A White Paper Produced by Yale Cordage

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ANCHORING TECHNOLOGY

New anchorline production technology yields significant benefits for anchorline strength, dynamic performance under load, handling qualities, and ease of stowage.

YALE CORDAGE

When there's a lot on the line.

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Table of Contents

Executive Summary

Given its centuries-old role in maritime applications, the art of anchoring has changed relatively little over the years. Anchoring technology relies on two key elements: a device capable of securing itself to the sea bottom, and a means of connecting this device to a vessel. Ground-tackle equipment, the first element, has seen incremental improvements with time; however, the means to connect a boat to the hardware secured to the bottom—rope or chain—has experienced minimal changes since its conception.

The rope specialists at Yale Cordage have pioneered a new product that radically improves the art and science of anchoring: Yale Brait anchorline. Nylon- and polyester-Brait sets a new standard for anchoring technology.

This paper will review briefly the evolution of anchoring technology, and then detail the superior performance characteristics and advantages of Yale Brait anchorlines. The first section provides an overview of the technology and recommendations; detailed technical and mathematical data follow in the addenda.

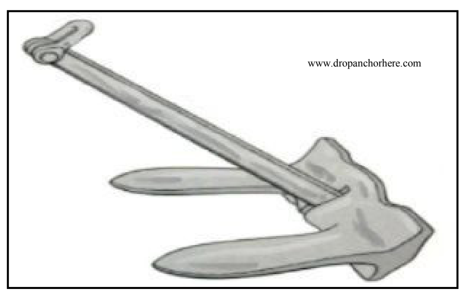
A Brief History of Anchor Technology

Ground Tackle

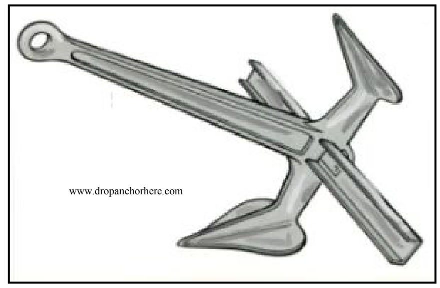
Anchoring technology spans some 4,000 years of maritime history, beginning with ancient mariners who simply tied a rock to a length of vine or crude rope to anchor their vessels. Anchoring evolution took a leap forward when seamen left the rocks on the beach and began utilizing simple iron hooks to keep their vessels stationary. Next, the Chinese added a stock to the crown end of a shank, perpendicular to the plane of the hooks. This technological innovation allowed the hook-arm to turn into the sea bottom and bite deeply, thereby providing a greater measure of holding power.

Before long, broad triangular flukes were added to the hook-arm to improve holding power. Sailing vessels well into the 19th century used this type of anchor—typically a kedge.

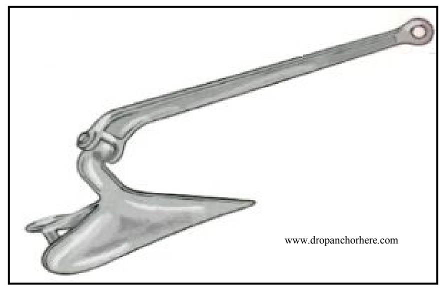
In 1821, the first stockless navy anchors came on the scene, representing a true breakthrough in anchoring technology. With the elimination of stocks, the shanks could be drawn up into a hawse pipe with the flukes stowed flat against the hull of the ship. This fundamental design change greatly improved big-ship anchor-handling characteristics.



The next step in the evolution of anchoring technology was a hybrid called the Northill anchor. This anchor combines the high holding power of a stock-design anchor with the convenience and easy handling of a stockless anchor. Wide, fixed flukes provide a tenacious bite, while a folding stock is fitted in the crown end of the anchor. When stowed, the stock lays flat against the anchor's shank.



Two new designs came to the forefront in the 1930s, representing a radical approach to anchor functionality: burying anchors. Plow- and Danforth-type anchors are typical of burying anchors. When properly set, they dig deep into the bottom until firm holding ground is reached, providing a significant mechanical advantage over anchors that rely on mass for holding power.



