WIRE ROPES

Application of Wire Rope

Wire rope is used in many industries such as oil and gas, cranes and lifting, construction, mining, military, and shipping.

Dynamic systems entailing wire ropes are material handling, elevators, shovels, and heavy lifting equipment for mechanical power transmission.

Static wire ropes are used to support towers and create suspension bridges.

Application of Wire Rope

Wire ropes must be properly selected for each application while being periodically inspected and maintained during the life of its operation. This will ensure that the wire rope's service life is longer and safer.

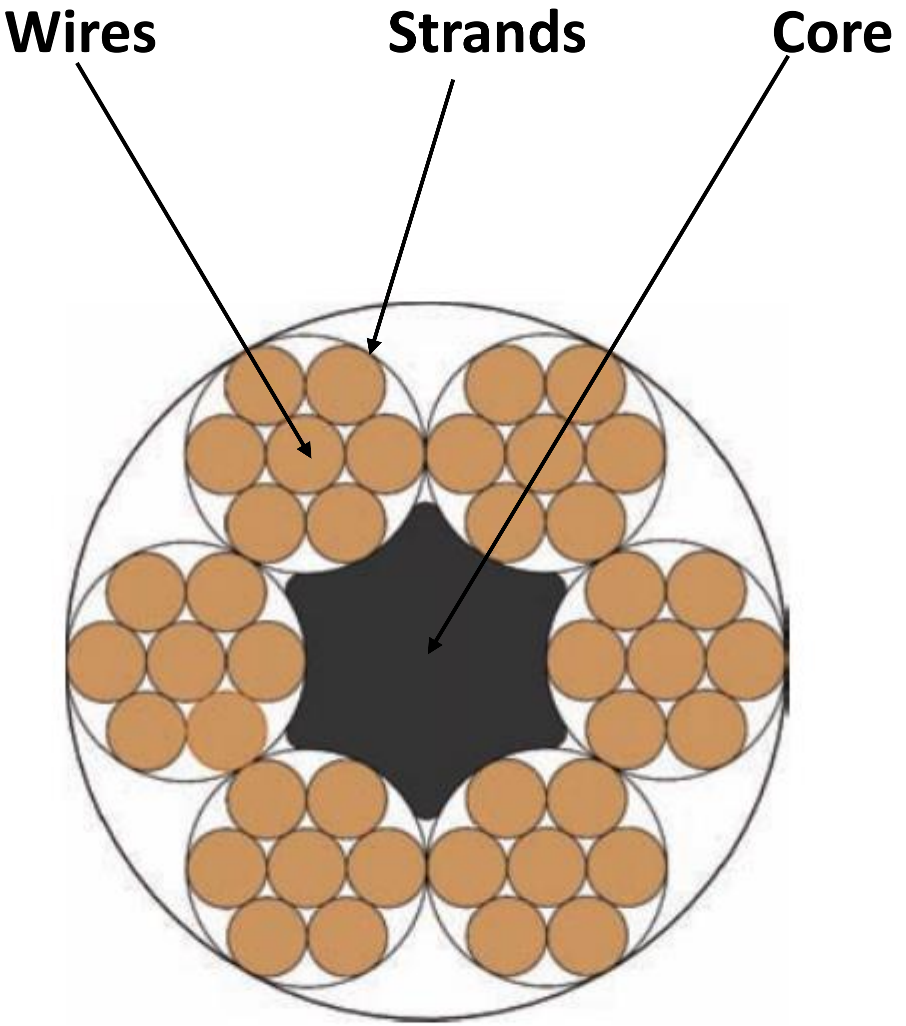
Wire Rope Construction

The various combinations of wire arrangement and size form a **strand**.

These strands are helically laid over the center or **core** to form the wire rope.

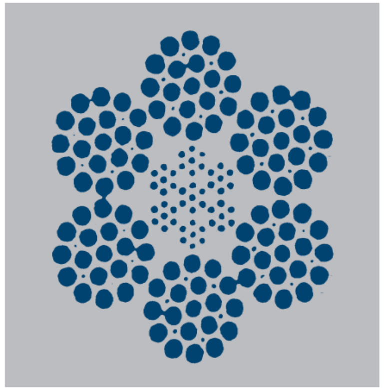
Most wire ropes are constructed with 6, 7, or 8 strands.

Core and is made from steel or fiber and its function is to provide support for the strands.



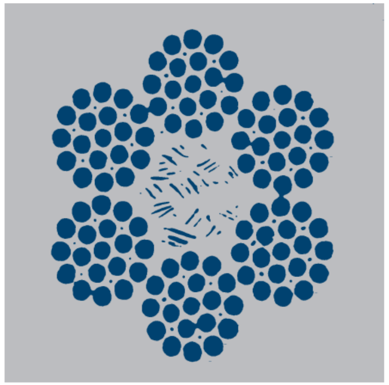
Wire Rope Construction

- Two commonly used core designations are a **fiber core (FC)** and an **independent wire rope core (IWRC).**
- **Fiber cores** are manufactured from natural or synthetic fibers and the independent wire rope core is made from steel.
- A **fiber core** provides excellent flexibility while the independent wire rope core provides crush resistance and increased strength.



Core

IWRC (Independent Wire Rope Core) provides good crush resistance and increased strength.



Fiber Core provides excellent flexibility.

