The Study of Knot Performance
Exploring the Secrets of Knotted Cordage to Understand How Knots Work

Knot Security

How Knots Perform Under a Normal Load

Part 1. The Security of Bowline-Type Knots

Part 2. The Security of Core-and-Wrap Knots

Part 1. of this study is a revised and expanded version of an oral presentation at the Annual Meeting of the International Guild of Knot Tyers, Weston Super-Mare, Avon, U.K., May 12–14, 2000. Part 2. is new.

Many experiments have been made with the object of determining the relative strength of knots. But so far as I know the quality of security has not been considered, or else has been regarded as one of the properties inherent in, or covered by, the term “strength.” Yet the two cannot be measured at the same time, and both are not present in any two knots in the same degree. A secure knot often breaks: a strong knot often slips. ...The security of a knot is determined by the stress it will endure before it slips. ... The strength of a knot is determined by the stress it will endure before it breaks.

– Clifford Ashley 16

A knot depends on friction, … and to provide friction there must be pressure of some sort.

– Clifford W. Ashley

It behooves the layman to speak skeptically rather than dogmatically about the way knots behave the way they do.

– Cyrus Lawrence Day

The background to this and the following studies is in the “Introduction to the Study of Knot Performance.”

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.

Key Words Knot security, knot structure, friction, pressure, structural analysis, structural devices, nip, normal load, abnormal load, stem, collar, anchor, Bowline, core-and-wrap knots

Summary

Knots hold together because the rope is intertwined so that it creates friction. The way any particular knot works is revealed in a set of procedures for analyzing its structure. Structural analysis shows that most knots work on principles that are similar to the way a Bowline works, while a small but important group of knots works on core-and-wrap and slide-and-block principles, the way a Double Fisherman’s Knot works.

Study Knot Security to Determine How Knots Hold Together

Everyone who use knots needs to know two things about them: How does any particular knot perform under a normal load? And which of the common knots are the most secure? This study gives you specific procedures for analyzing a knot that will help you understand why and how a knot stays tied. Even knot users with no technical training can use the procedures of structural analysis to discover how a knot’s structure affects its security. The analysis focuses attention on basic questions about the mechanisms of this knot: How is it built? What structural devices in the knot create security? How do these devices work? How secure is the knot?

Part 1. applies the procedures of structural analysis to knots of the Bowline type, which includes most knots. Part 2. applies them to core-and-wrap knots such as a Double Fisherman's Knot.

The Meaning of Knot Security

The term *knot security* refers to how well a knot keeps from slipping apart and failing under a normal load—that is when it is subjected to a moderate and steady load that comes from the direction the knot was designed to withstand.

Knot security is to be clearly distinguished from knot stability, which refers to how well a knot keeps its form when subjected to an abnormal load. And it must also be distinguished from knot strength, which refers to how much a knot weakens the rope it is tied in.

Part 1. The Security of Bowline-Type Knots

Through the ages, people have found a Bowline extremely useful both for general utility and for supporting life and heavy loads. It is quick to tie, easy to untie, and easy on the rope. But in a fixed-loop knot, the most important characteristic is that it will hold. Is a Bowline a secure knot? Under a normal load, does it effectively resist slipping and coming untied? Questions such as these are usually answered on the basis of experience, authority, and tests.

But our judgment of knot performance can be supplemented by structural analysis, a set of new procedures that lead to understanding of how knots work through guided observation and reasoning.

Terminology for Analyzing the Security of a Bowline

Several terms are useful for studying the security of knots of the Bowline type. Several terms used in this study are defined here, and others are defined in the discussion below. All of these terms are discussed more fully in the separate study of knot terminology.

Anchor

The anchor is the structure inside the nub of a knot that merges with the lower end of the stem. It moors the stem and gives the standing part a firm mooring to pull against. In a Bowline, the anchor is the upper arm of the hitch. The importance of this structure will become apparent in the study of knot strength later in these studies.

Collar

The collar is the structure that the stem passes over or through at the place the rope enters the nub. In a Bowline, the collar is formed by the arc of the bight, and in knots of the Bowline type, the stem curves as it passes over the collar. In knots of the core-and-wrap type, the stem does not curve as it passes through the collar, but curves after it has passed through wraps deeper inside the nub. In a Double Fisherman's Knot, the stem begins to curve after it has passed under the third wrap at the far end of the nub.

Normal Load

A normal load is the load that falls on the knot when it is used in the way it was designed to work best. A normal load falls on a Bowline, for example, when the standing part is attached to a fixed point above and a weight is suspended from the loop below, with no sideways pulls. This is the way we employ the knot when we use our wits and have good luck.

Nub

The nub is the knotted part or the body of a knot. The nub of a Bowline, for example, includes all of the structures except the standing part, the tail, and the loop.

Stem

The stem is the segment of rope that joins the standing part to the nub. The stem merges with the standing part at the top of the nub, crosses over the collar, and merges with the anchor below. The first curve of all knots is in the stem. In knots of the Bowline type, which includes most knots, the rope begins to curve as it enters the knot. Thus the stem and the first curve are conterminous; they have the same boundaries. In knots of the core-and-wrap type, which are treated in Part 2. below, the stem passes further into the nub before it makes the first curve.