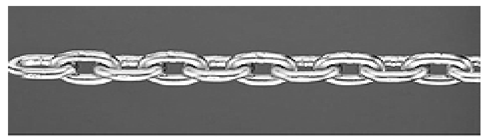
The plow was developed in England and introduced in 1933. Radical in design, it effectively did away with the arms, stock, and traditional flukes; they were replaced with a single blade cast in the shape of plow. A moveable shank was attached to the plow with a pivoting pin. Just as a farmer's plow digs deep into the soil, the nautical version buries itself deep into sand, mud, or gravel bottoms.

In 1939, R.S. Danforth introduced an ultra-lightweight design named after himself, which has since earned a reputation for having exceptional holding power for its weight. Danforth types feature long, broad flukes, a pivoting shank, an angled crown on both sides, and a lightweight stock at the crown.

Line and Chain

While the advancements in ground-tackle have been dramatic and significant to the anchoring process, the key to a successful anchoring system continues to be the means of attaching the vessel to the anchor. There have been two options available to mariners: chain rodes and natural or synthetic ropes.

Chain has two distinct advantages: its raw, brute strength and its weight. The very weight of a chain rode provides a significant caternary effect, reducing loads transmitted to the anchor, which might cause it to break loose. The sheer weight of the chain (more than one pound per foot for 5/16" BBB) tends to keep the loading at the anchor on a more horizontal plane, thereby helping it set firmly in the bottom. Chain, however, exhibits no elongation; and once taut



(as in a storm situation), chain transmits large, destructive loads to the boat and anchor. And because of its weight, chain is difficult to handle without a windlass, and can result in vessel trim problems when stowed in the typical chain locker in the vessel's bow.

While sailors have relied upon natural fibers like hemp, manila, and cotton for hundreds of years, rope technology changed little until the 20th century. These lines added little to the dynamics of anchoring beyond a relatively static level of strength. They were heavy, bulky, prone to becoming waterlogged, and subject to the degradating effects of rot, sun damage, and shipboard vermin. Natural fiber ropes exhibit little elongation capability; so, like chain, they tend to transmit heavy shock-loads to both vessel and anchor.

In 1945, synthetic lines were introduced. The first application of nylon fiber to rope making added a significant level of performance over chain or natural-fiber rope. In addition to being strong and resistant to sun and rot damage, nylon fiber brought a new dynamic to the party: elasticity. This allows the line to stretch without breaking, thereby absorbing a portion of the load placed on the anchoring system by wind and wave action on the boat.

With manila or hemp lines, heavy loads often cause the line to break or to pull the anchor free from the bottom. Three-strand nylon anchorline (the most common construction method using nylon fiber), on the other hand, absorbs much of this loading energy by stretching without breaking, allowing the anchor to remain set. A side benefit of this characteristic is that the diameter of the line required to anchor a vessel adequately is reduced somewhat from that required for natural-fiber ropes.

Three-strand nylon line is not without its problems, however. The very act of stretching and retracting over many cycles generates heat within the fibers, which breaks down the physical properties of the rope, ultimately leading to failure. Because of the way that three-strand nylon line is twisted during manufacturing, it has a tendency to kink or hockle, particularly when used with mechanical winches. And, once the line becomes wet and is subsequently dried, it can become difficult to handle, resisting flaking or coiling. Three-strand nylon is notorious for being stubborn and uncooperative when stuffed down a hawse pipe for stowage.

Brait—The Yale Cordage Solution

Yale Cordage introduced a new manufacturing process in 2000 for making rope with nylon fiber, which solved many of the problems associated with traditional, three-strand nylon line. Rather than weaving three strands of nylon fiber into a rope, Yale technicians pioneered a unique eight-strand weave. This new line is called Yale Brait. In 2005, Yale introduced a polyester version of Brait which delivers the same strength, plus additional abrasion-resistance.

