.