SECTION 26

AERIAL TRAMWAYS AND CABLEWAYS

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AERIAL TRAMWAYS AND CABLEWAYS

Definitions. An aerial tramway transports loads in carriers suspended from wire ropes forming the tracks, between fixed points, usually a long distance apart. Tramways are divided into 3 classes: (1) bi-cable (formerly called double rope), (a) continuous, (b) reversible. (2) twin-cable; (a) continuous; (b) reversible. (3) mono-cable (formerly called single-rope), continuous.

On continuous tramways, a series of loaded carriers travel in one direction on a track cable, and empty carriers return in the other direction. On reversible tramways, one carrier travels back and forth on a cable. Bi-cable tramways have a fixed track cable, along which the carriers are hauled by a traction rope. Twin-cable tramways are similar, except that carriers run on a pair of track cables. Mono-cable tramways have a single running rope to support and move the carriers. A cableway transports a load for a short distance, in a single carrier traveling back and forth on a single cable, or on multiple parallel cables, a hoisting operation being combined with the transfer of the load; the operation is intermittent.

GENERAL FORMULAS

1. CABLE FORMULAS

Catenary vs parabola. Theoretical curve taken by a cable of uniform weight when suspended from its ends is a catenary; it is the curve of the funicular polygon formed by a series of equal weights hung equidistant along the abc.

Its equation is complicated and difficult to apply.

A parabola is the curve of the funicular polygon formed by a series of equal weights hung equidistant along the chord between 2 supporting points. It nearly coincides with the catenary for the flat arcs occurring in tramways, its equations are simple, and results by its use are practically correct.

Equation of Parabola (Fig 1) is: \( y^2 = 2px \) (1)

Empty cable; level spans. In Fig 2, let: \( s = \) span, ft; \( h = \) deflection at center, ft; \( h_1 = \) deflection at any point of curve, as \( p, ft; t = \) tension in cable at center, lb = horizontal component of tension at any point; \( T = \) tension in cable at any point, lb; \( w = \) weight of cable per ft, lb; \( W = \) total weight of cable in span, lb = \( ws; R = \) total vertical reaction at a tower; for cable only, it is \( 1/2 W = 1/2 ws; m = \) sections into which point \( p \) divides span; \( \phi = \) inclination of tangent to the curve at any point, as \( B \).

Deflection at center. Take moments about point \( c \) of forces to left of center, then: \( 1/2 W 1/2 s - 1/2 W 1/4 s = th, \) or \( 1/4 W s = th. \) But \( W = ws, \) hence, \( h = ws^2 + 8 t \) (2)

Deflection at any point, as \( p. \) Take moments about point \( o \) of forces to left of it, then: \( 1/2 wsm - wms 1/2 m = h's, \) but \( wsm = wms (m + n), \) hence, \( h_1 = wms + 2 t \) (3)

Tension in cable at any point is: \( T = t + cos \phi \) (4)

It is also equal to tension at any other point + or − the product of vert distance
between the 2 points and the wt of cable per ft. Thus, if \( V = \text{vert distance between points} \) 
\( B \) and \( p \), the tension at \( p \) is: \( T'' = T - wV \) 
\[ (5) \]

Bib 10a gives many cable formulas. Simplified working equations may be obtained by substituting numerical values for \( w \) and \( t \) in Eq 2 and 3; for with any one kind of cable \( w \) and \( t \) bear fairly constant ratio to each other. Thus, with locked-coil track cables, the wt of all sizes is practically 3.7 lb per ft per sq in of cross-section. The breaking strength of cast-steel grades is 121 000 lb per sq in, and with factor of safety of 3.5, the working tension is 34 600 lb per sq in. These values, substituted in Eq 2, give:

\[ h = \frac{w^2t}{8t} = \frac{3.7t^2}{8 \times 34 600} = 0.000 012 \text{a} \]  
\[ (6) \]

Table 1 gives wt and strength of cables used for track; by substituting the values for different cables in Eq 2 and subsequent formulas, a simplified equation suitable for any case is obtained.

**Table 1. Weight and Strength of Track Cables**

<table>
<thead>
<tr>
<th>Diam, in</th>
<th>Locked-coil cables</th>
<th>Smooth-coil cables</th>
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<tbody>
<tr>
<td></td>
<td>Wt, lb per ft</td>
<td>Breaking strength, lb</td>
</tr>
<tr>
<td>1/8</td>
<td>1.42</td>
<td>50 000</td>
</tr>
<tr>
<td>5/8</td>
<td>1.92</td>
<td>64 000</td>
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<td>7/8</td>
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<td>130 000</td>
</tr>
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<td>1 1/4</td>
<td>4.73</td>
<td>156 000</td>
</tr>
<tr>
<td>1 1/2</td>
<td>5.63</td>
<td>186 000</td>
</tr>
<tr>
<td>1 3/8</td>
<td>6.60</td>
<td>216 000</td>
</tr>
<tr>
<td>1 1/4</td>
<td>7.6b</td>
<td>250 000</td>
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<td>1 1/8</td>
<td>8.79</td>
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<tr>
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<td>10.00</td>
<td>316 000</td>
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</tr>
<tr>
<td>2 1/2</td>
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<td>490 000</td>
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<td>2 1/4</td>
<td>18.30</td>
<td>640 000</td>
</tr>
<tr>
<td>3</td>
<td>22.20</td>
<td>1 000 000</td>
</tr>
</tbody>
</table>

The above weights and breaking strengths are given by Amer Steel and Wire Co (Bib 10a). The working strengths were calculated by author, using safety factor of 3.5 for locked-coil cable, and 4.5 for smooth-coil; these low factors are reasonable for reliable material like steel wire and where working stresses are nearly all tensile and can be determined with a high degree of accuracy. On tramways, it is customary to apply tension by means of weights, and hence overloading is improbable; also the cables are elastic and can absorb occasional shocks without injury. Where the tramway or cableway has a single span and track cable is anchored at both ends, there is a possibility of overloading; hence, it is advisable to increase the safety factors, but not above 4.5 and 6 respectively, for locked- and smooth-coil. On reversible tramways with a single heavy carriker, the cable can be treated as though counterweighted, even if anchored at both ends, because the slack will shift as the bucket travels. Track cables are also called track strand, and smooth-coil type, round-wire track strand. For aerial tramways, track cables have not exceeded 2 in diam (Art 7); for cableways all sizes are used (Art 23–27).

Slope of tangent to curve of empty cable. The tangent at end of span, when chord is horizontal, has a slope (Fig 3) of \( \tan \phi = \frac{h}{s} \)  
\[ (7) \]
Substituting value of \( h \) from Eq 2: \( \tan \phi = \frac{w}{s} + 2 t \)  
\[ (8) \]
but \( w + 2 t \) is the reaction \( R \), hence: \( \tan \phi = R + t \)  
\[ (9) \]
In any one case, \( w \) and \( t \) are constant; hence Eq 8 can be simplified by substituting numerical values. Thus, for cast-steel locked-coil cable, \( w = 3.7 \text{ lb} \) and \( t = 34 600 \text{ lb} \), giving \( \tan \phi = 0.0000854 \text{a} \).
Concentrated loads. Let Fig 4 be the funicular polygon resulting from 3 concentrated loads, \( g_1, g_2, g_3 \), and \( a, b, c \) be their respective distances from right-hand end. Then the reaction at left-hand end is: 
\[
R_1 = \frac{g_1a}{s} + \frac{g_2b}{s} + \frac{g_3c}{s}.
\]
Taking moments about \( o \) gives: 
\[
r_1m = h_3t, \text{ or } h_3 = r_1m \pm t \quad (10)
\]
If wt of cable be included, moments about point \( o \) are:
\[
R_1m - \frac{1}{2}w_m t^2 = Ht, \text{ or } H = \frac{R_1m - \frac{1}{2}w_m t^2}{t} \quad (11)
\]
In Eq 11, \( R_1 \) is reaction at left end, when both cable and concentrated loads are considered, and equals \( \frac{g_1a}{s} + \frac{g_2b}{s} + \frac{g_3c}{s} + \frac{1}{2}w_s \); and \( H \) is deflection at point \( o \). Hence, deflection at any point for any loading equals moment, \( M \), of all vert forces on one side of \( o \), divided by the horis tension, or \( H = M + t \). 
(12)
Experience shows that in spans carrying 3 or more equal loads, uniformly spaced, deflection at any point is practically the same as for a uniformly loaded cable of which the wt per ft is equal to the wt of cable plus that of one load divided by the spacing in ft. If value of \( R_t \) be substituted in Eq 11:
\[
H = \frac{R_1m - \frac{1}{2}w_m t^2}{t} = \frac{r_1m + \frac{1}{2}w_m t^2 - \frac{1}{2}w_m t^2}{t} = \frac{r_1m}{t} + \frac{1}{2}w_m (s - m)
\]
but \( (s - m) = n \), whence \( H = \frac{r_1m}{t} + \frac{wnn}{2t} \). Also \( \frac{r_1m}{t} = h_3 = \text{deflection at } p \text{ due to concentrated loads (Eq 10), and } \frac{wnn}{2t} = h_1 = \text{deflection at } p \text{ due to cable (Eq 3). Hence, total deflection at any point is the sum of the deflection due to cable alone and that due to load alone.}

Deflection due to one concentrated load. Three cases commonly occur: One load at any point. Deflection at that point, by Eq 11, is:
\[
H = (ws + 2g) \frac{mn}{2st} \quad (13)
\]
One load at center. Deflection at center is found from Eq 13, by making \( m = n = \frac{1}{2} s \); whence:
\[
H = (ws + 2g) \frac{s}{8t} \quad (14)
\]
One load at distance \( y \) from one end. Deflection at point distant \( w \) from same end is found by applying Eq 11. The reaction \( R \) at opposite end of span for 1 load plus cable is \( gy + s + 0.5w \). Taking moments at \( R \) gives: \( th = Rn = 0.5wn^2 \). Substituting above value of \( R, H = (wns + 2gy)n + 2st \).
\[
H = (wns + 2gy) \frac{n}{2st} \quad (15)
\]
Inclined Spans. Parabola with inclined axes. Let Fig 5 be such a parabola; then by analytical geometry:
\[
y^2 = \frac{2p}{\sin^2 \theta} x_1 \quad (16)
\]
Empty cable. Let Fig 6 represent such a case, \( l \) being length of chord. Applying principle of moments:
CABLE FORMULAS

Deflection at center, \[ h = \frac{wls}{8t} = \frac{\cos^3}{8t \cos \alpha} \] (17).

Deflection at any point, \[ h_1 = \frac{wml}{2t \cos \alpha} \] (18).

Cable carrying concentrated loads; chord inclined. Total deflection at any point is the sum of deflection due to cable alone and that due to loads alone. Deflection due to cable alone is given above. Deflection at any point due to loads alone equals moment of vert forces due to loads on one side of that point, divided by horis tension (similar to Eq 10), thus:

Load at any point of an inclined span. Deflection at load is:

\[ H = (wl + 2g) \frac{mn}{2t} \] (19).

Load at center of an inclined span. Deflection at load is:

\[ H = (wl + 2g) \frac{s}{8t} \] (20).

Load at distance \( y \) from one end of an inclined span. Deflection at a point distant \( m \) from same end, with moments taken about opposite end (see analysis for Eq 15):

\[ H = (wml + 2gy) \frac{n}{2t} \] (21).

Slope of tangent to inclined empty cable. Let Fig 7 be inclined span. Then slopes of tangents to the two ends are:

At \( B \), \( \tan \phi = \frac{M}{\frac{1}{2} s} = \frac{4h + V}{s} \)

At \( A \), \( \tan \phi_1 = \frac{M - V}{\frac{1}{2} s} = \frac{4h - V}{s} \)

Hence, slope of any tangent is: \( \tan \phi = \frac{4h \pm V}{s} \), in which \( V = \) vert distance between ends of span, ft. \( \) (22).

Loaded cable. Let Fig 8 be an inclined span with concentrated load at some point. Slopes of tangents to the two ends are: \( \tan \Delta = K + n \) and \( \tan \Delta_1 = K_1 + \frac{m}{s} \). But \( K \) and \( K_1 \) are made up of a series of known parts. Thus, \( K = AB + BC + CD + DE \), and

\[ AB = \frac{V}{s} \text{ ft}; \quad BC = \frac{wml}{et}; \quad CD = \frac{wml}{2t \cos \alpha}; \quad DE = \frac{4wnl}{8t \cos \alpha} \]
Substituting these in above, and simplifying:

$$
tan \Delta = \frac{sm}{at} + \frac{w}{2 l \cos \alpha} + \frac{V}{s}$$

$$
tan \Delta_1 = \frac{sm}{at} + \frac{w}{2 l \cos \alpha} - \frac{V}{s}$$

Length of parabolic curve. The length of a symmetrical parabolic curve, \( L \), when the rise is small, is closely approximated by equation (Weisbach's "Theoretical Mechanics," trans by E. B. Coxe, p 299)

$$
L = s + \frac{8A^2}{3s}, \quad or \quad A^2 = \frac{3}{8}s(L - s)
$$

If chord be inclined, the length, for taut curves common in tramway practice, may be taken as equivalent to a symmetrical parabola having same chord length and same deflection normal to the chord. The normal deflection is nearly equal to: vert deflection \( \times \cos \alpha \).

Bib 10a treats of length of curve when stretch of cable is considered.

Horiz tension \( t \). In tramway construction, cables are stretched by tension applied to one end of span (usually by a weight), equal to working tension of cable. This tension is used in formulas for the value of \( t \); it makes the actual horiz tension in cables a little less than that used in the calculations, and hence the sag will be greater than calculated. Owing to flatness of the curves, this error is not serious, when the chord is at a low angle. But on inclined spans it may make considerable difference; the error can be partly compensated by calling the applied tension \( t' \), and assuming that its direction is parallel to inclined chord; then the approx horiz tension will be \( t = t' \cos \alpha \).

Fig 9. Plotting a Parabola, Axes Rectangular

Fig 10. Plotting a Parabola, Axes Oblique

Plotting of parabolic curves may be done by points or by tangents. By POINTS: Series of offsets is calculated by Eq 1 or 3, if chord be horiz; or by Eq 16 or 18, if chord be inclined. These are plotted, and a curve is passed through their lower ends. By TANGENTS: Chord of span and center deflection are plotted to desired scale, as in Fig 9 or 10 (same method applying whether chord is horiz or inclined); deflection is prolonged to a total length of \( 2A \); lines drawn from ends of chord to this point are tangents to the curve. These tangents are then divided into same number of equal parts, numbered as shown. Lines are next drawn connecting corresponding numbers; these are tangents to the curve, and the curve can now be drawn tangent to them. By making a sufficient number of divisions in the two end tangents, the sides of the polygon formed by the tangents will be short and practically form the curve, as shown in Fig 9 and 10, where for clearness only the end tangents have been drawn.

2. OPERATING FORMULAS

Spacing of carriers. For a system operating a continuous series of carriers, let:

- \( t = \) time interval between carriers, sec;
- \( d = \) distance between carriers, ft;
- \( l = \) load in one carrier, lb;
- \( n = \) number of tons (2000 lb) to be carried per hr;
- \( v = \) velocity of tramway, ft per min.

Then, \( n \times 2000 + 3600 = \) lb per sec to be carried by tramway, and this divided into \( t \), gives time interval in sec, reducing to \( t = 1.8 l + n \).

Distance between carriers is, \( d = tv + 60 \), reducing to \( d = 0.03tv + n \).

Tension in traction rope. Tension in a rope holding any body at rest on an incline, neglecting friction, is \( T = W \sin \alpha \). Friction of a body moving on an incline is, \( F = f'W \cos \alpha \); in which: \( T = \) tension parallel to the plane, in same unit as \( W \); \( W = \) total weight of bodies on the plane, preferably in lb; \( \alpha = \) inclination of plane; \( f' = \) coeff of rolling friction = 0.02 with plain bearings for sheaves and carriage wheels, and 0.01 for ball or roller bearings; \( F = \) total friction, in same unit as \( W \).

When the body extends whole length of incline, as a rope lying on it, then total weight is \( W = wtL \), where: \( w = \) wt per ft, in same unit as \( W \), preferably in lb; \( L = \) inclined length.
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of the plane, ft. Substituting this value of $W$ in general equations for $T$ and $F$ above, gives:

$$T = \omega L \sin \alpha = \omega V$$  \hspace{1cm} (27)

$$F = f' \omega L \cos \alpha = f' \omega H$$  \hspace{1cm} (28)

in which: $V$ = vert distance between ends of plane, ft; $H$ = horis length of plane, ft.

Tension in traction rope of a double-rope tramway, or in endless rope of a single-rope tramway, at its upper end, taking friction into account, will be: $T = \omega V \pm f' \omega H$  \hspace{1cm} (29)

Sign of last term is $+$ when rope is being pulled up the incline and $-$ when it is moving down. If rope be empty, $\omega$ is the wt per ft of rope alone; but if carriers be attached, $\omega$ must be increased by wt of the carriers including their load, if any, uniformly distributed over whole length of incline, or else the effect of carriers must be calculated separately and added to value of $T$. Tension $T$ is further increased by pull exerted by tension weight applied to the floating sheave; half the pull on this sheave being added to traction rope tension on each side of tramway.

3. TRANSMISSION OF POWER BY BAND DRIVES

This discussion is applicable to any type of band or rope drive, or to band brakes where tension is known.

In a band drive, tension on slack side must bear a certain relation to tension on taut side, to develop sufficient friction to prevent slipping. The formula for this relation, from analytical mechanics, is:

$$T = Se^{\tan \alpha}$$  \hspace{1cm} (30)

in which $T$ = tension on taut side; $S$ = tension on slack side, both in same unit, preferably lb; $\varepsilon$ = base of Napierian logarithms = 2.71828; $\alpha$ = coeff of friction (values given in Table 2); $n$ = number of half laps on drum (number of turns of 180° each).

The useful effect of force transmitted by the drive, is the difference between tensions on the two sides, that is, $T - S$. If $S$ be subtracted from both sides of Eq 30, this becomes, on reducing: $T - S = S(e^{\tan \alpha} - 1)$  \hspace{1cm} (31)

which is an expression for force transmitted by a band drive, and is useful in determining $S$ for a given drive when force to be transmitted is known. Table 3 gives values for $e^{\tan \alpha}$ for a number of combinations, for saving time in applying Eq 30 and 31.

Table 2. Coefficients of Friction, $f$, for Band Drives. By William Hewitt

<table>
<thead>
<tr>
<th>Condition of surfaces</th>
<th>Iron on iron</th>
<th>Iron on wood</th>
<th>Iron on rubber and leather</th>
</tr>
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<td>Dry</td>
<td>0.170</td>
<td>0.235</td>
<td>0.495</td>
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<td>Wet</td>
<td>0.085</td>
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<td>0.400</td>
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<td>Greasy</td>
<td>0.070</td>
<td>0.140</td>
<td>0.205</td>
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Table 3. Values of $e^{\tan \alpha}$. By William Hewitt

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<tr>
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<th>1</th>
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<th>4</th>
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</tbody>
</table>

$n$ = Number of half laps about sheaves or drums
Most calculations for tramway drives and brakes are based on the coefficient of friction for wet ropes, as this often occurs; neither rope nor brake should ever be greasy.

Grip sheave, as in Fig 29, has a series of jaws about its circumference which are tightened by the rope's press; these multiply the press between rope and sheave by the ratio of lever arms of the jaws, and hence proportionately increase the friction. For a grip sheave with iron or steel jaws, having leverage of 1 : 3, the value of \( e^{m} = 2.238 \), and where the leverage is 1 : 3\( \frac{1}{3} \), \( e^{m} = 2.5 \), in both cases with rope for which \( f = 0.065 \).

**BI-CABLE TRAMWAYS**

4. GENERAL CONSIDERATIONS

Elements. A bi-cable tramway consists of: 1, two track cables stretched at required tension; 2, an endless traction rope for moving the loads; 3, numerous carriers for the loads, each fitted with carriage or trolley to run on track cable and a clamp or grip for seizing traction rope; 4, a station at each end to operate or control the traction rope and provide places for loading and unloading carriers; 5, intermediate towers for supporting track cable and traction rope.

In operation, each load is placed in a carrier while standing on a track in loading terminal; the carrier is then attached to traction rope, and hauled to discharge terminal; there it is released from traction rope and contents are discharged. Empty carrier is then attached to traction rope on return side and is hauled back to loading terminal.

Capacity. Economic limits of capacity for ordinary bi-cable tramways are approx 10 and 100 ton per hr. If less than 10 ton per hr, it is more economical to operate tramway fewer hours or on alternate days, than to reduce carrying capacity.

Demand for tramways for traffic exceeding 100 tons per hr has recently developed special heavy equipment and structures, permitting construction of lines carrying up to 300 tons per hr.

Length. It is seldom wise to use bi-cable tramways for distances less than 1,000 ft, because terminal machinery costs as much as for a longer line and so makes first cost excessive. Max limit, under favorable conditions, is about 4 miles; the resulting 8 miles of traction rope is as long as can be operated successfully; the tension in traction rope becomes excessive; an exceptional case occurred on the Benguet tramway, which is 49,500 ft long (Art 17). For very long distances, a series of tandem tramways can be built, and the carriers switched from one to another; but each division is practically an independent tramway.

Thus, a tramway at Chilecito, Argentine, 21 miles long (Art 17) has 8 divisions. In any tramway, the track cables are divided into sections of 3,000 to 5,000 ft each, one end of each section being anchored and tension being applied to the other end; each section of cable may be made up of as many pieces as desired, provided the couplings do not come close to tower saddles. As the carriers pass through anchorage and tension stations without interruption, lengths of cables limit neither operation nor possible length of line or division.

