Flat-Belts (1)

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⇒ Steps in analyzing flat belts:

① Find $\exp(f\phi)$ from flat belt drive:

$$\phi = \pi - 2\sin^{-1}\left(\frac{D-d}{2C}\right)$$ (ϕ is for the driving pulley)

To find f:

Table 17-2

Properties of Some Flat- and Round-Belt Materials. (Diameter = d, thickness = t, width = w)

Material	Specification	(t) Size, in	Minimum Pulley Diameter, in	Allowable Tension per Unit Width at 600 ft/min, lbf/in (F_a)	(ρ) Specific Weight, lbf/in³	(f) Coefficient of Friction
Leather	1 ply	$t = \frac{11}{64}$	3	30	0.035–0.045	0.4
		$t = \frac{13}{64}$	$3\frac{1}{2}$	33	0.035–0.045	0.4
	2 ply	$t = \frac{18}{64}$	$4\frac{1}{2}$	41	0.035–0.045	0.4
		$t = \frac{20}{64}$	6[a]	50	0.035–0.045	0.4
		$t = \frac{23}{64}$	9[a]	60	0.035–0.045	0.4
Polyamide[b]	F–0[c]	$t = 0.03$	0.60	10	0.035	0.5
	F–1[c]	$t = 0.05$	1.0	35	0.035	0.5
	F–2[c]	$t = 0.07$	2.4	60	0.051	0.5
	A–2[c]	$t = 0.11$	2.4	60	0.037	0.8
	A–3[c]	$t = 0.13$	4.3	100	0.042	0.8
	A–4[c]	$t = 0.20$	9.5	175	0.039	0.8
	A–5[c]	$t = 0.25$	13.5	275	0.039	0.8
Urethane[d]	$w = 0.50$ in	$t = 0.062$	See	5.2[e]	0.038–0.045	0.7
	$w = 0.75$ in	$t = 0.078$	Table	9.8[e]	0.038–0.045	0.7
	$w = 1.25$ in	$t = 0.090$	17–3	18.9[e]	0.038–0.045	0.7
	Round	$d = \frac{1}{4}$	See	8.3[e]	0.038–0.045	0.7
		$d = \frac{3}{8}$	Table	18.6[e]	0.038–0.045	0.7
		$d = \frac{1}{2}$	17–3	33.0[e]	0.038–0.045	0.7
		$d = \frac{3}{4}$		74.3[e]	0.038–0.045	0.7

② Find (F_c):

$$w = 12\rho b t \quad [\text{lbf/ft}]$$

$$V = \frac{\pi d n}{12} \quad [\text{ft/min}]$$

$$F_c = \frac{w}{g}\left(\frac{V}{60}\right)^2 = \frac{w}{32.17}\left(\frac{V}{60}\right)^2$$

③ Find the torque using: $T = \dfrac{63025\, H_{nom} K_s n_d}{n}$

(H_{nom} is given in the question)

(Assume $n_d = 1$ if not given in question)

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To find (K_s):

Table 17–15

Suggested Service Factors K_S for V-Belt Drives

Driven Machinery	Source of Power: Normal Torque Characteristic	Source of Power: High or Nonuniform Torque
Uniform	1.0 to 1.2	1.1 to 1.3
Light shock	1.1 to 1.3	1.2 to 1.4
Medium shock	1.2 to 1.4	1.4 to 1.6
Heavy shock	1.3 to 1.5	1.5 to 1.8

④ Find (F_{1a}) using:

$$F_{1a} = b\, F_a\, C_p\, C_v$$

To find (F_a) → table (17-2)

To find C_p:

