The Study of Knot Performance

Exploring the Secrets of Knotted Cordage to Understand How Knots Work

Knot Stability

How an Abnormal Load Affects a Knot

The Half Hitch, with the nip adjusted to bear at the top of the spar, is quite a different thing. So long as the pull is constant, and the adjustment is not altered by loosening or shaking, the hitch is adequate for almost any temporary purpose.

– Clifford Ashley (#1663) 290

The Groundline Hitch . . . is resistant to tugging under any angle.

– Peter van de Griend
“Knots at Sea” 145

Capsizing a knot is changing its form, rearranging its parts, usually by pulling on specific ends in specific ways.

– Charles Warner
“Studies in the Behaviour of Knots” 199

No knot is safe except under reasonable conditions.

– Clifford Ashley 186

The Manharness, most delightful of knots to make, . . . and excellent for a steady haul on a rope which is itself under tension from end to end, may become a slipknot when pulled about by alternate straining and slacking. Now these are just the conditions that occur in climbing, and they exact as the first quality in a good knot that it shall be unaffected by intermittent strain.

– Wright and Magowan, 120–121

Summary

Knot *stability* refers to the degree that a knot can keep its form or arrangement when it is subjected to an abnormal load. An unstable knot is apt to deform or to capsize or tumble. Although knot stability is an essential concept for understanding how knots behave, neither the term nor the concept has not come into general use, even among knot specialists.

In addition to knowing how knots behave when put to ordinary uses and loaded in the ordinary way, knot users need to understand how an abnormal load can deform an unstable knot. Subjected to a load from a direction it was not designed to withstand or subjected to an intermittent load or an overload, an unstable knot can lose its shape and become unable to bear a load.

The effect of instability can be beneficial or harmful. To unfurl a sail on a square-rigged ship, a sailor only had to pull on the tail if the Reef Knot. It would deform and come untied, releasing the sail. Instability makes this knot useful for this purpose—and dangerous if you use it to join two free ropes.

But today, even experienced knot tyers often fail to take into account the way many knots can deform and become useless when they are stressed by an abnormal load. And few users of practical knots seem to be aware of the many ways that knot insecurity can be useful to them.

Key Words

Knot stability, stable knots, unstable knots, instability, normal load, abnormal load, knot rearrangement, knot deformation, knot failure, one-stage failure, two-stage failure, levels of knot stability

This paper can be read alone, but it is easier to understand if you’ve read the previous ones of knot security and distinguishing security and stability.

If your analysis is different from mine, or if you have found a better way of stating things, let me hear from you on the knotblog or via email. Click here to open the blog or to send an email message.

Introduction: The Secret Flaw of a Bowline

Many experienced not tyers are surprised to discover that the Bowline, which they esteem so highly, has a secret flaw. This knot has long been the favorite fixed-loop knot because it is so easy to tie and it works so well. Everyone knows that it holds securely when arranged and applied in the normal way, with the standing part attached at one end and a weight suspended from the loop at the other end. What few knot users seem to realize is that a sharp jerk that pulls the tail to one side can deform a Bowline. If you happen to snag it so that the tail and the right leg of the loop are yanked hard in opposite directions, the structures may not be stable enough to resist deformation. The bight can straighten out and disappear and the hitch that circles the bight can be transformed into a slip knot. If the knot is deformed in this way, the hitch will no longer have either squeezing power or anything to squeeze against. It will not be able to create enough friction to hold the knot together and can be easily stripped off.

Every time I demonstrate this marvel to a group of knot tyers, someone responds “Wow,” and someone else calls out “Do that again.”

These responses indicate that there is a gap between the way unstable knots behave and our awareness and understanding of their instability. The fatal flaw of a Bowline is that it depends on the stability of one exposed bight. Although the tail is protected somewhat by its position inside the right leg, it can easily be snagged. Ashley comments that “Properly tied in ordinary rope, there is little or no danger of a Bowline Knot’s capsizing before the breaking point of the rope itself is reached” (186). But he says nothing about the effect of a strong snag or yank to the side on the tail.

Analysis of a few examples of unstable knots reveal some of the complexities of studying knot stability. Although these knots are quite secure when they are loaded in the way they were designed for, they can be unstable and become insecure when they are not loaded that way. The study of knot stability leads in numerous fascinating directions, with many applications, both practical and theoretical.

The Instability of a Square Knot—Useful or Dangerous

A Square Knot has two identities, one beneficial and the other dangerous.

In the days of square-rigged ships, every sailor was acquainted with the dramatic way that a yank downward on the tail of a Square Knot alters its form and causes it to come untied. As Ashley pointed out, this instability makes the knot useful for reefing sails:

> One of the distinguishing features of the Square Knot and the one which gives it its chief value as a reef knot is the ease with which it may be untied. Jerk one end

> in a direction away from its own standing part (that is, toward the other end) and the knot capsizes; all the turns are left in one end and these are easily stripped from the other end with a sweep of the hand (120).