Structural Devices

A structural device, made up of structures that intertwine, is a configuration of rope looked at from the point of view of its function in a knot. Each knot uses one or more structural devices in a unique arrangement that creates friction and makes it secure.

Structures

Structures are the identifiable configurations of rope in a knot such as tucks, wraps, hitches, and bights. The exact point where one structure begins to merge with another structure may be difficult to identify, but the boundaries are usually clear enough for practical purposes.

Terminology that pertains to the security of core-and-wrap knots is in Part 2., below.

The Security of a Bowline

Figure 1. below summarizes my analysis of security in a Bowline. The rope shown in the figure, which is made of twisted nylon, is intended to represent any kind of cordage.

SP Standing Part
The standing part transfers the load from the loop through the nub to a fixed point at the top.

Parts of the Nub
The nub is the knotted part—all of the knot except the loop, the tail, and the standing part. A hitch and a bight are intertwined here in such a way that a load can create enough friction to hold the knot together.

S The Stem
The stem begins where the standing part enters the nub, at the upper dotted line. It crosses over the collar and through the eye of the bight, then merges with the lower arm of the hitch. In a Bowline, the first curve is in the stem.

The Collar
The collar curves around the stem. In a Bowline, the collar is formed by the arc of the bight. The dotted lines indicate the crossover of the stem and the collar.

The Anchor
The anchor, the upper arm of the hitch, moors the stem and the standing part.

B The Bight
The bight enters the nub through the hitch, circles around the stem, and exits through the hitch.

H The Hitch
The hitch encircles the bight and squeezes it tight. The arc of the hitch is often mistaken for the nip of the knot, the place of greatest pressure.

C Crossover of the Hitch
The arms of the hitch cross each other at the left side of the knot. The nip is at this crossover.

T The Tail
The tail, an extension of the bight, exits the nub through the hitch and lies between the legs of the loop.

L The Loop
One end of the loop merges with the hitch and the other end merges with the bight. It is held in place by these two structures.

Identifying the Structures that Make a Bowline Secure

A Bowline is an asymmetrical fixed-loop knot tied in one piece of rope. The standing part at the top and the loop at the bottom are connected in the middle by the nub (the knotted part of the knot). In a Bowline, the nub is made up of a hitch and a bight. The hitch threads through the bight at one end and wraps around it at the other, then merges with the left leg of the loop. The way the hitch and the bight are intertwined creates the main structural device of the knot. Heavy loads that fall on both arms of the hitch cause the hitch to squeeze tight around the bight. Pressure of this squeeze creates the friction that holds the knot together. The nip, where the arms of the hitch cross over each other, is the place where a load creates the greatest pressure. The discussion below gives detailed procedures for determining where this crucial place is, how the knot works, and why it works as well as it does.

Procedures for Analyzing the Security of a Bowline

It may seem natural to think of a Bowline simply as a familiar general-purpose loop, one that can be quickly tied and untied and that holds well in many practical applications. The procedures described here will help you see a Bowline from a more analytical point of view—as a single cord that follows a unique path and becomes intertwined with itself in a particular way that creates a secure fixed loop. In following these procedures, you will closely observe a Bowline, analyze it, and apply concepts that help you understand its behavior. Similar procedures can be used to analyze the security of any other knot.

A Note on Following These Procedures

For each of the procedures, I will set a task, make necessary explanations, and tell how I would perform the task. You can enhance your understanding of the explanations by frequently referring to an actual Bowline or to the Figure above.

The procedures of this analysis develop concepts sequentially, and each succeeding step builds on the previous ones. They will draw on your general knowledge as well as to make fresh observations. The first few steps in the analysis, which entail identifying the basic structures, may seem simplistic and obvious. But at this stage of study, it is crucial to establish a clear idea of the knot’s configuration, and because these steps draw attention to the specific configuration of the knot, they form the basis for later procedures that lead to an understanding of how it works. Taken step by step, these procedures lead to concepts that are as fundamental for developing an understanding of knots as identifying the anatomical structure of organs is for the study of life forms.

The first time you analyze a knot in this way, you will need to follow the procedures systematically. It is important not to breeze quickly through the tasks of these procedures nor to skip over the details perfunctorily. In your haste to make an easy judgment, you can fail to take into account all of the details and reach a false conclusion. If you practice them deliberately on several different knots, you can soon make them a habitual way to increase your knot sense.

Procedure 1. Name and Describe the Knot and Its Use

The task in the first procedure is to name and describe the knot, to identify its main parts, and to explain its use.

A Bowline is an asymmetrical fixed-loop knot tied in a single rope. It is composed of a standing part, a stem, a nub made up of two parts, a loop with two legs, and a tail. The parts of the nub are a hitch and a bight. The purpose of the knot is to attach a load to the standing part of the rope. It is widely used as a loop that does not slip.

