USS Tiger Brand

Wire Rope Engineering Handbook

The widespread use of wire rope in almost every type of industry—and the many ramifications and variations of such service—requires constant and up-to-date knowledge of every technical advance pertaining to the construction of wire rope and to its application.

To make available such information to engineers—and to others who have need for exact facts relating to the subject—is the purpose of this Handbook.

It is our belief that you will find the contents not only of very real help—but that you will recognize in it a broadness of scope and a completeness that could only result from knowledge gained through many years of leadership in this important field.

This leadership has been achieved because of steadfast adherence to unvarying standards of quality—and because of ability to provide a perfect answer to the many usual and unusual application problems that are constantly occurring.

Contents Page

Stretch of Wire Rope

The stretch of a wire rope under load is the result of two components: the structural stretch, caused by lengthening of the rope lay, compression of the core, and adjustment of the wires and strands to the load; and the elastic stretch, caused by elongation of the wires.

The structural stretch varies with the size of core, the lengths of lays, and the construction of the rope. This stretch also varies with the loads imposed and the amount of bending to which the rope is subjected. For estimating this stretch the value of ½%, or .005 times the length of rope under load, gives an approximate figure. If loads are light, ¼% or .0025 times the rope length may be used. With heavy loads, this stretch may approach 1%, or .01 times the rope length.

The elastic stretch of a wire rope is directly proportional to the load and the length of rope under load, and inversely proportional to the metallic area and modulus of elasticity. This applies only to loads which do not exceed the elastic limit of a wire rope. The elastic limit of a conventional wire rope is approximately 55% of its breaking strength: the elastic limit of thermally stabilized wire rope is 75%. This may be expressed as:

$$\text{Elastic Stretch in feet} = \frac{\text{(Load in Lbs.) (Length of rope under load in feet)}}{\text{(Metallic area of rope in square inches) (Modulus of Elasticity)}}$$

The approximate metallic areas of the principal constructions of USS Tiger Brand Wire Ropes and Strands are shown below.

Approximate Metallic Areas in Square Inches

Dia.	6x7 6x17	6x19 Seale 6x21 FW	6x25 FW 6x37 Class	6x30 Type G	8x19	Galv. Wire Core Bridge Ropes	Galv. Strands	Track Strands: Locked Coil	Track Strands: Smooth Coil	Torque Balanced: 3x19 S	Torque Balanced: 3x25 FW	Torque Balanced: 3x46 SFW
⅜	0.054	0.055	0.057	0.062	0.050		.079				.060	
									19-Wire			
½	.095	.098	.101	.110	.088		.145		.143	.109		.115
9/16	.121	.124	.128	.140	.112		.184			.135		.143
⅝	.149	.154	.158	.172	.139		.228		.223	.165		.174
¾	.215	.221	.227	.248	.199		.328	.385	.301	.241	.245	.250
⅞	.294	.302	.309	.338	.270		0.450	.531	.438	.332	.341	.350
1	.380	.394	.404	.440	.352	.471	.596	.677	.576	.428	.444	.454
									37-Wire			
1⅛	.484	.498	.512	.560	.448	.596	.760	.850	.723	.537	.564	.571
1¼	.596	.616	.632	.688	.556	.745	.940	1.041	.897		.844	.718
1⅜	.725	.747	.762	.836	.670	.906	1.135	1.244	1.081			.859
1½	.860	.888	.908	.992	.796	1.076	1.350	1.490	1.292			1.017
									61-Wire			
1⅝		1.042	1.065	1.165		1.27	1.590	1.782	1.511			1.227
1¾		1.207	1.236	1.352		1.47	1.840	2.061	1.758			1.416
1⅞		1.386	1.419			1.69	2.110	2.334	2.007			
									91-Wire			
2		1.576	1.616			1.92	2.400	2.659	2.291			1.79
2¼		1.994	2.048			2.42	3.040	3.432	2.885			
2½			2.528			2.97		4.168	3.557			
2¾			3.048			3.58		4.987				
3			3.632			4.25		6.044				

Independent Wire Rope Cores add approximately 15% to the metallic area of ropes of six round strands; and approximately 10% to 6x30 Type G. Wire Strand Cores add approximately 20% to the metallic area of six-strand, round strand, wire ropes. For more accurate figures contact our Wire Rope Engineering Department.

Stretch of Wire Rope

Approximate Moduli of Elasticity

The modulus of elasticity of a wire rope varies throughout its life and is dependent on the construction of the rope and the conditions under which it operates. This modulus increases during the useful life of the rope. It is affected by the length of service of the rope, the intensity of working loads, whether these loads are constant or variable, and the amount of bending and vibration to which the rope is subjected.

The commonly used approximate values for moduli of elasticity of the various constructions are listed below.

New or unused wire ropes will have a greater elongation than used ropes, because the greater portion of the structural stretch of a rope occurs during the initial period of its useful life. The modulus of elasticity is also the smallest during this period.

Construction		Approximate Modulus of Elasticity
6x7 Fiber Core		12,000,000
6x7 IWRC		14,000,000
6x17 IWRC 6x19 Seale IWRC 6x21 FW IWRC 6x25 FW IWRC		13,000,000
6x19 Fiber Core 6x30, Type G Fiber Core		12,000,000
6x37 Fiber Core		11,000,000
6x37 IWRC		12,000,000
8x19 Fiber Core		10,000,000
Galvanized Wire Core Bridge Ropes	6x7	16,000,000
	6x19	15,000,000
	6x37	14,000,000
Prestressed Galvanized Wire Core Bridge Ropes		20,000,000
Galvanized Bridge Strands Galvanized Guy Strands	7 Wire	21,000,000
	19 Wire	19,000,000
	37 Wire	18,000,000
	61 Wire	17,000,000
	91 Wire	16,000,000
Prestressed Galvanized Bridge Strands		24,000,000 up to 2$\frac{9}{16}$ 23,000,000 2$\frac{5}{8}$ & Larger
Locked Coil Track Strand		19,000,000
Smooth Coil Track Strand		19,000,000
3x7 Torque Balanced Super Tensile Elevated Elastic Limit		20,500,000
3x19 Torque Balanced Super Tensile Elevated Elastic Limit		20,500,000
3x36 Torque Balanced Super Tensile Elevated Elastic Limit		20,000,000
3x46 Torque Balanced Super Tensile Elevated Elastic Limit		20,000,000
3x55 Torque Balanced Super Tensile Elevated Elastic Limit		20,000,000
6x25 Super Tensile Unit Lay IWRC		16,000,000
6x36 Super Tensile Unit Lay IWRC		16,000,000

The moduli of elasticity shown on this page are for wire ropes and strands of standard constructions and with standard lengths of lay.

Reserve Strengths

The reserve strength of a wire rope is the strength of the rope exclusive of the outer wires, which are the first to be destroyed by wear and abrasion. As the number of layers of wires in each strand increases, the reserve strength increases. Well lubricated ropes have the following approximate reserve strengths in terms of total strengths of new ropes.

Construction	Percentage of Total — Outer Wires	Percentage of Total — Inner Wires (Reserve Strength)
6x7; 6x6x7 Tiller Rope	83	17
6x17	73	27
6x19 Seale; 8x19 Seale	69	31
6x30 Type G w/AMERANGLE Core	66	34
6x21 Filler Wire	64	36
6x19 Warrington	59	41
6x25 Filler Wire; 8x25 Filler Wire	57	43
19x7 Non-Rotating	54	46
6x36 Filler Wire	50	50
6x41 Filler Wire & 6x49 SWS	46	54
6x46 SFW	43	57

Size of Outer Wires

Rope Construction	Factor for Determining Approx. Size of Outer Wires (Multiply Dia. of Rope by Factor)
6x7	1/9
6x17	1/12
6x19 Seale	1/13
6x19 Warrington (Large Outer Wires)	1/14
6x21 Filler Wire	1/14
6x30 Type G Flattened Strand w/AMERANGLE Core	1/14
6x12—7 Fiber Cores	1/15
8x19 Seale	1/15
6x25 Filler Wire	1/16
19x7 Non-Rotating	1/16
6x36 Filler Wire	1/18
8x25 Filler Wire	1/19
6x41 Filler Wire & 6x49 SWS	1/20
6x46 SFW	1/22
6x6x7 Tiller Rope	1/29

Effects of Bending

All wire ropes, except stationary ropes used as guys or supports, are subjected to bending around sheaves or drums. The service obtained from wire ropes is, to a large extent, dependent upon the proper choice and location of the sheaves and drums about which it operates.

A wire rope may be considered as a machine in which the individual elements (wires and strands) slide upon each other when the rope is bent. Therefore, as a prerequisite to the satisfactory operation of wire rope over sheaves and drums, the rope must be properly lubricated. (See Lubrication—page 57.) With this in mind, the effects of bending may be classified as:

Loss of strength due to bending.

Fatigue effect of bending.

Loss of strength due to bending is caused by the inability of the individual strands and wires to adjust themselves to their changed position when the rope is bent. Tests have shown that rope strength decreases to a marked degree as the sheave diameter grows smaller with respect to the diameter of the rope. The loss of strength due to bending wire ropes over the sheaves found in common use are not expected to exceed 6% and will usually be about 4%.

The bending of a wire rope is accompanied by readjustments in the positions of the strands and wires and results in actual bending of the wires. Flexing of the wires develops bending loads which, even though usually within the elastic limit of the wires, set up points of increased stress concentration.

The fatigue effect of repetitive bending appears in the form of small cracks in the wires at increased overstressed foci. These cracks propagate, under repeated stress cycles, until the remaining sound metal is inadequate to withstand the bending load and complete fracture occurs. This results in broken wires showing no apparent contraction of cross section.

Experience has established the fact that from the service viewpoint, a very definite relationship exists between the size of the individual outer wires of a wire rope and the size of the sheave or drum about which it operates. Sheaves and drums smaller than 200 times the diameter of the outer wires will cause permanent set in a heavily loaded rope. Good practice requires the use of sheaves and drums with diameters 800 times the diameter of the outer wires in the rope for heavily loaded fast-moving ropes. For mine hoists, the factors are usually about 1,000; for elevators, approximately 900.

It is impractical to give a definite minimum size of sheave or drum about which a wire rope will operate with satisfactory results, because of the other factors affecting the useful life of the rope. Reverse bends, where a rope is bent in one direction and then in the opposite direction, cause excessive fatigue and should be avoided whenever possible. When a reverse bend is necessary, larger sheaves are required than would be the case if the rope were bent in one direction only.

Tables I and II show the minimum tread diameters of sheaves and drums for use with the various sizes, grades, and constructions of wire rope. These diameters are based on factors of 600 times the diameters of the outer wires for the table covering iron ropes, and 400 for the table covering the higher grades of wire rope, with the exception of the 19x7 Non-Spinning, for which a factor of 500 is used.

It should be clearly understood that these are not the recommended diameters of sheaves and drums for use with USS Tiger Brand Wire Rope. These are the minimum sizes which, under favorable operating conditions, can be expected to give reasonable wire rope service. If the other features of operation, such as speeds and loads, are severe, larger sheaves and drums should be used; the amount by which they exceed these minimum figures depending upon the severity of the conditions of service. The use of sheaves and drums larger than shown in these tables will result in increased wire rope service, which usually will more than warrant the additional cost of the larger sheaves and drums.

Table I. **Minimum Tread Diameters of Sheaves and Drums in Inches**

Bright Iron Wire Ropes

Rope Dia.	6x7	6x19	8x19	6x6x7 Tiller
1/4	15 3/4	10	8	5
5/16	19 3/4	12 1/2	10	6 1/4
3/8	23 1/2	15	12	7 1/2
7/16	27 1/2	17 1/2	14	8 3/4
1/2	31 1/2	20	16	10
9/16	35 1/2	22 1/2	18	11 1/4
5/8	39 1/2	25	20	12 1/2
3/4	47 1/4	30	24	15
7/8	55 1/4	35	28	17 1/2
1	....	40	32	20
1 1/8	....	45	....	....
1 1/4	....	50	....	....

These Minimum Tread Diameters are based on factors of 600 times the diameters of the outer wires.

Table II. Minimum Tread Diameter of Sheaves and Drums in Inches

Steel Wire Ropes

Rope Dia.	3x19 Seale / 6x7	3x25, 3x36, 6x19 Seale / 6x17 Seale / 19x7 Non-Rot.	6x19 Warrington / 6x30 Type G / 6x21 FW	3x46, 6x25 FW / 8x19 Seale	6x36 SFW	6x41 SFW / 8x19	6x46 SFW	6x6x7 Tiller
¼	10½	8½	7½	6½	....	....	....	3½
5/16	13¼	10¾	9½	8¼	....	....	....	4½
⅜	15¾	12¾	11¼	9¾	8¾	8	6¾	5¼
7/16	18½	15	13¼	11½	10	9¼	8	6¼
½	21	17	15	13	11½	10½	9	7
9/16	23½	19¼	17	14¾	13	11¾	10¼	8
⅝	26¼	21¼	18¾	16¼	14½	13¼	11¼	8¾
¾	31½	25½	22½	19½	17¼	15¾	13½	10½
⅞	36¾	29¾	26¼	22¾	20¼	18½	15¾	12¼
1	42	34	30	26	23	21	18	14
1⅛	47¼	38¼	33¾	29¼	26	23¾	20¼	....
1¼	52½	42½	37½	32½	28¾	26¼	22½	....
1⅜	57¾	46¾	41¼	35¾	31¾	29	24¾	....
1½	63	51	45	39	34½	31½	27	....
1⅝	....	55¼	48¾	42¼	37½	34¼	29¼	....
1¾	....	59½	52½	45½	40¼	36¾	31½	....
1⅞	....	63¾	56¼	48¾	43¼	39½	33¾	....
2	....	68	60	52	46	42	36	....
2¼	....	76½	67½	58½	51¾	47¼	40½	....
2½	....	....	75	65	57½	52½	45	....
2¾	....	....	....	....	63¼	57¾	49½	....
3	....	....	....	....	69	63	54	....
3¼	....	....	....	....	....	68¼	58½	....
3½	....	....	....	....	....	....	63	....

These Minimum Tread Diameters are based on factors of approximately 400 times the diameters of outer wires for all except the 19x7 Non-Rotating Rope, for which a factor of 500 is used.

Stresses due to Acceleration

In order to cause a body to move from one point to another, a force must be applied to the body. If the rate at which the body moves from point to point does not change during successive intervals of time, we say that the body has a constant speed or a uniform velocity. Velocity is always expressed as a ratio of distance to time, and for our purposes, we shall use the ratio, feet per second (ft./sec.) as most convenient. The force necessary to move a body with uniform velocity is constant, and is that force required to overcome frictional and gravitational resistance.

On the other hand, if the velocity of a body changes, additional force is necessary to cause this change. Suppose a body initially at rest starts to move so that it has velocities at the end of certain time intervals as follows:

At end of 1st second velocity is 5 ft./sec.
At end of 2nd second velocity is 10 ft./sec.
At end of 3rd second velocity is 15 ft./sec.
At end of 4th second velocity is 20 ft./sec.

We see that at the end of each second the velocity has been increased 5 ft./sec., or, in other words, the body has been accelerated at the rate of 5 feet per second per secona. (written 5 ft./sec./sec. or 5 ft./sec.^{2}) If the acceleration is not at a uniform rate, we can only express the acceleration as it is at the end of a certain time interval. It will be found that the great majority of wire rope installations operate with a uniform acceleration, or that the acceleration decreases as the equipment gets up to maximum speed.

There are certain fundamental relations between weight, force, acceleration, velocity, distance and time which fortunately are very simple.

Let W = weight of a body and rope.
F = force necessary to cause a change of velocity. This is sometimes called the inertia force and does not include the forces needed to overcome friction or gravity.
g = acceleration due to gravity = 32.2 ft. per sec. per sec.
a = linear acceleration in ft.per sec.per sec.
v = linear velocity in ft. per sec.
s = distance in feet.
t = time in seconds of the acceleration period.

The formulas connecting these various quantities that we shall need to use are as follows:

$$(1)\ a = \frac{v}{t}$$

$$(2)\ a = \frac{2s}{t^2} \text{ when starting from rest}$$

$$(3)\ F = \frac{W}{g}\,a$$

From which

$$(4)\ F = \frac{W}{g} \times \frac{v}{t} = \frac{Wv}{32.2t}$$

$$(5)\ F = \frac{W}{g} \times \frac{2s}{t^2} = \frac{Ws}{16.1t^2}$$

Let us take, for example, a vertical mine hoist. W then represents the weight of the rope hanging in the shaft, the weight of the cage, the weight of the car, and the weight of whatever material is being brought to the surface. From the mine data, we can get v or the maximum speed of the hoist in feet per second. That still leaves the time t to be determined. By standing near the hoisting drum and listening to the engine during a few trips, the observer can very easily determine the number of seconds t it takes the engine to get up to speed. A stop watch will help considerably in determining this acceleration period. From formula (4), we can now get F, the extra force needed for acceleration.

In case the speed of the hoist is not available, then recourse is had to formula (5). t is determined as described above, and the acceleration distance s must also be found by observation. The hoist indicator can be used in estimating the distances traveled during the acceleration period, the uniform speed period, and the slowing

Stresses due to Acceleration

down period by noting the position of the indicator when the time is taken. A very close estimate of distance can be made in this manner. Local conditions may give the observer other means of determining the maximum speeds, time and distances.

The fact that all wire rope possesses a certain amount of elasticity makes conditions easier for long ropes on deep shafts or slopes. A certain amount of motion of the winding drum is absorbed in stretching the rope, and therefore the load is not accelerated as rapidly. The force necessary to overcome the inertia of sheaves, etc., in shallow shafts is also greater in proportion to the whole inertia force, and must be taken into consideration. Good practice therefore calls for the use of a higher factor of safety in shafts where the total hoisting distance is not great.

The rope user will find that acceleration stresses are generally much less in electrically operated hoists, for the automatic control prevents rapid starting as a protective measure for the electrical equipment. Steam hoists, on the other hand, are often started by opening the throttle wide, with consequent sudden jerks on the rope and extremely rapid acceleration for the first second or two. In such cases, it is a safe precaution to add arbitrarily about 25% to calculated stresses obtained as above.

The preceding discussion has only considered speeding up or acceleration. The same forces come into play when apparatus is slowing down during retardation. In most hoists, the acceleration forces are greater because loads are being lifted, but occasionally conditions of extremely rapid retardation are met which necessitate careful checking to avoid undue stresses being placed on the rope. The same formulas apply in either case.

The following table gives the percentage of increase over the static load in hoisting cables due to accelerations of from .25 to 32 feet per second per second. These are based on g = 32 ft. per second per second.

Acceleration Feet/sec./sec.	% Increase of Load	Acceleration Feet/sec./sec.	% Increase of Load
.25	0.78	14	43.75
.50	1.56	16	50.00
.75	2.34	18	56.25
1	3.13	20	62.50
2	6.25	22	68.75
4	12.50	24	75.00
6	18.75	26	81.25
8	25.00	28	87.50
10	31.25	30	93.75
12	37.50	32	100.00

Stresses in Guys

Guys are wire ropes or strands used to hold a vertical structure in position against an overturning force. The most common types of guyed structures are stacks, derricks, and masts for draglines, reversible tramways and radio transmission.

As a general rule stresses in guys from temperature changes are neglected, but in structures such as radio masts this is an important feature, and must be subject to special analysis.

The number of guys used for any particular installation is contingent on several variable factors, such as type of structure, space available for guys, contour of the ground, etc., and is not a part of this discussion.

It is desirable to space guys uniformly wherever possible in order to equalize the pull, P, on each guy insofar as possible, particularly against forces which change in direction, as when a derrick boom swings in its circle.

It is also desirable to equalize the erection tensions on the guys. When no external force is acting on the structure, the tension in each guy should be the same. A "Tension Indicator" is sometimes used to determine the tension in guys. If this instrument is not available, the tension can be approximated very closely by measuring the deflection at the center of the span from the chord drawn from the guy anchorage to the point of support on the structure. The formulas for uniformly loaded cables will be found under "Stresses in Suspended Cables", and the initial tension may be found when the deflection, span and weight per foot are known. A good average figure to use for erection tension of guys is 20% of the maximum working tension of the guy.

Our purpose is to outline the method of determining the stresses in guys. One of the first considerations is the location of the guy anchorages. The anchorages should be so located that the angle α, (Alpha) between the horizontal plane and the guy line, is the same for all guys (to equalize erection tensions). Angle α, in good practice,

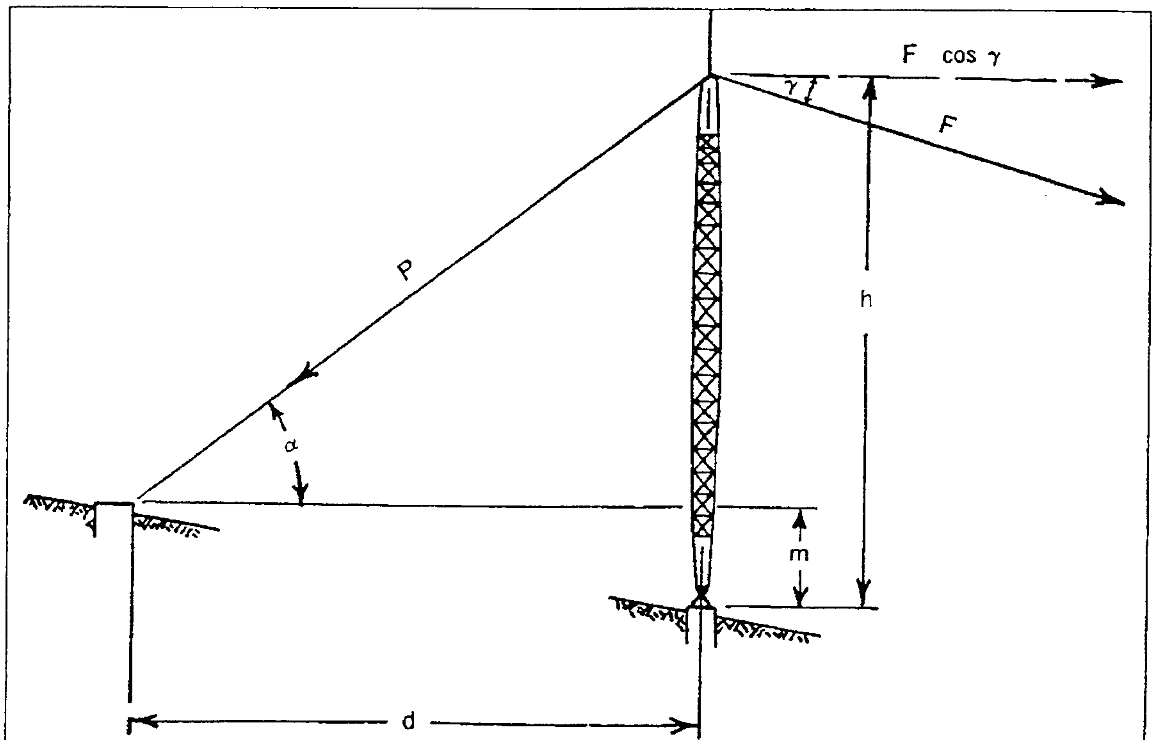


Figure 1

seldom exceeds 45 degrees; 30 degrees being quite commonly used. The tension in the guys decreases as angle α becomes less. The direct load on the structure is also less with smaller values of α.

To find the maximum extra tension, T, that will be applied to any single guy by the force, F; first, determine the pull, P, which is the amount required along the guys, in the same vertical plane as the force, F, to resist the horizontal component of the force, F. This pull, P, is entirely independent of the number of guys. Assume that the following are known:

F = The total resultant external force acting on the structure.

γ = Gamma = The angle between the horizontal plane and the force, F.

h = The height of structure.

d = The horizontal distance from structure to guy anchorage.

m = The vertical height of anchorage above or below base of structure.

The horizontal component of the force, F, = F cos γ.

α = Alpha = the angle whose tangent is $\frac{h \pm m}{d}$.

m is plus if the anchorage is below the base of the structure and minus if it is above.

$$P = \frac{F \cos \gamma}{\cos \alpha}$$

As cos α is always less than one, P is always greater than F cos γ, the horizontal component of force, F.

It must be remembered that P represents the total pull acting along the guys at an angle, α, with the horizontal and in the same vertical plane as the force, F.

If only one guy were used, P would represent the extra tension, T. In practice, however, a number of guys are always used and, therefore, the pull on any one guy will not be equal to P. The following table gives factors for any number of guys from 3 to 15, equally spaced about a central structure. To find the maximum extra tension, T, that will be applied to any single guy by the force, F, capable of rotating 360 degrees around a vertical axis, it is only necessary to multiply the value of P, as determined above, by the factor for the number of guys used. It must be clearly understood in using this table that the guys are uniformly spaced and under equal tension when no load is acting on the structure.

Table III

No. of Guys	Factors*	No. of Guys	Factors*
3	1.15	10	.45
4	1.00	11	.40
5	.90	12	.37
6	.75	13	.35
7	.65	14	.32
8	.55	15	.30
9	.50		

*These factors are for average conditions. If the guys are erected under accurately measured tensions of not less than 20% of the working load the factors for 5 or more guys may be reduced 10%. If the erecting tensions are low or not accurately equalized, the factors for 5 or more guys should be increased 10%.

Example—A derrick mast 90 ft. high is supported by nine equally spaced guys anchored at a horizontal distance of 170 ft. from the mast and the elevations of the guy anchorages are 10 ft. below the base of the mast. The load on the structure is equivalent to a force of 10,000 lbs. acting on an angle of 10 degrees below the horizontal. What is the maximum pull on any single cable and what size guy rope should be used?

From Fig. I

h = 90 Ft.
d = 170 Ft.
m = 10 Ft.
$\gamma = 10^\circ - 00'$
F = 10,000 Lbs.

$$\tan \alpha = \frac{90 + 10}{170} = \frac{100}{170} = .588$$

$$\alpha = 30^\circ - 28'$$

$$P = \frac{F \cos \gamma}{\cos \alpha} = \frac{10{,}000 \times .985}{.862} = 11{,}427 \text{ Lbs.}$$

From Table III, T = 11,427 × .50 = 5,714 Lbs.

If erection tension is 10 per cent of total working tension, 5,714 is 90 per cent of total working tension. Therefore, working tension $= \frac{5714 \times 100}{90} =$ 6,349 Lbs.

Stresses in Suspended Cables

Cable spans may be divided into two general classes, Anchored Spans, and Counterweighted Spans. In each of these divisions, we find it necessary to solve for stresses and deflections of uniformly loaded spans and also of spans supporting one or more individual concentrated loads. It is, therefore, necessary to analyze the conditions of each problem carefully and the following points must be considered:

1. Horizontal distance between supports.
2. Difference in elevation between supports.
3. Maximum allowable deflection, measured vertically from chord to cable.
4. Length of cable between supports.
5. Weight per foot of cable, to which must be added in certain cases the additional weight imposed by snow and ice.
6. Maximum load to be supported by the cable.
   a. Load uniformly distributed over the length of the span.
   b. A single load supported at any point in the span.
   c. Multiple individual loads.
7. Is the cable anchored at both ends or is it anchored at one end and counterweighted at the other end?
8. Modulus of elasticity in tension.
9. Wind loads on the cable and on the suspended load.
10. Changes in length of cable due to changes in temperature.

Since our purpose is to present means for obtaining results quickly, we will not give derivations of the following formulas. Computations are simplified by the assumption that uniform loading is distributed horizontally, and that the cable assumes a parabolic arc. For the great majority of cases encountered in practice, the results thus obtained are sufficiently accurate. If special cases occur where the ratio of deflection to span is very large, then the catenary equations should be applied. These are available in several textbooks.

The following nomenclature will be used:

A = Net cross sectional area of cable.

a = Horizontal spacing of loads.

b $= \frac{n(n-1)}{2}$ c $= \frac{u(u-1)}{2}$

e = Base of Naperian system of logarithms = 2.7182818.

E = Modulus of elasticity in tension.

G = Weight of an individual concentrated load.

h = Vertical difference in elevation of supports.

k = Ratio of deflection to span $= \frac{y}{s}$ for level spans and $\frac{ws\cos^2\alpha}{8t}$ for inclined spans.

L_1 = Length along cable when the cable only is supported in a span.

L_2 = Hypothetical length along cable at zero tension.

L = Length along cable when either a uniformly distributed load or one or more concentrated loads are suspended.

m = Horizontal distance from left support to the first load.

n = Number of concentrated loads.

P = Change in total length of cable per pound of tension $= \frac{L}{AE}$

s = Horizontal distance between supports.

s_1 = Chord length of sub-span between load and support or between two loads.

t = Horizontal component of cable tension.

t′ = Maximum cable tension at left support.

t″ = Maximum cable tension at right support.

t_e = Erection tension of empty cable in an anchored span.

u = Number of loads to left of xy in a multiple loaded span.

w = Weight per foot of horizontal length of span for a uniformly distributed load, $w = w' \sec\alpha$.

w′ = Weight per foot of uniformly distributed load along the cable, which is assumed for purposes of parabolic curve calculations, as equivalent to uniformly distributed load along the chord.

w″ = Weight per foot of uniformly distributed load along the cable for purposes of catenary curve calculations.

x = Horizontal distance from support to xy.

y = Vertical deflection from support to xy.

y_c = Vertical deflection from support at center of span.

z = A term in the general formula for multiple loaded counterweighted spans.

α = Alpha = Angle between the horizontal and a chord between supports.

β_1 = Beta$_1$ = Angle between the horizontal and a tangent to a cable curve at the left support.

β_2 = Beta$_2$ = Angle between the horizontal and a tangent to a cable curve at the right support.

β_3 = Beta$_3$ = Angle between the horizontal and a tangent to a cable curve at any point in a span.

Stresses in Suspended Cables

β_4 = Beta$_4$ = Angle between the horizontal and a tangent to a cable curve at a load.

λ = Lambda = Change in length of cable per foot of length, per pound of tension.

Δ = Delta = Total change in length of cable = λ t L_2.

θ = Theta = Angle between the horizontal and the chord of a half span.

sec = Secant of an angle = $\frac{1}{\text{cosine}}$

ANCHORED SPANS are principally employed for supporting electrical cables, for guy lines, for suspension bridges, and usually for track cables of cableways and reversible aerial tramways where a single moving load is supported in a clear span.

When a cable span is erected, anchored at both ends, and a load of any kind supported from the cable, the deflection increases because of the elastic properties of the cable. The tension also increases when the load is applied.

It is necessary to select the size, construction, and grade of the cable, with a proper factor of safety, after having determined the maximum tension in the cable due to dead and live loads. It is then necessary to erect the cable at such a deflection that the maximum safe working tension will not be exceeded when the load is applied.

In the case of cableways with high self-supporting towers, the cable tension and deflection may be affected by yielding of the supports. A complete study of such a span includes the application of the theory of deflection in framed structures, but such a special condition does not come within the scope of this handbook. In all cases we will assume that cables are anchored to rigid supports or immovable ground anchorages.

The determination of the proper erection deflection and tension involves the use of the modulus of elasticity in tension for the particular construction of cable which is being used.

It is well known that the modulus of elasticity ranges between 28,000,000 and 30,000,000 for structural steel, but the modulus of elasticity of a wire cable, considering the cable as a whole, has various values depending on its construction, and also on the work that has been put into it.

The modulus can be appreciably increased by a prestressing operation. This is frequently done to bridge cables. In the case of track cables carrying rolling loads somewhat the same effect is secured after a period of operation, as most of the structural stretch is removed. See Moduli of Elasticity page 4.