Table 17–4

Pulley Correction Factor C_P for Flat Belts*

* Use ($C_p = 1$) for urethane belts

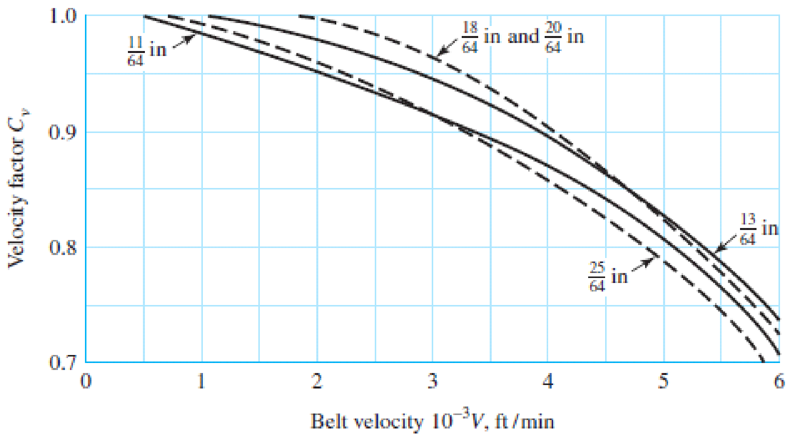
Material	Small-Pulley Diameter, in: 1.6 to 4	4.5 to 8	9 to 12.5	14, 16	18 to 31.5	Over 31.5
Leather	0.5	0.6	0.7	0.8	0.9	1.0
Polyamide, F–0	0.95	1.0	1.0	1.0	1.0	1.0
F–1	0.70	0.92	0.95	1.0	1.0	1.0
F–2	0.73	0.86	0.96	1.0	1.0	1.0
A–2	0.73	0.86	0.96	1.0	1.0	1.0
A–3	—	0.70	0.87	0.94	0.96	1.0
A–4	—	—	0.71	0.80	0.85	0.92
A–5	—	—	—	0.72	0.77	0.91

*Average values of C_P for the given ranges were approximated from curves in the *Habasit Engineering Manual,* Habasit Belting, Inc., Chamblee (Atlanta), Ga.

To find (C_v): (for leather belts only use figure (17-9))

Figure 17–9

Velocity correction factor C_v for leather belts for various thicknesses. (*Data source:* Machinery's Handbook, 20th ed., *Industrial Press, New York, 1976, p. 1047.*)



* For polyamide & Urethane belts, use $C_v = 1$

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⑤ Find (F_2) using:

$$F_2 = F_{1a} - \frac{2T}{d}$$

⑥ Find (F_i) using:

$$F_i = \frac{F_{1a} + F_2}{2} - F_c$$

⑦ Check the friction development where: ($f' < f$) → no slipping

$$f' = \frac{1}{\phi} \ln\left(\frac{F_{1a} - F_c}{F_2 - F_c}\right)$$

⑧ Find the factor of safety from: $n_{fs} = \frac{H_a}{H_{nom}\ K_s}$

⑨ To find the dip: $dip = \frac{C^2 w}{96 F_i}$

* The transmitted horse power is:

$$H_t = \frac{(F_{1a} - F_2)V}{33000} = \frac{T n}{63025\ K_s\ n_d}$$

* The allowable horsepower is: $H_a = n_d\ K_s\ H_{nom}$

⇒ Geometry:

* For open belt drive:

* The contact angles are:

$$\phi_s = \theta_d = \pi - 2\sin^{-1}\frac{D-d}{2C}$$
$$\phi_L = \theta_D = \pi + 2\sin^{-1}\frac{D-d}{2C} \qquad (17\text{–}1)$$

where D = diameter of large pulley
d = diameter of small pulley
C = center distance
θ = angle of contact

* The length of belt is:

$$L = [4C^2 - (D-d)^2]^{1/2} + \frac{1}{2}(D\theta_D + d\theta_d) \qquad (17\text{–}2)$$

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+ For crossed belt drive:
* The contact angle for both pulleys is the same, hence:

$$\theta = \pi + 2\sin^{-1}\frac{D+d}{2C} \qquad (17\text{–}3)$$

+ The length of the crossed belt is:

$$L = [4C^2 - (D+d)^2]^{1/2} + \frac{1}{2}(D+d)\theta \qquad (17\text{–}4)$$

+ Note: When the question requires a flat belt design, assume (d) & the type of belt only (do not assume (b))
→ Use the previous steps to find (F_{1a}, F_2, F_c) in terms of (b)
→ Substitute (F_{1a}, F_2, F_c) in the friction equation in step ⑦ to find (b), the equation will become:

$$b = \frac{1}{a_0 - a_2} \cdot \frac{2T}{d} \cdot \frac{\exp(f\phi)}{\exp(f\phi) - 1}$$

where: $a_0 = F_a C_p C_v$

$$a_1 = \frac{12\rho t}{32.17}\left(\frac{V}{60}\right)^2$$

→ hence for any value chosen > b ⇒ $f' < f$
→ Resolve and find (F_{1a}, F_2, F_c, F_i, f')

V-Belts (1)

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+ The analysis of V-belts can be consisted in the steps below:

① Find V, L_p, C, ϕ and $\exp(0.5123\,\phi)$

$$V = \frac{\pi d n}{12} \quad [ft/min]$$

$$L_p = 2C + \pi(D + d)/2 + (D - d)^2/(4C) \qquad (17\text{–}16a)$$

$$C = 0.25\left\{\left[L_p - \frac{\pi}{2}(D + d)\right] + \sqrt{\left[L_p - \frac{\pi}{2}(D + d)\right]^2 - 2(D - d)^2}\right\} \qquad (17\text{–}16b)$$

$$\phi = \theta_d = \pi - 2\sin^{-1}\frac{(D-d)}{2C}$$

To find (L_p):

Table 17–10

Inside Circumferences of Standard V Belts

Section	Circumference, in
A	26, 31, 33, 35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 66, 68, 71, 75, 78, 80, 85, 90, 96, 105, 112, 120, 128
B	35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 65, 66, 68, 71, 75, 78, 79, 81, 83, 85, 90, 93, 97, 100, 103, 105, 112, 120, 128, 131, 136, 144, 158, 173, 180, 195, 210, 240, 270, 300
C	51, 60, 68, 75, 81, 85, 90, 96, 105, 112, 120, 128, 136, 144, 158, 162, 173, 180, 195, 210, 240, 270, 300, 330, 360, 390, 420
D	120, 128, 144, 158, 162, 173, 180, 195, 210, 240, 270, 300, 330, 360, 390, 420, 480, 540, 600, 660
E	180, 195, 210, 240, 270, 300, 330, 360, 390, 420, 480, 540, 600, 660

where:

Table 17–11

Length Conversion Dimensions (Add the listed quantity to the inside circumference to obtain the pitch length in inches).

Belt section	A	B	C	D	E
Quantity to be added	1.3	1.8	2.9	3.3	4.5

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② Find Hd, Ha and Nb

$$H_d = H_{nom} K_s n_d$$

$$H_a = K_1 K_2 H_{tab}$$

where H_a = allowable power, per belt

K_1 = angle-of-wrap (ϕ) correction factor, Table 17–13

K_2 = belt length correction factor, Table 17–14

$$N_b \geq \frac{H_d}{H_a} \qquad N_b = 1, 2, 3, \ldots$$

To find Htab:

Table 17–12

Horsepower Ratings of Standard V Belts

Belt Section	Sheave Pitch Diameter, in	Belt Speed, ft/min 1000	2000	3000	4000	5000
A	2.6	0.47	0.62	0.53	0.15	
	3.0	0.66	1.01	1.12	0.93	0.38
	3.4	0.81	1.31	1.57	1.53	1.12
	3.8	0.93	1.55	1.92	2.00	1.71
	4.2	1.03	1.74	2.20	2.38	2.19
	4.6	1.11	1.89	2.44	2.69	2.58
	5.0 and up	1.17	2.03	2.64	2.96	2.89
B	4.2	1.07	1.58	1.68	1.26	0.22
	4.6	1.27	1.99	2.29	2.08	1.24
	5.0	1.44	2.33	2.80	2.76	2.10
	5.4	1.59	2.62	3.24	3.34	2.82
	5.8	1.72	2.87	3.61	3.85	3.45
	6.2	1.82	3.09	3.94	4.28	4.00
	6.6	1.92	3.29	4.23	4.67	4.48
	7.0 and up	2.01	3.46	4.49	5.01	4.90
C	6.0	1.84	2.66	2.72	1.87	
	7.0	2.48	3.94	4.64	4.44	3.12
	8.0	2.96	4.90	6.09	6.36	5.52
	9.0	3.34	5.65	7.21	7.86	7.39
	10.0	3.64	6.25	8.11	9.06	8.89
	11.0	3.88	6.74	8.84	10.0	10.1
	12.0 and up	4.09	7.15	9.46	10.9	11.1
D	10.0	4.14	6.13	6.55	5.09	1.35
	11.0	5.00	7.83	9.11	8.50	5.62
	12.0	5.71	9.26	11.2	11.4	9.18
	13.0	6.31	10.5	13.0	13.8	12.2
	14.0	6.82	11.5	14.6	15.8	14.8
	15.0	7.27	12.4	15.9	17.6	17.0
	16.0	7.66	13.2	17.1	19.2	19.0
	17.0 and up	8.01	13.9	18.1	20.6	20.7
E	16.0	8.68	14.0	17.5	18.1	15.3
	18.0	9.92	16.7	21.2	23.0	21.5
	20.0	10.9	18.7	24.2	26.9	26.4
	22.0	11.7	20.3	26.6	30.2	30.5
	24.0	12.4	21.6	28.6	32.9	33.8
	26.0	13.0	22.8	30.3	35.1	36.7
	28.0 and up	13.4	23.7	31.8	37.1	39.1