Procedure 2. Trace the Course of the Rope through the Knot

The second procedure is to trace with your finger the path that the rope takes through the knot and to describe its route from the place where it enters the knot to the place it exits.

As you trace this route, it is helpful to say to yourself, “Beginning from the top of the knot, the rope crosses over and down through a curved segment, crosses under itself, circles around two segments,” . . . and so on, until you have worked through to the other end of the knot. Some people find it useful to think of this procedure as following the route of a highway across an overpass, through a tunnel, around a curve, down an off-ramp, and so on. As you follow the sinuous line made by the single strand of this knot, note especially places where the rope crosses itself and where the loop exits and re-enters the nub.

Procedure 3. Identify the Structures in the Knot

In this procedure, trace the route of the rope through the knot again, but this time look for three additional things: 1) identify the individual structures in the knot, name each of them, and describe their form; 2) point out places where each structure merges with or crosses other structures; 3) point out how the most prominent structures are interlaced with each other.

If you don't know what to call a structure, give it a name of your own. You can pick up the terminology as you go along.

In a Bowline, the standing part is connected to the loop through structures in the nub. As the standing part enters the nub, it merges with the stem. The stem curves slightly as it crosses over the eye of the bight and enters the center of the nub. There the stem merges with the lower arm of the hitch. The lower arm crosses under the other arm of the hitch, then wraps around the bight. After making contact with the legs of the bight, both front and back, the hitch crosses back over itself, then exits the nub and merges with the left leg of the loop.

The left end of the loop exits the nub; then it circles around and merges with the bight at the other end. The leg of the bight curves as it passes through the hitch, then crosses around behind the stem and back down through the hitch. The legs of the bight lie parallel to each other and are encircled by the arms of the hitch. The tail hangs down from the bottom of the hitch.

Locate the Thread-the-Needle Device

The left leg of the hitch passes up through the bight in a structure I call thread-the-needle. This strut pulls the bight backward and the standing part forward, creating a curve in the stem.

Demonstrating How the Bight and the Hitch are Intertwined

The most prominent structures in the nub of a Bowline are the bight and the hitch. At the top of the knot, the stem passes through the eye of the bight, forming a sort of thread-the-needle structure. The hitch wraps around the legs of the bight in a 360° curve.

You can see more clearly how the hitch and the bight are interlaced if you tie the knot in a length of two-colored rope, so that the hitch is tied in one color and the bight in the other color. With the segments of rope identified in this way, you can dramatically demonstrate the way they are interlaced. Slightly loosen these two structures, then push them apart to make the hitch slide up and down over the legs of the bight. These structures and the way they are intertwined are to be especially noted because, as will be shown in Procedure 8, they are the structures that hold the knot together. This configuration of a Bowline is often overlooked.

Procedure 4. Identify Places Where the Segments Come into Contact

In this procedure, you are to point out the places where segments of rope in a Bowline come into contact with each other. First, identify the parallel segments and the crossovers. Then observe whether one segment simply crosses over another one or wraps around it, either part way or completely, and whether it crosses over or wraps around one segment of rope or two or more segments.

Identify Parallel Segments

A Bowline has one pair of parallel segments, where the two legs of the bight run next to each other but do not cross. These parallel segments come into contact with each other at the place where the arc of the hitch wraps around them.

Identify Crossovers

A *crossover* is a place where one segment of rope passes over another so that their surfaces come into contact. In some places, one segment wraps around another one, to some extent.

To locate the crossovers in a Bowline, tie the knot loosely, spread it out flat on a table, and separate the segments of rope. Be sure to lay out the parts without making additional twists or bights so that you reveal only the minimum number of crossovers. With the structures of a Bowline arranged in this way, you can easily identify the places where one segment of rope passes over another. (It may be useful to practice counting the crossovers in a knot by spreading out an Overhand Knot and counting the crossovers. There are three, which is the minimum number of crossovers in any ordinary knot.)

In a Bowline, there are six crossovers:

1) At S in the Figure, the stem passes over the arc of the bight, making a simple crossover.
2) At C, the two arms of the hitch cross over and wrap part-way around each other.
3) At H, the long arc of the hitch wraps completely around the bight, first in front of the legs, then in back of them, making four crossovers. In this circuit, the arms of the hitch come into contact with the hitch for almost 360° or virtually the entire inner surface of the wrap.

It should be noted that while the “crossovers” determined this way are similar to the topological “crossings” in mathematical knot theory, the crossovers are less rigorously defined.

Locating and tallying the crossovers will help prepare you to follow the next procedures. As we will see further along in these procedure, there appears to be no simple relation between the *number* of crossovers and the security of a knot. While many other knots have the same number of crossovers, they are arranged differently in each knot, so that it may be more or less secure. But counting them increases your general familiarity with the structures of the knot. And as will be explained in Procedure 6, crossovers are important because a knot remains knotted only when friction is created by surfaces of the rope coming into contact with each other at these crossovers. So it is worthwhile to count them. Of far greater importance, though, is the location of their surfaces, the way the segments are interwoven, and how the load falls on them, as we will also note later.