Nominal Wire Rope Diameter

The **wire rope diameter, d**, is measured at the extreme outer limits of the strand

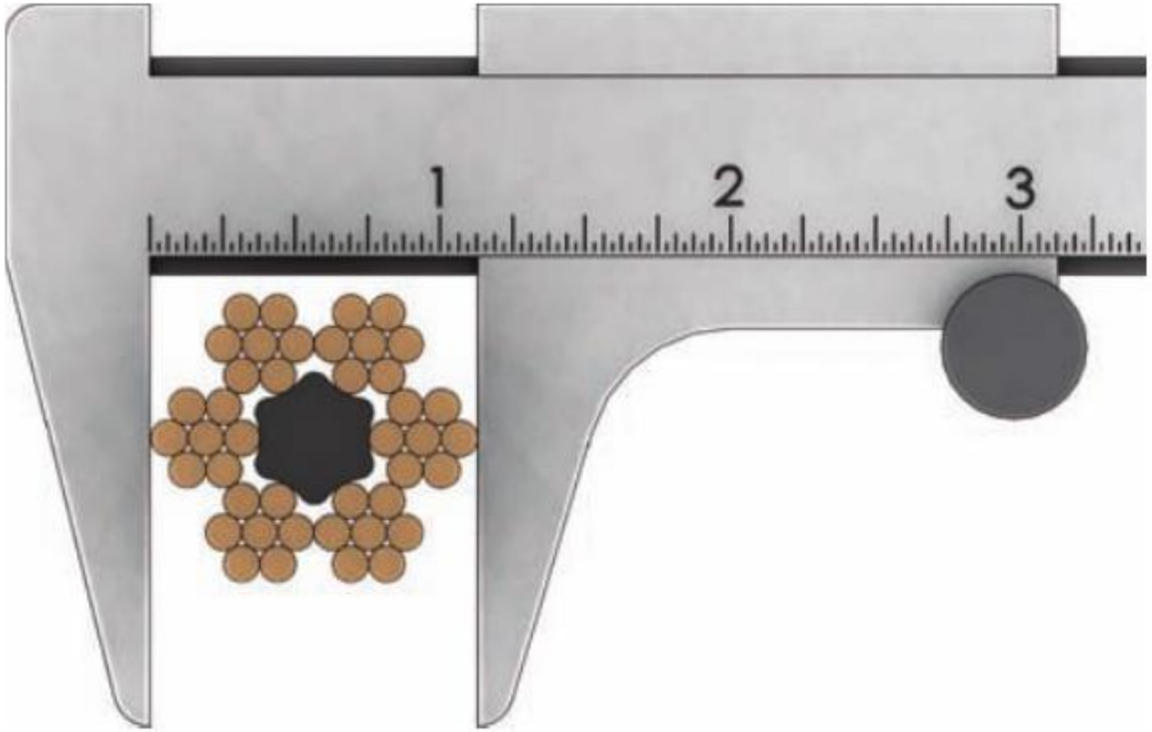


TABLE 7–19 Nominal Wire Rope Diameter

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

Wire Rope Classification

- **Wire ropes** are grouped into standard classifications based on the **number of strands** and the **number of wires per strand**
- A classification of **6 X 19** has a wire count of **16** through **26 wires per strand.**
- Wire ropes within a classification have the same strength, weight per foot, and cost.

TABLE 7–20 **Wire Rope Classification**

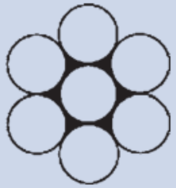
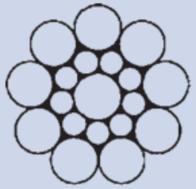
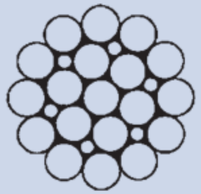
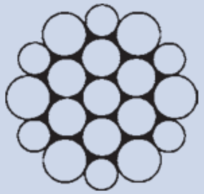
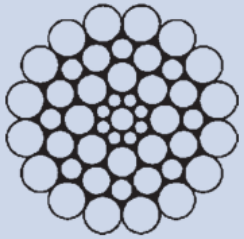
Classification	Wires per strand	Maximum number of outer wires in strand
6×7	7 through 15	9
6×19	16 through 26	12
6×36	27 through 49	18
6×61	50 through 74	24

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

Basic Strand Construction

- The strand design affects the physical characteristics of the wire rope's resistance to abrasion and fatigue.
- A strand made up of a large number of smaller wires will be less abrasion resistant and more fatigue resistant
- Strand made up of small number of large wires which will be more abrasion resistant and less fatigue resistant.

TABLE 7–21 Strand Construction

Single layer		Single wire in the center with six wires of the same diameter
Seale		Equal number of wires in each layer All wires in layer are the same diameter Large outer wires rest in the valley between the small inner wires
Filler wire		Inner layer having half the number of wires as outer layer Smaller filler wires equal in number to the inner layer are laid in the valleys of the inner layer
Warrington		One diameter of wire in the inner layer Two diameters of wire alternating large and small in the outer layer The large outer layer wires rest in the valleys The smaller wires rest on the crowns of the inner layer
Combined pattern		Strand is formed using two or more of the above constructions

Types of lay of wire rope

Regular Lay

Definition

Most common lay in which the wires wind in one direction and the strands the opposite direction. (right lay shown)

Characteristics

Less likely to kink and untwist; easier to handle; more crush resistant than lang lay.

Lang Lay

Definition

Wires in strand and strands of rope wind the same direction. (right lay shown)

Characteristics

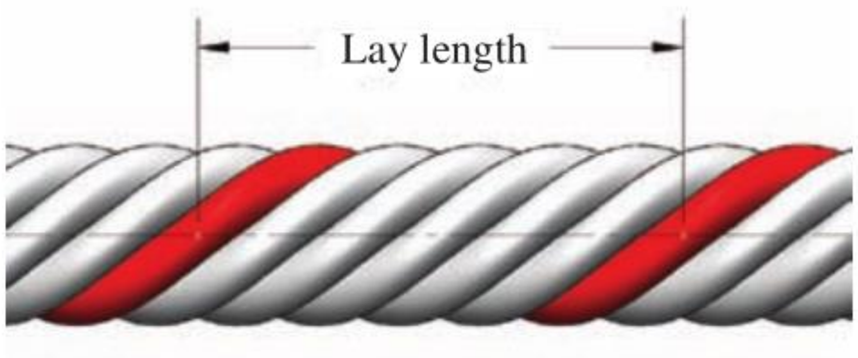
Increased resistance to abrasion; greater flexibility and fatigue resistance than regular lay; will kink and untwist.

