UNOLS

Research Vessel Safety Standards

Appendix A:

Wire & Cable Safe Working Loads

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Why Bother?

- Tension members (Wire Rope & Cables) are normally operated at 20 % of their breaking strength by shore side regulation.
- In order to meet scientific research requirements it is necessary to operate at 50% of the breaking strength or higher.
- Appendix "A" of the UNOLS Research Vessel Safety Standards was created in order to operate <u>**safely**</u> at these higher tensions.

Shipboard Priorities

1. People are not put in danger
2. Ship & Equipment are not put in danger
3. Meet Science Objectives -- Collect Data

Overview

- General Definitions
- 3x19 Oceanographic Wire Rope
- Oceanographic (Electromechanical) Cables
- Equipment Lowering Dynamics
- Operational Characteristics of Wire Rope and Cable
- LCI-90i Display Calibration and Use

Definitions

- Tension Member: Generic name used to describe a rope or cable in service for over-the-side work.
  - Rope: A woven, flexible tension member with no internal conductors. It may be made from natural fibers, synthetic fibers, or metal.
  - Cable: A woven, flexible tension member with internal conductors or other means of transmitting data such as glass fiber. It may be made from natural fibers, synthetic fibers, or metal.

It is a System

- Every component in the system needs to be considered
  - Appendix “A” applies to tension members
  - Appendix “B” applies to winches, over boarding structures (a-frames, j-frames etc.), sheaves and ship foundations.

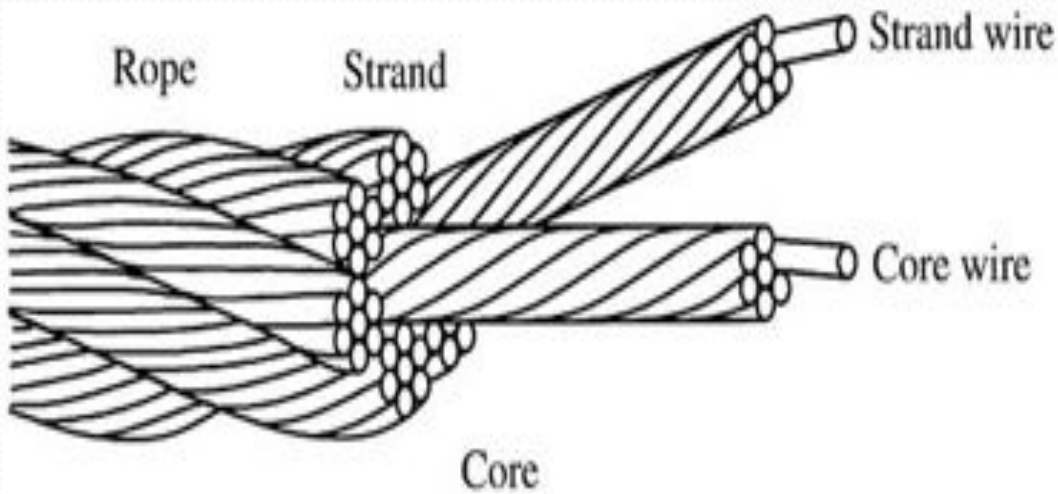
- Unless all of the components of the system are evaluated, you do not necessarily have a system capable of operating at the loads suggested by Appendix “A”!

Wire Rope

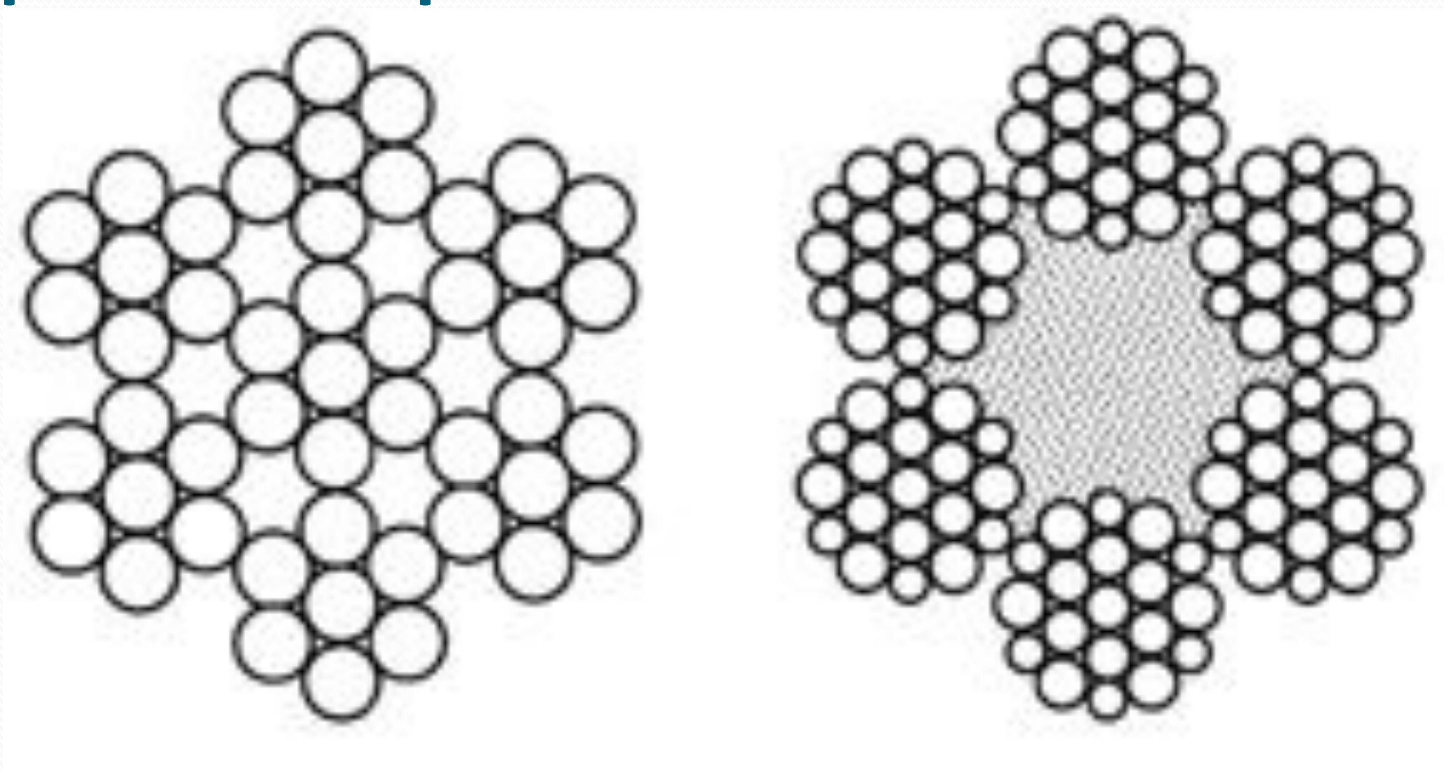
Construction & Characteristics

Diagram of Tension Member Components

- Individual metal wires make up either the strand or core
- Strands are then wound around the core



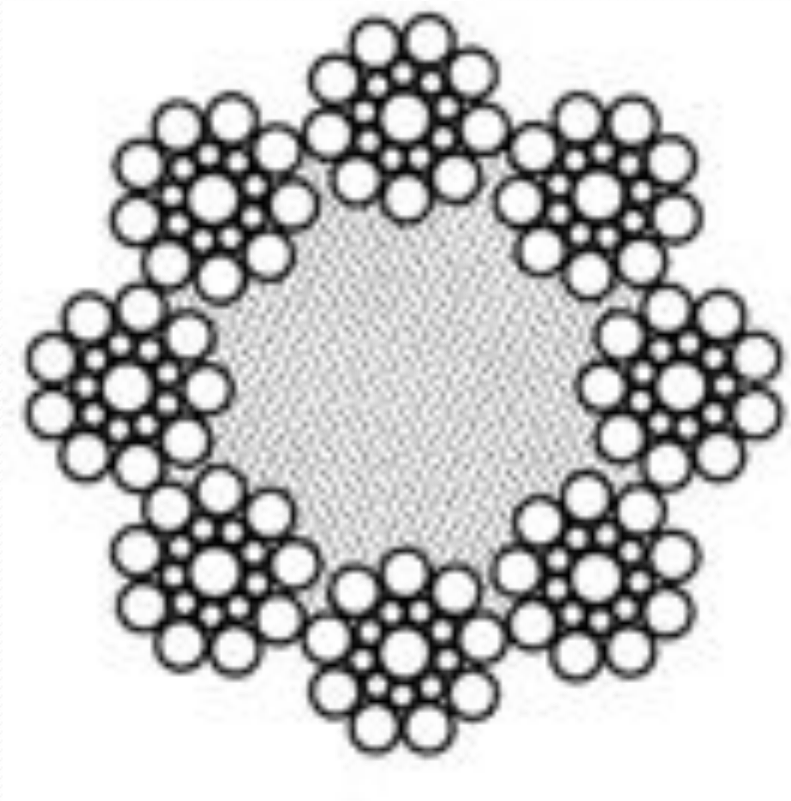
Typical Rope Construction



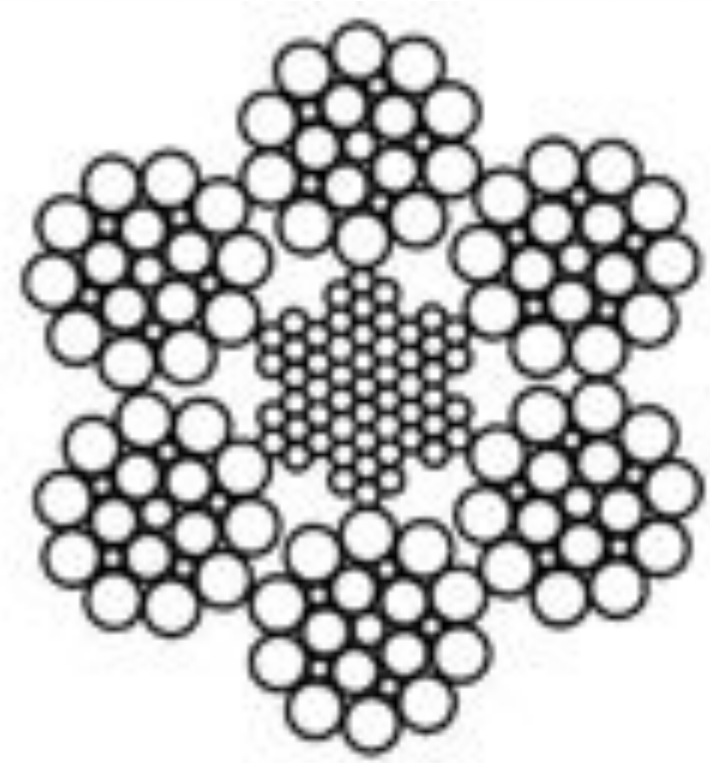
7x7 WSC
(Wire Strand
Core)

6x19 W FC
(Warrington with Fiber
Core)

Typical Rope Construction

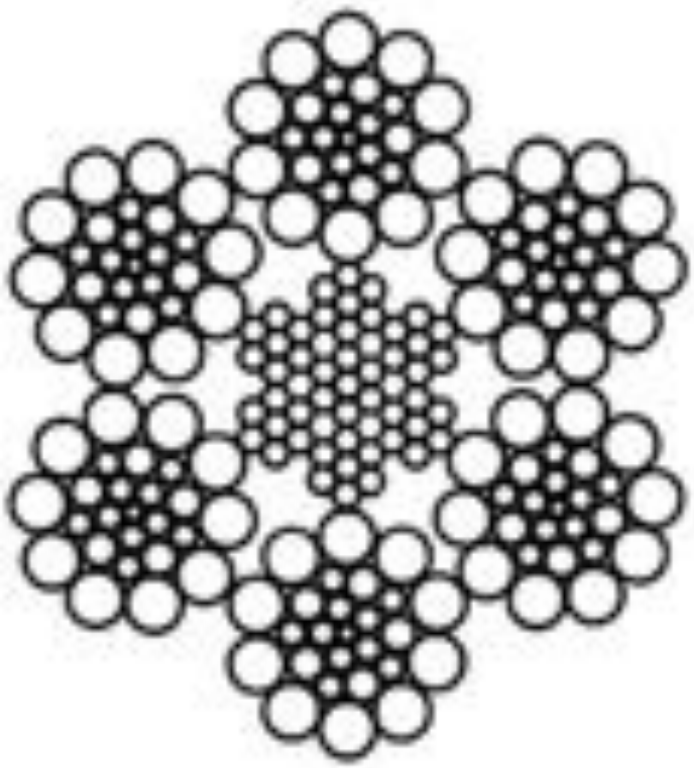


8x17 S FC
(Seale with Fiber Core)

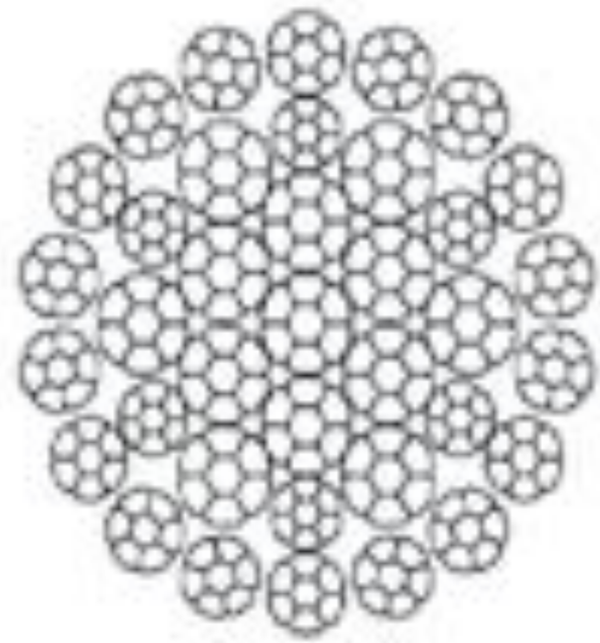


6x21 FW IWRC
(Filler Wire with Independent Wire Rope Core)

Typical Rope Construction

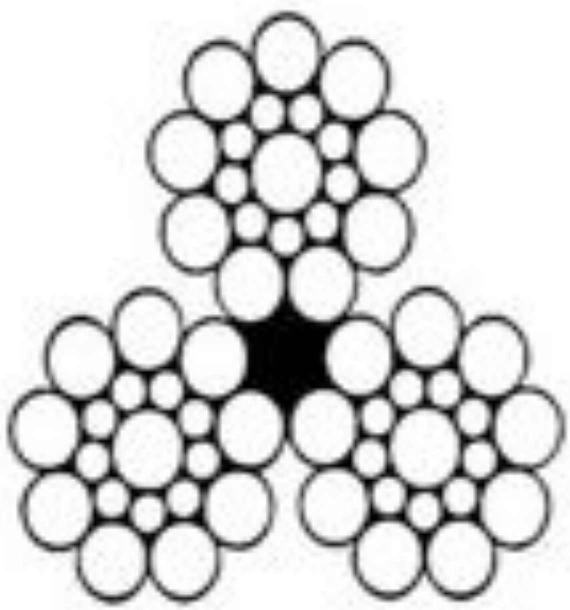


6x26 WS IWRC
Warrington Seale with
Independent Wire Rope Core



Compacted Strand
High Performance
Wire Rope

Typical Rope Construction



3x19
Seale

Grades of Wire Rope

- TS - Traction Steel
- PS - Plow Steel
- IPS - Improved Plow Steel
- EIPS or XIPS – Extra Improved Plow Steel (15% improvement over IPS)
- EEIPS or XXIPS – Extra Extra Improved Plow Steel (10% Improvement EIPS)

The 3 Meanings of Lay (1)

- The direction strands lay in the rope – right or left. When you look down a rope, strands of a right lay rope go away from you to the right. Left lay is the opposite. (It doesn't matter which direction you look.)

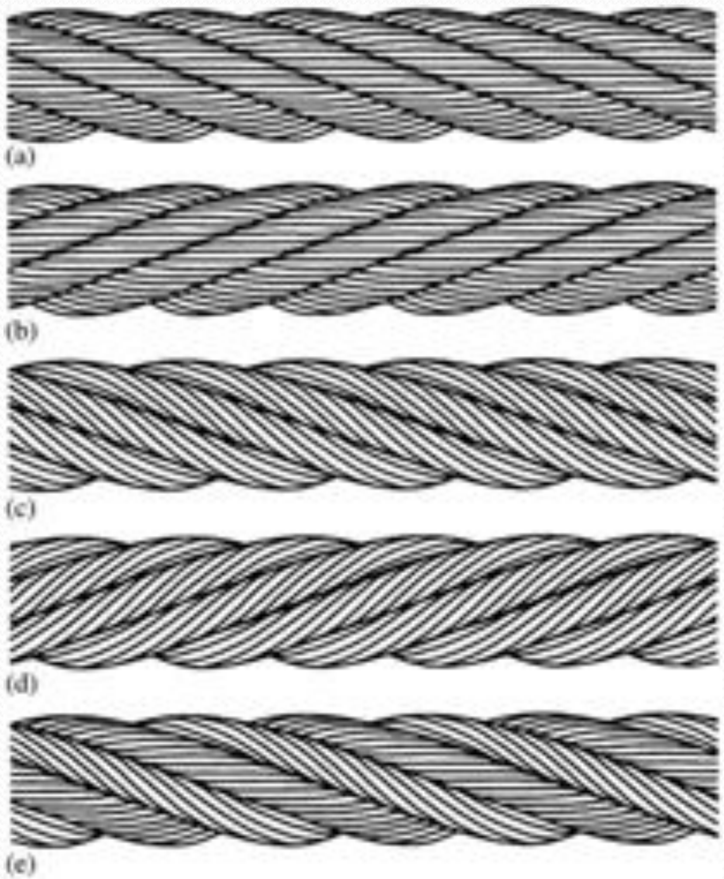
The 3 Meanings of Lay (2)

- The relationship between the direction strands lay in the rope and the direction wires lay in the strands.
  - In regular lay, wires are laid in the strand opposite the direction the strands lay in the rope.
  - In lang lay, the wires are laid the same direction in the strand as the strands lay in the rope.
  - In appearance, wires in regular lay appear to run straight down the length of the rope, and in lang lay, they appear to angle across the rope.

The 3 Meanings of Lay (3)

- The length along the rope that a strand makes one complete spiral around the rope core.

Diagrams of several standard wire rope lays



(a) RRL - Right Regular Lay

(b) LRL – Left Regular Lay

(c) RLL – Right Lang Lay

(d) LLL – Left Lang Lay

(e) RAL/LAL Alternate Lay

Each depiction is a single rope lay

Preforming

- Preformed - means that the strands and wires have been preset during manufacture into the permanent helical shape they take in the finished wire rope.
- The preformed operation in wire ropes confer more stability to them; it reduces internal stresses, giving a more homogenous distribution of load on wires and strands.
- When wires are broken, they tend to remain in position after breaking.
- Preforming while improving the rope makes it more difficult to visually observe broken wires.

Corrosion Protection (1)

- 2 different procedures to manufacture galvanized wire:
  - **galvanized to finished size wire** - is first drawn as a bright wire to a predetermined size that's smaller than the required finished wire size. This wire is then run through the galvanizing line.
  - The resultant coating of zinc increases the wire diameter to the finished size. Galvanized to finished size wire has a strength 10% lower than the same size and type of bright wire.
  - Ropes made from this wire therefore, have a minimum breaking strength that's 10% lower than the equivalent size and grade of bright rope.

Corrosion Protection (2)

- 2nd procedure to manufacture galvanized wire:
  - **drawn galvanized wire** is galvanized before the final drawing to finish size. Since the galvanized coating also goes through the drawing process, it is much thinner than the coating on galvanized to finished size wire.
  - Drawn galvanized wires are equal in strength to the same size and type of bright wire and drawn galvanized rope is equal in strength to the same size and grade of bright rope.

Galvanizing of UNOLS Tension Members

- **Galvanized to finished size wire**
  - **1/2" 3x19**
  - **9/16" 3x19**

- **Drawn galvanized wire**
  - **¼" 3x19**
  - **.322 conductor cable**
  - **.680 conductor cable**
  - **.681 fiber optic conductor cable**

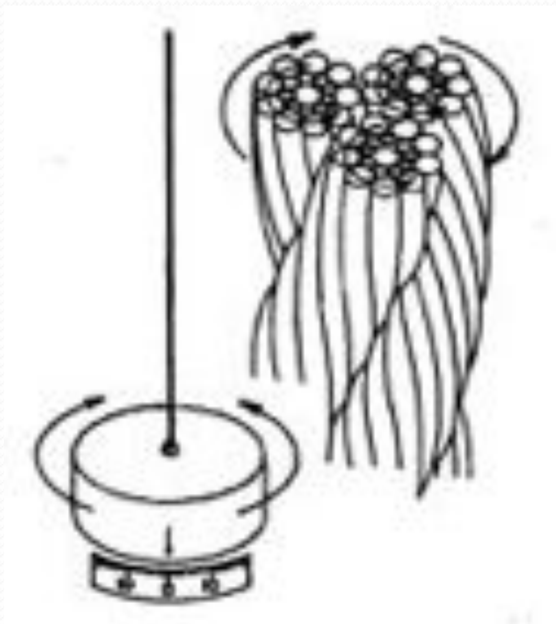
Elastic Limit

- Elastic Limit –The elastic limit or yield point of a material is the stress at which a material begins to deform plastically.
  - Prior to the yield point, the material will deform elastically and will return to its original shape when the applied stress is removed.
  - Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible. For rope or cable, this is the load that causes permanent set, or deformation, of the strands.
- At the elastic limit the wire permanently stretches and becomes thinner and thus weaker.
- A wire rope or cable must never be used at or near it's elastic limit even for a fraction of a second!!

Torque Balanced

- Under tension, each wire in the rope exhibits a torque directly related to the angle it makes with the rope axis. The sum of these torques are equally balanced by the opposing rope torque.

- WHAT THAT MEANS IS: When these forces are equal, the rope is virtually non-rotating under a free hanging load.



Non-Torque Balanced

- Non-torque balanced rope unwinds when suspending a free hanging load. Any momentary or sudden release of tension permits the wire rope to start winding back to its original design because of its spring-like properties.