But the same Square Knot, which is so useful for this purpose, can be dangerous if used to join two ropes. Ashley noted further that “There have probably been more lives lost as a result of using a Square Knot as a bend (to tie two ropes together) than from the failure of any other half dozen knots combined” (258). A good part of the reason for this baleful fact is no doubt the same characteristic that makes it so useful for releasing reefed sails. A yank to one side rearranges its structures to that they cannot hold the knot together.

If knot tyers fail to take into account the way that the structures of a knot can be rearranged when stressed by an abnormal load, they leave themselves vulnerable to mishap. They also fail to benefit from the utility of converting some knots to another useful form, and they may fail to observe the exquisite beauty of the way quite a few knots perform.

Rationale of this Study

We study knot stability with special attention because this crucial aspect of knot performance is often overlooked or misunderstood. Quite frequently, stability is not clearly distinguished from security. Closely observing and analyzing the way the structures of several knots can be disarranged and come undone when they are fouled by an abnormal load, and the way other knots resist disarrangement, will help us refine our understanding of the performance of all unstable knots. Assuming that knots are properly tied in uniform rope, dressed and snugged, and used under standard conditions, their stability depends on the way the segments of rope are shaped and intertwined. The conditions I assume are those suggested by Ashley’s phrase “properly tied in ordinary rope.” (#1010 186)

Studying this aspect of knot behavior will raise to the level of conscious awareness our latent sense of the relation between a knot’s structure and the way it works. Understanding these aspects of knot performance can help knot users recognize the earmarks of unstable knots and to deal with them appropriately.

Aims of this Study

The first aim here is to raise awareness that stability is a distinct characteristic of knots. Although knot stability and knot security are complementary aspects of knot performance and both strongly affect how we use knots, they are quite different properties.

The second aim is to show how the structure of a knot affects its stability. There are several aspects of this aim:

- To show how an abnormal load can affect an unstable knot.
- To identify various kinds of abnormal loads and the ways they can trigger rearrangement and deformation of the structures of a knot.
- To show that instability can be either hazardous in a knot that is deformed inadvertently or beneficial in a knot that is made to alter its form intentionally.
- To show effective and efficient ways to deal with hazardous instability of a knot.
- To show that a secure knot can be unstable.
- To show how an abnormal load on an unstable knot can trigger failure in two stages.

When we begin to look closely at this aspect of knot performance, we discover several fascinating truths about knots that often go unnoticed.

The Problem of a Fuzzy Concept of Knot Stability

People who use knots may have observed what happens when an abnormal load is placed on an unstable knot. But they may have overlooked the causes of the deformation, so the concept of knot stability continues to remain fuzzy for them.

To being with, few knot users distinguish knot security from knot stability. Although many knotting books mention knot stability, they usually refer to it only in passing as a secondary aspect of knot security, and some writers confuse the two. Stability is rarely thought of as a distinct property of knots, and knot books do not tell what it is or show its causes and effects. In describing the properties of the Grass Bend (#1490), Ashley uses the concept of stability without giving it that name: “When the ends have been arranged as shown, due to the flatness of the material, they cannot shift into an insecure position.” The concept is often entirely ignored. Charles Warner apparently had knot stability in mind when he commented in 1996, “I do not know of any systematic studies of capsizing as a mechanism of failure of knots in use” and pointed out that “many studies of failure do not mention the mechanism” (“Studies in the Behaviour of Knots,” 199). Not much has been done since that time.

Terms and Concepts for Studying Knot Stability

Several terms and concepts are essential for discussing knot stability.

Deformation

Under load, all knots tend to *deform* or lose their customary shape to some extent. When I use the term, I refer to gross deformation that affects the knot’s performance.

Normal and Abnormal Load

A *normal* load falls on the structures of a knot when it is used the way it was designed for. A Bowline, for example, is loaded normally when the standing part is attached above and a load is suspended from the loop below. This application places structures under stresses that the knot can ordinarily withstand without deforming. An *abnormal load* places a stress on a knot it was not designed to withstand. It may come from a non-standard direction, it may be intermittent, or it may simply overload the knot. This distinction between normal load and abnormal load is often overlooked.

Note that these terms refer to the way we customarily use the knot; a load is normal or abnormal for a particular knot used in a particular application.

Sometimes, the deformation of a knot is inconsequential. As people who have fooled around with knots may have observed, a Half Knot loosely tied over a rail or spar will easily deform into a left Half Hitch or a right Half Hitch, depending on which way you pull it. In most uses, it can hardly be said that one load is more normal or abnormal than the other.

Stability and Security

Stability and *security* are discrete properties of knots. When a secure knot bears a normal load and is used in the normal way, it creates enough friction at critical points in its structure to resist slipping and coming apart. An insecure knot tends to slip apart and come undone, even under a normal load.