Types of lay of wire rope

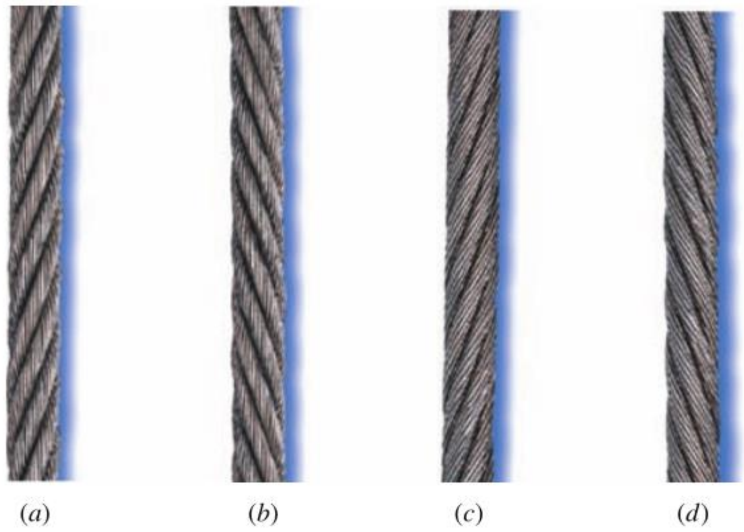
- **Lang Lay** wire ropes are more flexible than Regular Lay wire ropes.
- **Lang Lay** reduces stresses and has higher fatigue resistance due to lower bending stress.
- **Lang Lay** has higher abrasion resistance than Regular Lay due to wear distribution.
- **Regular Lay** is more resistant to crushing and tends to be more stable.
- A **stable wire rope** is resistant to kinking, does not tangle when relaxed, and spools smoothly on and off the drum.

Types of lay of wire rope

- The distance a strand makes as it is wound one complete revolution around the core of the wire rope is called **Lay Length**

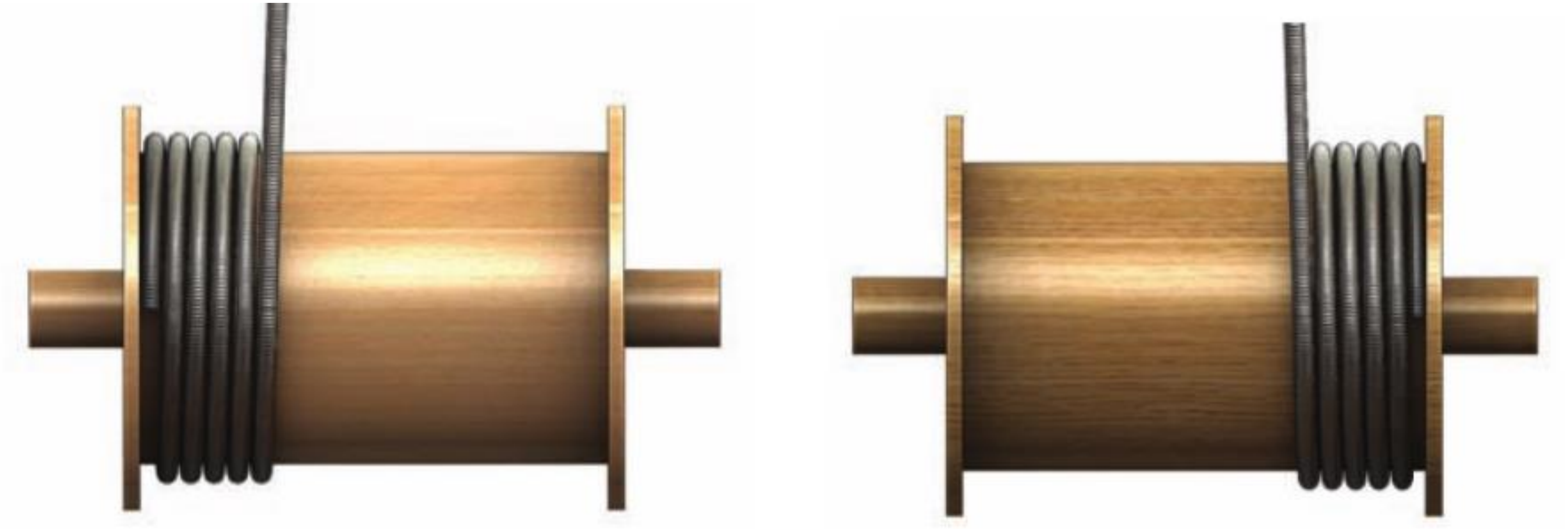


a. Right Lay – Regular Lay,
b. Left Lay – Regular Lay,
c. Right Lay – Lang Lay,
d. Left Lay – Lang Lay



Types of lay of wire rope

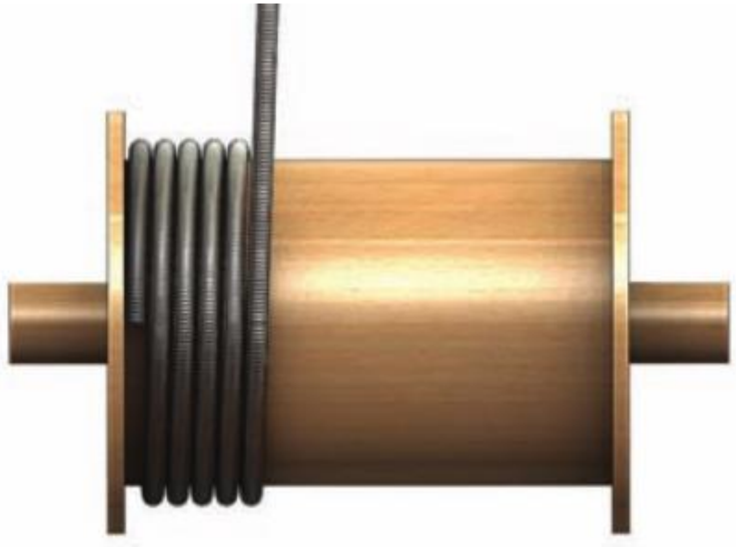
- The selection of the proper lay in the winding of wire rope on a smooth or grooved drum.
- **Right Lay wire rope** is used when winding from the left to the right on a drum rotating clockwise (looking from the left end of the drum)
- **Left Lay wire rope** is used when winding from the right to the left on a drum rotating clockwise (looking from the left end of the drum)



(*a*) Right Lay wire rope used on a smooth drum (*b*) Left Lay wire rope used on a smooth drum

Sheave and Drum Design

- The **wires** in a wire rope move relative to each other as the wire rope travels over a sheave or drum.
- The **inside wires** travel a shorter distance than the **outside wires**, which is compensated by relative movement.
- **Wire ropes** are subjected to cyclic bending stress over a sheave or drum, causing fatigue and eventual failure.
- **Magnitude of stresses** related to load, sheave diameter, and wire rope diameter.