- When this happens, hockles and kinks are formed.
  - Hockles – tight loops
  - Kinks - tight bends
  - Other terms are oft used in reference materials…

Advantages of Torque Balanced Wire Rope

- Torque-Balanced wire rope resists rotation. At loads approaching the elastic limit—75% of rope breaking load—tests show rotation to be less than 1° per foot of rope length.

- Even when there is a sudden release of load, Torque-Balanced wire ropes will not kink or form loops and hockles, as in conventional 6-strand wire ropes.

- Torque-Balanced wire rope will give you better and longer service life free of the problems associated with conventional wire ropes in undersea operations.

More Advantages…

- The elastic limit of Torque-Balanced wire rope is 75% of normal rope breaking load, compared to approximately 50% for 6-strand ropes.

- The importance is that the payload of a Torque-Balanced wire rope, at the elastic limit, is 50% greater than that of an equal strength 6-strand rope with no difference in diameter.

- Additionally, since a Torque-Balanced wire rope weighs less (about 10%) than a conventional 6-strand rope of the same size and strength. It has a much higher strength to weight ratio.

Great News!

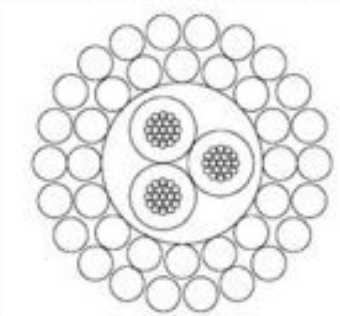
- UNOLS 3x19 wire ropes are torque balanced!

Inches	Construction	Weight in Air lbs/ft.	Weight in water lbs/ft.	Approx. Elastic Limit lbs.	Nominal Breaking Load lbs.
1/4	3x19 Seale	0.1	0.087	5,036	6.750
1/2	3x19 Seale	0.392	0.341	19,275	25,700
9/16	3x19 Seale	0.492	0.428	24,375	32,500

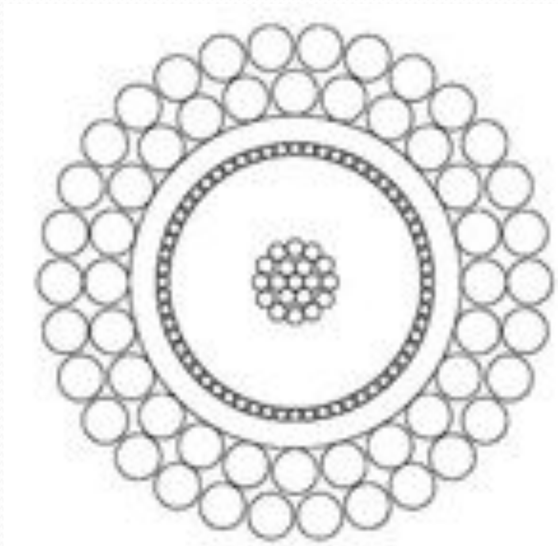
Cable

Construction & Characteristics

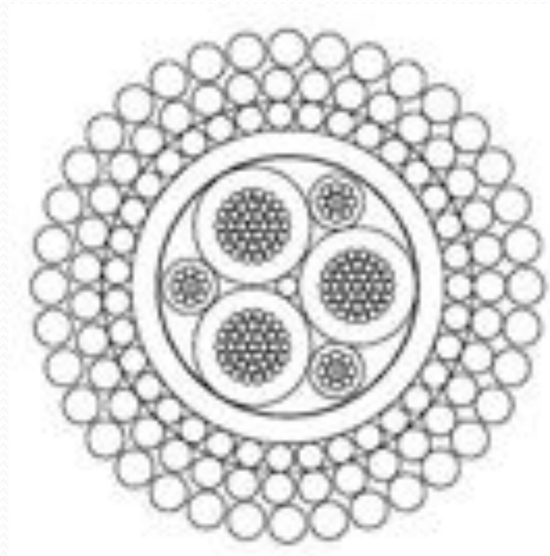
UNOLS Standard Cables



.322



.680



.681

Cables and Torque

- Cables are constructed with multiple layers of helically applied armor wires.
- Under load, each layer of wires develops torque.
- The torque developed by the inner armor opposes the torque of the outer armor because the direction of wire lay is opposite.
- The torque in each layer of armor wires is determined primarily by the total area of steel in each layer and the distance of the wires from the cable center.
- The outer armor wires are always further from the cable center than the inner armor and for practical reasons the outer armor layer has a greater area of steel.
- The outer armor layer, therefore, develops much greater torque than the inner armor layer.

Cables and Torque Imbalance

- The imbalance in torque can be partially, but not completely, offset by adjusting the lay angles of the inner and outer armor wires.
- Another method of reducing torque imbalance in cables is to add a third layer of armor.

Definitions

- FIXED ENDS (FE): Both ends of the cable being fixed without the ability to swivel. Most wire rope and cable load values are based on FE.
  - Example, FE application: towing a MOCNESS

- FREE TO ROTATE (FTR): The end of the cable is free to rotate either because a swivel is at the end of the tension member or the package at the end of the cable can rotate freely. Wires and Cables used in FTR applications have a load value below the fixed end load value.
  - Example, FTR application: a lowered CTD package

Cables With Fixed Ends

- When a cable is under load, with no rotation allowed, the outer armor wires are stressed slightly more than the inner armor wires.

- For this reason, when a fixed end cable breaks, the outer armor wires will always break first and the inner armor wires stretch out before they break.

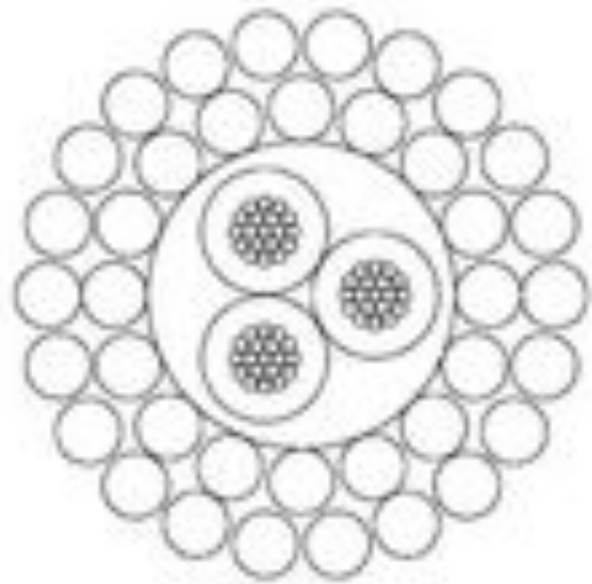
Cables Free to Rotate

- If a cable under load is free to rotate, such as a cable hanging vertically, the dominant torque of the outer armor wires will cause the cable to unwind the outer armor and reduce its stress.
- As the outer armor wires unwind, the inner armor wires are forced to wind tighter and this increases the stress in the inner armor.
- This unwinding will continue until the torque between the layers is equal and when this occurs the stress in the inner armor is much higher than in the outer armor.
- When a cable is free to rotate or is forced to unwind by improper operating conditions the breaking strength is significantly reduced and when it does break, the inner armor will break first and then the outer armor wires will stretch out before they break.

UNOLS Conductor Cable Specifications

.322 Cable Specifications

Description	Inch	mm
INSULATED CONDUCTOR (3)		
Cdr. #19 AWG (19/0.008")Bare Cu	0.039	0.99
Ins: .016" wall Polypropylene	0.071	1.80
ASSEMBLY		
3 ins. cdrs. cabled	0.153	3.89
BELT		
0.015" wall HD Polyethylene	0.183	4.65
ARMOR - 2 layers		
16/0.0375" GEIPS	0.247	6.27
22/0.0375" GEIPS	0.322	8.18



.322 Cable Specifications (CONT.)

Nominal Values @ 20°C	Metric	English
PHYSICAL		
Weight in Air	260 kg/km	175 lb/kft
Weight in Seawater	215 kg/km	144 lb/kft
Specific Gravity (SG = 1.028)	6.0	6.0
MECHANICAL		
Breaking Strength, Fixed End	52 kN	11,600 lbf
Breaking Strength, Free End	45 kN	→ 10,000 lbf
Working Load @ 4% Strain	11 kN	2,500 lbf
Maximum Working Load[1]	22.2	5,000 lbf
Recommended Bend Radius	15 cm	6"
Rotation @ 2,500 lbf	49°/m	15°/ft
ELECTRICAL		
Voltage Rating	1,000 V	1,000 V
Insulation Resistance	3,000 MΩ•km	10,000 MΩ•kft
dc Resistance		
Cdr.	30.8 Ω/km	9.4 Ω/kft
Armor	7.9 Ω/km	2.4 Ω/kft
Capacitance (cdr.-armor)	115 pF/m	35 pF/ft

.322 Cable Specifications (CONT.)

[1]"The cable working load as stated on the DATALINE (2,500 lbf) represents the maximum quasi-static load of the operational system that will be supported by the cable. Transient dynamic loads may be applied to the cable providing that the maximum dynamic load applied remains below 5,000 lbf and its period is smooth and gradual, greater than several seconds. Caution must be taken with rapid fluctuations in the loading condition that will result in conductor buckling (compression, otherwise known as "z" kinking). These rapid load variations include, but are not limited to, shock loading, the rapid and erratic removal and increasing of load. This load transient has a period less then a few seconds and can result in cable buckling and/or hockling. Extended excursions above the working load value may affect service life and increases the risk of component buckling."

Z-Kinking of Conductors

- Anytime the tension on a cable is suddenly released, the possibility exists of forming kinks in the cable conductor. This class of kinks is often referred to as z-kinks. The soft copper strands, which make up all conductors, are elastic over a narrow range. If the cable is pulled so that it stretches over 0.1%, the copper can be stretched permanently so that it is longer than the original length.

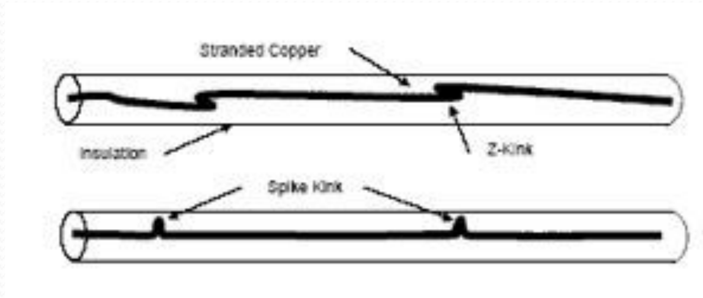
- The permanent elongation of the copper presents a problem when the tension on the cable is suddenly removed. Under such a condition, the elastic steel armor relaxes and may even overshoot - going into compression. The weaker, more pliable copper and plastic core is forced to follow the steel. If the tension on the cable is removed gradually, usually the cable has time to rotate. If rotation is allowed, some of the elongation may be absorbed. However, if there is no rotation, the extra length of copper has no where to go.

Z-Kinking of Conductors (CONT.)

- Under certain conditions, the copper can double back on itself. This "doubling back" often is in the shape of the letter "z" - thus the name "z-kink". Alternately, the lengthened copper strands instead of folding back on the conductor may form a spike extending perpendicular to the conductor.

- A z-kink is detrimental only to the extent that the distance between the conductor and the armor can be significantly less than normal. This increases the likelihood of an electrical short developing at the z-kink. Such shorts are more apt to show up when the line is put under higher tensions, causing the core to decrease in diameter slightly, or/and when the cables runs over a sheave.

Spike & Z-Kinks



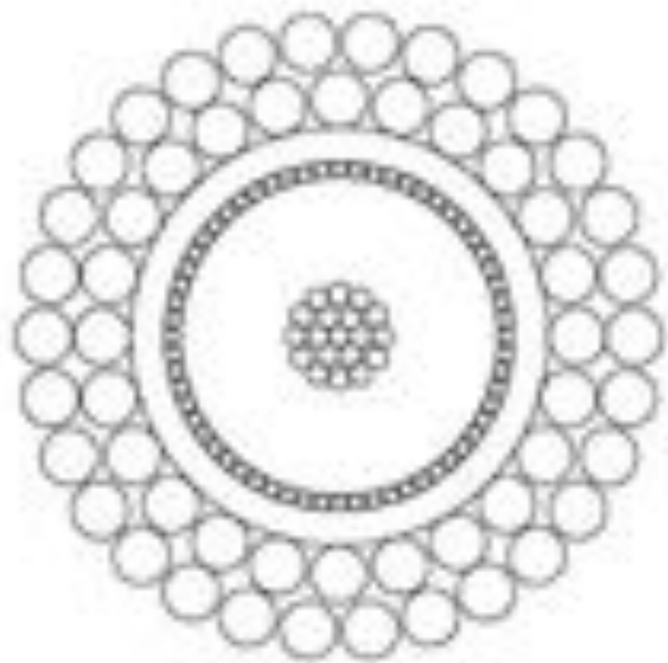
Spike Kink

Z-Kink

.680 Cable Specifications

Description

	Inch	mm
CONDUCTOR		
Core: Nylon Monofilament	0.024	0.61
1st Layer: 6/0.0226" HDBC	0.065	1.65
2nd Layer: 12/0.0226" HDBC	0.109	2.77
INSULATION		
0.110" Wall HDPE	0.330	8.38
SERVED SHIELD		
60/0.0159" HDBC	0.362	9.19
RETURN TAPE (2 Layers)		
0.0017" Cu Polyester	0.367	9.32
BELT		
0.040" Wall HDPE	0.446	11.33
ARMOR		
24/0.060" GEIPS	0.560	14.22
30/0.060" GEIPS	0.680	17.27



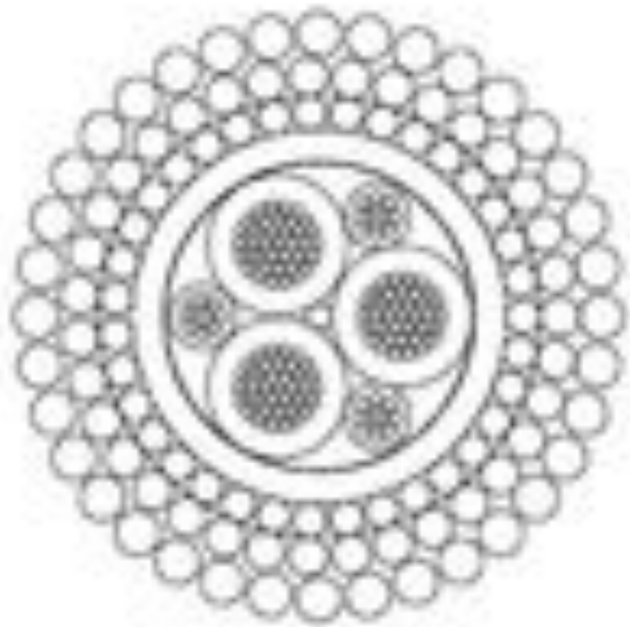
Note: All interstices are void filled.
This design is in accordance with UNOLS Specification (and Appendix A) as applicable.

.680 Cable Specifications (CONT.)

Nominal Values @ 20°C	Metric	English
PHYSICAL		
Weight in Air	1,030 kg/km	693 lb/kft
Weight in Seawater	823 kg/km	553 lb/kft
Specific Gravity	5.2	5.2
Operating Temperature	-40°C to 90°C	-40°F to 200°F
MECHANICAL		
Breaking Strength (Fixed Ends)	178 kN	40,000 lbf
Breaking Strength (Free End)	164 kN	37,000 lbf
Working Load @ 0.4% Elongation	44 kN	10,000 lbf
Torque @ 10,000 lbf	2.4 kg•m	17 lbf•ft
Rotation @ 10,000 lbf	16°/m	5°/ft
Recommended Bend Radius	36 cm	14 in
ELECTRICAL		
Voltage Rating	3,000 Vdc	3,000 Vdc
Insulation Resistance		
cdr – return @ 500 V	24,000 MΩ•km	80,000 MΩ•kft
return – armor @ 500 V	1,200 MΩ•km	4,000 MΩ•kft
dc Resistance		
cdr	4.1 Ω/km	1.25 Ω/kft
return	2.6 Ω/km	0.80 Ω/kft
loop	6.7 Ω/km	2.05 Ω/kft
Capacitance	108 pF/m	33 pF/ft
Attenuation Rate		
@ 0.5 MHz	4.1 dB/km	1.25 dB/kft
@ 1 MHz	5.8 dB/km	1.76 dB/kft
Characteristic Impedance @ 1 MHz	45 Ω	45 Ω

.681 Cable Specifications

Description	Inch	mm
ELEMENT A		
Fiber: 8.3/125/245 µm SMF		
Buffer: Hytrel®	0.024	0.61
Armor: 8/0.015" Plow Steel	0.054	1.37
Belt: Polyethylene	0.074	1.88
ELEMENT B		
Cdr: #11 AWG, Hard-drawn Cu		
Ins: Polyethylene	0.156	3.96
ASSEMBLY		
Core: Filler Rod	0.030	0.76
Layer 1: 3 Element B's with		
1 Element A in each interstice.		
Void fill and tape	0.344	8.74
Belt: Polyethylene	0.415	10.54
ARMORING		
1st Layer: 35 wires GEIPS	0.500	12.70
2nd Layer: 35 wires GEIPS	0.583	14.81
3rd Layer: 36 wires GEIPS	0.681	17.30



.681 Cable Specifications (cont.)

Nominal Values @ 20 °C	METRIC	ENGLISH
PHYSICAL		
Weight in Air	1,112 kg/km	747 lb/kft
Weight in Seawater	905 kg/km	608 lb/kft
Specific Gravity (seawater)	5.6	5.6
Operating Temperature	-30 °C to 80 °C	-22 °F to 175 °F
MECHANICAL		
Breaking Strength (Fixed End)	205 kN	46,000 lbf
Breaking Strength (Free End)	205 kN	46,000 lbf
Working Load @ 0.35% Strain	44.5 kN	10,000 lbf
Working Load @ 0.5% Strain	62.3 kN	14,000 lbf
Rotation @ 14,000 lbf	<3.3 °/m	<1 °/ft
Recommended Bend Radius @ 10,000 lbf	35 cm	14 inches
Recommended Bend Radius @ 14,000 lbf	61 cm	24 inches
ELECTRICAL		
Voltage Rating @ 123 volts/mil	2,800 Vdc	2,800 Vdc
Insulation Resistance	3,000 MΩ.km	10,000 MΩ.kft
dc Resistance	4.9 Ω/km	1.5 Ω/kft
OPTICAL		
Attenuation		
@ 1310 nm	0.7 dB/km	0.21 dB/kft
@ 1550 nm	0.7 dB/km	0.21 dB/kft
Proof Test	1,380 N/mm^2	200 kpsi

Loads on Tension Members

Breaking Loads

- ULTIMATE LOAD (UL): The theoretical load that produces failure. For the purposes of Appendix "A", the "Ultimate Load" is assumed to be either the Nominal Breaking Load (NBL) or the Assigned Breaking Load (ABL) as defined below.

- NOMINAL BREAKING LOAD (NBL): Manufacturer's minimum published breaking load for a rope or cable.

- TESTED BREAKING LOAD (TBL): The actual load required to pull a tension member to destruction as determined by testing. Depending on the intended use of the tension member testing may need to be done under fixed end and free to rotate conditions.

- ASSIGNED BREAKING LOAD (ABL): Will be the lowest of the Ultimate Load, Nominal Breaking Load and Tested Breaking Load. In practice, ABL will be equal to NBL used unless testing shows TBL to be less than NBL. A value greater than the NBL may never be used. Depending on the intended use of the tension member there may be two ABLs for fixed end and free to rotate conditions.

Breaking Loads (restated)

- ULTIMATE LOAD (UL): ENGINEERING CALCULATION
- NOMINAL BREAKING LOAD (NBL): MANUFACTURER STANDS BEHIND
- TESTED BREAKING LOAD (TBL): THE RESULT OF THE WIRE POOL TEST PULL
- ASSIGNED BREAKING LOAD (ABL): WHERE THE TENSION MEMBER WILL PROBABLY BREAK (Depending on the intended use of the tension member there may be two ABLs for fixed end and free to rotate conditions.)

Breaking Loads – Example 1

- The manufacturer calculates the *Ultimate Load* of ¼" 3x19 wire rope to be 6,900 pounds for a perfectly manufactured wire rope.
- In the data sheet the manufacturer states the *Nominal Breaking Load* to be 6,750 pounds to accommodate manufacturing tolerances.
- Before the wire is distributed from the wire pool a sample is pulled to destruction with a *Tested Breaking Load* of 6,825 pounds.
- **The *Assigned Breaking Load* is the lowest of the three values 6,750 pounds.**

Breaking Loads – Example 2

- The manufacturer calculates the *Ultimate Load* of ¼" 3x19 wire rope to be 6,900 pounds for a perfectly manufactured wire rope.
- In the data sheet the manufacturer states the *Nominal Breaking Load* to be 6,750 pounds to accommodate manufacturing tolerances.
- After being in use 1 year a sample is pulled to destruction with a *Tested Breaking Load* of 6,200 pounds.
- **The *Assigned Breaking Load* is the lowest of the three values 6,200 pounds.**

Breaking Loads – Example 3

- The manufacturer calculates the *Ultimate Load* of .322 cable to be 12,200 pounds of a perfectly manufactured cable.
- In the data sheet the manufacturer states when the end is free to rotate the *Nominal Breaking Load* is 10,000 pounds.
- After being in use 1 year a sample is pulled to destruction with a *Tested Breaking Load* of 10,950 pounds.
- **The *Assigned Breaking Load* is the lowest of the three values 10,000 pounds.**

VERY IMPORTANT!

SWL & FS

Terms

- SAFE WORKING LOAD (SWL): The maximum load that is allowed to be supported during normal operation.
- FACTOR OF SAFETY (FS): For the purpose of Appendix A: defined as Assigned Breaking Load / Safe Working Load.

