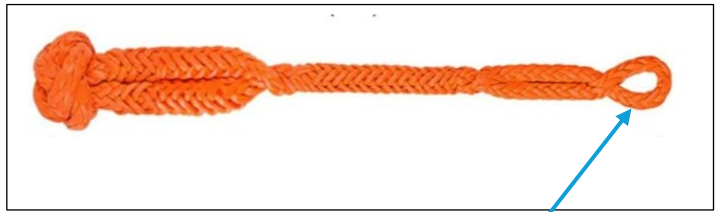
*A **hard shackle**, often referred to as a "**D-shackle**" or "**bow shackle,**" is best defined as a U-shaped piece of metal secured with a pin or bolt across the opening. The clevis pin is a specific type of pin used to close the shackle. **Anchor shackle**. **Screw Pin Shackle**.*



Soft Shackles:

tensile forces (strength) – the typical quoted rating. ***In-line*** forces/stresses.

sheer forces (strength) – sheer strength is typically less than tensile strength. ***Perpendicular*** forces/stress.

Knots generally weaken overall strength of rope – concentrates forces via bends/sheer, thus, lessening overall strength of rope.

A shackle system will generally rate 1.7 – 2.3 times the tensile strength of the rope.

Single strand loop subjected to sheer and tensile stresses.

Knot redistributes forces across a larger area via friction, with net effect of shackle system having greater strength than rope tensile strength.

Knot effect maximized by gentle bends, large size, and tightness. Button vs Diamond knot – geometry, size, geometry of loops. Botton knot generally > Diamond (2.3 x vs. 1.7x)

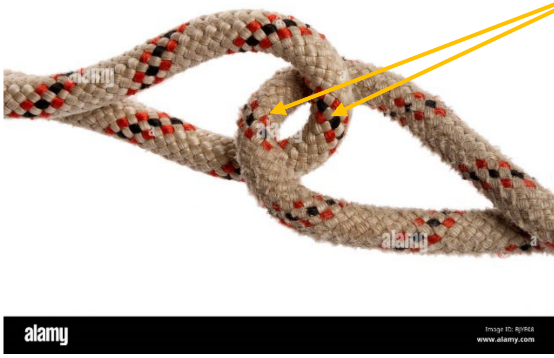
Shackle provides “mechanical advantage” to tensile rating of rope via redistribution of load across a greater area via knot/friction.

A loose knot does not redistribute forces efficiently. Tight knots hold shape under tension, maximizes friction for redistribution of stresses, minimizes slippage or prolapsing (internal collapse), minimizes movement within the knot.

Any knot within a rope reduces the tensile strength of the rope.

Paracord: 5/32” ~4mm	***½” = 12.5 mm***	***25mm x 1/2 = 12.5***
	3/8” = ~9.4 mm	***25mmx 3/8 = 9.375***
	5/16” = 7~7.8 mm	***25mm x 5/16 = 7.8125***