Inclined Span—Uniformly Loaded—Anchored

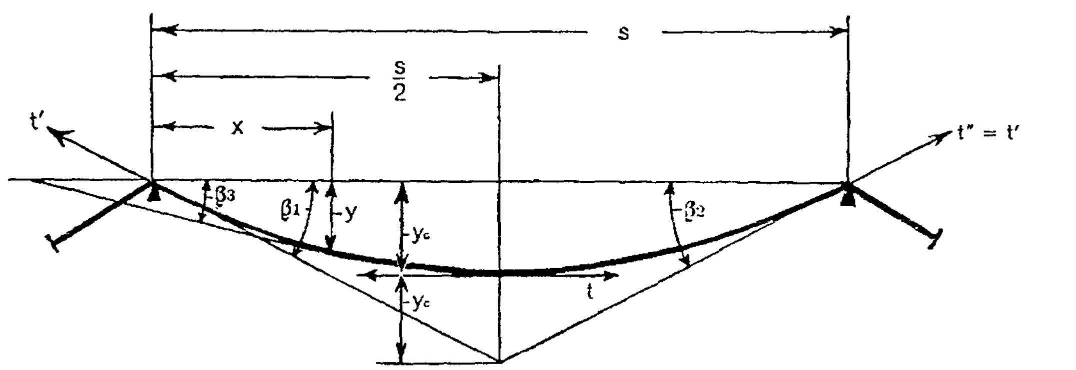


Figure 2

When the tension is known, the center deflection is found from:

$$y_c = \frac{ws^2}{8t} \quad (1)$$

and the deflection at any point in the span is:

$$y = \frac{wx(s\text{-}x)}{2t} \quad (2)$$

When the center deflection is known, the horizontal component of tension is found from:

$$t = \frac{ws^2}{8y_c} \quad (3)$$

When the deflection at some point other than the center of span is known:

$$t = \frac{wx(s\text{-}x)}{2y} \quad (4)$$

$$t' = t \sec \beta_1 \quad (5)$$

The cable slope at any point in the span is:

$$\tan \beta_3 = \frac{w}{t}\left(\frac{s}{2} - x\right) \quad (6)$$

At either support the cable slope is:

$$\tan \beta_1 \text{ or } \beta_2 = \frac{4y_c}{s} \quad (7)$$

Stresses in Suspended Cables

also tan β_1 or $\beta_2 = \frac{ws}{2t}$ (8)

When the tension is known, the length of cable is:

$$L_1 \text{ or } L = s + \frac{w^2 s^3}{24t^2} \text{(approx.)} \quad (9)$$

When the deflection is known:

$$L_1 \text{ or } L = s\left[\frac{1}{2}\sqrt{1+16k^2}+\frac{1}{8k}\log_e\left(4k+\sqrt{1+16k^2}\right)\right] \quad (10)$$

An easier formula, giving closely approximate results is:

$$L_1 \text{ or } L = s\left(1+\frac{8}{3}k^2-\frac{32}{5}k^4+\frac{256}{7}k^6\right) \quad (11)$$

Sufficient accuracy can be secured, for many of the cases encountered in practice, by contracting formula (11) to:

$$L_1 \text{ or } L = s\left(1+\frac{8}{3}k^2\right) \quad (12)$$

In determining the erection tension for a uniformly loaded span, the values of L_1 and t_e must satisfy the equation:

$$L - L_1 = \frac{(t-t_e)\,L}{AE} = P\,(t-t_e) \quad (13)$$

By substitution of (9) for L_1 in (13) and using corresponding values of w and t_e,

$$Pt_e + L - (Pt+s) = \frac{w^2 s^3}{24\,t_e^2} \quad (14)$$

This equation can be solved for t_e, using the trial and error method.

EXAMPLE:

A 750,000 C.M. bare, hard drawn, stranded copper cable is to be supported across a river. Supports will be at the same elevation and 1350 feet centers. The copper cable is .9981" diameter, and will weigh 2.325 pounds per foot. N.E.L.A. class "B" loading is to be used, that is, a coating of ice ½ inch thick plus a horizontal wind load of eight pounds per square foot on the projected area of the ice coated cable. The center deflection can not exceed 75 feet.

(a) What are the specifications of the necessary messenger cable, assuming the same ice and wind loads?

(b) What is the cable slope at supports and at the quarter points of the span?

(c) What is the erection tension and deflection for the messenger strand only, assuming there are no ice or wind conditions at time of erection?

It is necessary to assume the diameter of messenger strand to figure the loading on the span. It may then be necessary to revise the figures if the first selection does not prove suitable. We will assume a ⅞" diameter strand weighing 1.581 pounds per foot.

Copper cable + ice = 3.240 pounds per foot
Messenger strand + ice = 2.421 pounds per foot
Total vertical load = 5.661 pounds per foot

Horizontal wind load on both cables = 2.582 pounds per foot
Total resultant load = 6.222 pounds per foot

Then from (3) $t = \frac{6.222 \times 1350^2}{8 \times 75} = 18{,}900$ pounds

Then from (8) $\tan \beta_1 = \frac{6.222 \times 1350}{2 \times 18900} = .2222, \quad \beta_1 = 12°\text{-}32'$

Then from (5) $t' = 18900 \times \sec 12°\text{-}32' = 19365$ pounds

Then from (6) when x = 337.5 feet

$$\tan \beta_3 = \frac{6.222}{18900}(675 - 337.5) = .1111, \quad \beta_3 = 6°\text{-}20'$$

With a factor of safety of 4, the required breaking strength will be 4×19365 = 77460 pounds. For instance, a ⅞" diameter, 19 wire, Extra Galvanized Extra High Strength Strand has a breaking strength of 79,700 pounds, and will be satisfactory for the purpose intended. A = .4455 square inches. w = 1.581 pounds.

$$(9) \quad L = 1350 + \frac{6.222^2 \times 1350^3}{24 \times 18900^2} = 1361.110 \text{ ft.}$$

In order to set up (14) in convenient form, first calculate the following:

$$P = \frac{1361.110}{.4455 \times 19{,}000{,}000} = .0001608$$

$$Pt + s = (.0001608 \times 18900) + 1350 = 1353.039$$

$$\frac{w^2 s^3}{24} = \frac{1.581^2 \times 1350^3}{24} = 256{,}240{,}000$$

Substituting these values in (14),

$$.0001608\, t_e + 8.071 = \frac{256{,}240{,}000}{t_e^2}$$

The following shows the results of a series of slide rule computations for assumed values of t_e until the above equation is satisfied (the values in the last two columns are equal).

t_e	$.0001608\ t_e$	$+ 8.071$	$\frac{256,240,000}{t_e^2}$
5200	.836	8.907	9.476
5300	.852	8.923	9.122
5350	.860	8.931	8.952
5356	.861	8.932	8.932

$t_e = 5356$ pounds.

$$\text{From (1) } y_c = \frac{1.581 \times \overline{1350^2}}{8 \times 5356} = 67.25 \text{ ft.}$$

$$\text{From (9) } L_1 = 1350 + \frac{\overline{1.581^2} \times \overline{1350^3}}{24 \times \overline{5356^2}} = 1358.932 \text{ ft.}$$

Therefore:

(a) One piece ⅞" diam. 19 wire Extra Galvanized Extra High Strength Strand with sockets attached so as to give a length of 1358.93 feet center to center of supports.

(b) Maximum cable slope at supports = 12°-32′.
Maximum cable slope at quarter points of span = 6°-20′.

(c) Erection tension = 5356 pounds
Erection deflection = 67.25 ft.

The following table No. IV gives factors for obtaining maximum tension t′ at the supports of a uniformly loaded level span when w, the weight per horizontal foot and s, the horizontal length of span, are known. See column 2. The close relation between the parabola and the catenary is shown by a comparison of the values in columns 2 and 3. Column 3 gives the factor for obtaining t′ when w″, the weight per foot along the cable, and s is known. The length of a uniformly loaded level span, based on a parabolic curve, can be obtained from the factors in column 4. If the span is inclined see (24) and (25).

The factors in column 4 can also be used for the catenary for k ratios up to 0.12 with an error less than 0.02%, and for k ratios as high as 0.20 with an error of only 0.1%.

Table IV

Ratio of center deflection to chord length of span k	Factors For Maximum Tension		To get length of cable, multiply total span by factor below L_1 = s x factor
	When weight of load per foot of span, w, is known t′ = ws x factor	When weight of load per foot of cable, w″, is known t′ = w″s x factor	
COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
.01	12.510	12.51	1.00027
.012	10.429	10.43	1.00038
.014	8.942	8.94	1.00052
.016	7.828	7.83	1.00068
.018	6.962	6.96	1.00086
.02	6.270	6.27	1.00107
.022	5.704	5.70	1.00129
.024	5.232	5.23	1.00153
.026	4.834	4.83	1.00180
.028	4.492	4.49	1.00209
.03	4.196	4.20	1.00240
.032	3.938	3.94	1.00272
.034	3.710	3.71	1.00307
.036	3.508	3.51	1.00344
.038	3.327	3.33	1.00384

Stresses in Suspended Cables

Table IV (Cont.)

Ratio of center deflection to chord length of span k	Factors For Maximum Tension: When weight of load per foot of span, w, is known t' = ws x factor	Factors For Maximum Tension: When weight of load per foot of cable, w", is known t' = w"s x factor	To get length of cable, multiply total span by factor below L_1 = s x factor
COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
.04	3.165	3.17	1.00425
.042	3.018	3.02	1.00468
.044	2.884	2.88	1.00514
.046	2.763	2.76	1.00561
.048	2.652	2.65	1.00611
.05	2.549	2.55	1.00663
.055	2.327	2.33	1.00801
.06	2.142	2.14	1.00952
.065	1.987	1.99	1.01115
.07	1.854	1.86	1.01291
.075	1.740	1.74	1.01480
.08	1.640	1.64	1.01681
.085	1.553	1.56	1.01894
.09	1.476	1.49	1.02119
.095	1.408	1.42	1.02356
.10	1.346	1.36	1.02604
.105	1.291	1.31	1.02865
.11	1.242	1.26	1.03136
.115	1.197	1.22	1.03419
.12	1.155	1.18	1.03713
.125	1.118	1.14	1.04021
.13	1.084	1.11	1.04333
.135	1.052	1.08	1.04659
.14	1.023	1.05	1.04995
.145	0.997	1.03	1.05341
.15	0.972	1.005	1.05711
.16	0.928	0.964	1.06455
.17	0.890	0.930	1.07236
.18	0.856	0.900	1.08063
.19	0.826	0.874	1.08919
.20	0.800	0.853	1.09822
.21	0.777	0.834	1.10749
.22	0.757	0.820	1.11706
.23	0.738	0.807	1.12701
.24	0.722	0.796	1.13724
.25	0.707	0.788	1.14778

Stresses in Suspended Cables

Inclined Span—Uniformly Loaded—Anchored

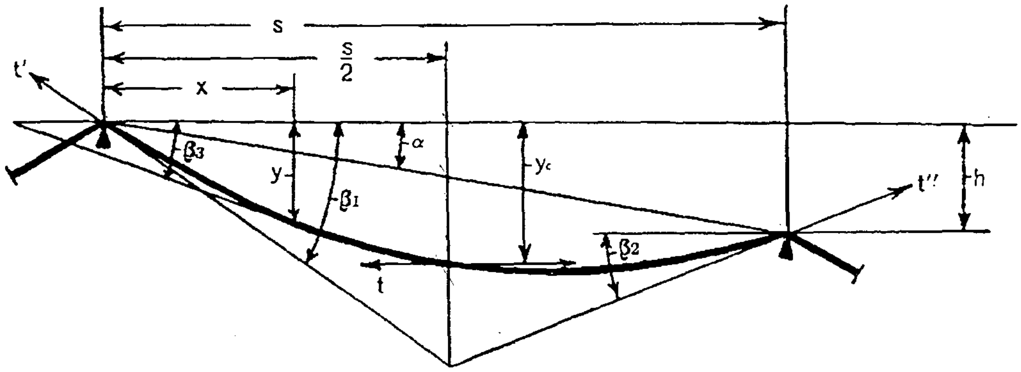


Figure 3

The following formulas give the increments of deflection and slope due to inclination of the chord.

"Down" slopes are usually considered as plus values and "up" slopes as minus values.

$$y_c = \frac{ws^2}{8t} + \frac{h}{2} \tag{15}$$

$$\tan \alpha = \frac{h}{s} \tag{16}$$

At any point—

$$y = \frac{wx(s-x)}{2t} \pm x \tan \alpha \tag{17}$$

$$\tan \beta_1 = \frac{ws}{2t} + \tan \alpha \quad \text{TAN}\alpha + ws/2t \tag{18}$$

$$\tan \beta_2 = \frac{ws}{2t} - \tan \alpha \quad \text{TAN}\alpha - ws/2T \tag{19}$$

$$\tan \beta_3 \text{ (at any point)} = \frac{w}{t}\left(\frac{s}{2} - x\right) \pm \tan \alpha \tag{20}$$

When center deflection is known:

$$t = \frac{ws^2}{8y_c - 4h} \tag{21}$$

Low point of an inclined span occurs when $\tan \beta_3 = 0$

$$\therefore x = \frac{s}{2} + \frac{t}{w} \tan \alpha$$

When deflection at any other point is known:

$$t = \frac{wx(s-x)}{2(y-x \tan \alpha)} \tag{22}$$

$$t' = t \sec \beta_1 \tag{23}$$

$$t'' = t \sec \beta_2$$

To find the lengths of cable in an inclined span formulas (9) and (11) are modified:

$$L_1 \text{ or } L = \sqrt{s^2 + h^2} + \frac{w^2 s^3 \cos^3 \alpha}{24t^2} \text{ (approx.)} \tag{24}$$

$$L_1 \text{ or } L = \sqrt{s^2 + h^2}\left(1 + \frac{8}{3}k^2 - \frac{32}{5}k^4 + \frac{256}{7}k^6\right) \tag{25}$$

It will be seen that the solutions for inclined spans are quite similar to those for level spans.

Stresses in Suspended Cables

Level Span—Single Load at Center—Anchored

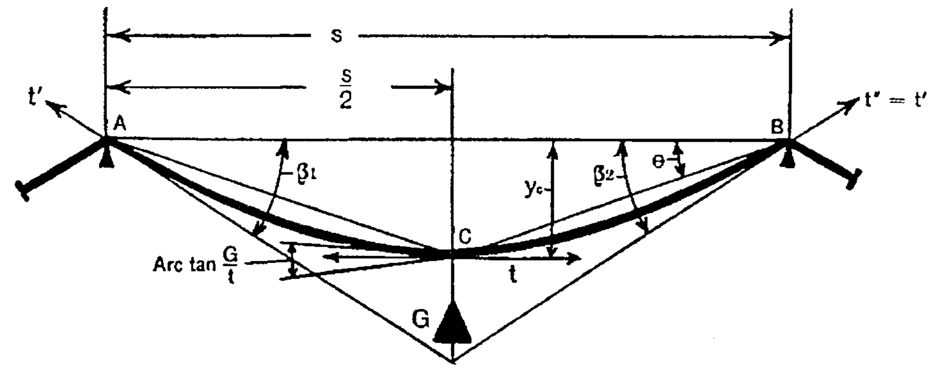


Figure 4

The deflection produced by a concentrated load suspended midway between two fixed points A and B forms two equal sub-chords AC and CB. The cable assumes two catenary arcs which intersect at C. The following formulas are, however, based on the parabola, as the difference in results is negligible.

The center deflection is found from:

$$y_c = \frac{Gs}{4t} + \frac{ws^2}{8t} = \frac{s\,(2G + ws)}{8t} \qquad (26)$$

$$\text{and } t = \frac{s\,(2G + ws)}{8y_c} \qquad (27)$$

$$t' = t \sec \beta_1 = t \sec \beta_2 = t'' \qquad (28)$$

$$\tan \beta_1 = \frac{G + ws}{2t} = \tan \beta_2 \qquad (29)$$

Example: A rolling load weighing 2000 pounds is to be supported in a level span 2000 ft. long by a cable anchored at both ends. The deflection must not exceed 83 feet. No wind or ice conditions.

(a) What are the specifications of the cable?

(b) What is the maximum tension in the cable?

(c) What is the slope at the supports with the load at center of span?

(d) What is the cable length between supports, with no rolling load on the cable?

(e) What is the erection tension and erection deflection of the cable?

It is necessary to assume a size and grade of cable for the calculations. If the first selection does not prove suitable, the calculations must be revised. We shall assume that a 1⅛" diameter Standard Locked Coil Cable will be suitable.

Since this is a level span, $\alpha = 0$ and $w = w'$

$w = 3.16$ pounds per foot $\qquad A = .8503$ square inches

From (27) $\quad t = \dfrac{2000\,(2 \times 2000 + 3.16 \times 2000)}{8 \times 83} = 31{,}084$ pounds

From (29) $\quad \tan \beta_1 = \dfrac{2000 + (3.16 \times 2000)}{2 \times 31084} = .1338 \qquad \beta_1 = 7°\text{–}37'$

From (28) $\quad t' = 31084 \times 1.0089 = 31360$ pounds

The maximum cable length occurs when load is at center of span.

$$s_1 = \sqrt{\left(\frac{s}{2}\right)^2 + y^2} = \sqrt{\overline{1000}^2 + \overline{83}^2} = 1003.439 \text{ ft.}$$

$$\tan\ \theta = \frac{83}{1000} = .083 \quad \theta = 4^\circ\text{–}45$$

$$L = 2\left(s_1 + \frac{w^2\left(\frac{S}{2}\right)^3\cos^3\theta}{24\ t^2}\right) = 2\left(1003.439 + \frac{\overline{3.16}^2 \times \overline{1000}^3 \times \cos^3 4^\circ - 45'}{24 \times \overline{31084}^2}\right) = 2007.730$$

In order to set up (14) in convenient form, first calculate the following:

$$P = \frac{2007.730}{.8503 \times 19{,}000{,}000} = .0001243$$

$$Pt + s = .0001243 \times 31{,}084 + 2000 = 2003.864$$

$$\frac{w^2 s^3}{24} = \frac{\overline{3.16}^2 \times \overline{2000}^3}{24} = 3{,}328{,}533{,}333$$

Substituting these values in (14)

$$.0001243 t_e + 2007.730 - 2003.864 = \frac{3{,}328{,}533{,}333}{t_e^2}$$

The following shows the results of a series of slide rule computations for assumed values of t_e until the above equation is satisfied (the values in the last two columns are equal).

t_e	$.0001243\ t_e$	$+ 3.866$	$\frac{3{,}328{,}533{,}333}{t_e^2}$
22,000	2.735	6.601	6.877
22,300	2.772	6.638	6.693
22,380	2.782	6.648	6.646

$t_e = 22{,}380$ pounds

from (1) $y_c = \frac{3.16 \times \overline{2000}^2}{8 \times 22380} = 70.60$ ft.

from (9) $L_1 = 2000 + \frac{\overline{3.16}^2 \times \overline{2000}^3}{24 \times \overline{22380}^2} = 2006.65$ ft.

(a) With a factor of safety of 3.2, the required breaking strength will be 3.2 x 31360 = 100352 pounds = 50.18 tons. The breaking strength of a 1⅛" diameter Standard Locked Coil Cable is 54 tons. Therefore, this size cable is satisfactory, and our Locked Coil Cable is the most suitable construction where rolling loads are to be handled. If the proposed installation is temporary, or if first cost of the cable is a prime consideration, we may consider the use of 1⅛" diameter High Strength, or 1" diameter Extra High Strength Smooth Coil Track Strands, as well as 1¼" diameter 6x19 MONITOR Rope. However, it would be necessary to revise the calculations for either of the latter selections, because the weight, area, and modulus of elasticity change.

(b) $t' = 31360$ pounds

(c) $\beta_1 = 7^\circ\text{-}37'$

(d) $L_1 = 2006.65$ ft.

(e) $t_e = 22380$ pounds

$y_c = 70.60$ ft.

Stresses in Suspended Cables

Inclined Span—Single Load at Center—Anchored

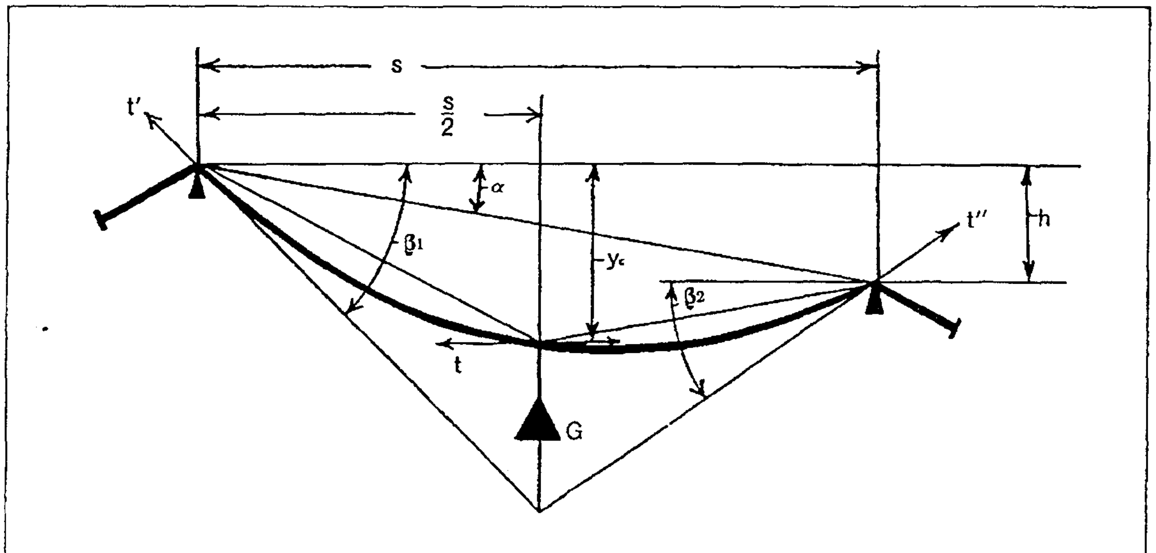


Figure 5

If the chord is inclined, similar to Fig. 5, then the center deflection is found by adding $\frac{h}{2}$ to (26). Then:

$$y_c = \frac{Gs}{4t} + \frac{ws^2}{8t} + \frac{h}{2} = \frac{s\,(2G + ws)}{8t} + \frac{h}{2} \quad (30)$$

$$t = \frac{s\,(2G + ws)}{8y_c - 4h} \quad (31)$$

$t' = t \sec \beta_1$ See (28)

$t'' = t \sec \beta_2$ See (28)

$\tan \beta_1 = \frac{G + ws}{2t} + \frac{h}{s}$ See (29)

$\tan \beta_2 = \frac{G + ws}{2t} - \frac{h}{s}$ See (29)

Level Span with Single Load at any Point

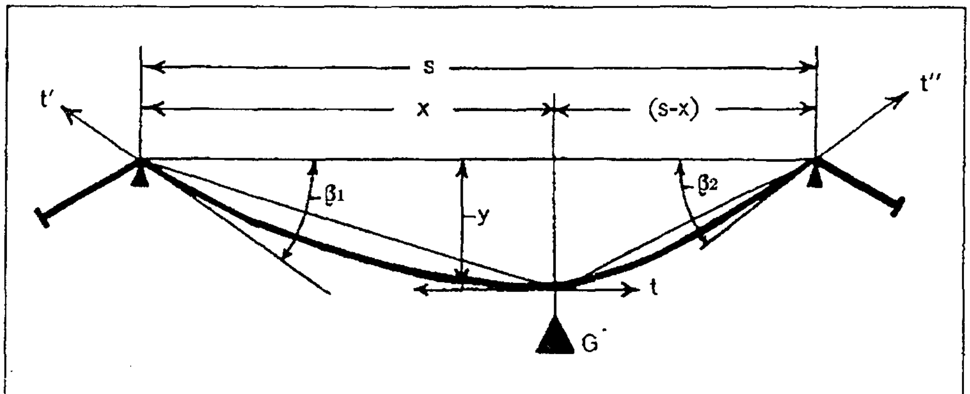


Figure 6

When the cable hangs between fixed points of suspension, with supports at the same elevation, the tension t varies with different positions of the load G and is a maximum only when G is at the center of the span.

Knowing the tension t at the center of the span from (27), the deflection at other points may be determined from:

$$y = \frac{x\,(ws + 2G)^2 \qquad (s-x)}{2t\,(ws^2 + 4G\ \sqrt{x(s-x)})} \qquad (32)$$

However, it must be understood this formula will only give approximate results, as it is based on constant cable length, neglecting the elastic properties of the cable. As the load moves away from center of span, the tension decreases and cable decreases in length. Therefore, the results obtained from (32) are somewhat greater than actual deflections. Formula (32) is, however, sufficiently accurate for many problems encountered in practice.

After determining the deflection by (32) for any position of the load, the corresponding approximate tension at xy can be found from:

$$t = \frac{x(s-x)\ (ws + 2G)}{2sy} \qquad (33)$$

To determine the deflection of the cable at any point, when the load is at xy, consider x or (s–x), Fig. 6, as separate inclined spans, with y as the difference in elevation. Then formula (17) can be applied.

Stresses in Suspended Cables

Inclined Span—Single Load at any Point—Anchored

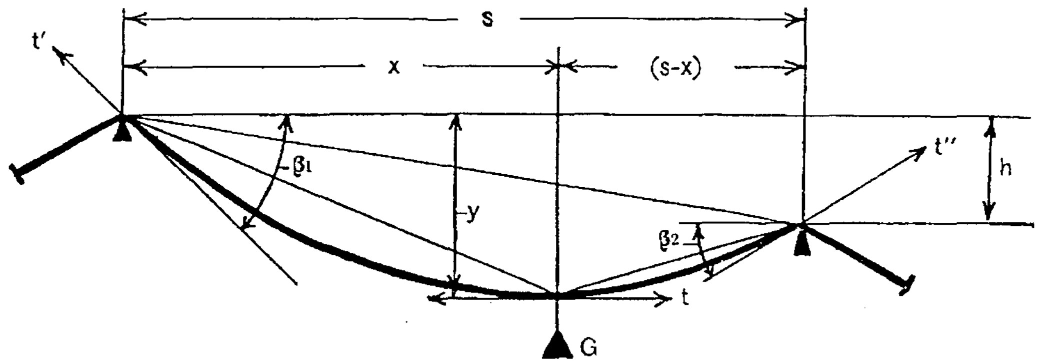


Figure 7

Formula (32) can be applied to inclined spans by adding $\frac{hx}{s}$, which becomes $\frac{h}{2}$ when $x = \frac{s}{2}$. Then, for inclined spans:

$$y = \frac{x\,(ws + 2G)^2\;(s-x)}{2t\left(ws^2 + 4G\sqrt{x\,(s-x)}\right)} + \frac{hx}{s} \qquad (34)$$

Multiple Loads in Anchored Spans

Multiple loads in anchored spans are seldom encountered in practice. However, the subject is important enough to merit some attention. When speaking of multiple loads, it will be assumed loads are equal in amount and spaced uniformly.

The loads should be placed symmetrically about the center line of the span to compute the maximum tension or deflection in the span. Use formula (52), page 28, to determine the deflection and formula (54) to determine the maximum tension. To determine the length along the cable at maximum tension, consider the loads as stationary in the position stated above and treat the lengths of cable between supports and the first load, and the lengths between loads, as separate spans. After this length, L, has been determined, the erection tension, deflection of empty cable, etc., are calculated by the trial method in a similar manner to that for a single load in an anchored span.

Stresses in Suspended Cables

Level Span — Uniformly Loaded — Counterweighted

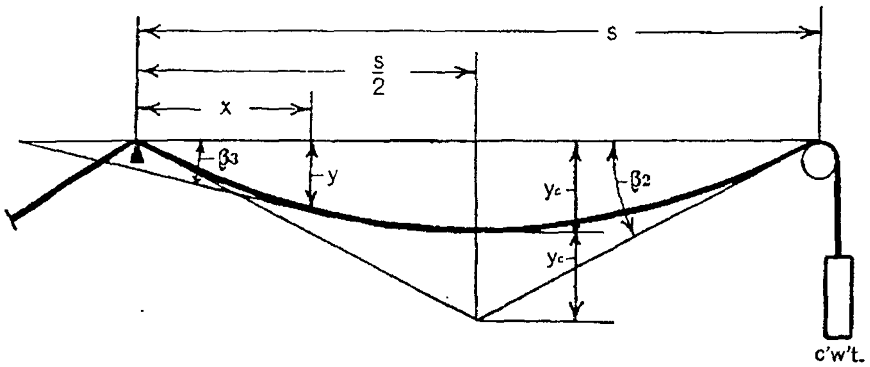


Figure 8

The tension and deflection of either an anchored or a counterweighted span are the same, under the same conditions of loading, when the cable supports a uniformly distributed load. However, an important difference occurs when the live load is removed. In the case of an anchored span, the deflection and length of the cable remain constant, except as they are affected by the elastic properties of the cable, backstays, and supports. The tension, however, decreases when the live load is removed. Comparing this performance with a counterweighted span, we find that the tension remains constant when the live load is removed, while the deflection and length of the cable decrease in proportion to the change in loading. These are the effects due to equalizing the moment-sum of all forces for any origin of moments.

The same comparison holds true of spans supporting one or more individual concentrated loads, when the loads are so placed as to produce the maximum deflection.

The use of a counterweighted track cable for rolling loads results in a constant angle under the load, the angle whose tangent is $\frac{G}{t}$, at all points of a span. Also, it produces a smaller angle at each support than would be the case with an anchored span. These two factors are of definite advantage in the design of aerial tramways having intermediate supports.

Apply formulas (1) to (12) inclusive, pages 13 and 14 under "Anchored Spans."

Stresses in Suspended Cables

Inclined Span—Uniformly Loaded—Counterweighted

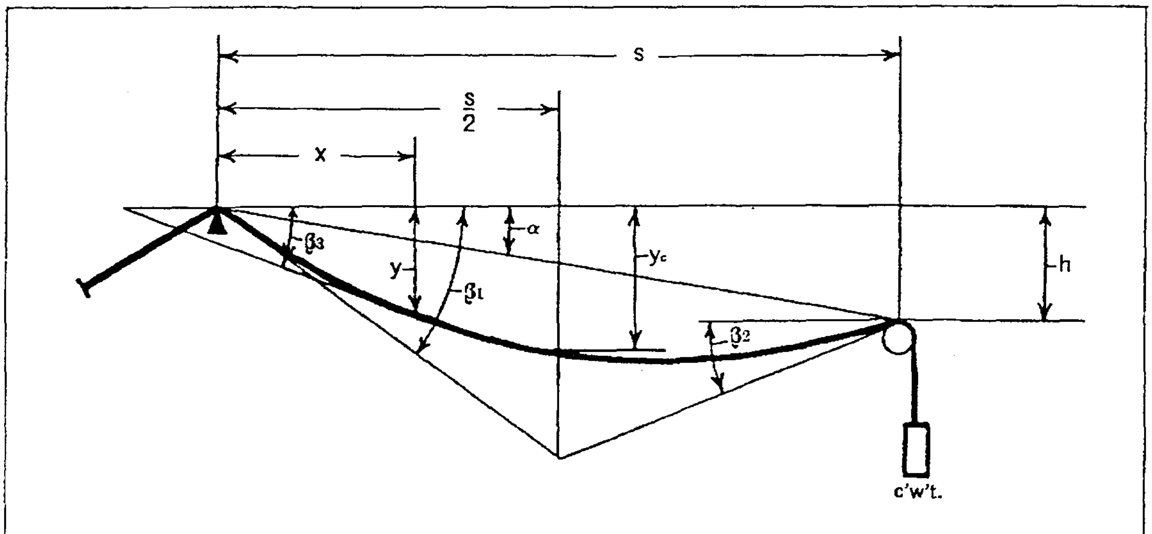


Figure 9

Apply formulas (15) to (25) inclusive, page 17 under "Anchored Spans."

Level Span—Single Load at Center—Counterweighted

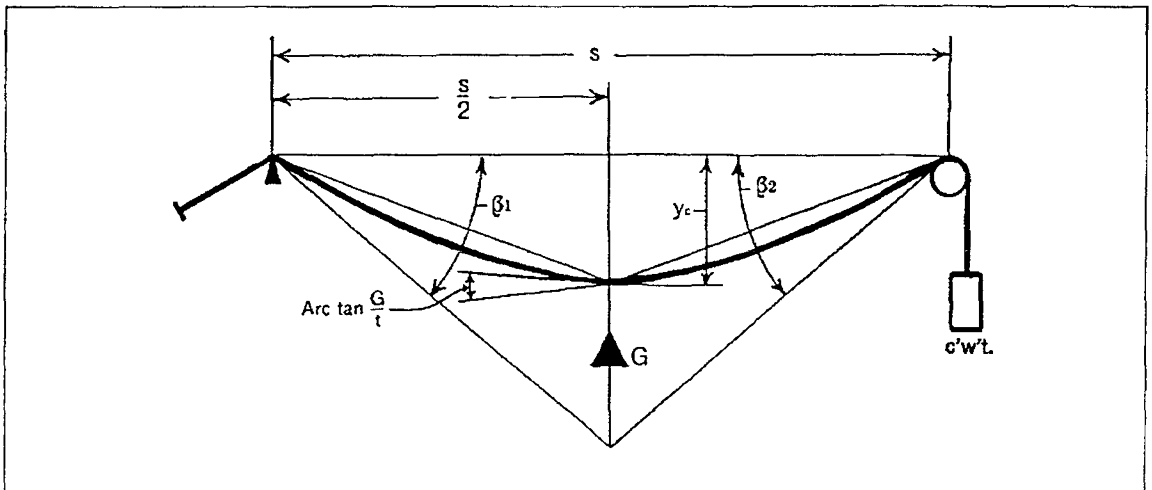


Figure 10

Apply formulas (26) to (29) inclusive, page 18, under "Anchored Spans."
Apply formulas (30) and (31) inclusive, page 20, under "Anchored Spans."