Ex: 10,000 lb / 2,000 lb = 5.0 FS

Practice

- SWL = ABL / FS
  - For the purposes of this standard, FS shall be considered the value selected by the operator. Because there may be two different ABL (fixed end & free to rotate) there may be two different SWLs.
- Section 6.0 of Appendix "A" defines the minimum standards that must be met to select specific FS values of:
  - 5.0 or greater
  - Less than 5.0 to 2.5
  - Less than 2.5 to 2.0
  - Less Than 2.0 to 1.5

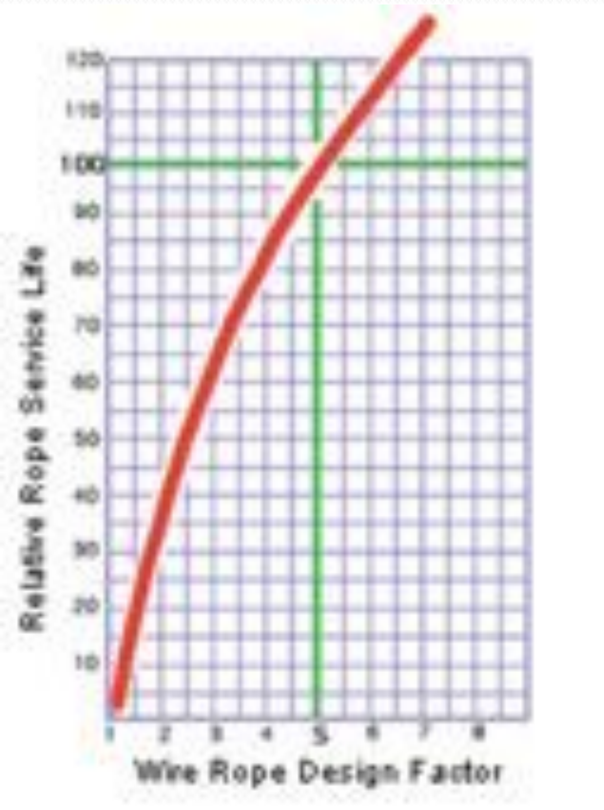
FACTOR OF SAFETY ISSUE IN APPENDIX A

- Issue: Current version of Appendix A specifies different procedures dependent on the FS being used. Currently, the ranges described in tables 6.1 through 6.4 are:
  - 5.0 and greater
  - 5.0 to 2.5
  - 2.5 to 2.0
  - 2.0 to 1.5

- Which table do I use if a safety factor of 5.0, 2.5, or 2.0 is being used that is specified on two different tables?

- Resolution: Consider it an administrative error and do an editorial correction that changes the ranges for the tables to be:
  - 5.0 and greater
  - Less than 5 to 2.5
  - Less than 2.5 to 2.0
  - Less than 2.0 to 1.5

FS and Service Life



- Reducing the Factor of Safety reduces service life of the wire significantly.

- Note:
  - Horizontal axis: FS
  - Vertical axis: % of designed life of tension member

Loads on Tension Members

- Static Loads
- Quasi-Static
- Dynamic Loads
- Transient Loads

Static Loads

- The weight in water of the package
  - Generally stays the same
- The weight in water of the tension member
  - Varies with the length of the tension member paid out

Quasi-Static Loads

- Hydrodynamic resistance (Drag) - caused by variation in movement of the deployed components through the water
  - either by towing, i.e. static is 2 kts, quasi-static is 4 kts (the higher speed has more drag)
  - movement of the winch, i.e. 30 m/s or 60 m/s
- Static (does not change) - if sea state is like glass, the ship speed remains constant and the winch speed remains constant
- Quasi (not reality) – the more likely scenario
- Tension member drag (friction)
  - directly proportional to the immersed length of the tension member
- Package drag
  - remains relatively constant (unless designed to change)
  - subtracts from the load on the tension member on pay out
  - adds to the load on pay in

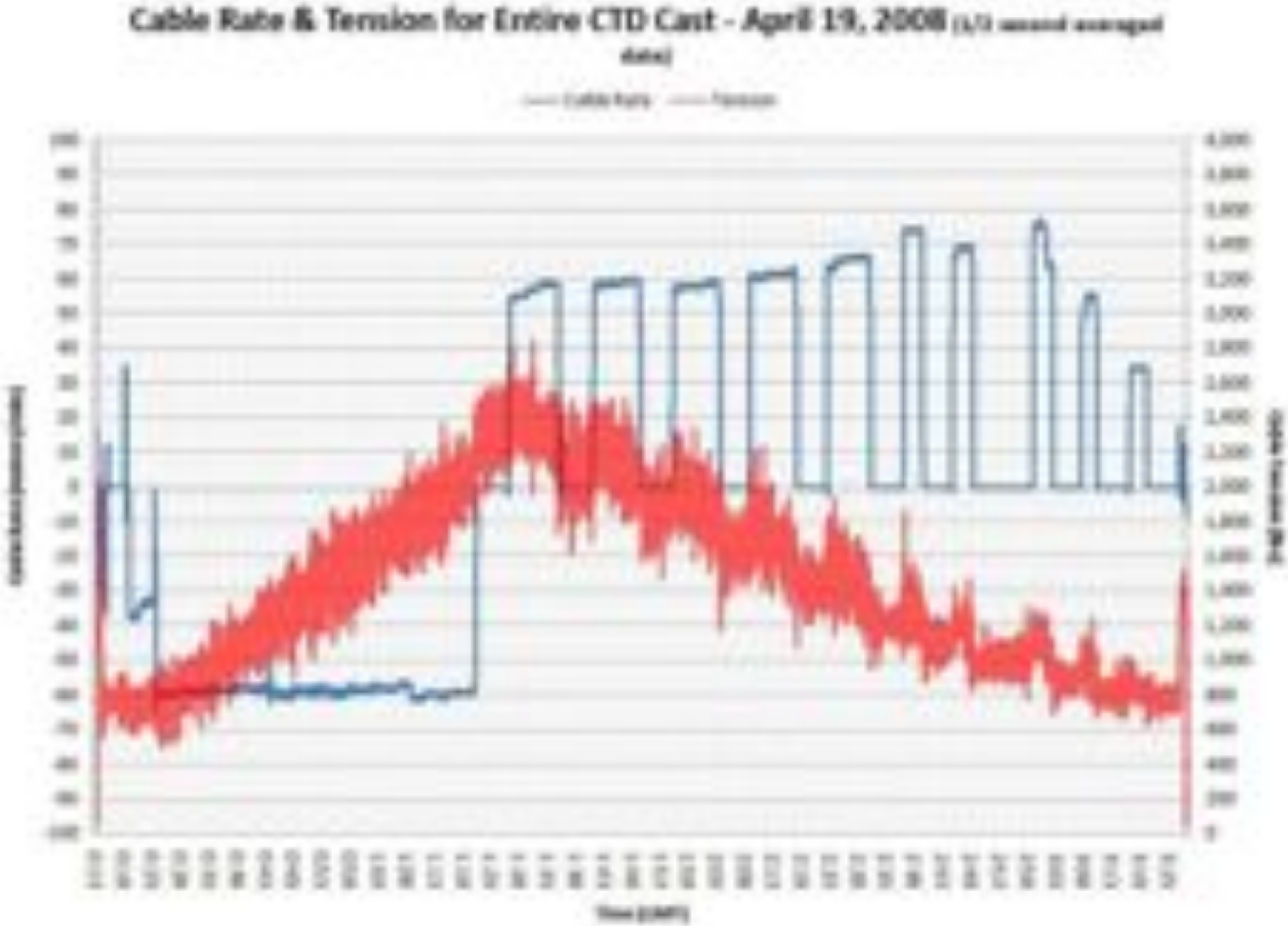
Dynamic Loads

- Load is induced by the motion of the overboarding sheave by the ship heaving, rolling and pitching.
- Dependent **on mass** of the overboard components **not the weight.** (Mass remains unchanged.)
- Weight = force
- Force = mass * acceleration
- Includes mass of entrained water
- Appendix A requires that in the absence of a way to measure the load on a tension member, that all load calculations be based on an acceleration of 1.75 (g=1.75).

Transient Loads

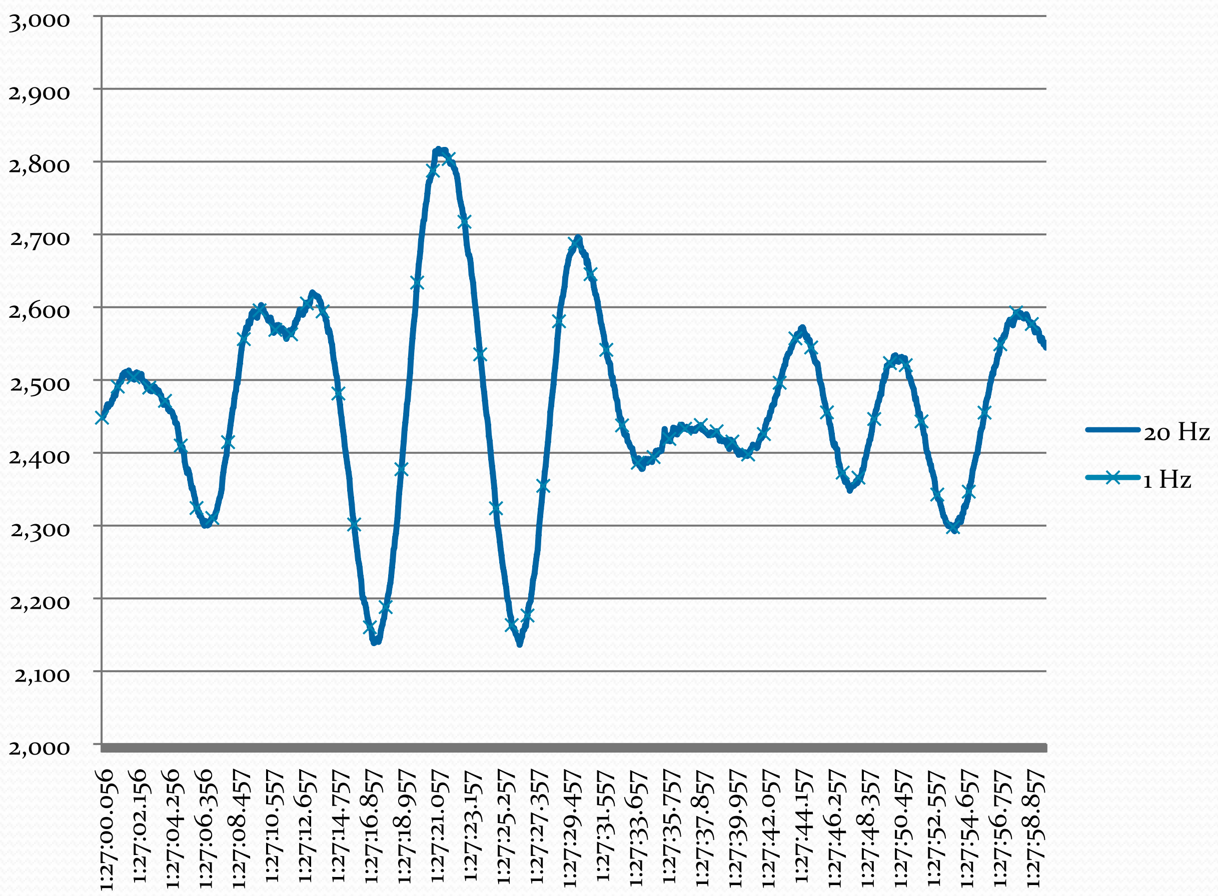
- Momentary load caused by an expected condition
  - Example: Pull-out of a corer.


Cable Rate & Payout for Entire CTD Cast - April 19, 2008
Cable Rate
Payout


Cable Rate & Tension for Entire CTD Cast - April 19, 2008 (1/1 second averaged data)
Cable Rate
Tension

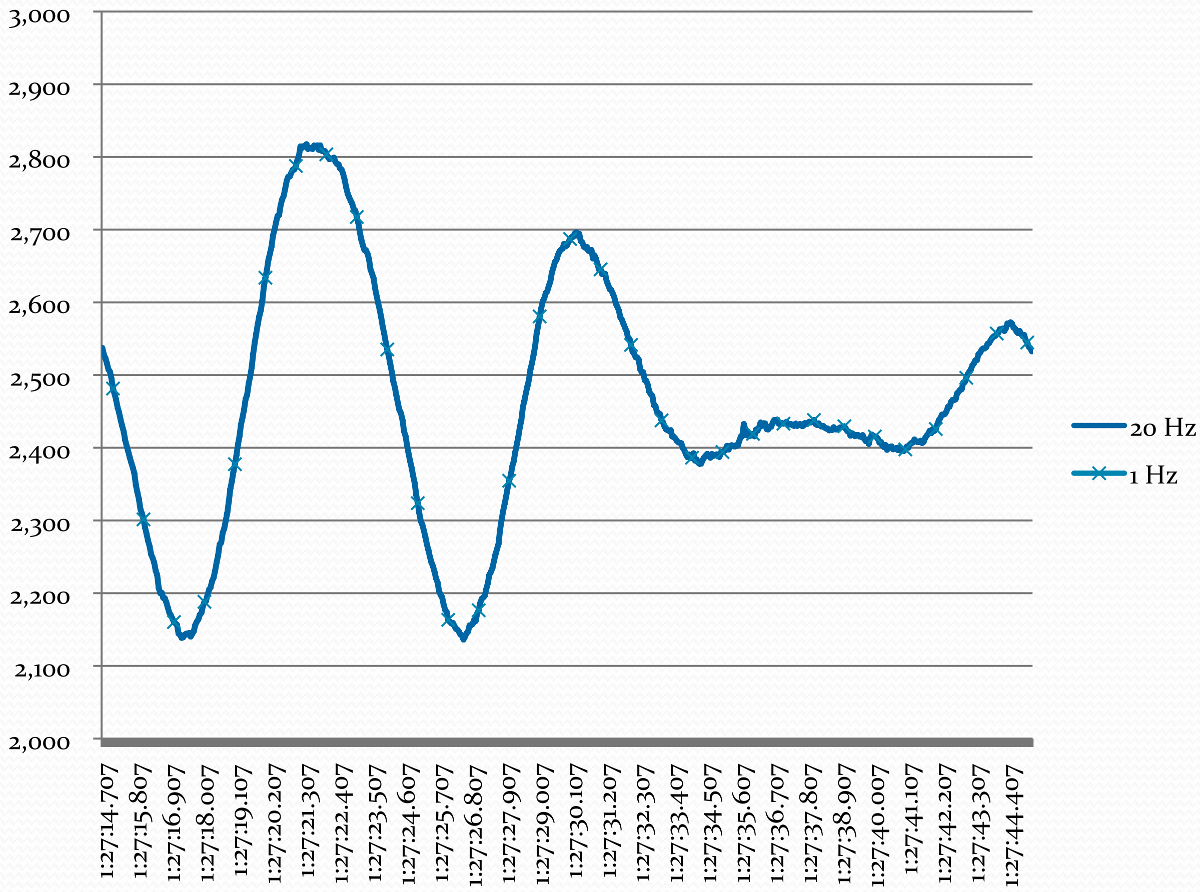

Payout & Tension for Entire CTD Cast - April 19, 2008

60 Seconds



3,000
2,900
2,800
2,700
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1:27:00.056
1:27:02.156
1:27:04.256
1:27:06.356
1:27:08.457
1:27:10.557
1:27:12.657
1:27:14.757
1:27:16.857
1:27:18.957
1:27:21.057
1:27:23.157
1:27:25.257
1:27:27.357
1:27:29.457
1:27:31.557
1:27:33.657
1:27:35.757
1:27:37.857
1:27:39.957
1:27:42.057
1:27:44.157
1:27:46.257
1:27:48.357
1:27:50.457
1:27:52.557
1:27:54.657
1:27:56.757
1:27:58.857
20 Hz
1 Hz

30 Seconds



3,000
2,900
2,800
2,700
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1:27:14.707
1:27:15.807
1:27:16.907
1:27:18.007
1:27:19.107
1:27:20.207
1:27:21.307
1:27:22.407
1:27:23.507
1:27:24.607
1:27:25.707
1:27:26.807
1:27:27.907
1:27:29.007
1:27:30.107
1:27:31.207
1:27:32.307
1:27:33.407
1:27:34.507
1:27:35.607
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1:27:37.807
1:27:38.907
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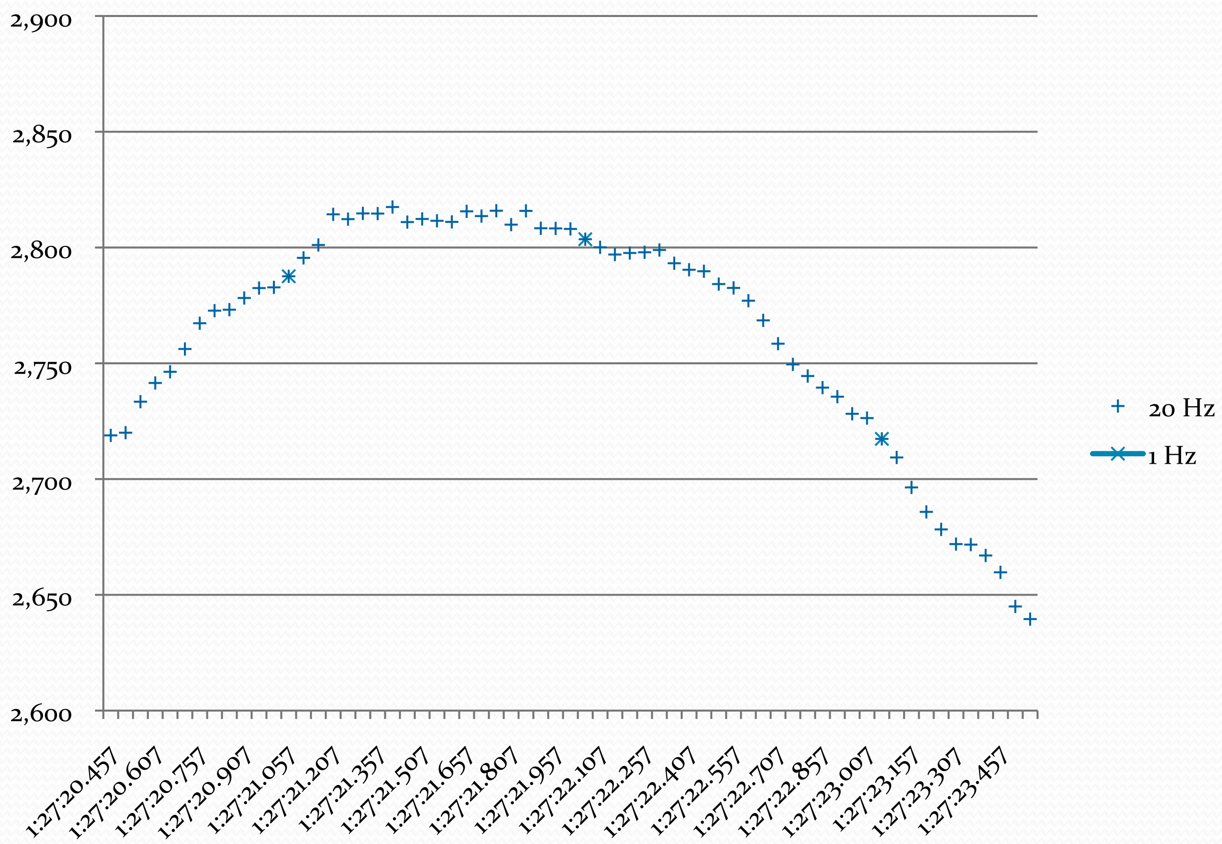
1:27:43.307
1:27:44.407
20 Hz
1 Hz

4 Seconds



2,900
2,850
2,800
2,750
2,700
2,650
2,600
1:27:20.457
1:27:20.607
1:27:20.757
1:27:20.907
1:27:21.057
1:27:21.207
1:27:21.357
1:27:21.507
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1:27:21.957
1:27:22.107
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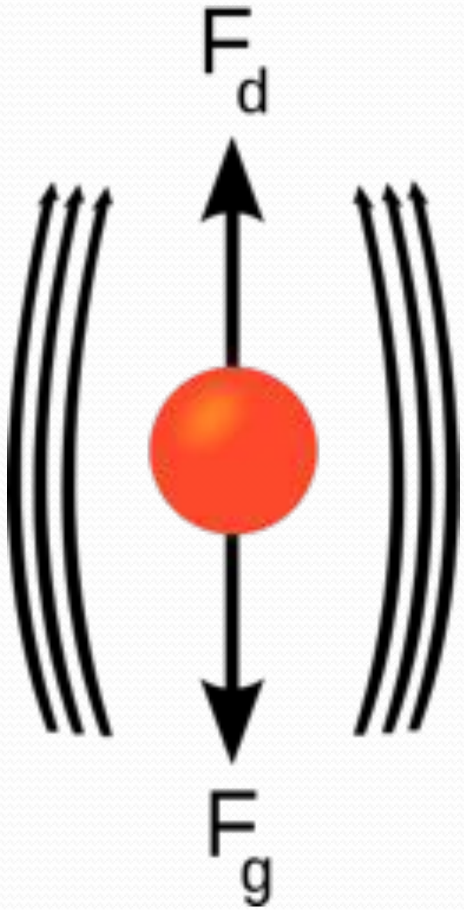
1:27:22.407
1:27:22.557
1:27:22.707
1:27:22.857
1:27:23.007
1:27:23.157
1:27:23.307
1:27:23.457
20 Hz
1 Hz

Terminal Velocity

- As the object accelerates (usually downwards due to gravity), the drag force acting on the object increases, causing the acceleration to decrease.
- At a particular speed, the drag force produced will equal the object's weight.
- At this point, the object ceases to accelerate altogether and continues falling at a constant speed called terminal velocity.
- Terminal velocity varies directly with the ratio of weight to drag. More drag means a lower terminal velocity, while increased weight means a higher terminal velocity.



Zero Load = Slack Conditions

- Caused when combined downward motion of the head sheave and the pay out rate of the winch exceed the terminal velocity of the package and/or the tension member
- Most likely to happen on the down roll of the ship
- Can happen in either direction
- Prelude to catastrophe
  - Can jump out of a sheave
  - May force tension member to un-lay
  - Stored torsional energy can cause one or a number of twisted loops (hockles)

Snap Loads = High peak load

- Happens right after slack tension member or near slack tension member conditions.
- Snap load can be 10x static load or greater.
- The tension member can be yielded in significantly less than a second.
  - Don't ignore momentary high tension alarms!!