Sheer forces applied here – at non-ends of rope



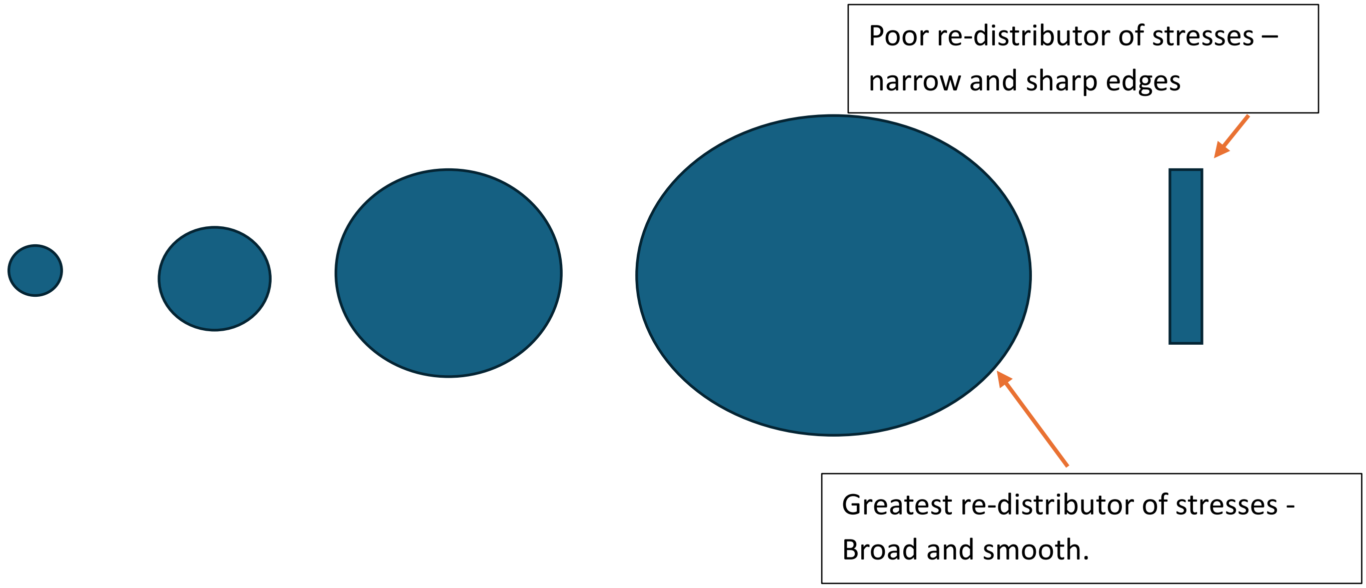
Tensile stress applied to ends

Diamond knot

Button Knot.

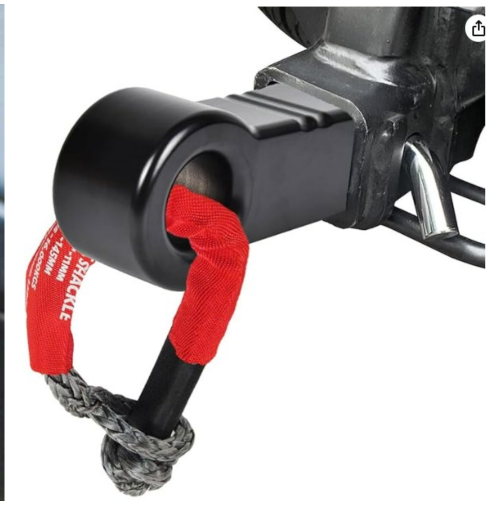
Bending of the fibers of the rope decrease its strength.
Bending also introduces shear forces.
Knots also decrease the functional cross sectional area of the rope.
A poorly tied knot unevenly distributes stress forces.
Frictional forces within the knot lead to "wear and tear" and heat generation.
Frictional forces provide knot stabilty and allow distribution of loads.

*In essence, knots impact rope strength due to the induction of additional stress types (**shear and bending**), concentration of these stresses at critical points, and changes in how the rope's material properties are engaged under load.*



results

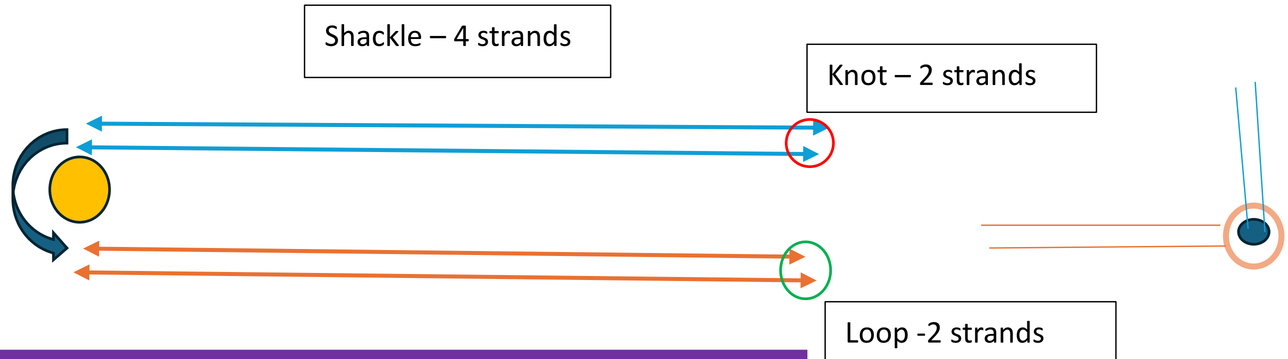
VS.