Level Span — Single Load at any Point — Counterweighted

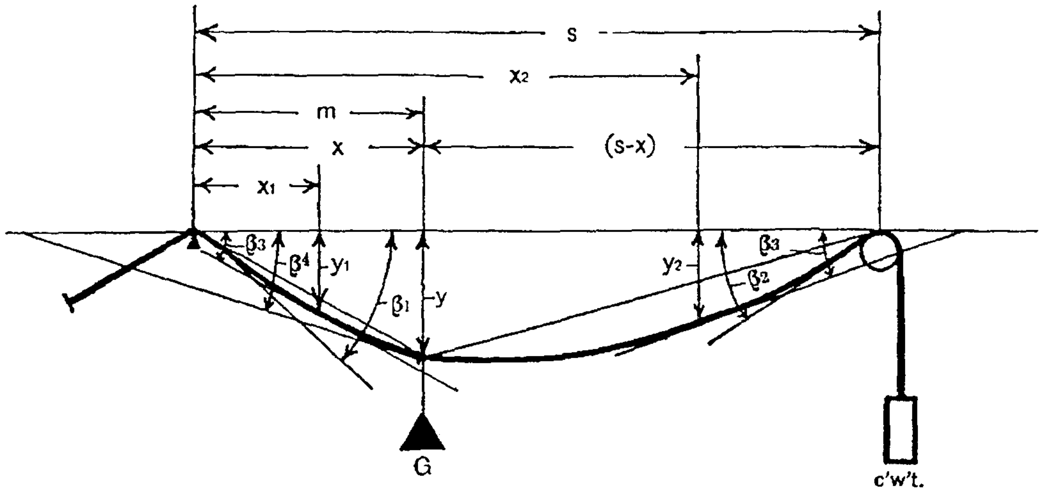


Figure 11

In a constant tension span the deflection *at the load* may be determined from:

$$y = \frac{Gx(s-x)}{st} + \frac{wx(s-x)}{2\,t} \qquad (35)$$

Also the deflection of the cable may be determined for any point in the span, with the load at any point, $x_1\,y_1$ being coordinates to points to the left of G and $x_2\,y_2$ being coordinates of points to the right of G.

$$y_1 \text{ (points left of G)} = \frac{Gx_1}{st}(s-m) + \frac{wx_1}{2t}(s-x_1) \qquad (36)$$

$$y_2 \text{ (points right of G)} = \frac{Gm}{st}(s-x_2) + \frac{wx_2}{2t}(s-x_2) \qquad (37)$$

The cable slope at left support, when $x_1 = 0$, is:

$$\tan \beta_1 = \frac{G}{st}(s-m) + \frac{ws}{2t} \qquad (38)$$

The cable slope at right support, when $x_2 = s$, is:

$$\tan \beta_2 = \frac{Gm}{st} + \frac{ws}{2t} \qquad (39)$$

The cable slope at any point between the load and either support is:

$$\tan \beta_3 \text{ (points to left of G)} = \frac{G}{st}(s-m) + \frac{w}{t}\left(\frac{s}{2} - x_1\right) \qquad (40)$$

$$\tan \beta_3 \text{ (points to right of G)} = \frac{Gm}{st} + \frac{w}{t}\left(x_2 - \frac{s}{2}\right) \qquad (41)$$

When $x = m$, the slope *at* and to the left of the load is:

$$\tan \beta_4 \text{ (sloping to left of G)} = \frac{G}{t} - \frac{Gx}{st} + \frac{w}{t}\left(\frac{s}{2} - x\right) \qquad (42)$$

The slope *at* and to the right of the load is:

$$\tan \beta_4 \text{ (Sloping to the right of G)} = \frac{Gx}{st} + \frac{w}{t}\left(x - \frac{s}{2}\right) \qquad (43)$$

The tangent of the angle under the load is equal to (42) + (43) = $\frac{G}{t}$

If we take half the difference between the angles obtained from (42) and (43), the tangent of the resulting angle will be the slope which a moving load must climb. The maximum slope thus obtained will determine the maximum pull on a haulage rope.

Inclined Span—Single Load at any Point—Counterweighted

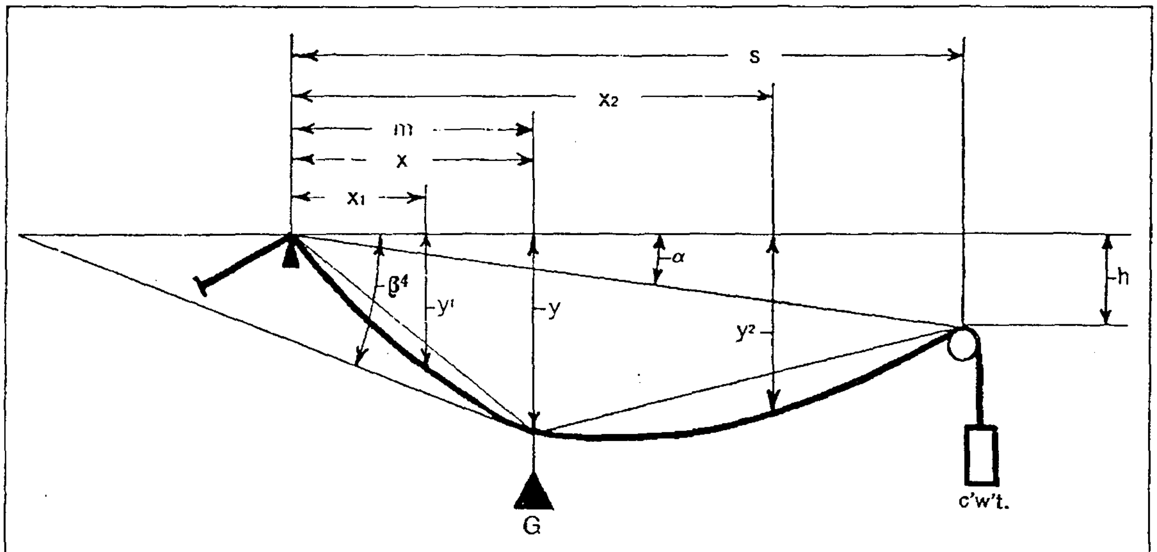


Figure 12

In these formulas, as in all others, we have placed the higher support at the left-hand end of span, and have made this point the origin of moments.

For y — at the load — add to formula (35)
$x \tan \alpha$ (44)

For y_1 — points left of G — add to formula (36)
$x_1 \tan \alpha$ (45)

For y_2 — points right of G — add to formula (37)
$x_2 \tan \alpha$ (46)

The cable slopes are determined by taking the chord into account as an additional term in the above equations

$\tan \beta_1$ — at left support — formula (38)
$+ \tan \alpha$ (47)

$\tan \beta_2$ — at right support — formula (39)
$- \tan \alpha$ (48)

$\tan \beta_3$ — points to left of G — formula (40)
$\pm \tan \alpha$ (49)

$\tan \beta_3$ — points to right of G — formula (41)
$\pm \tan \alpha$ (50)

$\tan \beta^4$ — at the load — formula (42) and (43)
$\pm \tan \alpha$ (51)

EXAMPLE: A 2,000 pound rolling load is to be supported on an inclined span 800 ft. long with difference in elevation of 67 ft. The cable is 1⅜" diameter Standard Locked Coil; w′ = 4.73 pounds per foot, A = 1.2437 sq. in. The center deflection must not exceed 18 ft. from the chord.

(a) What is the horizontal component of cable tension with load at center of span?

(b) What is the slope of the cable at the higher support (1) with the load at center of span, (2) with the load 100 ft. horizontally away from the upper support and (3) with the cable empty?

(c) What is the center deflection of the empty cable?

$$\tan \alpha = \frac{67}{800} = .08375 \qquad \alpha = 4°\text{—}\ 47', \sec \alpha = 1.0035$$

$$w = 4.73 \times 1.0035 = 4.75$$

$$\text{From (31), } t = \frac{800\ (2 \times 2000 + 4.75 \times 800)}{8 \times 51.5 - 4 \times 67} = 43{,}333 \text{ pounds}$$

$$\text{From (47), } \tan \beta_1 = \frac{2000 \times 400}{800 \times 43333} + \frac{4.75 \times 800}{2 \times 43333} + \frac{67}{800}$$

$$= .1507, \quad \beta_1 = 8°\text{-}34'$$

$$\text{From (47), } \tan \beta_1 = \frac{2000 \times 700}{800 \times 43333} + \frac{4.75 \times 800}{2 \times 43333} + \frac{67}{800}$$

$$= .1680, \quad \beta_1 = 9°\text{-}32'$$

$$\text{From (18), } \tan \beta_1 = \frac{4.75 \times 800}{2 \times 43333} + \frac{67}{800}$$

$$= .1276, \quad \beta_1 = 7°\text{-}16'$$

$$\text{From (15), } y_c = \frac{4.75 \times \overline{800}^2}{8 \times 43333} + \frac{67}{2} = 42.27 \text{ ft.}$$

(a) 43,333 pounds.

(b1) Slope 8°-34′ with load at center of span

(b2) Slope 9°-32′ with m = 100 feet

(b3) Slope 7°-16′ with cable empty

(c) Center deflection 42.27 feet with cable empty

Stresses in Suspended Cables

Level Span—Multiple Loads—Counterweighted

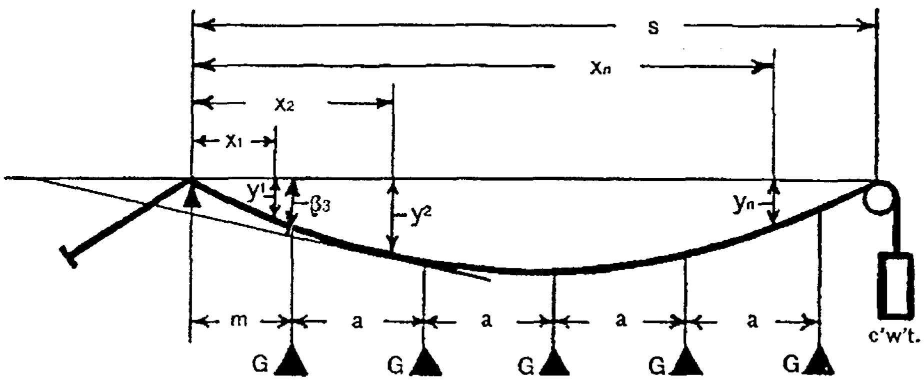


Figure 13

A cable supporting multiple loads forms a series of parabolic arcs between the loads. For many cases encountered in practice, it will be sufficiently accurate to calculate spans carrying more than five loads as uniformly loaded spans. If this is done, the load per foot equals weight of cable plus $\frac{G}{a}$.

However, the general formula for deflection y, at any point xy, of a span supporting n loads of uniform spacing and equal weight, the cable tension being constant, is:

$$y = \frac{G}{t}\left[x(n-u) - m\left(\frac{xn}{s} - u\right) - a\left(\frac{bx}{s} - c\right)\right] + \frac{wx(s-x)}{2t} \qquad (52)$$

$$\text{If } z = \left[x(n-u) - m\left(\frac{xn}{s} - u\right) - a\left(\frac{bx}{s} - c\right)\right]$$

$$\text{Then } y = \frac{2Gz + wx(s-x)}{2t} \qquad (53)$$

$$\text{and } t = \frac{2Gz + wx(s-x)}{2y} \qquad (54)$$

The cable slope at any point may be found from the general formula:

$$\tan \beta_3 = \frac{G}{t}\left[(n-u) - \frac{nm + ab}{s}\right] + \frac{w}{t}\left(\frac{s}{2} - x\right) \qquad (55)$$

Example: A 1½" diameter Standard Locked Coil Cable is to be used to support 5 loads, each weighing 2000 pounds, and spaced 400 feet. Length of span 2000 feet. Horizontal component of working tension t = 45,964 pounds.

$w = w' = 5.63$ pounds.

(a) What is maximum deflection?

(b) What is the slope of the cable at a point 500 feet from the support?

Maximum deflection occurs with one load at center of span.

$x = 1000$ ft.

$m = 200$ ft.

$u = 2$

$b = \frac{5 \times 4}{2} = 10$

$c = \frac{2 \times 1}{2} = 1$

From (52) $y_c = \frac{2000}{45964}\left[1000\,(5-2) - 200\left(\frac{1000 \times 5}{2000} - 2\right) - 400\left(\frac{10 \times 1000}{2000} - 1\right)\right]$

$$+ \frac{5.63 \times 1000 \times 1000}{2 \times 45964}$$

$$= 56.566 + 61.244 = 117.81 \text{ feet}$$

From (55) with $x = 500$ feet, $u = 1$

$$\tan \beta_3 = \frac{2000}{45964}\left[(5-1) - \frac{5 \times 200 + 400 \times 10}{2000}\right] + \frac{5.63}{45964}(1000-500)$$

$$= .0653 + .0612 = .1265, \quad \beta_3 = 7°\text{-}13'$$

(a) = 117.81 feet

(b) = 7°-13′

Stresses in Suspended Cables

Inclined Span—Multiple Loads—Counterweighted

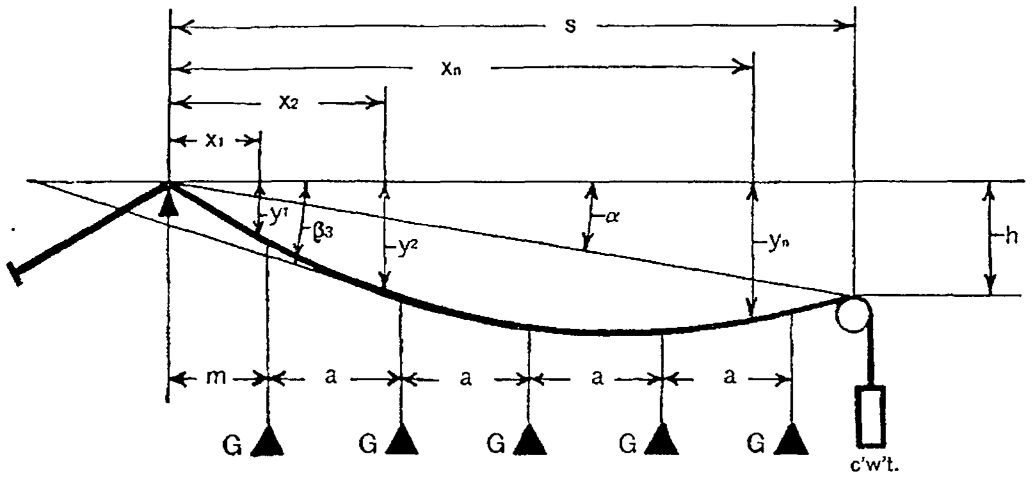


Figure 14

For y add to formula (52) and (53) x tan α (56)

Formula (54) becomes $t = \dfrac{2Gz + wx\,(s-x)}{2\,(y-x\tan\alpha)}$ (57)

tan β_3 is found by completing formula (55) with $\pm$ tan α (58)

Wind and Ice Loads

The change in length of cables due to change in temperature has not been taken into account in the examples given above. In counterweighted spans such a change in length results in a small movement of the counterweight, the tension and deflection remaining constant. However, in anchored spans the change in length due to temperature changes results in changes in cable tension, and frequently the effect of such changes must be carefully considered.

To find the change in length, multiply the length of the cable by the number of degrees (F.) variation in temperature and the product by the coefficient .0000069 for steel rope wire.

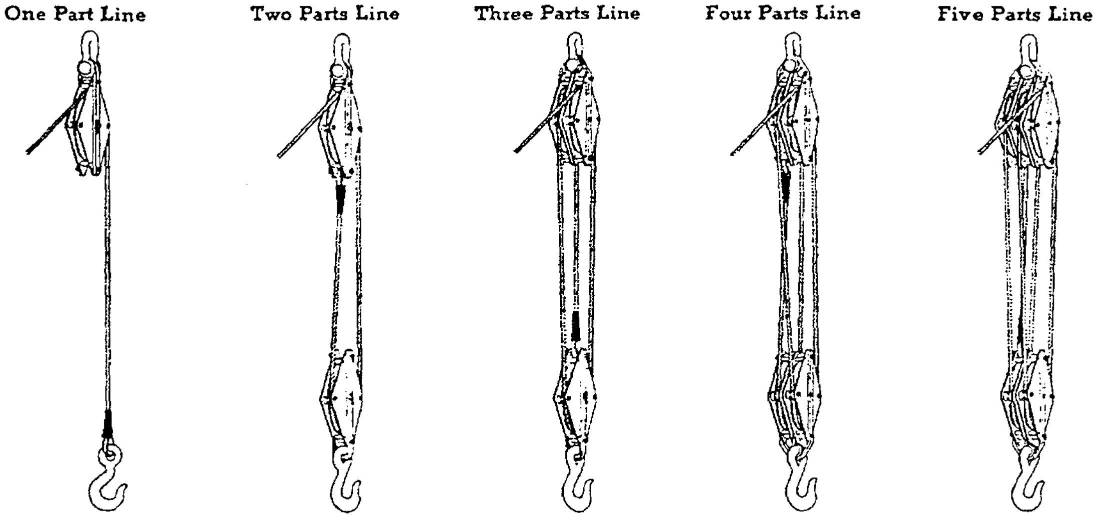
Wind loads on cylindrical surfaces, such as wire cables, are determined from maximum wind velocities. If P equals wind pressure in pounds per square foot of projected area and V = actual wind velocity in miles per hour, then $P = 0.0025\,V^2$. This gives 4.0 pounds per square foot for 40 miles per hour, 12.2 pounds per square foot for 70 miles per hour, and 20.2 pounds per square foot for 90 miles per hour.

Where exceptionally severe sleet conditions occur, the cables are assumed to be covered with a coating of ice ¾ inch thick, or a total of 1½ inches of ice plus the diameter of cable. Where the sleet conditions are less severe, the ice coating is assumed to be ½ inch thick, or a total of 1 inch plus the diameter of cable. Then wind load is based on the total diameter of ice plus cable, and the resultant cable load is determined from the horizontal wind load and vertical load of cable and ice. The weight of ice is approximately 56 pounds per cubic foot, or .0324 pounds per cubic inch.

Multiple Sheave Blocks

When a load is statically supported by multiple-part wire rope tackle, as shown in the illustrations below, the load on each part of rope and on the lead line is equal to the weight of the load supported, divided by the number of parts of rope supporting the load.

When the load so supported is raised by means of the tackle system, the stress in the rope increases progressively from the dead end to the lead line. This increased tension is due to the cumulative effect of friction in turning the individual sheaves, and of the force required to bend the rope about the sheaves. The amount of the increase in rope stress depends upon the size, grade and construction of the rope, size of sheaves and sheave pins and the coefficient of friction in the sheave pin bearings.



Efficiency of Wire Rope Tackle

The "efficiency" of a tackle system in raising a load is the ratio of the tension in each part of rope under static conditions to the tension in the lead line when the load is being raised at constant speed.

The "lead line factor" of the system is the ratio of the tension in the lead line when raising the load at constant speed to the total static weight of the load.

In order to determine the efficiency and lead line factor of a multiple-sheave system, we use the formulae:

$$\text{Efficiency} = \frac{K^N - 1}{K^S N (K-1)}$$

$$\text{Lead Line Factor} = \frac{1}{N \times \text{Efficiency}}$$

in which: N = Number of Parts of Rope Supporting the Load.

S = Number of Revolving Sheaves in the System.

K = Ratio of stress in rope unwinding from each sheave to the stress in the rope winding onto the sheave.

The factor "K" in this formula accounts for the friction at the sheave bearing and the resistance of the rope to flexure. When exact values of "K" are required, they can be determined by experiment. However, for practical purposes it has been found that for the usual constructions of hoisting ropes and average condition of the bearings, the following values for "K" are sufficiently accurate for most purposes:

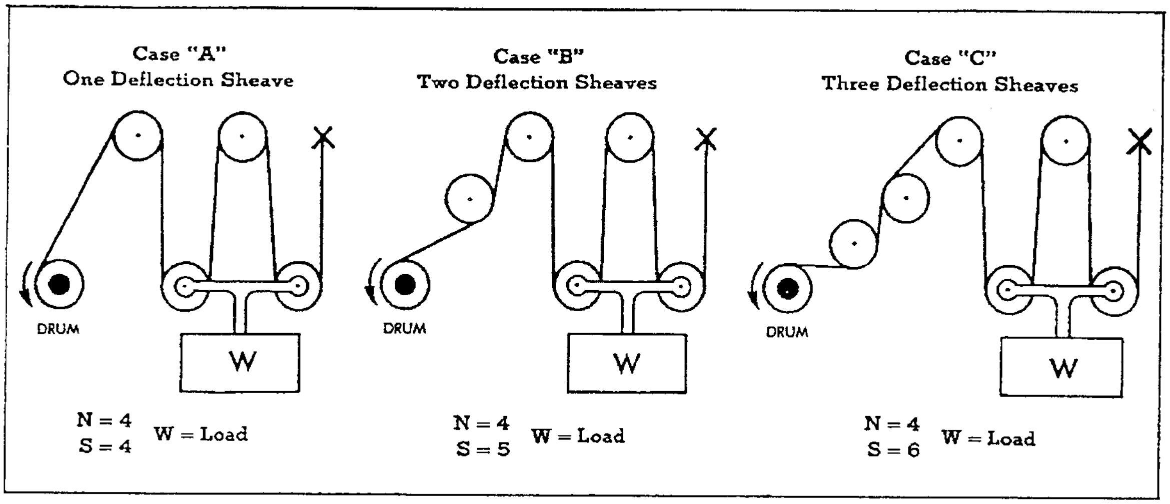
For plain bearing sheaves, K = 1.09

For roller bearing sheaves, K = 1.04

Efficiency of Wire Rope Tackle

Some of the common arrangements of wire rope tackle for boom hoists, derrick load lines, etc., are shown in the diagrams below, together with a useful table showing Efficiency and Lead Line Factor in each case, with various numbers of parts of line supporting the load.

In the case of overhead cranes, the drums are usually located overhead, and there are less idle deflector sheaves used in the system. It is also a common arrangement on equipment of this type for both ends of the rope to wind onto the drum, with an equalizing sheave or rocker connection in the center of the system to compensate for minor differences in rate of rope travel. Equalizer sheaves should not be counted as revolving sheaves in these calculations. Equalized systems may be divided at the equalizer and data for each half of the system determined, or



Efficiencies and Lead Line Factors for Derricks, Booms, etc.

Lead Line Stress = Lead Line Factor × Load

N	Plain Bearing Sheaves K=1.09						Roller Bearing Sheaves K=1.04					
	Efficiency			Lead Line Factor			Efficiency			Lead Line Factor		
	Case A	Case B	Case C	Case A	Case B	Case C	Case A	Case B	Case C	Case A	Case B	Case C
2	.880	.807	.740	.568	.620	.675	.943	.907	.872	.530	.551	.574
3	.844	.774	.710	.395	.431	.469	.925	.889	.855	.360	.375	.390
4	.810	.743	.682	.309	.336	.367	.908	.873	.839	.275	.286	.298
5	.778	.714	.655	.257	.280	.305	.890	.856	.823	.225	.234	.243
6	.748	.686	.629	.223	.243	.265	.874	.840	.808	.191	.198	.206
7	.719	.660	.605	.199	.216	.236	.857	.824	.793	.167	.173	.180
8	.692	.635	.582	.181	.197	.215	.842	.809	.778	.148	.154	.161
9	.666	.611	.561	.167	.182	.198	.826	.794	.764	.135	.140	.145
10	.642	.589	.540	.156	.170	.185	.811	.780	.750	.123	.128	.133
11	.619	.568	.521	.147	.160	.175	.796	.766	.736	.114	.119	.124
12	.597	.547	.502	.140	.152	.166	.782	.752	.723	.106	.111	.115
13	.576	.528	.485	.133	.145	.159	.768	.739	.710	.100	.104	.108
14	.556	.510	.468	.128	.140	.153	.755	.725	.698	.095	.099	.102
15	.537	.493	.452	.124	.135	.147	.741	.713	.685	.090	.094	.097

Note: The above cases apply also where the rope is dead ended at the lower or traveling block.

Efficiency of Wire Rope Tackle

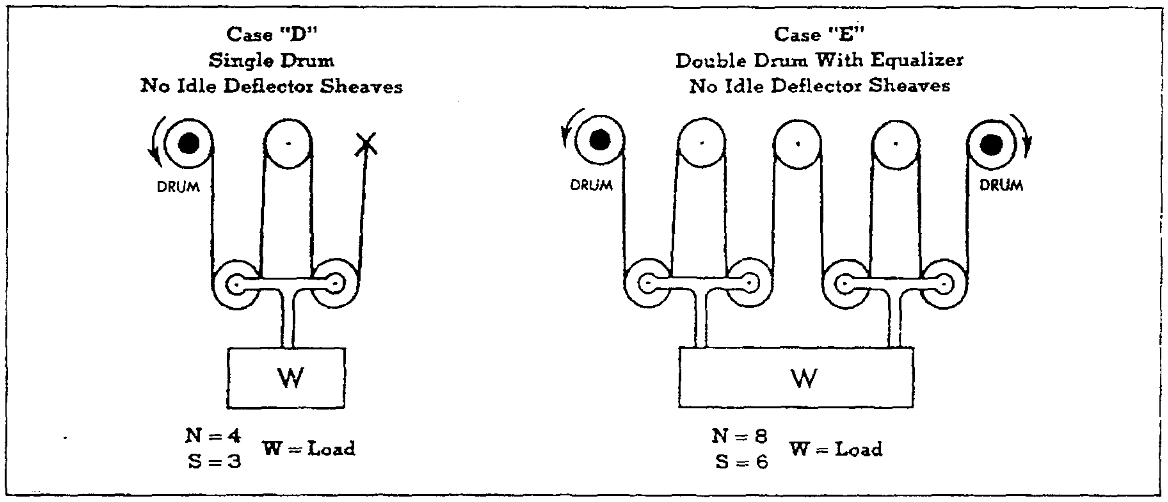
they may be solved by the formula:

$$\text{Efficiency} = \frac{2(K^{\frac{N}{2}} - 1)}{K^{\frac{S}{2}} N (K-1)}$$

$$\text{Lead Line Factor} = \frac{1}{N \times \text{Efficiency}}$$

in which N, S, and K have the same definitions as before.

Two common overhead crane arrangements are illustrated below, together with the applicable table for finding their Efficiencies and Lead Line Factors when various numbers of parts of line are used.



Efficiencies and Lead Line Factors for Overhead Cranes only

Lead Line Stress = Lead Line Factor × Load

N	Plain Bearing Sheaves K = 1.09				Roller Bearing Sheaves K = 1.04			
	Efficiency		Lead Line Factor		Efficiency		Lead Line Factor	
	Case D	Case E	Case D	Case D	Case D	Case E	Case D	Case E
2	.959	1.000	.522	.500	.981	1.000	.510	.500
3	.920		.362		.962		.346	
4	.883	.959	.283	.261	.944	.981	.265	.255
5	.848		.236		.926		.216	
6	.815	.920	.204	.181	.909	.962	.183	.173
7	.784		.182		.892		.160	
8	.754	.883	.166	.141	.875	.944	.143	.132
9	.726		.153		.859		.130	
10	.700	.848	.143	.118	.844	.926	.119	.108
11	.674		.135		.828		.110	
12	.650	.815	.128	.102	.813	.909	.101	.091
13	.628		.122		.799		.096	
14	.606	.784	.118	.091	.785	.892	.091	.080
15	.586		.114		.771		.086	

Note: The above cases apply also where the rope is dead ended or the equalizer is located at the lower or traveling block.

Stresses in Wire Ropes on Inclined Planes and Slopes

There are two methods of designating the grade or pitch of an inclined plane or slope. The first is by using the angle which the line of the incline or slope makes with the horizontal. The second is by using a percentage figure which is the ratio of the vertical rise to the horizontal distance, and which is equivalent to 100 times the tangent of the angle of incline.

Neglecting friction, the pull on the rope due to loaded cars on an incline or slope is equivalent to the total weight of the loaded cars multiplied by the sine of the angle of incline. In cases where this angle is not the same throughout, the value to be used must be the angle of that part on which the cars are resting. It must be remembered that the weight of the rope is to be added to the weight of the loaded cars, as this has a bearing on the final result, especially in the case of long inclines or slopes.

In most cases, friction must be considered in determining the pull on the rope. The frictional load is dependent on the car friction, which remains constant for a given angle of incline, and the rope friction, which varies depending on how much rope is resting on the incline or slope. Particular attention must be paid to the fact that when a rope is used to haul loaded cars up a grade, the frictional load is added to the pull caused by the weight of the material moved, while if the rope is used to lower loaded cars downhill, the friction load acts opposite to the main load, and is subtracted from it.

Car friction is greatest on a level stretch of track. On an incline, it depends on the cosine of the angle of incline and will usually be found to be equivalent to the weight of the loaded car multiplied by .03 times the cosine of the angle of incline.

Rope friction is an exceedingly variable factor. It depends on the spacing and condition of track rollers or rubbing boards, the contour of the incline or slope, and whether or not the tension on the rope is sufficient to raise it off its supports. In order to be sure of a large enough allowance, a coefficient should be used having at least twice the value of that used for car friction; therefore, the rope friction would be equivalent to the weight of the rope between car and drum multiplied by .06 times the cosine of the angle of incline. In this case, for the sake of safety, use the minimum angle where there is more than one grade.

To find the total pull on a rope, we must therefore determine three values. First, the gravity load; second, the car friction load; and third, the rope friction load.

The gravity load is found by multiplying the total weight of loaded cars plus the weight of rope between car and drum by the load factor for the proper grade as found in column 3 of table on page 36.

The car friction load is found by multiplying the weight of the loaded car by the proper car friction factor given in column 4.

The rope friction load is found by multiplying the weight of rope between car and drum by the rope friction factor (see column 5) for the minimum grade between car and drum.

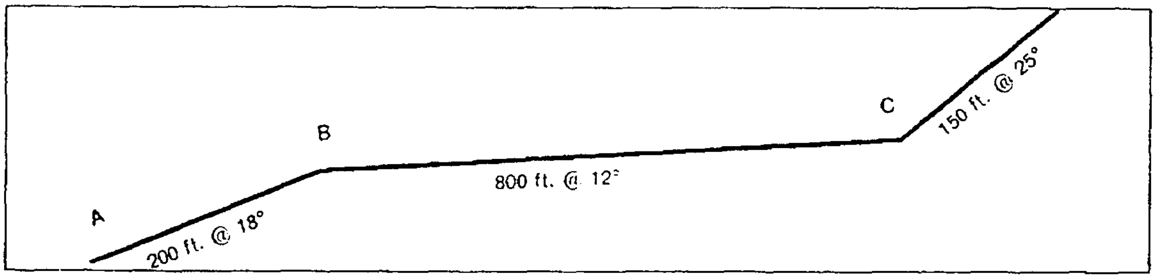
For ascending trips, the friction loads must be added to the gravity load, and for descending trips they must be subtracted. These values should be determined for the lowest point of each section when there is more than one grade.

To the sum of these three loads should be added a factor to cover the stress due to acceleration. For speeds below 500 ft. per minute, a 5% addition to the total stress in the wire rope is usually adequate. For speeds of 500 ft. to 1000 ft. per minute, the factor should be 10%. For higher speeds, the stress due to acceleration should be calculated. See Stresses due to Acceleration, page 8.

In selecting a proper rope, the total pull should be multiplied by a factor of safety of at least 6, and in cases where the abrasive conditions are particularly severe this factor should be increased in order to make allowance for the loss of strength that will result from wearing of the rope.