Loads. Net weights of 500 and 2,000 lb are the usual lower and upper limits for loads on ordinary tramways; below 500 lb there is no saving in cost of carriers, and for over 2,000 lb the wear on cables is great. The time interval between carriers is conveniently about \( \frac{1}{2} \) min. Then 2,000 lb every \( \frac{1}{2} \) min = 120 tons per hr, and is near the maximum capacity of bi-cable tramways, using two-wheel carriages. In recent practice, larger and stronger track cables permit use of higher cable tensions, and 4-wheel carriages are used to keep the wheel load down. Net loads to 4,000 lb are carried where the necessity for large tonnage warrants the extra cost of plant (Art 6a).

5. TRAMWAY SURVEYS

Survey of proposed route, with surface elevations, must be made and a profile of center-line must be plotted before a tramway of any type can be designed. At summits, or wherever sudden changes in profile occur, elevations should be determined at intervals of 25 or 50 ft. The stations staked out may be numbered 1, 2, 3, etc, for distances of 100, 200, 300, etc, ft from the origin, as in R R surveying; intermediate distances are noted as + ft from preceding station. In very rough country, distances and elevations of important points on summits may be determined by stadia measurements, and the position of additional points on each side by taping and leveling from the stadia points. In any case, the data collected must be such that an accurate profile can be plotted.
Design of Bi-Cable Tramways

Location line of tramway should generally be straight, as this is the shortest distance between terminals, and cheapest to build and operate. An exception occurs where tramway passes over a ridge, with a sharp summit in profile; then, for a large tonnage, or where the summit is high or slopes are steep, it is advisable to search for a lower pass, even if off the direct line; a second profile is made from loading terminal straight to this pass and thence straight to discharge terminal, making a horizon angle between the lines at the pass. It may be found, on laying out the two routes, that the one with the angle is the better. If the ground has a steep cross slope, say over 15° (or 1:4), cross-sections should be made at intervals, so as to describe the conditions.

Additional data. Besides profile of center-line, the survey should include plan of site of both terminals, with contours; and show position of all buildings to which tramway must be connected. These plans should cover an area considerably larger than the proposed terminal, say 50 ft on each side of center-line and 300 ft along it. Similar plans should be made of sites along the route where intermediate stations are likely to be located, in order to place all conditions before the designer.

Relation of plans and cross-sections to points on profile must be given by reference marks on each, and permanent marks left on the ground so that the line can be located when construction is begun. It is important to preserve survey points near terminals, and if these are likely to be destroyed by excavation for the structure, other reference points must be set. Survey should be plotted by profile, cross-sections, and plans, before leaving the locality, to assure that all necessary data have been secured; but survey notes giving distance to, and elev of, each point should be sent in with the plots, so that the latter can be redrawn, if desired, without having to scale the surveyor's drawings.

6. Design of Bi-Cable Tramways

Proportioning of interrelated parts of tramways depends on many variables and conditions. Values in Table 4 apply to lines with easy grades, and are useful for preliminary layouts. For conditions which increase difficulty of design, see Art 6a.

<table>
<thead>
<tr>
<th>Tons per hr</th>
<th>Diam of cast-steel Cables, in</th>
<th>Loads</th>
<th>Gage, ft</th>
<th>Carriage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loaded side</td>
<td>Empty side</td>
<td>Wt of material, lb</td>
<td>Wt of carrier, lb</td>
</tr>
<tr>
<td>5 to 10</td>
<td>1</td>
<td>7/8</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>15 to 20</td>
<td>1 1/8</td>
<td>7/8</td>
<td>700</td>
<td>400</td>
</tr>
<tr>
<td>25 to 30</td>
<td>1 1/8</td>
<td>7/8</td>
<td>900</td>
<td>425</td>
</tr>
<tr>
<td>40 to 50</td>
<td>1 1/8</td>
<td>7/8</td>
<td>1 200</td>
<td>450</td>
</tr>
<tr>
<td>60 to 75</td>
<td>1 1/8</td>
<td>1</td>
<td>1 600</td>
<td>500</td>
</tr>
<tr>
<td>80 to 100</td>
<td>1 1/8</td>
<td>1</td>
<td>2 000</td>
<td>550</td>
</tr>
</tbody>
</table>

* Wide gages are needed for long lines, where driving machinery must be large.

These combinations are based upon the fact that the size of load for a given tonnage determines the number of carriers on the line; if load be small, the cost of rolling stock is increased, due to the number of carriers, since part of cost of each unit is constant; if load be large, the size of track cable increases in proportion to the individual weight carried, although the loads may be few in number. An empirical rule sometimes used to determine size of cast-steel track cable is to permit a gross wt of carrier = to 1 200 lb per sq in of cross sec of cable on small sizes, and increase permissible load to 1 400 lb per sq in of section on larger cables, assuming sectional area equals that of solid bar of same diam. The gage (distance apart of track cables) may be 6 ft for small carriers, but must be 8 ft for large ones, and may need to be 10 ft to suit bulky materials.

Tramway speeds must be high to carry large tonnage without increasing weight of moving parts, nor the stresses due to their weight, but when speed is too high it is difficult to handle the carriers at terminals. The practical speed is about 8 ft per sec, with 10 ft per sec as max with favorable conditions and careful designing.

Let Fig. 11 be a typical profile on which is to be built a tramway to carry 60,000 lb broken ore per hr, weighing 100 lb per cu ft. By Table 4, the cables will be 1 1/8 and 7/8-in diam. Let carrier capac be 800 lb, and gage 8 ft. If speed be taken at 480 ft per min, the spacing of carriers will be (Eq 25 and 26): time interval t = 1.8 l + a = 1.8 × 800 + 30 = 48 sec, and distance apart d = l + a = 48 × 480 + 60 = 384 ft. An 8-cu ft bucket weighs 420 lb, making gross weight of one loaded carrier = 420 + 800 = 1 220 lb.
Locating the line. The profile is plotted to a natural scale, say 1 in = 40 ft on "Plate A" profile paper, 20 in wide, ruled 4 by 20 lines to the inch. If difference of elev between ends of line be great, several strips may be joined together to get required width. If line is too long to be operated as one division the junction points are determined and each division is laid out as a separate line; later, the junction stations are designed (Art 16).

By inspecting the profile, points where a rope stretched from one terminal to the other would first touch the ground can be seen; in Fig 11, these will be at Sta 21 and 50. The profile is then tacked to a long table, exposing one portion of the line, say from loading terminal to the first high point; and the terminal structure is plotted in outline to fit roughly the conditions imposed (Art 16). A pin is set in the terminal at point where cable leaves the horizon, another pin is set at the minimum height of tower at the ridge (say 12 ft if snow does not lie there over 3 ft deep); a silk thread is looped over one pin, passed around the other and led over the edge of the table where the spool's weight (a hitch having been taken in thread to prevent unwinding) draws it tight. If the profile paper be ruled in green, and red thread used, there will be no confusion with black ink or pencil lines that may be added. The thread represents a chord, from which the cable curve can be plotted by laying off deflections at as many points as necessary. If it develops that the chord is not in best place, it is shifted by moving the pins. It can be subdivided into shorter chords by holding it with intermediate pins. Tramways are usually laid out for the heavy cable; the light one carries only the empty carriers and will fit same supports as the loaded one, though sometimes it may be necessary to lay it out for separate study.

Towers. The location and height of towers must be such that: a, track cable will lie firmly in the saddles under all conditions of loading; b, angle made by cable over any saddle at a crest will not be excessive. These requirements are expressed by empirical rules: 1. The tops of towers are brought up to a construction curve, the tension of which is 1.5 times the working tension of track cable. 2. The deflection angle $\alpha$, Fig 12, made by empty cable over any saddle, shall not exceed $2^\circ 52'$; that is, an angle the tangent of which is 0.05. As these angles are conveniently laid out by their tangents, they are referred to as deflections of 0.05 or 5%. But, the tower at end of a long span should have no deflection over it when cable is empty. Angle $\alpha$ is the deflection between chords only for short spans; on others, it is the deflection between tangents to adjacent empty cable curves.

After preliminary layout is finished, different points on the line are studied separately (Art 6), the position of cable is determined mathematically and the design modified to fit the specific conditions.

Construction curve has a tension 1.5 times that of the working curve, hence its equation for cast-steel cables is:

$$\lambda = \frac{\\text{wt}}{8t} = \frac{3.7s^2}{8 \times 34600 \times 1.5} = 0.000009 s^2$$

in which 3.7 = wt per sq in of steel in cable 12 in long, and 34 600 is working tension per sq in of steel (Eq 6).

To plot construction curve, points are located at intervals by deflections from the chord, as marked by the thread, and construction curve is then drawn through them, by wooden curves. These curves should be 18-24 in long, made, by laying out deflections from a chord for a number of points, by Eq 3, using proper constants, and must be con-
DESIGN OF BI-CABLE TRAMWAYS

...structured on same scale as the plot. The towers are then plotted in outline at convenient points, with their tops at the construction curve and the curve of the cable at working tension (with or without loads) is drawn in between them, thus forming a slight angle at every tower.

On long spans, the loaded position of the cable should be calculated and plotted, and its relation to towers and ground investigated. If there are 3 or more loads on a span,

![Diagram](image)

Fig 11. Profile of Typical Bi-cable Tramway—Continued

their effect is practically the same as an equivalent load uniformly distributed; hence the wt per ft \( w \), in equation giving the deflection, will be:

\[
\frac{w}{lo} = \frac{w_{t cab} (lb \ per \ ft)}{\text{gros wt of carrier (lb)}} + \frac{w_{t cab} (lb \ per \ ft)}{\text{spacing (ft)}}
\]  

(33)

In Eq 33, spacing is found by Eq 26, and the traction rope, for preliminary determination, may be taken as 0.75-in diam, weighing 0.89 lb per ft. With only 1 or 2 loads on a span, the deflection at load points is found from Eq 11. Having determined deflection at one or more points, a smooth curve connecting them with the end points can be drawn. If spans are inclined, the formulas for deflections of inclined spans must be used (Art 1).

Application of rule 1 for locating towers is shown in Fig 11, from Sta 50 to the discharge terminal. A pin is set 15 ft above the ground on profile at Sta 50, another at end of rail in the terminal, and the thread is stretched. As the construction curve would strike surface at Sta 50, a pin is placed here about 10 ft above ground, giving 2 chords. From Sta 50 to terminal, the chord is not far above ground; hence the construction curve is drawn and towers 20 and 21 are placed under it, to divide the space about equally and avoid a tower in the hollow.

Exceptions are sometimes made to the rule requiring towers to reach up to the construction curve: 1, if spans are long, causing a great difference in sag between empty and loaded conditions of cable, involving sharp bends over the towers; 2, if the line crosses a ravine, where it could not be operated without towers, but where the towers would be unduly high if brought up to construction curve. In both cases, the tops of towers are placed along a slacker curve, and the empty cable is prevented from lifting out of saddles by steel plates bent over the cable and fastened to saddles. The curve through tops of towers should be high enough to cause cable to bear in the saddle when line is loaded, and so relieve the hold-down straps. When this construction is used, the position of traction rope must be investigated, as it may be taut enough to lift and foul track cable or tower saddles, if there are no buckets on the span to hold it in normal position. Designing on basis of loaded cable is further discussed in Art 6a, under Broad Valleys.

Construction at crests is a difficult problem. The principal wear on track cable occurs near towers, and this is aggravated at crests by the downward pressure due to pull of traction rope, added to weight of carrier. Downward pressure is minimised by making the curve over the crest as easy as possible, by introducing a series of towers at short intervals and distributing the bend among them.

Illustration of this occurs at Sta 60, Fig 11. A pin having been set at Sta 60, a tower is placed equidistant on each side of it; the one on upper side is so placed that the cable will make a 5% deflection over it when span is loaded, and the end tower on lower side is brought up to curve of the empty cable, with no deflection. Total deflection angle between tangents to the two curves is 8°. A deflection of 5% per tower corresponds to an angle of 2° 52', which, divided into 8°, indicates that 3 towers are needed. A fourth tower, No 19, is added and brought up to construction curve drawn from No 18, to take the bend due to a loaded carrier in the span from No 19 to No 20. The profile makes it convenient to place the towers 40 ft apart.

The location of towers at a crest is expedited by using a set of circular curves, finding by trial one that fits between tangents to the two cables and is best suited to the profile, and then building the towers up to this curve. If the towers are lined on a circular arc, and an equal deflection occurs at each, they will be spaced at equal chord-lengths along the arc, the radius of which can be calculated for any chord. Radius of the curve through
towers, for different deflections and tower spacings, is given in Table 5, the data on which it is based being shown in Fig 12.

<table>
<thead>
<tr>
<th>Deflection</th>
<th>Tangent</th>
<th>Angle $\alpha$</th>
<th>Cosec $1/2\alpha$</th>
<th>Spacing of towers, measured on the curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 : 20</td>
<td>0.025</td>
<td>1° 36'</td>
<td>79.95</td>
<td>400 800 1200 1600 2000 2400 2800 3200 3600 4000</td>
</tr>
<tr>
<td>1/4 : 20</td>
<td>0.0575</td>
<td>2° 52'</td>
<td>39.98</td>
<td>200 400 600 800 1000 1200 1400 1600 1800 2000</td>
</tr>
<tr>
<td>1 : 20</td>
<td>0.0875</td>
<td>3° 18'</td>
<td>26.66</td>
<td>133 267 400 533 667 800 933 1067 1200 1333</td>
</tr>
<tr>
<td>11/4 : 20</td>
<td>0.0625</td>
<td>5° 00'</td>
<td>22.93</td>
<td>115 230 345 460 575 690 805 920 1035 1150</td>
</tr>
<tr>
<td>2 : 20</td>
<td>0.10</td>
<td>5° 42'</td>
<td>20.11</td>
<td>100 200 300 400 500 600 700 800 900 1000</td>
</tr>
</tbody>
</table>

At crest at Sta 21, a similar group of towers occurs, and Fig 13 gives graphic solution of problem. A point $A$, at Sta 21 and El 1 600, is taken as a trial point and a chord drawn to Tower No 2. It is evident that a curve drawn to this chord will strike the ground, hence Sta 20 is a more suitable terminus for the chord. A point $B$ is therefore set at Sta 20 and El 1 605, and a new chord drawn to Tower No 3, giving a span from Sta 2 to Sta 20 = 1 800 ft horizontally. Next, the center deflection of loaded cable is computed and the tangent $B$ to $C$ is constructed. On the right of summit it is evident that the cable will follow slope of ground to Sta 28, hence a line $DE$ is drawn parallel to and 15 ft above ground. A trial of several circular curves shows that one of 20-in radius (which, at scale of 1 in = 40 ft, corresponds to 800 ft radius), laid tangent to the lines $BC$ and $DE$, conforms to the profile. By Table 5, the 800-ft curve corresponds to towers 40 ft apart, for deflections of 5% on each. This arc is then drawn in, towers are set near tangent points, with a distance between them equal to a multiple of 40 ft, and other towers are plotted up to the curve with a spacing of 40 ft, thus giving 9 towers for the vert curve.

**Tramway trestle** is a structure with a series of saddles mounted at intervals of 5–20 ft, with a slight deflection of cable at each saddle, and is used on a summit where a group of towers would be objectionable.

Fig 14 shows an application of this construction, for conditions at Sta 50 (Fig 11). The figure also gives, for comparison, the graphic solution for a series of towers, similar to arrangement at Sta 21.
investigated. Under these conditions, the saddles will lie on a curve of 200-ft radius (Table 5). This curve, placed tangent to the lines $AB$ and $AC$, is unnecessarily high at the left, hence line $AB$ is lowered, which moves point of intersection of tangents to the right. The structure adopted is shown by full lines.

In making final design of a trestle, the elevs of end points are scaled from profile, the inclinations of tangents to loaded cables are computed and the difference is the angle of deflection between the two tangents; this divided by the angle corresponding to desired deflection, gives number of saddles required. From this the slope of chord from saddle to saddle is found and the elev of each saddle calculated to nearest 0.1 ft. A similar process may be used to calculate elev of individual towers of a group, after locations of end towers have been determined by scaling.

Rail trestles are similar to type just described and have the same application, but a rail is added to take the rolling load and relieve the cable (Art 13).

Track cables are tightened by a weight or some tension device at one end, the other end being anchored (Art 11). On short lines, the anchorage is at one terminal and the tension is applied at the other. A section from 3000–5000 ft is as long as can be controlled from one tension point, hence long lines must be divided into sections of approx 4000 ft. Exact lengths of sections are controlled by choosing, along the line, suitable sites for stations. It is customary to place anchorage at the high end and apply tension at low end of section; then the wt of cable aids in working the slack down to the tension weight, and erection is also facilitated. Intermediate stations are necessary for long lines (Art 12). The typical tramway (Fig 11), being nearly 7000 ft long, requires one intermediate tension station, placed on the ridge near Sta 40. It is constructed as a combined anchorage and tension station (see end Art 12).

6a. MORE COMPLICATED PROBLEMS OF DESIGN

When a tramway is to carry heavy individual loads, or large tonnage, or the difference in elev between ends is great, serious problems are presented. Heavy loads require a large cable, or a carriage with more than 2 wheels, or both, to distribute rolling load and reduce bending stresses in the cable. Large tonnage or great difference in elev creates heavy traction stress (computed by Eq 29), which requires rope of large size or high tensile strength. The vert component (Fig 18) of a heavy rope stress augments the rolling load, which in turn injures the cable. Hence, when an unusually strong traction rope is needed, say over 0.75 in of cast-steel grade, it should be taken as a danger signal and the design carefully reconsidered. Heavy rolling loads also affect the design of structures and machinery, increasing bending stresses in saddle beams on towers and stations, and in the members of rail trestles (Art 13).

Determination of rolling load. A profile to scale of 1 in = 40 ft (or 1 to 500 metric measure) is generally convenient. Humps in the line can be located, and these replotted to twice the above scale for detailed study; choosing first those points, near upper end, where tension is greatest and conditions likely to be most severe. As the exact position of the cable can not be plotted in the early stages of design (some conditions being unknown), an approximation must be made.

For a given make or type of tramway certain mechanical parts have fixed and known dimensions, viz: the distance at carrier of traction rope below the carriage and distance of traction rope carrying sheaves or rollers below the grip. On these bases, a diagram is drawn to scale of 1 in = 20 ft (or 1: 250 metric), with locus of tower saddles as an arc, the path of grip or clip as a similar arc, and a third arc representing the locus of traction rope rollers. These arcs are concentric, and their distance apart are determined by the above mechanical features. Fig 14a shows such a set of curves (exaggerated). For any position of a carrier, lines drawn from its grip tangent to the arc will be chords of the traction rope, as lifted by a passing carrier. This is true unless the curve is so sharp that the chord of the traction rope to next carrier does not touch a roller, when a different construction will be needed, as in Fig 14b, discussed later. With traction rope chords drawn to roller arc (Fig 14a), a parallelogram of forces is laid out on them, and the vert component determined. If the traction rope stress is laid off as 100, the vert component is a percentage, which, multiplied by the actual tension in the rope (Eq 29) gives the vert stress due to tension. This can also be found analytically (see calculation below Fig 14a). Total rolling load is the sum of: wt of carrier and its load, if any, and vert stress found from the chords.

Radius of arc over saddle for any case should be the one best suited to shape of the crest, taking into account the sharpness of the ridge and breadth of the hill, and be as large as possible without making the ends too high from ground. Sometimes on a sharp ridge a cut or even a tunnel is needed to allow flattening of curves. Spacing of towers to fit the saddle arc is found from Table 5 for a desired deflection angle over individual saddles.
When radius of saddle arc can not be increased enough to reduce the rolling load to a desired amount, a rail structure can be built over the crest in place of several towers, thus carrying the load on solid track instead of on the cable. Such a structure often costs no more than a group of towers; sometimes it can be combined with an anchorage or a tension station, at little added cost. The rail must be long enough at each end to keep carriers off the cable, so as to prevent heavy vert stresses on cable when carriers are near the crest. See Fig 14b, where carrier P on tangent to the summit curve has a heavy vert stress due to traction rope tension, which, if on the cable, would cause serious bending. If the rail is extended down the tangent, so that a carrier, Q, is on the rail, the rolling load does not come on the cable. Use of supporting sheaves for the traction rope, close under grip or clip, makes the vert stresses much smaller than when rollers are below bucket. Fig 14a gives solutions of these stresses for the two types of construction.

When saddle arc has a large radius, is short, or carriers are close together, the traction rope may be supported by the carriers, not touching the rollers; this often occurs where traction rope rollers are below the buckets, but less frequently when rollers are close under the grips. When traction rope does not touch rollers, the position of next carrier on each side is plotted, and a force diagram plotted on the chords drawn between grips, as for carrier at N (Fig 14b). Note that the diagram would be the same if chords were drawn between the points on cable where the carriers stand, instead of from grip to grip.

**Fig 14a. Stress Diagram of Vertical Component**

Permissible rolling loads. Table 4, showing net loads that can be carried on cast-steel cables of different sizes, is useful in beginning to study a problem. The total rolling load must be considered; it consists of net load of material carried + wt of carrier, + vert component of the traction rope tension; and should not exceed 1 200 lb per sq in of cable section, when a 2-wheeled carriage is used. The metallic area of cable is found by dividing the wt of cable per ft (Table 1) by 3.7, and the working tension is 34 600 lb per sq in of area.