In a broad generalization, most working loads vary from 1/10 to 1/4 of the average break strength of the rope. Applications for rope used in life support or personal fall protection environments must use the 1/10 ratio.

Shackle has 4 strands of rope holding the load, ∴ theoretically 4 x the strength of individual rope.

Diamond Knot 25-40% of the strength of the line it is made from.



Diamond Knot:

Knot: 30% + 30% = 60% (2 strands)

Loop: 50% + 50% = 100% (2 strands)

*30% + 30% + 50% + 50% = **160%***

Remember, 4 strands theoretically could give 4x the strength of and individual rope. B/O of knots and loops reduces gain to 160-240%.

Button Knot:

Has strengthening effects via strength of knot and distribution of loop load:

Knot: 60% + 60% = 120%

Loop: 60% + 60% = 120%

*120% + 120% = **240%***

High Strength Soft Shackle (l-36.com)

*Recient work by Brion Toss, Evans Starzinger, and myself has led to the development of a high strength soft shackle that Evens has tested to 230% of line strength. The secret to this added strength in primarily an increase in the strength of the knot, the weak point in conventional soft shackles. I should point out that Evans testing shows **conventional soft shackles, with diamond knots, test at 170% of line strength**, considerable above the "higher than line strength" number I have been using. While these two statements are consistant, the more percise number is considerably higher and higher than the testing I had done at NE Rope.*

A soft shackle shares the load over four strands of the line. Theoretically, it would be 400% of the strength of the line it is made from. But the knot is generally the weak point. A diamond knot strength is somewhere between 25% and 40% the strength of the line it is made from. That means that a soft shackle made with a diamond knot will be between 100% and 160% as strong (actually a little higher by measurements) as the line it is made of. You get from 25% to 100% because there are two strands in the diamond knot each carrying 1/4 of the load of the shackle.

*The other limit is the eye. It is bent around the body of the shackle and the turning radius is about the diameter of the line it is made of. **This 1x bend radius makes the eye about 50% as strong as the line it is made of which would limit the soft shackle strength to 200% of the line, 50% of the 400% theoretical maximum (the eye only has half the load and an eye is two strands).***

*This stronger soft shackle has a much stronger knot, perhaps twice as strong. It basically makes the eye the weak point. But by having twice the number of strands in the area near the knot, **the eye bending radius is greater giving about 60% of line strength.** But as the eye has 1/4 the load of the shackle, this gives about 240% theoretical strength, measured at 230%.*

A soft shackle shares the load over four strands of the line. Theoretically, it would be 400% of the strength of the line it is made from. But the knot is generally the weak point. A diamond knot strength is somewhere between 25% and 40% the strength of the line it is made from.

from. That means that a soft shackle made with a diamond knot will be between 100% and 160% as strong (actually a little higher by measurements) as the line it is made of. You get from 25% to 100% because there are two strands in the diamond knot each carrying 1/4 of the load of the shackle. The other limit is the eye. It is bent around the body of the shackle and the turning radius is about the diameter of the line it is made of. This 1x bend radius makes the eye about 50% as strong as the line it is made of which would limit the soft shackle strength to 200% of the line, 50% of the 400% theoretical maximum (the eye only has half the load and an eye is two strands).
This stronger soft shackle has a much stronger knot, perhaps twice as strong. It basically makes the eye the weak point. But by having twice the number of strands in the area near the knot, the eye bending radius is greater giving about 60% of line strength. But as the eye has 1/4 the load of the shackle, this gives about 240% theoretical strength, measured at 230%.