Stresses in Wire Ropes on Inclined Planes and Slopes

EXAMPLE: A trip of cars weighing 27,500 lbs. when loaded is being hauled up a slope with contour as shown in the sketch. The speed is 850 feet per minute. What is the maximum rope pull? What rope should be used?



It is necessary to assume a certain size rope at the outset in order to get the gravity and rope friction loads. If the results are close to the assumed size, the figures may stand; but if there is much of a variation, the process should be repeated, using the size rope found to be approximately correct in the first solution. 1″ 6 × 7 Rope weighing 1.5 lbs. per ft. will be assumed, together with the fact that sheaves and drums are sufficiently larger for this construction. The values must be found for car load at points A, B, and C.

1″ 6×7 Monitor Lang Lay Excellay FC 150 lbs/Foot Breaking Strength 39.7 Tons, or 79,400 lbs.

Point A	Gravity Load	= [27,500 + (1,150 × 1.50)] × .3090	= 9,030
	Car Friction Load	= 27,500 × .0285	= 784
	Rope Friction Load	= 1,150 × 1.50 × .0587	= 101
			9,915
	10% Acceleration Stress		991
		Total	10,906
Point B	Gravity Load	= 27,500 (950 × 1.50) × .2079	= 6,013
	Car Friction Load	= 27,500 × .0293	= 806
	Rope Friction Load	= 950 × 1.50 × .0587	= 84
			6,903
	10% Acceleration Stress		690
		Total	7,593
Point C	Gravity Load	= [27,500 + (150 × 1.50)] × .4226	= 11,717
	Car Friction Load	= 27,500 × .0272	= 748
	Rope Friction Load	= 150 × 1.50 × .0544	= 12
			12,477
	10% Acceleration Stress		1,248
		Total	13,725
	For Descending Load (Point C)		
	Gravity Load		= 11,717
	Less Car Friction		= −748
	Less Rope Friction		= −12
			10,957
	10% Acceleration Stress		1,096
		Total	12,053

It will be seen from the above that the load is greatest when the cars are at point C, and are traveling on the steepest grade. This will be found true in the great majority of cases, but to be absolutely certain of the correct figures all problems should be solved as above. Again attention is called to the fact that for descending loads the friction values must be subtracted from the load values, and in this case the load at point C would be 12,053 lbs.

Assuming a factor of safety of 6, the rope selected should have a breaking strength of 6×13,725 = 82,350 lbs. A 1″ dia. 6×7 Monitor FC at 79,400 lbs. does not have sufficient strength. A 1″ dia. 6×7 Monitor AA FC at 87,400 lbs. is satisfactory. Calculations for the 1″ dia. 6×7 Monitor AA FC are the same as for the 1″ dia. 6×7 Monitor FC Rope.

Stresses in Wire Ropes on Inclined Planes and Slopes

Load Factors

Angle of Incline Degrees	% Grade	Load Factor	Car Friction Factor	Rope Friction Factor	Angle of Incline Degrees	% Grade	Load Factor	Car Friction Factor	Rope Friction Factor
0	0.0	.0000	.0300	.0600	46	103.5	.7193	.0208	.0416
1	1.7	.0174	.0300	.0600	47	107.2	.7313	.0205	.0409
2	3.5	.0349	.0300	.0600	48	111.1	.7431	.0201	.0401
3	5.2	.0523	.0299	.0599	49	115.0	.7547	.0197	.0394
4	7.0	.0698	.0299	.0599	50	119.2	.7660	.0193	.0385
5	8.7	.0872	.0299	.0598	51	123.5	.7771	.0189	.0377
6	10.5	.1045	.0298	.0597	52	128.0	.7880	.0185	.0370
7	12.3	.1219	.0298	.0595	53	132.7	.7986	.0180	.0361
8	14.0	.1392	.0297	.0594	54	137.6	.8090	.0176	.0352
9	15.8	.1564	.0296	.0593	55	142.8	.8191	.0172	.0344
10	17.6	.1737	.0295	.0591	56	148.2	.8290	.0168	.0335
11	19.4	.1908	.0294	.0589	57	154.0	.8387	.0163	.0327
12	21.3	.2079	.0293	.0587	58	160.0	.8480	.0159	.0318
13	23.1	.2249	.0292	.0585	59	166.4	.8572	.0154	.0309
14	24.9	.2419	.0291	.0583	60	173.2	.8660	.0150	.0300
15	26.8	.2588	.0290	.0580	61	180.4	.8746	.0145	.0290
16	28.7	.2756	.0288	.0577	62	188.1	.8829	.0141	.0282
17	30.6	.2924	.0287	.0574	63	196.3	.8910	.0136	.0272
18	32.5	.3090	.0285	.0571	64	205.0	.8988	.0131	.0263
19	34.4	.3256	.0284	.0567	65	214.4	.9063	.0127	.0253
20	36.4	.3420	.0282	.0564	66	224.6	.9135	.0122	.0244
21	38.4	.3584	.0280	.0560	67	235.6	.9205	.0117	.0234
22	40.4	.3746	.0278	.0556	68	247.5	.9272	.0112	.0224
23	42.4	.3907	.0276	.0552	69	260.5	.9336	.0107	.0215
24	44.5	.4067	.0274	.0548	70	274.7	.9397	.0102	.0205
25	46.6	.4226	.0272	.0544	71	290.4	.9455	.0098	.0195
26	48.8	.4384	.0270	.0540	72	307.8	.9511	.0093	.0185
27	50.9	.4540	.0267	.0535	73	327.1	.9563	.0088	.0175
28	53.2	.4695	.0265	.0530	74	348.7	.9613	.0083	.0165
29	55.4	.4848	.0262	.0525	75	373.2	.9659	.0078	.0155
30	57.7	.5000	.0260	.0520	76	401.1	.9703	.0073	.0145
31	60.1	.5150	.0257	.0515	77	433.1	.9744	.0067	.0135
32	62.5	.5299	.0254	.0509	78	470.5	.9781	.0062	.0124
33	64.9	.5446	.0252	.0503	79	514.5	.9816	.0057	.0114
34	67.4	.5592	.0249	.0497	80	567.1	.9848	.0052	.0104
35	70.0	.5736	.0246	.0491	81	631.4	.9877	.0047	.0094
36	72.6	.5878	.0243	.0485	82	711.5	.9903	.0042	.0083
37	75.3	.6018	.0240	.0479	83	814.4	.9925	.0036	.0073
38	78.1	.6157	.0237	.0473	84	951.4	.9945	.0031	.0063
39	81.0	.6293	.0233	.0467	85	1143.0	.9962	.0026	.0052
40	83.9	.6428	.0230	.0460	86	1430.0	.9976	.0021	.0042
41	86.9	.6561	.0226	.0453	87	1908.1	.9986	.0015	.0031
42	90.0	.6691	.0223	.0446	88	2863.6	.9994	.0010	.0021
43	93.2	.6820	.0219	.0439	89	5728.9	.9998	.0005	.0010
44	96.6	.6947	.0216	.0431	90	∞	1.0000	.0000	.0000
45	100.0	.7071	.0212	.0424					

Maximum Load on a Wire Rope

It is sometimes impossible to estimate the load imposed on a rope by totaling the stresses due to weight of live and dead loads, weight of rope, friction and acceleration. In these cases the maximum stress on the rope may be approximated by a more indirect method. This method is not intended for very close calculations, and should not be used where the rope is subjected to sudden jerks. It will serve as a guide, however, to show whether or not a rope is overloaded.

Practically every engine or electric motor has a known horse power rating. For short periods of time, these may usually be operated with a very high overload, such as 25% for steam and 50% for electricity. Knowing the horse power of the prime mover provides a basis for this calculation. When hard pulling is required, the overload values mentioned above should be added to the horse power rating.

One horse power is the equivalent of 550 ft. lbs. of work per second; therefore, the total horse power exerted by an engine or electric motor in pulling a rope may be expressed:

$$\text{Horse power} = \frac{\text{feet} \times \text{pounds}}{\text{seconds} \times 550}$$

where feet represents the number of feet of rope wound on the drum in the measured time.

By rearrangement:

$$\begin{matrix}\text{Pull on rope}\\ \text{in pounds}\end{matrix} = \frac{\text{Horse power} \times \text{seconds} \times 550}{\text{feet}}$$

There are now on the right hand side of the equation two unknown factors, time and distance. By placing a marker on the rope or watching the end connection, it is very easy, with the aid of a watch and a rule, to determine very closely what these factors actually are.

The time at which these observations are taken should be when the engine or motor is pulling the hardest, as indicated by sound and the slowing down of speed. If the equipment is stalled by excessive loads, these observations should be made just before motion ceases.

EXAMPLE: A slack-line excavator driven by a 25 h.p. electric motor is digging in very hard ground. When the bucket strikes the hard places, it digs 15 feet in 10 seconds. What is the pull on the line?

By using the formula we find:

$$\begin{matrix}\text{Pull on rope}\\ \text{in pounds}\end{matrix} = \frac{25 \times 1.5 \times 10 \times 550}{15} = 13{,}750 \text{ lbs.}$$

where the factor 1.5 in the above represents the 50% overload on the motor.

Providing a safety factor of five for the rope on this installation requires a rope with a strength of $5 \times 13{,}750 = 68{,}750$ pounds.

Grooves

Grooves in sheaves and drums should be slightly larger than the rope, in order to avoid pinching and binding of the strands, and to permit the rope to adjust itself to the radius of curvature. The greater the angle of approach to the groove, the larger the tolerance required to prevent excessive flange wear.

The diameter of an unused rope may exceed the nominal diameter by the amounts specified in the following table.

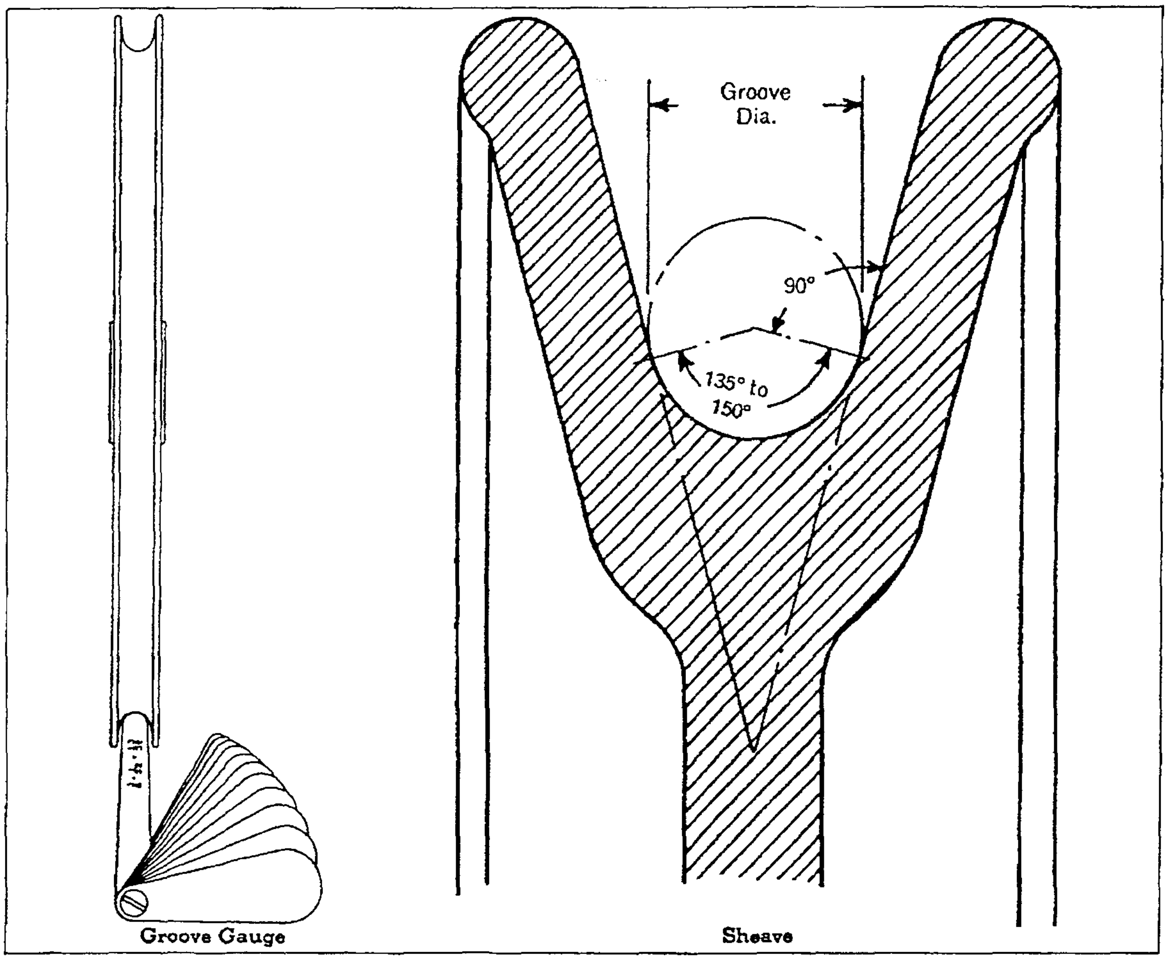
Diameter Tolerances for Wire Rope

Nominal Diameter of Rope in Inches	Undersize %	Oversize %
0 to 1/8	0	8
Over 1/8 to 3/16	0	7
Over 3/16 to 1/4	0	6
Over 1/4	0	5

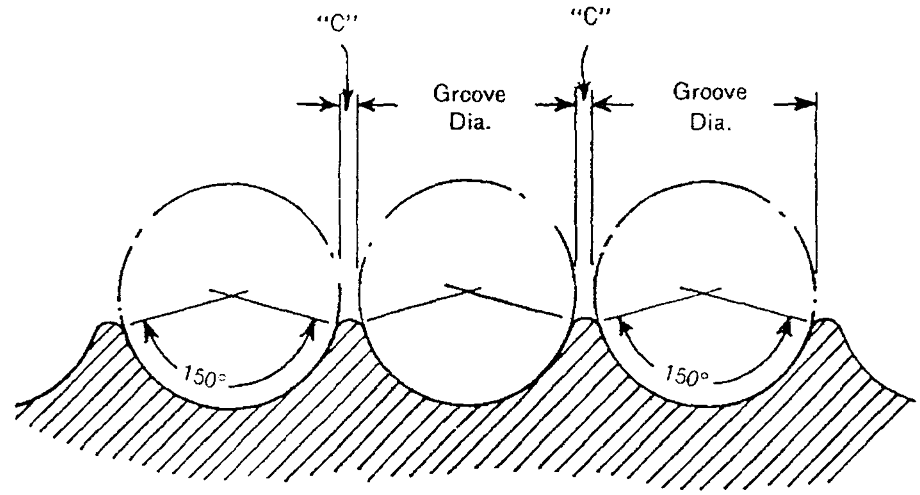
Grooves which have been worn to the minimum diameter shown in the table should be remachined to the minimum diameter shown for New or Remachined Grooves. Grooves of too large diameter do not properly support the rope, and permit it to become elliptical.

Tolerance Groove Diameter Should Exceed Nominal Rope Diameter

Nominal Diameter of Rope in Inches	Minimum (%)	New or Remachined Grooves (%)
0 to 1/8	4	8
Over 1/8 to 3/16	3.5	7
Over 3/16 to 1/4	3	6
Over 1/4	2.5	5



Grooves



Spiral Grooved Drum

Rope Dia. Inches	Clearance "C" in Inches
1/2 - 1 1/4	1/16
1 3/8 - 1 3/4	3/32
1 7/8 - 2 1/2	1/8

Grooved drums are recommended in preference to smooth drums as the grooves furnish better support for the rope than the flat surface of smooth drums, and the more uniform winding results in less abrasive operating conditions for the rope.

Annular, or concentric grooves in drums should not be greater in depth than 10% of the rope diameter. Deeper grooves will cause undue distortion of the rope at the points of cross-over from one groove to the next. Clearances recommended for spiral type grooves are suitable for annular grooves.

Grooves should be smooth. Those which have taken the imprint of the outer wires of previous ropes exert a grinding action on new ropes. A harder metal is recommended for installations where the radial pressure of the rope on the groove scores the groove. This radial pressure is directly proportional to the load on the rope, and inversely proportional to the diameter of the rope and the tread diameter of the sheave or drum. This may be expressed as:

$$P = \frac{L}{RD}$$

Where: P = pressure in pounds per square inch.

L = load on the rope in pounds.

R = tread radius (one-half tread diameter) of the sheave or drum in inches.

D = diameter of the rope in inches.

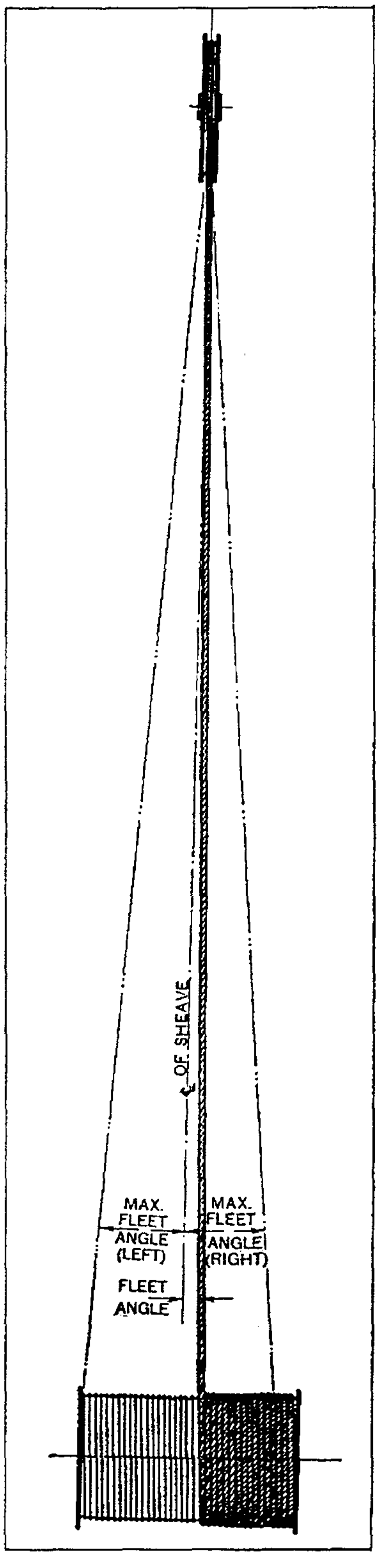
Maximum Radial Pressure

Rope Classification	Cast Iron	Cast Steel	Manganese Steel (11-13% mn.)
3x25 Torque Bal.	300	550	1500
6x7 Regular Lay	300	550	1500
6x7 Lang Lay	345	630	1725
6x19 Regular Lay	500	900	2500
6x19 Lang Lay	575	1035	2875
6x37 Regular Lay	600	1075	3000
6x37 Lang Lay	690	1235	3450
6x30 Type G	800	1450	4000

Fleet Angle

On installations where the wire rope passes over a lead sheave then on to a drum, it is important that the lead sheave be located at a sufficient distance from the drum to maintain a small fleet angle at all times. The fleet angle is the side angle at which the rope approaches the sheave from the drum. It is the angle between the center line of the sheave and the wire rope.

Experience has proven that the best wire rope service is obtained when the maximum fleet angle is not more than 1½ degrees for smooth drums and 2 degrees for grooved drums. The maximum fleet angle is the angle between the center line of the sheave and the rope when it is at the end of its traverse travel on drum. Fleet angles of 1½ and 2 degrees are the equivalents of approximately 38 and 29 feet, respectively, of lead for each foot of rope traverse travel either side of the center line of the sheave. Thus a smooth drum with 3 ft. traverse travel with the center of travel in line with the lead sheave should be located not less than 57 ft. from the lead sheave. If the drum were grooved, the minimum distance should be approximately 43.5 ft.



Unreeling and Uncoiling

When removing wire rope from the reel on which it is received, or from the coil if it is a coil shipment, it is imperative that the reel or coil

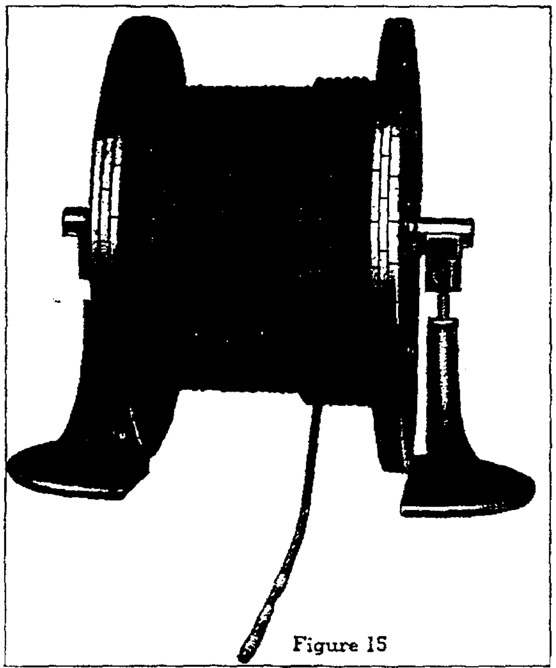


Figure 15

rotates as the rope unwinds. Attempts to unwind rope from stationary coils or reels will result in

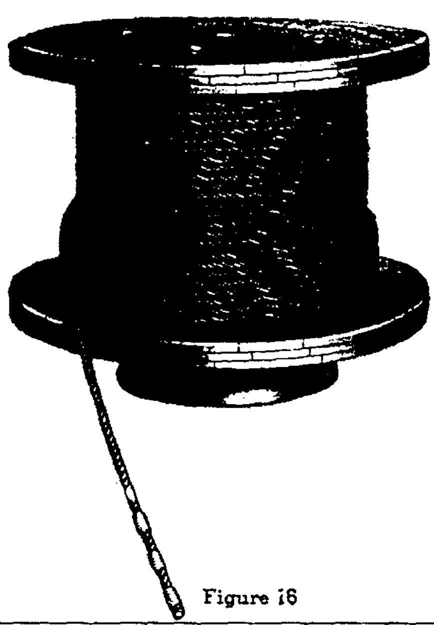


Figure 16

kinking the rope, and once a kink is formed the rope at that point is ruined beyond repair.

Unreeling: If the rope is to be unwound from a reel, there are three correct methods of unreeling.

1. The reel may be mounted on a shaft supported by two jacks as shown in Figure 15. The rope is then pulled from the reel by a workman holding the end of the rope and walking away from the reel which rotates as the rope unwinds. This is the common approved method of unreeling wire rope.

2. The reel may be mounted on an unreeling stand as shown in Figure 16. It is then unwound in the same manner as described above. Care must be exercised to keep the rope under sufficient tension to prevent slack accumulated and the rope dropping below the lower reel head.

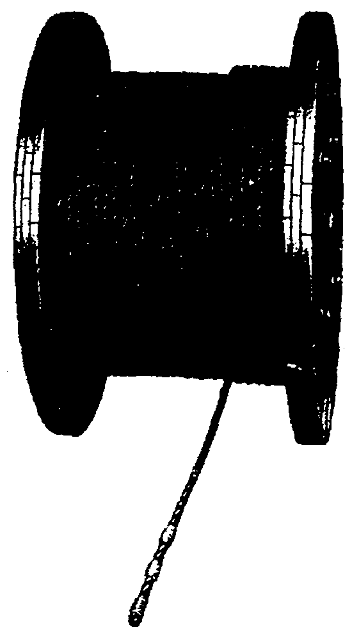


Figure 17

3. The end of the rope may be held and the reel rolled along the ground as shown in Figure 17.

When re-reeling rope from one horizontal reel to a second horizontal reel, the rope should travel from the top of the full reel to the top of the empty reel: or, from the bottom of the full reel to the bottom of the empty reel.

Unreeling and Uncoiling

When re-reeling rope from one vertical reel to a second vertical reel, the rope should travel in a line parallel to a line drawn between the axes of the two reels, and the reels should rotate in the same direction.

The object of these instructions is to avoid putting a reverse bend into the rope as it is being re-reeled. Reeling the ropes so that a reverse bend is put into the rope causes it to become livelier and harder to handle.

Uncoiling: If the rope is to be unwound from a coil, there is only one correct method of uncoiling. The end of the rope should be held and the coil rolled on the ground like a hoop as shown in Figure 18.

Failure to use one of these methods has ruined many lengths of wire rope. Hemp rope can be unwound by pulling through the eye of the coil or from the stationary reel standing on end without seriously injuring it. These methods should never be attempted when handling wire rope.

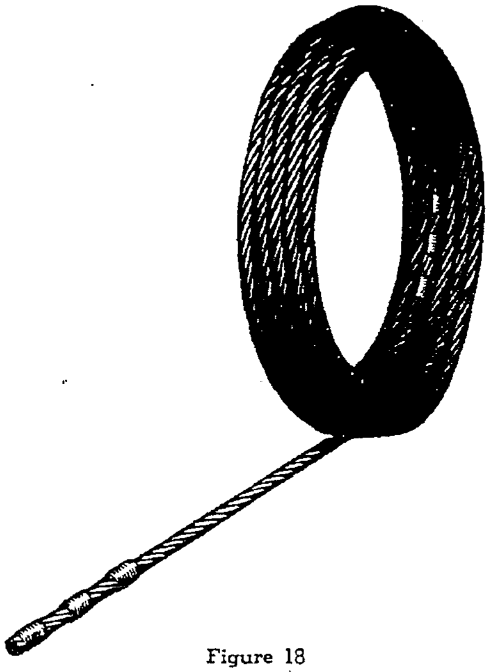


Figure 18

Spooling and Coiling

Correct Method of Winding
First Layer on Drum

When winding the first layer of wire rope on a smooth drum, it should be started from the side which causes the coils on the drum to hug together. This tends to produce a uniform and close wound first layer, which, in turn, tends toward uniformity of successive layers. It also results in an even wind of the coils of the first layer on the drum when the rope is re-wound after the load has been slacked off and then picked up.

When the first layer of wire rope is wound on a smooth drum in the wrong direction, the coils tend to spread apart. Coils of the second layer wedge themselves between the open coils, causing non-uniform winding, which may result in damaging the rope from crushing and abrasion. There is also a tendency for the remaining coils on the drum, when the rope is out and the load slacked off and then applied again, to cross other coils with resultant crushing of the rope at the points of cross-over.

The proper direction of winding the first layer on a smooth drum is determined by standing behind the drum and looking along the path the rope travels.

Right Lay Wire Ropes	Overwind:	From Left to Right
	Underwind:	From Right to Left
Left Lay Wire Ropes	Overwind:	From Right to Left
	Underwind:	From Left to Right

When overwinding the top of the drum rotates toward the observer while the rope is winding on. When underwinding the top of the drum rotates away from the observer while the rope is winding on.

Correct Method of Coiling Wire Rope

When hand coiling wire rope into a coil on the floor or bench, coil it in the direction that will take twist out of the rope. When coiled in the proper direction little difficulty will be encountered, but if coiled in the wrong direction twists are added and the rope becomes too lively to readily form into a coil.

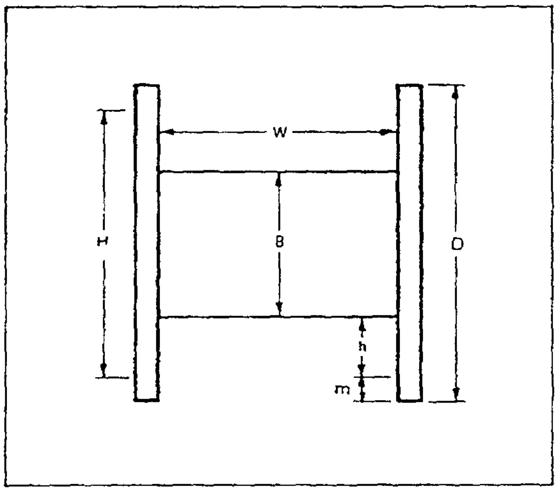
Looking down on the coil, the proper directions are:

Right Lay Wire Ropes—Coil in a Clockwise Direction.

Left Lay Wire Ropes—Coil in a Counter-Clockwise Direction.

Drum and Reel Capacities

Let D = Diameter of Head in Inches.
B = Diameter of Barrel in Inches.
h = Depth of Cable in Inches.
W = Width between Flanges in Inches.
d = Diameter of Cable in Inches.
L = Length of Cable in Feet.
m = margin



To Compute Length of Cable in Feet for any Reel or Drum: L = Factor × W × h × (B + h)

A table of factors for ropes to the maximum oversize tolerance (as shown previously in this handbook) is presented below.

Nominal Rope Diameter	Factor	Nominal Rope Diameter	Factor
1/4	3.728	2 1/4	.0469
5/16	2.432	2 3/8	.0421
3/8	1.689	2 1/2	.0380
7/16	1.241	2 5/8	.0345
1/2	.9498	2 3/4	.0314
9/16	.7505	2 7/8	.0287
5/8	.6079	3	.0264
3/4	.4222	3 1/8	.0243
7/8	.3102	3 1/4	.0225
1	.2375	3 3/8	.0208
1 1/8	.1876	3 1/2	.0194
1 1/4	.1520	3 5/8	.0181
1 3/8	.1256	3 3/4	.0169
1 1/2	.1055	3 7/8	.0158
1 5/8	.0899	4	.0148
1 3/4	.0775	4 1/4	.0131
1 7/8	.0675	4 1/2	.0117
2	.0594	4 3/4	.0105
2 1/8	.0526	5	.0095

The Formula can be readily derived:

(1) Length of Coil of Middle Layer

$$= \frac{\pi}{12}\left(B + \frac{H-B}{2}\right)$$

$$\text{Number of Coils} = \frac{W}{d}$$

$$\text{Number of Layers} = \frac{H-B}{2d}$$

$$L = \frac{\pi}{12}\left(B + \frac{H-B}{2}\right) \times \frac{W}{d} \times \frac{H-B}{2d}$$

$$= \frac{\pi W(H+B)(H-B)}{48d^2}$$

(2) Volume of Drum in Cubic Inches

$$= W\left(\frac{\pi H^2}{4} - \frac{\pi B^2}{4}\right)$$

$$L = \frac{W}{12d^2}\left(\frac{\pi H^2}{4} - \frac{\pi B^2}{4}\right) = \frac{\pi W}{48d^2}\left(H^2 - B^2\right)$$

$$= \frac{\pi W(H+B)(H-B)}{48d^2}$$

$$L = \frac{\pi W(H+B)(H-B)}{48d^2} = \frac{W(H+B)(H-B)}{15.28d^2}$$

$$= \frac{.06545\ W(H+B)(H-B)}{d^2}$$

$$= \frac{.2618\ Wh(B+h)}{d^2}$$

$$\text{Let Factor} = \frac{.2618}{d^2}$$

then

L = Factor × W × h × (B + h)

When the diameter of the rope is not full oversize or when strand is to be reeled the actual product diameter should be used with the formula

$$L = \frac{.2618\ Wh(B+h)}{d^2}$$

to determine capacities.

When shipping rope on reels, the reels should not be completely filled. A margin (m) should be left to protect the rope.

This Formula is based on the assumption that: the rope is oversize and does not flatten when coiled; and that it is in perfectly uniform layers with no meshing of the coils. These factors vary with size and construction of the cable and with the dimensions of the reel or drum. As these variables tend to offset each other, this method of computing reel and drum capacities has proved to be reliable.

Attaching Sockets

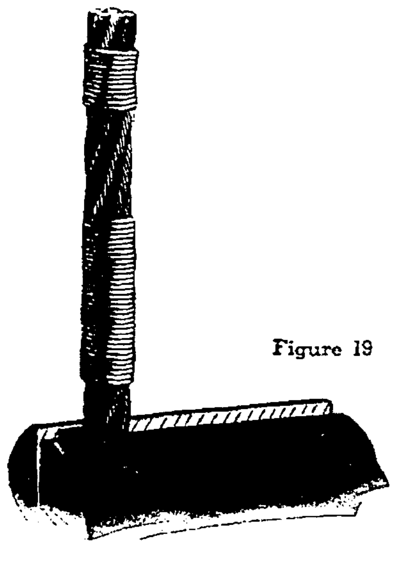


Figure 19

Place an additional seizing on the rope end to be socketed at a distance equal to the length of the basket of the socket from the end of the rope. It is important that this seizing be carefully applied

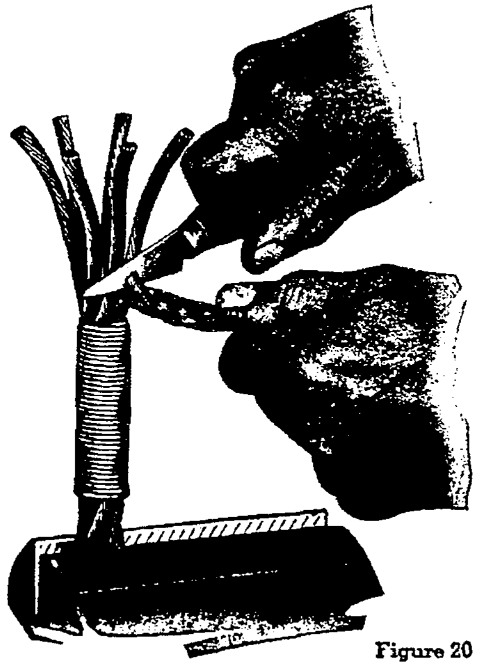


Figure 20

and of sufficient length to prevent any untwisting of the strands, which would result in unequal tension on the strands when socket is attached.