Bending of the cable under the traveling load decreases with increased tension. Where a cable had been injured, investigations indicate that a ratio of rolling load to horizontal tension was too great, and that a ratio $W + t = 0.035$ is about the limit of load that can be carried without undue wear. This ratio corresponds to a deflection angle, between the tangents to the cable on the two sides of the load, equal to $2^\circ$, with carriages having two
10-in wheels, 13-in centers. If the ratio exceeds 0.035, a larger track cable, or one of stronger wire, may be used; either will increase value of \( t \) by permitting the use of higher tension in the cable and so decrease the deflection angle at the load. If the tension cannot be so increased, the design of the carriage may be altered by using four 12-in wheels on 20-in centers, mounted in an equalizing frame. The load can then be doubled and still give a deflection angle under each pair of wheels not exceeding 2\(^\circ\); that is, the total deflection angle for a 4-wheeled carriage may reach 4\(^\circ\), the tangent of which is nearly 0.07.

Where the gross load is too great for the cable at a few points, and a larger cable throughout is not warranted, the deflection angle under a load can sometimes be decreased by building a section of the tramway with a larger cable, thus permitting a higher local tension, with the same effect as reducing the rolling load. This device can also be used on a long span, to reduce sag of the track cable.

**Angle over towers.** In Art 6 it was stated that the deflection angle of the empty cable over towers should not exceed 2\(^\circ\) 52', or a change of direction of 5%; this rule is applicable to many lines using fixed saddles, especially for capacities up to 60 tons per hr. But conditions may occur, especially if duty is high, where the rule is not applicable, as the difference between loaded and empty position of cable on long spans is so great, that the loaded position of cable must control the design.

**Example.** If a span is 1,000 ft long, empty cable weighs 3 lb per ft, total uniformly distributed wt of loaded cable is 9 lb per ft and cable tension 24,000 lb; then, from Eq 8, the slope of the empty cable at the end tower will be 6.25\% and slope of loaded cable 18.75\%. If the tower at end of span is set with relation to the next one, so that there is no angle over it when cable is empty, there will still be a 12.5\% deflection when span is loaded. No construction will permit so great a change in position of cable. In such case, the towers at ends of the span must be so set that there is an upward deflection on end tower when cable is empty; then, when loads come on the span, the cable will sag and deflect downward over that saddle. Thus, if the empty cable had a deflection of 6.25\% acting upward, the final deflection when span was loaded would be 12.5 – 6.25 = 6.25\% downward. To hold the cable in the saddle when it is empty, the saddle must then have a strap (hold-down saddle), and movable points to permit the passing carriers to leave and return to the cable. In trying to reduce the angle over the tower at the end of a long span, the position of cable determined by gravity and can not be altered, and to get an easy approach the positions of towers back of the end tower are the only conditions susceptible of change.

For the heavy lines discussed in this Art, saddles are preferably of the rocking type, some in use have arcs 10\(^\circ\) long, with radii of 15 ft for \( \frac{7}{8} - \frac{13}{8} \) in cables and 25 ft for 1.5-2 in cables, supplemented by arcs of smaller radius at each end. They may be used where the cable deflection over them is as much as 8\(^\circ\), or 14\%. When a load approaches such a saddle, the depression of the cable rocks the saddle toward the load and, after passing over it, the depression of the cable rocks it in the opposite direction. The rocking saddle is essential where tower spacing is long, as the deflection angle between tangents to the cable is then large; if it exceeds 8\(^\circ\), a double tower with 2 saddles for each cable may be used.

To determine type of saddle and construction needed at any location, the exact slope of the track cables must be found. The worst condition is when a load approaches or leaves a saddle and is a short distance from it; this distance varies with the saddle design and length of carriage, but may be assumed as 6 ft for a general study: the positions of the other loads are determined by the load spacing. The inclination of the cable at a saddle is the algebraic sum of: (1) inclination of the chord found from equation \( \tan \alpha = V + s \) (Fig 7), which may be up or down; (2) inclination of the empty cable with respect to its chord, from Eq 9, \( \tan \beta = \frac{u}{t} + 2 \); (3) inclination of the funicular polygon due to the loads; thus, in Fig 4 (from Eq 9) at the end \( A \), \( \tan \phi = r + t \), where \( r \), the reaction at opposite end \( B \) is due to the concentrated loads.

When one load is close to a saddle, the next one on opposite side will be nearly a load spacing away and the others will be multiples of the load spacing from it. Deflection angle of the cable over the saddle can be determined from the inclination of the 2 cable tangents, and with the rocking saddles described above would be limited to 5\(^\circ\). The deflection can be figured in percentage by adding the tangents, as they are practically proportional to the angles when the angles are small; the added deflection portion would then be 14\%. If the next saddle, on the side opposite the one where the load is close to the saddle, is less than a load spacing away, the inclination on that side will be due to the chord and the empty cable only; this condition may occur where towers are closely spaced, or where 2 saddles are mounted on a double tower.

**Broad valleys present another case where construction must be based on the loaded cable, especially if the valley is too deep to use ordinary towers, or is shallow enough for the loaded cable to touch the ground on a clear span. Loaded cable deflection would then be computed for a point in the valley where a tower could be built, using a tension**
25% or more greater than the working tension. If a tower is built up to this position of cable, the empty cable must be held down on it, but the loaded cable will bear upon it with only a moderate angle. Several trials may be necessary before a solution is found. In such case, the traction rope must remain below the track cable, so as not to foul, nor have a lifting action that will raise an empty carrier off the cable. The position of traction rope is determined from its wt per ft and its tension at this point. It may be possible to hold it down at towers by rollers placed above the grip.

Example. Suppose the valley is 3000 ft wide, and chord is horiz; empty cable weighs 3 lb per ft, loaded cable has a total uniformly distributed wt of 9 lb per ft and cable tension is 24 000 lb. Then, by Eq 2, the deflection of empty cable at center of span is 140 ft, and end slope is 18.67%; when loaded, deflection is 420 ft and end slope is 56%. For a construction curve at 1.25 times the working tension, deflection will be 336 ft, and topography may be such that a tower can be built up to the cable at this point. The end slopes of this construction curve will be 45%. Assuming that the surface on the flanks of valley has about this slope, towers can be placed under the cable at both ends of the 3000-ft span, and so reduce the half spans to say 1000 or 1200 ft from the flank towers to tower in mid-valley. The flank towers will probably need hold-down saddles. Several trials will be necessary before final solution is found, as the introduction of towers changes conditions. The tower in the center of valley will also need a device for holding down the cables. Sometimes hold-down saddles can be used; otherwise a short rail station should be built. An anchor or tension station, if needed, may be located in the valley and so hold down the cables. Where the traction rope does not naturally hang below the cable, it may be possible to hold it down by sheaves above the tower, but care must be taken not to produce an upward stress that will lift an empty carrier off the cable. If the traction rope can not be held below the cable, the valley tower must be raised to hold the cable above the curve of traction rope.

Anchored spans, having a take-up to produce tension in the track cables, are sometimes feasible. They require more judgment in erecting and in keeping the proper tension in cables than where weights are used, but this construction is usually cheaper than weighting, as the structures can be lower than those used with weights and the equipment is cheaper. The tension in cable is produced at one end of a section by a wire rope tackle, or a turn buckle, or rods with long threads, forming part of the permanent equipment.

On Ruisler tramways, cable tension is nearly always produced by wire rope tackle between end of cable and an anchorage. The tackle blocks have sheaves set tandem between 2 long steel plates; the sheaves in each block are of different diam, the one nearest the connection being the largest; this places the sheaves and ropes in one plane, but the ropes clear each other due to the different sheave diameters. The pull on the loose end of the tackle rope is obtained by winding it on a drum driven through worm gearing operated by hand. The fixed tackle block is attached to the drum frame, and the whole is anchored to a block of concrete or masonry.

In erecting a line with anchored spans, tension should be applied to empty cable to bring it a little higher than the computed position of the loaded cable when fully loaded, say with a center deflection 75% of that of loaded cable. Then, when loads are added and cable stretches, it will occupy approx the calculated position. The layout of tramway with anchored spans should be such that a concentration of loads on a long span (due to conditions in loading or stripping the line with buckets, or accidental uneven spacing during operation, causing the span to sag and pull up adjacent spans) does not lift the empty cable off its saddles. This also occurs in a reversible tramway with anchored cables (Art 20, 21), where there is a single heavy carrier. In such tramways the slack of the cable will move from span to span with the carrier, and adjacent spans will be taut. Bib 10a gives examples of anchored spans and calculations of effect of stretch of cable.

A condition identical with an anchored span is obtained by placing blocking under the tension wt, after the cables have been loaded. This holds cable in same position as if anchored, and prevents it from lifting when unloaded. The wt affords a safeguard, however, in that it can lift if the span is overloaded. This relief is absent from an anchored span; when load is increased the cable stretches somewhat, which increases the sag and counteracts some of the increased stresses of moderate overloading. Anchored spans and blocked weights require careful design. The operating conditions are easily misunderstood, and tightening of the cable, as it stretches and becomes slack, is neglected; hence, such spans should be used cautiously, and only under skilled supervision.

7. TRACK CABLES

Track cables for all types of aerial tramways are usually smooth-coil or locked-coil cables. They are made of large wires (Fig 16) in order to have long life under the surface wear of the carrier wheels. Ordinary haulage ropes, with 6 strands of 7 wires each, may be used on light tramways, where low first cost is desired; but usually the small wires wear so quickly that they are uneconomical. See Sec 12.
Locked-coil cables have a smooth exterior, the shape of outer wires resembling an angular oblique figure 8, so that they interlock. This locking holds one broken wire, but if several break near each other the outer layer will unravel. The center of a locked-coil cable is a 7-wire strand, and is surrounded by key and locked wires. In small sizes the key wires are omitted (Fig 15 b); larger cables (Fig 15 a), have one layer of key wires; very large ones, over 2 in diam (used on cableways), have 2 layers of key wires. For ordinary tramways, the cables are of C S wire, but for heavy capac lines the wire is of a special grade. For example, if conditions require a 2-in C S cable (Table 1), a stronger cable can be had in the 1.75-in size of special steel, making a saving of 23% in wt. A 2-in cable is considered as large as can be economically used, because couplings would be so large in diam as to require very wide carriage wheels to travel over them, which would increase the size of other equipment.

Smooth-coil cables, entirely of round wires, are not so smooth as locked-coil cables, but become fairly smooth by wear. As the wires do not interlock, a broken wire is apt to work out and repairs must be made promptly by applying a sleeve-like clamp, permitting carriage wheels to pass. They are easier and cheaper to make than the L-C. As they are of high tensile strength wire, their wt (Table 1) and cost are reduced; but they must be replaced oftener than L-C cables. One center wire is surrounded by 2 to 5 layers of wire, all of same size laid in opposite directions. The number of wires may thus be from 19 to 91; their diam, 0.15-0.22.

Couplings. Length of a piece of cable is limited by length of wire that can be manufactured. Sections required for long tramways are joined by couplings to form a continuous cable from anchorages to tension station. Each coupling (Fig 16) is in halves, one of which is wedged to end of each section, the halves then being connected by a plug having right- and left-hand threads. Couplings are as small in diam as consistent with strength, and the carrier wheels are wide enough to pass over them. At the ends, the cables are attached to sockets similar to that used for couplings, and designed so they can turn when cable is rotated. Couplings should not come within 15 ft of a tower, or within 10 ft of each other, so that the cable will be free to sag as a carrier passes over a coupling, and not receive sharp bends.

Attaching couplings and sockets. Cable is seized with wire for several inches from end to prevent distortion; then sawed off square; a clamp is put on beyond where fitting will come, the seizing is removed and wires are cleaned with gasoline. Cable is inserted in small end of the taper hole in fitting, the round wires are separated by annular wedges driven between them, spaces between wires are filled with slender steel wedges and any small spaces remaining are filled with slim shoe pegs.

This wedging grips each wire and makes a solid steel knob on end of cable which prevents it from pulling through the taper. Wedges and thimbles may be driven with a hammer and punches, but a screw press is quicker and better. With a press, the fitting is placed on cable as above, thimbles and wedges are inserted and driven part way down; then the fitting is placed in the press, the entire set of wedges forced home, and the bulged end of cable pushed firmly into the taper fitting.

Rotation of track cable. Every week or so the cable should be turned through 1/4 of a revolution. This distributes wear over its entire surface, prevents flattening of cable and displacement of wires. The turning should be in such direction as to tighten the outer wires of cable; thus, if wires have a left-hand lay (Fig 15), the cable should be rotated to the right, or clockwise.

Maximum wear on a track cable occurs in a length extending about 5 ft on each side of a summit saddle. Directly over the saddle the rolling pressure is greatest, due to pull of traction rope combined with wt of carrier; just off the saddle the cable gets a reversed bend between carrier wheels and saddle, especially on the side where loaded carriers approach the tower. The downward pull of traction rope can be reduced by proper location of towers and traction-rope rollers (Art 10), and bending minimised by stretching cable as taut as its strength will permit.
8. ROLLING STOCK

Each piece of rolling stock (carrier) consists of: carriage, container, hanger, and clamp or grip for attaching to traction rope.

Carriage runs on track cable; its wheels, 8–12 in diam, are mounted in a frame with a connection for the hanger supporting the container. For heavy loads, carriages have 4 wheels; they are practically 2 ordinary carriages, connected by a swivelled equalising frame, from which the load is suspended. This distributes the load and reduces wear of the cable due to bending.

Container for bulk material is a bucket; for other materials it may be a tank, platform, or cage. For timber, the hangers terminate in hooks, to which timbers are attached by slings; these are used in pairs, one at each end of load. Sometimes workmen are transported by a tramway during certain hours of the day. Long buckets, each holding 2 men, are best. One man sits in each end with his legs between those of the other man.

Hanger is of bar steel, with C-1 or steel parts to facilitate connection with carriage and container, and hold clamp for traction rope. Its form is largely governed by the parts to which it connects.

Clamp for traction rope may be a cam, which can be applied to or released from the rope at terminals, thus allowing carrier to be shunted to loading or discharge point; or it may be a clip, permanently attached to both carrier and traction rope.

Grips differ in design and often in principle on each make of tramway, and are shown in maker's catalogues. Devices used to obtain gripping pressure on traction rope are: (1) Levers and toggles. The latter, by passing a center clevis and locks the grip, as in the Webber grip (Maker 1, Art 29) extensively used in the past; obsolete for new work. Its motion was prescribed and it would not grip the rope where its size varied beyond the rope's compressibility. (2) Springs. By cushioning one jaw, grip can take ropes of varying size; levers are used to compress the spring and produce initial pressure; holding power depends on strength of spring and its leverage on grip jaw. Used formerly in modified Webber grip, and now in Wico grip (Maker 1, Art 29). (3) Screws. Grip jaws are brought together by a screw as in a machine's vise; the gripping force is large and jaws will seize ropes of considerable difference in diam and are locked wherever the screw stops turning. This type was originated by Otto in Germany, and in slightly different detail is now made by Makers No. 8, 3, 9 (Art 29). (4) Wedges. A slim sliding wedge is used to force jaws together on the rope; the taper being less than coef of friction there is no tendency for grip to release. They will hold on ropes whose diam varies due to stretch or wear. Made by 2 and 9 (Art 29). (5) Gravity. Wt of container, acting through levers, gives the holding force on traction rope. The closing motion stops when jaws have seized the rope; this permits gripping or ropes of varying sizes. The grip is usually attached to hanger below the carriage (under-hung grip); for special purposes it may be built into the carriage (over-head grip). Made by 5, 6, 7 (Art 29).

Most grips can be attached by hand, but are usually closed by an attacker; they are always released automatically when carrier enters terminal. A grip depending on the weight of container for its holding force requires a special system of rails for lifting the container, in order to open grip preparatory to inserting traction rope on outgoing side, and a similar device on incoming side to open grip and release traction rope.

Some grips occupy most of the space, not needed for clearance, between carriage and carrier, so that the rollers supporting traction rope at towers must be placed below the carriers. This construction is good on most lines. As the carrier is free to swing sidewise through considerable range, guards are often used to fend the rope onto the rollers. Other grips allow supporting sheaves to be placed close under their jaws, so that the traction rope is lifted but little as carrier passes the sheave. This requires carriers to be guided, to prevent colliding with the sheave, and to make the rope drop back on sheave after grip has passed. Guides are objectionable when applied to every tower, but to have the sheave close under the grip is advantageous in passing over crests, as it reduces the downward press. Guides can be easily constructed on summit structures. (See discussion regarding Fig 18, Art 10.)

Clip is a U-shaped band of steel, bent around traction rope and permanently clamped to it by bolts. As clip can not be released from rope while tramway is in operation, terminals must be so arranged that carriers can pass around and sheaves; the buckets are loaded while in motion by an automatic loader, and dumped while in motion by a tripper. Tramways with clips are obsolete. Disadvantages: wear on traction rope due to gripping is concentrated at clips; the non-stop feature makes terminals inflexible; speed of the line is limited by centripetal force developed by carriers passing around sheaves.
Dimensions of 3 sizes of ore carrier accompany Fig. 17. In a preliminary design these may be used for several sizes of buckets smaller and larger than those noted. The distance $A$ differs considerably; its minimum is about 3.5 ft, when the traction rope is carried on rollers below carriers. $A$ must be increased to clear sheaves supporting traction rope if close under the grips, to admit special latches and tripping mechanism, for clearance in terminals, and for loading. Distance from track cable to grip is kept constant on each system, at about 2 ft, so grip will pass under the cable saddle and end of its supporting beam.

<table>
<thead>
<tr>
<th></th>
<th>Capacity of bucket, cu ft</th>
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<tbody>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>9'-6&quot; with traction rope roller below carriers; 5'-6&quot; with traction rope sheave under grips</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1'-3&quot;</td>
</tr>
<tr>
<td>C</td>
<td>2'-7&quot;</td>
</tr>
<tr>
<td>D</td>
<td>3'-11&quot;</td>
</tr>
<tr>
<td>E</td>
<td>4'-5&quot;</td>
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Above are approximately applicable to buckets of 4 to 6, 7 to 15, 16 to 25 cu ft, respectively.

9. TRACTION ROPE

This is usually Lang lay, of as large wires as consistent with flexibility and to offer max wearing surface. For sizes of 0.75 in diam and less, there are 6 strands of 7 wires each, all of same diam, laid about a hemp center. For larger diam, the strands have 19 wires; 1 center and 9 outer wires of about 25% of diam of strand, and an intermediate layer of 9 wires half the diam of outer ones; this combines flexibility with good wearing surface. For moderate tensions the wire is of cast steel, to make a rope of such diam that the gripping surface is ample. For higher tensions (ropes over 0.75 in diam), plow-steel is used, to keep down size and wt and give the flexibility due to smaller wires. Factor of safety, 5. See also Sec 12.

Lubrication. Traction rope should be oiled frequently, to lubricate the interior. Lubricant must be carefully chosen, so as not to reduce holding force of grips. A thin oil may be used in abundance, to penetrate the interior, the surplus being wiped off to leave surface dry. It can be applied mechanically by an roller on the outgoing empty side of a terminal. Some operators prefer a thick sticky lubricant, which works well into the interior. Admixture of linseed or other drying oils in the lubricant is advantageous, in causing exterior surface to harden, and enabling grips to take a firm hold.

10. TOWERS

Stresses in towers have 3 sources: 1. Downward press on saddles, due to vert component of tension in track cables, wt of loaded carriers, and vert component of tension in traction rope. 2. Racking motion parallel to line of tramway, due to changes in direction of press from the cable when a load approaches and leaves the tower. 3. Side press, due to wind.

Fig 18. Stresses in Saddle Beams; Towers 40 ft Apart; Cable Deflected 5% on Each

1. Downward press on saddles is often so great that their supporting beams must be of oak or steel to resist bending stresses and crushing by the saddles; steel is preferable. At towers along the line, downward press from traction rope can be determined only when exact conditions are known, as the next point of support for traction rope is generally the next carrier on each side, and the positions
of these depend on their spacing and the sag of the track cable under them. For mode of determining vertical stresses, see Art 6 a. Fig 18 shows the vertical stresses in percentages of the tension for a single tower. The full lines show the vertical stresses when traction rope is supported on rollers below the carriers, and dotted lines show stresses when traction rope is supported on rollers 3 in below its position when in the grip. In practice a vertical resultant of 29.5% (Fig 18) would be prohibitive, unless traction rope tension is very small.

2. Racking. The problem of supporting the saddle beams and providing rigidity against racking is made difficult by necessity of maintaining a clear passage for the carriers.

3. Wind. Tower base is spread parallel to center line of tramway, so resultant of press of cables on saddle falls well within base, even when cables are moderately inclined; hence will usually resist overturning by wind parallel to line. High towers may be narrower in other directions and should be investigated for resistance to wind at right angles to line; they may need to be guyed.

Material. Steel with concrete or masonry foundations is best for permanent plants and where wood is costly. Riblet uses steel fabricated near tramway site and pre-cast concrete blocks for foundations (11). Wood is usually framed at the point nearest tramway site to which timber can be delivered; main posts are 6 by 6 to 8 by 8 in.; rarely 10 by 10; saddle beams are usually 8 or 10-in steel channels. In remote districts, towers have been of round timber with hewed bearing surfaces, but timber can usually be whipsawed or ripped in a portable saw mill; squared timber reduces cost of framing, distributing and erecting. Foundations should be concrete or masonry, but are often of such material as is procurable: logs, cribs with or without rock filling, or piers of stone laid up dry; such foundations will not resist up-lifting stresses and many towers must be guyed. Cones and masonry towers are sometimes used, especially when tramway serves a cement plant; they are bulky, and attractive designs have not been worked out.

Pyramid tower (Fig 19) is economical of materials. When of steel, a rigid head can be designed with shapes and plates securely fastened to the angle posts. When made of wood, the small area at top of posts makes it almost impossible to attach saddle beams so that they will not rack and work loose. In this type, whatever material is used, clearances between a large carrier and the side of a wooden tower are too small; the base also is small and provision must be made for wind stresses, and on steep lines for cases where resultant of cable stresses falls outside the base.