As a result of its unique construction process, Brait offers several advantages over traditional three-strand rope construction:

1) Less storage space is required

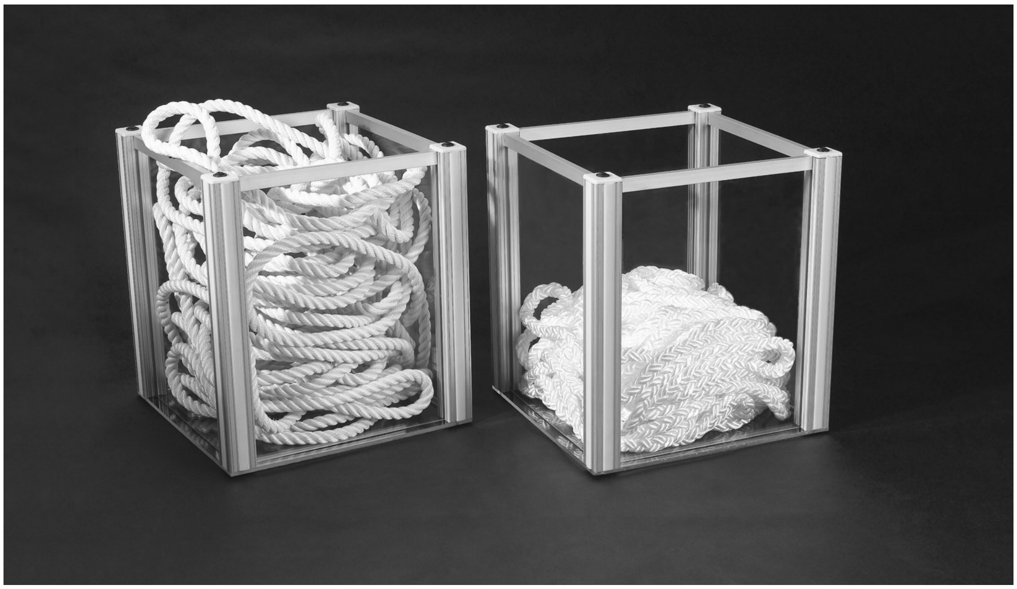
2) Lower pull-out force on the anchor compared to other types of rope and chain

3) Superior performance in power windlasses

4) Non-hockling; torque-balanced performance

Eight-strand Nylon Brait

Storage: Brait takes up much less storage space in anchor lockers than other rope constructions. Brait lies down flatter and lies more quickly into the locker, increasing the efficiency of windlasses. Because Brait requires significantly less storage space than its three-strand counterpart, it is also possible to carry a longer-length anchor rode in the same space.



On the left, 150' of three-strand nylon rope. On the right, 150' of Yale Nylon Brait. Brait's eight-strand weave makes it much more supple, easy to handle, and yields a very soft hand.

Pull-out force: Brait's superior energy absorption results in less pull-out force on the anchor, increasing the holding power of the entire system. This unique characteristic also minimizes destructive shock loading on fittings and deck hardware. As the system comes under load, the catenary of the rode begins to absorb energy. Once the line becomes taut, Brait begins to elongate (stretch), absorbing up to 75% more energy than three-strand nylon line. The combination of the catenary effect and Brait's elongation properties acts as a shock absorber.

Windlass performance: Brait's eight-strand, plaited construction provides exceptional surface area for a windlass gypsy to "grip" as the line comes aboard. Brait doesn't rotate on the windlass, so twist isn't introduced as the rope passes through the windlass and down into the rope locker. Because Brait remains supple and lies down quickly in the locker, it doesn't stack up into the windlass causing jams. Brait has become the line of choice by premium windlass manufacturers such as Maxwell and Lewmar.