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To find (K_1):

Table 17-13

Angle of Contact Correction Factor K_1 for VV* and V-Flat Drives

$\frac{D-d}{C}$	θ, deg	K_1 VV	K_1 V Flat
0.00	180	1.00	0.75
0.10	174.3	0.99	0.76
0.20	166.5	0.97	0.78
0.30	162.7	0.96	0.79
0.40	156.9	0.94	0.80
0.50	151.0	0.93	0.81
0.60	145.1	0.91	0.83
0.70	139.0	0.89	0.84
0.80	132.8	0.87	0.85
0.90	126.5	0.85	0.85
1.00	120.0	0.82	0.82
1.10	113.3	0.80	0.80
1.20	106.3	0.77	0.77
1.30	98.9	0.73	0.73
1.40	91.1	0.70	0.70
1.50	82.8	0.65	0.65

*A curve fit for the VV column in terms of θ is
$K_1 = 0.143\,543 + 0.007\,468\,\theta - 0.000\,015\,052\,\theta^2$
in the range $90° \leq \theta \leq 180°$.

To find (K_2):

Table 17-14

Belt-Length Correction Factor K_2^*

Length Factor	A Belts	B Belts	C Belts	D Belts	E Belts
	Nominal Belt Length, in				
0.85	Up to 35	Up to 46	Up to 75	Up to 128	
0.90	38–46	48–60	81–96	144–162	Up to 195
0.95	48–55	62–75	105–120	173–210	210–240
1.00	60–75	78–97	128–158	240	270–300
1.05	78–90	105–120	162–195	270–330	330–390
1.10	96–112	128–144	210–240	360–420	420–480
1.15	120 and up	158–180	270–300	480	540–600
1.20		195 and up	330 and up	540 and up	660

*Multiply the rated horsepower per belt by this factor to obtain the corrected horsepower.

To find (K_s) → (table (17-15))

③ Find F_c, ΔF, F_1, F_2, F_i and n_{fs}.

$$F_c = K_c\left(\frac{V}{1000}\right)^2$$

$$\Delta F = \frac{63\,025 H_d/N_b}{n(d/2)}$$

$$F_1 = F_c + \frac{\Delta F \exp(f\phi)}{\exp(f\phi) - 1}$$

$f\phi \rightarrow 0.513$

$$F_2 = F_1 - \Delta F$$

$$F_i = \frac{F_1 + F_2}{2} - F_c$$

$$n_{fs} = \frac{H_a N_b}{H_{nom} K_s}$$

To find (K_c):

Table 17–16

Some V-Belt Parameters*

Belt Section	K_b	K_c
A	220	0.561
B	576	0.965
C	1 600	1.716
D	5 680	3.498
E	10 850	5.041
3V	230	0.425
5V	1098	1.217
8V	4830	3.288

*Data courtesy of Gates Rubber Co., Denver, Colo.

④ Find N_p and t if possible

$$N_P = \left[\left(\frac{K}{T_1}\right)^{-b} + \left(\frac{K}{T_2}\right)^{-b}\right]^{-1}$$

$$t = \frac{N_P L_p}{720V}$$

$$T_1 = F_1 + \frac{K_b}{d}$$

$$T_2 = F_1 + \frac{K_b}{D}$$

To find (K_b) ⟶ use (table (17-16))

To find (K) & (b):

Table 17–17

Durability Parameters for Some V-Belt Sections

Source: M. E. Spotts, *Design of Machine Elements,* 6th ed. Prentice Hall, Englewood Cliffs, N.J., 1985.