Static
Dynamic

Tensile Strength
Working Load

Safety ratios: working load/tensile strength
Industrial
EMS
Fall prevention
EMS/Rescue
overhead

hemp/jute
cotton

nylon

*Nylon rope is known for its **elasticity and ability to absorb tremendous shock loads**. this rope will not rot and is resistant to oil, gasoline and most chemicals. Along with having good abrasion resistance, nylon rope also has a **good resistance to UV rays. SINKS***

Energy absorption(stretch):
Nylon higher than polyester

polyester

Similar to nylon, polyester offers a soft, silky hand. Polyester is resistant to most chemicals and will not mildew or rot. Another benefit of the polyester fiber, it ***has a lower stretch factor than that of nylon***
Generally less tensile strength than nylon, but better environmental resistance (uv/water/chemical).
SINKS

polypropylene

THE ROPE THAT FLOATS. UV Sensitive

- Rot proof
- Will not shrink
- Resistant to water
- Resistant to oil
- Resistant to gasoline
- Resistant to most chemicals

Polyethylene

Polyethylene rope is a synthetic rope that is often used in outdoor and marine applications. ***With a slightly heavier weight than polypropylene and a lower breaking strength, polypropylene is often chosen over polyethylene. Lower strength/weight ratio. FLOATS***

dyneema

*Dyneema is a synthetic rope that is a **variation of polyethylene called UHMPE**, which stands for ultra-high molecular weight polyethylene. These ropes are touted for their **high strength-to-weight ratio**. FLOATS*

Kevlar

paracord

*Parachute cord, often shortened to paracord, is made of **nylon** and it's extremely strong for its small size, making it handy for a variety of general-purpose tasks. **Kermantle** construction.*

550 cord – 7 strands = 78.6 lbs strength/strand
- 9 strands = 61.1 lbs strength /strand

outer core contributes ~25% of total strength.

The repeating unit in Dyneema is the same as in standard polyethylene, which is ethylene (C2H4). Dyneema is a type of ultra-high molecular weight polyethylene (UHMWPE), so the fundamental building block or monomer remains ethylene. What differentiates Dyneema from regular polyethylene is not the basic chemical structure but rather the molecular weight of the polymer chains and the way these chains are processed and aligned during manufacturing.

In Dyneema, these ethylene units are polymerized to form extremely long chains, and through the gel spinning process, these chains are highly oriented along the fiber axis. This orientation, combined with the extremely high molecular weight, gives Dyneema its exceptional strength and durability. Thus, despite having the same repeating unit as standard polyethylene, the physical properties of Dyneema are vastly superior due to these structural and processing differences.

The molecular weights of polyethylene can vary significantly depending on the type of polyethylene and its *intended use. For Dyneema, which is an ultra-high molecular weight polyethylene (UHMWPE), the molecular weight is exceptionally high. Here's a comparison:*

1. ***Standard Polyethylene**:*
   - ***Low-Density Polyethylene (LDPE)** typically has a molecular weight ranging from about 10,000 to 500,000 g/mol.*
   - ***High-Density Polyethylene (HDPE)** usually features molecular weights in the range of 200,000 to 500,000 g/mol.*
2. ***Dyneema (UHMWPE)**: ultra high molecular weight polyethylene.*
   - *Dyneema has molecular weights typically in the range of 2 million to 5 million g/mol, and sometimes even higher. This extremely high molecular weight is one of the primary reasons for its outstanding strength and durability.*

This stark difference in molecular weight is a key factor in the superior physical properties of Dyneema compared to standard types of polyethylene. *The longer polymer chains in UHMWPE lead to more effective load transfer and interaction between molecules, which translates into higher tensile strength and abrasion resistance.*