Non-hockling; torque-balanced performance: The manufacturing process induces a natural twist to each strand of line, creating right-hand or left-hand laid strands. Brait's unique eight-strand construction matches these right-hand and left-hand laid strands with rotating elements in the final braiding process to create a torque-balanced line that does not kink up as it is coiled or as it moves through a windlass. The result is a supple, easily handled line that coils and stows without difficulty, and delivers improved pay-out characteristics as the anchor is lowered.

Nylon Brait Physical Properties

Diameter (inches)	Average Breaking Strength (lbs.)	Weight(lbs. per 100 ft.)
3/8	3700	3.4
1/2	6300	6.2
5/8	10400	10.3
3/4	16200	13.5
7/8	22000	19.0
1	27000	23.7

What Does Brait Mean for Your Boat?

Brait's extra energy absorption means several improvements in anchoring. Most significantly, the pull-out force on the anchor is greatly reduced, which increases the holding power of the entire ground-tackle system. That means better anchor-sets and fewer dragged anchors in the middle of the night in crowded anchorages

There is also less strain on the deck gear on board the boat. The effects of deck-gear loading have long-term degradation as well as catastrophic failure implications; continued cyclic loading on fittings like fairleads, cleats, or mooring bitts may lead to leaks and delamination or water-intrusion damage of the surrounding deck at the points where the fittings are attached. In addition, the cumulative effects of this high-energy loading may cause metal fatigue in the bolts or screws used to attach the fittings to the vessel, or even in the fittings themselves. In this weakened state, during extreme loading situations (storm conditions), the fittings may fail or pull out of the deck structure.

Additionally, Brait's ability to absorb up to 75% more energy than three-strand nylon results in a softer ride at anchor—that means less jerking and fewer abrupt changes in vessel motion as wind and waves move the vessel.

Finally, by selecting a Brait anchorline that provides the same or better strength as three-strand, the mariner also benefits from increased stowage space, allowing for either a smaller anchor locker or an increased length of rode.

Anchor-System Recommendations

Prudent skippers carry multiple anchoring systems; typically a primary or working system, a lightweight lunch-hook, and a storm system. A proper anchoring system consists of a length of synthetic fiber line, a length of chain, and a wired shackle connecting the rode to the anchor. While Brait has many physical advantages over ordinary three-strand line, it is still subject to abrasion from rocks, coral, or other obstructions on the sea floor. Adding a length of chain between the anchor and the Brait rode offers two primary advantages:

1. The chain will sustain most of the abrasion on the bottom as the boat swings at anchor and the anchor rode moves during the loading cycles.

2. The additional weight of the chain on the bottom enhances the anchor rode's catenary effect, improving the energy absorbing capabilities of the system. And because of its weight, a chain lead tends to keep the pull on the anchor on a horizontal plane, minimizing the risk of the anchor breaking loose of the bottom.

Yale recommends selecting a high-test chain of between one and two times the length of the boat for most applications.

Primary-anchor Gear Selection Chart

Boat Length (Feet)	**Brait Diameter** (Inches)	**Brait Length** (feet)	**Chain Size** (Inches)	**Chain Length** (Feet)
16–20	3/8	100–150	3/16	16–20
21–25	3/8	100–150	3/16	21–25
26–30	1/2	150–200	1/4	26–30
31–36	1/2	200–250	1/4	31–36
37–40	5/8	250–300	5/16	37–40
41–45	5/8	250–300	5/16	41–45
46–50	3/4	300–350	3/8	46–50
55–60	3/4	300–350	3/8	55–60

Addendum 1

The Physics of Rope and Chain

When a rope holds a vessel in place it is performing "work." The measure of a rope's ability to do work varies with the fiber and construction (lay) of the rope.

The amount of work a rope or chain can perform can be indicated graphically by plotting its performance in a stress-strain curve. The larger the area under the curve, the more energy the rope or chain can absorb before failure.

A vessel at anchor is subjected to varying forces, including both wind and wave action. These forces impart measurable loads (energy) on the hull and superstructure of a vessel. This energy must be absorbed either by movement of the boat through the water, or by the anchor system's ability to absorb this energy. The anchor rode, to the extent of its physical properties, acts as a shock absorber, preventing the anchor from being pulled out of the bottom, or stopping the fittings from being pulled free of the vessel.