A stable knot is able to resist alteration of its form. Some knots are so stable that they firmly resist distortion or alteration and do not easily change form even when subjected to an abnormal load. Stability and instability range from the considerable stability of a Double Fisherman’s Knot to the extreme fragility of a Slippery Hitch (Ashley #82). A Bowline comes somewhere in between.

An abnormal load falling on an unstable knot can change the form and arrangement of the individual structures. This rearrangement can cause a knot to lose its gripping power so that it is no longer secure and will fail to hold itself together well enough to bear a load. Or it can cause a useful or beneficial change to a different form. Other words for this change of form and arrangement are *capsize, tumble, upset, or distort*. I generally use the term *rearrange* for neutral or beneficial change of form and use *deform* for undesirable change that reduces the knot’s ability to hold together and leads to failure.

These two properties, insecurity and instability, affect knot performance in very different ways, their causes are very different, and their remedies are very different. Although they are both important aspects of knot performance and are closely related, they are clearly distinct. They are, of course both relative qualities, not absolute.

The Effects of Instability on a Knot

An abnormal load on an unstable knot may only alter the arrangement of its structures or it may cause the knot to come untied. Any of the changes in arrangement of structures occur most readily if the knot is only loosely tied. After being tightened by a heavy load, many knots do not yield to destabilizing forces, even to a strong abnormal load.

The Effects of Instability 1. Knot Failure in Two Stages

As shown in the previous study of knot security, an insecure knot can fail because it simply slips apart. This is what I call *one-stage failure*.

In the classic process of knot failure caused by instability, an unstable knot comes undone in *two stages*. Subjected to an abnormal load, the knot deforms and loses its holding power. Then it slips apart. This is the kind of change described in the scenario in item #1 in “Distinguishing Security and Stability” and in Ashley’s comment on the Square Knot used as a bend. The change is brought about because of a lack of stability followed by further change caused by insecurity.

This is how two-stage failure works. In the *first stage*, an abnormal load pulls an unstable knot out of shape. Deformation alters the structures that create pressure at key locations and destroys the knot’s ability to produce enough friction to hold it together. In a typical first stage, a vulnerable and exposed segment of rope is yanked to the side, the bights lose their curve and straighten out, hitches lose their friction points and have nothing to squeeze against, and doglegs in the knot cease to exist. At the end of this first stage, a secure knot becomes an insecure knot.

In the *second stage* of failure, a continued load on the standing part will cause the insecure knot to slip apart and come undone. Ashley describes these two stages of failure of a Square Knot. First, the knot will capsize, he notes, then the deformed knot can be stripped “with a sweep of the hand” (220). The demonstration of the Bowline described above illustrates the same two-phase kind of failure. This complete destruction of the knot can be dangerous, particularly for the unwary.

In brief, after the knot has become insecure, continued application of the load causes it to slip apart.

Distinguishing One-Stage and Two-Stage Failure

Two-stage failure caused by instability should be distinguished from one-stage failure caused by insecurity. In one-stage failure, an insecure knot under load simply slips apart and comes untied all at once, like Oliver Wendell Holmes’s wonderful “one-hoss shay,” that

… went to pieces all at once
Just as bubbles do when they burst.

A Granny knot often comes undone in this way, and other knots are vulnerable in the same way if they are tied in slippery cordage or not tightened up. Two-stage failure works in a very different way.

Everyone who uses rope for life support should be alerted to the danger of these kinds of knot failure. Experience may be the best teacher, but, as one correspondent has noted, “some errors lead to the end of experience.”

The Effects of Instability 2. Useful Alteration of Knot Structures

While the effects of rearranging the structures of a knot may be disastrous, many rearrangements are beneficial. In some cases, alteration of form can be used to untie a knot. In other cases, the structures of an unstable knot can be rearranged so that it takes on a useful new shape with enhanced characteristics or even a new identity and entirely different uses.

2.1 Use an Unstable Structure as a Quick-Release Device

Special release devices can make a knot collapse and disappear when you pull a particular structure. Yank the correct cord, and Poof! the knot’s gone. This kind of mechanism is handy for immediately untying the knot. We have become so accustomed to the magical disappearance of the Double Bow in our shoelaces that we no longer notice it. The Double Bow is actually a Square Knot fitted with two bights so that both tails are “slipped.” Having released the bow, you are left, of course, with the original Half Knot.

Several other knots can be slipped for quick release without leaving a trace. A Chain Stitch, the quick-release stitching on feed bags and bird-seed bags, can be undone by holding one thread and pulling the other—if you can figure out which one to pull. Triggering the release device destroys the knot completely. Many of these, such as the Slipped Half Hitch (#52), are quite secure, but their collapse-on-demand makes them especially useful. Sometimes the knot is so tightly snugged or so heavily loaded that the release device doesn’t work very well.