A seizing iron as shown in Fig. 46 page 55 is recommended for applying seizings to ropes one inch diameter and larger.

Place rope end upright in bench vise as shown in Fig. 19.

Remove any seizing above the one referred to in previous paragraph. Cut the fiber core at the seizing. See Fig. 20.

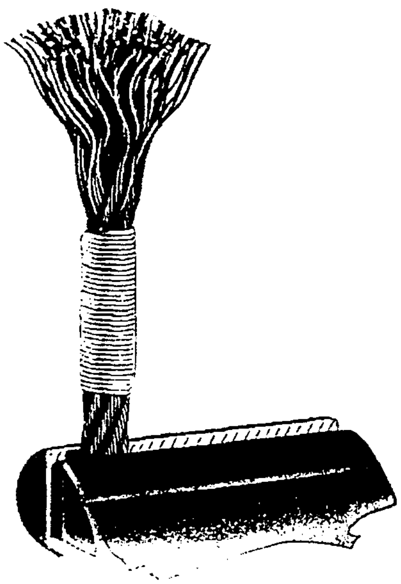


Figure 21

Untwist the strands and broom out the wires. The wires should be separated but not straightened. See Fig. 21.

The wires for the distance they are to be inserted in the socket should be carefully cleaned with a degreaser, and then dipped in a bath of muriatic acid solution (50% commercial muriatic acid and 50% water) for about 30 seconds to one minute, or until the acid has thoroughly cleaned each wire. Care should be taken to prevent acid coming in contact with the fiber core or any portion of the rope other than the broomed wire ends. The acid should be neutralized by next dipping the wires into boiling water to which has been added a small amount of soda.

Draw the ends of the wires together with a piece of seizing wire so that the socket can be forced down over them. See Fig. 22.

Attaching Sockets

Force the socket down over the rope end until it reaches the seizing on the wire rope. Remove the seizing wire from the wires and allow the wires to expand within the socket basket. The ends of the wires should be level with the upper end of the socket basket.

Figure 22

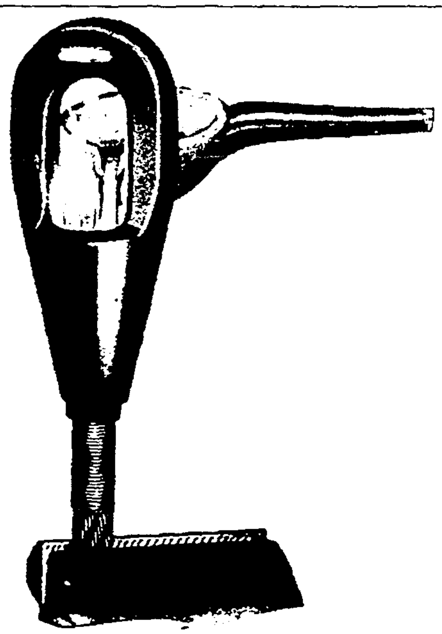


Figure 23

Care should be taken to see that the axis of the socket is in line with the axis of the rope.

Seal the base of the socket with putty, clay, or similar substance.

It is advisable to preheat the basket of the socket to expel any moisture and to prevent the molten zinc from congealing before it has completely filled the lower end of the basket.

Fill the socket basket with molten zinc. The zinc must not be too hot or it will anneal the wires, particularly on small ropes or ropes of small wires. From 850 to 1050 degrees Fahrenheit is the correct temperature. See Fig. 23.

When the zinc has congealed the socket can be plunged into cold water to cool it.

The seizing shall then be removed.

The rope shall then be lubricated adjacent to the socket nose.

Fig. 24 shows a Tiger Wire Rope Socket applied by this method before the seizing was removed.

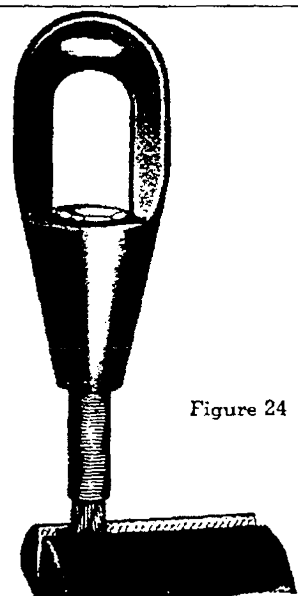


Figure 24

If the socketing is properly done, when tested to destruction, a wire rope will break before it will pull from the socket.

For directions for attaching sockets to strands we recommend that you confer with us stating size and grade of strand. We also suggest that you consult us regarding the socketing of stainless steel.

Splicing Wire Rope

Directions for Splicing 6 Strand Ropes

When a rope is spliced endless, or two similar ropes are spliced together, a short length of each of the two ends is consumed in making the splice. This should be considered when ordering the lengths to be spliced.

There are two endless splices: the Standard Short Splice used for splicing most six strand ropes; and the Long Splice used for splicing Haulage Ropes and long lengths of wire rope operating under heavy loads. The Long Splice differs from the Standard Short Splice in that the distance between tucks and length of tuck is greater and more rope is consumed in making the splice. Otherwise the two are the same.

The total amount of rope to allow for making endless splices is:

Diameter of Wire Rope in Inches....		¼-⅜	½-⅝	¾-⅞	1-1⅛	1¼-1⅜	1½
Length of Rope to Allow in Feet....	Standard Short Splice...	15	20	24	28	32	36
	Long Splice...	30	40	50	60	70	80

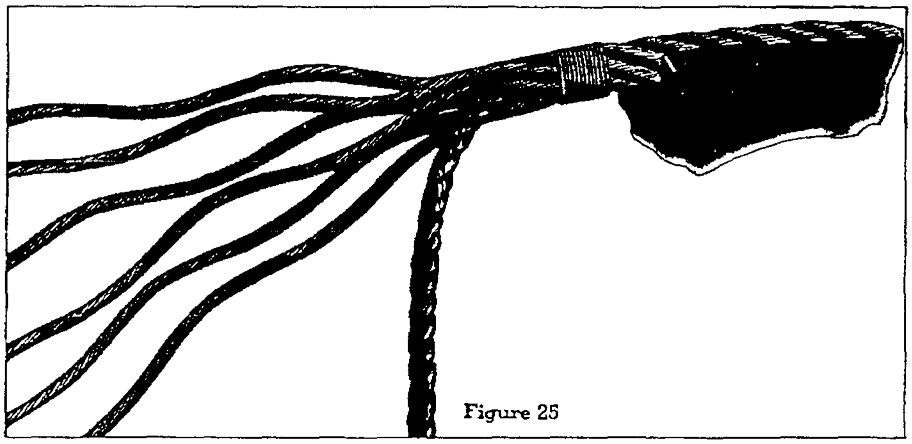


Figure 25

Place a seizing on each of the two rope ends to be spliced together at a distance from the end equal to one-half the allowance for splicing. As an example, if splicing two lengths of ½ inch diameter rope together by the Standard Short Splice, the seizings would be placed ten feet from the ends.

Unlay the strands of each end to these seizings. See Fig. 25.

Cut off the fiber cores as near the seizings as possible.

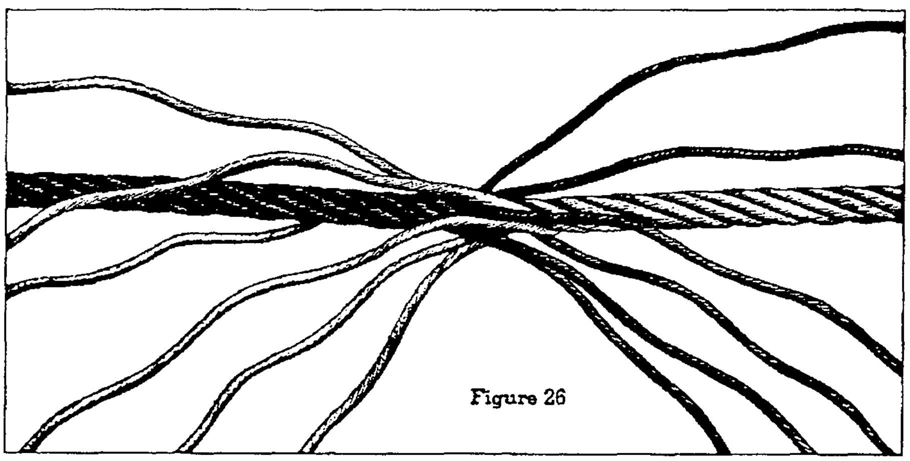


Figure 26

Splicing Wire Rope

Interlock the six strands of each end in a finger lock position. Force the ends together so that seizings are as near each other as possible. Remove the seizings. See Fig. 26.

Unlay one strand, filling the groove vacated by this strand with a strand from the other rope end. Fig. 27 shows the first strand from each rope end being replaced by a strand from the other rope end.

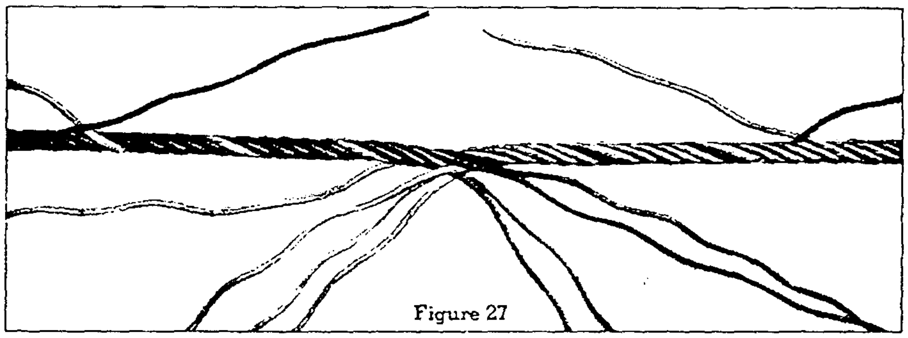


Figure 27

This process should be continued with the first strand from each rope end until only strand equal to the length of tuck remains.

The length of tuck is approximately one-twelfth the amount of rope allowed for the splice.

Diameter of Rope in Inches		1/4–3/8	1/2–5/8	3/4–7/8	1–1 1/8	1 1/4–1 3/8	1 1/2
Length of Tuck in Inches...	Standard Short Splice...	15	20	24	28	32	36
	Long Splice...	30	40	50	60	70	80

The second strand from each rope end should be unlayed and replaced by a strand from the other rope end in the same manner, but stopped at a distance of twice the length of tuck from the point where the first pair of strands protrude. In a similar manner, the third strand from each end should be replaced by a strand from the other end for a distance equal to the length of tuck.

The twelve strands now protrude from the rope in pairs at points separated by twice the length of tuck.

The protruding strand ends should next be cut off leaving lengths equal to the length of tuck. Fig. 28 shows two of the six pairs of strand ends.

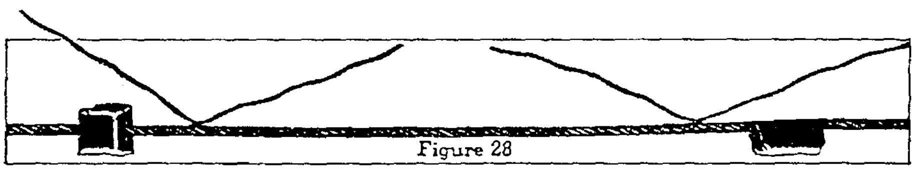


Figure 28

The strand ends of preformed wire ropes should be straightened. It is not necessary to straighten the strand ends of non-preformed ropes. With this exception the method of splicing is the same for both.

The strand ends should be wrapped with friction tape or twine. A layer of tape or twine helps hold the tucked ends in place as it makes them larger in diameter and increases the binding action of the outer strands. It is advisable to build up the diameter of the strand ends with tape or twine as much as possible without making the rope oversize when the strand ends are tucked.

The method of tucking the six pairs of strand ends is the same for each pair.

If a vise is available, it should be used as it facilitates the tucking operation. If a vise cannot be obtained, a manila rope sling and a short wooden lever may be used to untwist and open the rope.

Place the rope in the vise so that the vise grips the rope and one of the two strand ends just beyond the point where a pair of strand ends protrude from the rope. See Fig. 29. Drive marlin spike under three strands, opening the rope so that the fiber core may be cut and the end pulled through the opening made by the point of the marlin spike. Start the wrapped strand end into the space left vacant by the removal of the fiber core. Rotate the marlin spike so as to force out the fiber core and force the strand end into the center of the rope.

Splicing Wire Rope

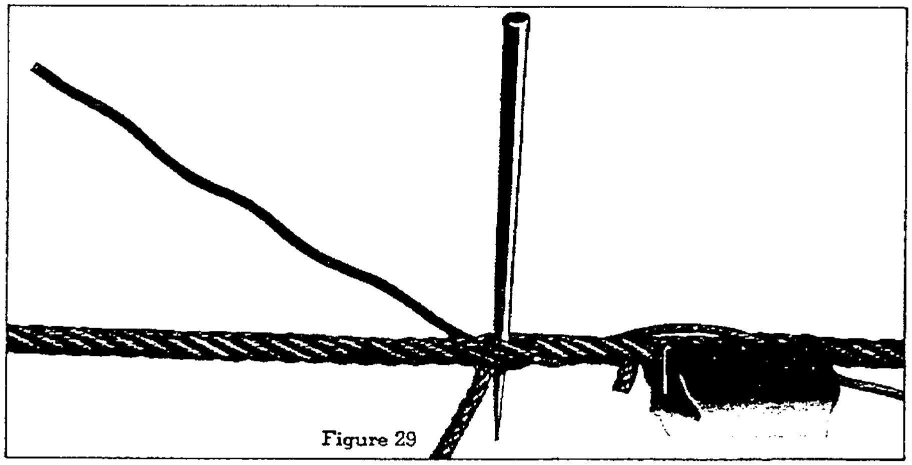


Figure 29

By rotating the spike, the strand end is tucked its entire length. See Fig. 30.

The rope is then regripped in the vise so that the second strand end can be tucked. See Fig. 31.

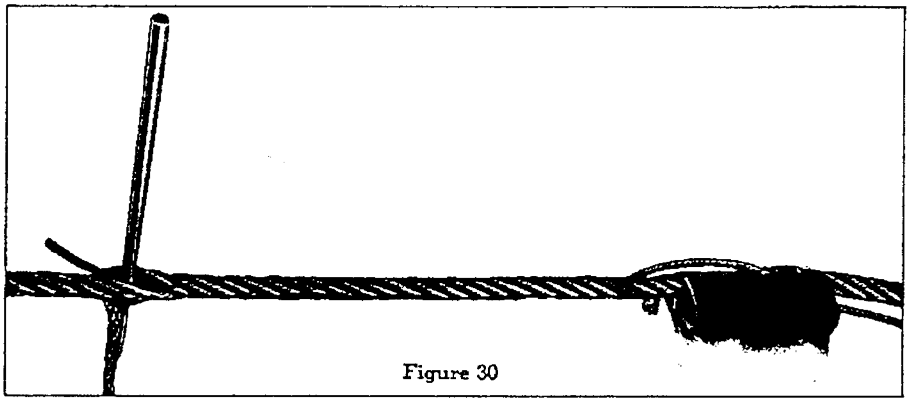


Figure 30

Drive the marlin spike under three strands as before.

In order to start the second strand end into the rope without any slack, a pair of splicing tongs or some other form of clamp should be used to force this strand into its proper position. See Fig. 31.

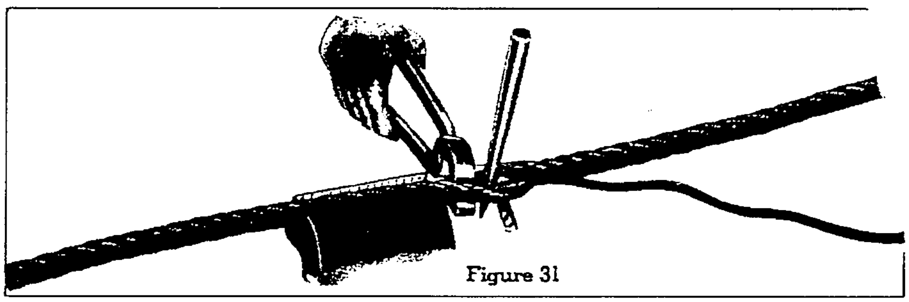


Figure 31

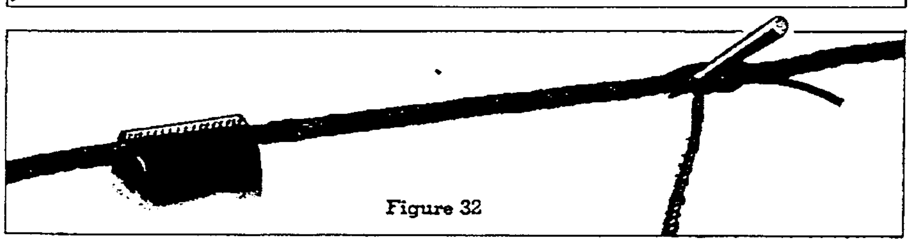


Figure 32

The marlin spike is then rotated forcing the fiber core from the rope and forcing the wrapped strand end into the space vacated by the fiber core. The strand end is tucked its entire length in this manner. See Fig. 32.

When splicing regular lay ropes the strand ends should not cross at the point where the tucks begin. See Figs. 32, 33 and 34.

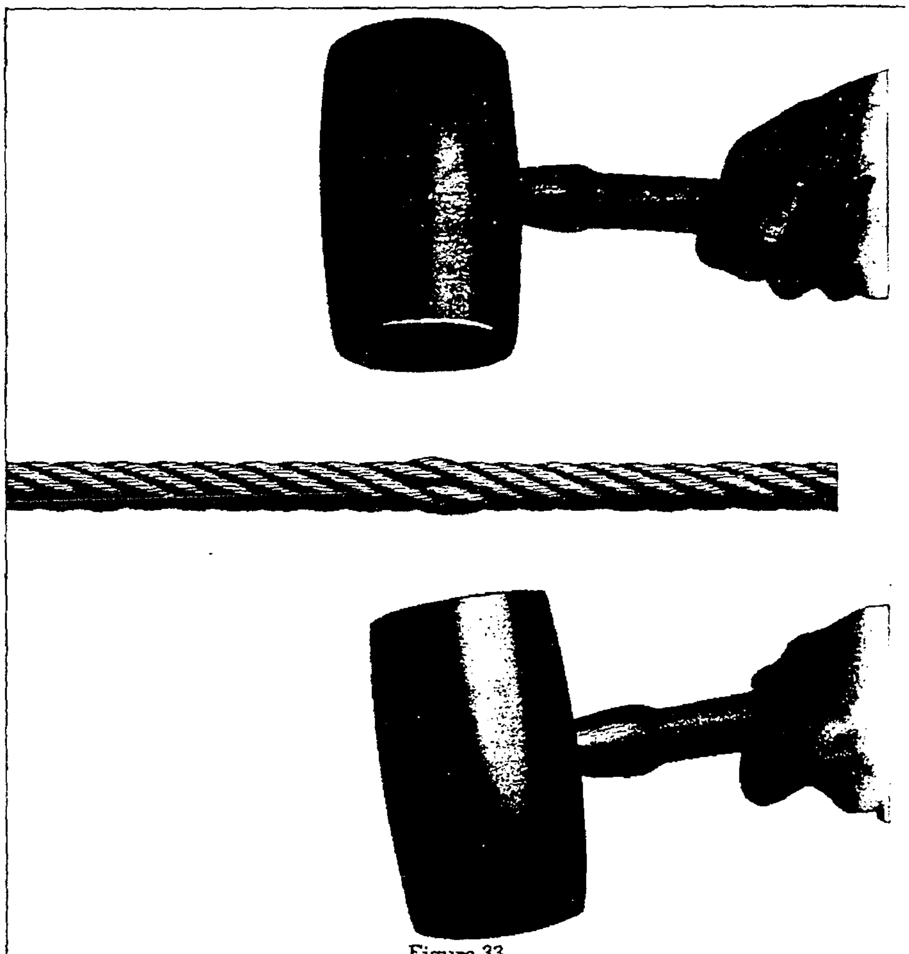


Figure 33

When splicing Lang lay ropes, it is advisable to have the strand ends cross at the points where the tucks begin, as this increases the holding power of the splice. This is accomplished by inserting the marlin spike under the strand end which has been tucked when starting the tucking operation on the second strand end.

The rope will be somewhat deformed at the point where the tucks start. This can be remedied by hammering the rope at this point with wooden mallets. See Fig. 33.

Figure 34

Fig. 34 shows one of six similar points of the finished splice where one pair of tucked strands start. A rope spliced in this manner is nearly as strong as the original rope. After running a few days, a well made splice cannot be detected except by a careful examination of the rope.

Splicing Wire Rope

Directions for Splicing 8 Strand Ropes

Because the fiber core in an eight strand rope is so much greater in diameter than the strands, it is not practical to tuck the strand ends by the method outlined for splicing six strand ropes. The strand ends are secured by twisting or tying them together. This is known as the Nash Tuck.

The process for splicing together two similar eight strand ropes, or splicing an eight strand rope endless, is similar to that for splicing a six strand rope up to the point where the strands are to be tucked. See Fig. 28. The only difference is that the length of tuck is approximately one sixteenth the amount of rope allowed for splicing.

The method of tucking the eight pairs of strand ends is the same for each pair.

Place seizings on rope each side of point where the strands project. Split the strand ends in two back to the seizings. See Fig. 35.

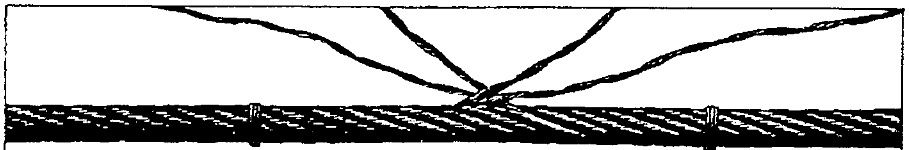


Figure 35

Take one-half of each strand end and tie a double knot. See Fig. 36.

Knot should be drawn down tight by a hand clamp or some similar tool.

Insert spike under the three strands beyond the knot and pull the half strands through. Fig. 37 shows one-half strand pulled through and the second half strand in the process of being pulled through.

The two half strands which have been tied and tucked are cut off close to the rope and each short end forced into the valley between the strands.

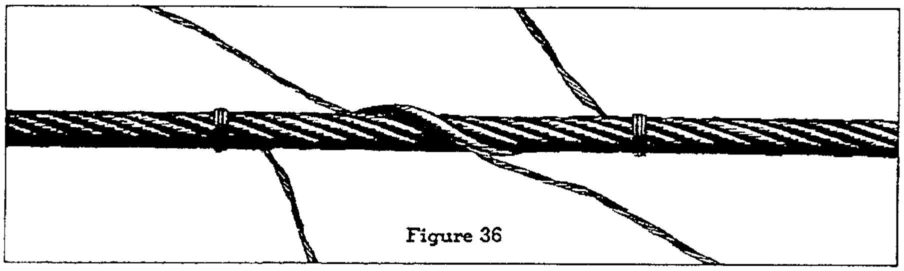


Figure 36

The other two half strands are tucked by inserting a marlin spike under the adjacent strand and pulling the half strand through. The ends are then cut off close to the rope and the short ends forced into the valleys between the strands.

Any unevenness in the rope should be removed by hammering with wooden mallets in the manner shown by Fig. 33.

Fig. 38 shows one of eight similar points of the finished splice.

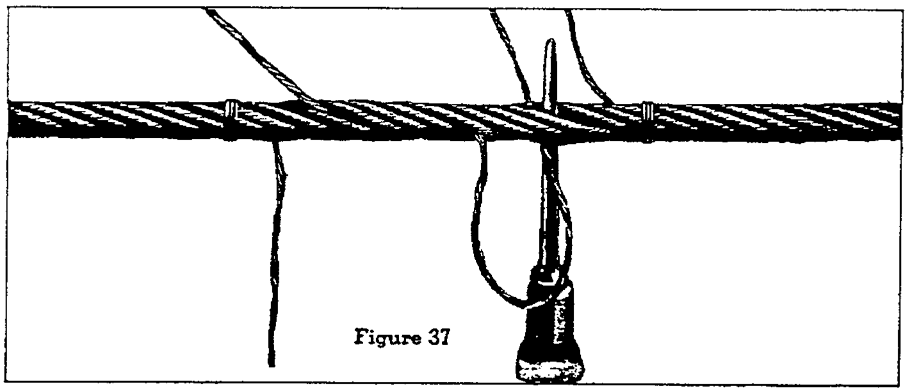


Figure 37

Figure 38

Splicing Wire Rope

Directions for Eye Splicing Wire Ropes

While the following directions cover splicing a galvanized thimble into a six strand wire rope, the process is also used for eight strand ropes and for splicing eyes into ropes when thimbles are not used.

The process of splicing a thimble into a rope consists of bending the rope about the thimble and fastening the short end by tucking the individual strands under similar strands of the long end of the rope a sufficient number of times to hold them securely. Four tucks are usually sufficient for all ropes containing not more than nineteen wires to the strand. For ropes with more than 19 wires to the strand five tucks should be used.

A short length of wire rope is consumed in making an eye splice. The amounts required for Light and Heavy wire thimbles are shown in the opposite column. For larger thimbles, a proportionally greater amount of rope is required.

Diameter of Rope in Inches	1/4–3/8	1/2	5/8–3/4	7/8–1	1 1/8	1 1/4	1 1/2
Length to Allow in Feet	1	1 1/2	2	2 1/2	3	3 1/2	4

A riggers vise as shown in the following illustration is best adapted for eye splicing. A common bench vise can be used if a riggers vise is not available.

Measure off the amount of rope allowed for making the splice. Bend the rope about the thimble at this point and place rope and thimble in vise. See Fig. 39.

In these illustrations the strands of the short end of the rope have been numbered 1 to 6, inclusive, and the strands of the long end of the rope have been lettered A to F, inclusive. Strand 1 is to be tucked under Strand A; Strand 2 under Strand B; Strand 3 under Strand C; etc. Each strand of the short end of the rope is to be tucked under its corresponding strand of the long end of the rope four times.

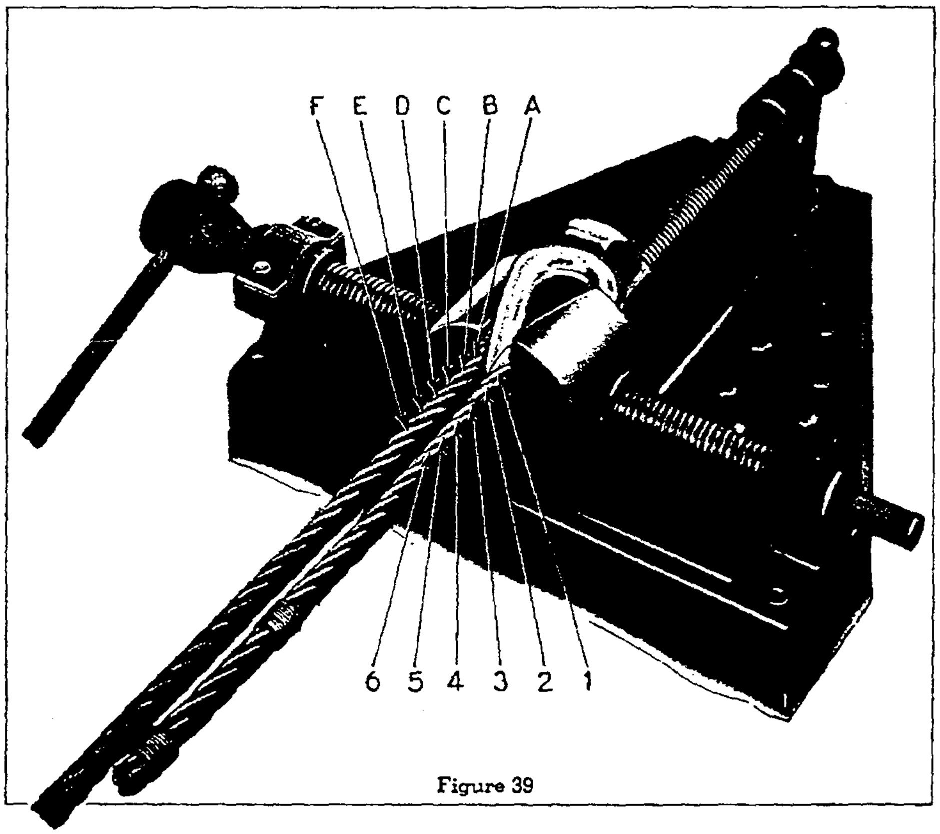


Figure 39

Splicing Wire Rope

Remove seizings from the short end of the rope and separate the strands. Cut off the fiber core at the point where the strands separate. See Fig. 40.

Insert a marlin spike under the first two strands nearest the point of the thimble, Strands A and B, and rotate the spike a half turn away from the thimble. Insert Strand 1 through the opening so formed and rotate spike back towards the thimble taking Strand 1 with it and pull Strand 1 tight. This gives Strand 1 one tuck. See Fig. 41.

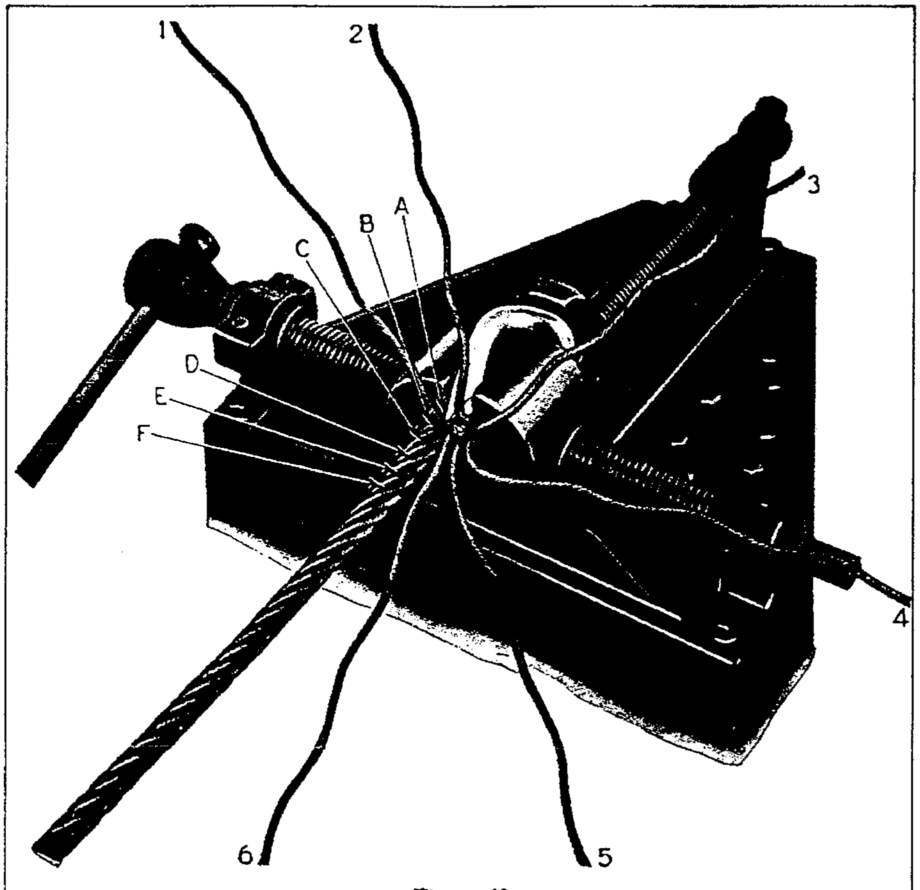


Figure 40

Insert marlin spike under next single strand, Strand B, and tuck Strand 2 by the same method.

