8.3.5 Wire Ropes

**This guide follows both Mott and Shigley, but mostly Mott*

This section will have multiple guides for wire ropes. I would suggest that for exam situations, use the Mott Guide[32], unless it is a Mine Hoist problem, then use the corresponding Mine Hoist guide, which is from Shigley. Only use the Mine Hoist guide for sizing wire ropes with an acceleration or deceleration occurring. If you just need to find the Maximum Working Load, use the Mott Guide. For Wire Rope Sizing in Shigley, I will present a brief portion on it as well just in-case.

As for the calculator, I have created one for the mine hoist problems only. Otherwise, the other designs simply require way too many table look-ups, and use very simple equations outside of the look-ups. Therefore, I believe that the guides are clear and should suffice in getting you through as fast as possible.

8.3.5.1 Wire Rope Design (Mott)

1. **In a typical design question, you will have to start with your rope type and rope diameter (d)**. If these are given, skip to the next step. If not, see below.

    - If the diameter is not given, consult the figure below for some possible nominal diameters.

TABLE 7–19 Nominal Wire Rope Diameter

inches	mm	inches	mm
1/4	6.5	2 1/8	54
5/16	8	2 1/4	58
3/8	9.5	2 3/8	60
7/16	11.5	2 1/2	64
1/2	13	2 5/8	67
9/16	14.5	2 3/4	71
5/8	16	2 7/8	74
3/4	19	3	77
7/8	22	3 1/8	80
1	26	3 1/4	83
1 1/8	29	3 3/8	87
1 1/4	32	3 1/2	90
1 3/8	35	3 3/4	96
1 1/2	38	4	103
1 5/8	42	4 1/4	109
1 3/4	45	4 1/2	115
1 7/8	48	4 3/4	122
2	52	5	128

[32] Our final exam asked for a Warrington Wire Rope design, which is only mentioned in Mott, but designing using Shigley should also be completely possible

- If the rope type is not given, you will be given "Wires per Strand" and "Max. No. of outer wires in Strand" instead. Use the next figure to determine your rope classification.

TABLE 7–20 Wire Rope Classification

Classification	Wires per strand	Maximum number of outer wires in strand
6×7	7 through 15	9
6×19	16 through 26	12
6×36	27 through 49	18
6×61	50 through 74	24

*Classifications are the same in 7 and 8 strand wire ropes

2. **Next, use the table below to find the (D/d) ratio** where D is the Tread diameter and d is the rope diameter. Use the ratio alongside your rope diameter to find the tread diameter.

$$D = Ratio \times d$$

TABLE 7–22 Sheave and Drum Diameter Factors

Construction	Suggested *D/d* ratio	Minimum *D/d* ratio
6×7	72	42
6×19 Seale	51	34
6×21 Filler Wire	45	30
6×25 Filler Wire	39	26
6×31 Warrington Seale	39	26
6×36 Warrington Seale	35	23
6×41 Seale Filler Wire	20	20
6×41 Warrington Seale	32	21
6×42 Tiller	21	14
8×19 Seale	41	27
8×25 Filler Wire	32	21

3. **Start by designing the Drum.** Find the minimum groove depth, h, for the drum using

$$h_{drum} = 0.374d$$

Then, the drum diameter is

$$Drum\ Diameter = D + 2h$$

The **fleet angle** should be at least 0.5° but no more than 2°

The pitch distance, p, has a range:

$$2.065r < p < 2.18r$$

where r is the groove radius, given in the figure below for different wire rope diameters. Use "new" unless specified otherwise![33]

[33] EXTRA: if the groove radius is less than the "worn" specification, it must be replaced!!

TABLE 7–23 Recommended Sheave and Drum Groove Radius

Nominal wire rope diameter		Groove radius			
		New		Worn	
inches	mm	inches	mm	inches	mm
1/4	6.5	0.137	3.48	0.129	3.28
3/8	9.5	0.201	5.11	0.190	4.83
1/2	13	0.271	6.88	0.256	6.50
5/8	16	0.334	8.48	0.320	8.13
3/4	19	0.401	10.19	0.380	9.65
7/8	22	0.468	11.89	0.440	11.18
1	26	0.543	13.79	0.513	13.03
1 1/4	32	0.669	16.99	0.639	16.23
1 1/2	38	0.803	20.40	0.759	19.28
1 3/4	45	0.939	23.85	0.897	22.78
2	52	1.070	27.18	1.019	25.88
2 1/2	64	1.338	33.99	1.279	32.49
3	77	1.607	40.82	1.538	39.07
3 1/2	90	1.869	47.47	1.794	45.57
4	103	2.139	54.33	2.050	52.07
4 1/2	115	2.396	60.86	2.298	58.37
5	128	2.663	67.64	2.557	64.95

4. **Next, design the sheave.** Every sheave has a hub and bore for a bearing (don't worry about this yet). You already have determined the tread diameter, D, and the groove radius, r. The **throat angle** must be between 35° and 45°.