Cyrus Day comments that a tug on the tail of the Highwayman’s Cutaway “releases it instantaneously, without pulling any part of the line back through the ring or round the spar”

(106). This insecure knot is the Jesse James of hitches, made for a quick getaway after robbing a bank. But it is also unstable, so that it may come apart inadvertently, even under normal load (Lehman). It has nothing to do with Alfred Noyes’ “The Highwayman,” which mentions two knots, neither of which is a Highwayman’s Cutaway.

For more about quick-release knots, see Peter Suber’s article, “Exploding Knots” on the web: earlham.edu/~peters/ writing/explode.htm.

2.2 Loosen a Knot by Rearranging its Parts

It is easier to untie some knots if you first deform them. If a knot hasn’t been loaded too heavily or jammed too tight, the nub can sometimes be loosened by deforming a particular segment. As described above, tension in the nub of a Square Knot or a Bowline can be released by a yank on the tail. Then it will be easier to untie. In a different maneuver, which is equally effective, a Bowline can be loosened if you fold the bight down over the standing part. A Carrick Bend and a Square Knot can be loosened in the same way. After the knot has lost its holding power, the altered parts can often be pulled apart more easily.

2.3 Create a Different Knot by Rearranging the Segments

Sometimes rearrangement can be used as an alternative way of tying a knot. By pulling on one of the standing parts of a Half Knot, for example, it is converted to a Half Hitch, and a Granny can be converted to Two Half Hitches. In an awkward spot, it may be convenient to create a Bowline by starting out with a Slipknot with a long tail, poking the tail through the loop, then pulling on the standing part. This causes the segments of rope to be rearranged as a Bowline. You can restore the original form by reversing the process. In addition to convenience, this procedure also makes a suitable demonstration for impressing colleagues. I’ll never forget the first time I saw it done.

2.4 Lock a Knot by Rearranging the Segments

A knot’s propensity to change shape can sometimes be used to increase its security. The final stage in tying a Carrick Bend, for example, is to pull the standing parts in opposite directions so that the lattice form of the Josephine Knot—a design used in macramé—rearranges itself naturally into a locked Carrick Bend. The Clark Kent knot is transformed into Superknot and changes from a decorative knot to a strong and secure practical knot, without the aid of a phone booth.

2.5. Use an Altered Knot as Part of Another Knot

Sometimes the various forms of a particular knot are used as part of more complex knots. An Overhand Knot can be used by itself as a binding knot or a backup knot, as the first part of a Bow Knot, or as both the first and second parts of a Square Knot and a Granny Knot. The Overhand can be rearranged so that it forms the first part of Two Half Hitches, either left or right. Analysis of a Constrictor Knot shows that its lower segments cross over and tuck under each other in an overhand configuration. Both an Overhand Knot and a Figure Eight Knot can be used as part of a slipped knot or a loop, such as in the Trucker’s Hitch. These mutations often go by without notice because they are so much a part of our ordinary knot use.

26. Adjust a Knot by Rearranging its Parts

Closely related to structural alteration and deformation are the workings of adjustable knots. The load placed on them is not really abnormal, the structures aren’t deformed in usual way, and the knot doesn’t necessarily break down and come apart. But the load is released temporarily while the knot parts are rearranged. A Taut-Line Hitch (Adjustable Hitch #1800) is designed so that it can be easily adjusted by releasing the tension, then pulling the sliding part of the nub along the standing part. In this knot, which is made with a Magnus or Rolling Hitch (Ashley #225, #1734, #3833), a load from a normal direction restores the kink that keeps the nub in place and makes the knot secure. The Capstan Knot (#1831) is adjustable in a similar way. A Timber Hitch (#1665) is secure when it is supplemented by a half hitch to guide it, but used alone it “practically falls apart when pull ceases.” (Ashley #290) Under load, all of these knots are secure, but they are adjustable so they may be useful in ascending and descending. As Ashley comments, these knots “may be slid up and down with the hand, but they remain firm under a pull on the standing part” (77).

Ashley’s Adjustable Bend (#1472) joins two ropes “by tying a Rolling Hitch in each end around the standing part of the other. The knots may be easily slid, even when the rope is under tension, and will hold when the hand is removed.” Ashley’s Tug-of-War Knot (#2558) uses the same combination of knots, but now as a trick. Closely related are the Midshipman’s Hitch (#1993) as well as the various slipknots and lariat loops. See also Ashley #1030, #1991, and #1994.

The structure of a Munter Hitch and the way it works make it highly unusual among knots. It is the Janus of knots, capable of looking both ways. Placing the main load on one standing part and then on the other cause the nub to switch back and forth between two forms. When the main load shifts from one standing part to the other, the nub merely rearranges its segments automatically and performs the same task in the opposite direction. It retains the same form, but with a different loaded end. Although a Munter Hitch is unstable in this way, it is as secure and effective in one form as the other. There may be other knots with this handy way of shifting forms, but I don’t know any.