Later procedures point out that crossovers form *contact surfaces.* Contact surfaces are crucial to the performance of a knot because when the knot is loaded, they become the primary bearing surfaces. Without crossovers, the segments of rope in a knot would have little surface to press against. Without crossovers, there would be little pressure, little friction, and no knot.

How the Parts Function: The Physiology of a Bowline

In the first four procedures, you have identified the parts of a Bowline and have seen how they are intertwined. The aim of these procedures has been to help you become familiar with these structures and to think of them as the components of the knot. In the next five procedures, you will examine in more detail how the parts function interdependently. This will help you discover the secrets of how the knot works. This shift of focus and aim is like moving from describing the knot’s anatomy to studying its physiology. As things begin to fall into place, close attention will be rewarded.

Procedure 5. Determine the Effect of Normal Loading

The next procedure is to determine how a normal load affects the structures of the knot.

To find out what happens when a knot is placed under load, observe how a load affects its individual parts, the surfaces in contact, and the knot as a whole.

When the properly-tied knot is placed under a load, the first effect is to tighten all of the structures. The knot is more compact than it was when sprawling on the table, and most of the space between segments has disappeared.

But a normal load does not only draw the parts together; its main effect is to shorten the segments and the radius of the curves and to increase pressure between the bearing surfaces. As we will observe in Procedure 8, when the knot is loaded, the hitch tightens around the legs of the bight.

Where Does the Load Fall?

When a Bowline is arranged and loaded in the usual way, it can be seen that the load is transmitted from the two legs of the loop through the nub to the standing part. About half of a normal load is borne by each leg of the loop. You will notice that the load is transmitted in the same general direction as the route taken by the rope (which you traced in Procedure 2), but that it travels much more directly from the loop through the nub to the standing part. (As Newton showed, of course, the load is actually transmitted in both directions.)

The Effect of a Heavy Load on Bearing Surfaces

Another effect of a load is to press together the *bearing surfaces*, that is, surfaces that come into contact under pressure so that one bears on the other. It can easily be seen that each crossover and each pair of parallel segments form bearing surfaces in the knot. But what may be overlooked is that a load draws the segments together so that the bearing surfaces are widened and elongated. The effect is to increase the area of close contact between the bearing surfaces.

The Spray-Paint Demonstration

How can we determine how much a load increases the area of bearing surface? In normal use, of course, we are able view a loaded knot only from the outside. We can get a view of the interior of a knot only when the structures have been loosen and separated. Examining a loosened knot gives little idea about what is happening between the surfaces inside a loaded knot. But there is a way to get an inside view of the effect of a load.

A simple demonstration described to me by a correspondent shows how a load increases the extent of the bearing surface. Tie a Bowline in a length of white single-strand plastic-coated electrical cable, pull the knot tight, and spray-paint it with black paint. After the paint dries, untie the knot, slit off the plastic coating, and flatten it out. Surfaces that were on the exterior of the original knot will be black, but the bearing surfaces will be left white.

To show the effect of a heavier load on a knot, tie the same knot in another length of the same kind of cable, fasten the standing part to a beam, attach a weight to the loop, and drop it from a convenient height. Again let the paint dry, untie the knot, slit the plastic open, flatten it out, and examine the surfaces.

Under a light load, the white bearing surfaces will be short and clearly separated, but under a heavy load, the white bearing surfaces will be enlarged and, depending on the kind of knot and the amount of load, more or less elongated. The individual areas of contact may even converge into one bearing surface that runs more or less continuously from one end of the knot to the other.

Note particularly how tightly the load has caused the hitch to squeeze around the bight and create close contact between the bearing surfaces on the legs of the hitch.

While it is obvious that a load would tighten the structures of a knot, we can see the effect of the load on the inside structures. This dramatic visual demonstration shows how the configurations of a Bowline interact to make the knot hold together when it is placed under a heavy load.

Procedure 6. Determine Where and How Friction is Created

The task in this procedure is to determine the factors that affect the amount of friction between segments at any contact area and to show where pressure and friction will be greater and lesser. The task entails understanding the function of parallel segments, of crossovers in which one segment merely passes over another, and of crossovers in which one segment partially or entirely wraps around another. It also entails taking into account the effect of different amounts of load.

First, a definition: Beginning with this procedure, we think of the various parts of a knot not merely as structures but as *structural devices*. A structural device is a configuration of rope considered from the point of view of its interaction with other structures, its function and its effect on performance.

And an explanation: At each parallel structure or crossover, contact between the bearing surfaces creates a certain amount of pressure. At these places where one segment of a knot touches another segment, the amount of friction produced is in proportion to the amount of pressure on the bearing surfaces. The more pressure, the more friction. Because all knots depend on friction to hold them together, this procedure comes close to the heart of the analysis.

Factors that Affect the Amount of Friction

The amount of pressure and friction created on any bearing surface is governed by the way the segments are intertwined and by the load that falls on them. To create an appreciable amount of friction in a knot, three conditions are necessary: 1) A considerable load falls on one or both of these segments; 2) One of these segments is anchored at one end so that it can resist the pull of a load from the other end; 3) The anchored segment holds the other segment stationary.