   The sheave groove depth is given by a range:

$$1.5d \leq < h_{sheave} \leq 1.75d$$

   The pitch diameter and rim diameter can also be found:

$$Pitch\ Diameter = D + 2d$$

$$Rim\ Diameter = D + 2h$$

5. **Choose the Wire Rope Grade** [34] between Plow Steel (PS), Improved Plow Steel (IPS) and Extra Improved Plow Steel (XIP). Use the table below for some strength references.

TABLE 7–24 Grades of Wire Rope

Grade	Tensile strength
Plow Steel	1570 N/mm^2
Improved Plow Steel	1770 N/mm^2
Extra Improved Plow Steel	1960 N/mm^2

6. **Calculate the maximum working load**. Firsts, find the minimum breaking force of the wire rope based on your diameter and rope grade from the figure on the next page. The force is given in US Tons (2000 lb/ton). The weight per foot is also given in case you need to find the total weight of the rope!

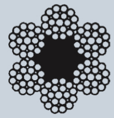
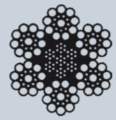
   The Maximum working load is given by

$$Max.\ Working\ Load = \frac{Min.\ Breaking\ Force}{SF}$$

   Where SF is a service factor. A minimum SF of 5 is required for activities concerning human safety such as overhead cranes, gantry cranes, hoists, ... etc.[35]

[34] this may already be given, so skip it
[35] Just use 5 if not sure

TABLE 7–25 6×19 and 6×36 Classes Technical Data

	Fiber core			IWRC		
						
Diameter	Weight per foot	Min breaking force		Weight per foot	Min breaking force	
		IPS	XIP		IPS	XIP
in	lb/ft	tons	tons	lb/ft	tons	tons
1/4	0.105	2.74	3.02	0.116	2.94	3.4
5/16	0.164	4.26	4.69	0.18	4.58	5.27
3/8	0.236	6.1	6.72	0.26	6.56	7.55
7/16	0.32	8.27	9.1	0.35	8.89	10.2
1/2	0.42	10.7	11.8	0.46	11.5	13.3
9/16	0.53	13.5	14.9	0.59	14.5	16.8
5/8	0.66	16.7	18.3	0.72	17.9	20.6
3/4	0.95	23.8	26.2	1.04	25.6	29.4
7/8	1.29	32.2	35.4	1.42	34.6	39.8
1	1.68	41.8	46	1.85	44.9	51.7
1 1/8	2.13	52.6	57.8	2.34	56.5	65
1 1/4	2.63	64.6	71.1	2.89	69.4	79.9
1 3/8	3.18	77.7	85.5	3.5	83.5	96
1 1/2	3.78	92	101	4.16	98.9	114
1 5/8	4.44	107	118	4.88	115	132
1 3/4	5.15	124	137	5.67	133	153
1 7/8	5.91	141	156	6.5	152	174
2	6.72	160	176	7.39	172	198
2 1/8	7.59	179	197	8.35	192	221
2 1/4	8.51	200	220	9.36	215	247

**IWRC = Independent Wire Rope Core*

You are done!

8.3.5.2 Wire Rope Design (Shigley)

**Shigley doesn't provide guides on sizing sheaves and drums, so use the Mott guide instead for those type of questions*

1. **If asked to design a wire rope system via shigley, start by using the 2 figures below** (and whatever is given in the problem, such as rope type) to determine:
   - d [in.], rope diameter
   - D [in.], sheave diameter (use minimum or recommended values if not given one)
   - Weight per foot [lbf]
   - If needed:
     - Material
     - Size of outer wires
     - Modulus of Elasticity
     - Wire Strength
     - A_m $[in^2]$, Area of metal (given in 2nd figure for some types)