Through tower (Fig 20) is rigid and efficient, but contains about 100 bd ft of timber per ft of height up to 60 ft, which is nearly double the amount for pyramid towers. Sometimes, on light lines, the outside center posts are omitted below roller deck, especially on high towers.
Composite tower (Fig 21) has a top identical for all towers, the base being varied to give desired height. Base stands with its diagonal on center line, hence its long dimension is in line with main stresses. Its top is rigid against racking. Framing is simpler than it seems in a drawing. These towers contain less timber than those of through type.

Side-hill tower (Fig 22) is of through type and designed for steep lines to ensure that line of pressure shall fall within base, and slope of inclined side is made to suit direction of press.

The principle of the through tower can be used for steel towers with good results.

11. ANCHORAGE AND TENSION OF TRACK CABLES

Track cables must be taut enough to support the load and minimize bending under the carriage wheels, both on spans and when carriers approach tower saddles.

Tension weights to keep cables taut are wooden boxes filled with stone or scrap iron, or are moulded concrete blocks. It would be desirable to weigh the tension wt, but, this being usually impracticable, the wt of the box is computed and added to that of its contents, taken as 100 lb per cu ft for broken stone or 350 lb for packed scrap iron; concrete blocks are taken to weigh 140 lb per cu ft. Form and dimensions of weight are influenced by the allotted space. A tension wt can keep taut 3,000 to 5,000 ft of cable depending on profile of line and the care with which saddle grooves are kept clean and well greased. The weight usually equals the working tension of the cable, unless the slope is so great that the added wt of cable would overstrain the upper end; then the tension wt should be reduced.

Anchorages at opposite end of cable from tension point must be designed to cover fact that slope of line may increase tension due to the wt alone. Sometimes the cables terminate in station framework. For steel construction this is simplest; for timber it is often difficult to design the structure to take these stresses, and it is usually economical to deflect cables to the center, carry them through station and attach them directly to a masonry anchorage. See terminal stations (Fig 33, 34), also Fig 23.

The anchorage block must be a monolith, equal in wt to the vert component of the tension, allowing 140 lb as wt per cu ft of masonry or concrete, and the front must have sufficient area to give a bearing resistance against the earth equal to horiz component of tension. Horiz resistance of aver earth may be taken as 1,000 lb per sq ft for a deep block, but on a down-hill slope the anchorage must be carried into the hill by a tunnel. For an anchorage in rock, a T-shaped trench is excavated and the anchorage bars set in it, the space around them being filled with concrete. Metal parts of the anchorage must be designed for required tension, and also to allow the cable to be turned (Art 7) while under tension. Anchorage bars must be enclosed in masonry to a point above water level, and extend above dampness before coupling to cables, to avoid injury to the wires from rust.

12. INTERMEDIATE STATIONS

These are needed to apply working tension to track cables which are too long for terminal apparatus to be effective throughout (see end of Art 6). There are 3 types: Double-anchorage; double-tension; anchorage and tension. In all, the track cables are deflected to center of structure, out of the way of carriers, and pass downward to anchorage or to tension weights. Space between sections of track cable is bridged by rails, to allow carriers to pass through without being detached from traction rope.

When both pairs of cables are in place and under full tension, the pull of those on one side of station will counteract the pull on other side, but the structures must be so designed as to be secure if cables on either side are released while the others remain under tension, a condition which may occur during erection, while making repairs, or in case of accident. These stations are similar on all tramways, but must be designed to suit conditions on each profile. They may be of wood or steel; if steel, the bends can be simplified and all parts placed between the cables, somewhat like the steel tower, Fig 19, or wooden summit station, Fig 26. Cable sockets are designed to allow cables to be turned (Art 7).

Double-anchorage stations can be as low as profile conditions will permit, provided there is ample clearance for carriers above the ground. Where there is no snow, they
need not be over 10 ft high. Fig 23 shows essential features, with cables anchored to the structure. It is preferable, however, to continue the cables to masonry anchor blocks set in the ground, as shown in terminal, Fig 23.

![Double-anchorage Station](image)

**Fig 23. Double-anchorage Station**

Double-tension stations must be built high enough to allow tension weights a vertical motion of 6 to 8 ft, and still have their tops below path of carriers. Even with squat weights, this makes stations 20 to 30 ft high to the rail (Fig 24).

![Double-tension Station](image)

**Fig 24. Double-tension Station**

**Tension weights** are attached to chains or wire rope, passing over sheaves on short axles, resting in bearings. Horiz pull is transferred to main beams by gains in the timbers, into which the bearings fit. Main beams support the vertical load and transfer horis stresses to inclined braces, which in turn transfer them to foundations. Inclined braces may develop an upward thrust when design is such that the full tension box does not come on end of inclined brace, or when all cables are not under tension. These upward forces are resisted by giving the foundations a mass equal to the uplift, and bolting the posts to them. Tension stations may be no higher than anchorage stations when take-up tackle replaces floating weights (see end of Art 6a).

**Anchorage-and-tension stations** provide for anchoring the cables of one section and applying tension to those of the other. They are practically half of a double-tension station, combined with half of a double-anchorage station of same height.
13. ANGLE AND SUMMIT STATIONS

Angle stations are required for horizontal deflections. Main cables are terminated, traction rope passes through and is deflected by sheaves; carriers are detached from incoming traction rope, run over a rail bridging gap between cables, and reattached to outgoing traction rope. Fig 25 shows a simple station, with both pairs of cables anchored; in it, the carriers detach automatically, but 2 men are required to reattach them to traction rope. Occasionally, angle stations are designed so that carriers detach and reattach automatically, or are arranged so that they make the turn without being released. Either arrangement complicates details and adds to first cost of the tramway, but reduces operating expenses by saving attendants at angle station. See end of Art 16 for similar problems. An angle station may be introduced at a junction, between two divisions of a tramway, without increasing first cost or operating expense (Art 17).

Summit trestles are introduced at crests in a line to save erection of a group of towers (see near end of Art 6), and carry a series of saddles with a slight bend of rope on each (Fig 26); they have limited application; a rail station (see below) being preferable. Rail stations are similar in purpose to summit trestles with saddles. The main cables are carried through the station, but rails are mounted above them, on which the carriers run, and so relieve cable wear. Each end of the rail has a point, to lead the carriage from cable.
to rail and let it down from rail to cable (Art 16, par 3). Rail stations are used where
rolling press is heavy, due to heavy loads, limited space for structure, heavy tension in
traction rope, or where conditions prevent a reduction of vert component.

Traction rope, in both forms of summit station, is supported at a uniform distance
below the track. The larger the radius of track cable, or rail, the less will be the deflection
of traction rope at the grip, and consequently both press and wear of carrier wheels on the
track are reduced. Fig 26 shows a trestle with saddles set on an arc of 150-ft radius,
with rollers below the carriers. Downward stresses due to traction rope could be reduced
for this trestle by increasing the radius of the curve through the saddles; or, if the design
of grips and carriers permit, by supporting the rope on rollers close under the grips
(Art 6a). Vert stresses are found by similar methods to those in Fig 14 a, b, 18.

14. POWER REQUIRED OR DEVELOPED BY TRAMWAY

Tensions. Given: wt of individual load = l; wt of empty carrier = e; spacing of
carriers = d; wt per ft of traction rope = r. Then the weights per ft of uniformly dis-
tributed load corresponding to wt of carriers plus wt per ft of traction rope, are:

\[ w_l = \frac{l + e}{d} + r \quad (34) \]

For loaded side, \( w_l \); for empty side, \( w_e = \frac{e}{d} + r \) (35)

If \( w \) be the total uniformly distributed wt per ft for any case, then tension in traction
rope at upper end of line (Eq 29) is \( t = \omega f V \pm \omega f H \). If load is descending, the sign of
last term is minus; if ascending, plus. Total tension equals the tension thus found plus
that put into the rope by tension \( w_l \) applied to a sliding sheave. The tension added to
each rope by tension \( w = \frac{\omega}{u} \).

Power. Let gross tension on taut side = \( T \); and gross tension on slack side = \( S \).
Then \( (T - S) \) is the force to be applied to move the traction rope, or to be opposed to
traction rope, to restrain it. This force multiplied by veloc of rope in ft per min (e)
gives the work done or by the traction rope per min; hence, power required or developed
(omitting friction of terminal machinery) is

\[ H_p = \frac{(T - S) v}{33 000} \quad (36) \]

Friction losses. Power thus computed will be increased when power is required, or
decreased when power is developed, by friction of driving machinery at terminals. If
friction coeff of this machinery be 0.33 1/16% of its wt, the power to overcome friction will be

\[ \text{Friction } h_p = \frac{0.001/16 W e}{33 000} = 0.000 000 1 W e \quad (37) \]

in which \( W = \) wt of moving terminal machinery in lb, and \( v = \) veloc of rope in ft per min.
Combining Eq 36 and 37, gives total power of tramway as

\[ H_p = \left( \frac{T - S}{33 000} \pm 0.000 000 1 W e \right) v \quad (38) \]

Inertia. At instant of starting, inertia of the line is to be overcome, and moving
resistance is higher than when running. To insure sufficient starting power, the following
empirical rule may be used: in determining the power developed by a gravity line in start-
ing, divide wt of individual load \( l \) by 2; or for the power required to start a power-driven
line, multiply \( l \) by 2, before substituting in Eq 34.

Return freight may be carried on a tramway. This at times increases tension on
slack side, a condition which must be recognized in power calculations. On a gravity
line considerable up freight can be carried when line is running at full capac of descending
loads, but when there is little descending material, driving machinery must be supplied,
for use at such times.

To solve Eq 36 and 38, \( T \) and \( S \) must be known. But when a drive is first investigated,
these factors are unknown, since each is composed of the stresses due to loads, plus half
the tension wt, the amount of which has not yet been determined; but, as half the tension
wt is applied to each side, the value of \( (T - S) \) will be equal to the difference of the stresses
on the two sides due to the loads, as determined by Eq 29, without considering tension wt.

Tension weight. A sheave which will furnish friction necessary to drive or restrain
the traction rope is found by Eq 31, by substituting the value of \( (T - S) \) as above and
the value of \( f \) and \( \alpha \) suitable for the friction surface, and number of half laps under con-
sideration, and then solving for \( S \), the tension on slack side. If \( S \) be less than the tension
for this side as found by Eq 29, no tension wt need be applied by sliding sheave to provide the necessary friction. If $S$ be greater than the tension on empty side, the deficiency must be supplied by a tension wt equal to twice this difference, applied to a sliding sheave. Trial calculations may indicate several possible types of drive with their respective tension weights, and the merits of each can be considered. If $S$ be less than the tension produced by loads on slack side, a sliding sheave is needed simply to take up slack in traction rope, and the wt applied need be sufficient only to keep the rope taut near sheave. If the resulting tension, after tension wt is added, is greater than necessary, it shows that the power sheave is capable of doing more than is required. Having found the wt to be applied to sliding sheave, $T$ is found by adding $t_w$ to tension on taut side, due to the loads as found by Eq 29. This is the stress that finally determines size of traction rope required.

Application of these principles to the typical tramway, Fig 11, illustrates method of computation. Fixed data for this line are: wt of load $= l = 800$ lb; wt of carrier $= c = 420$ lb; spacing of carriers $= d = 384$ ft; wt of traction rope $= r = 0.89$ lb per ft; horiz length of tramway $= 6900$ ft; difference in elev of ends of tramway $= 1806 - 350 = 1456$ ft. As carriage wheels have plain bearings, $f = 0.02$.

Let Fig 27 represent CONTROLLING MACHINERY AT UPPER END, the most probable arrangement for this tramway. Calculation of forces developed by descending loads and required for ascending loads, to accompany the figure, is as follows:

### LOADED CARRIERS DESCENDING (By Eq 29, $t = wV \pm wfH$)

<table>
<thead>
<tr>
<th>Loaded side; descending.</th>
<th>Empty side; ascending.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w = w_l = \frac{l + c + r}{d} = 1220$</td>
<td>$w = w_e = \frac{c + r}{d} = 420$</td>
</tr>
<tr>
<td>$= 384$</td>
<td>$= 0.89 = 0.98$</td>
</tr>
<tr>
<td>$t_l = 4.07 \times 1516 - 4.07 \times 6900 \times 0.02$</td>
<td>$t_e = 1.98 \times 1516 + 1.98 \times 6900 \times 0.02$</td>
</tr>
<tr>
<td>$= 562 - 5608$</td>
<td>$= 3002 - 273 - 3275$</td>
</tr>
<tr>
<td>$(T - S) = t_l - t_e = 5608 - 3275 = 2333$ lb = force developed.</td>
<td></td>
</tr>
</tbody>
</table>

### LOADED CARRIERS ASCENDING (By Eq 29, $t = wV \pm wfH$)

<table>
<thead>
<tr>
<th>Empty side; descending.</th>
<th>Loaded side; ascending.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w = w_l = \frac{c + r}{d} = 1.98$</td>
<td>$w = w_f = \frac{l + c + r}{d} = 4.07$</td>
</tr>
<tr>
<td>$t_e = 4.07 \times 1516 + 4.07 \times 6900 \times 0.02$</td>
<td>$t_f = 4.07 \times 1516 - 4.07 \times 6900 \times 0.02$</td>
</tr>
<tr>
<td>$= 6170 - 273 = 5737$</td>
<td>$= 6170 + 562 = 6732$</td>
</tr>
<tr>
<td>$(T - S) = t_e - t_f = 6732 - 6729 = 4003$ lb = force required.</td>
<td></td>
</tr>
</tbody>
</table>

In above case, for descending loads, $(T - S) = 2333$ lb. For a gravity line, controlled by hand brakes, a pair of plain sheaves might be used (stressess being too great for wood filling). This assumption gives $f = 0.085$ and $n = 2$; hence from Table 3, $e^{\sqrt{n}} = 1.706$, which substituted in Eq 31 gives $(T - S) = S(e^{\sqrt{n}} - 1)$, or $2333 = S(1.706 - 1)$; hence $S = 2333 + 0.706 = 3300$ lb. This practically equals value of $t_l$; hence $t_l$ might be zero if there is to be no margin of power. For a power margin of 25%, new value of $S$ is 4125; substituting this in the expression $S = t_l + t_w$ gives $t_w = 4125 - 2375 = 850$ lb; hence tension wt should be 1700 lb, which is reasonable.

To haul the same loads up the line, a grip sheave with steel jaws (Fig 29) would be necessary to develop required pull. Let the jaws have a ratio of 1:3; then $f = 3 \times 0.085$, $n = 1$ and $e^{\sqrt{n}} = 2.228$ (Art 3). Substituting these values in Eq 31 gives $(T - S) = S(e^{\sqrt{n}} - 1)$, or $4125 = S(2.228 - 1)$ and $S = 4125 + 2.228 = 3250$ lb, which is greater than $t_f$. Hence, with no margin of power, a tension wt of 2(3250 - 2729) = 1042 lb is essential for power purposes. It is well, however, to add 25% and make up the increased tension on slack side by adding to the tension wt.

Another combination occurs with CONTROLLING MACHINERY AT LOWER END of tramway (Fig 28). Then the tension in slack side due to loading will be zero, and the only tension on slack side of driving sheave will be that given by tension wt attached to sliding sheave: that is, $S = t_w$. Tension on slack side will be $T = (w_l - w_l)V \pm (w_f + w_f)fH \pm t_w$; the plus sign being for ascending loads, the minus for descending. From these equations the force to control movement of loads $(T - S)$ can be determined. For ascending loads, power is always required, but for descending loads there are two combinations: (1) on a steep slope, first term may be the larger and the value
of \((T - S)\) positive, indicating that force is developed; (2) on a gentle slope, second term may be
the larger and \((T - S)\) negative, indicating that force is required to pull the loads down. With
large powers, either required or developed, it is not practicable to place power machinery at lower
end, because all tension on slack side must be obtained artificially, and by so doing tension on loaded
side is increased prohibitively. Value of \((T - S)\) is substituted in Eq 31, together with trial
values of \(f\) and \(n\), and the value of \(S\) is determined. Since \(S = t_u\), for this arrangement of driving
machinery, the required tension \(wt\) is known at once.

15. POWER MACHINERY

Rope drives on plain sheaves may have one or several half laps on the sheaves. A
C-I sheave with a single groove, giving a half lap on the sheave, makes a satisfactory
drive, but the pull exerted is small. Two or more grooves in a C-I sheave, where the
grooves are positively connected, is objectionable, because the rope in first groove has
more tension; hence this groove wears faster and becomes of smaller diam than the others,
producing a differential stress of large but unknown amount. Multiple-groove drives
are satisfactory if the grooves can slip or creep to compensate for this differential stress.
Elliptical-grooved sheaves with several laps about them, as used on capstans, are not
applicable to tramways, as the rotation of the rope down the slope in one di-
rection will twist it and give trouble by
titling empty carriers.

Wood-filled sheaves can be used
for transmission of considerable power,
where \((T - S)\) is large, but actual
tensions are small. If tensions are
heavy, the wood will be cut out. RUB-
BER AND LEATHER-FILLED SHEAVES give
max friction for rope drives, but are
easily cut and not applicable to tram-
ways.

Grip sheaves give a strong hold on
rope for a single half lap on sheave,
and do not produce differential stresses
in rope. The Hallidie pattern (Fig 29)
is well adapted to transmit considerable
power, and does not injure traction

![Fig 29. Hallidie Grip Sheave](image)

rope. The jaws multiply the rope press by 3 or 4, increasing the friction. This increases
\(f\) in Eq 30, 31 by same amount, whence the power transmitted by a single grip sheave is
equivalent to that of a 3 or 4-grooved iron sheave. The grip sheave costs about the
same as the multi-grooved sheave and its idler.

Band brakes may be used with machinery running constantly in one direction. The
force absorbed by the brake is \((T - S)\) and ratio of \(T\) to \(S\) is given by Eq 30. Brake
should be so arranged that the greater tension \(T\) will come at fixed end; the \(S\) is the pull
exerted on other end in applying the brake. If the conditions are reversed, the max
stress comes on movable end and the brake tends to release itself. The bands are about
1/8 in thick, lined with blocks of maple to increase friction. Frequently operated brakes
must not absorb too much power per unit of area, or they get excessively hot and destroy
the blocks. A good rule is to allow 72 sq in of brake surface for each hp absorbed.

Automatic speed regulators for gravity lines save brakeman’s wages and the tram-
way runs smoothly; on power-driven lines they assure constant speed. The best controller
is an elec motor, belted or geared to the tramway drive sheave. It furnishes operating
power when conditions prevent the tramway from running by gravity, and turns current
back into the power line when being driven by the tramway. It will run about 5% under
speed when acting as a motor, and 5% over speed when generating current. Current
may be either d c or a c. If a c, the motor may be of constant-speed type to say 30 h p;
above that, the variable-speed type avoids excessive line loads or starting shocks. Motor
should have an ELECTRIC BRAKE capable of stopping the line if current fails; without a
brake, the line would run away when the motor ceases to offer resistance. Hand brakes
are also required, to shut down and hold the line, or for use when the motor is not acting.
The starting device should admit current to the elec brake and release the brake when it
connects the motor to power line. A d-c motor can be made to generate current under
any line condition, but an induction motor acts as a generator only when connected to a
line supplied with current by a separate a-c generator. Current turned back into the line
can be utilised elsewhere.
Other automatic regulators having limited application: (a) hydraulic controllers, offering resistance by pumping water or oil against a pressure, which is automatically changed in proportion to the power absorbed; (b) fans running at high speed in the air, with blades arranged to swing out, like governor balls, thus acting with longer radius and more resistance as speed increases. They can be adjusted to keep tramway speed constant; (c) water may be pumped or air compressed to absorb surplus power; the water or air can be utilized or run to waste; (d) where mill or other machinery is adjacent, a tramway can be connected to the line shaft; the governor for the mill machinery then controls tramway speed and power generated by the tramway aids in driving the mill.

Brakes may be operated by levers, handwheels and screws, or combination of the two. Levers are quicker to operate, but not so powerful as handwheel and screw. The operating stand may be on the terminal floor or on an elevated platform. When brakes are operated by levers, the latter can be extended by rods to any point.

Power-driven tramway. When using less than 20 h p, a connection to the vert shaft is conveniently made by bevel gears placed either at top or bottom end of shaft. With a gear ratio of 1:5, the horiz shaft runs at convenient speed for belting to motor or engine. When power exceeds 20 h p, torsion in vert shaft is considerable. This is avoided by bolting brake wheel to one side of main sheave and a spur gear to the other side and driving latter by a pinion mounted on a parallel vert shaft, the latter being driven through bevel gears from a horiz shaft. On heavy drives the sheave will usually be a grip sheave. Bevel gearing may be avoided by deflecting traction rope over a pair of vert sheaves, and causing it to pass under main driving sheave mounted on a horiz shaft. Sheave is bolted to a spur gear, driven by a pinion on a parallel shaft to which motor or regulator is geared. As the ropes tend to lift main sheave, the downward press of the shaft in its bearings is reduced. When the traction rope tension is sufficient to lift the driving sheave, with any gear or brake wheel attached to it, the bearings should be inverted, with lubricating grease well below the shaft, like a R R car wheel, the bearings being placed on under side of supporting beam. The connection between motor and tramway sheave may include a belt drive (not as reliable as gearing). Silent-chain drives and speed reducing gears have also been used. A machine-moulded spur gear attached to main sheave, followed by cut gears with rawhide pinion on motor, give a good drive at reduced cost.

Gravity lines. Where power is absorbed by automatic regulator, or utilized for any purpose, connection to main sheave is made by gearing, as above, for power driving.

Tension sheave at lower end may slide in a horiz or slightly inclined plane (Fig 32), or the rope may be deflected so as to make it travel vertically (Fig 40), or in any other direction.