Resistance to the pull on a loaded segment is essential for creating significant pressure between the contact areas. To create an anchor, at least one of the segments must wrap around the other segment to some extent. The wrap resists a pull and provides a more or less firm contact area for a loaded segment to get a purchase on and to pull against. While a straight or slightly-curved segment tends to slip without offering much resistance, a segment that curves around another segment tends to offer more resistance. In general, the more a loaded segment wraps around another segment, the more firmly the anchor will hold. A curve that wraps entirely around another segment offers the most resistance.

Friction will be greatest between bearing surfaces where the load is heavy and the anchor is stable.

Procedure 7. Locate and Describe the Nip of the Knot

In this procedure, you are to locate the nip of a Bowline. While the term *nip* is defined in various ways, as used here it refers to the place in a knot of the Bowline type where the pressure and friction are greatest. Based on what we observed in Procedure 6, the nip is to be found where a heavy load falls on a well-anchored segment that wraps at least part-way around another segment. While the heaviest load does not fall on the nip, the greatest pressure is created at that place.

How to Locate the Nip of a Bowline

To locate the nip of a Bowline, inventory the areas of contact identified in Procedure 4. Consider the firmness of the anchor, the extent of the wrap, and the amount of load that falls on the bearing surfaces at each of these locations:

1) Is the Nip in the parallel legs of the bight?

The parallel segments between the legs of the bight can be eliminated immediately. Inspection shows that although they come in contact, neither segment wraps around the other and neither is anchored. This is clearly not the location of the nip.

2) Is the Nip in at S in the Figure, where the stem crosses over the bight?

The crossover at S in the Figure, the place where the stem crosses over the bight, can also be eliminated. Although the load on the stem is virtually 100% and the stem crosses at the midpoint of the curve of the bight, it makes only a gently-curved crossover that does not wrap around the bight. This crossover gives the fully-loaded standing part very little to anchor to. Further, the load that falls on the bight at that crossover is slight. In fact, the bight can be loosened and rearranged so that virtually no load falls on it.

3) Is the Nip in at H, where the hitch wraps around the legs of the bight?

The wrap at H, where the arms of the hitch encircle the two legs of the bight, can be eliminated. The friction created by this full wrap is no doubt greater than the friction between the parallel segments or at point S. But the load on the wrap has been greatly diminished by the main crossover of the hitch. For this reason, the pressure between the arc of the hitch and the legs of the bight cannot be as great as it is at the hitch itself.

4) Is the Nip in at C, where the arms of the hitch wrap around each other?

Having eliminated the other possible locations of the nip, we can infer that the greatest amount of pressure is created at C, where the two arms of the hitch cross over and wrap part-way around each other. Analysis of the structure and load at this place confirms this selection because 1) nearly a full load from the standing part pulls one arm of the hitch from above, and virtually half of the load on the loop pulls the other arm of the hitch from below; 2) both arms of the hitch are well anchored by the arc of the hitch.

At the hitch itself, the place where the arms of the hitch cross over and pull against each other, both segments are heavily loaded and both are highly resistant to the load. The strong pulls in opposite directions on the segments at this crossover create the greatest pressure and friction to be found in this knot. This is the nip.

Procedure 8. Explain How the Knot Works

The next procedure is to bring together what has been determined in previous steps and to state as concisely as possible how the knot works. What structures create its form or general design? What structures create sufficient friction to hold the knot together?

A Bowline works because the standing part and the two legs of the loop are attached to the nub by an interlocking hitch and bight. These devices create the form of the knot and provide enough friction to hold it together under a normal load.

Procedure 9. Locate the Crux of the Knot

What remains to be done is to identify the most important structural device in the knot, the specific configuration of rope that I call the *crux* of the knot. The crux clearly accounts for the effectiveness of a particular knot. It is the distinguishing structural device of the knot. In some knots, but not all, it is the device that most clearly holds this knot together. The tasks in this procedure are to locate the crux, describe its structure, explain the principles it works on, and show that it is the essential and distinguishing structural device of a Bowline.

Locating the Crux of a Bowline

An explanation: Locating the crux of the knot is to be clearly distinguished from identifying the nip. Although the nip is often part of the crux, they are not the same. This distinction is clearly illustrated by a Bowline Bend (Ashley #1455) which is made by interlocking two Bowlines. In this knot, the nips are located in the two hitches, while the crux, the most distinctive and most important device, is the interlocking of the loops. In addition, in some knots, the most characteristic and most important device is not a structure that produces friction—as essential as friction is in every knot—but a device in which opposing structures of the knot block each other in opposing pulls. This principle is found in a Blood Knot and in a Fisherman’s Knot, which are discussed in Part 2. below.

The way to go about locating the crux of a knot is to inventory the structures that are candidates for the most important structural device, eliminate them one by one, then tell how the actual device does the job. What we are looking for is a device that grips and holds tight. It will be the device that is most essential for keeping the knot together.