Table 17–24 Wire-Rope Data

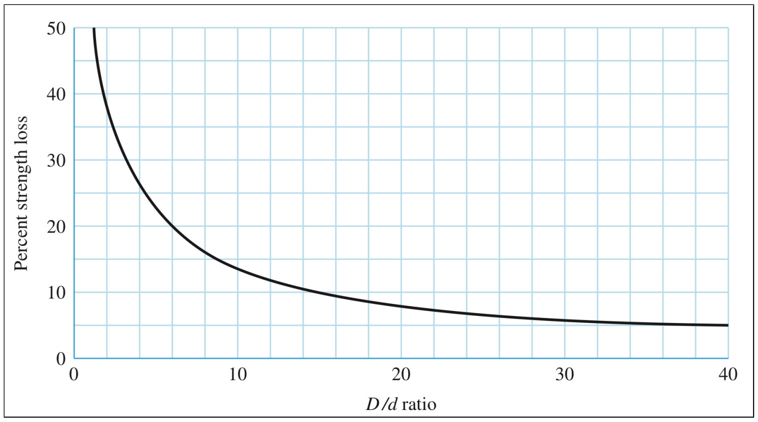
Rope	Weight per Foot, lbf	Minimum Sheave Diameter, in	Standard Sizes d, in	Material	Size of Outer Wires	Modulus of Elasticity,* Mpsi	Strength,† kpsi
6 × 7 haulage	$1.50d^2$	$42d$	$\frac{1}{4}$–$1\frac{1}{2}$	Monitor steel	$d/9$	14	100
				Plow steel	$d/9$	14	88
				Mild plow steel	$d/9$	14	76
6 × 19 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

*The modulus of elasticity is only approximate; it is affected by the loads on the rope and, in general, increases with the life of the rope.
†The strength is based on the nominal area of the rope. The figures given are only approximate and are based on 1-in rope sizes and $\frac{1}{4}$-in aircraft-cable sizes.
Source: Compiled from *American Steel and Wire Company Handbook.*

Table 17–27 Some Useful Properties of 6 × 7, 6 × 19, and 6 × 37 Wire Ropes

Wire Rope	Weight per Foot w, lbf/ft	Weight per Foot Including Core w, lbf/ft	Minimum Sheave Diameter D, in	Better Sheave Diameter D, in	Diameter of Wires d_w, in	Area of Metal A_m, in^2	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

2. **Next you will find the the sum of the static loads on your wire rope, and then use the figure below to reduce the strength based on the (D/d) ratio.** The final number will be your F_u, or the ultimate wire load.



Use this value for your safety factor:

$$n = \frac{F_u}{F_t}$$

where F_t is the largest working tension. Often, you will determine a safety factor for the operation and find F_t instead of n by rearranging the equation above. The safety factor is 5 for average operations, but see the figure below for some specific operations.

Table 17–25 Minimum Factors of Safety for Wire Rope*

Track cables	3.2	Passenger elevators, ft/min:	
Guys	3.5	50	7.60
Mine shafts, ft:		300	9.20
Up to 500	8.0	800	11.25
1000–2000	7.0	1200	11.80
2000–3000	6.0	1500	11.90
Over 3000	5.0	Freight elevators, ft/min:	
Hoisting	5.0	50	6.65
Haulage	6.0	300	8.20
Cranes and derricks	6.0	800	10.00
Electric hoists	7.0	1200	10.50
Hand elevators	5.0	1500	10.55
Private elevators	7.5	Powered dumbwaiters, ft/min:	
Hand dumbwaiter	4.5	50	4.8
Grain elevators	7.5	300	6.6
		500	8.0

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

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

3. **Next, you can calculate the bearing pressure, P [psi], and choose a suitable Sheave Material** for your rope type using the figure below.

$$P = \frac{2F}{dD}$$

Where F [lbf] is the tensile force on the rope

Table 17–26 Maximum Allowable Bearing Pressures of Ropes on Sheaves (in psi)

	Sheave Material				
Rope	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

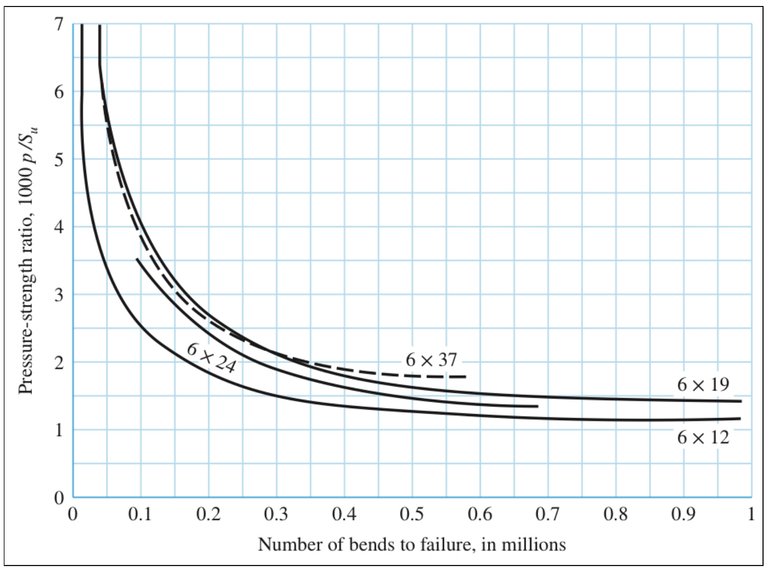
[a]On end grain of beech, hickory, or gum.
[b]For H_B (min.) = 125.
[c]30–40 carbon; H_B (min.) = 160.
[d]Use only with uniform surface hardness.
[e]For high speeds with balanced sheaves having ground surfaces.
Source: Wire Rope Users Manual, AISI, 1979.