16. TERMINAL AND JUNCTION STATIONS

Purposes. Every terminal station must be designed for 3 distinct functions: 1. To secure track cables. 2. To operate traction rope. 3. To transfer carriers from cables to rail, lead them to loading or discharging point, and return them to the cable.

1. Cables are secured in same manner as at anchorage and tension stations (Art 12), with changes in details to suit conditions.

2. Traction rope is operated by power drive, or controlled by a brake system at one end, usually the upper, and is tightened by passing over a sliding sheave, usually placed at lower end. Occasionally power machinery and tighteners are at same end. Type and arrangement of controlling and tension mechanism depend on local conditions, and are subject to considerable modification (Art 14 and 15).

Manner of deflecting and guiding traction rope in terminals is influenced by the process of getting the rope into or out of the grip, and of attaching or detaching carriers. For a grip opening at side, the rope must be brought through a point where it will be opposite the grip jaws at the instant that grip comes into the vert plane through the rope, as the carrier moves toward rope in running along rail. Thus, in Fig 30, the carrier moves along rail from A to B, the grip travels in horiz plane abc, and when carrier reaches B, the traction rope must be at b so as to enter the grip, which is then closed, after which the carrier supports the rope. A second case, where rail and traction rope slope downward, is shown by dotted lines. In detaching, these operations are reversed.

Fig 30. Attaching Point for Grips Opening Sidewise (Dotted lines show alternative position of rail and traction rope)
For a grip opening downward, the carrier moves so as to bring grip into plane of rope, but somewhat above it, then advances toward inclined rope, or is lowered onto rope, if it is horiz., until it bears in the grip when jaws are closed. Thus, in Fig 31, carrier moves from A to B, with grip above rope, then advances until point C is reached, when rope will be in jaws of grip, which can be closed. In detaching, the process is reversed. If grip jaws open upward, the grip will pass under the rope before taking it.

3. Transfer of carriers, from cables to rail, or vice versa, must be done as smoothly as possible, to prevent lunging of carriers and hammering of cable where carrier leaves the rail. Lunging of the carrier is reduced by accelerating it on entering the attacher, to approx. speed of traction rope. Experience shows that wear on cable is least when carriers run on to cable outside the terminal saddle, where cable is free to deflect when load comes on it. This requires a terminal point movable vertically. When carriers take the cable at a rigidly supported point, the cable is hammered and the wires are displaced and worn.

At terminal saddle, rail is placed parallel with track cable, but back of terminal point the rail is curved vertically so as to change from the inclination of cable to the horiz. before reaching point

where grip is released from traction rope. Where cables slope downward from a terminal, rails are bent on convex vertical curves at the front of a terminal, resembling a rail station at a crest, until they are parallel to slope of cables; the curved rail saves cable from downward press of carriage, and reduces wear on cable. When cables leave a terminal on an upward slope, the rails are bent on concave curves, and provision must be made for holding traction rope down, to make it change its direction without lifting carriers off rail.
Back of detaching point, the rail is bent horizontally on easy curves so that the incoming bucket, running at high speed, will take curves smoothly. On outgoing side, the curve leading to attaching point may be a little sharper, as the carriers are pushed by hand or move by gravity and travel at a slower speed. The rail must form a loop large enough for carriers to clear the terminal machinery and the framing used for its support. Rail can be extended by switches and loops into as elaborate a system as desired, to reach loading and discharge points (see dotted rails in plan of Fig 32). Rail is often graded, so that parts of the run can be made by gravity. At a loading terminal for bulk materials, carriers are filled from bin chutes, and at discharge end are run over pockets into which they are dumped. Fig 32 and 33 show typical arrangements of terminals for tramways with grips opening at side, with horis curves to release traction rope from grip. Fig 34 shows a terminal for grips opening downward. In this the horis curves are not necessary for gripping operations, but are required for the carriers to clear the center post.
Quarry loading terminals may be designed to transfer buckets from tramway hangers to flat cars, for conveyance to quarry face. Larger rocks than those that will pass through bin gates, or material too sticky to handle in chutes, can thus be loaded directly into buckets. The loaded cars are hauled back to tramway terminal and the buckets replaced in hangers (tramway makers 1-8, Art 29). Buckets can be transferred from hangers to cars by running the ear track under tramway rail and grading track or rail so that the hanger hooks or unhooks from the bucket as required, when car and hanger are moved along together.

Transfer by a mechanical lift (maker 5, Art 29); see The Engineer, London, Oct 9, 1936. At loading terminal of a tramway transporting clay to brick works at Reading, England, buckets are hauled to the pit on cars and filled by an excavator. The cars have a platform movable vertically about 6 in by a lever. To transfer an empty bucket to a car standing beneath it, the operator raises the platform under the bucket and lifts it out of the hooks on tramway hanger. After loading, the platform is lowered so that the bucket trunnions again ride in the hanger hooks (Maker 6, Art 29).

Underground tramways and terminals. Where entrance to mine is by tunnel, with its mouth in steeply sloping ground, the rear part of the loading terminal has been built in an underground chamber below the tunnel, with an ore pocket at tunnel level.

At San Francisco del Oro mine, Mex, a bi-cable tramway extends 4,715 ft from discharge terminal at mill to a point where tramway makes a deflection angle of 67°, enters an adit, 3.5 m high by 4 m wide, and runs underground 3,000 ft to a terminal from which loops extend to 2 loading points at bottoms of old stopes lined with concrete to form storage bins. At one loading point the rails are hung from bottom of the bin; at the other, supported from the floor. From the terminal, the track cables are carried on rocking saddles, 30 m apart, resting on hangers suspended from 8-in channels concreted into hitches in the adit walls. The traction rope, free for full length of adit, is supported entirely by the buckets. Tramway cables are locked-coil, 1.5 and 1.5 in; carriers weigh 200 kg and hold 800 to 1,000 kg of ore, giving a capacity of 100 to 125 metric tons per hr. Traction rope is 3/4 in, plow steel; speed, 180 m per min. Buckets are filled by hand-operated chutes and coast to the terminal, where they are dispatched at proper intervals, travel to the angle station where they detach; then coast through structure and re-attach automatically. From mill terminal, buckets coast to bin, where a tripper is set, dump load, and run to return side. For a round trip, a bucket is handled by a loader and a dispatcher at each end terminal. Cost of operating the above and a feeder tramway for more than a year was 2.3¢ U.S. per metric ton per km; covering labor, power, supplies and rope replacements (14). Maker 1, Art 29.

Automatic discharge terminals can be built to return carriers without detaching them from the rope and without attendance. They contain a horis tail sheave, usually 12 ft diam, around which the traction rope travels and, parallel with it, a curved rail on which the carriers run. At the terminal, buckets leave cable and run on a rail, dumping in transit either when on terminal loop or when on cable outside of terminal; the carriers, preferably empty, pass around the loop and run off the rail onto the return cable. This eliminates labor at the terminal, but requires a large diam sheave, to which the speed of travel for whole line must be proportioned, to keep down the centrifugal action of the carriers in making the end turn. Tramway speed is 300 ft per min with 12-ft sheave and 500 ft with 16-ft sheave. Loading terminals are of the usual type (Fig 33, 34), including
TRAMWAY INSTALLATIONS

26–31

release of the carrier grips. Angle stations can be designed so that carriers will pass around them at low speed without being detached from the rope; but more carriers are needed than for the ordinary tramway, thus increasing direct stresses on the line. The grips must be designed to pass around the sheaves. These conditions increase first cost, but decrease operating costs. Makers No 1–8, Art 29.

Junction stations are practically 2 terminals placed back to back where divisions of a long tramway meet. An angle may occur between center-lines of the divisions without increasing cost of operation, and with only a slight complication of design. Fig 35 shows a junction station at an angle, which contains the driving machinery for one division and the tension sheave for traction rope of the other. The cables from one right-hand division are deflected and anchored; those from the other being stretched by tension weights.

17. TRAMWAY INSTALLATIONS

Ordinary tramways. Until about 1920, bi-cable tramways had capacities under 100 tons per hr; net loads seldom exceeded 2000 lb; carriages had two 8-in. or 10-in. wheels; many are still being built. Following examples are illustrative; see also Bib 18.

Argentine Government tramway, built about 1910, connects a mining field in Mejiaans Mte with smelter and RR at Chiloeito. Length, 34.3 km (21 miles); fall, 3 528 m (11 600 ft). As there are 6 divisions, each with its own drive and traction rope, the line consists of 6 independent tramways, connected by junction stations; at these the buckets, detached from incoming traction rope of one division, coast on rails to outgoing rope of the next and are there attached automatically. At several junctions the line makes horis angles. Control machinery for divisions is at junction stations, each division being subdivided into sections by suitable anchorage and tension stations for the track cables. Country is rugged, requiring rail trestles on crests, and long spans over ravines (2 of 258 m and 540 m); through one sharp crest is a tunnel 150 m long, 4.5 m wide, by 6 m high. All structures are steel. Capac of line, 40 tons per hr of ore down from mine, and 4 tons per hr up freight. Buckets hold 1 125 lb ore; speed, 510 ft per min. Track cables are both locked- and smooth-coil, 35–30 mm diam on loaded side and 25–20 mm on empty side (approx 1 1/2–1 3/4 in and 1–0.75 in). Cables are stressed by weights hung on wire ropes passing over sheaves. Cables oiled by traveling oiler (Maker 7, Art 29) (15). See Bib.

Spanish Peak lumber tramway transports lumber from saw mill in forest to plaining mill at Gray’s Flat, Calif. Length, a little over 5 miles. From loading terminal line rises 1 200 ft in 3 miles and then drops 2 100 ft to discharge terminal. Loads consisted of packages of lumber not over 16 by 32 in by 32 ft, containing 300–600 bd-ft, weighing about 1 250 lb; hung by chain slings from a carrier near each end. Nominal capac, 10 000 bd-ft per hr, about 15 tons. Loads were sent out every 3 min, spaced 1 242 ft apart. Lang-lay traction rope, 6/6 in diam, runs normally at 414 ft per min. Cables are locked-coil, 1 1/8 and 7/8 in. Running normally, line develops about 10 hp, but requires 20 hp when loading up empty line. It is controlled by two 24-in Pelton water wheels opposing each other; a governor admits water to forward-turning wheel when tramway slows down 5% below normal, and to reverse wheel when speed exceeds 5% above normal.

Tramway was built in 1918 by maker 1 (Art 29); in 14 years carried over 150 million bd-ft of lumber; idle 5 years and put to use again in 1935, by Meadow Valley Lumber Co, Quincy, Calif (16).

Consol Coal Co, W Va, installed a 3 400-ft bi-cable tramway for mine waste disposal. The first half passed over a summit and across a ravine with a clear span of 1 700 ft, from which buckets were dumped. Tramway operated by 1 man at loading terminal; the empty buckets detach automatically, coast to loading chute, and are filled from an air-operated under-cut rotary gate. Loaded buckets coast to an automatic dispatcher which released them at intervals to coast into an attacher, gripping them to traction rope. On the long span, the rotating self-righting buckets passed through a frame which dumped them automatically; they then went to outer terminal, passed around a horis sheave without detaching and returned to loading terminal, which contains driving and traction rope tension machinery. Outer terminal contained return sheave and tension weight for track cables. Buckets, hung from 4-wheel carriages, held 0.75 cu yd (2 000 lb). Traction rope, 2/6 in; driven 350 ft per min by 75-hp motor. Track cables, locked-coil, 1 1/8 and 7/8 in; tensions, 22 000 and 34 000 lb (Maker 1, Art 29) (17). Line had capac when built of 30 cu yd per hr, to be increased to 50 cu yd by adding more buckets and reducing the spacing from 525 to 315 ft, with 5 sec time interval.

Banguet Consol Mining Co, Philippine Is, has a 40 500-ft tramway with fall of 873 ft, in a straight line, driven by power as one unit; 0.75-in endless traction rope is nearly 10 miles long; buckets, 6 cu ft; capac of line 15 tons per hr; 8 spans are 2 770–5 180 ft long. Flat profile, grade in favor of loads and light tonnage, give a low traction-rope tension (Maker 1, Art 29).

Ribbit Tramway Co has built bi-cable tramways containing unique features. Northern Penn Mining Co has 4 interconnected tramways, connecting 3 mines with mill and smelter, so that ores, concentrates, smelter products and supplies can be sent to any point without reloading buckets. The system, 30 miles long, was put in operation in 1927. One division, 9 000 ft long, feeding smelter with coal and ores, has capac of 50 tons per hr; the others, 15 tons per hr. Track cables are 1/4 and 1 in plow-steel smooth-coil, and 1/4 and 1/2-in cast-steel locked-coil. Steepest incline, 35°; longest span, 4 351 ft. Traction ropes, all 0.75-in plow-steel Lang lay have speed of 500–550 ft per min; 10 motors, totaling 510 hp, start the line, but when running only 7 are needed, with total capac of 410 hp (11, 12). In Bolivia, a 6.5-mile tramway starts at mine at elev
AERIAL TRAMWAYS AND CABLEWAYS

14,000 ft, crosses summit of Andes at 16,000 ft and ends at concentrator at 9,000 ft. One span of 3,000 ft crosses a chasm so rugged that a 7-mile detour is required (11). At GLORETTA, N Mex, a tramway with capas of 50 ton per hr, has 2 divisions at an angle; junction station contains the controls for both; 1 span is of 4,000 ft. HYDE, Alaska, tramway is 11 miles long, in 1 unit. Unusual features: (1) a continuous traction rope; (2) 3 angles in the line, all deflecting in same direction; (3) braced deflection, 171°, so that the direction of travel at the ends is nearly reversed. Line has speed of 600 ft per min; was designed for capas of 15 tons per hr, which has greatly increased (12a).

Heavy-duty tramways. Since 1929, there has been demand for tramways of larger capas; an important recent application is in hauling aggregate for concrete at dam sites, the concrete being carried and deposited by cableways (Art 26). Bi-cable lines with capas to 300 tons per hr, have been built to carry 4,000-lb loads suspended from carriages with four 12-in. wheels. For rapid loading, a measuring hopper holding 1 bucket load, may be filled by a chute with under-cut arc gate; or, if material is coarse, by pan conveyor or vibrating feeder; hopper discharges quickly into the buckets, which can be dispatched at rate of 3 or 4 per min.

A typical plant was used on the PARDEE DAM, for water supply for San Francisco Bay cities. Length of line, 18,255 ft, total rise, 389 ft. One summit was 458 ft above loading terminal; near discharge terminal a cross was crosed by a span of 1,320 ft. Carriers were 32-cu ft end-dump buckets, holding 3,000 lb, hung from 4-wheel carriages; speed, 470 ft per min; spacing, 192 ft; time interval, 24.5 sec; capas, 220 tons per hr. Track cables, locked-coil, 1/2 in. and 1-3/8 in., except for river span, where they were 1.75 and 1-3/8 in. Cables of first division, anchored at loading terminal and at angle station, were stressed by concrete weights at a double-tension station about the middle of the second. Cables of second division, anchored at the angle station, were stressed at a tension station near the middle. The river span, with larger cables, was stressed independently from discharge terminal. All structures of wood. Traction rope, 7/8-in.; that for the first division was from angle station; for second division, from discharge terminal; each drive comprised a grip sheave and spur gear, driven by a 125-hp motor. Traction-ropes slack was taken up by floating sheaves at ends of each division. At loading terminal, empty buckets detached from rope loaded to the chutes, were chuted in 4 or 6 sec, and coated to the dispatcher, which held the bucket until the one ahead had traveled the length of the spanning; then released it to coast down grade to acquire the traction-ropes speed; the attacher closed the grip and the bucket departed. At the angle station, empty and loaded buckets, detached from traction rope, coated on rails between the divisions, and took the out-going rope of the other division. At discharge terminal, buckets coated across the bins, dumped while in motion by trip- pers, rounded the loop, gripped the outgoing rope, and began their return trip. All operations were automatic, supervised by 1 man (18). At CONCHAS DAM, N Mex, a bi-cable tram- way was built in 1937–8 to transport concrete aggregate. Region rather flat, favoring a truck road, yet contractor decided low cost of tramway operation more than offset its greater cost. Line crossed river with 1,085-ft span. High winds are common, but caused only slight delays to operations. To prevent freezing of wet aggregate in zero weather, steam was forced into load at lower terminal, preventing freezing in transit. The line was unloaded at night during cold weather; the bucket loads being reduced 1.5 cu ft successively until all were empty. Operating crew per shift: foreman, 4 men at terminals, and a lineman. Details of tramway are: length, 9,963 ft; rise, 235 ft; capas, 224 tons per hr; 36-cu ft end-dump buckets, with 4- wheeled carriages, were spaced 284 ft; net load, 3,600 lb. Track cables, 1/8-in. and 1-in. locked-coil. Traction rope, 7/8-in by 19 Lang lay plow steel; speed, 550 ft per min; interval between buckets, 28.8 sec. Driven from lower terminal and by 150-hp motor. At discharge terminal bucket turn around a 16-ft sheave without detaching (Maker 1, Art 29) (19). For details of other dam construction, see Bib 20–22.

Heavy-duty tramways have recently (before 1938) been built by Maker I (Art 29) as follows. U. S. GYPSUM Co, Alabaster, Mich. Line 6,800 ft long to dock in Lake Huron, to carry 260 tons per hr, with provision to increase capas to 300 tons, is carried on 8 towers 750 ft apart, built on crib in lake. PENNSYLVANIA-DIXON CEMENT Co, 1 mile long to carry 250 tons per hr. Line 3,412 ft long transports 200 long coal per hr in 62-cu ft end-dump buckets, hung from 4-wheel carriages. Having a fall of 150 ft, line runs by gravity, and develops 20 hp, which is absorbed by a 25-hp induction motor. Cables, locked-coil, are anchored at both terminals; stressed by weights at a double-tension station on the Cheat River, whence they make a clear span of 1,500 ft to discharge point and thence to anchorage. Buckets are loaded at a chute with air-operated under-cut arc gate, and are automatically attached to traction rope, hauled over the line and back to loading terminal where they coast to loading chute. Enroute they are dumped at the discharge point and returned around a tail sheave. Line speed, 450 ft per min; spacing of buckets, 195 ft = 26 sec time interval. Operated by 1 man, with another available for relief and chores at loading terminal (23).

18. COST OF EQUIPMENT AND OPERATION

Cost of a tramway comprises: 1. First cost of machinery. 2. Freight to the tramway site. 3. Cost of timber and foundation materials. 4. Distributing machinery and material along the line. 5. Framing and erection. 6. Installing machinery, including
cables, saddles, terminals, etc. 7. Superintendence and contingencies. If structures are of steel, cost of fabricated steel replaces cost of timber and its framing in items 3 and 5 above. Attempts to give costs are almost futile, as conditions and prices vary greatly, but the following discussion (repeated from 2nd Ed) will aid in estimating by indicating the items to be considered. See also the 1938 costs given below.

1. First cost of machinery for a bi-cable tramway of grip type, for average conditions and ordinary equipment, in 1926, was approx as follows:

<table>
<thead>
<tr>
<th>Table 6. Price and Weight of Machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capac. t ons</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Line machinery, including tower equipment, cables, ropes and carriers. Towers taken as 250 ft apart; line-speed, 500 ft per min</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

Machinery for 2 terminals, including all metal-work, but no motor or automatic regulator

<table>
<thead>
<tr>
<th>Price Wt, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4,000</td>
</tr>
<tr>
<td>$6,067</td>
</tr>
<tr>
<td>$1,667</td>
</tr>
</tbody>
</table>

Intermediate station machinery, motors, with solenoid brake, controller, transformer, oil switch, 500 r.p.m. and 1000-1200 v, cost per h.p.: 25 h.p., $50; 50 h.p., $32; 100 h.p., $24; 150 h.p., $20.

2. Freight by R.R., boat or team from maker's factory can be estimated from above weights and prevailing traffic rates. Hauling by motor truck on highway costs roughly 6-10¢ per ton per mile.

3. Timber and foundation materials are usually obtained locally. Timber needed: 2-in planks, 6-12 in wide; timbers 3 by 6 to 10 by 10 in.; a few beams and struts, for terminals and intermediate stations, 10 by 12 to 12 by 16 in. No timber need be over 30 ft long. Foundations should be of masonry or concrete.

Average conditions require an intermediate station every 4,000 ft, which may be assumed to contain the same material as an anchorage and tension station.

4. Cost of distribution is a local matter. Wt. of machinery and quantity of timber are stated above. Length of haul to destination depends on topography, and these data, with local charge for hauling, form basis for estimate; roughly, say 50¢ per ton mile, from freight terminus to last points accessible to motor trucks or wagons.

5. Cost of framing and erecting timber depends on local wages and quality of labor. An approx figure is $50 per 1000 ft B M for terminals, bins, intermediate stations and towers. Foundations, including excavation, approx $15-$20, per cu yd. Steel structures and towers cost in 1921-22, $0.5-6.4 per lb fabricated ready for erection.

6. Cost of installation varies greatly. Rough estimate is: for heavy cables, 3.5¢ per lb; light cables and traction rope, 5¢ per lb; machinery, 1.5¢ per lb. These figures include cost of distribution of machinery along the line, by dragging or sledding from end of truck or wagon haul.

7. Superintendence and contingencies may be figured as 20% of total estimated cost.

If a quotation is obtained on the machinery, the allowance for this item may be put at 30% on the remaining items of the estimate.

On a 4-mile tramway in Tenn, erected 1903, in rolling country, where all parts of the line were accessible for teams, and discharge terminal was near the R.R., costs per 1000 lb were very low (see accompanying table).