What to do Before the Cruise

- Maximize the terminal velocity first by reducing drag of the package, add weight if necessary but be careful that you don't over do it
- Have an engineer analyze the system
  - Good place to start – Chapter 9 of UNOLS Winch and Wire Handbook
- Use an active compensation system
  - Ram tensioners (rough on tension member)
  - Bobbing booms
  - Controllable Winches
- Use a passive compensation system
  - A poorly designed spring system can actually make the slack and snap loading conditions worse.

What Can You do?

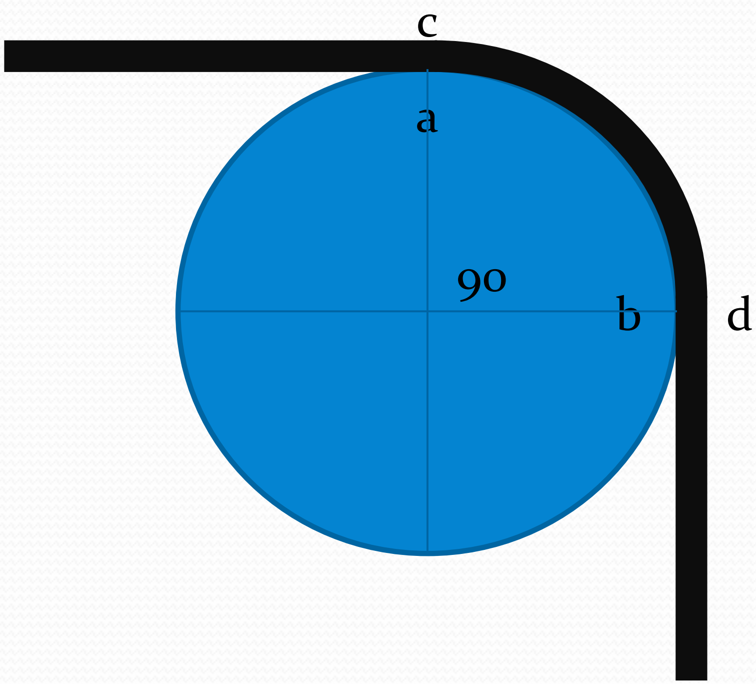
- Slow down on both up and down cast
- Minimize the ship motion
  - When working from the side, don't let the ship lay or fall into the trough
  - When working off the stern laying in the trough would be best for tension member loading
    - Dangerous due to rolling of the vessel
    - Could get helmsman keel hauled
    - Do what works best for your ship to minimize pitching
- Limit depth of deployment

Sheaves…

…and rollers

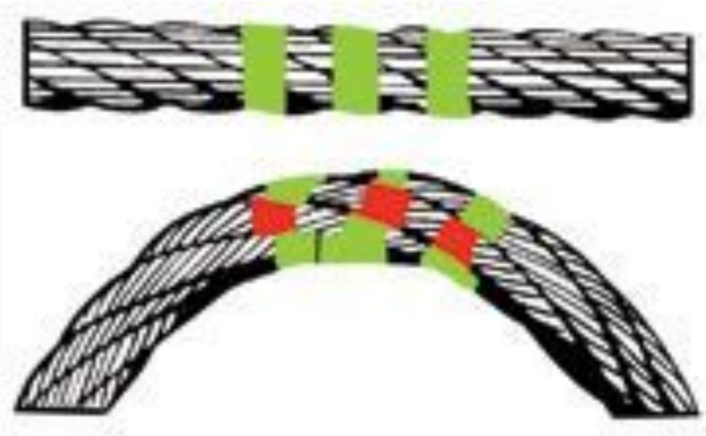
Round and round she goes where she stops nobody knows!

Tension Member Behavior in Bending (Simplified Explanation)



- The distance from ‘a’ to ‘b’ is less than the distance from ‘c’ to ‘d’.
- Therefore, the wires closest to the sheave are not loaded as much as the wires on the outside of the sheave.
- Stated differently, the wires on the outside are carrying most of the load.
- If the load is high enough, the wires on the outside yield, or stretch permanently and become thinner and weaker.

Sheave and Drum Diameter



This drawing graphically illustrates the movement of strands when wire rope is bent over a sheave or drum. Note that the marked area on the outer strands moves as the outer wires elongate and inner wires compress.

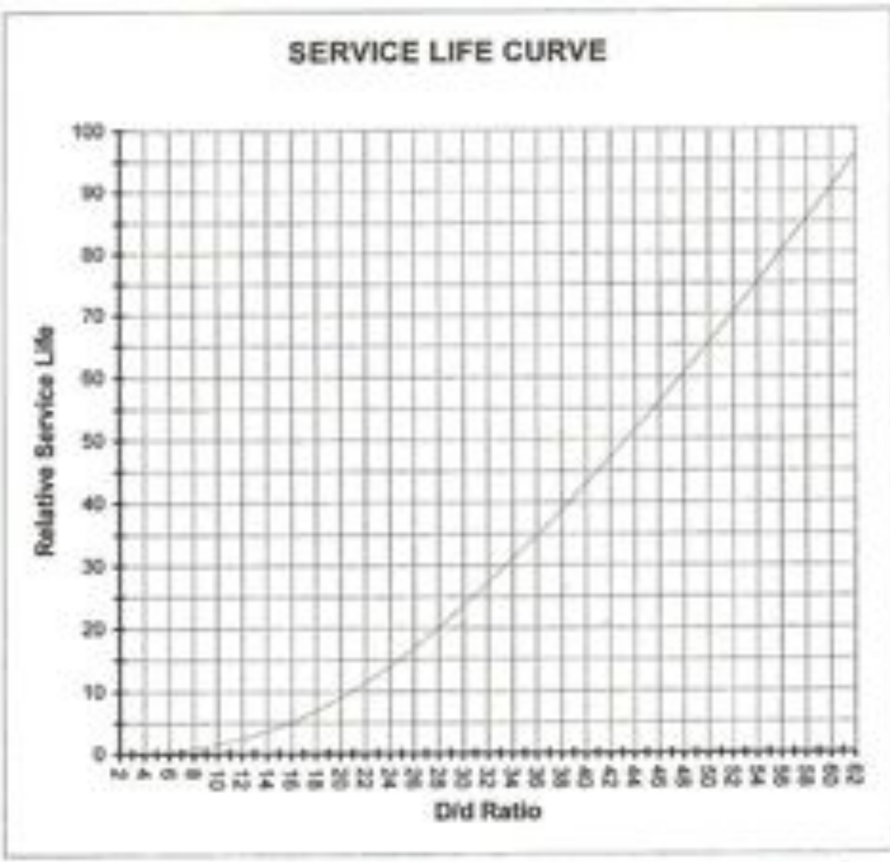
Sheave Definitions

- “D” = The root (sometimes referred to as tread or thread) diameter of the sheave.
- “d” = The outside diameter of the cable or rope.
- "d_1" = For cable the largest diameter wire in the armor wires. For wire rope the largest of the outer wires.
- “w” = The width of the sheave groove supporting the sides of the wire or cable.

Sheave and Drum Diameter (cont.)

- All wire ropes operating over sheaves and drums are subjected to bending stresses, which eventually cause the wire rope to fatigue.
- The severity of these stresses are directly related to the rope load and the D/d ratio, or the ratio of the tread diameter of the sheave or drum (D) to the diameter of the rope (d).
- In order to bend around a sheave or drum, the rope's strands and wires must move in relation to one another to compensate for the bend.
- The wires on the top side of the rope elongate while the wires on the underside compress.
- Simply put, the top side has farther to travel around the sheave then the underside.
- This continual shifting causes the inner wires to move against one another when the rope is under load.
- If the sheave or drum is too small, causing a severe bend in the rope, wire movement is adversely affected because the wires cannot easily move to adequately compensate for the bend.
- Fatigue breaks, high stranding, looped wires, and eventually failure will result.

Service Life based on D/d

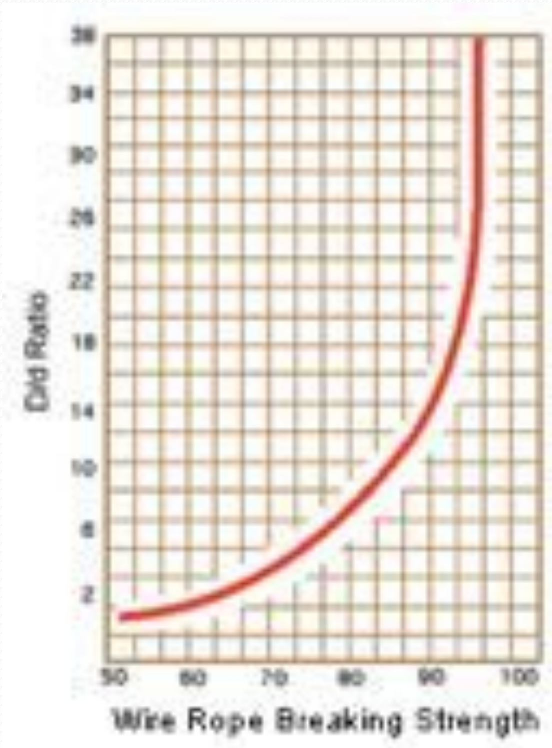


- Graph shows the effect of sheave size on service life.
- Assume that a 1” tension member is used over a 16” sheave, D/d=16.
- From the graph the relative service life would be 5.
- Now assume the same tension member is used over a 40” sheave, D/d=40.
- From the graph the relative service life would be 43.
- This means that the increase in service life would be 43/5 = 8.6.

Performance Over a Rolling Sheave

- When a steel tension member passes over a rolling sheave, up to a 30% reduction in breaking strength can occur
- For a tension member with a nominal breaking load of 10,000 lbs., this would be a reduction in strength of 3,000 lbs. leaving a theoretical breaking load of 7,000 lbs.
- Using a FS of 1.5 on this example tension member, the Safe Working Load equals 6,667 lbs (10,000/1.5 =6,667) – or a reduction of 3,333 lbs. – just above the reduction in strength anticipated.
- Since all oceanographic tension members pass over at least one sheave, this is the primary argument for not exceeding a FS of 1.5.

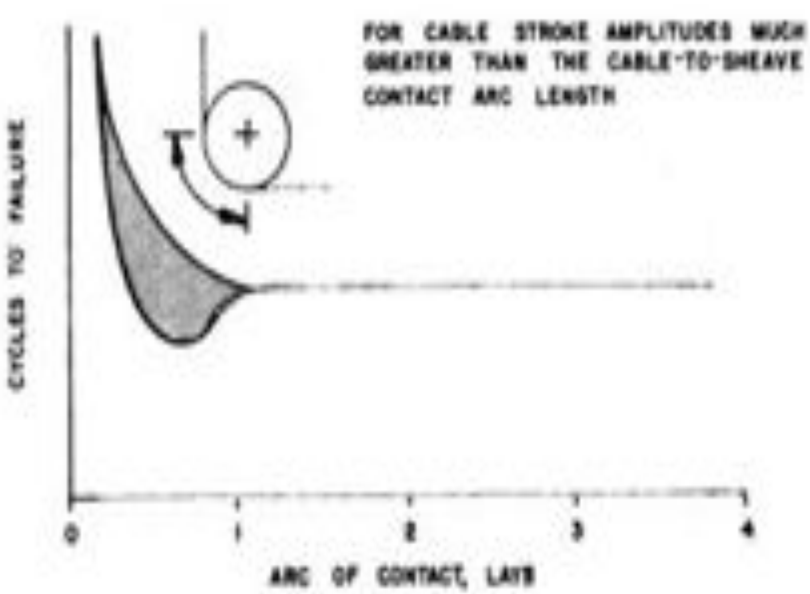
Breaking Strength Based on D/d



- This graph is based on a non – rotating bend, i.e. the sheave or roller is not turning.

- Note that with a small roller, you reduce the breaking strength by 50%.

Effect of Sheave Contact Arc on Bending Fatigue Life



- For typical deployment and retrieval operations, the bending fatigue life of a cable is not influenced by the wrap angle on a sheave as long as at least one lay length of the tension member is in contact with the sheave.
- Tension members which are deployed and retrieved through a series of fairlead sheaves will have a bending fatigue life which will be the same regardless of the tension member wrap angles on the sheaves, at least for contact arcs equal to one or more lay lengths of the strength members.
- For a contact arc of less than one lay length, the bending fatigue damage produced by a sheave is typically less, but there are notable exceptions to this rule.
- Depending on the specific tension member design, the sheave-to-cable diameter ratio, and the operating tension, a cable contact arc of one-half lay may be more damaging than a longer contact arc.
- One of the important conclusions which can be drawn from these considerations is that a sheave diameter should not be arbitrarily reduced just because a cable happens to have a relatively small wrap angle on that sheave.
- A single, small deflection sheave or roller can produce more cable damage than all of the other sheaves in the fairlead system.
- Even worse is the replacement of a sheave with a series of small rollers in the interest of saving space.
- This procedure can quickly destroy a cable which supports any significant tensile load.

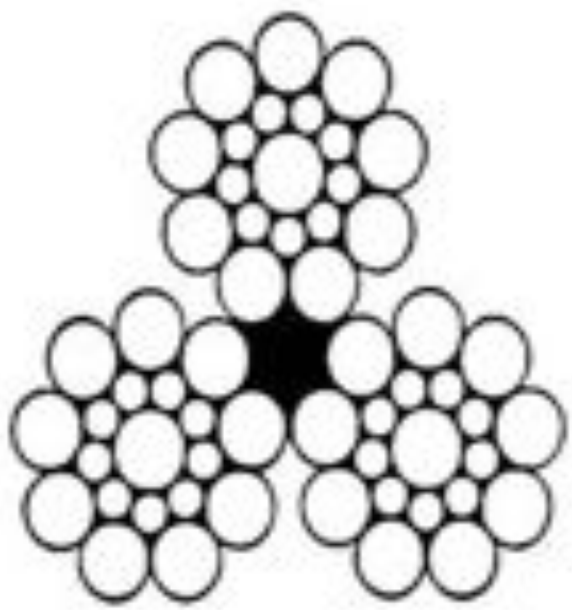
Wire Eater

Current

Minimum Sheave Diameter for UNOLS Tension Members

Tension Member Description	Manufacturer's Recommendation Diameter	Tension Member Diameter D	Wire Diameter d1	Minimum Sheave Diameter d x 40	Minimum Sheave Diameter d1 x 400
¼" 3x19	12.4"	.250"	.0375"	10.00"	15.00"
½" 3x19	23.2"	.500"	.071"	20.00"	28.40"
9/16" 3x19	26.4."	.563"	.080"	22.50"	32.00"
.322"	12"	.322"	0.0375"	12.88"	15.00"
.680"	28"	.680"	0.060"	27.20"	24.00"
.681" @ 10,000 lbs.	28"	.681"	0.049"	27.24"	19.60"
.681" @ 14,000 lbs.	48"	.681"	0.049"	27.24"	19.60"

3 x 19 Rope Construction (review)



3x19
Seale

- The center core wire in each stand is actually the largest wire in the 3 x 19 wire ropes used by UNOLS.
- The original text in Appendix A caused the sheaves requirements to be larger than needed.

Proposed Changes to Appendix A

Limit	Current	Proposed
5	The D/d ratio must be equal to or greater than the manufacturer's recommendations	The sheave diameter must be at least equal to or greater than the manufacturer's recommendations
2.5	The D/d ratio must be at least 40:1 or 400d1 (whichever is greater) throughout. Grooving of the sheaves should be as close to "d" as practical, and generally no larger than 1.5d	The sheave and roller diameter(s) throughout should be equal to or greater than the larger of either: the manufacturer's recommendation; 40 x d; or 400 x d1 (use the largest). Grooving of the sheaves should be as close to "d" as practical, and generally no larger than 1.5d
2	The D/d ratio must be at least 40:1 or 400d1 (whichever is greater) throughout. Grooving should be per Ref A.1.1, Chapter 1, and Section 11.0 to provide adequate support.	The sheave and roller diameter(s) throughout should be equal to or greater than the larger of either: the manufacturer's recommendation; 40 x d; or 400 x d1 (use the largest). Sheave grooving should be per Ref A.1.1, Chapter 1, and Section 11.0 to provide adequate support.
1.5	The D/d ratio must be at least 40:1 or 400d1 (whichever is greater) throughout. Grooving should be per Ref A.1.1, Chapter 1, and Section 11.0 to provide adequate support.	The sheave and roller diameter(s) throughout should be equal to or greater than the larger of either: the manufacturer's recommendation; 40 x d; or 400 x d1 (use the largest). Sheave grooving should be per Ref A.1.1, Chapter 1, and Section 11.0 to provide adequate support.

d1	d1" = The diameter of largest single strand wire in a rope or cable armor.	"d1" = For cable the largest diameter wire in the armor wires. For wire rope the largest of the outer wires.

Proposed
Minimum Sheave Diameter for UNOLS Tension Members

Tension Member Description	Manufacturer's Recommendation Diameter	Tension Member Diameter D	Largest Wire Diameter d1	Minimum Sheave Diameter d x 40	Minimum Sheave Diameter d1 x 400
¼" 3x19	**12.4"**	.250"	.0375"	10.00"	**12.4"**
½" 3x19	**23.2"**	.500"	.071"	20.00"	**23.2"**
9/16" 3x19	**26.4"**	.563"	.080"	22.50"	**26.4"**
.322"	12"	.322"	0.0375"	12.88"	**15.00"**
.680"	**28"**	.680"	0.060"	27.20"	24.00"
.681" @ 10,000 lbs.	**28"**	.681"	0.049"	27.24"	19.60"
.681" @ 14,000 lbs.	**48"**	.681"	0.049"	27.24"	19.60"

Good To Remember!

- The larger the sheave or drum diameter, the better the tension member fatigue and breaking strength performance.

Bending Cycle Fatigue Tests

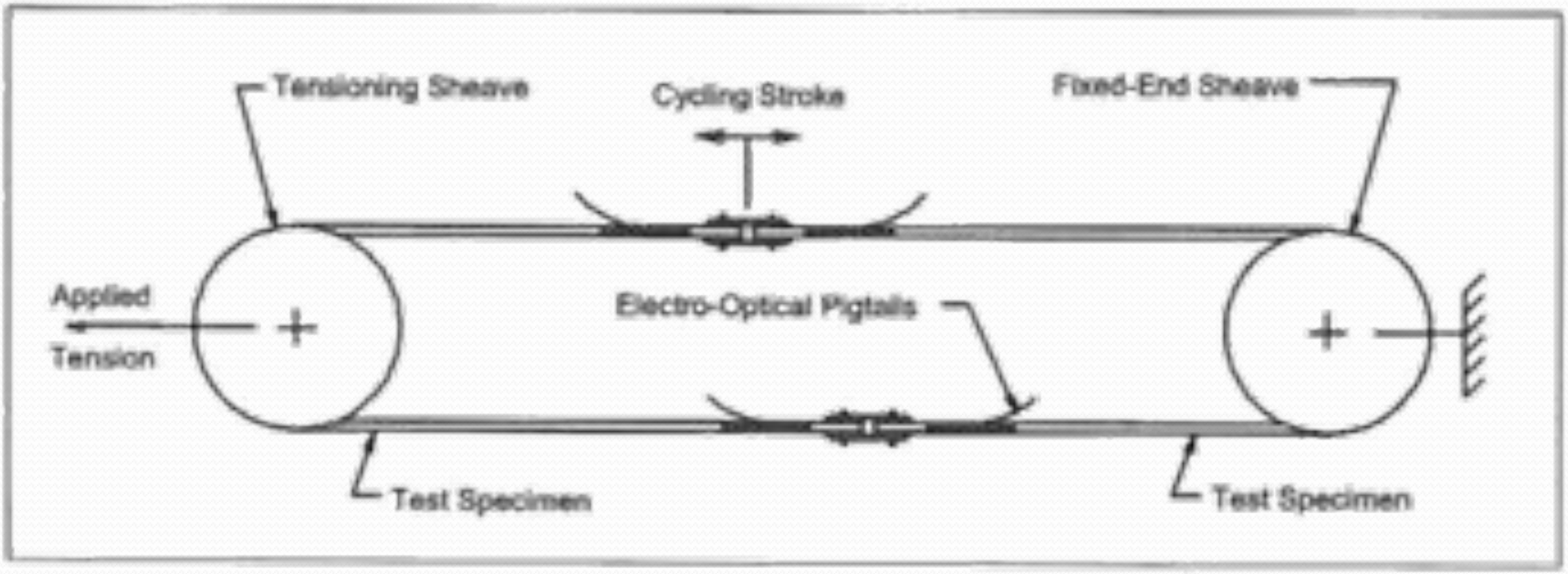
- Completed to assess the bending fatigue performance of new 9/16” Trawl wire

This report was done by Rick Trask at WHOI

Bending Fatigue Tests

- Testing conducted by Tension Member Technology (TMT) under the direction of Phil Gibson
- Results obtained in late 2008
- What was tested?
  - 9/16" diameter 3x19 Torque Balanced wire rope
  - Wire rope from WireCo World Group (current supplier of majority of wire pool 3x19 wire rope)
  - Test samples taken from a 1500 ft. continuous length that was part of a 90,000 ft. wire rope order currently in wire pool inventory
  - Individual test pieces cut and terminated by TMT