Sheave and Drum Design

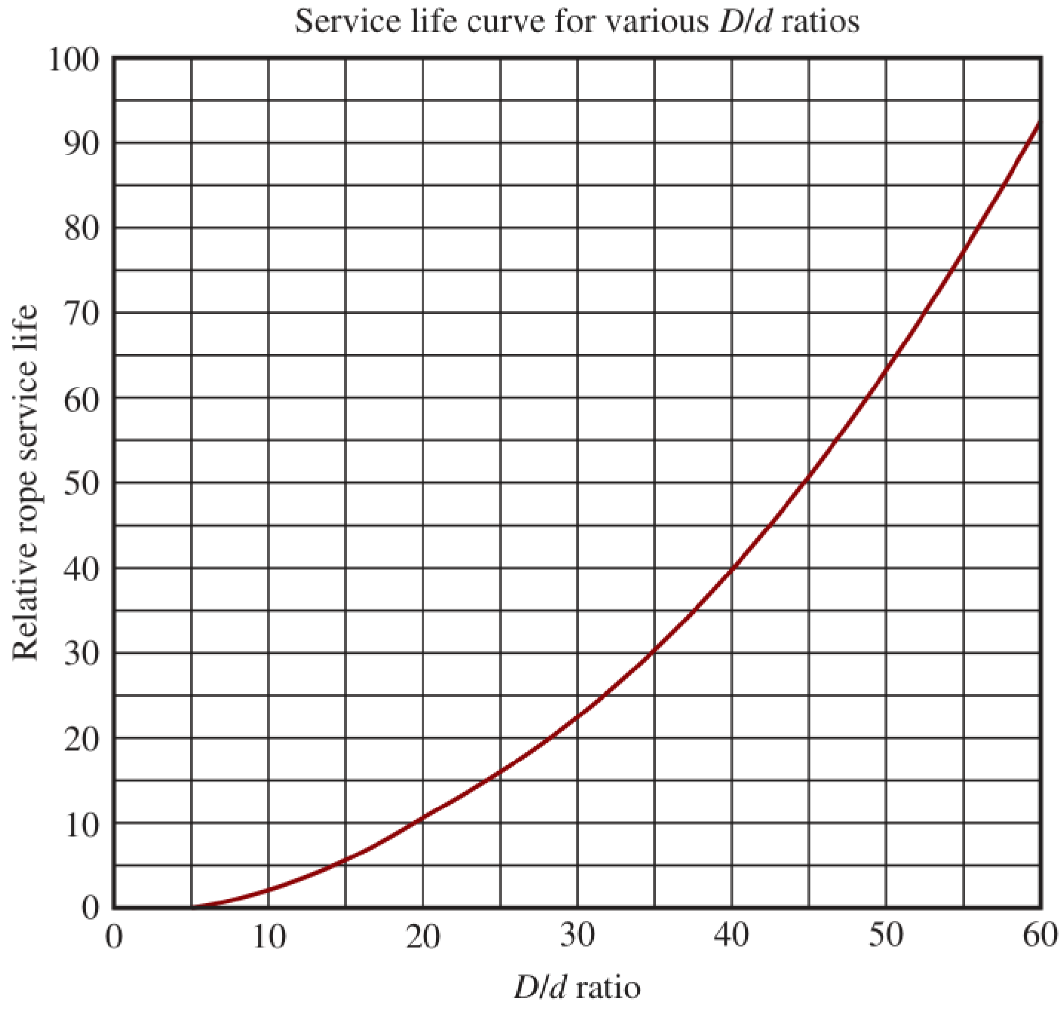
- **Sheave or drum** diameter selected based on wire rope diameter and construction.
- **Tread diameter** (D) is where wire rope rides on sheave or grooved drum.
- **D/d ratio** measures tightness of wire rope bend over sheave, with smaller ratios meaning tighter bends.
- Suggested and minimum D/d ratios based on wire rope construction shown in **Table 7-22.**

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

Sheave and Drum Design

- **Figure 7-48** illustrates the impact of D/d ratio on wire rope service life.
- **Larger D/d** ratios extend wire rope and sheave life.
- Practical limits, cost, and weight should guide selection of D/d ratio.
- **Small-diameter sheaves** cause excessive wear by bending and straightening wire rope.
- **Reverse bending** of wire rope accelerates fatigue and should be avoided.