In general, cost of timber, framing and erecting the structures and installing machinery, on lines carrying 40 tons per hr and over, is a little under the price of machinery; on lines of less than 40 tons
per hr, a little over that price. Conditions under which tramways are built are so variable that it is difficult to specify averages; hence all the above prices must be taken as approx., and may easily be changed 25% by local conditions.

Quantities of material in structures, weights and costs of equipment and cost of erecting in 1927, were discussed and conclusions tabulated by Carstarphen (7). In 1938, a tramway engineer for an important maker furnished following figures.

Tramway costs: lumber, per M bd-ft erected, $80-$100; structural steel, per ton (2000 lb) erected, $100-$200; installing cables and machinery, per ton, $60-$70. Quantities of concrete in foundations: 25 to 30-ft towers (higher towers take more), 4 cu yd; anchorage and tension stations (2.5), 25-30 cu yd; terminals (min), 30-40 cu yd. For costs of construction and operation of tramways, see Bib 8a, 12a, 19, 24.

Cost of operating consists of labor, repairs, interest on investment and a sinking fund allowance.

Operating labor for a line carrying 50 ton per hr or less will be: 1 brakeman, 1 laborer at each terminal and an oiler half time if line is not over 2 miles long. On heavier lines, 2 laborers may be required in each terminal and the oiler would work full time. Oiler should travel over the line daily, inspecting machinery, tightening loose parts and making petty repairs; when his whole time is given, he may be the line foreman. Automatic regulators, or a power drive, will save the brakeman; on light lines, loader may act as brakeman; sometimes buckets can be dumped automatically and all labor at discharge terminal be dispensed with.

Repairs for first 2 or 3 yr will be light, due mostly to accidents; in 4th and 5th yr, all parts will show wear, and renewals may amount to 2% per yr on first cost; after 5 yr, repairs may be 5% per yr on first cost.

Carstarphen discusses comparative costs of hauling by truck and by aerial tramway, and concludes that only on short hauls (say 1 mile) and moderate tonnage (as 100 tons per day) are trucks cheaper than tramways (24).

OTHER TYPES OF TRAMWAYS

19. TWIN-CABLE TRAMWAYS

These, invented by W. C. Lawson, have carriers running on parallel track cables on same level. Carriers have 2 or more sheave-wheels on each side and are hauled by a single traction rope (Maker 3, Art 29); they resemble a system of cars running on rails and hauled by a wire rope. If tramway is continuous, there are 2 pairs of track cables, one pair over the other; loaded carriers travel on the upper cables and empties return on the lower. At each end, traction rope passes around a vert sheave 6 or 8 ft diam, and carriers leave track cables and travel on rails, which are curved at the ends to parallel the sheave circumference, and having a radius about 18 in greater than the sheave radius. As carriers stop at up and lower pair of cables, carriers are inverted for discharging; they return inverted to starting point and are righted in passing around the vert sheave at that end. As carriers are permanently attached to traction rope by clamps or sockets, they are filled while in motion by a mechanical loader, automatically drawing material from bin and measuring proper load. Speed of ropes must be slow enough to permit loading without spilling, and maintain a moderate centrifugal force at the curved ends. Fig 36, 37 show diagrams of terminals of typical automatic tramways (Interstate Equipment Corp).

Carriers may be attached to traction rope by grips; by detaching them, loading of other than bulk material is facilitated; but this eliminates some automatic features, and few lines have been thus designed. By detaching, return cables may be on same level and to one side of outgoing cables; carriers then return right side up, and may be used to haul back freight.

Towers are open through the center at their tops, and track cables are supported on rocking saddles attached to insides of tower posts, the carriers passing through towers and between saddles. Traction rope is supported on wide-faced sheaves, a little below clearance line of carriers.

Horiz angles can be turned by ending cables at a structure with curved track rails on which carriers travel and are hauled by traction rope as in a rope haulage system on the ground. After leaving the curve, carriers again run onto the cables. The curve must have a radius of 57 ft or more. As curve is horiz, the line speed must be reduced, or radius of curve must be large enough to prevent excessive centrifugal force.
Carriers for bulk material are usually shallow rectangular steel cars, of 10–60 cu ft capacity for different hourly tonnages and weights per cu ft of load. In dumping, a baffle plate causes the material to flow instead of being dropped; this prevents breakage in case of coal.

Track cables are either locked- or smooth-coil, 0.5–1 1/8 in in diam, and are stressed as on bi-cable tramways (Fig 15 and Table 1). On short lines, the stressing devices are at one end; on long lines, the cables are anchored or stressed at intervals of 2000–3000 ft, to preserve the desired tension.

Traction ropes are 6 by 19 hoisting rope, their size and grade depending on working conditions; 0.5 in to 1 in are common; safety factor of 5 should be used. The rope is made up of lengths equal to spacing of carriers with sockets on both ends of each length; sockets are then attached to bottoms of carriers by pins, and tension is applied by equipping an occasional carrier with special splicing devices. The splice carriers are spaced not more than 5000 ft apart, and have means for holding the traction rope in any position after being stressed to desired tension. When the rope stretches, the slack is taken up at a splice. When carriers are attached to traction rope by grips, traction rope is endless and slack can be taken up at a terminal by a sliding tension sheave. If loads cause very heavy tension in traction rope, it may be necessary to divide the tramway into sections, each dumping its loads into the bin of the following section.

Capacity. Lines have been built to carry 300 tons coal per hr, using 60-cu ft carriers running on 0.5-in locked-coil cables. Speed of travel directly influences capacity: it is usually about 400 ft per min (Table 8).
Table 8. Recent Twin-cable Installations

<table>
<thead>
<tr>
<th>Company</th>
<th>Horizon, ft</th>
<th>Material</th>
<th>Capacity, tons per hr</th>
<th>Fall, ft</th>
<th>Carriers, per min, ft</th>
<th>Speed per min, ft</th>
<th>Trac- tion type &amp; diam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Spring Mining Co, Cold Spring, Va</td>
<td>13,000</td>
<td>Mine run kaolin</td>
<td>30</td>
<td>650</td>
<td>9</td>
<td>360</td>
<td>5/8</td>
</tr>
<tr>
<td>Blue Diamond Co, Arden, Nev.</td>
<td>3,600</td>
<td>Mine run gypseum</td>
<td>80</td>
<td>700</td>
<td>20</td>
<td>400</td>
<td>3/4</td>
</tr>
<tr>
<td>Nephi Plaster &amp; Mig Co, Nephi, Utah</td>
<td>9,500</td>
<td>Mine run gypseum</td>
<td>75</td>
<td>700</td>
<td>18</td>
<td>400</td>
<td>5/8</td>
</tr>
<tr>
<td>Keystone Mining Co, East Brady, Pa.</td>
<td>2,200</td>
<td>Coal</td>
<td>170</td>
<td>300</td>
<td>18</td>
<td>400</td>
<td>1/8 &amp; 3/4</td>
</tr>
<tr>
<td>Anchor Coal Co, Highcoal, W Va.</td>
<td>1,500</td>
<td>Coal</td>
<td>180</td>
<td>240</td>
<td>20</td>
<td>420</td>
<td>1/8 &amp; 3/4</td>
</tr>
<tr>
<td>Bruise Smokeless Coal Co, Ouweg, W Va.</td>
<td>4,000</td>
<td>Coal</td>
<td>150</td>
<td>100</td>
<td>40</td>
<td>450</td>
<td>5/8</td>
</tr>
<tr>
<td>Stowe-Fuller Refract Co, Alexandria, Pa</td>
<td>5,000</td>
<td>Crushed stone</td>
<td>30</td>
<td>800</td>
<td>9</td>
<td>400</td>
<td>5/8</td>
</tr>
<tr>
<td>Koppers Coal Co, Kopperston, W Va</td>
<td>600</td>
<td>Mine refuse</td>
<td>100</td>
<td>300</td>
<td>20</td>
<td>400</td>
<td>3/4</td>
</tr>
</tbody>
</table>

*SC = smooth-coil.  LC = locked-coil.

20. REVERSIBLE TRAMWAYS

These, sometimes called "jig-back" or "to-and-fro" tramways, consist of: 1. One or two track cables. 2. Traction rope for carriers. 3. One carrier on each track cable, moved to and fro by traction rope. 4. Station at each end for operating machinery, and filling or dumping carriers. 5. Sometimes intermediate towers are used to support track cable and traction rope, but are disadvantageous, as they limit speed to 1,000 ft per min, while without them carriers may be run at 2,000 ft per min. Carriers drop automatically at discharge terminal; the machinery is then reversed and carrier returns on same cable. One man fills the carrier and operates the line. Made by all tramway builders.

Limitation. Cost of erection and operation is low, but capacity is limited by the reciprocating movement. With ordinary construction this limit occurs, with a 2-cable system, when product of tonnage per hr multiplied by distance in ft approximates 50,000; that is, a tramway 1,000 ft long can handle 50 tons per hr. With special construction much larger tonnages are carried. With a single-track cable, capacity is a little less than half the above.

Sizes of carrier and cable are governed by same conditions as other bi-cable tramways; the load must not cause excessive bending in the cable (Art 6, 6a), but, as loads pass at longer intervals than on a continuous tramway and therefore cable receives fewer bends per hr, heavier loads may be used, subjecting cable to more bending than on a continuous tramway. When loads must be heavy to secure tonnage, carriages may have 4 wheels. For a cheap plant, the track cables may be smooth coil, or, for temporary use, standard 7-wire strand rope.

Track cables are seldom weighted, but are made taut by turnbuckles or wire-rope tackles. The cable tension is judged by deflection of empty cable at center of span. For a single span with anchored cable and single heavy load, see discussion at Fig 45, Art 27.

Carriers, when there are 2 track cables with 1 carrier each, are clamped to traction rope so that one will be at loading terminal when the other is at discharge terminal; thus one is loading while the other is discharging. If there are no intermediate towers, the carrier hangers can be extended down from both sides of carriage, thus preventing carriers from jumping off the cable, and permitting higher speeds. At each end, in any case, carriers stop just before terminal saddles are reached, for loading and discharging. When loads are descending, the system will often operate by gravity like a gravity inclined plane. A reversible tramway may be operated with 1 track cable and 1 carrier. This is practically half a double system, and always requires power.

At loading terminal, when there are 2 track cables, they are sometimes brought close together, one above the other, so that a carrier on either cable can be loaded from one chute. Between the terminals the cables are far enough apart to permit carriers to pass each other. They may be brought close together again at the outer end.

Installations. The principle of reversible tramways can be utilized to transport very light loads to loads of several tons. In general, this tramway is the simplest and cheapest for moderate distances. Tonnage per hr is limited by long time interval between loads,
due to the intermittent action, and by size of the load. The time is fixed; size of load is the only variable, and when increased, the size of cable and strength of construction must be increased also, and an economic limit is reached if more than 100 tons per hr are carried.

Table 8a. Typical Installations of Reversible Tramways

<table>
<thead>
<tr>
<th>Capac., tons per hr</th>
<th>Material</th>
<th>Length</th>
<th>Net load, lb</th>
<th>Loads per hr, cap + wt</th>
<th>Time interval, min</th>
<th>Loading time, min</th>
<th>Speed, ft per min</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Coal waste</td>
<td>755</td>
<td>2 500</td>
<td>20</td>
<td>3.0</td>
<td>0.5</td>
<td>650</td>
</tr>
<tr>
<td>25</td>
<td>Coal</td>
<td>1 200</td>
<td>2 700</td>
<td>18.5</td>
<td>3.25</td>
<td>0.5</td>
<td>673</td>
</tr>
<tr>
<td>40</td>
<td>Coal waste</td>
<td>1 320</td>
<td>4 000</td>
<td>20</td>
<td>3.0</td>
<td>0.5</td>
<td>656</td>
</tr>
<tr>
<td>75</td>
<td>Coal waste</td>
<td>440</td>
<td>4 200</td>
<td>35.7</td>
<td>1.68</td>
<td>0.4</td>
<td>687</td>
</tr>
<tr>
<td>90</td>
<td>Coal</td>
<td>1 250</td>
<td>5 000</td>
<td>30</td>
<td>2.0</td>
<td>0.5</td>
<td>667</td>
</tr>
<tr>
<td>100</td>
<td>Coal</td>
<td>1 600</td>
<td>6 667</td>
<td>25</td>
<td>2.0</td>
<td>0.4</td>
<td>2 000</td>
</tr>
<tr>
<td>100</td>
<td>Coal</td>
<td>1 600</td>
<td>8 000</td>
<td>25</td>
<td>2.0</td>
<td>0.4</td>
<td>1 600</td>
</tr>
</tbody>
</table>

21. DESIGN OF REVERSIBLE TRAMWAYS

Fig 38 is a profile of a typical reversible tramway, with cables anchored at both ends; 1 tower; horis length, 610 ft; fall, 228 ft. Assume line is of double-cable type, to carry 20 tons per hr, aver 30 loads per hr. This requires a load every 2 min. Allowing 0.5 min for loading, running time per load, is 1.5 min. On the steep grade shown (37.4%), the inclined length of 661 ft, divided by time of 1.5 min, gives running speed of 434 ft per min, which is reasonable for this length of line. Net wt of load is capac per hr + number of loads, or 1 333 lb. Assume nearest size bucket is 15 cu ft, and that it might be loaded with 1 500 lb. Its empty wt (Table 9) is 500 lb. Assume traction rope weighs 0.75 lb per ft.

Track cables. Having chosen a load suitable for desired tonnage at a speed practicable for the length of line, the gross load = wt of carrier + net load + wt of traction rope hanging on carrier. As these can be closely determined and are not subject to increase, the size of track cable can be based on a load of 1 500 lb for each sq in of section for cast steel cable; then \( W + t = 1 500 + 34 600 = 0.0435; \) this is 25% more than is allowable for continuous tramways (Art 6, 6a), but this work is intermittent. Then, gross load + 1 500 = cross-sec of cable; this multiplied by 3.7 = wt per ft of whatever type of track is used, and by Table 1, the size of suitable track is found. If a light-weight rope is desired, one of higher grade steel but equal strength may be used. In this example, load is 2 250 lb; hence, \( 2 250 + 1 500 \times 3.7 = 5.55 \text{ lb per ft of cable, which corresponds to 1.5 in CS locked- or } 3_8 \text{ in smooth-coil cable.} \)

Path of load must be investigated. When cable is weighted, the position of loaded cable at different points is determined by Eq 13 or 19, but, when stretched by turnbuckle or tackle, and not weighted, position of loaded cable must be determined by method used for cableways (Art 27, Fig 45), because cable has fixed length, and tension is neither constant nor fully known.

Max stress in traction rope occurs when loaded carrier is on steepest part of line, which will probably be when it is at the top. Its size is determined by: Tension = \( (\text{wt loaded carrier} \times \sin \text{inclination of cable}) + wV + tw; \) in which \( wV \) comes from Eq 27,
and $t_w = \text{tension due to wt applied to sliding sheave}$. If the sheaves are large, the wear on rope will be mostly on its surface, and a 7-wire strand rope is suitable; for small sheaves, 19-wire strand should be used.

Fig 39. Loading Terminal, Double Reversible Tramway

On gravity lines, relation of operating force to resistance must be investigated at all points, with especial attention to conditions at discharge end, for there the slope of cable is flat and little power is generated, while the other carrier is climbing steepest part of its track and offers max resistance. Momentum of carriers may complete the trip after loaded carrier has ceased to generate power, but this should be counted on with caution, as it requires a skillful operator to run loaded carrier with sufficient speed to take it into its terminal and stop without undue shock. On flat inclines, or with a heavy carrier and slack cable, the lowest point in path of carrier may be at a distance from the discharge terminal, and momentum of carrier may not be sufficient to complete the trip. In such circumstances, this type of tramway should not be installed, or power should be provided to complete the trip of carriers; or, a large track cable should be used, so it can be stressed at higher tension and give a track more nearly approaching the chord.

Controlling machinery may be either brakes or a power drive. The drive must provide for stopping and for running in either direction.

Shifting belts are satisfactory for this reversing mechanism. They wear well, are simple and easily repaired. Band brakes may be double, with bands applied in opposite directions, so that one
22. REVERSIBLE TWIN-CABLE TRAMWAYS

These may have either a single or a double pair of cables (Art. 19). Twin track cables permit heavy loads. Carriers for bulk material are usually steel cars, with sloping bottoms, swinging end doors, and 2 or more wheels on each side, traction rope being attached near the wheel line; they dump into a bin at discharge terminal, or are dumped along the line (Art 25). Use of end doors gives a gradual discharge and avoids the upward snap of the cable caused by sudden dropping of the load.

Lines are in use with carriers to 125 cu ft cap, traveling at 1,500 ft per min over towers on pairs of 1 5/8-in locked-coil track cables and hauled by a 0.75-in 6 by 19 plow-steel rope (Maker 3, Art 29).

A heavy twin-cable type of single reversible tramway was built across the American River, Calif (13). Span, 2,600 ft, with approx horiz chord; four 2-in cables, 2 on each side of a cradle, carried a standard-gage freight car, which loaded with lumber weighed 58,000 lb. The cradle had 8 wheels on each cable, and was hauled at 1,500 ft per min by an endless rope (Maker 1, Art 29).

23. MONO-CABLE TRAMWAYS

These are also called ropeways and single-rope tramways. They comprise: (1) a single endless rope running around large sheaves at each terminal and over small supporting sheaves at towers; (2) carriers suspended at intervals from running rope; (3) terminal machinery for driving the rope and loading and unloading carriers. They are of 2 forms: (a) carriers permanently attached to running rope by clips; (b) carriers suspended from running rope by "box-heads" (see below) which ride on the rope and are detached at the terminals for loading and unloading.

Clip type. The clip consists either of a thin steel strap encircling the rope, or a steel forging inserted in the rope by slightly separating the strands. Due to this permanent connection, the carriers must be loaded while in motion; where they are small, this may be done manually with scoop shovels, but usually by a mechanical loader; at discharge end, the carrier latch is tripped automatically and load is dropped. One man attends to loading, and operates the control, if this is at the loading end.

The control, by brakes or a power drive, is attached to a grip-sheave at upper end (Fig 29). At lower end, the rope passes around a plain sheave with means for applying tension to the rope. These terminal sheaves are horiz and usually 8 ft dia; carriers passing around them develop centrifugal force, which is kept low by limiting speed to 180 ft per min. Towers have a sheave, 24-in diam at each end of top cross timber, on which the running rope travels. Where downward press of rope is heavy 2 or more sheaves mounted on a rocking beam are used to reduce bending of the running rope. To hold the rope down, sheaves can be placed above the running rope, but, as this adds a load to the rope, bending stresses should be small, and avoided if possible.

Angles in the line are made by deflecting the rope around sheaves of the same diam as terminal sheaves, but without releasing clips from the rope; the sheaves being arranged so that the carrier hanger never comes between it and the rope; the clip projects outward from the sheaves at all times. The rope on the convex side of the angle can be deflected by a single sheave, but that on the inside requires 2 sheaves; these are placed beyond the angle point and at different elevations, so carriers can pass over the other ropes.

Junctions between 2 tramways, where the running ropes turn around terminal sheaves, are made by the carriers of one line dumping into bins, from which the material is reloaded into carriers of the second line. The structure has practically 2 terminals, one above the other. The 2 lines may be at an angle without materially affecting the construction. Fig 41 shows the profile of a short line, and Fig 42, a general standard terminal; with slight changes, it can be adapted to nearly all conditions at loading or discharge end of line, or at junctions.

Limitation. These tramways give good service to a cap of 15 tons per hr, a length of 2 miles, and a difference in elev of 2,500 ft. For greater cap, length, or inclination, running rope becomes heavy and wear is excessive. The limited field for this type has resulted in its being dropped by makers in the US, although for a light line it is cheaper, in both first cost and operation, than any other tramway. They are still made by English firms 4, 5, 6 (Art 29).
Box-head type of tramway. A box-like casting, a few inches square and 10–20 in long, rides on the running rope and from it the carrier is suspended. There are 2 designs: (1) with a lug at each end, having corrugated V-shaped grooves in their lower ends to increase friction and prevent length-wise slipping (Makers 4 and 5, Art 29); (2) with a grip operated by wt of the carrier; one style (Maker 6) has a tong-like action which closes the jaws about the upper two-thirds of the running rope and gives a positive hold. Another (Maker 8) has a pair of rollers at each end of the box-head, the axes of which are parallel to the rope; the rollers are grooved to match the strands of the rope, each pair being contained in a chamber with tapering sides. When the box-head is set on the rope, the rollers mesh with the rope strands and the tapered surfaces cause them to grip the rope. Both styles are released at terminals, when the side wheels take the load. The box-head, of whatever design, has 2 wheels on one side. At a terminal, an angle or a junction station, a shunt rail is placed parallel to the running rope, a few inches from it and at such a grade that when the box-head wheels engage the rail, the box-head lifts off the rope and runs on the rail. The rail system can be arranged to suit conditions as for bi-cable tramway stations, and lead the carriers to loading or discharge points; or it may simply overcome a gap where the running rope is deflected or interrupted. The rail leads the carrier to the point where it is replaced on the running rope, by depressing the rail with respect to the rope (4). By grading the rail the carrier coasts to or from its stopping points and may sometimes attach itself to the running rope automatically. The rail, if long, may be replaced by a moving chain, which conveys the carriers at about one-third the rope speed across the gap to the attaching point on the running rope (Maker 4, Art 29).