Omit the next strand, Strand C, and insert marlin spike under the two strands beyond, Strands D and E, and tuck Strand 6 by inserting it through the opening in the direction opposite to which Strands 1 and 2 were tucked. Rotate the marlin spike back to the point of the thimble, forcing Strand 6 with it, and pull Strand 6 tight. Figure 42 shows the splice at this point. Strands 6, 1, and 2 have been tucked once under Strands F, A, and B, respectively.

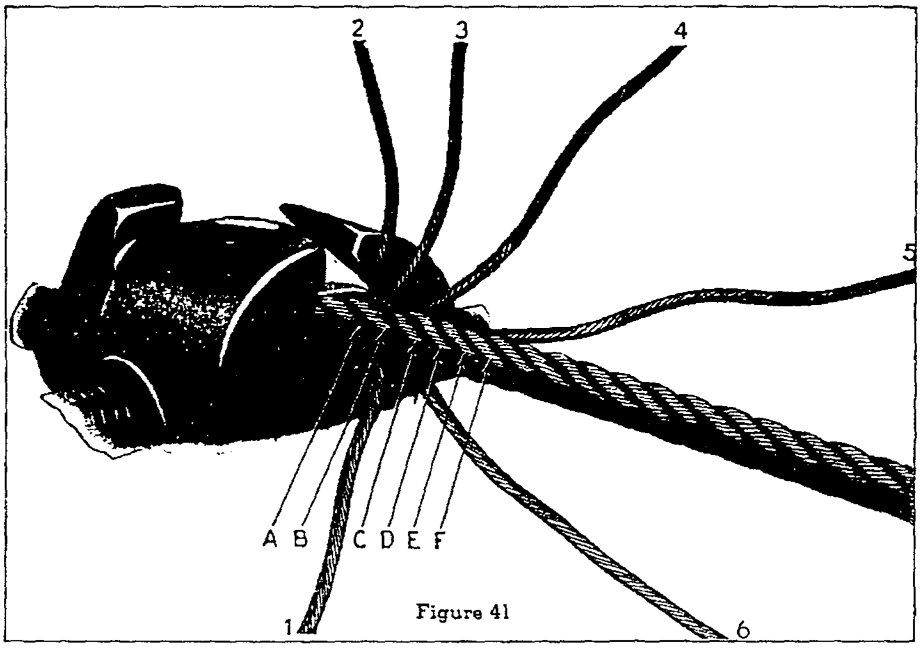


Figure 41

Insert marlin spike under Strand E and tuck Strand 5 in the same manner as Strand 2 was tucked. See Fig. 43.

Without removing the marlin spike give Strand 5 three additional tucks. This is accomplished by winding Strand 5 spirally around Strand E three

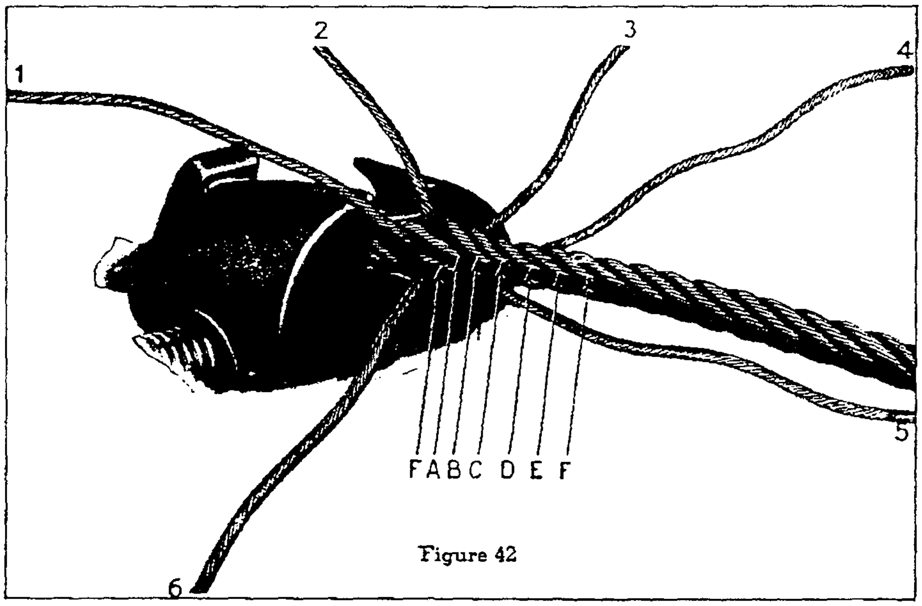


Figure 42

times. Each tuck is made by rotating the spike a half turn, pulling Strand 5 through the opening, and rotating the spike back toward the thimble to tighten the tuck.

Give Strand 4 four tucks by winding it about Strand D in the same manner.

Tuck Strand 3 four times about Strand C.

Fig. 44 shows Strands 3, 4, and 5 after these strands have been given four tucks.

Splicing Wire Rope

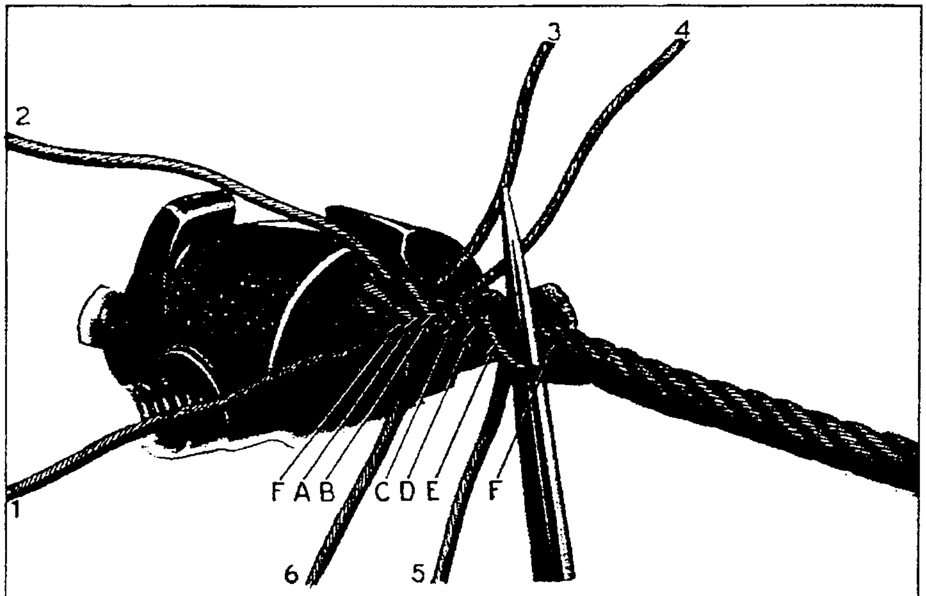


Figure 43

Strands 6, 1, and 2 should be given three additional tucks about Strands F, A, and B, respectively, in the manner outlined for Strand 5. Fig. 45 shows four completed tucks in each of the six strands. If the rope contains more than nineteen wires per strand, each strand should be given an additional tuck.

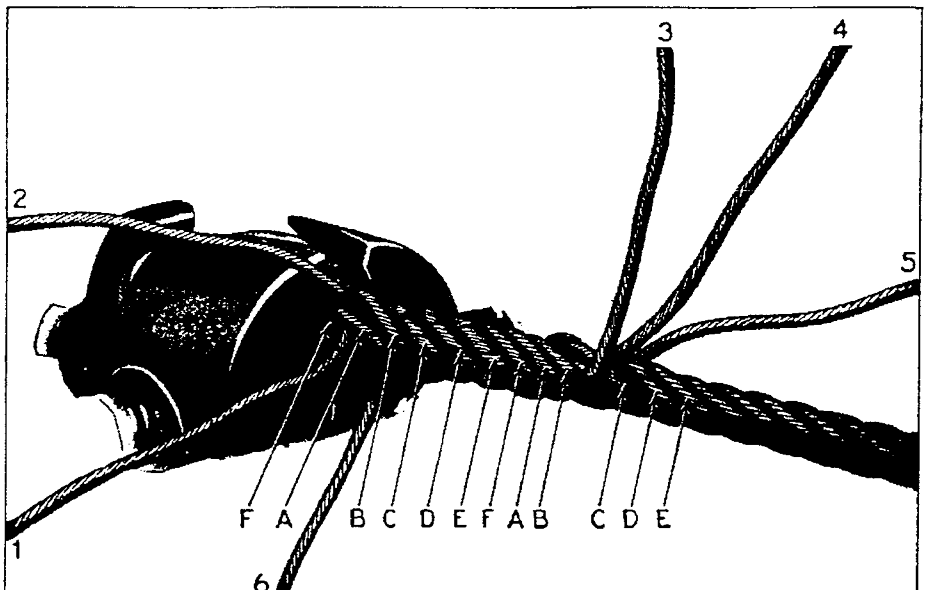


Figure 44

An eye splice made in this manner will have a slight taper as shown in Figs. 46 and 47. If a more pronounced taper is desired, this can be secured by splitting each strand before the final tuck and cutting off a portion of the wires.

Splicing Wire Rope

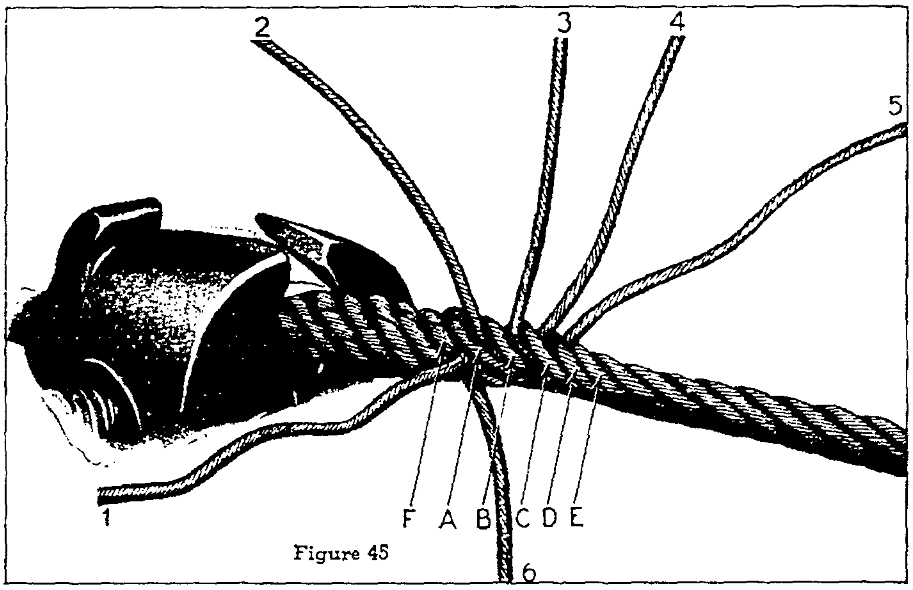


Figure 45

The protruding strand ends are cut off close to the rope.

Any inequalities in the splice should be removed by hammering with wooden mallets as shown by Fig. 33, page 49.

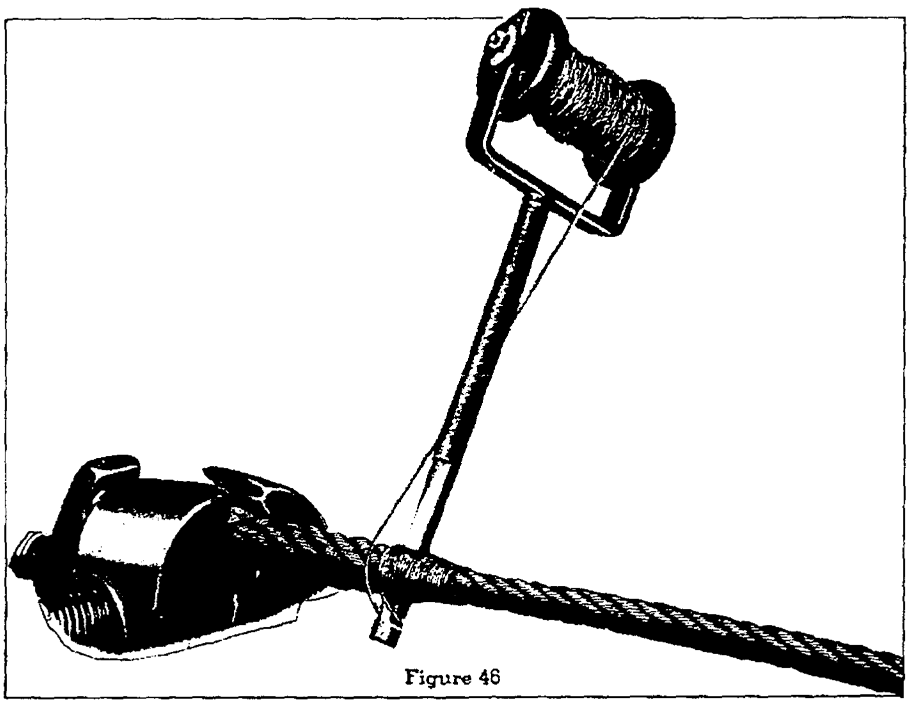


Figure 46

The splice should be wrapped with serving wire to protect the hands of workmen handling the rope. This is best accomplished by using a serving iron as shown in Fig. 46.

Fig. 47 shows a Galvanized Heavy Wire Rope Thimble spliced into the end of a 6x19 wire rope by the method here outlined.

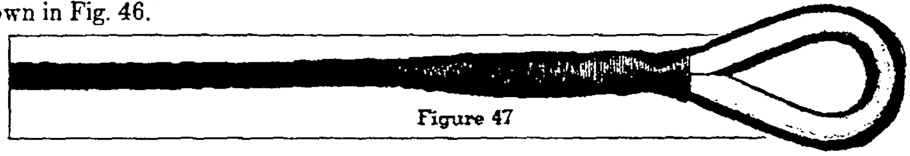
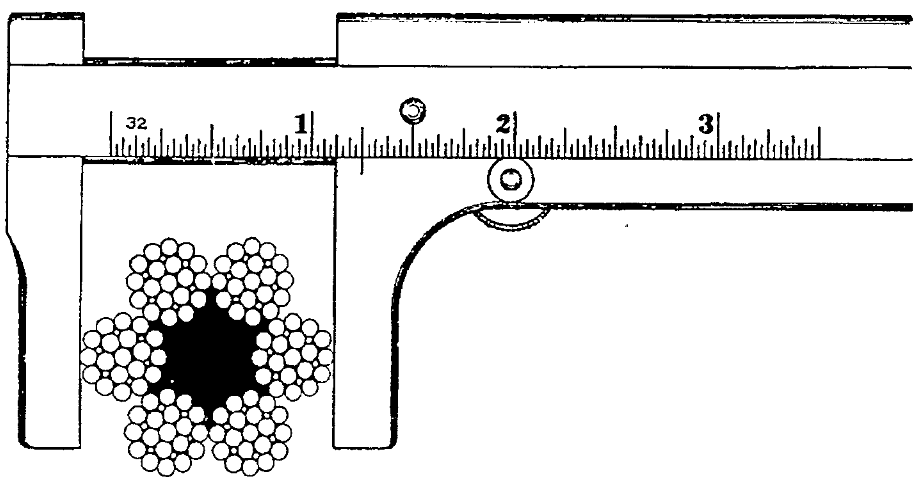


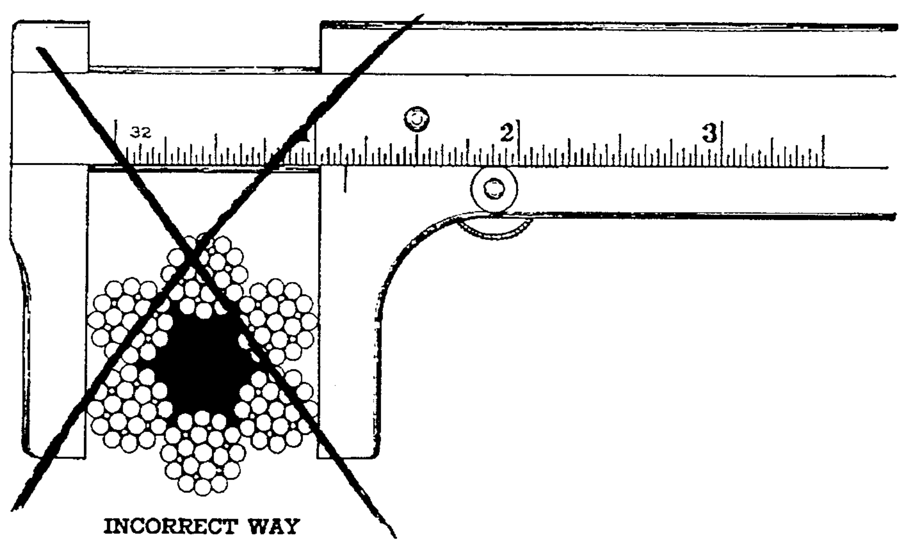
Figure 47

Gauging Wire Rope

The diameter of a wire rope is the diameter of the circle which will just enclose all of the strands. In the case of strands, the diameter is that of the circle which will just enclose all of the wires. The correct diameter is the greatest diameter of the rope or strand.



CORRECT WAY
This gives correct diameter.



INCORRECT WAY
This does not give correct diameter.

Care of Wire Rope

To obtain maximum useful rope life and greatest economy, there are several simple rules to observe.

Lubrication

Wire Ropes are lubricated during fabrication. The amount and grade of lubricant used depends upon the size and type of rope. As this initial lubrication is generally not sufficient to last the useful life of the rope, periodical applications of a good grade of oil or grease should be made. The lubricant should be free from acids and alkalies; should have sufficient adhesive strength to stay on the rope; should be able to penetrate between the wires and strands; should be non-soluble under the conditions prevailing where the rope operates; should have a high film strength; and should resist oxidation.

The importance of periodical lubrication is apparent from the fact that a wire rope is a machine with many moving parts. Each time a rope bends or straightens, the wires in the strands and the strands in the rope must slide on each other. This requires a film of lubricant on each moving part.

A second important reason for lubricating iron and steel wire ropes is to prevent corrosion of the wires and deterioration of the fiber core. There is no known means of inspection which will even approximate the strength of a corroded rope. A rusty rope is a liability.

Used ropes should be cleaned before they are lubricated. The cleaning may be accomplished by means of wire brushes or scrapers, or by compressed air or superheated steam. The object is to remove all foreign material and old lubricant from the valleys between the strands and from the spaces between the outer wires. The lubricant may be applied in any manner suitable to field conditions. It may be brushed onto the rope with a stiff brush; applied by passing the rope through saturated waste; or by passing the rope through a trough or box of lubricant; or the lubricant may drip onto the rope, preferably at a point where the rope opens slightly from bending. The object is to apply a uniform coating to the entire length of rope.

When a wire rope is taken out of service for an appreciable length of time, it should be cleaned and lubricated. It should be stored in a dry place protected from the elements.

Cutting Back

The object of cutting short lengths of rope from the drum end is to change the position of the rope. Wear and fatigue are usually most severe at certain definite points on wire rope using equipment, and the removal of a short length of rope subjects different portions of it to these destructive forces. Cutting back the outer end removes that section next to the fitting where maximum localized fatigue from vibration often occurs.

In order to take advantage of this method of obtaining increased service, it is often advisable to use a length of rope slightly longer than normally required.

Reversing Ends

A rope is changed end for end to distribute the wear and fatigue from bending and vibration. If these destructive forces are uniform throughout the system, no economy is effected by such a change. On most installations these forces are more severe for one-half of the rope than for the other half, and reversing the ends increases the rope service.

Seizings

Seizings are required to prevent the untwisting of all non-preformed wire ropes unless the rope ends have been eye spliced, socketed, or attached to some other type of permanent fitting. Non-preformed rope should have seizings applied to both sides of the point where it is to be cut. Inadequate seizings which do not preserve the rope structure, but permit the strands to untwist, result in shortened service because of the unbalanced condition of the rope. One seizing applied to each side of the point of cutting a preformed wire rope is recommended in order to prevent distortion of the rope ends from the pressure applied during the cutting operation.

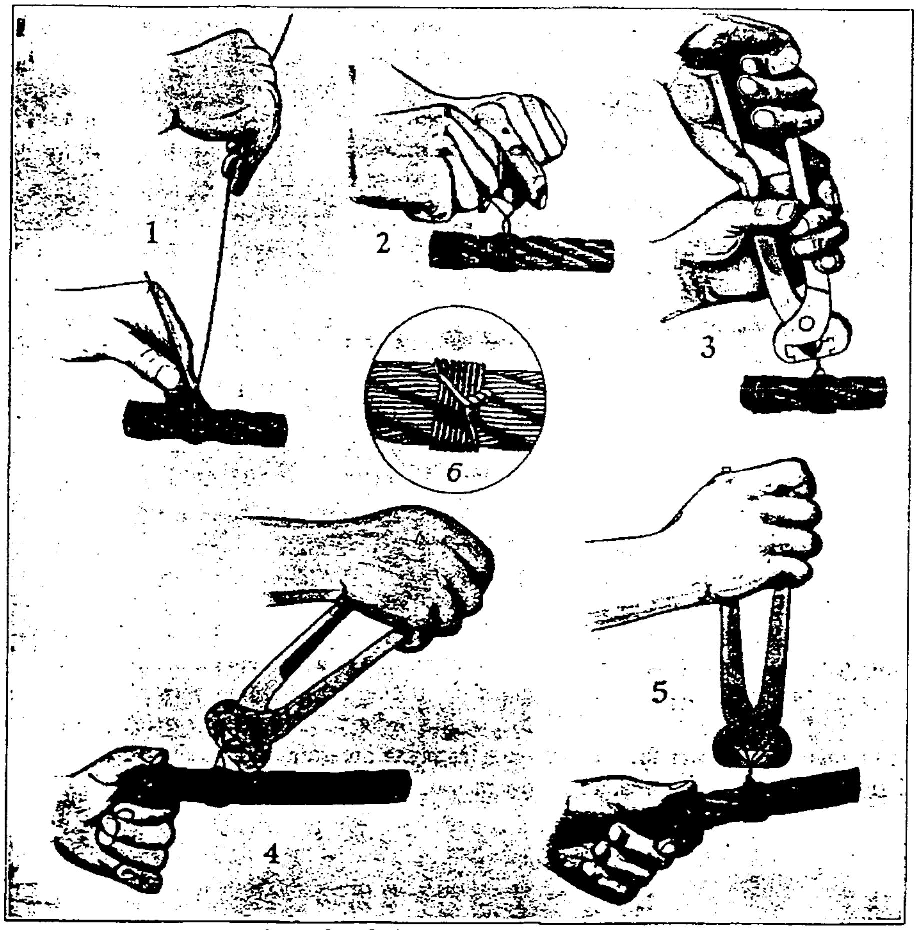
Care of Wire Rope

Seizings Recommended

Rope Dia. in Inches	Number of Seizings: Regular Lay Fiber Core Ropes	Number of Seizings: 19 x 7 Non-Spinning; Lang Lay; and Wire Core Ropes	Length of Seizings in Inches	Distance between Seizings in Inches	Approx. Size of Seizing Wire in in Inches
½ and Smaller	2	3	½	1	.020–.030
9/16– ⅞	3	3	1	2	.040–.060
1 –1¼	3	4	1½	2	.060–.090
1⅜–1⅝	4	4	2	2	.080–.125
1¾–2	4	4	3	2	.105–.125
2⅛ and Larger	4	4	4	3	.105–.125

Seizing wire should be annealed iron grade. Galvanized annealed iron wire should be used for seizing galvanized ropes. Hand cutters may be used for applying seizings to ropes one inch diameter and smaller. For larger ropes a seizing iron as shown in Fig. 46, Page 55, or a round bar ½ to ⅝ inch diameter by 18 inches long is recommended.

The following illustrations and instructions for applying seizings are from the United States Government Master Specification for Wire Rope. A neater seizing made with hand cutters for ropes one inch diameter and smaller can be obtained by laying the seizing wire in the groove between two strands when starting the operation. See Fig. 49, page 59.



(1) Wind the seizing wire on the rope by hand, keeping the coils together and considerable tension on the wire. (2) Twist the ends of the wire together *counter clockwise* by hand so that the twisted portion of the wires is near the middle of the seizing. (3) Using "Carew" cutters, tighten the twist just enough to take up the slack. Do not try to tighten the seizing by *twisting*. (4) Tighten the seizing by prying the twist away from the axis of the rope with the cutters. (5) Tighten the twist again as in (3). Repeat (4) and (5) as often as is necessary to make the seizing tight. Cut off the ends of the wires and pound the twist flat against the rope. (6) The appearance of the finished seizing.

Fig. 48. Method of applying seizings with hand cutters

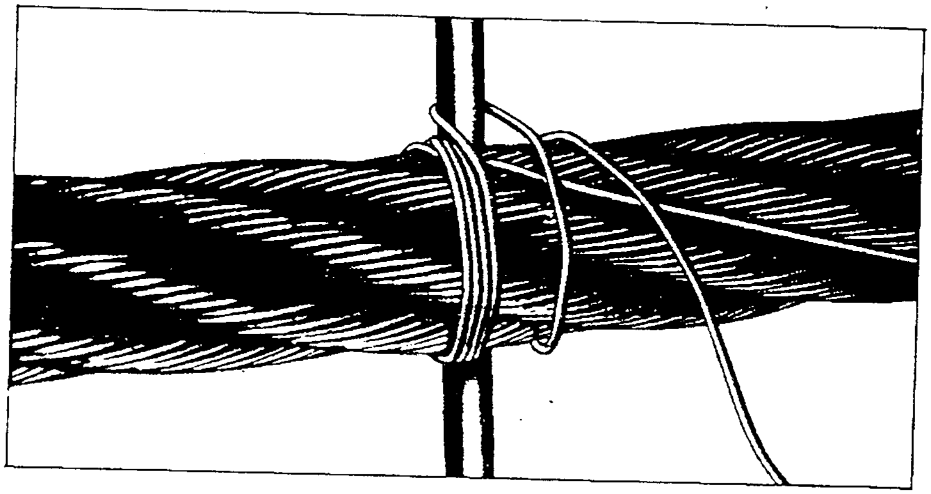


Fig. 49. Method of applying seizings with round bar

Lay one end of the seizing wire in the groove between two strands and wrap the long end back over this portion. If a seizing iron is used (See Fig. 46), tension of the seizing wire is obtained by adjusting the nuts on the shaft about which the spool rotates, or by wrapping the wire around the shaft of the seizing iron. If a round bar is used, the necessary tension in the wire is secured by giving the free end one or two turns about the rope. The ends of the seizing wire are twisted together and tightened as in Fig. 48.

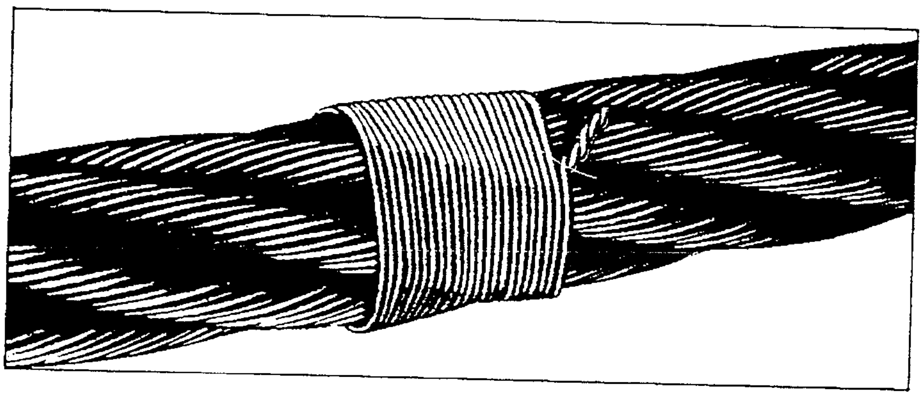


Fig. 50. A well made seizing

Sheaves

Sheaves should be aligned so that the axis of the rope is parallel to a line drawn from the center of the groove of one sheave to the center of the groove of the next sheave. This is important in order to prevent excessive wear on the rope caused by it bearing against flanges or dragging across shoulders. This excessive and unnecessary wear will destroy the outer wires long before the rope has given nominal service. The use of sheaves with broken flanges produces the same undesirable results.

(See "Effects of Bending," page 6. "Grooves" page 38, and "Fleet Angle," page 40.

Care of Wire Rope

Supporting Sheaves and Rollers

The use of supporting sheaves and rollers to prevent the rope dragging decreases the wear on the rope and results in increased service. Sheaves and grooved rollers should have grooves sufficiently large to prevent pinching the rope. See "Grooves", page 38. All sheaves and rollers should be machined or replaced when scored by the rope to prevent unnecessary wear on the outer wires of the rope. They should be free to rotate, large enough in diameter to avoid unnecessary bending of the rope, and to provide adequate support for the rope, and light in weight so as to readily start and stop as the rope starts and stops. Guide Sheaves and Rollers should be at least 6 times the rope diameter if grooved, and 9 times the rope diameter if flat faced. Heavy sheaves and rollers build up momentum when turning, which causes slippage when the rope stops. They are slow to pick up speed when the rope starts, and this produces additional slippage of the rope on the sheaves or rollers. Slippage, in turn, produces abrasion of the outer wires of the rope.

The installation of supporting rollers at irregular intervals tends to dampen vibration. This is of particular benefit on long inclines operating at comparatively high speeds.

Handling

"Unreeling and Uncoiling", pages 41 and 42, gives directions for properly removing rope from reels and coils. Improper methods produce kinks. Kinks also result from improper handling of rope after it is unwound. A kink is formed by pulling a looped rope until the loop becomes so small that the rope cannot adjust itself by bending to the required arc. The rope is distorted at this point, damaging the individual wires and the rope structure.

Avoid kinks by not permitting loops to form in a rope.

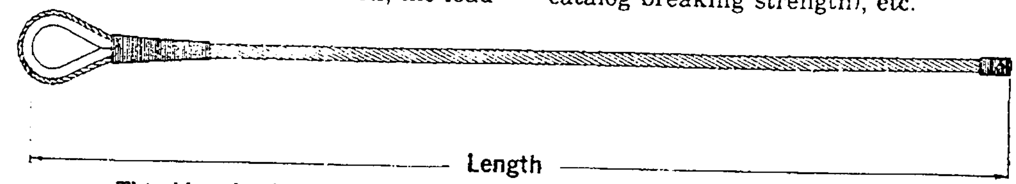
Common Cause of Wire Rope Failures

Of the many forms of abuse of wire ropes, the most commonly encountered are:

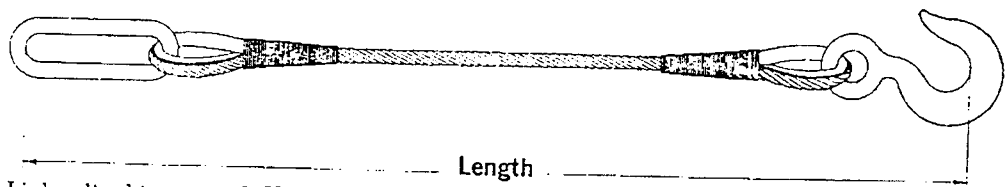
- Ropes of incorrect size, construction, or grade.
- Ropes allowed to drag over obstacles.
- Ropes not properly lubricated.
- Ropes operating over sheaves and drums of inadequate size.
- Ropes overwinding or crosswinding on drums.
- Ropes operating over sheaves and drums out of alignment.
- Ropes operating over sheaves and drums with improperly fitting grooves or broken flanges.
- Ropes permitted to jump sheaves.
- Ropes subjected to moisture or acid fumes.
- Ropes with improperly attached fittings.
- Ropes permitted to untwist.
- Ropes subjected to excessive heat.
- Ropes kinked.
- Ropes subjected to severe overloads due to inefficient operation.
- Ropes destroyed by internal wear caused by grit penetrating between strands and wires.