Sheave and Drum Design and Dimensions

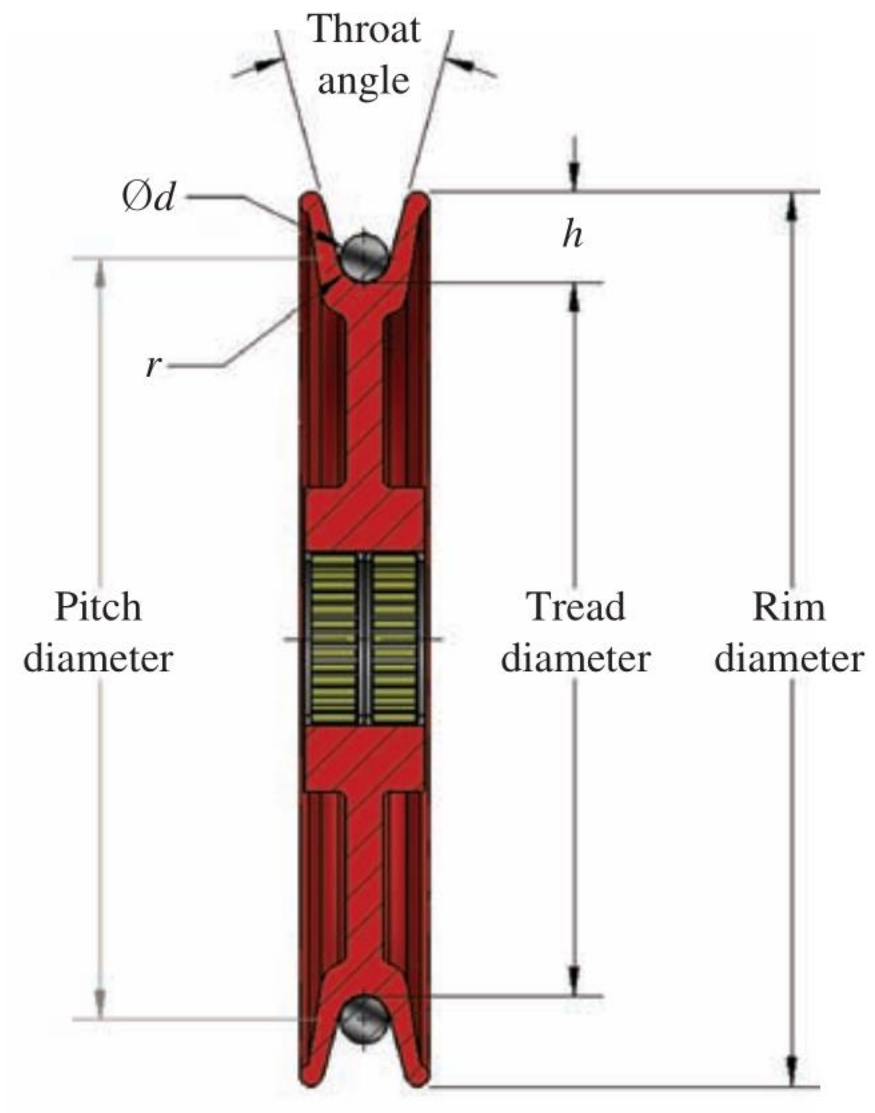
- Typical sheave design includes a hub and bore for mounting a bearing element.
- **Bearing element** (ball bearing, roller bearing, or bronze bushing) selected based on rotational speed, loading, and operating conditions.
- **Sheave groove** designed in the rim for wire rope to ride in.
- **Web supports** the rim and may have lightening holes to decrease sheave inertia.

Sheave and Drum Design and Dimensions

- **The tread diameter (D)** is based on the suggested minimum D/d ratio.
- The **sheave throat angle** should be between **35°** and **45°**.
- The groove depth of a sheave should be between

$$\mathbf{1.5(d) \leq h \leq 1.75(d)}$$

- The **throat angle**, along with the **groove depth (h),** allows the wire rope to enter and exit the sheave with minimum wear on the wire rope and sheave.



Sheave and Drum Design and Dimensions

- The **proper groove radius (r)** of a sheave will give the maximum support to the wire rope.
- **If the groove radius is tight or small**, it will pinch the wire rope and increase the groove pressure along this contact point.
- **If the groove radius is oversized**, the wire rope will not be properly supported and will tend to flatten out.
- This will cause the wire rope to be unbalanced and will lead to wire rope crushing and early fatigue.

TABLE 7–23 Recommended Sheave and Drum Groove Radius

Nominal wire rope diameter		Groove radius: New		Groove radius: 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

Sheave and Drum Design and Dimensions

- The **correct groove radius** and **angle of contact** will improve wire rope support and **maximize the wire rope's lifespan**.
- A **groove gage** is used to measure the size and contour of the groove for both new and used sheaves.
- The gage should make an angle of contact of **150°** with the groove and verify the radius.
- If the groove radius measures smaller than the value listed as "**Worn**", the sheave groove should be re-machined to the "**New**" radius dimension.

TABLE 7–23 Recommended Sheave and Drum Groove Radius

Nominal wire rope diameter		Groove radius			
		New		Worn	
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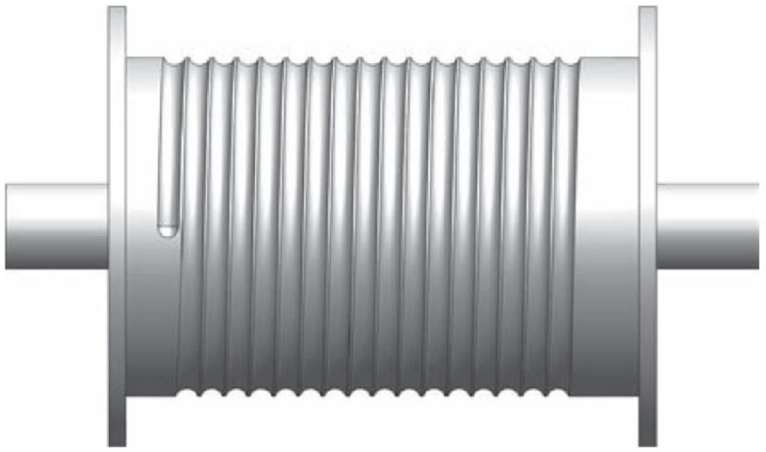
5	128	2.663	67.64	2.557	64.95

Sheave and Drum Design and Dimensions

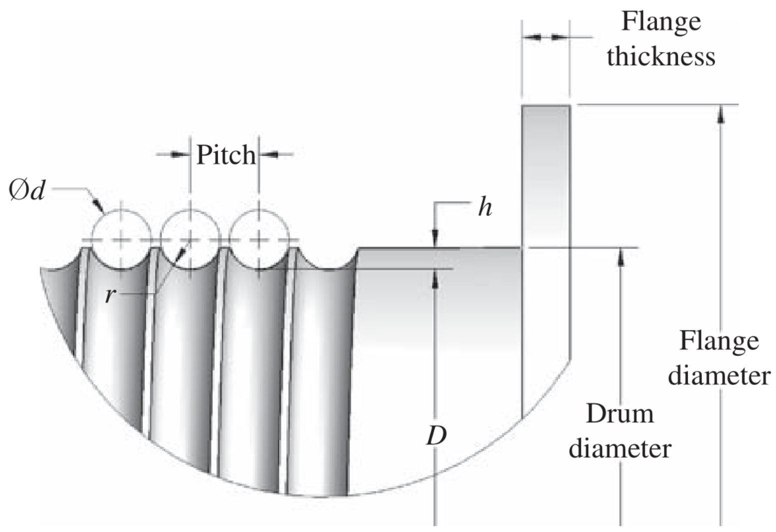
- The **groove radius (r)** must be proper for the wire rope diameter used.
- The **pitch (p)** of the helical groove is the distance from one groove to the next adjacent groove along the pitch diameter of the wire rope.
- The pitch distance should range

$$\mathbf{2.065(\boldsymbol{r}) \leq \boldsymbol{p} \leq 2.18(\boldsymbol{r})}$$

- The **minimum groove depth (h)** is the distance from the drum diameter to the tread diameter (D) on a helically grooved drum.
- This distance is given by $\boldsymbol{h} = \mathbf{0.374}(\boldsymbol{d})$