To build a device or ascending a fixed rope, climbers have devised several configurations of slings that form multiple wraps. To create a sling of this kind, the Prusik Knot, the Klemheist, the Bachman, and the Autoblock all use multiple wraps that grasp a larger rope (Raleigh 47–51). In each of these ascenders, where the load is moderate, ease of release of grip and adjustment is more important than strength. While each of these depends on the principles of a core-and-wrap knot, none of them uses a slide-and-block device. Under extreme load, they may well slip, but they hold surprisingly well. This is yet another application of Ashley’s adage about “a few turns of line” (77).

Several of the adjustable knots may not be familiar to everyone, but their names tell their applications: the Flagpole Sling (#454), the steeplejack’s Safety-Belt Hitch (74 #452), the Camel Hitch (#215) In addition, most of the simple knots for belaying and making fast the lines on a ship are adjustable. (Ashley, Chapter 20).

The Tag Knot (#1126) is secure enough in the usual sense, but only as long as a load is on it.

Adjustable knots are different from *running knots*, such as the Running Bowline, Lariat Loop, and Slipknot. Usually these knots nip up close and tight to bind a bundle or make fast to an object; unless drawn up tight, they will slip all the time. They can loosen when the load is released, and so might dump their load or allow it to slip.

Levels of Knot Stability and Instability

To understand knot stability better and to distinguish it more clearly from knot security, it is instructive to contrast the structures and performance of a few knots at four levels of stability.

A reminder about stability and instability: a stable knot is not easily pulled out of shape, even by stresses it was not designed to resist. It is not seriously compromised by abnormal loading such as slacking, shaking, jerking, snagging of a strand, excessive loading, or loss of load. The more stable a knot is, the more it is able to resist distortion and deformation.

An unstable knot, on the other hand, will deform and fail. A loose tail may snag, a hitch may shake out, or a bight may straighten out.

The Lowest Level of Stability

Balancing Pole Hitch: Adequate Security, Minimal Stability

The Balancing-Pole Hitch

The most dramatic illustration of the distinction between security and stability is the Balancing-Pole Hitch (Ashley #84, #218). When used skillfully, this amazing knot is secure enough to support the weight of a human body without slipping in the least, but it is among the most unstable of knots.

The purpose of this hitch is “to support a man from the top of his balancing pole while he is climbing aloft.” As shown in Ashley’s illustration of this hitch being used in a circus act, one man holds a pole out at an angle while another man walks nimbly up it, suspending himself by means of a rope fixed to the top of the pole. When part way up the pole, he twitches the rope to relieve tension on the hitch, which immediately releases the knot and spills him to the ground (Ashley 19). This spectacular stunt leads the audience to wonder "How does he do that?" The secret is that the hitch holds only by pressure of a segment of rope wrapped in a clever way around end of the pole.

The construction of this knot is highly unusual. The rope wraps only once around the pole and once around the tail, then crosses over the end of the pole. There are no tucks. The segment that crosses over merely presses against another segment of the rope to create enough friction to make it secure. In the ordinary sense of the word (as well as in the mathematical sense), this is no knot at all. But so long as the load presses the rope onto the end of the pole in exactly the right way, it holds.

The Balancing Pole Hitch is a special type of quick-release knot. It appears to fail completely all at once. But it actually comes undone in two phases. Virtually any reduction of tension will upset it. Doubtless, tugging on the tail would have the same effect, but I doubt that anybody ever tried that procedure.

The performer suspends himself from a knot that seems to be entirely secure, then is shown to be extremely unstable. This knot illustrates quite clearly the important distinction between knot security and knot stability. When used in the way prescribed, its structures make it secure, but no structural devices make it stable. In the sense of the terms used here, the Balancing Pole Hitch is one of the best examples of a knot that is both secure and unstable.

Other examples of extreme instability are the Single Hitch (#49), the Slippery Hitch (#82 #1603, #1605, #1606), and the Precipice Knot (62 #391). These knots are so unstable that if you twitch or flirt the standing part of the rope, they actually fall apart of their own weight. What Ashley says about the Precipice Knot applies to all of them: this is "no knot to trifle with."