At this point in the analysis, identifying the crux of a Bowline may seem obvious or redundant, but following up this procedure leads to some new concepts and new understanding that will lead to the final step.

A bit of reflection shows two things: First, the device we look for will not be a simple structure of the knot, like the standing part, the stem, the tail, or the loop. As essential as these structures are in the knot, they do not account for its holding power. So we can eliminate them immediately. Second, in most knots, a single device does not produce friction. The device we are looking for will most likely entail the interaction of two or more structures. So we can also eliminate the hitch and the bight *as individual structures*.

The devices that remain are 1) the interaction of the stem and the bight, 2) the thread-the-needle device, and 3), the interaction of the hitch and the bight. Note that these are the same structures that we examined while searching for the nip of the Bowline, but we are now looking at them with quite a different aim and applying different yardsticks.

It is sometimes easy to eliminate a particular device as the most important one by slightly altering the structure of the knot, then testing the security of the altered knot. By this method, you can eliminate both 1) the interaction of the stem and the arc of the bight and 2) the thread-the-needle device: Simply unthread the standing part from the bight, load the knot, and observe what happens. Even without the thread-the-needle device at the top of the knot, under a normal load, the altered Bowline is still quite secure, just as it is in a Sheepshank. The only structural device that remains is 3), the interaction of the hitch and bight.

The hitch and bight device seems like a good candidate because it stands to reason that the most important structural device is likely to be found in a location where considerable pressure is created. That is, the most likely device would probably be a major structure somewhere near the location of the nip, and the crossover at the nip may even be part of the crux. Since neither of these structures *by itself* could produce friction, all indicators point to the fact that the most important structural device of a Bowline is the *interaction* between the hitch and the bight. That’s it.

Structure and Performance of the Crux in a Bowline

The next step in this procedure is to describe the structure of the crux and to explain how it works.

Loosening the segments of rope, then drawing them together the way a normal load does, shows that when you load a Bowline, the hitch tightens around the legs of the bight. This squeezing hitch, which clutches the bight in a tight grip, keeps the parallel legs of the bight fixed in place and counteracts the tendency of the right leg of the loop to pull the bight out of the nub. This interaction between the hitch and the bight produces friction at the bearing surfaces and inhibits movement by either of these parts. It becomes increasingly apparent that without this interaction, there would be no knot.

You can test this selection of the crux by altering its structure. What would happen, for example, if the strangle hold of the hitch around the legs of the bight were loosened? The bight would crawfish out of the hitch and the knot would collapse.

Having followed this line of reasoning, there can be little doubt that the main structural device of a Bowline is the interaction of the hitch and the bight. And it is no accident that the nip is located at the place where the two arms of the hitch cross. This coincidence of the nip and the crux account for the central genius of the Bowline.

Procedure 10. Assess the Security of the Knot

The last step in this analysis is to judge whether the knot is secure. To make this final assessment, you need to explain how you can tell that the most important structural device is effective and that all of the other structures produce sufficient pressure and friction to hold the knot together. In short, that all of the systems work.

This is the time to review the effectiveness of the structural devices in the nub:

- Tell how the main structural device works. Refer to the way the structures are interlaced and their function.
- Review the effect of simple crossovers, wraps, and partial wraps.
- Recall the relative amount of pressure that falls on structures at crucial places in the knot.
- Tell why a load will pull the nip tight and which structures are affected by a tight nip.

To do these things, draw on the concepts and conclusions that you have developed in the first eight procedures.

Summary: How a Bowline Works

The main structural device of a Bowline, the crux, is made of is a heavily-loaded and well-anchored hitch that encircles the legs of a bight and squeezes them together. A load on both the standing part and the left leg of the loop fall on the hitch and pull it tight around the bight. This tight squeeze prevents the tail from slipping out and spilling the knot.

Drawn up snugly and loaded in the normal way, this is a highly functional knot, quite effective in transferring a load from the loop through the nub to the standing part. We can conclude from this review that when a Bowline is loaded in the normal way, it is quite secure. This judgment jibes with the experience of countless knot users. But having completed the analysis, we can now explain why this is so.

It is easy to see why a Bowline has been so popular for so long as a general-purpose fixed-loop knot. Its forms are simple and elegant. It is quite secure when used in the way it is intended, and it is versatile and easy to tie, adjust, and untie. It is one of the most clever and useful of early human inventions.

There is a good deal more to know about the performance of a Bowline, particularly the way it is apt to deform and fail when an abnormal load jerks the tail to one side. Weaknesses in knot structure are the topic of a later study in this series.

Part 2. The Security of Core-and-Wrap Knots

The Performance of Bowline-Type Knots and Core-and-Wrap Knots

If we make due allowance for the wide differences in their structures, most practical knots behave in much the same way as a Bowline. But a few other knots perform in quite a different way. These are knots built with a *core-and-wrap* structure and which use a *slide-and-block* device. Familiar examples of this group are the Double Fisherman’s Knot and the Blood Knot. Some knots, such as the Stevedore Knot, use only some features of the core-and-wrap structure. And some other knots, such as the hangman’s noose, also use some features of the slide-and-block device. Analysis of a Double Fisherman’s Knot shows that these knots work on very different principles from knots of the Bowline type.