Single Braid

- ***Best for:** Outdoor use, climbing, arborist rigging*

*Single-braid is a type of synthetic rope formation that consists of **eight or 12 strands wrapped around a solid core** in alternating directions. Single-braid rope is **highly flexible** and feels good in the hand, making it an ideal rope for hands-on applications.*

Double Braid

- ***Best for:** Outdoor use, nautical use, arborist rigging, climbing*

*Double braid rope is a type of synthetic rope formation that utilizes **one single braid rope as the core and a second single-braid rope as the outer jacket.** This gives it significantly more strength and shock absorption than single-braid rope.*

Hollow

- ***Best for:** Light-duty outdoor use, nautical use*

*Hollow rope is a rope that **has no inner core**. The benefit of this is that it sheds water easily, making it a great option for use in wet and moist environments. While it isn't as strong as single or double-braid ropes, it is lightweight, which makes it easier to handle for jobs that don't require much strength.*

Diamond Braid

- ***Best for:** Outdoor recreation, camping, crafting, equine*

Diamond braid rope is a type of synthetic rope formation typically made using nylon and polypropylene. Diamond braid rope is geared toward practical use that doesn't require high strength. It's a great option for anything from crafts to making horse halters.

Plaited

- ***Best for:*** *Outdoor use, recreation, camping, knot tying*

Plaited rope is a type of rope formation that resembles traditionally braided hair. A plaited rope is ideal for knot tying, as it's kink-resistant and highly flexible.

Twisted

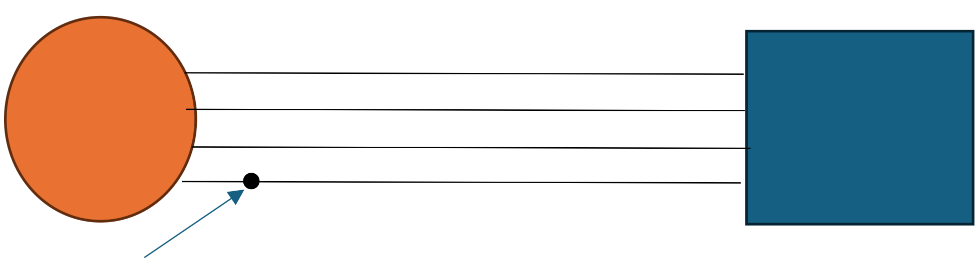
- ***Best for:*** *Decorative use, exercise equipment, indoor use, crafts, porch swing*

Twisted rope is a common type of rope formation that is associated with natural rope like cotton, hemp, manila, and jute. Twisted rope is ideal for purposes that will involve a lot of hand contact with the rope, as it provides a fair amount of grip.

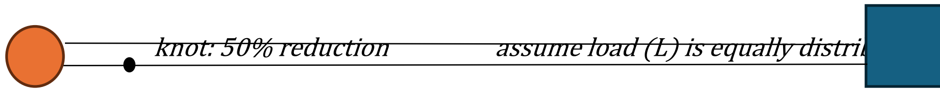
UV Resistance:

Summary:

- ***Polyester*** *ropes are the best choice for high UV exposure environments due to their superior resistance to UV degradation.*
- ***Polypropylene*** *offers a middle ground but may require additional treatments for prolonged UV exposure.*
- ***Nylon and Polyethylene*** *generally have poorer resistance to UV light but are still widely used in many applications due to their other desirable properties (e.g., strength, elasticity). They may need UV stabilizers for outdoor use.*
- ***Dyneema****, while moderately resistant, often receives treatments to enhance its UV stability, making it suitable for applications that require high-strength and light-weight properties alongside moderate UV resistance.*



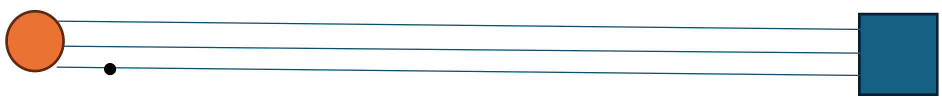
Each rope “sees” ¼ load. Weak link is rope with knot 50% strength (TS).



if knot reduction of 50%, *when load L > than this, rope breaks - effective TS of 50%*
TS = Tensile Strength

each strand sees ½ L.