4. After that, you can calculate the allowable fatigue tension under flexing, F_f:

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

where (p/S_U)[36] *is the pressure strength ratio from the figure on the next page, and* S_u *is the ultimate tensile strength of the wire, given in ranges for these three materials*[37]*:*

Improved plow steel (monitor)	$240 < S_u < 280$ kpsi
Plow steel	$210 < S_u < 240$ kpsi
Mild plow steel	$180 < S_u < 210$ kpsi



5. Calculate Safety Factors:

   - In Fatigue:

$$n_f = \frac{F_f - F_b}{F_t}$$

   - For Static Loading:

$$n_s = \frac{F_u - F_b}{F_t}$$

[36]Note that the figure gives 1000(p/S_u), so divide whatever you get by 1000. Also, if the number of bends to failure is not given, be as conservative as you can. For example, use 1 million bends for 6x19 ropes

[37]Use the lower bound values to be more conservative. If for some reason you have to find the S_u value, an equation in the book gives it as $S_u = \frac{2000F}{dD}$ for a rope with long life

Where F_t was the largest working tension you determined, and F_b is the bending load, given by:

$$F_b = \frac{E_r d_w A_m}{D}$$

- E_r is the Modulus of Elasticity of the Rope
- d_w is the diameter of the WIRE (not ROPE)
- A_m is the area of the metal

These values are given in the figure from step 1

Calculate whatever you need and you should be done!

8.3.5.3 Mine Hoist Problems (Shigley)

**NOTE: Usually you will not be given d in these types of questions and your goal is to find the best value at the end. Therefore, leave most equations in terms of d!*

1. In mine hoist problems, you will almost always be given the following:
   - a [ft/s^2], maximum acceleration or deceleration experienced
   - W [lbf], weight at the end of the rope
   - L [ft], maximum suspended length of rope
   - m, number of ropes supporting the load
   - Rope Type, one of three[38]:
     - 6 x 7
     - 6 x 19
     - 6 x 37

   In some case, you'll also be given:

   - D [in.], sheave diameter
   - Extra information, such as neglecting bending loads

   In cases where D is not given, use the figure below.

   Table 17–27 Some Useful Properties of 6 × 7, 6 × 19, and 6 × 37 Wire Ropes

Wire Rope	Weight per Foot w, lbf/ft	Weight per Foot Including Core w, lbf/ft	Minimum Sheave Diameter D, in	Better Sheave Diameter D, in	Diameter of Wires d_w, in	Area of Metal A_m, in^2	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

2. Do some initial calculations (or just write down the values) from the figure above. Find:
   - d_w [in.], Diameter of Wires
   - A_m [in^2], Area of Metals
   - E_r [psi], Young's modulus of rope
   - w [lbf/ft], Weight per foot (No core, unless asked!)

3. Next, find different Tension Values (likely in terms of d):

[38] I hope only these three are possible, since it will be hard for you otherwise

- F_t [lbf], Rope Tension

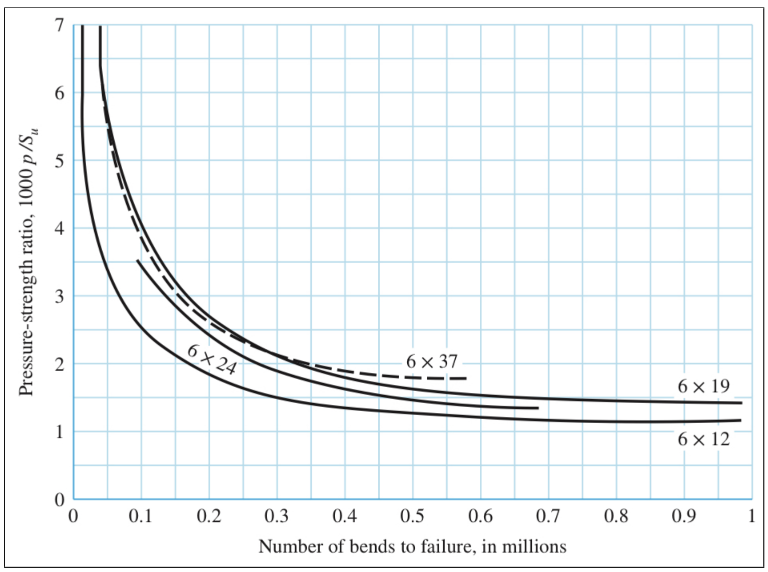
$$F_t = (\frac{W}{m} + wL)(1 + \frac{a}{32.2})$$