Additional Terminology For Studying Core-and-Wrap Knots

The terms *barrel knot* and *blood knot* refer to one application of this kind of structure. While the term *core-and-wrap* is cumbersome, it specifically designates one knot structure without referring to any particular knot.

In general, I use the word *wrap* to mean a series of two or more turns of one segment of rope around another segment. Ashley consistently uses the word *turn* to designate this configuration of rope; see, for example, Ashley 295 (#1413).

The core-and-wrap structure is used in the wound wire strings of instruments such as guitars and harps as well as in some art work. These words are also used to describe a process in some art work. But so far as I am aware, the term “core-and-wrap knots” is not generally used among knot tyers.

Procedures for Analyzing a Core-and-Wrap Knot

Despite the great differences between knots of the core-and-wrap type and knots of the Bowline type, the ten procedures of structural analysis apply in much the same way to both types of knots. The results of the analysis, of course, are very different.

You are again urged to perform the task yourself and to arrive at your own conclusions before reading mine. And if your analysis is different from mine, or if you can suggest a better way of stating things, let me hear from you.

Figure 2. The Double Fisherman’s Knot

Double Fisherman’s Knot

In the upper photograph, the Double Fisherman's Knot is shown with the two halves separated and in the lower photograph, taken from the opposite side, with the two halves snugged together.

Analysis of a Double Fisherman’s Knot illustrates the procedures for examining the security of core-and-wrap knots. It will be helpful to inspect an example of this knot while analyzing it.

Procedure 1. Name and Describe the Knot and Its Use

A Double Fisherman’s Knot is a symmetrical knot which is used to join two ropes. It is also called a Grapevine or a Double English Knot (Ashley #294, #498, #1415). As in all bends, there are two standing parts and two tails. The nub is composed of two halves, each made of a double wrap around a core. Looked at from one side, the four wraps line up like a row of knuckles, and from the other side as two Xs. Guided by the core, the wraps slide together and meet in the center of the knot.

Procedure 2. Trace the Course of the Rope Through the Knot

In a Double Fisherman’s Knot, a standing part enters the nub from each end of the knot. As each standing part enters the nub, it becomes a core which passes through a double wrap formed by the other segment; then it forms a double wrap of its own, wound from the outside toward the center of the knot. This segment then tucks between its own wrap and the core. It emerges from the nub and forms the tail, which lies parallel to the other standing part.

Procedure 3. Identify the Structures in the Knot

The most evident structures of a Double Fisherman’s Knot are the two double wraps. Another is the tuck-under-turn device found at each end. The knot is tightened by pulling the standing parts in opposite directions. Drawing the halves apart by pulling on the tails reveals the cores. Each of the double wraps forms a half knot that slides along a core and butts up against the other half knot.

Procedure 4. Identify Places Where the Segments Come into Contact

As the two standing parts enters the nub, they pass through the first wrap and then through a second wrap at the other end of the knot. The tucked ends of the wraps and the tails lie parallel to the cores at each end. At each of these places, the segments come into contact with each other. In an unusual and distinctive structure, the wraps meet in the center of the knot in end-to-end contact.

Procedure 5. Determine the Effect of Normal Loading

The effect of a normal load on a Double Fisherman’s Knot, as in most other knots, is to tighten all of the structures and shorten the radius of the curves. In knots of the slide-and-block type such as this, a normal load draws the two halves of the knot tight up against each other. The cores and wraps are so arranged that neither half knot can move further along the core than the opposite half.

This is the most evident characteristic of the small group of knots of this type and distinguishes them from knots of the Bowline type.

Procedure 6. Determine Where and How Friction is Created

In a Double Fisherman's Knot, friction is generated by pressure at all points of contact between the wraps, the cores, and the tucked segments.

Procedure 7. Locate and Describe the Nips of the Knot

The nips in a Double Fisherman’s Knot are located and structured in a very different way from the nip in a Bowline. First, there are two nips, located at the extreme ends of the nub; these are at the places where each of the cores begins to curve and form a wrap around both the core and the tucked-in segment. It is at these points where a load on the standing parts pulls the wraps tightly around the cores and the segments that are tucked under them.

While the location of the nips in this knot affects its security only indirectly, it becomes crucial in studying the knot’s strength and breaking point. This is shown in later studies.

Procedure 8. Explain How the Knot Works

The task of this procedure is to bring together and build on what has been determined in previous steps. First, state concisely the form or general design created by the structures, then explain how these structures create enough friction to hold the knot together. Finally, go on to describe and demonstrate the slide-and-block device. Given what the analysis has shown about these devices, explain how the knot works.

Because each nip is formed in a segment of rope that has passed through two wraps that squeeze the parts together, pressure between the core and the wraps has converted a good deal of the load to friction. For this reason, the pull on the nips has been diminished to considerably less than the full load.