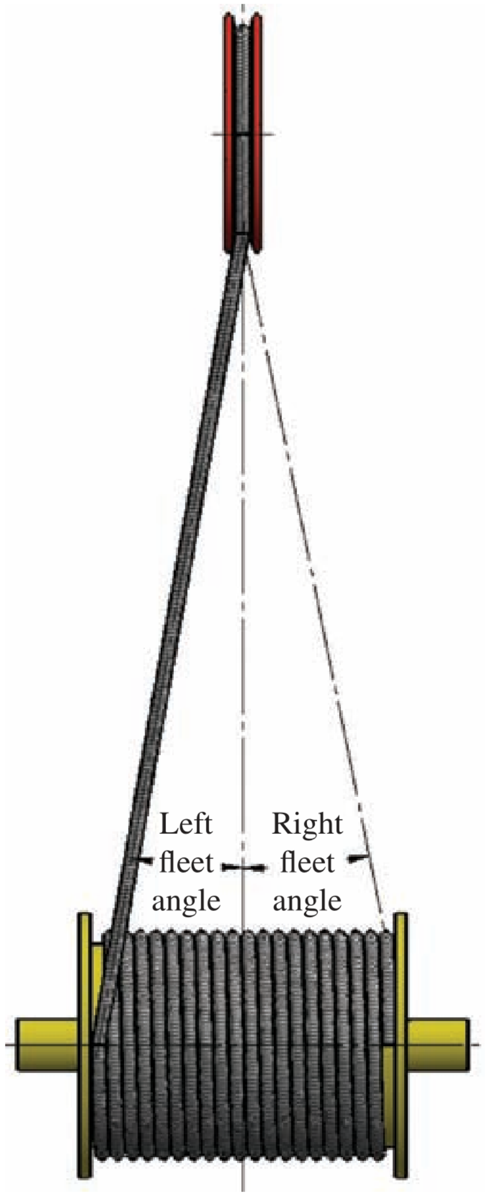
(*a*) Grooved drum with flanges and journal ends



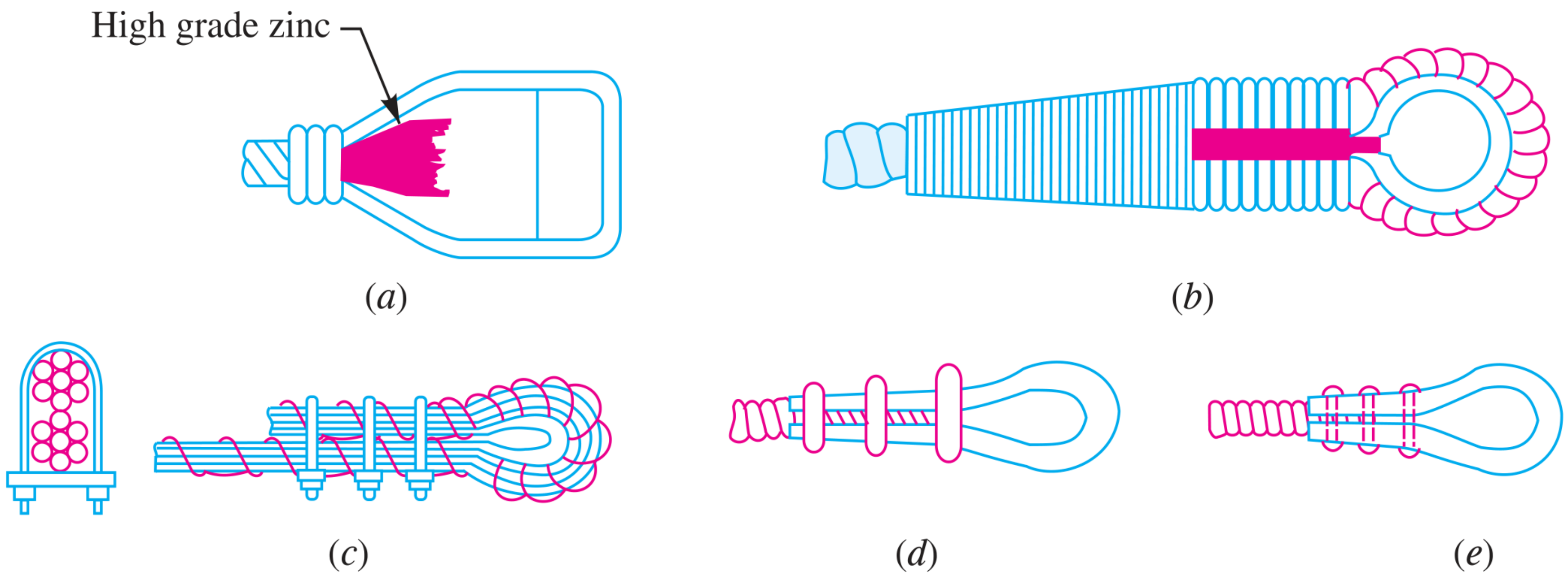
(*b*) Grooved drum dimensional specifications

Sheave and Drum Design and Dimensions

- The **fleet angle** is the included angle between the wire rope which extends from the sheave to the drum and the perpendicular line to the axis of the drum.
- It is desirable to have a small fleet angle to reduce wear between the wire rope and flange of the sheave as the wire rope wraps the drum.
- The **minimum fleet angle should be 1/2°** to prevent the wire rope from piling up on the drum.
- The **maximum fleet angle should be 1 1/2 °** on a smooth drum and 2° on a grooved drum.