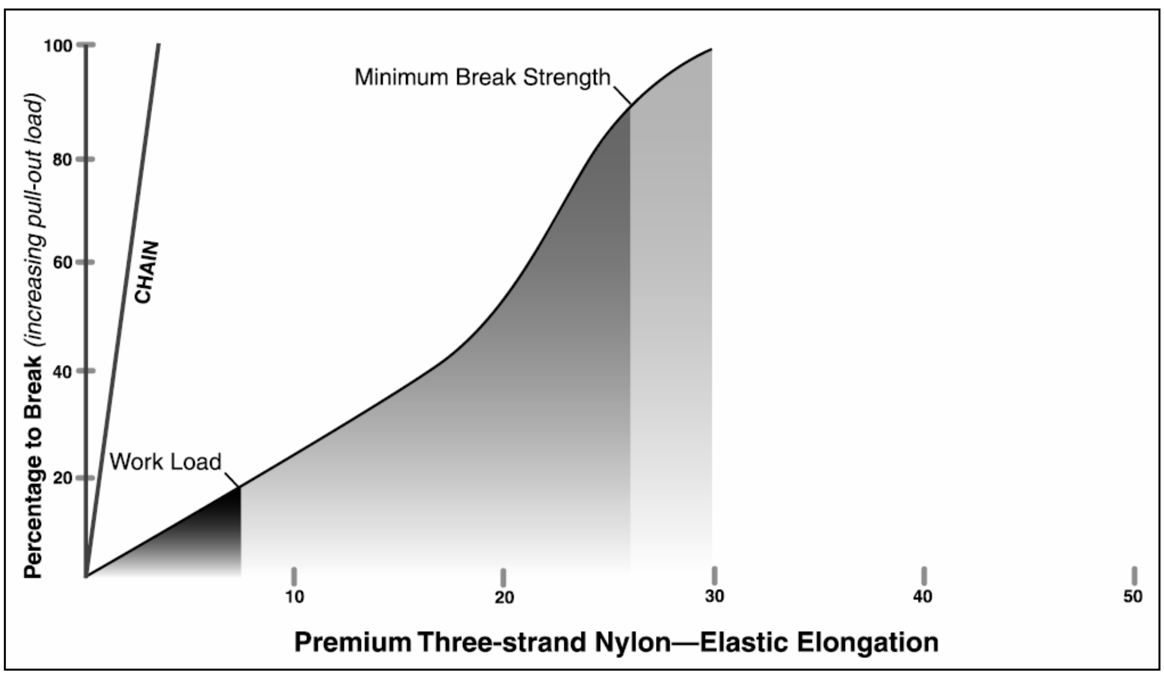
Strength vs. Elongation Chart

	Average Breaking Strength (lbs.)	Horizontal Energy Absorption (ft. lbs./100')
5/16" BBB Chain	7,600 lbs.	0
1/2" Three-strand Nylon	5,750 lbs.	67,665
1/2" Nylon Brait	6,300 lbs.	114,452

In the case of chain, most of the energy absorption comes from the ability of the chain's catenary to resist lifting the chain off the bottom. But, during a storm, that capacity is reached quickly and the chain fast approaches its inherent failure point. As the failure point is reached, the chain becomes bar-taut and the pull-out loads on the anchor build quickly, as do destructive loads on the deck fittings.