CBOS Fatigue Test Apparatus

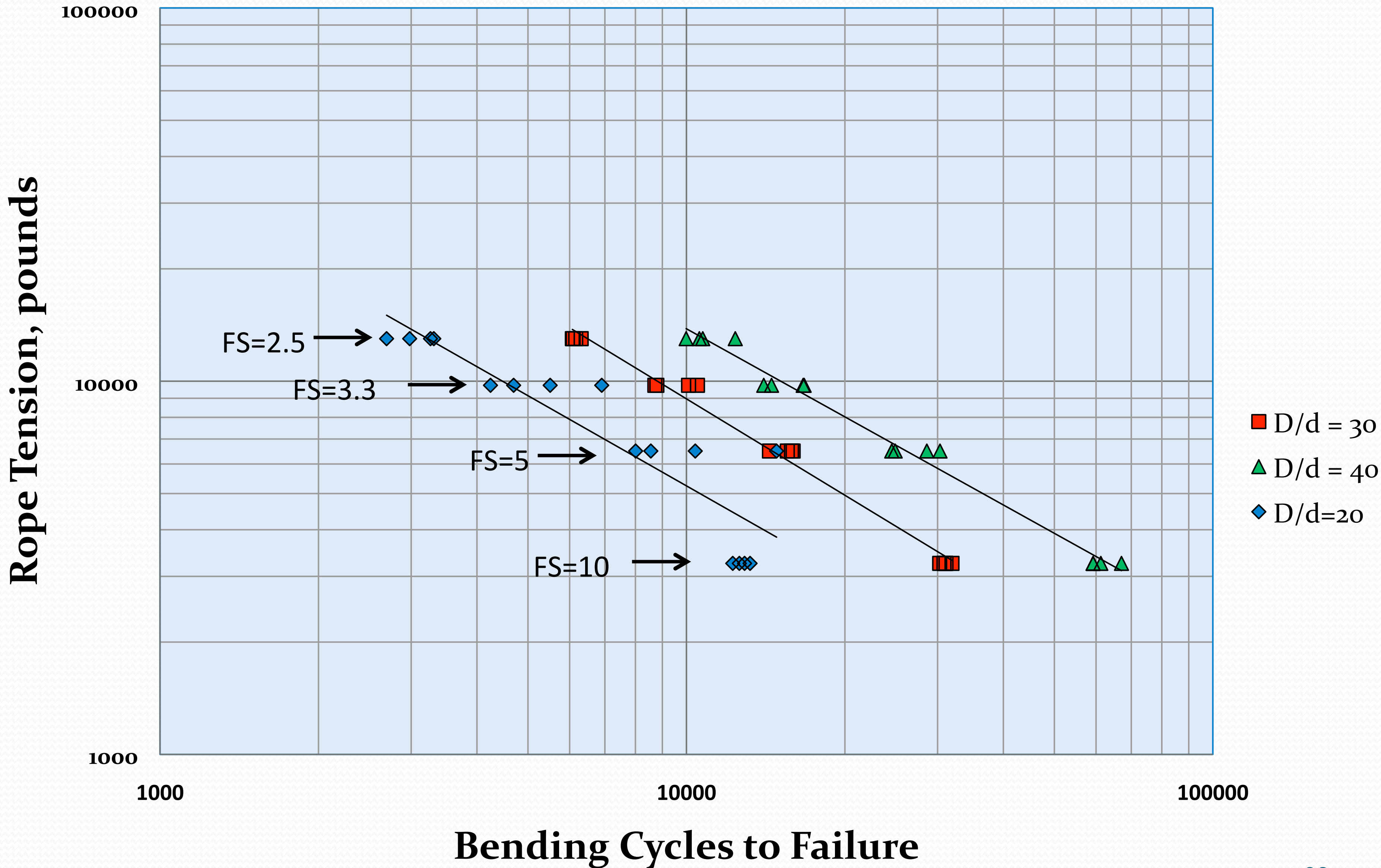


- Two samples tested at a time over pair of identical sheaves.
- Rope tension applied by hydraulic cylinder and monitored by strain gauge load cell.
- Samples were cycled back and forth over the sheaves using a variable speed electric motor attached to fixed end sheave

Test Parameters

- Tests conducted on pairs of sheaves of three specific diameters so as to simulate three D/d ratios.
  - D/d=20, 11.3" sheave tread diameter
  - D/d=30, 16.9" sheave tread diameter
  - D/d=40, 22.5" sheave tread diameter
- For each of the three D/d sheave configurations, tests conducted at four Factors of Safety (FS).
  - FS of 10 or 10% of Rope NBL of 32,500 which is 3,250 lbs.
  - FS of 5.0 or 20% of Rope NBL of 32,500 which is 6,500 lbs.
  - FS of 3.3 or 30% of Rope NBL of 32,500 which is 9,848 lbs.
  - FS of 2.5 or 40% of Rope NBL of 32,500 which is 13,000 lbs.

9/16" 3x19 Wire Rope
Bending Fatigue Life vs Tension



Test Phase 2

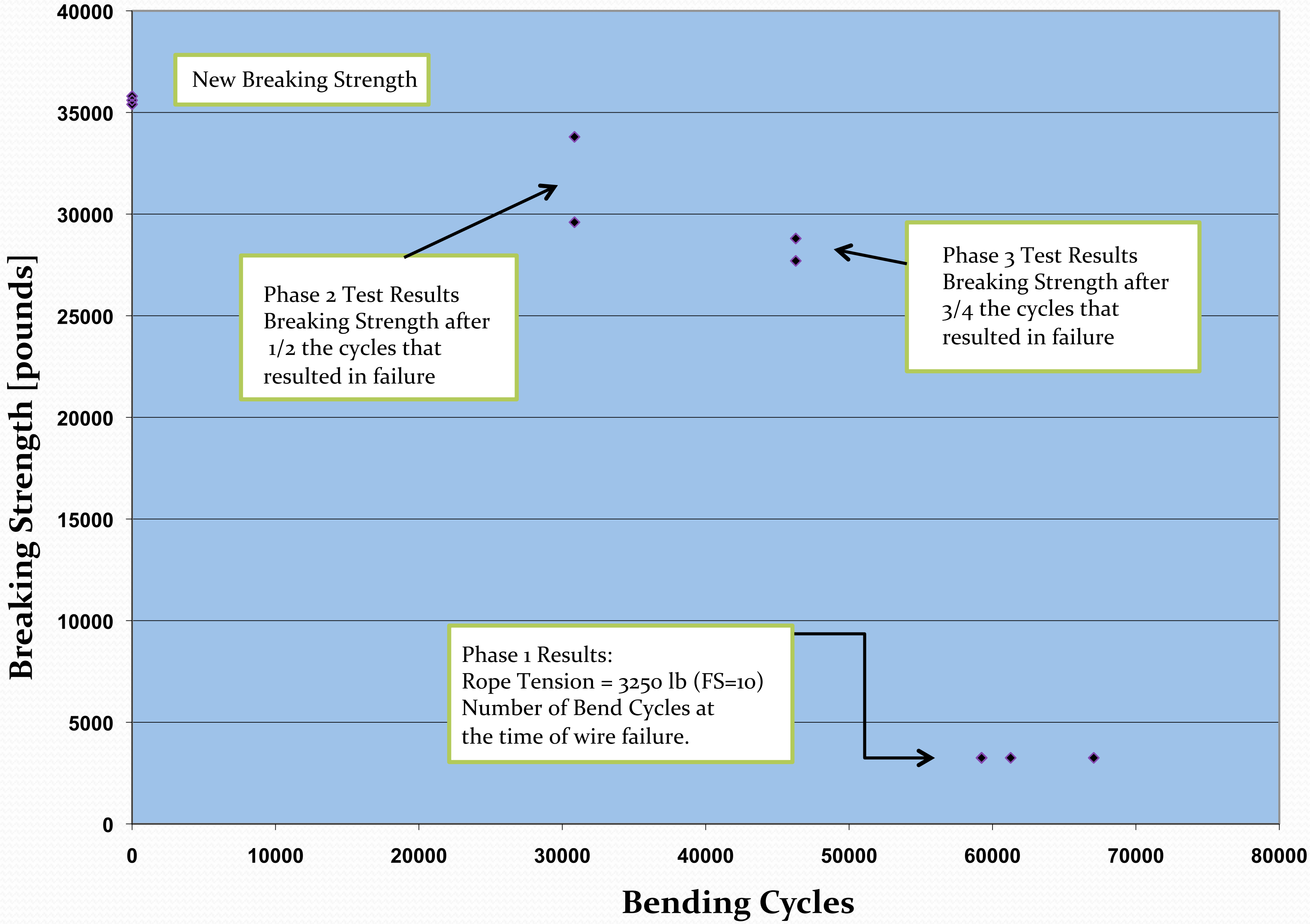
- Test set up was the same as that for Phase 1.
- Tests were stopped at the **half life** of the rope samples as determined in the previous tests (bend cycles to failure from Phase 1 divided by 2).
- Each of the samples was then pulled to failure in order to determine the rope's residual breaking strength at the half life point.

Test Phase 3

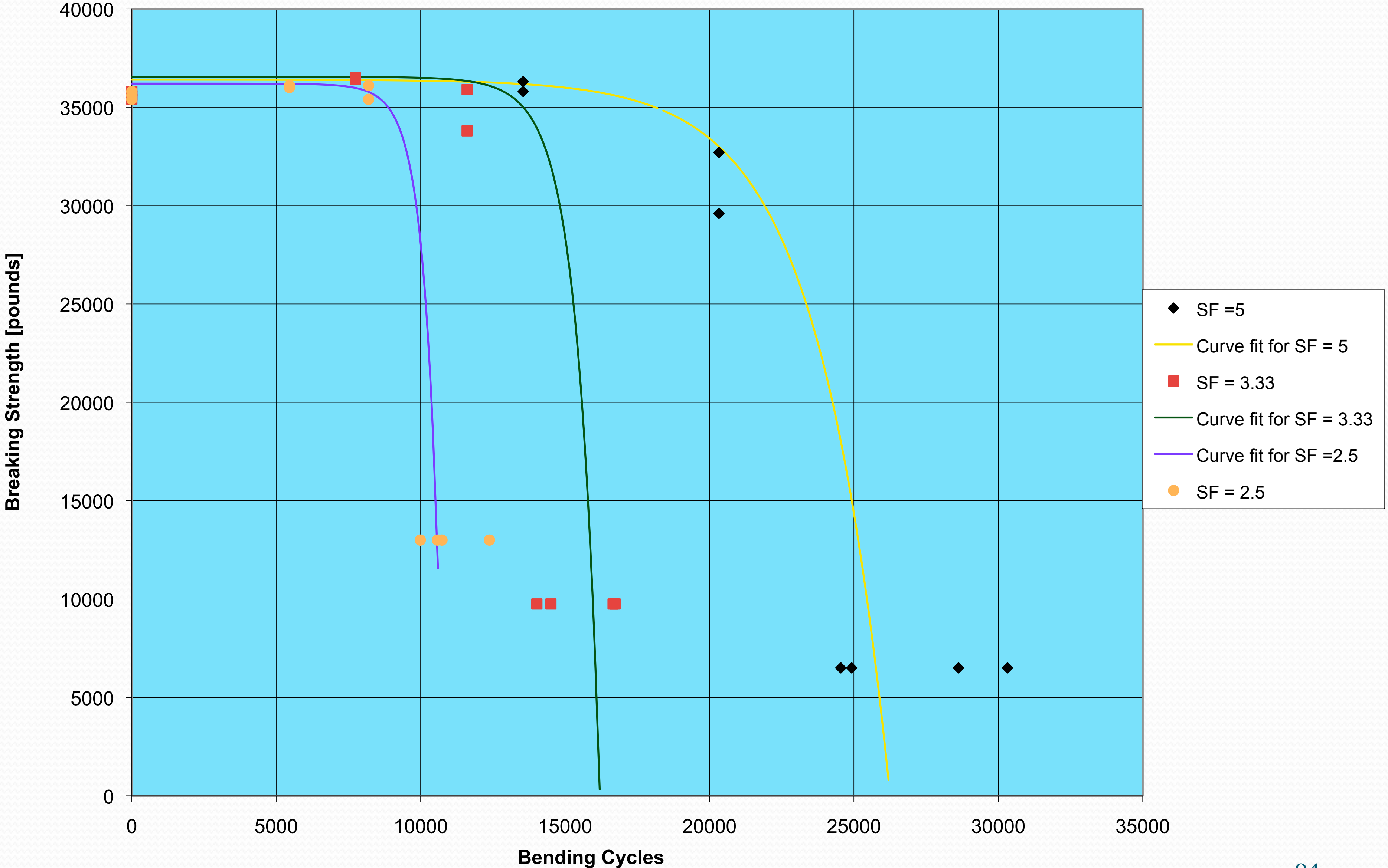
- Same as Phase 2, except the test was stopped at **three-fourths** of the life of the rope samples as previously determined by the Phase 1 test.

- Each of the samples was then pulled to failure in order to determine the rope's residual breaking strength at the three-fourth's life point.

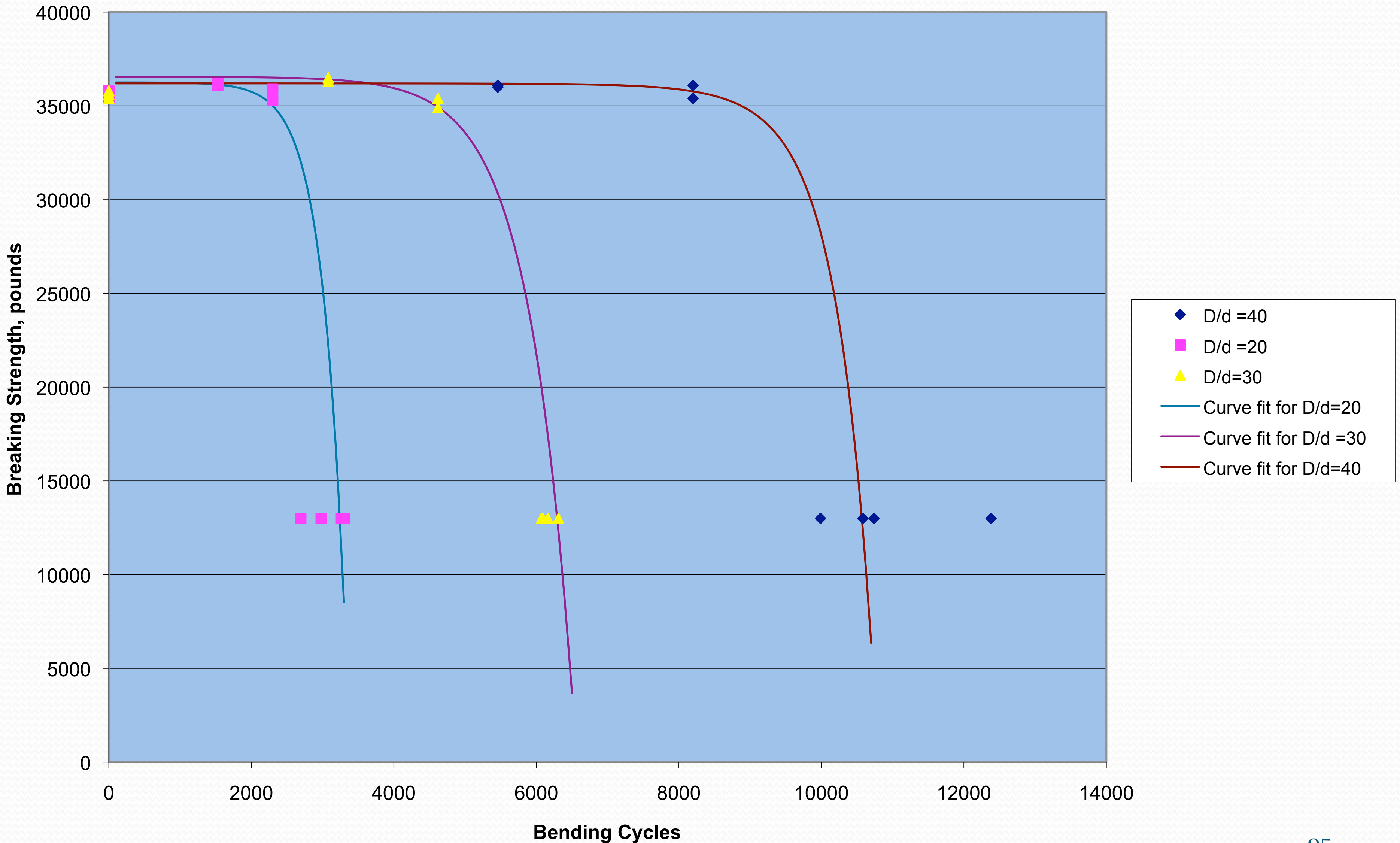
D/d =40, FS=10, Residual Breaking Strength vs Bending Cycles



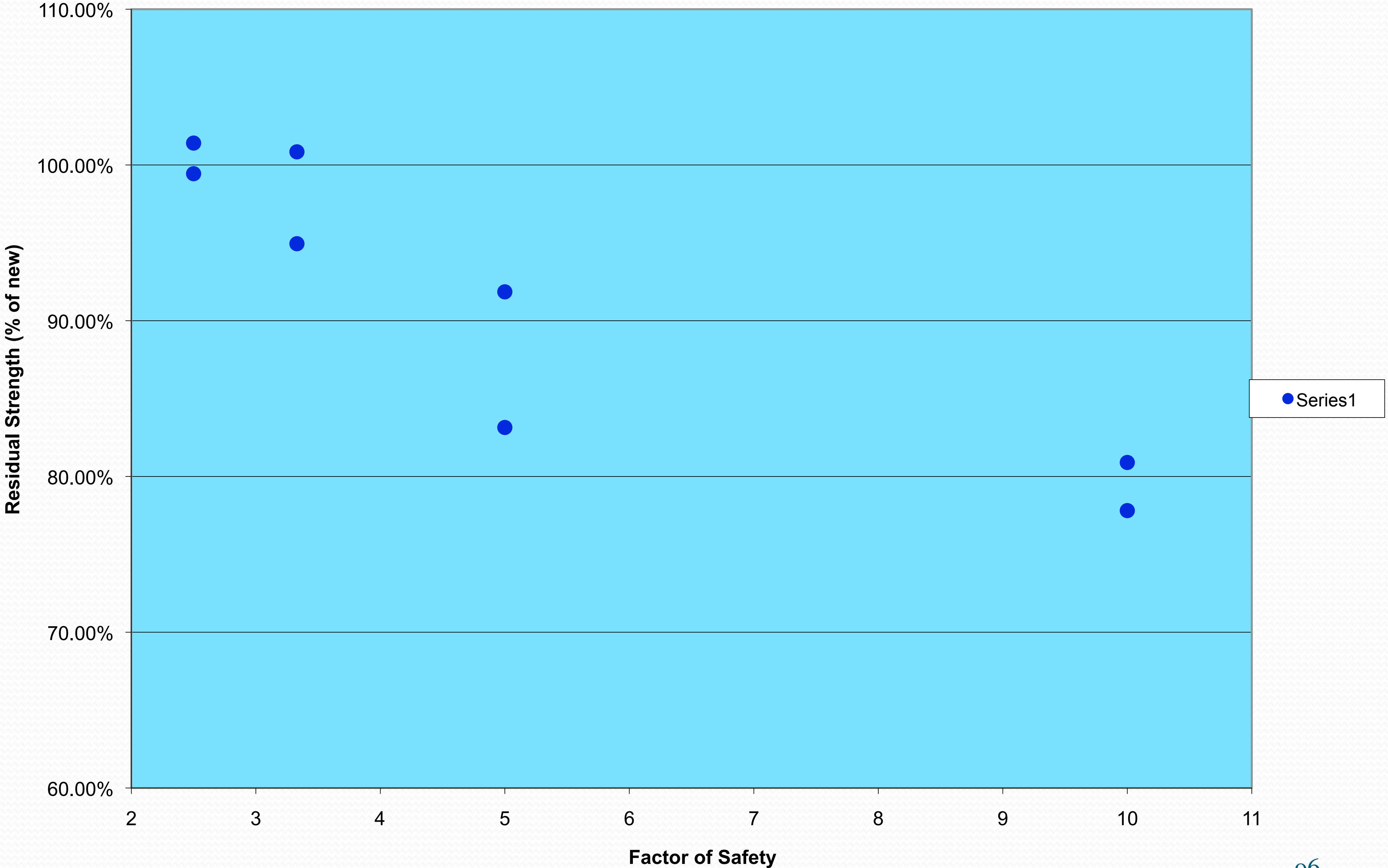
D/d=40, SF=5.0, 3.33 and 2.5
Residual Breaking Strength vs Bending Cycles



Safety factor of 2.5, Residual Breaking Strength vs Bending Cycles for D/d =20, 30, and 40



Residual Breaking Strength (% of new) vs Safety Factor At 3/4 Life



Life Factor

$$\text{Life Factor} = FS(D/d)$$

FS = Factor of Safety

D= Sheave Diameter

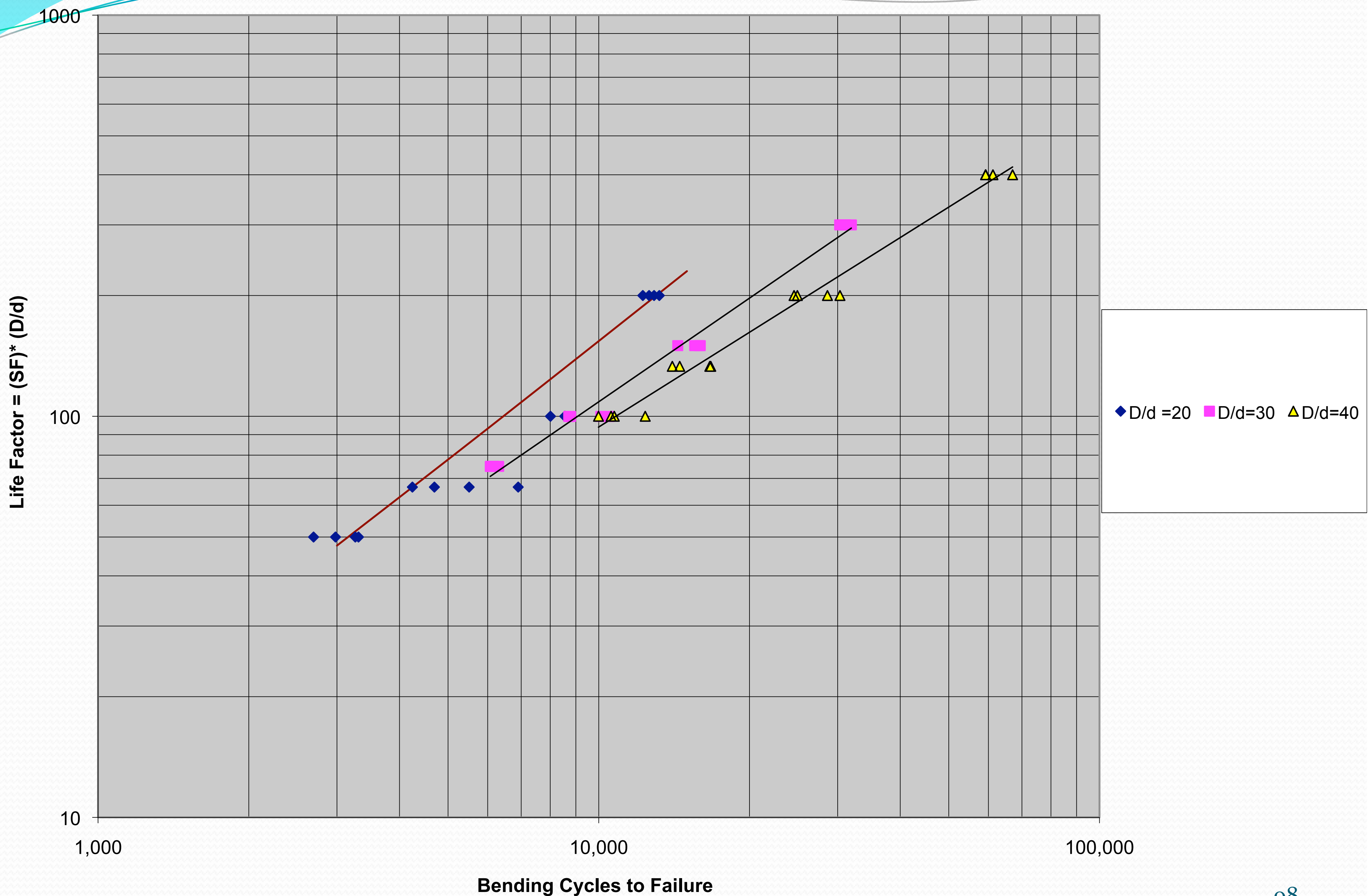
d = rope diameter

Therefore:

- Configurations resulting in large values for Life Factors would be associated with large Factors of Safety and large sheave diameters which presumably results in a longer wire life.