- F_f [lbf], Fatigue Tension

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

where (p/S_U)[39] *is the pressure strength ratio from the figure on the next page, and* S_u *is the ultimate tensile strength of the wire, given in ranges for these three materials*[40]*:*

Improved plow steel (monitor)	$240 < S_u < 280$ kpsi
Plow steel	$210 < S_u < 240$ kpsi
Mild plow steel	$180 < S_u < 210$ kpsi



- F_b [lbf], Bending Tension

$$F_b = \frac{E_r d_w A_m}{D}$$

[39] Note that the figure gives 1000(p/S_u), so divide whatever you get by 1000. Also, if the number of bends to failure is not given, be as conservative as you can. For example, use 1 million bends for 6x19 ropes

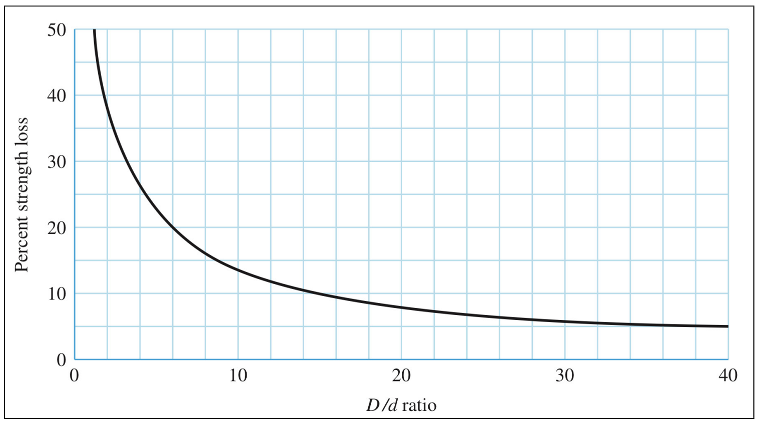
[40] Use the lower bound values to be more conservative.

4. After that, solve the safety factor equations (see which you need):

   - n_s, static safety factor:

     $$n_s = \frac{F_u - F_b}{F_t}$$

     sometimes written as only F_u/F_t.For this factor, F_u, the ultimate wire load, is the sum of the static load, with the percent strength loss of the figure below applied[41].

   - n_f, fatigue factor of safety:

     $$n_f = \frac{F_f - F_b}{F_t}$$

   With these expressions in terms of d, you will likely solve for the diameter value that will give you the maximum (or desired) safety factor. Use Desmos to easily figure it out. After you find the best diameter, choose the closes standard wire rope size. For standard wire rope diameters, use the figure below, albeit from Mott, or search on the internet!

[41] We were never asked for F_u, but I think maybe the value of W would suffice, since you'll likely not have the value of d anyways

TABLE 7–19 Nominal Wire Rope Diameter			
inches	mm	inches	mm
1/4	6.5	2 1/8	54
5/16	8	2 1/4	58
3/8	9.5	2 3/8	60
7/16	11.5	2 1/2	64
1/2	13	2 5/8	67
9/16	14.5	2 3/4	71
5/8	16	2 7/8	74
3/4	19	3	77
7/8	22	3 1/8	80
1	26	3 1/4	83
1 1/8	29	3 3/8	87
1 1/4	32	3 1/2	90
1 3/8	35	3 3/4	96
1 1/2	38	4	103
1 5/8	42	4 1/4	109
1 3/4	45	4 1/2	115
1 7/8	48	4 3/4	122
2	52	5	128

You're done!

For Wire Rope problems, there are 2 calculators, one where it will find you the best d value in a mine hoist question, and one where you give it some initial values and it will calculate things like the safety factors, forces, and what not for you in a regular design question. Only the fatigue safety factor will be used to find the best d value. It will choose the closest standard diameter for you as well.[42]

[42] Make sure to choose on of the three ropes I mentioned (6x7, 6x19, and 6x37) or else the calculator will not work, since you need to input the type