Wire Rope Fasteners



Type of fastening	Efficiency (%)
(*a*) Wire rope socket with zinc, Fig. 20.10 (*a*)	100
(*b*) Thimble with four or five wire tucks, Fig. 20.10 (*b*)	90
(*c*) Special offset thimble with clips, Fig. 20.10 (*c*)	90
(*d*) Regular thimble with clips, Fig. 20.10 (*d*)	85
(*e*) Three bolt wire clamps, Fig. 20.10 (*e*)	75

Wire Material and Grades

- The most common wire material is an uncoated (bright) **high-carbon steel**.
- The properties of steel allow it to be drawn into wires with **high strength**, and **good wear** and **fatigue resistance**.
- **Stainless steel or galvanized steel** wire are used in applications with corrosive environments.
- **Plow steel** is a term used for wire rope grades. Each different plow steel grade has improved tensile strength
- **Improved plow steel (IPS)** is the most commonly used grade for wire rope, while
- **Extra improved plow steel (XIP)** is used for specialapplications.

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

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Extra Improved Plow Steel	1960 N/mm^2

Wire Rope Selection

- Wire rope construction determines its operating characteristics
- **Attributes of wire rope:** strength, flexibility, resistance to bending fatigue, abrasion resistance, resistance to crushing
- **Strength** measured as minimum breaking force in tons. Strength can be increased by increasing diameter, using better steel, steel core, or increasing steel content
- **Flexibility** relates to bending around sheaves or drums. Flexibility can be increased by using more smaller-diameter wires in a strand or a fiber core
- **Fatigue resistance** required for repeated bending over sheaves and drums. More smaller wires increase fatigue resistance

Wire Rope Selection

- **Abrasion resistance** refers to wearing of wires, weakens rope. Abrasion can occur from dragging through gritty material or rope-to-rope contact
- Proper sheave alignment, groove diameter, and drum winding minimize abrasion
- Large-diameter wires improve abrasion resistance
- **Crushing resistance** is the ability to maintain shape under external pressure
- **IWRC core,** six strand, and regular lay construction improve crush resistance
- **Fiber core** has lower crush resistance compared to IWRC core

Wire Rope Selection

- **Small number of larger-diameter wires:** improves abrasion resistance, lower resistance to bending fatigue
- **Large number of small-diameter wires:** improves resistance to bending fatigue, reduces resistance to abrasion
- **Fiber core:** more flexible, less crush resistance and strength compared to IWRC core
- **Lang lay wire rope:** higher abrasion resistance, fatigue resistance, more flexible than regular lay
- **Regular lay wire rope:** more resistant to crushing, more stable than Lang lay
- Selection of wire rope design requires compromise between characteristics based on application

Wire Rope Selection

Several characteristics of the design application should be considered:

- **Speed of operation**
- **Acceleration and deceleration**
- **Length of rope**
- **Number, size, and location of sheaves and drums**
- **Conditions of the environment**
- **Human and property safety concerns**

Design Factors and Working Loads

- Industry standards and regulations require minimum design factors for wire rope.
- **Design factor** is applied to the minimum breaking force of the wire rope.
- **Minimum design factor** of **5** is used in overhead cranes, gantry cranes, and overhead hoists.
- **Maximum working load** can be determined by dividing minimum breaking force by design factor.
- **Maximum working load** considers static loading, accelerations, and shock loading conditions.
- **Shock loads** can be much higher than static loads. Shock loading occurs with sudden changes or jerking movements of the load and should be avoided.

Application of wire rope	Factor of Safety
Track cables	4.2
Guys	3.5
Mine hoists : Depths	
Up to 150 m	8
300 – 600 m	7
600 – 900 m	6
over 900 m	5
Miscellaneous hoists	5
Derricks	6
Haulage ropes	6
Small electric and air hoists	7
Over head and gantry cranes	6
Jib and pillar cranes	6
Hot ladle cranes	8
Slings	8
Power passenger and freight elevators	7-12

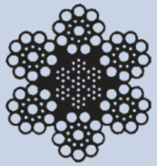
Design Factors and Working Loads

- The **minimum breaking force** is given for both **improved plow steel** and **extra improved plow steel** with a **fiber core** and an **IWRC core.**
- The **weight per foot** is shown for both **fiber** and **IWRC** cores.
- The **6x19 steel core** and **fiber core** classifications of wire rope are the most widely used.
- The combination of flexibility and wear resistance makes it suitable for diverse types of machinery and equipment.
- Compared to the 6x19 classification, the 6x36 classification of wire rope is more flexible but less abrasion resistant.

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

Fiber core

IWRC



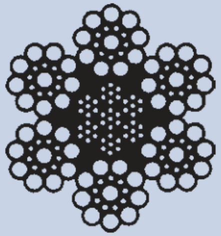
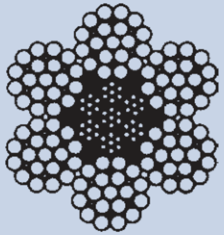
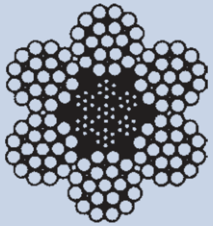
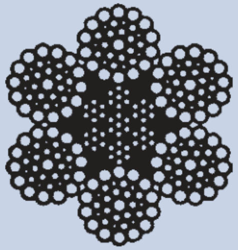
Diameter	Fiber core: Weight per foot	Fiber core: Min breaking force IPS	Fiber core: Min breaking force XIP	IWRC: Weight per foot	IWRC: Min breaking force IPS	IWRC: Min breaking force XIP
in	lb/ft	tons	tons	lb/ft	tons	tons
1/4	0.105	2.74	3.02	0.116	2.94	3.4
5/16	0.164	4.26	4.69	0.18	4.58	5.27
3/8	0.236	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

Design Factors and Working Loads

- The nomenclature of a wire rope defines the length, size (diameter), direction of lay, grade of rope, finish, construction, and type of core.
- An example of a complete wire rope designation is

500 ft x 5/8 in diameter 6x19 Filler Wire – Right Lay– Left Lang Improved Plow Steel IWRC"

TABLE 7–26 Properties of Standard 6×19 and 6×36 Wire Ropes

6×19S (Seale)		Good resistance to abrasion and crushing Fatigue resistance is less than 6×25
6×25F (Filler Wire)		Higher resistance to fatigue than 6×19 class Best combination of flexibility and wear resistance for 6×19 class Filler wire provides support and stability to the strand
6×26 (Warrington Seale)		High resistance to crushing Good wear resistance Good Flexibility
6×36 (Warrington Seale)		Provides good fatigue resistance without having wires that are too small Most flexible due to large number of small wires Susceptible to crushing, use IWRC to minimize

Recommend the diameter for a grooved drum on which a wire rope with a diameter of 16 mm is to be wound as part of a winch system. The construction of the rope is to be 6x36 Warrington Seale type.