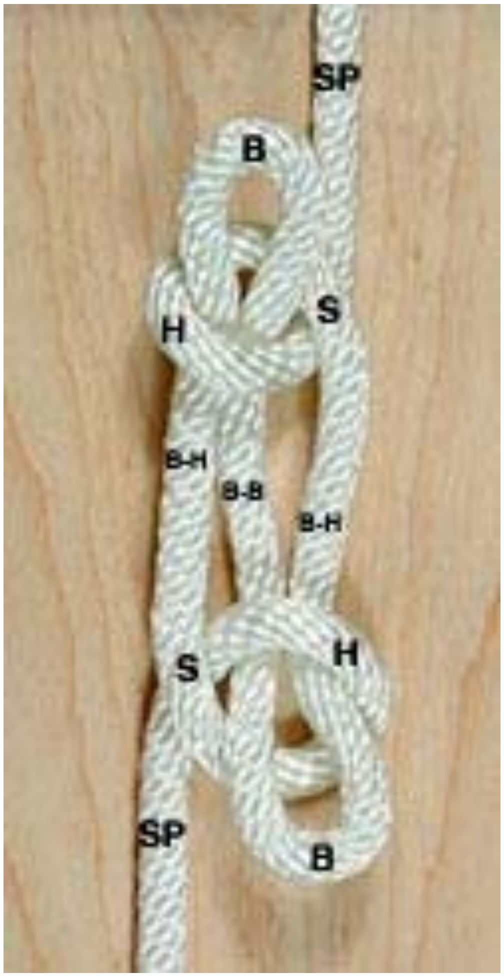
A Moderate Level of Stability

Sheepshank: More Stable than You Might Expect

A Sheepshank is a more or less long and stringy knot tied in a single rope, with a hitch and a bight at each end that are connected by three parallel strands in the middle. It has a distinctive ungainly form made up of unusually prominent knobby-kneed structures. It is long, scrawny, timid, awkward, somewhat insecure. I think of it as the Ichabod Crane of knots.

The stated function of a Sheepshank is to shorten a rope temporarily without involving either end. As Cyrus Day noted in 1922, a Captain Felix Riesenberg remarked that it is used now "about as often as the cross-bow" (116). In the movie *Jaws*, the knot serves as a shibboleth. The crusty old sea captain tested the ability of a potential recruit by throwing him a length of rope and demanding that he tie a Sheepshank. I've seen it tied by several methods and with numerous variations by knot tyers who were showing off their skills. And I have actually talked to a couple of sailors who claim that they have used it.

The figure below summarizes the results of my analysis of the stability of a Sheepshank.



SP Standing Parts

The two standing parts or loaded ends of a Sheepshank enter the nub of the knot at S, the places where the hitches cross at each end.

The Nub

The nub is the knotted part of the knot. In a Sheepshank, the two-part nub is made up of a bight and a hitch at each end. Three strands in between connect them—a most unusual arrangement.

H The Hitches

The hitches wrap around the legs of the bights and squeeze them together. This embrace of the hitches around the bights is the most important structural device in a Sheepshank, as it is in a Bowline.

B The Bights

The bights emerge from the encircling grip of the hitches and stick out at each end of the knot.

B-B The Bight-to-Bight Connector

The central connecting segment merges with the bights at each end.

B-H The Bight-to-Hitch Connectors

A connecting segment on each side of the knot joins each of the bights to its own hitch.

The Unusual Structure and Performance of a Sheepshank

Unlike most knots, a Sheepshank has two distinct functional parts, in which the lower parts have the same form as the upper parts. It has a middle but no center. It is made up of six kinds of structures. At each end, there is a standing part, a bight, a stem, and a hitch that wraps around the two legs of a bight. Between these structures, one segment connects the bights, and a pair of segments connects the hitches to the bights. Each end of a Sheepshank has five crossovers, more or less simple ones, and one wrap, making a total of twelve areas where the segments of rope come into contact. The two nips (another unusual aspect of this knot) are at the crossovers of the hitches. There are two standing parts or loaded ends, but no tail. This knot can be tied in various forms, with the stems and the connectors arranged in different ways. A standard form of this remarkable knot is shown here.

The Security and Stability of a Sheepshank

For dramatic illustration of the contrast between knot security and knot stability, the Sheepshank has few rivals among familiar knots. On the one hand, it is surprisingly secure. When loaded steadily in the standard direction, the hitches tighten around the legs of the bights, squeezing them together and creating friction that inhibits their movement. A Sheepshank is actually able to bear a normal load even if you sever the rope in three particular places, at the two bights marked B and at the middle connector marked B-B. Examination of the knot shows why this is possible. (This practice is recommended only as a trick or for demonstrating this principle and is not to be tried out over a cliff or chasm.)

As interesting as the ungainly appearance and security devices a Sheepshank may be, studying its stability is more revealing. Since it is tied with a hitch at each end and is provided with no other structures that prevent them from loosening their squeeze and becoming disengaged from the bights, it proves to be somewhat unstable. The ISV term *metastable*, coined according to Webster’s Collegiate Dictionary in 1897, applies to a Sheepshank: “Having or characterized by only a slight margin of stability.” Although its crux is the same as in a Bowline, the Sheepshank has no segments threaded through the bights to keep them in line; it is unstable for very different reasons.

Only tension on the connecting strands holds the hitches of a Sheepshank in place, and if the rope is alternately made taut and lax, they are easily dislodged. Flips or twitches on either standing part, which alternately load and unload the structures, will loosen the hitches and cause the bights to untuck. Deformed in this way, the friction-creating devices fail and the knot slips and comes untied. Experience shows that a Sheepshank is more stable if the protruding bights are quite long and if the connecting segments are relatively short. Yet even tied with long bights and short connectors, it is somewhat unstable under an abnormal load.