- Configurations with small Life Factors (Short life) would be associated with small Factors of Safety and small sheave diameters.

9/16 inch Diameter 3x19 Wire Rope, Bending Fatigue Life vs Life Factor



Summary of Bending Cycle Fatigue Test

- Residual breaking strength of 3x19 rope drops abruptly after a certain number of accumulated bending cycles, especially when operating with small Factors of Safety (high tensions).

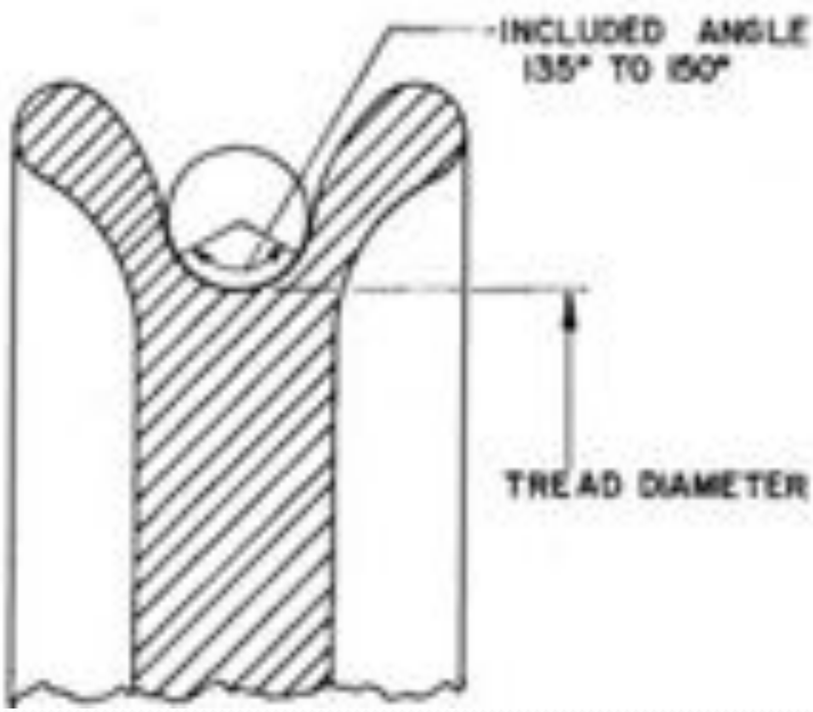
- The tension member may provide little evidence of impending fatigue failure. In effect, this complicates the application of meaningful retirement criteria based on visual inspections.

Reverse Bending

- Reverse bending can decrease the resistance to fatigue bending by 2 to 10 times the usual indicative figures for single bending.
- A permanent distance of less than 10-12 lay lengths between the two respective tangential contact points can be considered as critical.
- The classic 3 sheave level wind is a prime example of what not to do!

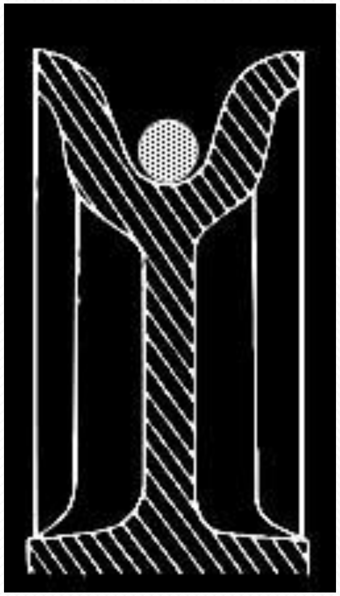
Sheave Width

Sheave Width (w)

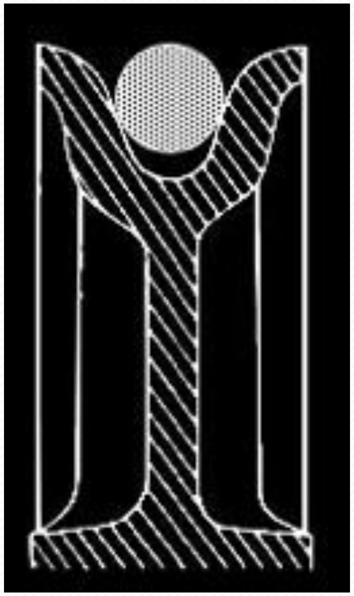


- A sheave that is too wide will allow the cable to flatten
- A properly designed sheave will support the tension member through an included angle of 135-150 degrees.

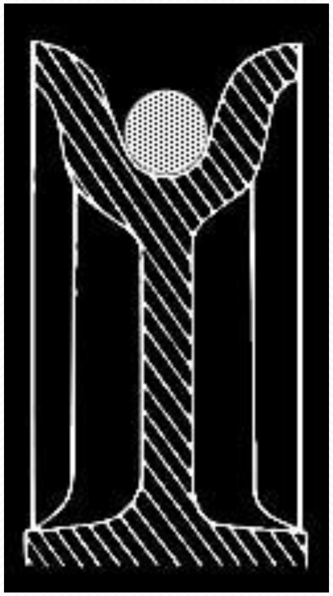
Proper Sheave Width



Too Large
Tension Member
is Unsupported



Too Narrow
Tension Member
Is Pinched



Correct Match

Worn Sheave

- The sheave profile on the right is of a worn groove.
- The “shoulders”, as indicated by the arrows, should be machined to prevent wear of the tension member.

Sheave Gauges

- Sheave gauges come in sets.
- Note that in the picture the sheave is too wide.

Examples of improper groove width

- Sheave in rear appears to be correct width but appears to be supporting rope almost 180 degrees with rubbing on side of sheave.

- Forward sheave only provides support of cable for ~ 100 degrees.

Wire Spooling

Tension Member Spooling Objectives

- Tightly thread-lay the cable under tension to ensure that the cable cross-section has resistance to crushing.
- Provide sufficient rigidity of cable in lower layers to prevent nestling, or “keyseating”, of the tension coil.
- Provide sufficient spooled tension to balance some of the deployment tensions to reduce coil slippage caused by tightening of the tension coil.

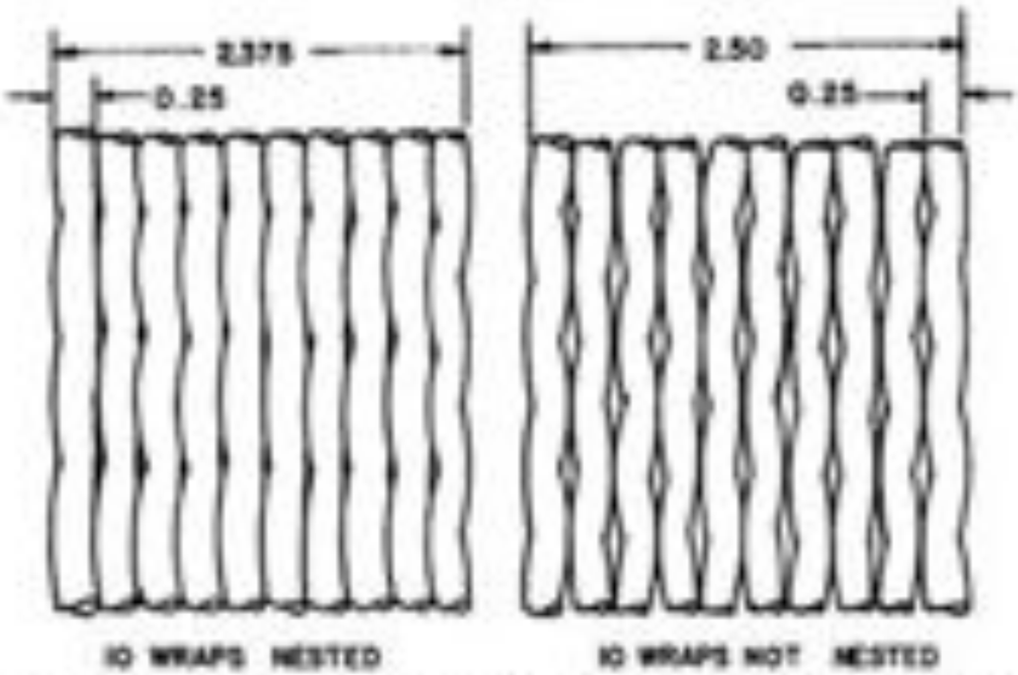
Smooth Drum Spooling

- Smooth drum spooling uses a plain cylindrical winch drum. It is most commonly used on small oceanographic winches containing 1,000 to 2,000 meters of tension member and Factors of Safety greater than 5.

- Because of the low deployment forces involved, the spooling onto these winches is less critical.

- Good practice dictates that a uniform thread-lay be used.

Smooth Drum Spooling (cont.)

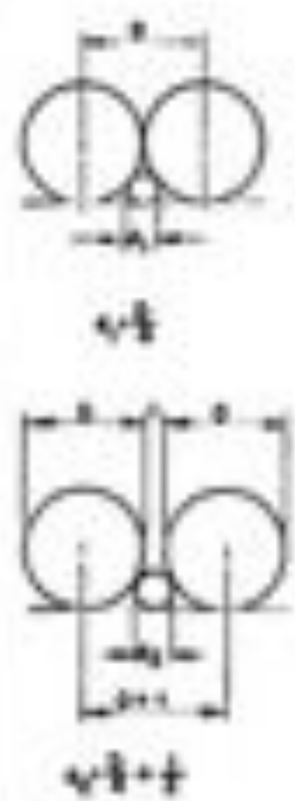


EFFECT OF ROPE NESTING ON SMOOTH FACED DRUM

- The object is to space the turns evenly across the drum without causing nesting.
- Measure width between flanges at drum.

Smooth Drum Spooling (cont.)

Nom Rope Dia. [in.]	Construction	Calculated Rope Dia. [in.] D	Spacing Tolerance t	d_1 [in.]	d_2 [in.]
5/32	3 x 7	.173	1/32	.043	.059
11/64	″	.190	″	.0457	.063
3/16	″	.205	″	.051	.067
7/32	″	.233	″	.058	.074
1/4	″	.268	″	.067	.083
5/16	″	.328	″	.082	.097
3/8	″	.395	″	.099	.111
7/16	″	.458	″	.116	.130
1/2	″	.523	″	.131	.146
9/16	″	.589	″	.147	.163
11/64	3 x 19	.190	″	.0475	.063
3/16	Seale	.205	″	.051	.067
7/32	″	.236	″	.059	.075
1/4	″	.265	″	.066	.082
5/16	″	.328	″	.082	.098
3/8	″	.392	″	.098	.114
7/16	″	.460	″	.115	.131
1/2	″	.522	″	.1305	.146
9/16	″	.586	″	.1465	.162
5/8	″	.647	″	.162	.177



- Determine how many full wraps can be accommodated with spacing from center to center of wrap being from d1 to d2 inches.
- The closer to d1 the better the spooling.

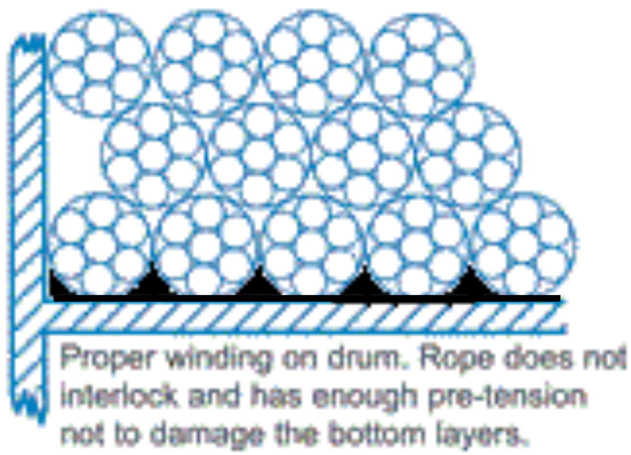
Smooth Drum Spooling (cont.)

- Insert filler ($d_1 <= d_2$) simultaneously as bottom layer is spooled onto the drum.
- Practically anything can be used as a filler, but steel strands or IWRC ropes are preferred.
- The bottom layer must be tight.
- If a whole number of wraps cannot be accommodated on the bottom layer, a filler or spacer should be added to the flange.
- After placing the bottom layer, spooling can proceed in normal fashion for a parallel grooved drum.

Grooved Drum (Lebus Shell) Spooling

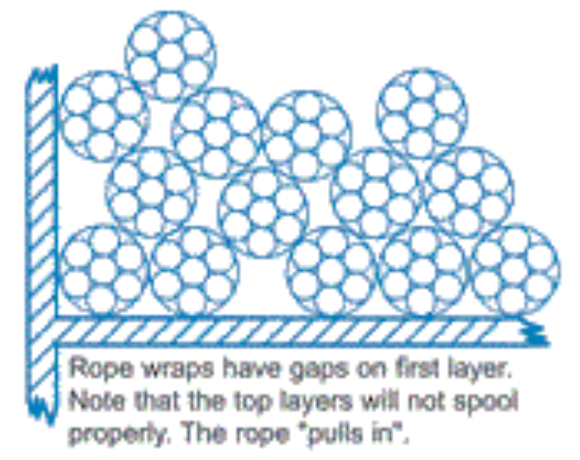
- The Lebus shell is essentially a grooved cylinder, manufactured from either steel, aluminum or fiberglass, that is designed to assure the proper seating of a specific rope or cable and the proper movement and spacing of that wire between the flanges of the winch drum.
- In order to effectively use the Lebus shell, the winch drum must have flanges that are perpendicular to the barrel, or core, of the smooth winch drum. When delivered, the shells are split for easy installation on the winch or take-up spool.
- Attachment can be accomplished by either welding or bolting the shell in place.
- It is recommended that the bolt-on technique be used when winch systems utilize more than one size of wire or cable during their operational life.
- Except in special situations, most research winches **NEED** this shell.

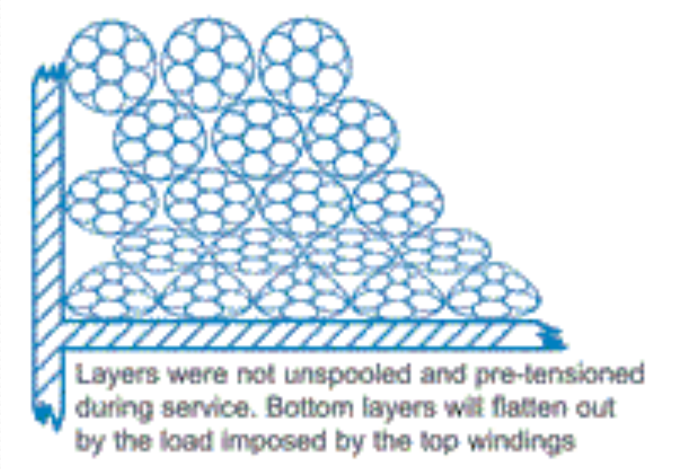
Tension Member Spooling



- This what we want to obtain.
  - Typically can only be obtained with a Lebus shell
- This is what you get without a Lebus shell or filler wires.

Tension Member Spooling (cont.)



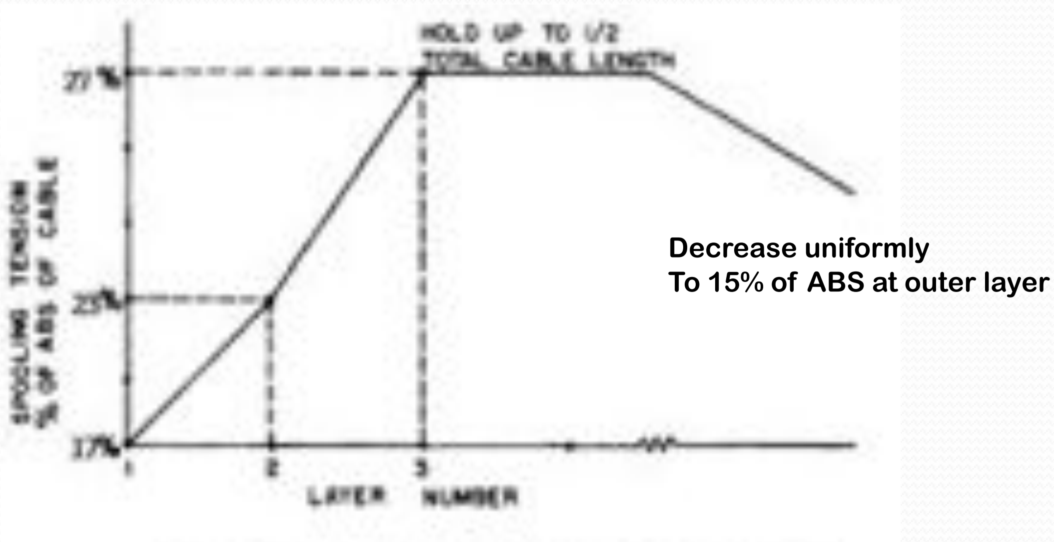


Wire Spooling

- Even if wound properly during installation, the first layer will loosen somewhat during service. When the first layer becomes slack (the pre-tension is gone), this initial procedure MUST be repeated in regular intervals.

- Otherwise, the tensioned 'hard' wraps will severely crush the bottom layers.

Spooling Tension



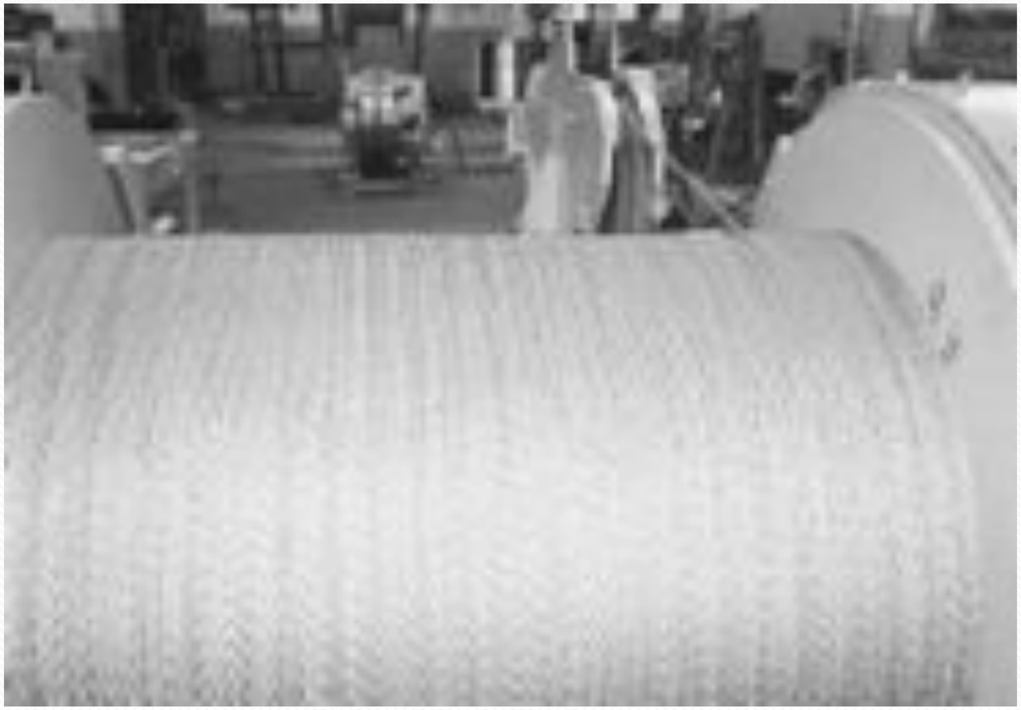
SPOOLING TENSION SCHEDULE

- Spool first layer at 17% of Assigned Breaking Load (ABL).
- Spool 2nd layer at 23% of ABL
- Spool 3rd layer at 27% of ABL
- Hold at 27% of ABL until half of total length is spooled
- Uniformly decrease each layer as to reach 15% of ABS on outer layer

Spooling with a Lebus shell

- 0.322" cable being factory spooled onto the first layer of a DESH-5.
- The shipping reel is fed through a factory-owned "Traction retarder" with air-cooled disk brakes.
- The winch's instrumentation is used to maintain the desired tension.

Spooling 3 X 19 Wire rope



- Even 3 x 19 torque-balanced wire rope can be cleanly spooled -- at least under factory conditions.
- The traction retarder is visible beyond the winch's three-sheave fairleader.