TABLE 7–22 Sheave and Drum Diameter Factors

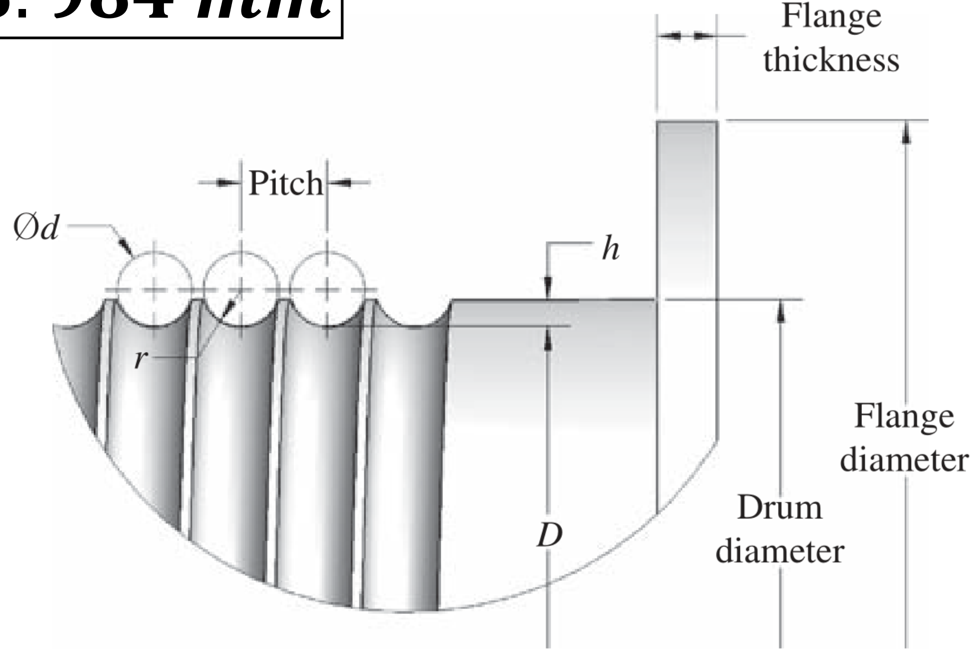
Construction	Suggested D/d ratio	Minimum D/d ratio
6×7	72	42
6×19 Seale	51	34
6×21 Filler Wire	45	30
6×25 Filler Wire	39	26
6×31 Warrington Seale	39	26
6×36 Warrington Seale	35	23
6×41 Seale Filler Wire	20	20
6×41 Warrington Seale	32	21
6×42 Tiller	21	14
8×19 Seale	41	27
8×25 Filler Wire	32	21

$$35 = D/d \qquad 35 = D/(16\text{ mm})$$

$$\boxed{D = 560\ mm}$$

$$h = 0.374(d) = 0.374(16\ mm)$$

$$\boxed{h = 5.984\ mm}$$



(b) Grooved drum dimensional specifications

Recommend the allowable working load for a wire rope having 6x36 construction, a diameter of 1.25 in, and made from XIP steel to be used in a crane application.

$$\boldsymbol{IWRC}$$

$$d = 1.25\ in.$$

$$Min\ Breaking\ Force\ for\ XIP$$

$$65\ tons\ x\ 2000\,\frac{Ib}{1\ ton}\ \ 130{,}000\ Ibs$$

$$SF = 5$$

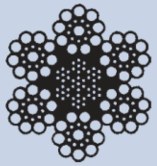
$$Allowable\ working\ load$$

$$= Min\ Breaking\ Force/SF$$

$$= 130{,}000/5$$

$$\boxed{= 26{,}000\ Ib.}$$

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

Select a 6x36, IWRC wire rope for a vertical mine hoist to lift a load of 55 kN from a depth 300 metres.

$$Allowable\ working\ load = 55\ KN$$

$$SF = 7$$

$$Min\ Breaking\ Force = 55\ KN(7)$$

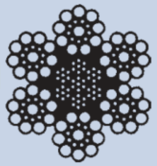
$$385\ KN\ (0.2248\ lb/1N)(1000N/1KN)$$

$$86548\ lb\ x\left(\frac{1ton}{2000lb}\right) = 43.274\ tons$$

$$\boxed{d = 1\ in.}$$

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

Fiber core 

IWRC 

Diameter	Fiber core: Weight per foot	Fiber core: Min breaking force IPS	Fiber core: Min breaking force XIP	IWRC: Weight per foot	IWRC: Min breaking force IPS	IWRC: Min breaking force 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
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1	1.68	41.8	46	1.85	44.9	51.7
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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

PRACTICE PROBLEM

1. Recommend the allowable working load for a wire rope having 6x19 construction, a diameter of 1.25 in, and made from XIP steel to be used in a Jib crane application.
2. An overhead crane requires the use of 4 ropes made of 6x36 Warrington Seale XIP IWRC wire rope. The ropes need to have a length of 200 ft and support a maximum load capacity of 10,000 lb.

   a. What is the min breaking force of each individual wire rope, considering the given rope construction and the application requirements?
   b. Based on the breaking force per rope and the load capacity of the crane, what should be the minimum required diameter of each wire rope?
   c. Considering the rope diameter, what should be the suggested drum diameter for the overhead crane?
   d. Calculate the total weight of wire ropes.