When ½ L > TS of 50%, rope breaks, ∴ when L > 2 x 50% TS, rope breaks (i.e. 2/2 = 1)



each strand sees 1/3 of load
when 1/3 L > 50% TS rope breaks. ∴ when L > 3/2 TS line breaks

with 4 strand system, each line sees ¼ of load, ∴ when ¼ L > 50% TS line breaks, ∴ when L > 4 x 50%TS = 2 x TS

# strands	***Load allowance f(TS)***		***Load allowance f(TS)***
1 strand	*50% TS*	*½*	*50% TS*
2 strand	*TS (2 x 50%)*	*2/2*	*100% TS*
3 strand	*TS x 3x 50%*	*3/2*	*150% TS*
3 strand	*TS x 4 x 50%*	*4/2*	*200% TS*

Example: for a 4 rope system, the load can maximally be 2 x TS of rope!

for a 1 rope system with knot, the load can only be 50% of the tensile strength of the rope.

Buoyancy	***UV protection***	***Elasticity***	***Strength***

1. ***Polypropylene:***
   Buoyancy: *Floats* — *Moderate UV protection* — *Moderate/Low Elasticity* — *Moderate Strength*

1. ***Polyethylene:***
   Buoyancy: *Floats* — *Poorer UV protection* — *Low Elasticity* — *Moderate Strength*

2. ***Dyneema:***
   ***Buoyancy**: Floats* *Moderate UV protection* *Very Low Elasticity* *Extremely Very Strong*
3. ***Nylon:***
   ***Buoyancy**: Sinks* *Poor UV Protection* *High Elasticity* *Highly Strong*
4. ***Polyester:***
   ***Buoyancy**: Sinks* *Best UV protection* *Moderate elasticity* *Moderate/Highly Strong*

Best for knot tying

*Typically, the **working load limit** is determined by **dividing the tensile strength by a safety factor**. The safety ... ding on industry standards and applications, commonly ranging from **5:1 to 8:1 for***

*For **overhead lifting**, the safety factor is usually higher **(e.g., 10:1)** to accommodate additional risks like dynamic loads or uneven loading.*

According to ChatGPT:

Summary of Strength Reductions

- **Bowline**: 30-40% reduction
- **Yosemite Bowline: 25-35% reduction**
- **Figure of Eight Loop**: 20-25% reduction
- **Overhand Loop**: 40-50% reduction
- **Alpine Butterfly Knot**: 20-30% reduction
- **Double Fisherman's Knot**: 20-30% reduction
- **Square Knot**: 45-55% reduction
- **Water Knot**: 20-30% reduction

Note effect of adding half hitch which passes through original closing loop.

Approximately 50% reduction from these 2 knots.

The tensile strength reductions for knots are often derived from a combination of empirical testing and expert consensus within the climbing, rescue, and rope work communities. While specific values can vary slightly depending on the source, the figures I provided are generally accepted in the field. Here are some references that provide detailed information on knot strength and their effects on rope tensile strength:

1. **"On Rope: North American Vertical Rope Techniques for Caving... and Other Applications"** by Bruce Smith and Alan Padgett:
   - This book provides comprehensive information on rope techniques and includes data on knot strength reductions.
2. **"The Ashley Book of Knots"** by Clifford W. Ashley:
   - Although this classic book primarily focuses on knot tying, it includes some information on the relative strength of different knots.
3. **UIAA (International Climbing and Mountaineering Federation) Safety Standards**:
   - The UIAA provides safety standards and guidelines for climbing equipment, including ropes and knots. Their standards often reflect empirical testing and industry consensus.
4. **Petzl Technical Institute**:

- Petzl, a leading manufacturer of climbing and rescue equipment, provides technical notes and guides that include data on the strength of knots and ropes. They often conduct their own testing.