Ordering Wire Rope with Fittings Attached

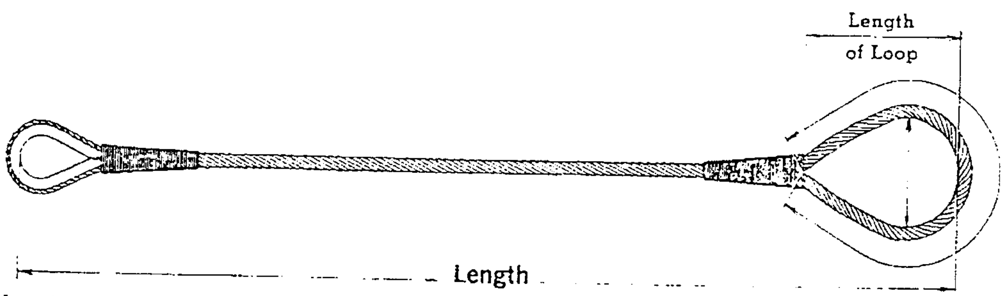
When ORDERING WIRE ROPE WITH FITTINGS ATTACHED, the lengths should be specified as shown below. In addition, the load at which this measurement shall be taken should be specified (i.e., at no load or at 20% of catalog breaking strength), etc.



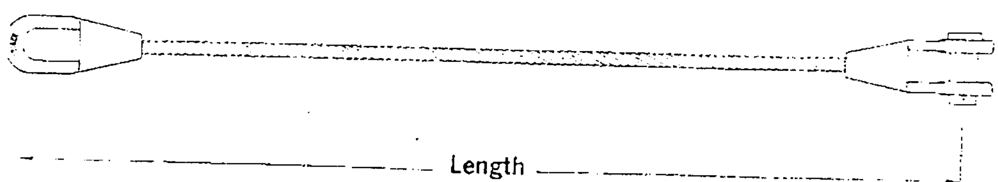
Thimble spliced in one end. Measurement: Pull of Thimble to End of Rope.



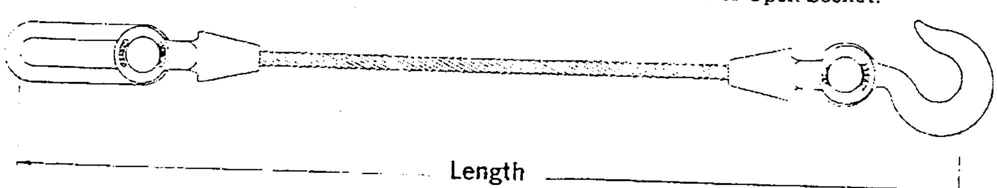
Link spliced in one end; Hook spliced in other end. Measurement: Pull of Link to Pull of Hook.



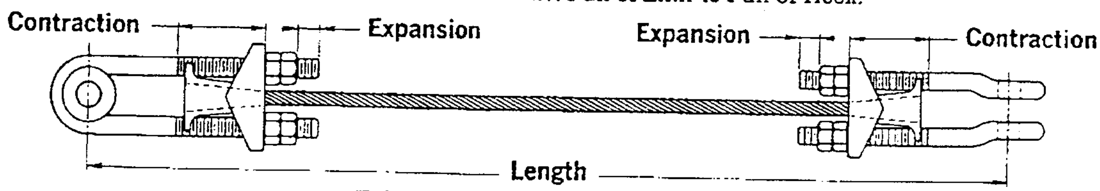
Thimble spliced in one end; Loop spliced in the other end. Measurements: Pull of Thimble to Base of Loop, and Circumference of Loop.



Tiger Closed Wire Rope Socket attached to one end; Tiger Open Wire Rope Socket attached to other end. Measurement: Pull of Closed Socket to Center Line of Pin of Open Socket.



Tiger Open Wire Rope Socket and Link attached to one end; Tiger Open Wire Rope Socket and Hook attached to other end. Measurement: Pull of Link to Pull of Hook.



Takeup = (Contraction) + (Expansion)

Closed Bridge Socket attached to one end; Open Bridge Socket attached to other end. Measurements: Center Line of Pin Closed Socket to Center Line of Pin Open Socket, and two of the three values, Takeup, Contraction, Expansion, required.

Useful Information

Decimal of an Inch and of a Foot

Fractions of Inch or Foot		Inch Equivalents to Foot Fractions	Fractions of Inch or Foot		Inch Equivalents to Foot Fractions	Fractions of Inch or Foot		Inch Equivalents to Foot Fractions	Fractions of Inch or Foot		Inch Equivalents to Foot Fractions
	.0052	1/16		.2552	3 1/16		.5052	6 1/16		.7552	9 1/16
	.0104	1/8		.2604	3 1/8		.5104	6 1/8		.7604	9 1/8
1/64	.015625	3/16	17/64	.265625	3 3/16	33/64	.515625	6 3/16	49/64	.765625	9 3/16
	.0208	1/4		.2708	3 1/4		.5208	6 1/4		.7708	9 1/4
	.0260	5/16		.2760	3 5/16		.5260	6 5/16		.7760	9 5/16
1/32	.03125	3/8	9/32	.28125	3 3/8	17/32	.53125	6 3/8	25/32	.78125	9 3/8
	.0365	7/16		.2865	3 7/16		.5365	6 7/16		.7865	9 7/16
	.0417	1/2		.2917	3 1/2		.5417	6 1/2		.7917	9 1/2
3/64	.046875	9/16	19/64	.296875	3 9/16	35/64	.546875	6 9/16	51/64	.796875	9 9/16
	.0521	5/8		.3021	3 5/8		.5521	6 5/8		.8021	9 5/8
	.0573	11/16		.3073	3 11/16		.5573	6 11/16		.8073	9 11/16
1/16	.0625	3/4	5/16	.3125	3 3/4	9/16	.5625	6 3/4	13/16	.8125	9 3/4
	.0677	13/16		.3177	3 13/16		.5677	6 13/16		.8177	9 13/16
	.0729	7/8		.3229	3 7/8		.5729	6 7/8		.8229	9 7/8
5/64	.078125	15/16	21/64	.328125	3 15/16	37/64	.578125	6 15/16	53/64	.828125	9 15/16
	.0833	1		.3333	4		.5833	7		.8333	10
	.0885	1 1/16		.3385	4 1/16		.5885	7 1/16		.8385	10 1/16
3/32	.09375	1 1/8	11/32	.34375	4 1/8	19/32	.59375	7 1/8	27/32	.84375	10 1/8
	.0990	1 3/16		.3490	4 3/16		.5990	7 3/16		.8490	10 3/16
	.1042	1 1/4		.3542	4 1/4		.6042	7 1/4		.8542	10 1/4
7/64	.109375	1 5/16	23/64	.359375	4 5/16	39/64	.609375	7 5/16	55/64	.859375	10 5/16
	.1146	1 3/8		.3646	4 3/8		.6146	7 3/8		.8646	10 3/8
	.1198	1 7/16		.3698	4 7/16		.6198	7 7/16		.8698	10 7/16
1/8	.1250	1 1/2	3/8	.3750	4 1/2	5/8	.6250	7 1/2	7/8	.8750	10 1/2
	.1302	1 9/16		.3802	4 9/16		.6302	7 9/16		.8802	10 9/16
	.1354	1 5/8		.3854	4 5/8		.6354	7 5/8		.8854	10 5/8
9/64	.140625	1 11/16	25/64	.390625	4 11/16	41/64	.640625	7 11/16	57/64	.890625	10 11/16
	.1458	1 3/4		.3958	4 3/4		.6458	7 3/4		.8958	10 3/4
	.1510	1 13/16		.4010	4 13/16		.6510	7 13/16		.9010	10 13/16
5/32	.15625	1 7/8	13/32	.40625	4 7/8	21/32	.65625	7 7/8	29/32	.90625	10 7/8
	.1615	1 15/16		.4115	4 15/16		.6615	7 15/16		.9115	10 15/16
	.1667	2		.4167	5		.6667	8		.9167	11
11/64	.171875	2 1/16	27/64	.421875	5 1/16	43/64	.671875	8 1/16	59/64	.921875	11 1/16
	.1771	2 1/8		.4271	5 1/8		.6771	8 1/8		.9271	11 1/8
	.1823	2 3/16		.4323	5 3/16		.6823	8 3/16		.9323	11 3/16
3/16	.1875	2 1/4	7/16	.4375	5 1/4	11/16	.6875	8 1/4	15/16	.9375	11 1/4
	.1927	2 5/16		.4427	5 5/16		.6927	8 5/16		.9427	11 5/16
	.1979	2 3/8		.4479	5 3/8		.6979	8 3/8		.9479	11 3/8
13/64	.203125	2 7/16	29/64	.453125	5 7/16	45/64	.703125	8 7/16	61/64	.953125	11 7/16
	.2083	2 1/2		.4583	5 1/2		.7083	8 1/2		.9583	11 1/2
	.2135	2 9/16		.4635	5 9/16		.7135	8 9/16		.9635	11 9/16
7/32	.21875	2 5/8	15/32	.46875	5 5/8	23/32	.71875	8 5/8	31/32	.96875	11 5/8
	.2240	2 11/16		.4740	5 11/16		.7240	8 11/16		.9740	11 11/16
	.2292	2 3/4		.4792	5 3/4		.7292	8 3/4		.9792	11 3/4
15/64	.234375	2 13/16	31/64	.484375	5 13/16	47/64	.734375	8 13/16	63/64	.984375	11 13/16
	.2396	2 7/8		.4896	5 7/8		.7396	8 7/8		.9896	11 7/8
	.2448	2 15/16		.4948	5 15/16		.7448	8 15/16		.9948	11 15/16
1/4	.2500	3	1/2	.5000	6	3/4	.7500	9	1	1.0000	12

Areas of Round Wire

Areas in Square Inches of Round Wire

Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area
.005	.00001963	.030	.0007068	.070	.003848	.110	.009503
.0055	.00002375	.031	.0007547	.071	.003959	.111	.009676
.006	.00002827	.032	.0008042	.072	.004071	.112	.009852
.0065	.00003318	.033	.0008552	.073	.004185	.113	.01002
.007	.00003848	.034	.0009079	.074	.004300	.114	.01022
.0075	.00004417	.035	.000962	.075	.004417	.115	.01038
.008	.00005026	.036	.001017	.076	.004536	.116	.01056
.0085	.00005674	.037	.001075	.077	.004656	.117	.01075
.009	.00006361	.038	.001134	.078	.004778	.118	.01093
.0095	.00007088	.039	.001194	.079	.004901	.119	.01112
.010	.00007854	.040	.001256	.080	.005026	.120	.01131
.0105	.00008659	.041	.001320	.081	.005153	.121	.01150
.011	.00009503	.042	.001385	.082	.005281	.122	.01169
.0115	.0001038	.043	.001452	.083	.005410	.123	.01188
.012	.0001131	.044	.001520	.084	.005541	.124	.01207
.0125	.0001227	.045	.001590	.085	.005674	.125	.01227
.013	.0001327	.046	.001661	.086	.005808	.126	.01246
.0135	.0001431	.047	.001734	.087	.005944	.127	.01266
.014	.0001539	.048	.001809	.088	.006082	.128	.01286
.0145	.0001651	.049	.001885	.089	.006221	.129	.01307
.015	.0001767	.050	.001963	.090	.006361	.130	.01327
.0155	.0001887	.051	.002042	.091	.006503	.131	.01348
.016	.0002010	.052	.002123	.092	.006647	.132	.01368
.0165	.0002138	.053	.002206	.093	.006792	.133	.01389
.017	.0002269	.054	.002290	.094	.006939	.134	.01410
.0175	.0002405	.055	.002375	.095	.007088	.135	.01431
.018	.0002544	.056	.002463	.096	.007238	.136	.01453
.0185	.0002688	.057	.002551	.097	.007390	.137	.01474
.019	.0002835	.058	.002642	.098	.007542	.138	.01496
.0195	.0002986	.059	.002734	.099	.007697	.139	.01517
.020	.0003141	.060	.002827	.100	.007854	.140	.01539
.021	.0003463	.061	.002922	.101	.008011	.141	.01561
.022	.0003801	.062	.003019	.102	.008171	.142	.01584
.023	.0004154	.063	.003117	.103	.008332	.143	.01606
.024	.0004523	.064	.003217	.104	.008494	.144	.01629
.025	.0004908	.065	.003318	.105	.008659	.145	.01651
.026	.0005309	.066	.003421	.106	.008824	.146	.01674
.027	.0005725	.067	.003525	.107	.008992	.147	.01697
.028	.0006157	.068	.003632	.108	.009160	.148	.01720
.029	.0006605	.069	.003739	.109	.009331	.149	.01744

Useful Information

Area of Round Wires

Areas in Square Inches of Round Wires

Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area
.150	.01767	.183	.02630	.216	.03664	.249	.04869
.151	.01791	.184	.02660	.217	.03698	.250	.04909
.152	.01815	.185	.02688	.218	.03732	.251	.04949
.153	.01839	.186	.02717	.219	.03767	.252	.04988
.154	.01863	.187	.02747	.220	.03801	.253	.05027
.155	.01887	.188	.02776	.221	.03836	.254	.05067
.156	.01911	.189	.02806	.222	.03871	.255	.05107
.157	.01936	.190	.02835	.223	.03906	.256	.05147
.158	.01961	.191	.02865	.224	.03941	.257	.05187
.159	.01986	.192	.02895	.225	.03976	.258	.05228
.160	.02011	.193	.02926	.226	.04011	.259	.05268
.161	.02036	.194	.02956	.227	.04047	.260	.05309
.162	.02061	.195	.02986	.228	.04083	.261	.05350
.163	.02086	.196	.03017	.229	.04119	.262	.05391
.164	.02112	.197	.03048	.230	.04156	.263	.05432
.165	.02138	.198	.03079	.231	.04191	.264	.05474
.166	.02164	.199	.03110	.232	.04227	.265	.05515
.167	.02190	.200	.03141	.233	.04264	.266	.05557
.168	.02217	.201	.03173	.234	.04301	.267	.05599
.169	.02243	.202	.03205	.235	.04337	.268	.05641
.170	.02270	.203	.03237	.236	.04374	.269	.05683
.171	.02297	.204	.03269	.237	.04412	.270	.05726
.172	.02324	.205	.03301	.238	.04449	.271	.05768
.173	.02351	.206	.03333	.239	.04486	.272	.05811
.174	.02378	.207	.03365	.240	.04524	.273	.05853
.175	.02405	.208	.03398	.241	.04562	.274	.05896
.176	.02433	.209	.03431	.242	.04600	.275	.05939
.177	.02461	.210	.03464	.243	.04638		
.178	.02488	.211	.03497	.244	.04676		
.179	.02517	.212	.03530	.245	.04714		
.180	.02545	.213	.03563	.246	.04753		
.181	.02573	.214	.03597	.247	.04792		
.182	.02602	.215	.03631	.248	.04831		

Weight of Steel Wires

Weights in Pounds per 1,000 Feet of Round Steel Wires

Dia.	Weight	Dia.	Weight	Dia.	Weight	Dia.	Weight
.005	0.0667	.032	2.731	.074	14.61	.116	35.89
.0055	0.0807	.033	2.905	.075	15.00	.117	36.52
.006	0.0960	.034	3.083	.076	15.41	.118	37.14
.0065	0.1127	.035	3.267	.077	15.82	.119	37.77
.007	0.1307	.036	3.457	.078	16.24	.120	38.41
.0075	0.1500	.037	3.652	.079	16.65	.121	39.06
.008	0.1707	.038	3.853	.080	17.07	.122	39.70
.0085	0.1927	.039	4.057	.081	17.50	.123	40.35
.009	0.2160	.040	4.268	.082	17.93	.124	41.00
.0095	0.2407	.041	4.484	.083	18.37	.125	41.68
.010	0.2667	.042	4.705	.084	18.82	.126	42.34
.0105	0.2941	.043	4.931	.085	19.27	.127	43.02
.011	0.3228	.044	5.164	.086	19.72	.128	43.70
.0115	0.3527	.045	5.401	.087	20.18	.129	44.39
.012	0.3841	.046	5.644	.088	20.65	.130	45.08
.0125	0.4168	.047	5.894	.089	21.13	.131	45.78
.013	0.4508	.048	6.145	.090	21.60	.132	46.47
.0135	0.4861	.049	6.404	.091	22.09	.133	47.18
.014	0.5228	.050	6.668	.092	22.58	.134	47.89
.0145	0.5608	.051	6.939	.093	23.07	.135	48.61
.015	0.6001	.052	7.212	.094	23.57	.136	49.33
.0155	0.6408	.053	7.493	.095	24.07	.137	50.07
.016	0.6828	.054	7.778	.096	24.58	.138	50.80
.0165	0.7261	.055	8.068	.097	25.09	.139	51.54
.017	0.7708	.056	8.364	.098	25.61	.140	52.28
.0175	0.8168	.057	8.665	.099	26.14	.141	53.03
.018	0.8642	.058	8.972	.100	26.67	.142	53.78
.0185	0.9128	.059	9.286	.101	27.21	.143	54.55
.019	0.9630	.060	9.602	.102	27.75	.144	55.31
.0195	1.014	.061	9.925	.103	28.30	.145	56.08
.020	1.067	.062	10.25	.104	28.85	.146	56.86
.021	1.176	.063	10.59	.105	29.41	.147	57.64
.022	1.291	.064	10.92	.106	29.97	.148	58.42
.023	1.411	.065	11.27	.107	30.54	.149	59.22
.024	1.536	.066	11.62	.108	31.11	.150	60.01
.025	1.667	.067	11.97	.109	31.69	.151	60.80
.026	1.804	.068	12.33	.110	32.27	.152	61.61
.027	1.945	.069	12.70	.111	32.86	.153	62.44
.028	2.091	.070	13.07	.112	33.45	.154	63.26
.029	2.243	.071	13.44	.113	34.06	.155	64.08
.030	2.400	.072	13.82	.114	34.66	.156	64.91
.031	2.562	.073	14.21	.115	35.27		

Useful Information

Weights of Steel Wires

Weights in Pounds per 1000 Feet of Round Steel Wires

Dia.	Weight	Dia.	Weight	Dia.	Weight	Dia.	Weight
.157	65.74	.188	94.28	.219	127.9	.250	166.7
.158	66.59	.189	95.28	.220	129.1	.251	168.0
.159	67.43	.190	96.28	.221	130.2	.252	169.4
.160	68.28	.191	97.30	.222	131.4	.253	170.7
.161	69.14	.192	98.32	.223	132.6	.254	172.1
.162	70.00	.193	99.34	.224	133.8	.255	173.4
.163	70.87	.194	100.4	.225	135.0	.256	174.8
.164	71.74	.195	101.4	.226	136.2	.257	176.2
.165	72.61	.196	102.4	.227	137.4	.258	177.5
.166	73.48	.197	103.5	.228	138.6	.259	178.9
.167	74.38	.198	104.6	.229	139.8	.260	180.3
.168	75.28	.199	105.6	.230	141.1	.261	181.7
.169	76.18	.200	106.7	.231	142.4	.262	183.1
.170	77.08	.201	107.8	.232	143.6	.263	184.5
.171	77.98	.202	108.9	.233	144.8	.264	185.9
.172	78.91	.203	109.9	.234	146.1	.265	187.3
.173	79.83	.204	111.0	.235	147.3	.266	188.7
.174	80.75	.205	112.1	.236	148.6	.267	190.1
.175	81.68	.206	113.2	.237	149.8	.268	191.6
.176	82.62	.207	114.3	.238	151.1	.269	193.0
.177	83.56	.208	115.4	.239	152.4	.270	194.4
.178	84.51	.209	116.5	.240	153.6	.271	195.8
.179	85.46	.210	117.6	.241	154.9	.272	197.3
.180	86.42	.211	118.7	.242	156.2	.273	198.8
.181	87.38	.212	119.9	.243	157.5	.274	200.3
.182	88.36	.213	121.1	.244	158.8	.275	201.7
.183	89.34	.214	122.2	.245	160.1		
.184	90.32	.215	123.3	.246	161.4		
.185	91.30	.216	124.4	.247	162.7		
.186	92.28	.217	125.6	.248	164.0		
.187	93.28	.218	126.7	.249	165.4		

Measures and Weights

Linear Measure

1000 mils	= 1 inch
12 inches	= 1 foot
3 feet	= 1 yard
2 yards	= 1 fathom; 6 feet
5½ yards	= 1 rod; 16½ feet
40 rods	= 1 furlong; 660 feet
8 furlongs	= 1 mile; 5280 feet
1.15156 miles	= 1 nautical mile, or knot; 6080.26 feet
3 nautical miles	= 1 league; 18,240.78 feet

Square Measure

144 square inches	= 1 square foot
9 square feet	= 1 square yard
30¼ square yds.	= 1 square rod; 272¼ square feet
160 square rods	= 1 acre; 43,560 square feet
640 acres	= 1 square mile; 27,878,400 square feet

A circular mil is the area of a circle 1 mil, or 0.001 inch in diameter.

1 square inch = 1,273,239 circular mils

A circular inch is the area of a circle 1 inch in diameter = 0.7854 square inches.

1 square inch = 1.2732 circular inches

Cubic Measure

1728 cubic inches	= 1 cubic foot; 7.4805 gallons
27 cubic feet	= 1 cubic yard
128 cubic feet	= 1 cord

Liquid Measure

4 gills	= 1 pint
2 pints	= 1 quart
4 quarts	= 1 gallon; 231 cubic inches; .134 cubic feet
31½ gallons	= 1 barrel
2 barrels	= 1 hogshead

Dry Measure

2 pints	= 1 quart
8 quarts	= 1 peck
4 pecks	= 1 bushel; 2150.42 cubic inches; 1.2445 cubic feet

Weight—Avoirdupois or Commercial

437.5 grains	= 1 ounce
16 ounces	= 1 pound
112 pounds	= 1 hundredweight
20 hundredweight	= 1 gross, or long ton; 2240 pounds
2000 pounds	= 1 net, or short ton
2204.6 pounds	= 1 metric ton

Useful Information

Metric System of Measures and Weights

Linear Measure

1 millimeter	= 0.03937 inches
1 centimeter	= 0.3937 inches
1 decimeter	= 3.937 inches
1 meter	= 39.37 inches 3.28083 feet 1.09361 yards
1 kilometer	= 3280.83 feet 1093.61 yards 0.62137 miles
1 inch	= 25.4 millimeters
1 inch	= 2.54 centimeters
1 inch	= .254 decimeters
1 inch	= .0254 meters
1 foot	= .3048 meters
1 yard	= .9144 meters
1 mile	= 1.60935 kilometers

Cubic Measure

1 cubic centimeter	= 0.061 cubic inches
1 cubic decimeter	= 61.0234 cubic inches 0.035314 cubic feet
1 cubic meter	= 35.314 cubic feet 1.308 cubic yards

Weight

1 gram	= 15.432 grains
1 kilogram	= 2.204622 pounds
1 metric ton 1000 kilograms	= 2204.6 pounds 0.9842 gross tons 1.1023 net tons
1 grain	= 0.0648 gram
1 pound	= 0.4536 kilogram

Capacity

1 Liter	= 61.0234 cubic inches 0.03531 cubic feet 0.2642 gallons
1 cubic foot	= 28.317 liters
1 gallon	= 3.785 liters

Square Measure

1 square millimeter	= 0.00155 square inches 1973.5 circular mils
1 square centimeter	= 0.155 square inches
1 square decimeter	= 15.5 square inches
1 square meter	= 1550 square inches 10.7639 square feet 1.196 square yards
1 square kilometer	= 0.386109 square miles 247.11 acres
1 square myriameter	= 38.6109 square miles
1 square inch	= 645.2 square millimeters
1 square inch	= 6.452 square centimeters
1 square inch	= 0.06452 square decimeters
1 square foot	= 0.0929 square meters
1 square yard	= 0.836 square meters

Compound Units

1 gram per square millimeter	= 1.422 pounds per square inch
1 kilogram per square millimeter	= 1422.32 pounds per square inch
1 kilogram per square centimeter	= 14.2232 pounds per square inch
1 kilogram per square meter	= 0.2048 pounds per square foot 1.8433 pounds per square yard
1 kilogram meter	= 7.2330 foot pounds
1 kilogram per meter	= 0.6720 pounds per foot
1 pound per square inch	= 0.07031 kilogram per square centimeter
1 pound per square foot	= 0.0004882 kilogram per square centimeter
1 pound per square foot	= 0.006944 pounds per square inch
1 pound per cubic inch	= 27679.7 kilograms per cubic meter
1 pound per cubic foot	= 16.0184 kilograms per cubic meter
1 kilogram per cubic meter	= 0.06243 pounds per cubic foot
1 foot per second	= 0.30480 meters per second
1 meter per second	= 3.28083 feet per second
1 meter per second	= 2.23693 miles per hour

Nominal Dia. In.		Nominal Dia. mm
3/16		5
	1/4	6.5
5/16		8
	3/8	9.5
7/16		11
	1/2	13
9/16		14.5
	5/8	16
3/4		19
	7/8	22
1		26
	1 1/8	29
1 1/4		32
	1 3/8	35
1 1/2		38
	1 5/8	42
1 3/4		45
	1 7/8	48
2		51
	2 1/8	54
2 1/4		57
	2 3/8	61
2 1/2		64
	2 5/8	67
2 3/4		70
	2 7/8	74
3		77
	3 1/8	80
3 1/4		83
	3 3/8	86
3 1/2		90
	3 5/8	93
3 3/4		96
	3 7/8	99
4		103
	4 1/8	106
4 1/4		109
	4 3/8	112
4 1/2		115
	4 5/8	118
4 3/4		122
	4 7/8	125
5		128

Useful Information

Table of Multiples

Circumference of Circle	= Diameter × 3.1416
Area of Circle	= Square of Diameter × 0.7854, or, Square of Radius × 3.1416, or, Square of Circumference × 0.07958
Area of Triangle	= Base × one-half altitude
Surface of Sphere	= Circumference × diameter, or, Square of diameter × 3.1416
Volume of Sphere	= Surface × one-sixth diameter, or, Cube of diameter × 0.5236
Area of Hexagon	= Square of Diameter of Inscribed Circle × 0.866
Area of Octagon	= Square of Diameter of Inscribed Circle × 0.828

Engineering Units

1 Horsepower	= 33,000 foot pounds per minute 550 foot pounds per second 746 watts .746 kilowatts
1 Horsepower Hour	= .746 kilowatt hours 1,980,000 foot pounds 2,545 heat units (B.T.U.)
1 Kilowatt	= 1,000 watts 1.34 horsepower 737.3 foot pounds per second 44,240 foot pounds per minute 56.9 heat units (B.T.U.) per minute
1 Kilowatt Hour	= 1,000 watt hours 1.34 horsepower hours 2,654,200 foot pounds 3,412 heat units (B.T.U.)
1 British Thermal Unit	= 1,055 watt seconds 778 foot pounds .000293 kilowatt hour .000393 horsepower hour
1 Watt	= 1 joule per second .00134 horsepower 3,412 heat units (B.T.U.) per hour .7373 foot pounds per second 44.24 foot pounds per minute

Useful Information

Specific Gravities and Weights

Substance	Specific Gravity	Weight, Lbs. per Cu. Ft.
METALS, ALLOYS, ORES		
Aluminum, cast-hammered	2.55–2.75	165
Aluminum, bronze	7.7	481
Antimony	6.62–6.72	416
Arsenic	5.73	358
Bismuth	9.70–9.78	608
Brass, cast-rolled	8.4–8.7	534
Bronze (gun metal)— copper 88, tin 10, zinc 2%	8.7	544
Bronze (Phosphor)— copper 80, tin 10, lead 10%	9.0	562
Chromium	6.80–6.92	428
Cobalt	8.72–8.95	552
Copper, cast-rolled	8.8–9.0	556
Copper, ore, pyrites	4.1–4.3	262
Gold, cast-hammered	19.25–19.35	1205
Iron, cast, pig	7.2	450
Iron, wrought	7.6–7.9	485
Iron, Spiegel-eisen	7.5	468
Iron, ferro-silicon	6.7–7.3	437
Iron, ore, hematite	5.2	325
Iron, ore, hematite in bank	....	160–180
Iron, ore, hematite loose	....	130–160
Iron, ore, limonite	3.6–4.0	237
Iron, ore, magnetite	4.9–5.2	315
Iron, slag	2.5–3.0	172
Lead	11.28–11.35	706
Lead ore, galena	7.3–7.6	465
Magnesium	1.74	109
Manganese	7.20–7.42	456
Manganese ore, pyrolusite	3.7–4.6	259
Mercury	13.59	848
Molybdenum	9.01	562
Nickel	8.57–8.90	545
Nickel monel metal	8.8–9.0	556
Platinum, cast-hammered	21.1–21.5	1330
Silver, cast-hammered	10.4–10.6	656
Steel	7.8–7.9	490
Tin, cast-hammered	7.2–7.5	459
Tin, babbitt metal	7.1	443
Tin, ore, cassiterite	6.4–7.0	418
Tungsten	18.7–19.1	1180
Vanadium	5.5–5.7	350
Zinc, cast-rolled	6.9–7.2	440
Zinc, ore, blende	3.9–4.2	253
VARIOUS SOLIDS		
Carbon, amorphous, graphitic	1.88–2.25	129
Cork	0.24	15
Ebony	1.22	76
Fats	0.92–0.94	58
Glass, common, plate	2.40–2.72	160
Glass, crystal	2.90–3.00	184
Glass, flint	3.15–3.90	220
Phosphorous, white	1.83	114
Porcelain, china	2.30–2.50	150
Resins, Rosin, Amber	1.07	67
Rubber, caoutchouc	0.93	58
Silicon	2.49	155
Sulphur, Amorphous	2.05	128
Wax	0.95–0.98	60
TIMBER, U. S. SEASONED		
Ash, white	0.65	41
Beech	0.70	44
Birch, yellow	0.68	43
Cedar, Port Orford	0.47	29
Cedar, white, red	0.35–0.37	22–23
Chestnut	0.48	30
Cypress, southern	0.51	32
Douglas Fir, coast type	0.54	34
Douglas Fir, mountain	0.48	30
Elm, American	0.56	35
Hemlock, eastern, western	0.45	28
Hickory, bigleaf	0.77	48
Hickory, pignut	0.85	53
Larch, western	0.58	36
Maple, red, black	0.61–0.64	38–40
Maple, silver	0.52	33
Oak, Oregon white	0.82	51
Oak, red	0.71	44
Pine, red	0.53	33
Pine, white, yellow, western	0.43–0.45	27–28
Poplar, yellow	0.45	28
Redwood	0.48	30
Spruce, black, red	0.45	28
Spruce, Engelmann	0.37	23
Tamarack	0.60	37
Walnut	0.63–0.64	39–40
Moisture Contents:		
Seasoned timber 12%	....	....
Green timber up to 50%	....	....
VARIOUS LIQUIDS		
Alcohol, 100%	0.79	49
Acids, Muriatic 40%	1.20	75
Acids, nitric 91%	1.50	94
Acids, sulphuric 87%	1.80	112
Lye, soda 66%	1.70	106
Oils, vegetable	0.91–0.94	58
Oils, mineral, lubricants	0.90–0.93	57
Petroleum	0.88	55
Gasoline	0.66–0.69	42
Water, 4° C, max. density	1.0	62.428
Water, 100° C	0.9584	59.830
Water, ice	0.88–0.92	56
Water, snow, fresh fallen	.125	8
Water, sea water	1.02–1.03	64
GASES		
Air, 0° C, 760 mm	1.0	.08071
Ammonia	0.5920	.0478
Carbon dioxide	1.5291	.1234
Carbon monoxide	0.9673	.0781
Gas, illuminating	0.35–0.45	.028–.036
Gas, natural	0.47–0.48	.038–.039
Hydrogen	0.0693	.00559
Nitrogen	0.9714	.0784
Oxygen	1.1056	.0892

The specific gravities of solids and liquids refer to water at 4°C., those of gases to air at 0°C. and 760 mm pressure. The weights per cubic foot are derived from average specific gravities, except where stated that weights are for bulk, heaped or loose material, etc.