Effect of Failure to Spool Wire Under Proper Tension

Lubrication

Lubrication

- Tension Members are machines
  - 3x19 wire rope has 57 moving parts
  - .322 cable has 38 moving parts
  - .680 cable has 54 moving parts
  - .681 cable has 106 moving parts
- Tests shown on previous slides were done on a ***new*** wire rope
- It was a wire rope which was freshly lubricated which allows movement of all the component wires.
- There were no salt crystals or white rust causing friction between the wires and stands.
- There wasn't any corrosion weakening the wires.
- **<u>Imagine testing on in-service tension members!</u>**

Lubrication - Appendix "A" Requirements

- A.3.16 Lubrication: As long as these testing and inspection programs are adhered to, lubrication of ropes and cables is **not expressly required**. However, if an operation determines that it is cost effective, and does not affect the quality of the science data collected, lubrication is highly encouraged since it generally extends cable life.

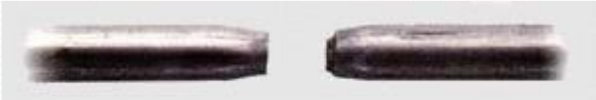
- A.3.17 Fresh Water Wash Down: While understanding that fresh water is limited at sea, an automatic system that washes the rope or cable on retrieval **is highly encouraged** since it greatly extends cable life.

Wire Failure

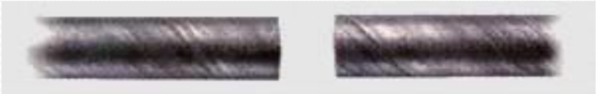
Common modes of wire failure

- **Never Allow Wire Ropes To Kink or Bird Cage As They Will Be Permanently Damaged**
  - A permanent kink or "bird-cage" cannot be repaired.
  - Either of these conditions, almost invariably caused by improper handling, results in greatly decreased service or immediate removal of the rope.
  - In addition, the kink or "bird-cage" is a weak spot in the rope and greatly reduces the tensile strength of the rope.
- **Do not set a package on the bottom that is supported by a Tension Member that is not Torque balanced!**
- **Do not allow slack wire and snap loading conditions to occur!**

Wire Breaks



- Here's what happens when a wire breaks under tensile load exceeding its strength. It's typically recognized by the "cup and cone" appearance at the point of failure. The necking down of the wire at the point of failure to form the cup and cone indicates failure has occurred due to overloading while the wire retained its ductility, or malleable properties.



- This is a wire with a distinct fatigue break. It's recognized by the square end perpendicular to the wire. This break is similar to wire failures in the field caused by fatigue.

Wire Rope Inspections

- All wire ropes should be thoroughly inspected at regular intervals. The longer it has been in service or the more severe the service, the more thoroughly and frequently it should be inspected.
- Ensure maintenance records of each inspection are kept.
- Inspections should be carried out by a person who has learned through special training or practical experience what to look for and who knows how to judge the importance of any abnormal conditions they may discover.
- It is the inspector's responsibility to obtain and follow the proper inspection criteria for each application inspected.

Appendix A

Page by Page (Groan)

Appendix A

- We already been through all of these definitions except A0.1 which is fairly straight forward.


APPENDIX A

UNOLS Rope and Cable Safe Working Load Standards

A.0 DEFINITIONS

- The only new term is A.0.23.

- The only new term is A.0.24
- The HANDBOOK OF OCEANOGRAPHIC WINCH, WIRE AND CABLE TECHNOLGY is on the CD you received.

precise effects on breaking strength, or tension member life, as a result of system design. Instead, each vessel must have a testing program in place, which suits how their tension members are used, and routinely evaluates the status of each. The assumption is that the results of testing will indicate the effect of both the loading and system design on the breaking strength of the tension member.

A.3.2 The testing program followed shall be based on the FS selected by the Owner, which is in turn based on use and the particulars of the handling system employed. The Owner shall have documentation in place specifying the FS for each tension member in use.

A.3.3 Tension member test samples shall be a clean, "representative" length from the end that will be put into future use, not simply the end immediately adjacent to the existing termination. Although this may not be the location of maximum loading during operations, this represents a practical means of determining ABL from an operational standpoint.

A.3.4 The initial ABL shall be assigned through testing by the UNOLS Wire Pool before distribution to the fleet. If the initial test results in an ABL less than the NBL, the Wire Pool shall reject the tension member.

A.3.5 If subsequent testing results in a TBL that is greater than or equal to the initial ABL, the initial ABL shall be used by the Vessel Operation for the purposes of this standard.

A.3.6 If subsequent testing results in a TBL that is less than the initial ABL, then the new TBL shall be used in lieu of the initial ABL by the Vessel Operation for the purposes of this standard.

A.3.7 Method of determining (TBL) – Steel Wires and Cables: ASTM A931-96, "Standard Test Method for Tension Testing of Wire Rope and Strand" (Re-approved 2002) shall be used. Tests shall be done with one end of the tension member free to rotate.

A.3.8 The Vessel Operator shall send samples to a UNOLS-accepted test facility (WHOI Wire Pool as of November 2010) for consistency of testing purposes and maintaining statistics. For steel cables and wire rope, the Operation shall send a five-meter (16 ft) test sample (as described in Section 4.2) terminated on both ends with the fittings normally used in the field. If the field terminations are found to not develop full breaking strength, a test may be conducted using standard poured epoxy resin terminations.

A.3.9 The Vessel Operator shall also provide a copy of the wire history or wire log information with the sample and, as a minimum, this should include the following:

- UNOLS wire identifier, as described in Chapter 7 UNOLS Winch and Wire Handbook, Third Edition
- Winch and system manufacturer
- Number and/or duration of deployments since last test

- Maximum tension of each deployment.
- Maximum payout of each deployment.
- Description of wire train: the number of sheaves between winch and water. Sheave material and values of "D" and "w" for each sheave.

A.3.10 A hard copy and/or electronic copy of the TBL test results and ABL will be provided to the Vessel Operator for each sample tested.

A.3.11 Method of determining (TBL) – Synthetic Ropes and Cables: [RESERVED]

A.3.12 Electromagnetic Testing: [RESERVED]

A.3.13 DC Resistance Testing: [RESERVED]

A.3.14Retirement – Steel Ropes and Cables: Beside obvious physical damage (kinks, bird caging, abrasion, broken strands, excessive corrosion, etc.), a length of tension member shall be removed from service, or cut back so that the unacceptable length is removed, if any of the three following criteria are met:

- If the ABL, with the appropriate FS applied as described above, does not meet future scientific requirements.
- If the ABL deteriorates below 50% of NBL.
- Peak tension over turning sheaves at any time during operations exceeds the Elastic Limit.

A.3.15 Retirement – Synthetic Ropes and Cables: [RESERVED]

A.3.16 Lubrication: As long as these testing and inspection programs are adhered to, lubrication of steel tension members is not expressly required. However, if an operation determines that it is cost effective, and does not affect the quality of the science data collected, lubrication is highly encouraged since it generally extends service life.

A.3.17 Fresh Water Wash Down: While understanding that fresh water is limited at sea, an automatic system that washes the tension member on retrieval is highly encouraged since it greatly extends service life.

A.4 BACKGROUND INFORMATION

A.4.1 Performance Over a Rolling Sheave: When a steel wire rope or cable passes over a rolling sheave, up to a 30% reduction in breaking strength can occur (Ref 1.1, Section 6.4, Fig 6-22). For a tension member with a nominal breaking load of 10,000 lbs, this would be a reduction in strength of 3,000 lbs. Using a FS of 1.5 in this example, the Safe Working Load equals 6,667 lbs – or a reduction of 3,333 lbs – just above the reduction in strength anticipated. Since all oceanographic tension members pass over at least one sheave, this is the primary argument for not exceeding a FS of 1.5.

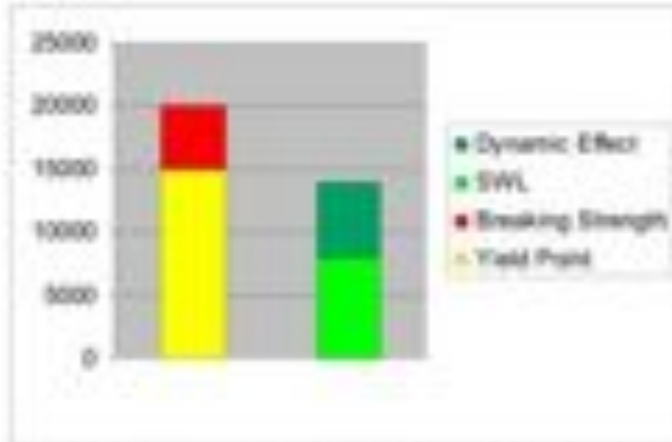
A.4.2 Yield Point and Elastic Limit: "Yield Point" is where continued deformation will occur without adding significantly more load. The "Elastic Limit" is considered to be the load, which induces permanent set or deformation. For steel, the "Yield Point" and "Elastic Limit" are essentially the same for all practical purposes. However, these two points may be quite different for other materials such as synthetics and glass fiber. Since wire rope and cables are made of strands and are not solid bars of steel, the precise Yield Point can be hard to determine by testing. A point on the stress-strain curve known as "0.2% Offset Yield" is used instead. The 0.2% Offset Yield for three-strand wire rope can be found in Section 2.2 (pg 1-5) of Reference 1.

A.4.3 For cables with copper conductors, the yield point generally occurs anywhere from 50-55% of the breaking strength (FS = 1.8) at which point the performance of conductors deteriorates. This is the principle argument for not exceeding a FS of 2.0 for steel cables with copper conductors, the goal being to maintain conductor performance over the life of the cable.

A.4.4 For wire rope, the yield point generally occurs around 75% of the breaking strength (FS = 1.33). This is the other reason for not exceeding a FS of 1.5 on steel wire rope, the goal being to maintain the useful life of the wire rope. This limit matches well with the performance over rolling sheaves above.

A.4.5 When using low FS in oceanographic research, the capabilities of the tension member monitoring system become critical with respect to capturing and displaying dynamic loads. This standard is divided into three primary sections (Tables 6.1 – 6.4) because of this; with each section having increasingly stringent requirements for the monitoring system. If the monitoring system is not capable of reliably capturing peak (or low)-dynamic loads, then the chosen FS must keep the tension member below its yield point.

A.4.6 For example, on a wire with a breaking strength of 20,000 lbs, the approximate yield point would be 20,000 x 0.75 = 15,000 lbs. Using a FS of 2.5, the allowable loading would be 20,000/2.5 = 8,000. If the system is not capable of reliably capturing dynamic effect, then a worst case scenario of 1.75 times static load would have to be assumed (i.e. "g" = 1.75), or 8,000 x 1.75 = 14,000. 14,000 is below the approximate yield strength of 15,000 so the integrity of the tension member would be preserved despite the monitoring system. The graph below illustrates this, and is why a FS of 2.5 is used as the lower limit in Table 6.2.



A.4.7 When a tension measuring system is not available which forces using a nominal FS of 5:2, estimates of tension due to 'dynamic loading' must be done based on mass not weight. In general, the weight of the package, entrained water and the cable or rope in air is roughly equal to the mass. Do not use weight in water for the dynamic loading estimates.

A.5 WINCHES AND HANDLING SYSTEM DESIGN

A.5.1 All handling systems and winches, whether portable or permanently installed, must be properly designed to an appropriate standard as described in Appendix B of the RVSS.

A.5.2 A calibrated weak link or "Auto render" may be used by the vessel to ensure the chosen wire FS that best meets operational demand is maintained.

A.5.3 For operations where the weak link itself might be entangled or buried, then Auto Render shall be the preferred method of strain relief.

A.5.4 Depending on the particular handling system and the type of vessel per Appendix B, when the NBL is at or below the Safe Working Load (SWL) of all components in the handling system, a weak link or Auto Render may be set to the desired FS that best meets operational demand per Tables 6.1 – 6.4. (See Example 7.4)

A.5.5 Depending on the particular handling system and the type of vessel per Appendix B, when the ABL is higher than the SWL of any component in the handling system then the weak link or Auto-Render may be set equal to or below the SWL of the weakest component. (See Example 7.5)

A.6 REQUIREMENTS

General Concept

- OPERATING REQUIREMENTS – FS of ....:
- Ropes and cables of *steel construction may be operated to a nominal FS = x.x on the NBL, including transient and dynamic loads, as long as the following precautions* in this section are adhered to.
- The deployment must be halted, or the next level of standards described in Table n.n adhered to, when the subsequent SWL is reached. To some extent, this will depend upon sea conditions and the resulting ship motion. Thus, the trend in prevailing weather should be assessed before committing to a deployment, which could approach the limits specified above.

Factor of Safety 5.0 or higher

Table 6.1 – Wire Rope or Cable – Factor of Safety 5.0 or greater	
General	Wire Rope or Cable of steel construction may be operated to a nominal FS = 5.0 on the ABL, including transient and dynamic loads, as long as the following precautions in this section are adhered to.
	When the minimum Factor of Safety of 5.0 is reached, the deployment must be halted, or the next level of standards described in Table 6.2 must be used.
	Sea conditions and the resulting ship motion will affect the transient loads created on the wire. Thus, the trend in prevailing weather should be assessed before committing to a deployment, which could approach the limits specified above.
Tension Monitoring	Tension may be determined by calculation of instrument weight, wire weight and entrained volume of water, including transient and dynamic loads, as long as the Owner is confident that a FS of 5.0 will not be compromised. If no other precise information is available on package drag and/or vessel accelerations, the Vessel Operator should use the ABS "a" factor of 1.75 as a minimum.
Alarms	None
Sheaves	The sheave diameter should be at least equal to or greater than the manufacturer's recommendations.
Deck Safety	Personnel on deck should follow good safety practices when working in the vicinity of wires and ropes during use.
Testing	No routine break testing is required. Wires shall only be tested every two years to the desired SWL, along with the handling system.
Logbooks	At a minimum, the Owner shall maintain logs showing cutbacks, spooling operations, lubrication, wire train description and maximum loading (as determined by monitoring system or by calculation for each cast) for the full service life of the rope or wire. The wire log shall transfer with the wire if it is removed and placed in storage, or transferred to another winch or Owner.
Winch Operator	The Owner and the Master of the vessel must deem competent, in writing, all winch operators. "Deemed Competent" means that both the Owner and the Captain are confident, given the particulars of the winch and the overall operational scenario (weather conditions, equipment being deployed, etc.), that the Winch Operator has the necessary experience to operate the winch safely.

Factor of Safety LT 5.0 to 2.5

What Changed?

- Motion compensation added
- Tension Monitoring Required
- Alarms added
- Sheave requirement tightened
- Deck Safety upgraded
- Break testing every 2 years
- Logbooks requirements increased
- Winch Operator must now be certified

Factor of Safety LT 2.5 to 2.0

What Changed?

- This is as far as you can go with a cable
- Tension monitoring requirements & accuracy stricter
- Sheave requirements tightened
- Deck safety upgraded
- Break testing every year

What Changed?

- Only wire rope is allowed to less than FS 2.0
- Haul back required every 500 meters

Summary

Nominal Factor of Safety (lower Limit)	5	2.5	2	1.5
Expressed as a % of ABL	20% of ABL	40% of ABL	50% of ABL	66.6% of ABL
Specific to Conductor Cable				**Forbidden!**
Tension Monitoring	By calculation, must use "g" of 1.75	Display updated at 3 Hz and data recorded at 3 Hz Calibrated every 6 months @ 4% accuracy	Display updated at 10 Hz, recorded at 20 Hz Graphic Display, Calibrated every 6 months @ 3% accuracy	No additional
Alarms	None	Audio/visual @ FS 2.7 Logged with data	Audio/visual @ FS 2.2	Audio/visual @ FS 1.7
Sheave Requirements	should be at least equal to or greater than the manufacturer's recommendations.	should be equal to or greater than the larger of either: the manufacturer's recommendation; 40 x d; or 400 x d1 (use the largest). Grooving of the sheaves should be as close to "d" as practical, and generally no larger than 1.5d	Grooving should be per Ref A.1.1, Chapter 1, and Section 11.0 to provide adequate support.	No additional
Deck Requirements	Good Safety Practices	"Danger Zones" created personnel excluded	Physical barriers and signage	No additional
Haul Back. See section 5.3				Every 500 meters
Testing	Every 2 years to SWL	Break test every 2 years, increase to every year if ABL drops 10%	Break test every year, increase to every 6 month if ABL drops 10%	No additional
Logbooks	Spooling, cutbacks, lubrication, wire train description and max load (by calculation)	Max load recorded		
Operator	Deemed Competent	Certified Competent	No Additional	No additional

- It is important to note that Appendix A does not address synthetic tension members.

Table 6.5 Synthetic Tension Members (Reserved)

- All of the examples in Appendix A need to be edited because of a change in how dynamic loads are calculated.

A.7 EXAMPLES

A.7.1 Examples where a SF of 5 has to be used because a tension measuring system is not available.

Estimation of Tension Member Loads

- Tension = sum of
  - Static Loads
    - Weight of tension member in seawater + weight of package in seawater + weight of sample in seawater
  - Quasi-Static Loads
    - Drag when retrieving or towing
  - Dynamic Loads
    - (g-1) x (weight of tension member in air + weight of package in air + weight of entrained water, mud or sample)
  - Transient Loads
    - Pull out

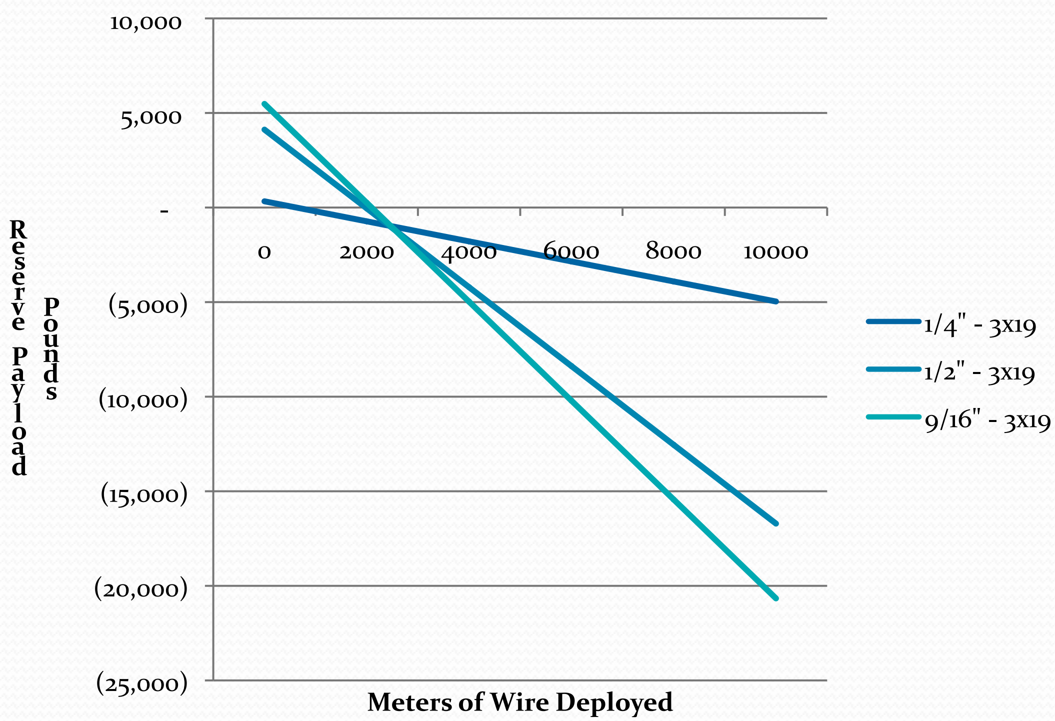
Calculation of Reserve Payload

- Reserve Payload =
  - (Assigned Breaking Load / Factor of Safety) – Estimated Tension
- Negative Answers are **NOT** Good.

Gravity Corer Example, FS = 5.0, g=1.75

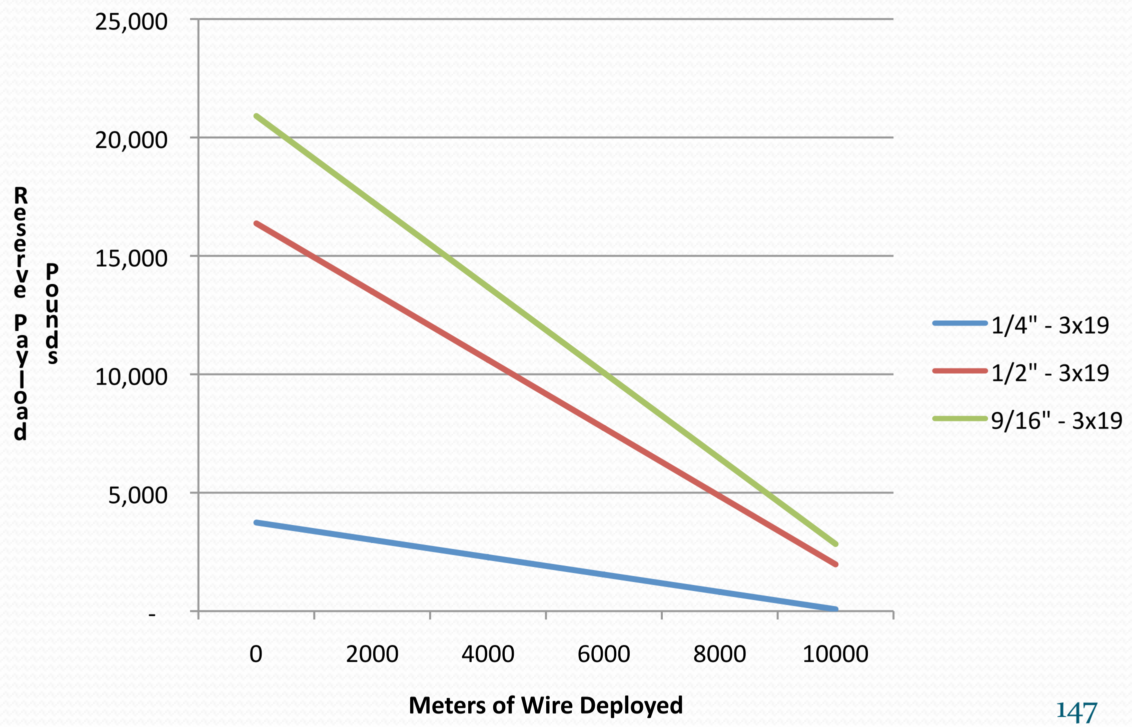
Weight of equipment package in seawater (lb.)	400
Weight of equipment package in air (lb.)	500
Entrained Water/Mud Weight in seawater (lb.)	10
Entrained Water/Mud Weight in air (lb.)	20
Package Drag on retrival or while towing (lb.)	20
Dynamic Load "g"	1.75
Transient Load e.g. Pull Out (lb.)	200
Factor of Safety	5

Without a tensiometer you are very limited in capability even with a 9/16" wire.