Controlling machinery for the running rope is best located at highest point of the line and preferably includes a grip sheave (Fig 29); to which, for manual control, brake wheels are attached. For power drives or automatic control, the grip-sheave shaft is geared, or a bull gear is bolted to the sheave. See Art 14, 15 for data on power machinery applicable to mono-cable tramways.
Towers are usually pyramidal, of steel, with a cross beam at the top to support the sheaves. For light lines, 3-legged towers may be used; with 2 legs on a line normal to center line of tramway and 1 on the center line. The cross beam for the sheaves is attached to the first 2 legs. On moderately heavy lines, 4 sheaves in an equalising frame are used on the loaded side and 2 on the empty side. In case of a sharp angle over a summit, the tower is replaced by a structure carrying several groups of 4 sheaves each. On light lines, 2 sheaves may be used on the loaded side and 1 on the empty side.

Running rope is usually Lang lay, 6 strands of 7 wires and hemp center; a more flexible rope is sometimes used; rarely, one with wire-strand core. For severe service, plow-steel rope may be needed. Rope sizes are $\frac{5}{8}$ to $1\frac{1}{8}$ in. Initial safety factor should be 6, so that the factor will not fall below 4.5, after rope is worn. Bending stresses are reduced by high rope tension, and those due to large angle over a tower by multiple sheaves.

Installations. Some of the longest tramways yet built are mono-cable, made up of a series of sections operating in tandem (Makers 4 to 8, Art 29).

Examples. Hollinger Consolidated Gold Mines, Canada, has a 3.75-mile line, over flat country, driven by 100-hp motor; it holds the capac for mono-cable, of 190 tons per hr; buckets, 19 cu ft, run at 527 ft per min. During 1934, the tramway averaged over 162 tons per hr, while operating crew was on duty, including repairs. From 1927, when started, to June 17, 1935, it carried 5,758,634 tons. During a representative year, transport cost was (cents): loading buckets, 1.23; unloading, 1.56; operating (including power and maintenance), 2.1; repairs and replacement of cable, 1.6; total, 6.49 per ton. The running rope, replaced 1938, carried 2.5 million short tons (28). Maker 4, Art 29.

Tilmanstone Colliery, Kent, England, hauls coal to bunkers in Dover harbor (28). Line is over 7 miles long. Loading terminal is at elev of 198 ft; line rises to 357 ft, and drops to 80 ft. Capacity, 120 tons per hr. From bunkers, ships are loaded by belt conveyors at 1,000 tons per hr. Buckets hold 450 lb coal; running rope, 1.25 in; speed, 390 ft per min.; bucket spacing, 138 ft; time interval, 21.4 sec, requiring 60-68 hp. Line is in 2 sections: the first, 18,090 ft, is straight, from loading terminal to a control station at 286 ft elev; the second, to discharge terminal, 20,222 ft, contains 2 angles and passes through twin tunnels about 0.25 mile long. Two divisions were necessary, due to wt and length of the line. The control station contains the driving machinery and tension mechanism for both divisions. At this station and the 2 angle stations, the box-hedged leg of the running rope at incoming points and coat on rails to the outgoing point, taking the rope automatically. Total cost of tramway, about £120,000, or $15 per ft. Started, Feb, 1930. Operating cost at full capac, 9.4¢ per ton (Maker 4, Art 29).

Indian Copper Corp, Chota Nagpur, India, has a 31,050-ft tramway, over rolling country, with 1 hour angle to make a crossing normal to river with span of 975 ft (25) (Maker 4, Art 29). A single endless running rope, at light tension, serves entire line. When built in 1928, capac was 40 tons ore per hr and return freight, delivering 100 loads of 800 lb per hr; bucket spacing, 201 ft; time interval, 21.3 sec; running rope, 1 in, 6 by 7,000 ft long; breaking strength, 70,000 lb. Later capac was increased to 70 tons per hr in 1933, with larger rope. First rope carried 743,000 tons; second, 712,000 tons; replacement cost, 1.3¢ per ton. Operating cost for 1 month in 1931 (after line had been running 3 yr, single shifts), for labor, power, stores, repairs and supervision, 8.2¢ per ton, for 16,000 tons. Adding 1.3¢ for replacing first rope, total cost was 6.9¢ per ton. After company report gives cost of 5.5¢ for the entire line. Labor, all native at low wages, was approx 33¢ per man per day, 13 men and foreman being required.

Maker No 4 has also built tramways for Central Provinces Manganese Ore Co, India (97,650 ft), and Rahman Tin Mines, Malay States (7,600 ft).

Cost of materials for a mono-cable tramway, steel construction, in £ and English, 1938, is stated by one engineer as approx: (a) capac, 20 tons per hr; line material, $1.53 per ft; terminal machy and frame, $3.640. (b) capac, 100 tons per hr; line, $4.40 per ft; 2 terminals, $6.800.

Operating cost (stated in general terms by Harrison Roe, So Af Min & Eng's Jour, Aug 22, 1936) for either mono- or bi-cable tramways, about 2 miles long and carrying 15-150 tons per hr, is between 2¢ and 4¢ per ton-mile, at English wages. On short lines, cost is higher, as same labor is required and its cost distributed over fewer miles. On long lines, direct cost may be lower, but more obstacles may tend to increase cost.

General data. Longest mono-cable tramway yet built in one unbroken line is 31,200 ft (nearly 12 miles of running rope); capac, 55 tons per hr. In rugged country, practical length of a tramway, or a section, is about 3 miles. Spans to 3,000 ft can be operated where capac is moderate and tension in running rope is high, but these favorable conditions seldom occur together. Usually, a span of 1,000 ft causes severe stresses and is near the practical limit. In general, spans on bi-cable tramways can be longer than on mono-cable. Capac is limited to about 150 tons per hr by size and weight of running rope needed; max size in use is about 1 1/8 in; max speed, 400 ft per min. As heavy loads increase bending of running rope, the max is about 1,800 lb. Grades of 50% are possible, but 40% is about the practical limit.
24. DESIGN OF BOX-HEAD MONO-CABLE TRAMWAYS

The economic size of individual loads, determined by experience, is about 1% of hourly tonnage; with small capacity they may exceed and with large capacity may be under it. For lines carrying 10 tons per hr, loads are 350–400 lb and ratio is nearly 2% of hourly tonnage; for 100–150 tons per hr, loads are about 1 800 lb and ratio is 0.8–0.55%. Speed of running rope is about 400 ft per min; distance traveled per hr divided by number of loads gives the carrier spacing; see Eq 26 (Art 2), which reaches same result by different analysis.

For a tramway of moderate gradient, over rolling country where towers can be placed at short intervals, the running-rope tension at highest point determines size of rope; for tension due to loading, see Eq 29 (Art 2). As the wt per ft in the equation must include that of the running rope, the rope size is found by assuming a wt, say 1 lb per ft for lines carrying 20 tons or less per hr, and 2 lb for heavier tonnage. Total tension equals the above, plus half the wt applied to tension sheave at lower end, which may be taken as 10 000 lb, and a cast-steel rope with a breaking strength 6 times this tension is chosen. The actual wt of this rope is then used in Eq 20, giving a closer value for tension. By a few trials a suitable rope is found; if a rope of cast steel is too large, use a plow-steel rope. The tension wt at lower end must be such as to prevent excessive sag; it may be the only source of tension in the running rope for some distance from lower end. Here the need for large tension can be reduced by making the tower spacing less than at higher parts of the line. Tension varies from a max at the highest point to a minimum at the lowest. If rope is too small, there may be steep slopes at upper ends of inclined spans, exceeding those at which box-heads will hold. These slopes may be reduced by shortening the spans and holding the rope nearly up to its chord. Attempts to decrease sag by increasing the tension wt at lower terminal sheave adds to rope tension throughout the line, which must be considered. On clip tramways, steep slopes offer no difficulties from endwise slipping.

After the proposed profile has been plotted, the tramway can be laid out by methods analogous to those in Art 5, 6. The process is simpler than for a bi-cable tramway, as the running-rope tension is less for the wt carried than that of track cables; hence the rope can follow the topography more closely. The running rope is supported on each end of top beams of towers by 24-in sheaves, and, to limit bending stresses, the deflection over any sheave must be moderate. On clip-type mono-cable tramways, where running rope is 0.625 to 1 in, and tension is low due to light loading, one 24-in sheave is set on each end of tower beam; for larger tensions, one 36-in sheave, or a pair of 24-in, may be used on loaded side. On box-head tramways, the running rope and its tension are often large, so that the rope approximates the curve of sheave, if only one is used, giving high bending stresses. Hence a series of 4 to 6 sheaves, with equalizers is set on loaded side to distribute bending; fewer are needed on empty side. If a tramway makes large vertical angles over summit towers, 2 series of sheaves may be used; or, in a severe case, a summert structure with several clusters of sheaves may be substituted for a tower. Such structures are like Fig 26, except that the running rope and sheaves would occupy the top instead of cable and saddles. In making a large deflection angle over a sheave the rope tends to conform to the sheave, causing great bending stresses. But, with a small deflection the rope curve has a much larger radius than that of the sheave (see Sec 12). Thus, in a series of sheaves at 36-in centers, and a chord deflection of 2° at each, if the rope is assumed to bend to a uniform curve like a solid steel bar, the radius of rope curve will be 86 ft (Fig 12 and accompanying discussion). The total deflection angle between tangents to rope on both sides of a summit, divided by chord deflection angle between sheaves, gives the number of sheaves required.

Long spans. If the country is rough and a long span is needed to cross a depression, the tension required by this span influences the total tension. The tension in this span is found by transposing Eq 2 (Art 1) thus: \( t = \frac{wa^2 + 8h}{h} \), in which \( w = \) wt per ft of running rope, plus the uniformly distributed wt per ft of loads on span (see discussion of Eq 33, Art 6). If the long span has a steeply inclined chord, the tension formula must be modified as under "Horiz tension," Art 1. If the long span is near the upper end, its tension may not exceed that due to difference in elev between that point and the lower terminal; but, if near the lower end, the required tension must be supplied by the tension weight; this affects the whole line and may need too large a rope. If so, the line may be in 2 sections, one including the long span, the other having a tension due to its gradient and a moderate tension weight; or, it may be best to change to a bi-cable tramway.

Example illustrating design of a mono-cable tramway for 150 long tons per hr (4): horiz length, 8 125 ft; fall, 623 ft; max horiz span, 690 ft; permissible sag when loaded, 52 ft; assumed position of long span's lower end, 4 200 ft from lower terminal and 300 ft above it; gradient of span chord, 1 in 15; loaded carriers, 2 464 lb, spaced 140 ft, giving uniformly distributed load of 17.6 lb per ft;
SPECIAL APPLICATIONS OF TRAMWAYS 26–43

assume 1.25-in plow-steel running rope, at 2.7 lb per ft, breaking strength, 115 600 lb; then, total load is 20.3 lb per ft. These data, substituted in Eq 22 (Art 2), give slope of tangent to rope at lower end of long span, 0.2368, and at upper end, 0.3651, corresponding to grades of 15° 13' and 20° 13' respectively. The horizontal tension at any point of a rope curve, from Eq 17 transposed, is: \[ T = \frac{W}{\cos \alpha} \cdot \frac{1}{\sqrt{1 - \left(\frac{1}{a^2}\right) \cdot \left(\frac{h}{R}\right)}} \] where \( W \) = the weight of the rope, \( \alpha \) = 3° 49' inclination of chord, and \( a \) = deflection of driving, the horizontal tension, in long span is 23 284 lb. Rope tensions at ends of this span, by Eq 4 (Art 31), are: lower, 23 900; upper, 24 800 lb. From upper end of span to upper terminal, the rise is 277 ft in 3 235 ft horizon; this gives rope tension due to loading (Eq 29, Art 2) of 4 400 lb, which added to upper span-end tension gives max rope tension at upper terminal of 29 200 lb. As the rope's breaking strength is 115 600 lb, the safety factor is 3.96. For these conditions, the tension wt at lower terminal = \( 3 \times (23 900 - 4 400) = 29 000 \) lb. Note. In this example, of a tramway built in 1912, the author had to assume some data not given by Blyth (4), but the results are close to his final figures. The author believes the conditions are too severe for a single-rope line, and that a bi-cable, in which max traction-rope stress will not exceed 10 000 lb, would be preferable.

25. SPECIAL APPLICATIONS OF TRAMWAYS

In the U S, tramways are chiefly for long distance transport over rough country. In Europe, where industrial plants may be cramped for space, aerial transport leaves the ground free for other purposes. This fact has emphasized certain features less common elsewhere. The first cost of such installations is secondary to low operating cost, safety or effic. Industrial tramways must provide for loading and discharging at fixed points, which often results in angles, steep grades, and automatic loading and discharge.

Examples. (A) A complicated bi-cable system was installed at Imperial Chemical Industries, Billingham, England (29), comprising a main line, feeder tramway and several minor lines. Main line carries 170 tons per hr, plus 35 tons per hr from the feeder. Locked-coil cables are 2 1/16 and 1.25-in respectively; breaking strengths, 300 000 and 110 000 lb. Traction rope is 1/16-in, flattened strand; breaking strength, 58 000 lb; driven by an 8-ft triple-groove sheave, geared to a 60-hp motor. Buckets weigh 1 200 lb and carry 3 500 lb; they rotate for dumping when latch is released by trip, and are righted by a finger on the bottom, contacting with a spiral rail. Carriage have 4 wheels, wheel base, 3 ft 8.5 in (Maker 5, Art 29). At another part of the plant, 104 tons ore per hr are brought from a mine, and dumped at treatment points by a bi-cable tramway (Maker 5). Traction rope is driven from loading terminal, and the line contains 2 angle stations which the buckets pass without detaching. The cables terminate at the plant and the carriers travel on rails, though still hauled by the traction rope. The rail section is at an elev of 60-85 ft, to leave the ground unobstructed. To limit the number of structures, and to protect men working below from spill from buckets, the rails are supported by floored bridges of light trusses. Buckets dump automatically at a series of bins. (B) At a dynamite plant, a complicated tramway was installed to deliver explosive “dope” to any of 3 mixing houses (13). A carrier took the sidings at the desired point, as determined by a “selector” on its carriage, set by the dispatcher at the loading point. As the dope is highly inflammable, the loads are spaced far apart on the rope, to prevent fire from spreading in case of accident in any one building (Maker 1, Art 29).

Aerial dumping provides for dumping loads at any point along the line, by continuous or reversible tramways. On continuous bi-cable lines, a tripping device, set at any desired dumping point, is suspended from the track cable, has a finger to release the bucket latch and allows the load to drop. If the load is large, the tripper may be a sizeable frame, guyed to the ground to prevent the supporting cable from snapping upward when the load is suddenly released and so throwing the empty bucket off the line. When the tripper is to be shifted to a new position, a man goes out in a bucket, releases its clamps, slides it along cable and reclamps it. Maker 5 (Art 29) attaches a small wire rope to the frame, for moving it along the cable by a hand winch at one of the towers. On reversible tramways, a tripper like the above may be used; or a mechanism in the carriage trips the latch: (1) when a carrier has traveled a predetermined distance, a slow-moving disk with a crank pin pulls the latch, the disk being driven through gearing by a carriage wheel; (2) a device on the carriage comes into action when direction of travel is reversed, and releases the latch (Makers 1, 5, Art 29). The device is well adapted to single-rope lines. The reversal can be made manually, or automatically by switches controlling the current driving the motor. When done manually, a load can be discharged at any point, permitting the material to be stacked in different piles. With double reversible lines, the travel of loaded carrier harmonizes with that of the empty; the loaded carrier being at the outer end when the empty is at the loading chute. The dumping point can be at one point for a period and then moved (4). Maker 5, Art 29. With the mono-cable system, the tripper is suspended from a stationary rope stretched above the tramway, between 2 adjacent towers. The tripper frame has a supporting sheave to keep the rope and tripper in the proper relation for dumping. The towers carrying the stationary rope are extended
upward, and from them the rope goes to dead men or to a winch; the tripper can then be moved by shifting the rope.

Stocking ore. A Scottish iron plant has a bi-cable tramway (30, 31) (Maker 6). Ore from RR cars goes to a hopper, is conveyed to 2 storage areas, dumped into piles and reloaded by steam shovels into cars going to furnaces. The piles are 25 ft high and 50 ft base diam. One area is served by outgoing cable, the other by the return cable. From the loading terminal the cables rise steeply to two 45-ft towers, 125 ft apart, a cable going to each dumping area; there they terminate in 2 angle stations, connected by a cross cable. These stations have large sheaves to deflect the traction rope, with track rails for the buckets, which are dumped by tripplers. Buckets hold 4 000 lb; lock-coil track cables, 2-in; traction rope, 1-in; capas of line, 300 tons per hr. Buckets are filled and pushed into the running-ropes attached by 2 men; after dumping, they return, are detached automatically, and coast to filling chutes.

Dumping of waste material, as for building embankments, resembles stock-piling, except that the pile is constantly growing. If on level ground, guyed steel towers, thin or mast-like, as high as 250 ft, have been used. When they are buried in the pile, the line is extended on new towers (32). As such tramways usually run up hill, a power drive is needed (Art 14). DUMPING TRESTLES MAKE VERY HIGH TOWERS UNNECESSARY. A tramway is built to the dumping terminal; the buckets run onto rails on a lattice truss trestle, inclined upward at angle of repose of the waste (say 36°). At end of trestle is a large return sheave for the traction rope, the buckets dumping as they pass around it. The trestle is extended as required (Makers 8 to 8, Art 29). Dumps have thus reached heights of 500 ft. For waste disposal, several types of tramway are suitable: twin-cable (Art 22), single- or double-reversible (for moderate tonnage and distance) (Art 20), and mono-cable (Art 23).

Loading ships with bulk material. Where ships cannot be docked, tramways are sometimes used. The discharge terminal may be built on bison on an island-like wharf, where water is deep enough for ships; the intermediate towers being on pile foundations. From the bine, the ship is loaded by belt conveyor or other means (Makers 1 to 8, Art 29).

Freight tramways for bulky materials, built as adjuncts to RR's, to carry goods over difficult topography, must be designed for necessary clearance over summits. Carriers are buckets, crates, tanks, hanging platforms, or chain slings for barrels, lumber and pipe (Makers 1 to 8, Art 29).

Passenger tramways. On ordinary tramways, 2 persons are carried in long buckets, sitting facing each other. Some Rocky Mt. mines have no other means of transport in winter.

Special passenger tramways. About 50 have been built from 1912 to 1936 by Makers 7 and 8, for various services, chiefly in mountainous regions. Most of them are of double reversible type (Art 20), with 1 car suspended from each track cable; cars hold 20–35 persons; grades, up to 50%; carriages have 8 or 12 wheels, with equalisers to distribute the load; speed, 100–300 ft per min. A double reversible passenger line of Bleichert design (Maker 1, Art 29), began operation in 1936 on Cannon Mtn, N H; hors length, 5 000 ft, 3 tracks; rise, 3 022 ft; cars, hung from 5-wheel carriages ending 27 persons; running time, 5.5 min; locked-coil track cables; terminal sheaves for running rope, 13 ft diam; shock absorbers reduce force and aff oscillation and brakes seize running rope in case of accident. There is an auxiliary rope and mechanism to land passengers from a sailed car. Similar Bleichert and Pohlig tramways have been built in the Tyrold and Swiss Alps.

CABLEWAYS

26. GENERAL DESCRIPTION (see also Sec 5)

A cableway comprises: (a) fixed track cable; (b) carriage running on cable; (c) hoisting- or fall rope, to raise and lower cable by tackle suspended from carriage; (d) hauling rope to move carriage back and forth; (e) 2 towers; (f) hoister at head tower; (g) carriers of various types. Fig 43, 44 show typical designs.

Track cables are up to 3 in. dia, locked coil, cast-steel, or plow-steel where load stress is great. At each end is a swivel socket, for turning the cable to distribute the wear from carriage wheels. For cables 2 in. and over, ball-bearing sockets are used at one end, cable is anchored; at other end, a take-up tackle provides tension.

Carriages for light loads have 3 track wheels; for heavy loads, as many as 8, mounted in equalising frames, which also carry the head-block sheaves for hoisting and dumping tackles, provide connections for the hauling rope, support the button rope, and carry the tower horn for collecting the fall-ropes carriers. On large cableways, 6-wheel carriages operate in tandem, with considerable space between them, one being rigged with the hoisting tackle, the other with the dumping tackle; this distributes the load on the cable, and checks the swinging of the carriage when brought to a stop.

Hoisting ropes are cast- or plow-steel, 5/8 in, with 6 strands of 19 wires; wear on rope due to bending is kept low by using large tower sheaves. The rope runs from drum to the head-tower sheaves, thence through the fall-ropes carrier, over the carriage sheaves, around fall-block sheaves, and ends at the carriage. The tackle is usually reeved, so that 6 parts of the rope carry the load. The fall-ropes carriers support the rope at intervals, to
prevent undue sagging when there is a light load. The rope-supporting system consists of a stationary button-rope, on which are placed buttons of different diameters, increasing in size toward the tail tower; the carriers being fitted with rings of correspondingly increasing sizes, through which the button-rope passes. These carriers are stored on the horn on the tower end of the carriage, the one having the largest ring being next to the carriage. As the carriage travels from the head tower, the first button passes through all the rings except the outer one, which is smaller than the button; this pulls the carriers off the horn one by one and sets them on the cable. On the return trip, the carriers are picked up by the horn, and kept ready for next trip.

The entire load sometimes hangs from the fall block and is dumped or detached manually; or, when the skip is dumped mechanically, the main fall block is attached to a chain bridle on the open end of skip, with a second block on the rear end, which is raised by a dumping rope. In the latter case, the dumping rope goes back to a third drum on the hoist. Drums, ropes, and tackles for hoisting and dumping are identical, and operate in unison until a skip is to be dumped, when the speed of one line is slowed by a clutch and brake on that drum, and skip is tilted. The 2 fall blocks permit handling extra heavy loads, by attaching both to a single load.