Specific Gravities and Weights

Substance	Specific Gravity	Weight, Lbs. per Cu. Ft.
MINERALS		
Asbestos	2.1–2.8	153
Barytes	4.50	281
Basalt	2.7–3.2	184
Bauxite	2.55	159
Borax	1.7–1.8	109
Chalk	1.8–2.6	137
Clay, marl	1.8–2.6	137
Dolomite	2.9	181
Feldspar, orthoclase	2.5–2.6	159
Granite, gneiss	2.6–2.9	172
Greenstone, trap	2.8–3.2	187
Gypsum, alabaster	2.3–2.8	159
Hornblende	3.0	187
Limestone, crystalline	2.4–2.7	160
Limestone, oolitic	2.3	144
Magnesite	3.0	187
Marble	2.7–2.8	168
Phosphate rock, apatite	3.2	200
Porphyry	2.6–2.9	172
Pumice, natural	0.37–0.90	40
Quartz, flint	2.5–2.8	165
Sandstone, bluestone	2.2–2.5	147
Slate, shale	2.7–2.8	172
Soapstone, talc	2.6–2.8	169
STONE, QUARRIED, PILED		
Basalt, granite, gneiss	....	96
Limestone, marble, quartz	....	95
Sandstone	....	82
Shale	....	92
Greenstone, hornblende	....	107
BITUMINOUS SUBSTANCES		
Asphaltum	1.1–1.5	81
Coal, anthracite	1.4–1.7	97
Coal, bituminous	1.2–1.5	84
Coal, lignite	1.1–1.4	78
Coal, peat, turf, dry	0.65–0.85	47
Coal, charcoal, pine	0.28–0.44	23
Coal, charcoal, oak	0.47–0.57	33
Coal, coke	1.0–1.4	75
Graphite	1.9–2.3	131
Paraffine	0.87–0.91	56
Petroleum, crude	0.88	55
Petroleum, refined	0.79–0.82	50
Petroleum, benzine	0.73–0.75	46
Petroleum, gasoline	0.66–0.69	42
Pitch	1.07–1.15	69
Tar, bituminous	1.20	75
COAL AND COKE, PILED		
Coal, anthracite	....	47–58
Coal, bituminous, lignite	....	40–54
Coal, peat, turf	....	20–26
Coal, charcoal	....	10–14
Coal, coke	....	23–32

Substance	Specific Gravity	Weight, Lbs. per Cu. Ft.
ASHLAR MASONRY		
Granite, gneiss	2.6–2.9	172
Limestone, crystalline	2.4–2.7	160
Limestone, oolitic	2.3	144
Marble	2.6–2.8	168
Sandstone, bluestone	2.2–2.5	147
MORTAR RUBBLE MASONRY		
Granite, gneiss	2.5–2.8	165
Limestone, crystalline	2.3–2.6	156
Limestone, oolitic	2.2	138
Marble	2.5–2.7	162
Sandstone, bluestone	2.1–2.4	140
BRICK MASONRY		
Pressed brick	2.2–2.3	140
Common brick	1.8–2.0	120
Soft brick	1.5–1.7	100
CONCRETE		
Cement, stone, sand	2.2–2.4	144
Cement, slag, etc.	1.9–2.3	130
Cement, cinder, etc.	1.5–1.7	100
VARIOUS BUILDING MATERIAL		
Ashes, cinders	....	40–45
Cement, Portland, loose	....	90
Cement, Portland, set	2.7–3.2	183
Lime, gypsum, loose	....	65–75
Mortar, set	1.4–1.9	103
Slags, bank slag	....	67–72
Slags, bank, screenings	....	98–117
Slags, machine slag	....	96
Slags, slag sand	....	49–55
EARTH, ETC., EXCAVATED		
Clay, dry	....	63
Clay, damp, plastic	....	110
Clay and gravel, dry	....	100
Earth, dry, loose	....	76
Earth, dry, packed	....	95
Earth, moist, loose	....	78
Earth, moist, packed	....	96
Earth, mud, flowing	....	108
Earth, mud, packed	....	115
Riprap, limestone	....	80–85
Riprap, sandstone	....	90
Riprap, shale	....	105
Sand, gravel, dry, loose	....	90–105
Sand, gravel, dry, packed	....	100–120
Sand, gravel, wet	....	118–120
EXCAVATIONS IN WATER		
Sand or gravel	....	60
Sand or gravel and clay	....	65
Clay	....	80
River mud	....	90
Soil	....	70
Stone riprap	....	65

The specific gravities of solids and liquids refer to water at 4°C., those of gases to air at 0°C. and 760 mm pressure. The weights per cubic foot are derived from average specific gravities, except where stated that weights are for bulk, heaped or loose material, etc.

Useful Information

Strength of New Manila Ropes

Circumference in Inches	Nominal Diameter in Inches	Minimum Tensile Strength in Pounds
9/16	3/16	420
3/4	1/4	550
1	5/16	950
1 1/8	3/8	1,275
1 1/4	7/16	1,750
1 3/8	15/32	2,250
1 1/2	1/2	2,650
1 3/4	9/16	3,450
2	5/8	4,400
2 1/4	3/4	5,400
2 1/2	13/16	6,500
2 3/4	7/8	7,700
3	1	9,000
3 1/4	1 1/16	10,500
3 1/2	1 1/8	12,000
3 3/4	1 1/4	13,500
4	1 5/16	15,000
4 1/2	1 1/2	18,500
5	1 5/8	22,500
5 1/2	1 3/4	26,500
6	2	31,000
6 1/2	2 1/8	36,000
7	2 1/4	41,000
7 1/2	2 1/2	46,500
8	2 5/8	52,000
8 1/2	2 7/8	58,000
9	3	64,000
9 1/2	3 1/8	71,000
10	3 1/4	77,000
11	3 1/2	91,000
12	4	105,000

Useful Information

Strength of Materials
Stresses in Pounds per Square Inch

Building Materials	Ultimate Average Stresses			Modulus of Elasticity	Safe Working Stresses		
	Compress.	Tension	Bending		Compress.	Bearing	Shearing
STONE							
Granite, gneiss, bluestone	12,000	1,200	1,600	7,000,000	1,200	1,200	200
Limestone, marble	8,000	800	1,500	7,000,000	800	800	150
Sandstone	5,000	150	1,200	3,000,000	500	500	150
Slate	10,000	3,000	5,000	14,000,000	1,000	1,000	175
MASONRY							
Granite					420	600	
Limestone, bluestone					350	500	
Sandstone					280	400	
Rubble					140	250	
Rubble, coursed					170	250	
Brick, medium burned	10,000				170	300	
Brick, hard burned	15,000				210	300	
Brick, pressed, paving brick	6,000						
Terra Cotta	5,000						
CEMENT, PORTLAND							
Neat, 28 days	7,040	740					
Neat, 90 days	7,350	740					
1:3 sand, 28 days	1,290	320					
1:3 sand, 90 days	1,490	340					
CONCRETE, P. C.							
1:1:2 Granite, trap rock	3,300						
1:1:2 Furnace Slag	3,000						
1:1:2 Lime and Sandstone, hard	3,000						
1:1:2 Lime and Sandstone, soft	2,200						
1:1:2 Cinders	800						
1:1½:3 Granite, trap rock	2,800						
1:1½:3 Furnace Slag	2,500						
1:1½:3 Lime and Sandstone, hard	2,500						
1:1½:3 Lime and Sandstone, soft	1,800						
1:1½:3 Cinders	700						
1:2:4 Granite, trap rock	2,200						
1:2:4 Furnace Slag	2,000						
1:2:4 Lime and Sandstone, hard	2,000						
1:2:4 Lime and Sandstone, soft	1,500						
1:2:4 Cinders	600						
1:2½:5 Granite, trap rock	1,800						
1:2½:5 Furnace Slag	1,600						
1:2½:5 Lime and Sandstone, hard	1,600						
1:2½:5 Lime and Sandstone, soft	1,200						
1:2½:5 Cinders	500						
1:3:6 Granite, trap rock	1,400						
1:3:6 Furnace Slag	1,300						
1:3:6 Lime and Sandstone, hard	1,300						
1:3:6 Lime and Sandstone, soft	1,000						
1:3:6 Cinders	400						
MISCELLANEOUS							
Glass, common	30,000	3,000					
Plaster	700	70	3,000	8,000,000			

REINFORCED CONCRETE

Modulus of Elasticity	
3,000,000	for ult. compression over....2,900.
2,500,000	for ult. compression up to...2,900.
2,000,000	for ult. compression up to...2,200.
750,000	for ult. compression under... 800.

Safe Working Stresses in Percent of Ultimate Compression

Compression	Plain Concrete Piers, length 4 dia.	22.5%
	Reinforced Columns, length 12 dia.	22.5%
	Reinforced Beams	32.5%
Bearing	Surface twice the loaded area	35.0%
Shear and Diag. Tension	Horizontal Bars, no web reinforcement	2.0%
	Horizontal Bars, vertical stirrups	4.5%
	Bent Bars and vertical stirrups	5.0%
	Same, securely attached	6.0%
Bond Stress	Drawn Wire	2.0%
	Plain reinforcing bars	4.0%
	Deformed Bars, best type	5.0%

For complete data see Transactions of the American Society of Civil Engineers, Vol. LXXXI-No. 1398, Dec. 1917

Useful Information

Strength of Materials
Stresses per Square Inch

Metals and Alloys	Stresses in Kips: Tension, Ultimate	Elastic Limit	Compression, Ultimate	Bending, Ultimate	Shearing, Ultimate	Modulus of Elasticity	Elongation, %
Aluminum, cast	15	6.5	12		12	11,000,000	
Aluminum, bars, sheets	24–28	12–14					
Aluminum, wire, hard	30–65	16–30					
Aluminum, wire, annealed	20–35	14					
Aluminum, 2% to 7% Ni, Cu, Fe, etc.	40–50	25					
Aluminum Bronze, 5% to 7½% Al	75	40	120				
Aluminum Bronze, 10% Al	85–100	60					
Copper, cast	25	6	40	22	30	10,000,000	
Copper, plates, rods, bolts	32–35	10	32				
Copper, wire, hard	55–65					18,000,000	
Copper, wire, annealed	36	10				15,000,000	
Brass, 17% Zn	32.6	8.2		23.2			26.7
Brass, 23% Zn		7.6	42	22.3			35.8
Brass, 30% Zn	28.1	8.6		26.9			20.7
Brass, 39% Zn	41.1	17.4	75	39			20.7
Brass, 50% Zn	31	17.9	117	33.5			5.0
Brass, cast, common	18–24	6	30	20	36	9,000,000	
Brass, wire, hard	80						
Brass, wire, annealed	50	16				14,000,000	
Bronze 8% Sn	28.5	19	42	43.7		10,000,000	5.5
Bronze 13% Sn	29.4	20	53	34.5			3.3
Bronze 20% Sn	33		78	56.7			0.04
Bronze 24% Sn	22	22	114	32			0
Bronze 30% Sn	5.6	5.6	147	12.1			0
Bronze gun metal, 9 Cu, 1 Sn	25–55	10		52		10,000,000	
Bronze Manganese, cast } 10% Sn.	60	30	125				
Bronze Manganese, rolled } 2% Mn.	100	80					
Bronze Phosphorus, cast } 9% Sn.	50	24					
Bronze Phosphorus, wire } 1% P.	100						
Bronze Silicon, cast, 3% Si	55						
Bronze Silicon, cast, 5% Si	75						
Bronze Silicon, wire	108						
Bronze Tobin, cast } 38% Zn	66						
Bronze Tobin, rolled } 1½% Sn	80	40				4,500,000	
Bronze Tobin, cold rolled } ⅓% Pb	100						
Delta Metal, cast } 55% to 60% Cu	45						
Delta Metal, plates } 38% to 40% Zn	68						
Delta Metal, bars } 2% to 4% Fe	85						
Delta Metal, wire } 1% to 2% Sn	100						
German Silver, 25% Zn, 20% Ni							
Iron, see next page							
Gold, cast	20	4				8,000,000	
Gold, wire	30						
Gold, copper, 5 Au, 1 Cu	50						
Lead, cast	1.8					1,000,000	
Lead, pipe, wire	2.2–2.5					1,000,000	
Lead, rolled sheets	3.3					720,000	
Platinum, wire, unannealed	53						
Platinum, wire, annealed	32						
Silver, cast	40						
Steel, see next page							
Tin, cast	3.5–4.6	1.5–1.8	6	4		4,000,000	
Tin, antimony, 10 Sn, 1 Sb	11						
Zinc, cast	4–6	4	18	7		13,000,000	
Zinc, rolled sheets	7–16						

Strength of Materials
Stresses per Square Inch

Metals and Alloys	Stresses in Kips: Tension, Ultimate	Elastic Limit	Compression, Ultimate	Bending, Ultimate	Shearing, Ultimate	Modulus of Elasticity	Elongation, %
STEEL							
Shapes, Plates, Bars*							
Bridges	55–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	27.3–23.1
Buildings	55–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	25.5–21.5
Cars	50–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	30.0–23.1
Locomotives	55–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	27.3–23.1
Ships	60–72	½ tens.	tensile	tensile	¾ tens.	29,000,000	25.0–21.1
Boiler Plates*							
Flange plates	55–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	27.3–23.1
Fire box	52–62	½ tens.	tensile	tensile	¾ tens.	29,000,000	28.8–24.2
Rivets*							
Boilers	45–55	½ tens.	tensile	tensile	¾ tens.	29,000,000	33.3–27.3
Bridges	52–62	½ tens.	tensile	tensile	¾ tens.	29,000,000	28.8–24.2
Buildings	52–62	½ tens.	tensile	tensile	¾ tens.	29,000,000	28.8–24.2
Cars	52–62	½ tens.	tensile	tensile	¾ tens.	29,000,000	28.8–24.2
Ships	55–65	½ tens.	tensile	tensile	¾ tens.	29,000,000	27.3–23.0
Concrete Bars*							
Plain, structural grade	55–70	33	tensile	tensile	¾ tens.	29,000,000	25.5–20.0
Plain, intermediate	70–90	40	tensile	tensile	¾ tens.	29,000,000	18.6–14.3
Plain hard	80	50	tensile	tensile	¾ tens.	29,000,000	15.0
Deformed, structural grade	55–70	33	tensile	tensile	¾ tens.	29,000,000	22.7–17.9
Deformed, intermediate	70–90	40	tensile	tensile	¾ tens.	29,000,000	16.1–11.3
Deformed, hard	80	50	tensile	tensile	¾ tens.	29,000,000	12.5
Cold twisted	......	55	tensile	tensile	¾ tens.	29,000,000	5.0
Castings*							
Soft	60	30	tensile	tensile	¾ tens.	29,000,000	26
Medium	70	38	tensile	tensile	¾ tens.	29,000,000	24
Hard	80	43	tensile	tensile	¾ tens.	29,000,000	17
Forgings*	......	......	......	......	......	......	......
STEEL ALLOYS							
Nickel Steel,* 3.25% Ni.							
Shapes, plates, bars	85–100	50	tensile	tensile	¾ tens.	29,000,000	17.6–15.0
Rivets	70–80	45	tensile	tensile	¾ tens.	29,000,000	21.4–18.8
Eye bars, unannealed	95–110	55	tensile	tensile	¾ tens.	29,000,000	15.8–13.6
Eye bars, annealed	90–105	52	tensile	tensile	¾ tens.	29,000,000	20.0
STEEL SPRINGS AND WIRE							
Springs, untempered	65–110	40–70	......	......	......	......	......
Wire, unannealed	120	60	......	......	......	......	......
Wire, annealed	80	40	......	......	......	......	......
Wire, bridge cable	220	150	......	......	......	......	......
WROUGHT IRON							
Shapes	48	26	tensile	tensile	⅚ tens.	28,000,000	......
Bars	50	27	tensile	tensile	⅚ tens.	28,000,000	......
Wire, unannealed	80	......	......	......	......	15,000,000	......
Wire, annealed	60	27	......	......	......	25,000,000	......
CAST IRON							
Common	15–18	6	80	30	18–20	12,000,000	......
Gray	18–24	......	......	25–33	......	......	......
Malleable	27–35	15–20	46	30	40	......	......

*See Specifications of the American Society for Testing Materials.

Useful Information

Sines and Cosines
Natural Trigonometric Functions

Degrees	Sines							Cosines
	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cosines							

Sines and Cosines
Natural Trigonometric Functions

Degrees	Cosines 0′	10′	20′	30′	40′	50′	60′	Sines
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	0.99973	0.99966	0.99958	0.99949	0.99939	88
2	0.99939	0.99929	0.99917	0.99905	0.99892	0.99878	0.99863	87
3	0.99863	0.99847	0.99831	0.99813	0.99795	0.99776	0.99756	86
4	0.99756	0.99736	0.99714	0.99692	0.99668	0.99644	0.99619	85
5	0.99619	0.99594	0.99567	0.99540	0.99511	0.99482	0.99452	84
6	0.99452	0.99421	0.99390	0.99357	0.99324	0.99290	0.99255	83
7	0.99255	0.99219	0.99182	0.99144	0.99106	0.99067	0.99027	82
8	0.99027	0.98986	0.98944	0.98902	0.98858	0.98814	0.98769	81
9	0.98769	0.98723	0.98676	0.98629	0.98580	0.98531	0.98481	80
10	0.98481	0.98430	0.98378	0.98325	0.98272	0.98218	0.98163	79
11	0.98163	0.98107	0.98050	0.97992	0.97934	0.97875	0.97815	78
12	0.97815	0.97754	0.97692	0.97630	0.97566	0.97502	0.97437	77
13	0.97437	0.97371	0.97304	0.97237	0.97169	0.97100	0.97030	76
14	0.97030	0.96959	0.96887	0.96815	0.96742	0.96667	0.96593	75
15	0.96593	0.96517	0.96440	0.96363	0.96285	0.96206	0.96126	74
16	0.96126	0.96046	0.95964	0.95882	0.95799	0.95715	0.95630	73
17	0.95630	0.95545	0.95459	0.95372	0.95284	0.95195	0.95106	72
18	0.95106	0.95015	0.94924	0.94832	0.94740	0.94646	0.94552	71
19	0.94552	0.94457	0.94361	0.94264	0.94167	0.94068	0.93969	70
20	0.93969	0.93869	0.93769	0.93667	0.93565	0.93462	0.93358	69
21	0.93358	0.93253	0.93148	0.93042	0.92935	0.92827	0.92718	68
22	0.92718	0.92609	0.92499	0.92388	0.92276	0.92164	0.92050	67
23	0.92050	0.91936	0.91822	0.91706	0.91590	0.91472	0.91355	66
24	0.91355	0.91236	0.91116	0.90996	0.90875	0.90753	0.90631	65
25	0.90631	0.90507	0.90383	0.90259	0.90133	0.90007	0.89879	64
26	0.89879	0.89752	0.89623	0.89493	0.89363	0.89232	0.89101	63
27	0.89101	0.88968	0.88835	0.88701	0.88566	0.88431	0.88295	62
28	0.88295	0.88158	0.88020	0.87882	0.87743	0.87603	0.87462	61
29	0.87462	0.87321	0.87178	0.87036	0.86892	0.86748	0.86603	60
30	0.86603	0.86457	0.86310	0.86163	0.86015	0.85866	0.85717	59
31	0.85717	0.85567	0.85416	0.85264	0.85112	0.84959	0.84805	58
32	0.84805	0.84650	0.84495	0.84339	0.84182	0.84025	0.83867	57
33	0.83867	0.83708	0.83549	0.83389	0.83228	0.83066	0.82904	56
34	0.82904	0.82741	0.82577	0.82413	0.82248	0.82082	0.81915	55
35	0.81915	0.81748	0.81580	0.81412	0.81242	0.81072	0.80902	54
36	0.80902	0.80730	0.80558	0.80386	0.80212	0.80038	0.79864	53
37	0.79864	0.79688	0.79512	0.79335	0.79158	0.78980	0.78801	52
38	0.78801	0.78622	0.78442	0.78261	0.78079	0.77897	0.77715	51
39	0.77715	0.77531	0.77347	0.77162	0.76977	0.76791	0.76604	50
40	0.76604	0.76417	0.76229	0.76041	0.75851	0.75661	0.75471	49
41	0.75471	0.75280	0.75088	0.74896	0.74703	0.74509	0.74314	48
42	0.74314	0.74120	0.73924	0.73728	0.73531	0.73333	0.73135	47
43	0.73135	0.72937	0.72737	0.72537	0.72337	0.72136	0.71934	46
44	0.71934	0.71732	0.71529	0.71325	0.71121	0.70916	0.70711	45
Cosines	60′	50′	40′	30′	20′	10′	0′ Sines	Degrees

Useful Information

Tangents and Cotangents
Natural Trigonometric Functions

Degrees	Tangents							Cotangents
	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54674	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cotangents							

Useful Information

Tangents and Cotangents
Natural Trigonometric Functions

Degrees	Cotangents 0′	10′	20′	30′	40′	50′	60′	Tangents
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60478	14.92442	14.30067	86
4	14.30067	13.72674	13.19688	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33693	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92098	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35142	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Cotangents	Tangents 60′	50′	40′	30′	20′	10′	0′	Degrees

Useful Information

Secants and Cosecants
Natural Trigonometric Functions

Degrees	Secants							Cosecants
	0′	10′	20′	30′	40′	50′	60′	
0	1.00000	1.00000	1.00002	1.00004	1.00007	1.00011	1.00015	89
1	1.00015	1.00021	1.00027	1.00034	1.00042	1.00051	1.00061	88
2	1.00061	1.00072	1.00083	1.00095	1.00108	1.00122	1.00137	87
3	1.00137	1.00153	1.00169	1.00187	1.00205	1.00224	1.00244	86
4	1.00244	1.00265	1.00287	1.00309	1.00333	1.00357	1.00382	85
5	1.00382	1.00408	1.00435	1.00463	1.00491	1.00521	1.00551	84
6	1.00551	1.00582	1.00614	1.00647	1.00681	1.00715	1.00751	83
7	1.00751	1.00787	1.00825	1.00863	1.00902	1.00942	1.00983	82
8	1.00983	1.01024	1.01067	1.01111	1.01155	1.01200	1.01247	81
9	1.01247	1.01294	1.01342	1.01391	1.01440	1.01491	1.01543	80
10	1.01543	1.01595	1.01649	1.01703	1.01758	1.01815	1.01872	79
11	1.01872	1.01930	1.01989	1.02049	1.02110	1.02171	1.02234	78
12	1.02234	1.02298	1.02362	1.02428	1.02494	1.02562	1.02630	77
13	1.02630	1.02700	1.02770	1.02842	1.02914	1.02987	1.03061	76
14	1.03061	1.03137	1.03213	1.03290	1.03368	1.03447	1.03528	75
15	1.03528	1.03609	1.03691	1.03774	1.03858	1.03944	1.04030	74
16	1.04030	1.04117	1.04206	1.04295	1.04385	1.04477	1.04569	73
17	1.04569	1.04663	1.04757	1.04853	1.04950	1.05047	1.05146	72
18	1.05146	1.05246	1.05347	1.05449	1.05552	1.05657	1.05762	71
19	1.05762	1.05869	1.05976	1.06085	1.06195	1.06306	1.06418	70
20	1.06418	1.06531	1.06645	1.06761	1.06878	1.06995	1.07115	69
21	1.07115	1.07235	1.07356	1.07479	1.07602	1.07727	1.07853	68
22	1.07853	1.07981	1.08109	1.08239	1.08370	1.08503	1.08636	67
23	1.08636	1.08771	1.08907	1.09044	1.09183	1.09323	1.09464	66
24	1.09464	1.09606	1.09750	1.09895	1.10041	1.10189	1.10338	65
25	1.10338	1.10488	1.10640	1.10793	1.10947	1.11103	1.11260	64
26	1.11260	1.11419	1.11579	1.11740	1.11903	1.12067	1.12233	63
27	1.12233	1.12400	1.12568	1.12738	1.12910	1.13083	1.13257	62
28	1.13257	1.13433	1.13610	1.13789	1.13970	1.14152	1.14335	61
29	1.14335	1.14521	1.14707	1.14896	1.15085	1.15277	1.15470	60
30	1.15470	1.15665	1.15861	1.16059	1.16259	1.16460	1.16663	59
31	1.16663	1.16868	1.17075	1.17283	1.17493	1.17704	1.17918	58
32	1.17918	1.18133	1.18350	1.18569	1.18790	1.19012	1.19236	57
33	1.19236	1.19463	1.19691	1.19920	1.20152	1.20386	1.20622	56
34	1.20622	1.20859	1.21099	1.21341	1.21584	1.21830	1.22077	55
35	1.22077	1.22327	1.22579	1.22833	1.23089	1.23347	1.23607	54
36	1.23607	1.23869	1.24134	1.24400	1.24669	1.24940	1.25214	53
37	1.25214	1.25489	1.25767	1.26047	1.26330	1.26615	1.26902	52
38	1.26902	1.27191	1.27483	1.27778	1.28075	1.28374	1.28676	51
39	1.28676	1.28980	1.29287	1.29597	1.29909	1.30223	1.30541	50
40	1.30541	1.30861	1.31183	1.31509	1.31837	1.32168	1.32501	49
41	1.32501	1.32838	1.33177	1.33519	1.33864	1.34212	1.34563	48
42	1.34563	1.34917	1.35274	1.35634	1.35997	1.36363	1.36733	47
43	1.36733	1.37105	1.37481	1.37860	1.38242	1.38628	1.39016	46
44	1.39016	1.39409	1.39804	1.40203	1.40606	1.41012	1.41421	45
Secants	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cosecants							

Secants and Cosecants
Natural Trigonometric Functions

Degrees	Cosecants							Secants
	0′	10′	20′	30′	40′	50′	60′	
0	∞	343.77516	171.88831	114.59301	85.94561	68.75736	57.29869	89
1	57.29869	49.11406	42.97571	38.20155	34.38232	31.25758	28.65371	88
2	28.65371	26.45051	24.56212	22.92559	21.49368	20.23028	19.10732	87
3	19.10732	18.10262	17.19843	16.38041	15.63679	14.95788	14.33559	86
4	14.33559	13.76312	13.23472	12.74550	12.29125	11.86837	11.47371	85
5	11.47371	11.10455	10.75849	10.43343	10.12752	9.83912	9.56677	84
6	9.56677	9.30917	9.06515	8.83367	8.61379	8.40466	8.20551	83
7	8.20551	8.01565	7.83443	7.66130	7.49571	7.33719	7.18530	82
8	7.18530	7.03962	6.89979	6.76547	6.63633	6.51208	6.39245	81
9	6.39245	6.27719	6.16607	6.05886	5.95536	5.85539	5.75877	80
10	5.75877	5.66533	5.57493	5.48740	5.40263	5.32049	5.24084	79
11	5.24084	5.16359	5.08863	5.01585	4.94517	4.87649	4.80973	78
12	4.80973	4.74482	4.68167	4.62023	4.56041	4.50216	4.44541	77
13	4.44541	4.39012	4.33622	4.28366	4.23239	4.18238	4.13357	76
14	4.13357	4.08591	4.03938	3.99393	3.94952	3.90613	3.86370	75
15	3.86370	3.82223	3.78166	3.74198	3.70315	3.66515	3.62796	74
16	3.62796	3.59154	3.55587	3.52094	3.48671	3.45317	3.42030	73
17	3.42030	3.38808	3.35649	3.32551	3.29512	3.26531	3.23607	72
18	3.23607	3.20737	3.17920	3.15155	3.12440	3.09774	3.07155	71
19	3.07155	3.04584	3.02057	2.99574	2.97135	2.94737	2.92380	70
20	2.92380	2.90063	2.87785	2.85545	2.83342	2.81175	2.79043	69
21	2.79043	2.76945	2.74881	2.72850	2.70851	2.68884	2.66947	68
22	2.66947	2.65040	2.63162	2.61313	2.59491	2.57698	2.55930	67
23	2.55930	2.54190	2.52474	2.50784	2.49119	2.47477	2.45859	66
24	2.45859	2.44264	2.42692	2.41142	2.39614	2.38107	2.36620	65
25	2.36620	2.35154	2.33708	2.32282	2.30875	2.29487	2.28117	64
26	2.28117	2.26766	2.25432	2.24116	2.22817	2.21535	2.20269	63
27	2.20269	2.19019	2.17786	2.16568	2.15366	2.14178	2.13005	62
28	2.13005	2.11847	2.10704	2.09574	2.08458	2.07356	2.06267	61
29	2.06267	2.05191	2.04128	2.03077	2.02039	2.01014	2.00000	60
30	2.00000	1.98998	1.98008	1.97029	1.96062	1.95106	1.94160	59
31	1.94160	1.93226	1.92302	1.91388	1.90485	1.89591	1.88709	58
32	1.88708	1.87834	1.86970	1.86116	1.85271	1.84435	1.83608	57
33	1.83608	1.82790	1.81981	1.81180	1.80388	1.79604	1.78829	56
34	1.78829	1.78062	1.77303	1.76552	1.75808	1.75073	1.74345	55
35	1.74345	1.73624	1.72911	1.72205	1.71506	1.70815	1.70130	54
36	1.70130	1.69452	1.68782	1.68117	1.67460	1.66809	1.66164	53
37	1.66164	1.65526	1.64894	1.64268	1.63648	1.63035	1.62427	52
38	1.62427	1.61825	1.61229	1.60639	1.60054	1.59475	1.58902	51
39	1.58902	1.58333	1.57771	1.57213	1.56661	1.56114	1.55572	50
40	1.55572	1.55036	1.54504	1.53977	1.53455	1.52938	1.52425	49
41	1.52425	1.51918	1.51415	1.50916	1.50422	1.49933	1.49448	48
42	1.49448	1.48967	1.48491	1.48019	1.47551	1.47087	1.46628	47
43	1.46628	1.46173	1.45721	1.45274	1.44831	1.44391	1.43956	46
44	1.43956	1.43524	1.43096	1.42672	1.42251	1.41835	1.41421	45
Cosecants	60′	50′	40′	30′	20′	10′	0′	Degrees
	Secants							

U. S. Steel Supply
Division of United States Steel

STEEL SERVICE CENTERS—COAST TO COAST

Atlanta
3400 Malone Drive
Chamblee, Georgia 30341
(404) 451-4204

Baltimore
1600 Bush Street
Baltimore, Maryland 21230
(301) 837-4900

Birmingham
P.O. Box 8252
Birmingham, Alabama 35218
(205) 783-4381

Boston
P.O. Box 276
Brighton, Massachusetts 02135
(617) 782-9400

Buffalo
P.O. Box 222
Buffalo, New York 14212
(716) 891-7500

Chicago
P.O. Box 7310
Chicago, Illinois 60633
(312) 646-3211

Cincinnati
4524 W. Mitchell Ave.
Winton Place
Cincinnati, Ohio 45232
(513) 541-4285

Cleveland
7105 Bessemer Avenue
Cleveland, Ohio 44127
(216) 441-3434

Dallas—Ft. Worth
2920 E. Randol Mill Rd.
Arlington, Texas 76011
(817) 261-3881

Denver
4305 E. 60th Ave.
Commerce City, Colorado 80022
(303) 288-0781

Detroit
P.O. Box 368
Taylor, Michigan 48180
(313) 292-8000

Hartford
P.O. Box 2308
Hartford, Connecticut 06114
(203) 247-3259

Houston
P.O. Box 2489
Houston, Texas 77001
(713) 672-8351

Indianapolis
P.O. Box 1972
Indianapolis, Indiana 46206
(317) 898-3000

Kansas City
P.O. Box 4931
Kansas City, Missouri 64120
(816) 483-0944

Los Angeles
P.O. Box 2826
Vernon, California 90054
(213) 588-0111

Memphis
P.O. Box 13069
Memphis, Tennessee 38113
(901) 948-2744

Milwaukee
P.O. Box 2045
Milwaukee, Wisconsin 53201
(414) 645-7500

Moline
41st Street & Railroad Avenue
Moline, Illinois 61265
(309) 797-2511

Newark
P.O. Box 479
Newark, New Jersey 07101
(203) 242-8000

Orlando
1755 Directors Row
Orlando, Florida 32809
(305) 855-0492

Philadelphia
Washington & Poplar Sts.
Conshohocken, Pa. 19428
(215) 242-0590

Phoenix
P.O. Box 6906
Phoenix, Arizona 85005
(602) 272-0436

Pittsburgh
P.O. Box 2069
Pittsburgh, Pa. 15230
(412) 237-6408

Portland
2345 N. W. Nicolai Street
Portland, Oregon 97210
(503) 222-3283

Salt Lake City
P.O. Box 1216
Clearfield, Utah 84016
(801) 363-6501

St. Louis
P.O. Box 27
St. Louis, Missouri 63166
(314) 535-0440

St. Paul
2545 University Avenue
St. Paul, Minnesota 55114
(612) 646-7311

San Francisco
P.O. Box 368
San Francisco, California 94101
(415) 621-4988

Seattle
P.O. Box 3807
Seattle, Washington 98124
(206) 623-3014

Tulsa
3633 Charles Page Boulevard
Tulsa, Oklahoma 74127
(918) 583-0139

West Wego
P.O. Box 188
West Wego, Louisiana 70094
(504) 340-3526