Belt Section	10^8 to 10^9 Force Peaks K	b	10^9 to 10^{10} Force Peaks K	b	Minimum Sheave Diameter, in
A	674	11.089			3.0
B	1193	10.926			5.0
C	2038	11.173			8.5
D	4208	11.105			13.0
E	6061	11.100			21.6
3V	728	12.464	1062	10.153	2.65
5V	1654	12.593	2394	10.283	7.1
8V	3638	12.629	5253	10.319	12.5

Wire Ropes (1)

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The wire rope tension F_t due to load and acceleration

$$F_t = \left(\frac{W}{m} + wl\right)\left(1 + \frac{a}{g}\right) \qquad (17\text{–}47)$$

where W = weight at the end of the rope (cage and load), [lbf]

m = number of wire ropes supporting the load

w = weight/foot of the wire rope, [lbf/ft] → table (17-24)

l = maximum suspended length of rope, [ft]

a = maximum acceleration/deceleration experienced, [ft/s^2]

g = acceleration of gravity, [ft/s^2]

To find (w):

Table 17–24

Wire-Rope Data *Source:* Compiled from *American Steel and Wire Company Handbook.* (d = rope diameter)

Rope	(w) Weight per Foot, lbf	Minimum Sheave Diameter, in	Standard Sizes d, in	Material	Size of Outer Wires	Modulus of Elasticity,* Mpsi	(Su) Strength,† kpsi
6 × 7 haulage	$1.50d^2$	$42d$	$\frac{1}{4}$–$1\frac{1}{2}$	Monitor steel	$d/9$	14	100
				Plow steel	$d/9$	14	88
				Mild plow steel	$d/9$	14	76
6 × 19 standard hoisting	$1.60d^2$	$26d$–$34d$	$\frac{1}{4}$–$2\frac{3}{4}$	Monitor steel	$d/13$–$d/16$	12	106
				Plow steel	$d/13$–$d/16$	12	93
				Mild plow steel	$d/13$–$d/16$	12	80
6 × 37 special flexible	$1.55d^2$	$18d$	$\frac{1}{4}$–$3\frac{1}{2}$	Monitor steel	$d/22$	11	100
				Plow steel	$d/22$	11	88
8 × 19 extra flexible	$1.45d^2$	$21d$–$26d$	$\frac{1}{4}$–$1\frac{1}{2}$	Monitor steel	$d/15$–$d/19$	10	92
				Plow steel	$d/15$–$d/19$	10	80
7 × 7 aircraft	$1.70d^2$	—	$\frac{1}{16}$–$\frac{3}{8}$	Corrosion-resistant steel	—	—	124
				Carbon steel	—	—	124
7 × 9 aircraft	$1.75d^2$	—	$\frac{1}{8}$–$1\frac{3}{8}$	Corrosion-resistant steel	—	—	135
				Carbon steel	—	—	143
19-wire aircraft	$2.15d^2$	—	$\frac{1}{32}$–$\frac{5}{16}$	Corrosion-resistant steel	—	—	165
				Carbon steel	—	—	165

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The fatigue tensile strength in pounds for a specified life is

$$F_f = \frac{(p/S_u)S_u D d}{2}$$

where (p/S_u) = specified life, from (Fig. 17–21)

S_u = ultimate tensile strength of the wires, [psi]

D = sheave or winch drum diameter, [in]

d = nominal wire rope size, [in]

$$F_u = (S_u)_{nom} A_{nom}$$

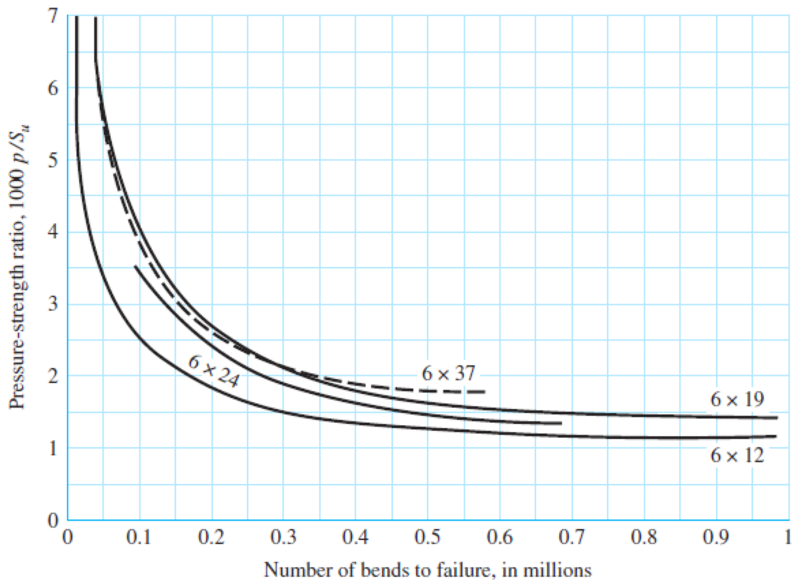
where:

$$A_{nom} = \frac{\pi d^2}{4}$$

To find (p/S_u):

Figure 17–21

Experimentally determined relation between the fatigue life of wire rope and the sheave pressure.