5. **DMM Wales**:
    - DMM, another prominent manufacturer, offers detailed technical articles and research findings related to rope and knot strength.
6. **National Speleological Society (NSS)**:
    - The NSS publishes research and technical reports on caving techniques, including the effects of knots on rope strength.
7. **Canyon Guides International (CGI)**:
    - CGI provides guidelines and technical information for canyoneering, including the strength reduction of various knots.

Example Studies and Articles

1. **"The Effect of Knots on the Breaking Strength of Static Climbing Ropes"**:
    - A study by Dr. David Merchant, which can often be found in climbing and rescue journals, details the effects of different knots on rope strength.
2. **"Rope Knots and Their Influence on Rope Strength"**:
    - An article by the American Alpine Club, available in their annual publication "Accidents in North American Mountaineering".

While specific empirical data from these sources might vary, the general consensus aligns with the figures provided earlier. For precise applications and critical safety calculations, consulting specific empirical studies and manufacturer data is always recommended.

NOTE:
1/4" amsteel dyneema has tensile strength of 8,600 lbs
½" amsteel dyneema has tensile strength 34,000

The radius or diameter has increased by a factor of 2, and ∴ the cross sectional area has increased by a factor of 4, since area = πr^2. Tensile strength related to the cross sectional area of fibers.

Bend:Rope Diameter Ratios

D/d Ratio Explanation

- **D**: Diameter of the object the rope is bending around.
- **d**: Diameter of the rope.

Bend Radius and Tensile Strength Reduction

1. **Sharp Bends (Small Radius)**: Sharp bends can cause a significant reduction in tensile strength. The tighter the bend, the greater the reduction.
    - **D/d Ratio < 2**: Reduction can be as much as 50% or more.
2. **Moderate Bends (Medium Radius)**: Moderate bends still cause a reduction but less severe than sharp bends.
    - **D/d Ratio 2 to 4**: Reduction can range from 30-40%.

3. **Gentle Bends (Large Radius)**: Gentle bends with a larger radius cause the least reduction in tensile strength.
    - **D/d Ratio > 4**: Reduction can be around 10-20%.

- ***Sharp Bend Example (Small Pulley or Carabiner)****:*
  If a rope with a diameter of 10 mm bends around a carabiner with a diameter of 20 mm (D/d = 2):
    - ***Expected reduction: 30-40%.***
- ***Moderate Bend Example (Medium Pulley or Object)****:*
  If the same 10 mm rope bends around a pulley with a diameter of 40 mm (D/d = 4):
    - *Expected reduction: 20-30%.*
- ***Gentle Bend Example (Large Pulley or Object)****:*
  If the 10 mm rope bends around an object with a diameter of 100 mm (D/d = 10):
    - *Expected reduction: 10-20%.*

Lynch pin
10pc 3/16"x 1-7 / 16",

10pc 1/4"x 1-3 / 4",

5pc 5/16"x 1-3 / 4",

5pc 7/16 "x 1-3 / 4"

Assaultline 11.4 mm x 46 m Non-Dry Rope

Rope Diameter (mm)	11.4 millimeters
Strength	32.9 kilonewtons

Newton = force = Mass x Acceleration

$32.9N/9.8m/sec^2 = 3.357$ kgs

3.357 kg = 3.357 x 2.2 lbs/kg = 7.3857 lbs

7.3857 lbs x 1,000 = ***7,385.7 lbs***

*A **hard shackle**, often referred to as a "**D-shackle**" or "**bow shackle**," is best defined as a U-shaped piece of metal secured with a pin or bolt across the opening. The clevis pin is a specific type of pin used to close the shackle. **Anchor shackle**. **Screw Pin Shackle**.*

Clevis pin – bar held in place with pin (cotter or the like).

Clevis (bolt & pin) shackle – uses bar with pin vs. ***Screw Pin*** Shackle