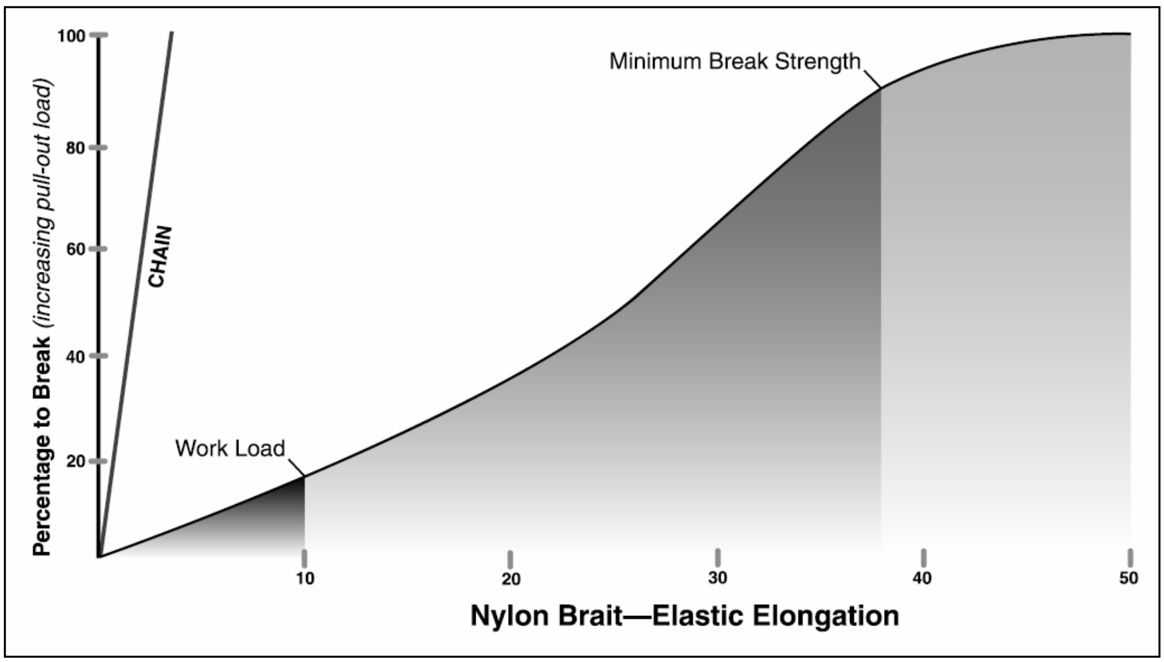
Premium Three-strand Nylon Line

Three-strand nylon line stretches quite easily when a load is first placed on it, absorbing little energy. It quickly gets busy as the load passes 20% of the line's breaking strength; however, that puts it beyond its recommended working load. The stretching process within the three-strand lay generates heat within the fibers, accelerating the rapid fatigue failure of the line.