A Higher Level of Stability

The Bowline: Less Stable than You Might Think

Even though a Bowline is quite secure, a single demonstration of the way it can deform when an abnormal load is applied, as described above, reveals that while it is secure, it is somewhat unstable. A closer look at a Bowline shows why. The nub of this knot is made up of only two main structures, a single hitch that squeezes a single bight that merges with the tail. This arrangement provides sufficient security, yet because the bight has no protective devices, it is vulnerable to deformation when subjected to an abnormal load such as a sideways jerking motion. Even the workhorse Clove Hitch demonstrates the same principle. Ashley notes that “The hitch may be unwound with a rotating pull in one direction, particularly if it is tied to a square post and the rope is stiff.” (302)

Knots as different from each other as a Balancing-Pole Hitch, a Bowline, a Sheepshank, and a Close Hitch all how that it is quite possible for a knot to be secure without being especially stable.

The Highest Level of Stability

Climbers and rescue workers generally use stable knots such as a Double Fisherman’s Knot and a Figure Eight Loop. Inspection will show why they are stable.

Why a Figure Eight Loop is So Stable

A Figure Eight Loop is much more stable than the Bowline or Sheepshank. The tail, which is so vulnerable in a Bowline, is held firmly by two hitches. When properly tied, these hitches draw tight and create the greatest pressure and friction at the place where the tail exits the nub. Segments that are under only minimal load and pressure are buried deep in the middle of the knot.

The hitches at each end of a Figure Eight Loop are doubled up so that if one part of the structure fails, another is there to perform its function. Even if extreme conditions happen to cause the tail to back out so that the second hitch is lost, the duplicate structures will keep the knot stable and preserve its form. This is a remarkable property of a Figure Eight Loop.

A Figure Eight Loop is constructed with doubled hitches that look solid, feel solid, are solid. It is in fact among the most stable of common loops. While the Bowline has been dubbed the king of knots (Chisnall *Forensic*) and the Butterfly as the queen (Budworth 2004), the Figure Eight Loop is surely the prince of fixed loops.

Similar principles apply to a Flemish Bend, often called a “Figure Eight Follow-Through.” Tests have shown that this knot is not extremely stable, so the Double Fisherman’s Knot is preferred for joining two lengths of rope.

Why a Double Fisherman’s Knot is So Stable

No matter how you tug at a Double Fisherman’s Knot, it does not easily deform. And even if one or both of the half knots is deformed in one way or another so that the wraps no longer form the distinctive “Double X” pattern, the knot remains stable. Why is this so? The answer is a powerful device, the series of wraps around the straight core. Instead of tending to pull the knot apart, as in other knots, a load squeezes the wraps more tightly around the core while at the same time drawing the two halves closer together. Observation shows that a sharp sideways yank on the tail of a Double Fisherman’s Knot would pull it up against the outermost wrap. But this wrap is pressed so tightly against the core that there is hardly a chance that such a side-ways load would separate it from the standing part. That wrap is so strongly bound to the tail because the load on the standing part extends in a straight line along the length of the core of the knot and pulls it tight. That is the main value of a straight-line core-and-wrap knot. The net effect is that if you yank the tail of a Double Fisherman’s Knot to the side, away from the standing part, the parts barely budge.

Tricks and Games for Teaching Knot Stability

Greater understanding of the various ways that knots deform and can be rearranged can be taught through tricks and games. A teacher of knot tying can use these entertaining activities to capture students’ attention and focus their thoughts on the concept of structure and the principles of knot performance.

In his chapter on Tricks and Puzzles (33), Ashley shows how a parlor or stage magician can mystify an audience by rearranging the segments of a Square Knot or a Granny Knot (#2552, #2553). In one of the tricks he describes, the performer ties a Granny, then capsizes it into Two Half Hitches. “If the single jerk, which is all that is required to effect the change, is somewhat obscured,” he notes, “the mystification is complete and the fact that most everyone knows both these knots adds greatly to the interest” (410). In another trick (#2577), Ashley illustrates the same property of a Square Knot. He shows a similar way to convert Two Half Hitches and Reversed Half Hitches into varieties of the Bowline, and provides a story to go along with the demonstration (409–410). These tricks reverse the process of rearrangement of a Bowline that even many experienced knot tyers find remarkable. He shows alternative ways to tie several other knots in a similar way (#1788, #1987–1990). Popular books on stage magic describe numerous other tricks based on the principles of stability and instability.

After the performance, a demonstration and explanation of how the trick works does nothing to decrease the initial pleasant surprise, but can alert students to unstable structures that make a knot vulnerable to failure and can pique the students’ desire to understand more.