To find $(S_u)_{nom}$ → use (table (17-24))

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The *equivalent bending load* F_b is

$$F_b = \frac{E_r d_w A_m}{D} \qquad (17\text{–}41)$$

where E_r = Young's modulus for the wire rope, Table (17–24) or (17–27) [psi]

d_w = diameter of the wires, [in]

A_m = metal cross-sectional area, (Table 17–27) [in^2]

D = sheave or winch drum diameter, [in]

To find (E_r): use table (17-24)

or

Table 17-27

Some Useful Properties of 6 × 7, 6 × 19, and 6 × 37 Wire Ropes

Wire Rope	(w) Weight per Foot w, lbf/ft	Weight per Foot Including Core w, lbf/ft	Minimum Sheave Diameter D, in	Better Sheave Diameter D, in	(d_w) Diameter of Wires d_w, in	(A_m) Area of Metal A_m, in^2	(E_r) Rope Young's Modulus E_r, psi
6 × 7	$1.50d^2$		$42d$	$72d$	$0.111d$	$0.38d^2$	13×10^6
6 × 19	$1.60d^2$	$1.76d^2$	$30d$	$45d$	$0.067d$	$0.40d^2$	12×10^6
6 × 37	$1.55d^2$	$1.71d^2$	$18d$	$27d$	$0.048d$	$0.40d^2$	12×10^6

To find (A_m) & (d_w): use table (17-27)

+ Factors of safety with bending:

The static factor of safety n_s is

$$n_s = \frac{F_u - F_b}{F_t} \qquad (17\text{–}46)$$

sometimes defined as F_u/F_t. The fatigue factor of safety n_f is

$$n_f = \frac{F_f - F_b}{F_t} \qquad (17\text{–}45)$$

+ Factors of safety without bending:

→ The static FOS: $n_s = \frac{F_u}{F_t}$

→ The fatigue FOS: $n_f = \frac{F_f}{F_t}$

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+ The allowable pressure is:

$$p = \frac{2F}{dD}$$, where: F : tensile force on rope

d : rope diameter

D : Sheave diameter

Table 17–26

Maximum Allowable Bearing Pressures of Ropes on Sheaves (in psi)

Source: Wire Rope Users Manual, AISI, 1979.

(To find P_{max})

Rope	Sheave Material: Wood[a]	Cast Iron[b]	Cast Steel[c]	Chilled Cast Irons[d]	Manganese Steel[e]
Regular lay:					
6 × 7	150	300	550	650	1470
6 × 19	250	480	900	1100	2400
6 × 37	300	585	1075	1325	3000
8 × 19	350	680	1260	1550	3500
Lang lay:					
6 × 7	165	350	600	715	1650
6 × 19	275	550	1000	1210	2750
6 × 37	330	660	1180	1450	3300

[a]On end grain of beech, hickory, or gum.

[b]For H_B(min.) = 125.

[c]30–40 carbon; H_B(min.) = 160.

[d]Use only with uniform surface hardness.

[e]For high speeds with balanced sheaves having ground surfaces.

+ Recommended FOS for applications:

Table 17–25

Minimum Factors of Safety for Wire Rope*

Source: Compiled from a variety of sources, including ANSI A17.1-1978.

Track cables	3.2
Guys	3.5
Mine shafts, ft:	
Up to 500	8.0
1000–2000	7.0
2000–3000	6.0
Over 3000	5.0
Hoisting	5.0
Haulage	6.0
Cranes and derricks	6.0
Electric hoists	7.0
Hand elevators	5.0
Private elevators	7.5
Hand dumbwaiter	4.5
Grain elevators	7.5

Passenger elevators, ft/min:	
50	7.60
300	9.20
800	11.25
1200	11.80
1500	11.90
Freight elevators, ft/min:	
50	6.65
300	8.20
800	10.00
1200	10.50
1500	10.55
Powered dumbwaiters, ft/min:	
50	4.8
300	6.6
500	8.0

*Use of these factors does not preclude a fatigue failure.