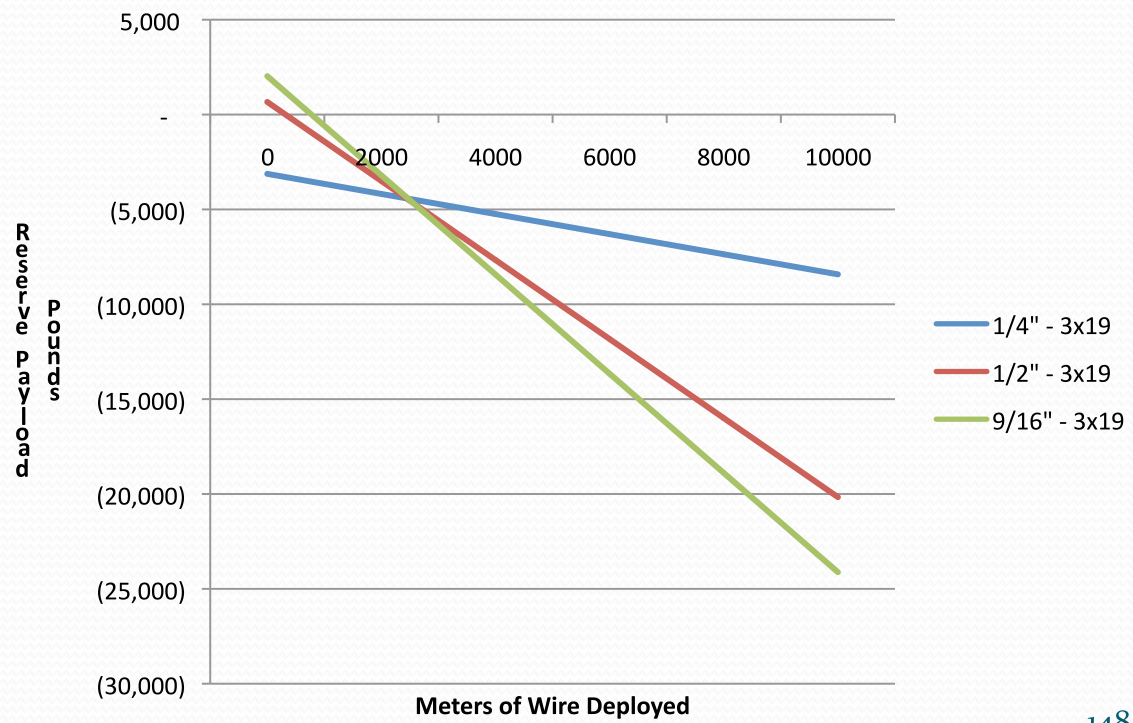
Gravity Corer Example, FS=1.5, g=1.25

Weight of equipment package in seawater (lb.)	400
Weight of equipment package in air (lb.)	500
Entrained Water/Mud Weight in seawater (lb.)	10
Entrained Water/Mud Weight in air (lb.)	20
Package Drag on retrival or while towing (lb.)	20
Dynamic Load "g"	1.25
Transient Load e.g. Pull Out (lb.)	200
Factor of Safety	1.5



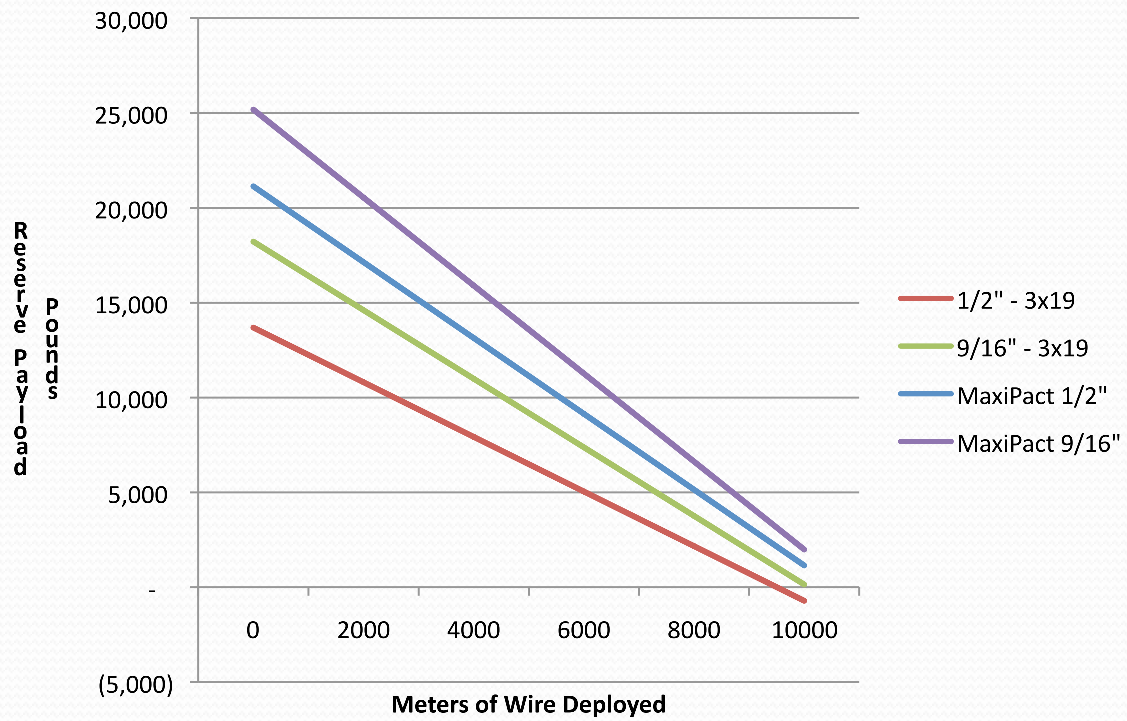
Piston Corer Example, FS=5.0, g=1.75

Weight of equipment package in seawater (lb.)	1800
Weight of equipment package in air (lb.)	2000
Entrained Water/Mud Weight in seawater (lb.)	30
Entrained Water/Mud Weight in air (lb.)	60
Package Drag on retrival or while towing (lb.)	100
Dynamic Load "g"	1.75
Transient Load e.g. Pull Out (lb.)	1000
Factor of Safety	5.0



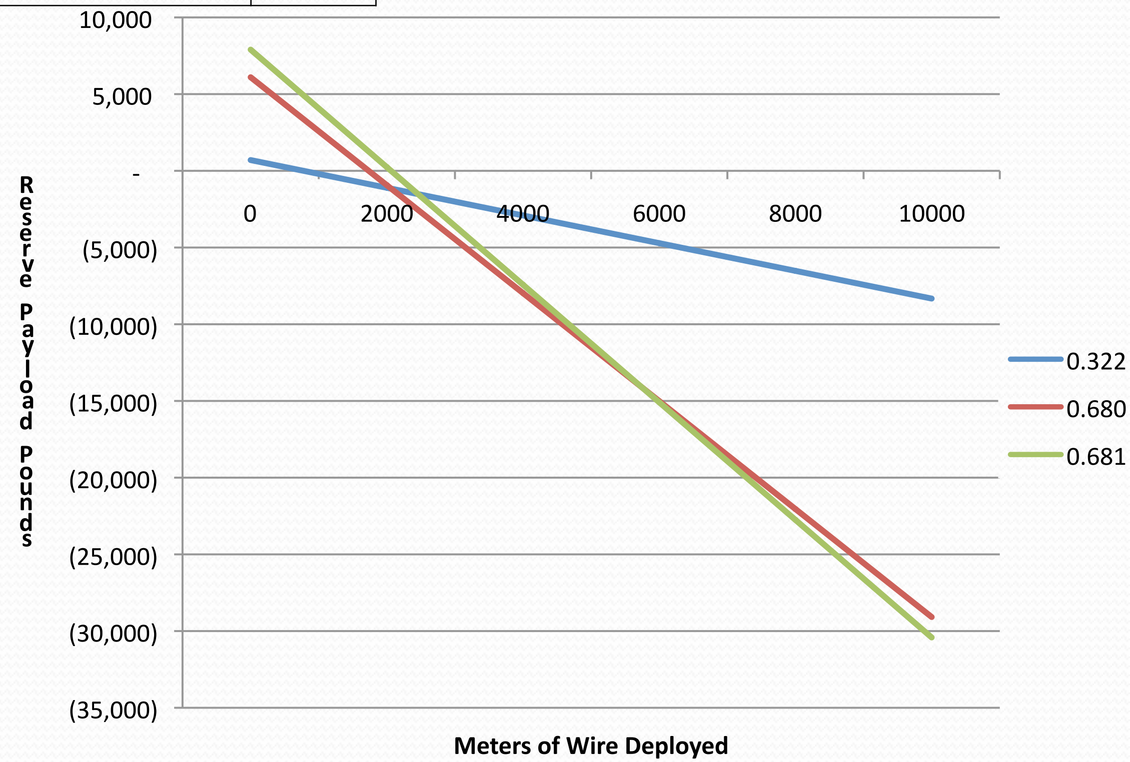
Piston Corer Example, FS=1.5, g=1.25

Weight of equipment package in seawater (lb.)	1800
Weight of equipment package in air (lb.)	2000
Entrained Water/Mud Weight in seawater (lb.)	30
Entrained Water/Mud Weight in air (lb.)	60
Package Drag on retrival or while towing (lb.)	100
Dynamic Load "g"	1.25
Transient Load e.g. Pull Out (lb.)	1000
Factor of Safety	1.5



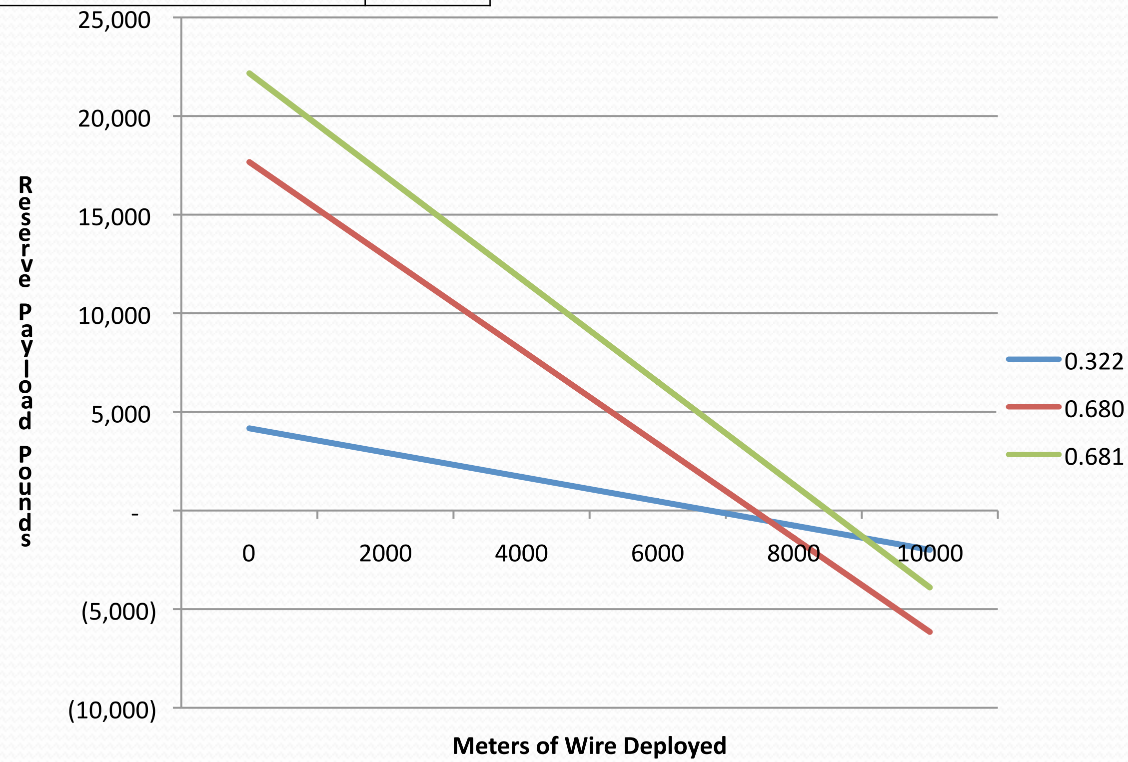
Small CTD, FS=5.0, g=1.75

Weight of equipment package in seawater (lb.)	500
Weight of equipment package in air (lb.)	800
Entrained Water/Mud Weight in seawater (lb.)	0
Entrained Water/Mud Weight in air (lb.)	132
Package Drag on retrival or while towing (lb.)	100
Dynamic Load "g"	1.75
Transient Load e.g. Pull Out (lb.)	0
Factor of Safety	5.0



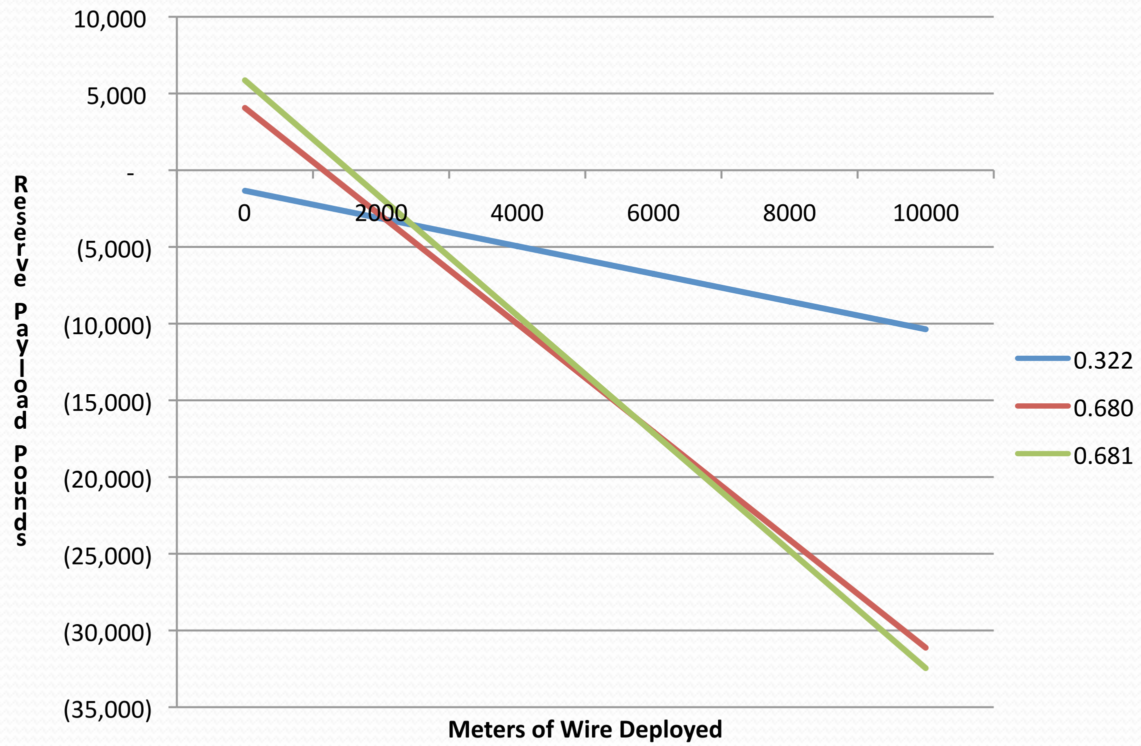
Small CTD, FS=2.0, g=1.25

Weight of equipment package in seawater (lb.)	500
Weight of equipment package in air (lb.)	800
Entrained Water/Mud Weight in seawater (lb.)	0
Entrained Water/Mud Weight in air (lb.)	132
Package Drag on retrival or while towing (lb.)	100
Dynamic Load "g"	1.25
Transient Load e.g. Pull Out (lb.)	0
Factor of Safety	2.0



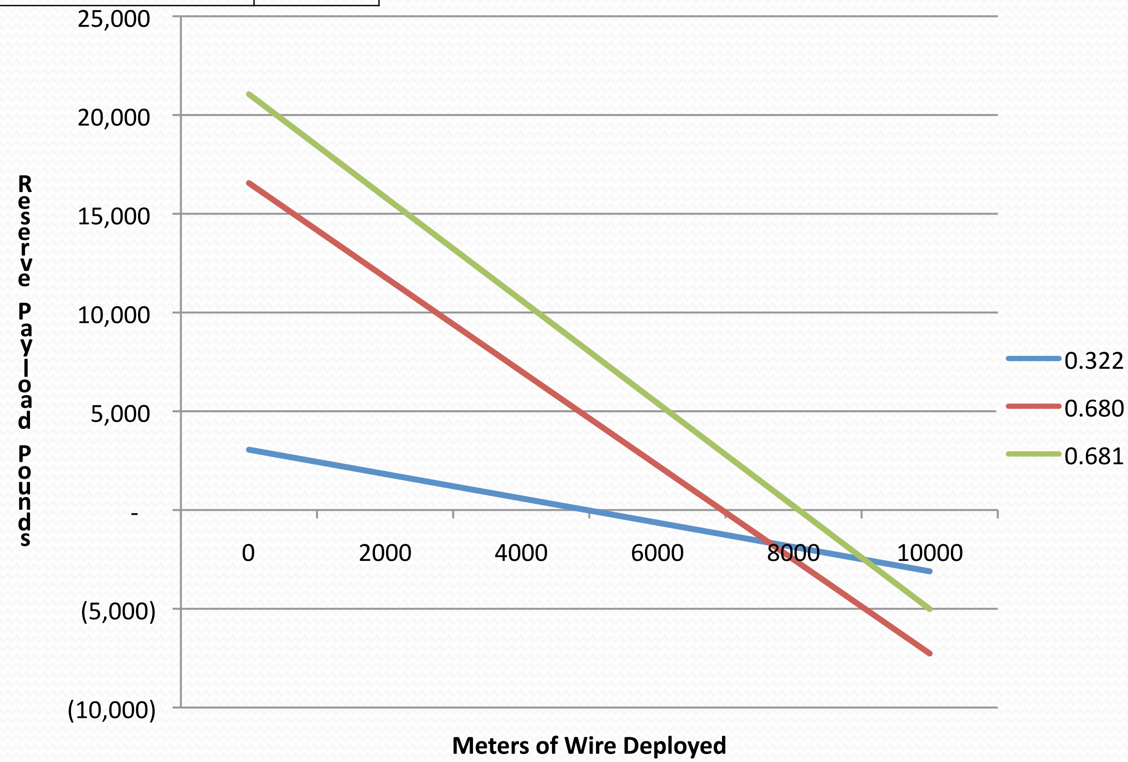
Large CTD, FS=5.0, g=1.75

Weight of equipment package in seawater (lb.)	850
Weight of equipment package in air (lb.)	1200
Entrained Water/Mud Weight in seawater (lb.)	0
Entrained Water/Mud Weight in air (lb.)	1584
Package Drag on retrival or while towing (lb.)	400
Dynamic Load "g"	1.75
Transient Load e.g. Pull Out (lb.)	0
Factor of Safety	5.0



Large CTD, FS=2.0, g=1.25

Weight of equipment package in seawater (lb.)	850
Weight of equipment package in air (lb.)	1200
Entrained Water/Mud Weight in seawater (lb.)	0
Entrained Water/Mud Weight in air (lb.)	1584
Package Drag on retrival or while towing (lb.)	400
Dynamic Load "g"	1.25
Transient Load e.g. Pull Out (lb.)	0
Factor of Safety	2.0



Implications

- Applies to all winches and tension members including those supplied by scientists!
- No logbooks -- you can not operate!
- Ship operators and their seagoing staff must understand that if, by force of circumstance or by their wish to maintain scientific operations while on a cruise, they do not meet operating requirements as described in tables 6.1 through 6.4, they are embarking on a potentially dangerous activity. The consequences of this activity could be loss of valuable equipment, damage to the vessel and its fixed equipment, and, in the worst case, injury to personnel.

Tension Calibration

Calibration Loads

- This chart shows all of the load measurement combinations that would be required for the high end calibration point as required in Appendix A.
- For all standard UNOLS tension members, a single 25,000 dynamometer with an accuracy of 0.1% will meet the requirements.

Tension Member	Nominal Breaking Load lbs.	FS	Calibration Load lbs.	Accuracy Required	Accuracy in lbs.
1/4" 3x19	6,750	2.5	2,700	4%	108.0
1/4" 3x19	6,750	2.0	3,375	3%	101.3
1/4" 3x19	6,750	1.5	4,500	3%	135.0
1/2" 3x19	25,700	2.5	10,280	4%	411.2
1/2" 3x19	25,700	2.0	12,850	3%	385.5
1/2" 3x19	25,700	1.5	17,133	3%	514.0
9/16" 3x19	32,500	2.5	13,000	4%	520.0
9/16" 3x19	32,500	2.0	16,250	3%	487.5
9/16" 3x19	32,500	1.5	21,667	3%	650.0
.322 Cable	11,600	2.5	4,640	4%	185.6
.322 Cable	11,600	2.0	5,800	3%	174.0
.680 Cable	40,000	2.5	16,000	4%	640.0
.680 Cable	40,000	2.0	20,000	3%	600.0
.681 Cable	46,000	2.5	18,400	4%	736.0
.681 Cable	46,000	2.0	23,000	3%	690.0

Dynamometer with Remote Display

- Dillon EDx-25K
  - +/- 0.1% accuracy
  - +/- 25 pound accuracy
- Remote Display
  - Wireless
  - Allows personnel to be far from load
- Dynamometer **must** be calibrated annually

Quick Check

- Dillon "Quick Check" 8000
  - Wire sizes: 3/16 inch through 3/4 inch
  - +/- 3% accuracy (+/- 240 lbs. calibrated to specific wire size & type)
  - +/- 5% accuracy (+/- 400 lbs. with same wire diameter as calibrated but different wire type)
  - Concern about small diameter rollers
  - Must be calibrated annually

LCI 90i

- There will be a separate presentation on calibrating the LCI 90