Use the Activity “Square in a Circle”

Many important lessons about knot stability can be learned by playing with a knot tied in a circle or loop of rope. The equipment is easy to make. Just tie a Square Knot in a convenient length of nylon rope, say 18 inches or so, then make the rope into a circle by melting the ends and fusing them. (Melted nylon is extremely hot, so be careful.) then have students rearrange the knotted circle into as many distinctive shapes as they can. Have them comment on the shapes they create. At the end see if they can restore the original Square Knot for, then see if they can find a way to reconstruct it in the fewest moves possible.

Deconstructing and reconstructing a knot tied in a circle of cord illustrates the principle that while rearrangement creates numerous distinctive shapes, it does not cause the knot to lose its basic pattern of over-and-under tucks. Dealing with unstable knots in this way can help students observe the close structural relation between two knots. Anyone who fools with this simple apparatus can discover at an intuitive level some fundamental principles of flypes, Reidemeister moves, and knot theory. Following up with comments can make the lesson more memorable.

Teaching Knot Stability and Degrees of Allowable Risk

One of the chief practical benefits of a working knowledge of knot stability is that it permits a knot user to be flexible when selecting knots for life support. When leading a client, when on a rescue mission, or during bad weather, for example, professional guides typically use the most stable knots they know. But under certain conditions they may sacrifice stability for speed. When climbing with a trusted partner and on a long and difficult pitch, or when quick release is important during a fast emergency ascent, they may use a less-stable knot such as Bowline rather than a Figure Eight Loop. They compensate for the reduced stability by increased vigilance.

Writing of the Balancing-Pole Hitch, Ashley comments, “I know of no knot with a smaller margin of safety” (41). As its name suggests, this knot is used to in a side show act. In the hands of professional circus performers, it is secure and safe, but when inexpertly used, it could lead to a fall. How wide a margin of safety should you strive for? When you are depending on a knot to support you while dangling over a cliff, it seems prudent to strive for a greater margin of safety than when you are performing stage tricks.

Learning about Devices for Increasing Knot Stability

Developing Techniques for Enhancing Knot Stability

The principles of knot stability and instability are particularly useful for helping students develop techniques for enhancing the performance of knots. Once given the idea that a few simple changes can increase stability in various ways, students can be led to discover several devices on their own, such as duplicating a tuck, threading an end through a convenient bight, or adding a Grapevine around an unstable structure. Even small children can learn how to tie a Half Knot over another knot to make it more stable, and to distinguish between the effectiveness of a Half Knot and a Half Hitch for this purpose. Older students can be led to see that backups usually add very little more friction to the knot but are excellent stabilizers because they keep the tail from being snagged to the side and deforming the knot.

Meeting the Needs of Advanced Knot Users

The study of knot security develops the concepts that meet the specialized needs of advanced knot users:

- To show how to distinguish the holding properties of various structures in particular applications and to recognize when a backup knot is necessary.
- To find ways to remedy hazardous instability with appropriate backup devices.
- To determine whether a particular device used for backup actually makes a knot more stable or whether it is just another half hitch that can slide right off.
- To determine when enough is enough so that fear of deformation does not create a piling up of backup after backup that merely creates a wob.
- To realize that by increasing stability, the gain in knot security is indirect, but significant.

The Indirect Effect of Backup Knots

Climbers and rescue workers know that if they prevent the tail of a Bowline from being snagged they can keep the knot from deforming and coming apart. They may be unaware of the mechanism of deformation, that the sideways yank on the tail causes the bight to straighten out and lose its friction-producing capability. But they can come to recognize at a conscious level that many backup devices are simply ways to increase knot stability by reducing the likelihood that a vulnerable structure will deform.

Demonstrating the Indirect Effect of Backup Knots

Using adhesive tape to bind the tail of a Bowline to the leg of the loop would provide little additional friction at the crux of the knot, so it would not directly affect the knot’s ability to resist slippage. But making the knot more stable may keep it from deforming. In this way, the tape, like a backup knot, indirectly increases security because it increases stability and decreases the chance of two-stage failure.

Uses of Analyzing Knot Stability

We have got along fairly well through the ages without clearly distinguishing knot security from knot stability. Why should we spend time on it now? One of the main benefits is to satisfy curiosity and follow up the interest of people who enjoy tying knots and who are curious to see how they work and how they fail to work. More practically, analyzing knot stability reveals potential sources of knot failure. It shows how far we can rely on a knot, how its instability can be used practically, and how to distinguish useful from dangerous instability. It also suggests ways to remedy instability.

Knot users soon learn many of the principles of knot stability by experience. But beginners can profit by having them pointed out dramatically, and everyone can benefit from dramatic demonstrations without risk.

Afterword

At whatever level it is conducted, study of this neglected aspect of knot performance takes us into some of the most interesting mysteries of knot performance and leads to insights that apply to a variety of knot uses. I suggest that this subject, like other aspects of knot performance, should be part of every knot user’s basic knot skills and part of every course on knot tying and knot use for learners at all levels.