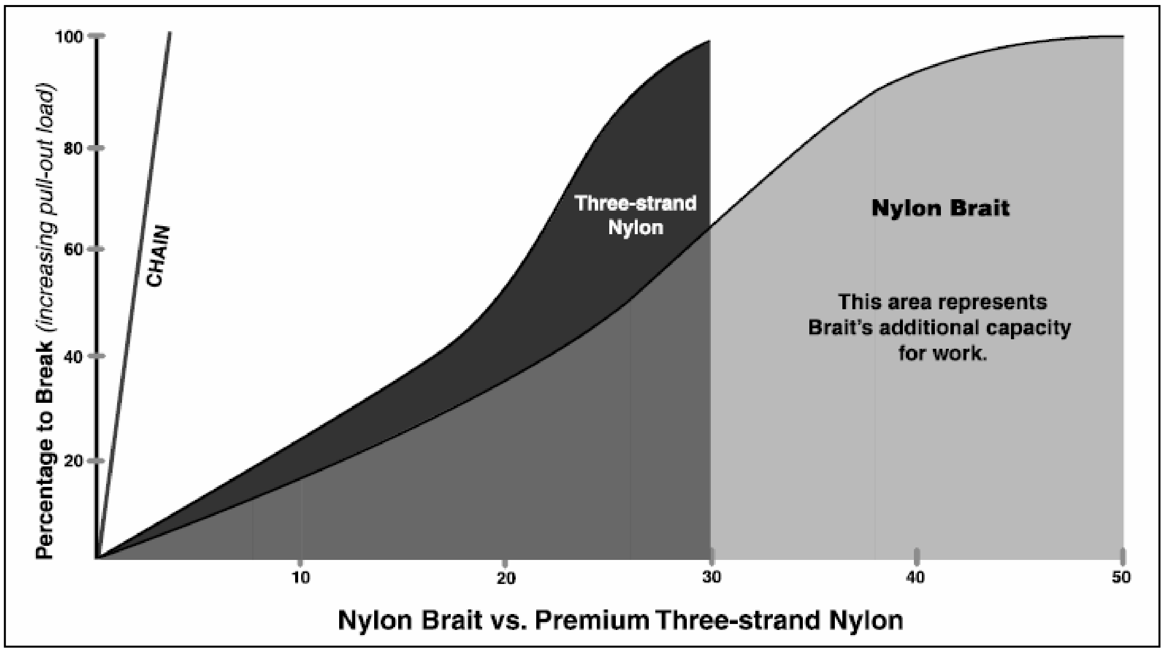
New Yale Nylon Brait Line

Yale Nylon Brait capitalizes on the elasticity of nylon fiber, and incorporates a unique construction lay to yield similar breaking strength as three-strand, but with far greater energy-absorption capability. More energy is absorbed at lower loads (note in the graph that the shallow slope of the curve is longer), minimizing the pull-out load on the anchor and deck fittings. Plus, the strain on the nylon fiber itself is lower, reducing heat buildup and lessening fiber fatigue.



Brait-to-Three-Strand Comparison

Combining these diagrams onto one graph, the superior ability of Brait to absorb energy is easily seen in comparison to chain and three-strand line. In simple terms, Brait demonstrates a much larger capacity for work as indicated by the area under the stress-strain curve.



In this diagram, the break strengths of nylon Brait and premium three-strand nylon are similar (see top of the curve), but three-strand reaches its failure point much sooner than Brait. Additionally, Brait shows nearly 75% more energy absorption, as illustrated by the extended length of the area under the curve. Chain, on the other hand, has little energy-absorbing ability (without the catenary) once it is strained to its breaking point.

Addendum 2

The Math Behind the Physics of Rope

Mathematically, the maximum energy-absorption capacity (EAC) of a rope is measured in foot-pounds (ft. -lbs.). EAC is equal to the weight of the rope in tension in pounds (W) multiplied by the energy-absorption characteristics of the rope expressed in foot-pounds per pound (EA): W x EA = EAC

Examples

A) 200' of three-strand nylon

W x EA = EAC

13 lbs x 10,410 ft.-lbs./lb. = 135,330 ft.-lbs.

B) 200' of nylon Brait

W x EA = EAC

12.4 lbs. x 18,460 ft.-lbs./lb. = 228,904 ft.-lbs.

Note that weight (W) is an important part of the equation. To put more pounds of rope into play (increasing W), a larger-diameter (heavier) rope must be used, or the scope must be increased (more rope under tension).

Application in the Real World

The pull-out load on a 1/2" x 200' length of premium, three-strand anchor rode at 16 percent of its breaking strength is 920 pounds. The line would have stretched 7.5% in length to 215'. The energy absorbed at this point is equal to 6,900 ft.-lbs. An identically sized Brait anchor rode at 16% of its breaking strength has a pull-out load of 1,260 pounds and would have stretched 10% to 220'. The energy the Brait rode has absorbed at this point is 12,600 ft.-lbs. Not only does Brait exhibit more energy absorption at its calculated breaking strength, it also delivers increased energy absorption under any real-world condition. In this case, 82% more energy absorption at 16% of the rope's breaking strength.

By using Brait with its superior energy absorption advantage, the anchorline is effectively lengthened without having to increase diameter or add more scope, as compared to three-strand rope.

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Anchoring Technology is published by Yale Cordage, 77 Industrial Park Road, Saco, Maine 04072, Tel: (207) 282–3396, Fax: (207) 282–4620, www.yalecordage.com.

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