Together, these devices serve three purposes: 1) they create the slide-and-block form of the knot, 2) they create enough friction to hold the parts together, and 3) they cause the ends of each half to block each other in the center of the knot.

Procedure 9. Identify the Crux of the Knot

What remains to be done is to identify the *crux* of the knot, which is the most distinctive and important structural device in the knot because it makes the knot work. The tasks here are to locate the crux, describe its structure, explain how it works, and show that it is the essential and distinguishing structural device of a Double Fisherman's Knot.

The Double Fisherman's Knot is strikingly different in both structure and performance from a Bowline. Each half of this knot is constructed of a pair of wraps that form a helix around a core. Each of the cores enters the nub at one end, runs the length of the knot, then curves sharply at the far end to form a wrap. The segments that emerge as the tails are likewise sheathed in wraps. This distinctive configuration, of course, suggested the origin of the name *core-and-wrap* construction.

The Double Fisherman's Knot uses this construction in a *slide-and-block* device. The cores provide runners that direct the half knots. Wraps at each end slide together along these cores. When a normal load on the opposite standing parts hauls the halves together, they meet at the center of the knot and press tightly against each other, so that each half blocks further movement by the other half. The two halves jam against each other in a symmetric relationship, each half preventing the other from moving further.

Each of the halves of the slide-and-block device is held together by friction, but the device itself does not create friction. For this reason, identifying the nips or analyzing the devices that create friction in this kind of knot do not lead immediately to identifying the main structural device or to determining how the knot works. In addition, the nips in this knot are less heavily loaded than the nip in knots of the Bowline type. These characteristics distinguished knots of the core-and-wrap type from knots of the Bowline type.

In this type of knot, the distinction between the nip and the crux stands out clearly.

Procedure 10. Assess the Security of the Knot

The arrangement of the structural devices of a Double Fisherman's Knot make it extremely secure. At each end, the standing part, the core, and the first curve are arranged in a continuous line that is drawn up tight when a load is applied. The wraps are likewise drawn tight around the tucks and the cores. As long as the wraps hold together and can be drawn along the core, there is little chance that this knot would slip apart, even in slippery rope.

The extreme security of a Double Fisherman's Knot can be attributed to its two distinctive structures, the two pairs of wraps and the slide-and-block construction. This combination of devices makes a Double Fisherman's Knot one of the most secure knots ever devised. This is no doubt the main reason that it is the favorite bend of climbers and rescue personnel.

Other Core-and-Wrap Knots

In the Blood Knot, the tails jam up against each other just before they emerge from the nub at the center of the knot. This structure makes the knot extremely secure.

The Blood Knot, loosely tied

In his section on occupational knots of The Fisherman, Ashley indicates that the Barrel Knot (#295, 345, 1413) is very secure for making up a leader, being "the best bend here is for small, stiff or slippery line" (259). Day (54, 110) has interesting comments about the structure, form, varieties, and method of tying of the Barrel Knot. The various forms that Day calls "Blood Knot or Multiple Overhand Knot" (38) use the core-and-wrap structure but not the slide-and-block device. They are close relatives of the Stevedore Knot.

Several of the droppers that Ashley illustrates use the slide-and-block principle in quite a different way for attaching a snelled hook (a dropper fly) to a line (#335, 336, 343, 344, and 345). He comments that the Barrel Knot (#1413), illustrated in (#345) is "the most secure" of the last three.

How Anyone Can Profit From Structural Analysis

These procedures for identifying the security devices of individual knots and for showing how they work were originally designed to benefit expert knot users and professionals who teach knots used life support. Yet both the procedures and the concepts they develop can be taught, at a level appropriate to their development, to virtually anyone who ties and uses knots. These procedures can be applied to any knot used for either utility or life support, where the findings of structural analysis can influence the choice of knots.

An everyday example of a useful everyday application of these procedures and the principles they make clear is the comparison of two kinds of double bows used for tying shoelaces.

If you use an ordinary Double Bowknot to tie slippery shoelaces, they are apt to slip apart, while a Double Double Bowknot will hold together better. To tie this knot, pass the doubled shoelace end twice under the opposite bow. This forms two wraps around the slipped ends.

These procedures will be adapted for studying the other aspects of knot performance, stability, breaking point, and strength. In addition to giving you the general idea of how knots work, this introduction to knot performance ought to provide a framework for more technical investigation.

Sources

The most important printed sources I have consulted are Clifford Ashley, *The Ashley Book of Knots*, 1944 (#295, #345, #1413, and #1415); Stanley Barnes, *Angling Knots*, 1947; Cyrus Day, *The Art of Knotting and Splicing*, 1947 (38 54 100); Duane Raleigh, *Knots and Ropes for Climbers*, 1998; J. C. Turner and P. van de Griend, *History and Science of Knots*, 1996; Tom Vines and Steve Hudson, *High Angle Rescue Techniques*, 1982, 1992, and Charles Warner, "Studies on the Behaviour of Knots" in Turner and van de Griend. I also received encouragement and suggestions from the persons listed in Acknowledgments.

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