Hauling rope has one end linked to near end of carriage, passes to sheave on head tower, then down to make several turns on a concave-faced drum on the hoist; returns to head tower sheave, passes above the track cable to top of tail tower, thence around a sheave and back to the carriage. The rope is usually the same size as the hoisting rope, but has less bending stress, and may be of larger wires, to withstand surface wear due to slippage on drum.

Towers at each end support the entire equipment and must be high enough for loads to be hoisted to the elevs desired at any point. Stationary towers are often 150 ft and movable towers 100 ft high; usually of steel. Contractors prefer steel, with bolted connections, so the towers can be taken down and re-used. For stationary towers, the cables are anchored back of the tower (Fig 43). When the back cable has the same slope as the normal main-cable slope, the resultant stresses are nearly vertical, and a 4-leg pyramid tower is suitable. Sometimes guyed A-frames or masts are sufficient. Movable towers are used when the cableway must be moved at intervals, to serve a large area. They are usually steel, mounted on platforms on railroad-like trucks, with wheels on multiple tracks. As they can have no anchored back stay, the cables terminate at the towers, which are designed to take the horis tension. This has developed a tower design (34) with vert back legs in tension and inclined front legs in compression; a massive weight being placed close to the vert legs (Fig 44). Towers are moved by a winch in lower part of rope, anchored at both ends, as given a few turns on the winch drum, and the tower pulls itself along the rope. For heavy cableways (as at Conchas Dam, with 1 650-ft span) each tower has 2 motors, geared to 4 of the supporting wheels.

Movable cableways are of 2 kinds: (a) both towers travel on straight tracks; (b) 1 tower is stationary, the other moving on a circular track, with the stationary tower as center of arc. When both move their winches are operated in unison by a switch in head tower; rate of travel, 50-150 ft per min. At Norris Dam, 2 cableways (spans, 1 925 ft) cover an area 800 ft long in their travel (36).

Hoist comprises: (a) hoisting drum, holding the rope in one layer; (b) hauling drum, having wide enough face for the rope, with several laps, to travel to and fro across it (for light work; a capstan-like drum is used); (c) dummying drum; (d) small auxiliary drum for moving towers. Hoisters are elec-driven; controlled like elec hoisting engines (Sec 12).

Carriers. Skips are used for excavated material; chain or wire-rope slings for large rocks, quarried stone, or heavy equipment; bottom-dump buckets, sometimes as large as 8 cu yd, for depositing concrete.

27. DESIGN OF CABLEWAYS

Data required: 1. plan and cross-sections, or contours, of volume to be excavated, the sections showing probable max depth of excavation; 2. position and elevation of discharge points; 3. kind, size, and wt per piece, or per cu ft, of material to be handled; 4. quantity handled, tons per hr; 5. nature of power to be used.

Weight of load sometimes depends on size of individual pieces or units. In stripping it is usually determined by quantity of loose material to be handled per hr, although wt of single blocks of stone may be the controlling factor.

Time between loads is time to hoist load, transport and dump it, return empty skip to pit and change connections to a loaded skip. Speed of hoisting is usually 300 ft per min,
but may be up to 400 ft; lowering time is usually less than for hoisting; with regenerative braking, speed can be one third greater. Max speed of carriage along cable, 1 800 ft per min; usually, 1 200 ft. Max distance hauled is about 80% of span; aver distance, rarely more than 60%. Hence, time per load = \( \frac{2 \times \text{depth of pit} + 2 \times \text{distance hauled}}{\text{hoisting speed} + \text{hauling speed}} + 0.5 \text{min, the last item being allowance for changing and dumping. Round trips are often made in 2 or 3 min. As cableways are intermittent conveyors, with limited max speed, large tonnage can only be handled with large loads.}

Size of cable depends on gross load, span and allowable deflection. In beginning a design, assume a deflection of 0.05 of span, when load is at center; if this deflection gives towers of reasonable height, it is adopted and tension in cable is found by solving Eq 14 (Art 2) for \( t \); but, as both \( w \) and \( t \) are unknown, see Table 1 for the relation between them; \( w \) can be expressed in terms of \( t \). For 1.5 to 2-in locked-coil, cast-steel cables, \( t = 9 300w \) (approx); for 2 to 3-in plow-steel, \( t = 12 500w \), when the minimum safety factor used is 3.5. If the 5% deflection requires undesirably high towers to clear obstacles, the tension is increased by using: (a) larger track cable; (b) cable of higher grade steel; (c) a smaller safety factor, unless the minimum factor of 3.5 has already been used in the trial calculation. This factor is small, but sufficient where the max load is definitely known, because, the strength of cable is accurately determined and not subject to shock loading. Also, a taut cable suffers less from bending under the wheel load than a slack one. On long spans, the deflection increases faster than the span, due to wt of cable (see Eq 14), and it is often 0.06 or even 0.065 of span; on short spans, it may be less than 0.05, if load is light and cable taut.

Tension tackle for track cable is of wire rope; it must be long enough to connect socket on end of cable with the anchorage, when the cable has been drawn near to final position with ordinary tackle. At first the tension rope is passed over only part of the tackle sheaves; then, as cable becomes tighter, the rope is threaded over the others for the final pull, and is clamped; it may be pulled by a winch-head on the hoister, or by a special drum.

Path of load. Tension is max when load is at lowest point, and decreases as load moves either way. This variation is unknown, hence the equations of Art 1 for deflection, which involve tension, can not be used for determining deflection with load at various points. Path of load may be found approx by assuming that the two supports \( A \) and \( B \) (Fig 45) are the foci of an ellipse. Then lines \( AC + CB \) equal the major axis, and the ellipse can be calculated. If origin \( C \) be at center of span, and \( OC \) be deflection due to wt of cable and concentrated load at center, then \( OC = H \) (Eq 14, Art 2) = the semi-minor axis, while \( CB \) = the semi-major axis of ellipse. The ordinates of any point \( P \) are \( x \) and \( y \). The equation of an ellipse referred to its center is:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1
\]

But \( b = H \) and, from Fig 45, \( a^2 = H^2 + (H^2 + 4) \); hence, by substituting a series of values for \( s \), corresponding values of \( y \) can be calculated and path of load determined for a number of points. If \( s \) be distance of load from end of span, the deflection at the load is \( y = s \tan \alpha \), which gives slope of chord \( AP \) when load is near tower, and this is practically the slope of cable. From last expression, or from path of load, it is seen that the cable becomes so steep, as load approaches either tower, that it is not feasible to run the carriage within 10% of the span from either tower.

This method of finding path of loaded point assumes that the sum of the 2 chords \( AP \) and \( PB \) is constant for all positions of load, which is not quite true. As load approaches tower, the long section of cable will sag and raise the load a little higher than position indicated by Eq 39. The deflection is further decreased by the pull of hoisting and hauling ropes, which take a varying part of load in holding carriage on the inclined part of cable. These errors are all on safe side, as path of load is usually ascertained to make sure that the load will clear some object. The same problem occurs with single heavy loads on reversible tramways (Art 21). Bib 10a treats of cable spans and length of curve when stretch of cable is included.

Towers on stationary cableways are designed chiefly to resist the vert resultant of the cable tensions; those for movable cableways have a base, parallel to line of cableway, of approx halt the height. Hence, to overcome the pull of the track cable and other ropes at top of tower, a balance weight of more than twice these tensions is required at rear of the tower to resist rotation about lower end of inclined front leg. Towers must also be designed to resist a moderate side pull, if cable system is out of line, and to resist wind press acting on the tower and on the half span of cable and ropes. For towers of movable cableways, these side forces require additions to the weights on the bases. These weights are usually precast concrete blocks, which can be removed when towers are dismantled.
Examples of cableways. Advances in practice began about 1910, with 2 plants at Gatun Locks, Panama Canal: span, 800 ft; cable, 225-in.; load, 6 tons; 85-ft steel towers on parallel tracks; also hoist, 150 hp; traveling speed, 1,000 ft per min; hoisting, 335 ft. U.S. Reclamation Serv, N Mex, 3 plants: span, 1,200 ft; loads, 10-15 tons; also hoist, 300 hp. Buffalo Filter Plant, N Y, built 1925. Two spans, 600 ft; load, 15 tons; 85-ft towers, on parallel tracks, traveled 150 ft per min by engines in towers. Mannen Dam plant, Canal Zone, built 1935, marked further progress in heavy-duty work: span, 1,250 ft; gross load, 25 tons; buckets for concrete, 6 cu yd, 20 tons gross load; rock skips, 10 cu yd; cable, 3-in locked-coil; 2 carriages ran tandem, each on 6 wheels, with equalizers; 3-drum hoist, driven by 400-hp motor; traveling speed, 1,200 ft per min; hoisting, 300 ft. Steel towers, movable 410 ft by 100-hp motor, were on 32 wheels, in 4 groups, with equalizers, running on 2 tracks, 80 ft apart, at 56 ft per min (20, 21). All the above installations were built jointly by Makers 1 and 12 (Art 29).

From 1932 to 1938, 9 other plants were built for 25-ton loads; and 8 for 15 to 20-ton. Largest of these were 2 spans of 2,575 ft for Hoover Dam, Ariz. Hoist driven by 500-hp motors; 3 tandem drums, 53-in by 70-in face. Traveling towers moved at 50 ft per min by a concave-face winch drum in each tower, geared to 100-hp motor, and controlled from head tower to run in unison. On upper deck of each tower were 2 50-cu ft compressors for operating brakes and clutches. Tandem 6-wheel carriages, 40 ft apart, were used, preventing oscillation of buckets due to the long drop of 700 ft; hoisting and dumping lines were 3/8-in plow-steel rope, running through a 4-part tackle; roller bearings for all tower sheaves and fall blocks. Track cable, 3-in locked-coil, had 6% deflection with load in middle of span; it terminated at tail tower in swivel sockets for turning, to distribute wear, and was tightened by a 10-part take-up tackle, with 1.5-in rope. On this dam were 3 other similar cableways, with shorter spans (34, 35). Norris Dam, Tenn, has twin cableways, each for 18-ton load, but can be combined to lift 36 tons; spans, 1,928 ft; 3-in cables; towers movable (36). Boullion Dam, Ariz, cableway was designed for 150-ton load (largest on record). Span, 1,250 ft; loaded RR cars can be lowered from canyon rim to the bottom, about 600 ft below dam. Track cable consists of 6 super plow steel, 3.5-in Lang lay ropes (6 x 37), with wire centers, placed at 18.5 in centers. Carriage has 48 wheels, 24 in diagonal, 8 on each cable. Hoisting is done by 2 super plow steel 1/4-in ropes, with hemp centers, each reeved through twin fall blocks, to make 2 5-part tackles to an equalizing frame from which load is suspended. Hoisting ropes wind on 2 drums, 15 ft drum by 17 ft face, each driven by a 175-hp dc motor, but operating in unison. Two hauling ropes, same as hoisting ropes, wind on a third drum, geared to a 400-4c motor. Speeds: traversing, 240 ft per min; hoisting, 120 ft for loads under 40 tons and 30 ft for heavier. Towers: a 100-ft 4-leg steel tower at one end, with tension take-up; at other end, a steel and concrete saddle; at both ends, the cable is anchored in concrete, which fills a 60-ft tunnel. Cableway is a permanent equipment for the power plant (37).

All of above installations were supplied jointly by Makers 1 and 12, Art 29.

28. OTHER FORMS OF CABLEWAYS

Light cableways are used for sewers, subways, and similar long, narrow, shallow excavations (Fig 46). Towers are single A-bents, 25-40 ft high; whole plant designed for portability. After an excavation has been made for length covered by 1 span, plant is moved ahead for another section. Spans about 300 ft long and fall rope carriers usually dispensed with, as empty bucket keeps hoisting rope taut. But if loads are hoisted near center of span and run to tail tower, a single-fall carrier may be run out on track cable and fastened by a chain dropped to the ground. It is set where it will not interfere with carriage, but will hold up center of hoisting rope when carriage is at tail tower.

Equipment. Machinery for a portable cableway for a net load of 2.5 tons on a 300-ft span consists of: 1.5-in cable, with anchorage and take-up fittings; 1/8-in hoisting and hauling ropes; carriage with 12-in wheels and 16-in sheaves; fall block with 16-in sheave, to give a 2-part tackle; 2 fall rope carriers; 1 cu yd self-dumping and self-righting tube, 48 in wide by 46 in long by 31 in deep; 30-hp reversible hoist, cylinders 8.25-in diam by 10-in stroke, drum 24 in diam by 26 in face, hauling drum 25 in diam in concave face; vert tubular boiler, 42-in diam by 90 in high; engine car with 10 by 16-ft timber platform, housed and mounted on four 15-in wheels; 180 ft of 22-lb T rail; 2 towers of 8 by 10-in timbers, 40 ft high, with 1-in galvanized guy ropes. Engine and boiler can be replaced by also hoist.
OTHER FORMS OF CABLEWAYS 26-49

Capacity. These plants will hoist net load of 2.5 ton at 225 ft per min, and convey it at 450 ft per min. If tubes are loaded in a trench, 30-40 loads can be handled per hr.

Operating cost. Labor: 1 engineman, 1 firman (if steam-driven), 1 signalman, and 2 dumpmen, when loading wagons or dumping into a hopper. One man can dump buckets when machine is back-filling rear end of trench. These cableways can be moved in 2 or 3 days with good organization, if new anchorages (deadman and slings) are set in advance.

Force: 5 laborers, 1 handy man, and part of foreman's time.

Semi-permanent cableways have towers, A-frames, or masts of wood or steel. Track cables, 8 by 7 standing rope or locked-coil cable; anchorage is weighted with rock or concrete blocks. Hauling rope is 0.8 in. or larger, with fall-rope carriers of button type. Carriage may have 3 track wheels, and, with fall-block, make a 2 or 3-part tackle. Buckets are bottom-dump, or skips with knock-off at open end; tripped by hand, or mechanically by a clamp on hoisting rope above the fall-block, or by an arm on the carriage; either device engages a lever on the skip and releases the load. Hoistmen are run by steam, oil or elec (Makers 12, 13, Art 29). These inexpensive cableways are applicable where heavier plant is not warranted.

Inclined cableways (“Blondins”) have a high head tower at discharge end and a low one at other end. The carriage is held at loading point by an endless rope, passing around a brake sheave at head tower; this sheave acts as the fall sheave. While the carriage is in any position, when loaded, the carriage is hoisted with the brake on the holding rope sheave is released and the hoisting rope pulls carriage up the inclined cable. At discharge point, the carriage is held by a “gate,” while the load is dumped and empty skip hoisted to the carriage again. On raising the gate, the carriage returns by gravity. As one rope does both hoisting and hauling, resistance to hoisting with a 3-part fall must be less than hauling resistance; hence, the fall-block stays against the carriage during hauling. This requires a grade of about 29% in the cable, and limits this type to short spans and favorable conditions. None of these cableways are applicable to cases requiring mechanical excavation before transport.

Grab-bucket type (with clam-shell or orange-peel bucket) operates with regular equipment (Art 26), except that an extra hoisting rope and drum are needed, with extra sheaves in towers and fall-rope carriers. As resistance to lifting the bucket out of the soil after filling adds to the load, heavier cables and operating ropes are needed than when digging stresses are absent (Maker 12, Art 29). Another type of grab bucket operated by one fall rope has been adapted to cableways having grade of 10°-15°; fall rope hoists carriage and load, up grade, the return being by gravity. This outfit is limited to about 500 ft max span. The carriage is latched to main cable stop, attached to cable at loading and discharge points and the fall block is hooked to carriage when fully raised. Dumping is automatic. After dumping, the bucket is hoisted until fall block hooks to carriage and unlatches latter, when it is free to return by gravity, latches to stop which unhook fall block which descends for a new load. Carriage thus shuttles between 2 stops, the position of which may be altered.

Stacking and reloading can be done with cableways and grab buckets. Usually, one man can operate the cableway. With stationary towers, a long narrow pile can be stocked; if tail tower travels on a curved track, so cableway can take various radial positions from head tower, a triangular pile can be made; if both towers travel on parallel tracks, a rectangular pile of any length can be stocked. These cableways usually have spans of 500-1 000 ft (Maker 12, Art 29).

Existing plants have following features: (a) Span, 420 ft; 3.5-cu yd clam-shell bucket; capa, 225 ton per day of hard and soft coal; max 1 000 ton; both towers travel. (b) Span, 396 ft; 3.5-cu yd clam-shell bucket; max 225 ton per hr, when stocking and 175 ton when reclaiming; max 2 200 ton coal in 9 hr. Head tower is stationary, and 216 ft high to permit bucket to clear obstructions; tail tower, 90 ft high and travels on a curved track. Due to conditions, operator is at a distance from head tower and runs elec hoist by distant control. During 1924-25, it handled 288 000 net tons, cost for labor, power and lubrication, 3.5¢ per ton. (c) Span, 725 ft; 3.5-cu yd clam-shell bucket; aver capa, 225 net tons per hr. Towers travel on parallel tracks. Total cost for handling first 200 000 net tons, 1.77¢ per ton.

Slack-line cableways are used to strip orebodies or coal seams near the surface (Sec 10), reclaim mill tailing for retreatment, build earth dams, and dig canals (Sec 3). They comprise a track cable, a carriage from which a skip-like scraper is suspended, hauling rope, high head tower and low tail tower, and a drum on hoister for rapidly varying the track cable tension. Spans, usually 300-1 000 ft. Towers may be fixed; or tail tower movable, for a triangular area; or both towers movable, to serve a rectangular area. Speeds: for digging, 100-200 ft per min; hauling, 300-600 ft. Economical loads: 1/3 cu yd for 300-ft span, to 3.5 cu yd for 1 200 ft; digging depth may be 50-100 ft below water line, with total lift of 150 ft or more. Some large plants handle 10 to 15 cu yd loads (38, 39).

In operation, by slackening the cable, the carriage runs down by gravity until the scraper reaches the loading point; the hauling rope then pulls scraper toward head tower, and when filled the cable is tautened to lift the scraper and simultaneously the hauling rope pulls it to dumping point, where the carriage engages a stop on the track cable. Thus, one operation digs, conveys, elevates and dumps, and at less cost per cu yd, than any other means; all controlled by 1 man at head tower (40, 41). These cableways are long-distance excavators, useful where material is to be delivered at a high point, or which a drag-line (Sec 27) is not applicable. By adding an out-haul rope, they can work with a flat span, the load being dumped near tail tower.
AERIAL TRAMWAYS AND CABLEWAYS

20. MAKERS OF TRAMWAYS AND CABLEWAYS

1. American Steel & Wire Co, 350 Fifth Ave, New York: bi-cable tramways, passenger tramways, wire rope, track cables
2. Riblet Tramway Co, W 20 Main Ave, Spokane, Wash: bi-cable tramways
3. Interstate Equipment Co, 18 W Jersey St, Elizabeth, N J: twin-cable tramways (Lawson type), bi-cable tramways, successors of Broderick & Bascom
5. British Ropeway Engineering Co, 14 High Holborn, London: bi-cable tramways (Bleichert type), mono-cable tramways, cableways (taut and slack-line)
6. R. White & Sons, Widnes, Lancashire, England; waste disposal plants, mono-cable tramways, bi-cable tramways, movable dumping treaties
7. Bleichert Transportanlagen, Leipzig, Germany: bi-cable, mono-cable and passenger tramways, cableways (taut and slack-line)
8. J. Pohlig Aktiengesellschaft, Köln, Germany: bi-cable, mono-cable and passenger tramways, cableways
9. Cerretti & Tannias, Milan, Italy: tramways and cableway (in use, but present manuf acturing activity uncertain)
10. John A. Roebling's Sons Co, Trenton, N J: tramways and cableways designed for specific projects, wire rope
11. Monorail wire rope makers build occasional tramways or cableways of moderate capasities
12. Lidgerwood Manuf Co, 775 Lidgerwood Ave, Elizabeth, N J: taut-line cableways, hoisters
13. Steuerman Bros, 438 S Clinton St, Chicago: taut-line and taut-line cableways, hoisters

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9a. Part 2 of No 8, Ind Cire 7093, Feb, 1940, on costs
9b. Trade publications of makers, listed in Art 26

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13. Morrison, M. P. Application of Aerial Tramways to Long and Short Hauls. Trans ASME; pub in Mech Handling Sect of Trans, Jan.-April, 1930. Describes several installations with photos and line drawings
23. Morrison, M. P. One-man Aerial Tramway. Coal Age, Feb 1928, p 88
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29. Aerial Ropeways at a Chemical Works. The Engineer, London, July 1, 1932

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31. McCook, W. W. Some Notes on Handling of Raw Materials for Iron and Steel Works. Trans West of Scotland Iron & Steel Inst (description of same plant as Bib 30)

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Descriptive Articles on Cableways (see Bib 20, 21)
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35. Nelson, W. R. Construction of Hoover Dam. Compressed Air Mag, Apr, 1933 (article is one of series entitled “Story of Boulder Dam”)
36. Twin Cableways of Long-span Place Concrete at Norris Dam. Eng News-Rec, Dec 13, 1934
37. 150-ton Permanent Cableway at Boulder Dam (see Bib 34, 35) Engineering, London, Sep 1, 1933 (Reprint of Bib 34, 35)

 Slack-line cableways
38. Bruckman. Recent Drag-line Excavator Practice in Germany. The Engineer, London, Oct 10, 1930 (good article, with photos and line drawings of slack-line cableways)
40. Roe, H. A. Functions of Power Scrapers and Slack-line Cableway Excavators. Trans Am Inst Min Eng, Feb 15, 1937 (good article with photos, data and diagrams, comparing slack-line cableways with other excavators of similar application)
41. Sauerman Bros. Excavating for Profit, 1929. Treatise on slack-line cableways, descriptions of machines, applications and methods of operating; with photos, tables of capacities and line drawings, 55 pp, 8 1/2 by 11 in (catalogue of Maker No 13)