Knot and cord strength: answers to common questions

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As a guide and instructor I am often asked picky little questions about the strength and performance characteristics of ropes, knots, and climbing gear. Most of these I can answer in a general way but when I do so in the absence of test data I feel like I've provided an incomplete answer. I've often thought it would be great to have some test data to back up my opinions on these questions. In December of 2002 fellow rock guide Alan Jolley and I traveled to the BlueWater Rope factory in Carrolton, Georgia in search of test-based answers to many of these questions.

I had asked Scott Newell, president of BlueWater Ropes, a year previous if they would be able to help us test some ropes and knots and he had replied with an enthusiastic "yes" as well as stating willingness to generously donate the necessary ropes, cords, slings, machine time, and staff to help us run the tests. At the time we had hoped to do it remotely, that is we'd hoped to send them a wish-list of knots and configurations to test, have them perform the tests, and send us the data. This proved to be impractical, however, as we had a difficult time relating some of the nuances of the tests we wanted performed.

Traveling to the factory proved to be a benefit on a number of different levels. First and foremost it was quite a treat to tour a rope manufacturing facility and learn more about the general process of making ropes and the specific testing processes used by BlueWater. Especially useful was seeing the custom designed static pull testing machine used to perform our knot and cord tests in action as well as seeing a UIAA drop test performed on their test tower. The fall you never want to take…I have gained more confidence in ropes and cords but also a better understanding of the "Achilles heels" of the gear and, parenthetically, I would highly recommend that anyone who claims to be an authority on climbing ropes make the effort to tour a rope manufacturing facility.

The testing machine that we used consists of a steel frame about sixteen feet long and six feet wide and about a foot and a half high. It sits lengthwise on a concrete floor and so has a footprint of about sixteen by six feet. One end of whatever is being tested is attached to the end of the frame via a choice of different diameter "pins" and the other end of the tested piece connects in a similar way to a sled device which moves lengthwise within the frame, on rails. A hydraulic arm pulls the sled via a load sensing cell which in the case of the BlueWater machine is a Beowulf with 20,000 lbf capacity. The test pins offer a variety of diameters depending on what situation is being tested. We used carabiner diameter pins when we wanted to test strength of material over a carabiner and two or four inch diameter pins when tensile strength of the material or a knot was being tested.

Scientists and engineers out there will quickly point out that our testing was not very scientific. We did not set out to do a definitive test and some of the results do merit more looking into. However, we do feel like we satisfied our quest for "answers based on data rather than intuition". It is worth pointing out that we used one manufacturer's equipment, that all tests were done in static pull situations, that we generally did only three tests of any given configuration and that there are many variables such as temperature and humidity that we did not attempt to quantify or control in our investigations. We only were concerned with climbing anchoring tools: 7mm, 8mm, and 5.5 spectra cords, nylon and spectra webbing, and static and dynamic climbing ropes. Since this is not a research paper I'll take the liberty of presenting our conclusions while including only a minimum of hard data. If you are curious about the numbers, send me an e-mail.

Conclusions

Tensile strength versus loop strength

The tensile strength of a rope or webbing is derived by setting up the machine to play tug-of-war with a single piece of material. Each end of material is wrapped around a large diameter test pin to eliminate the sharp edge of the pin being the weak spot in the material. In the case of webbing a vise-like device is used rather than a pin or capstan. But we climbers don't use our cords and webbing that way, we always have at least one loop. How relevant is tensile strength to loop strength? If you tie it in a loop is it twice the strength of the rated tensile strength? How much does the carabiner affect the overall strength? The tensile strength of BW 7mm static cord is 2,600lbf. Loop strength on carabiner diameter test pins was 4,200lbf or about 80% of double strength. It was virtually the same percentage in BW 8mm static cord. Cords were tied with double fisherman knots and failure mode was the cord broke at the test pins. In 5.5 spectra we observed loop strength of 3,900lbf or 60% of double tensile. Failure mode with a triple fisherman knot was breakage at the test pin but with a double fisherman (not recommended to make loops in 5.5 Spectra) the failure mode was at the knot and at a slightly lower value. This was different than expected and it would be interesting to see if other high strength cords behaved similarly in single loop testing. Spectra seems to be much more affected than larger cord by the small radius of a carabiner.

Myths about "knot efficiencies"

It is common to refer to a certain knot as having a certain percentage of the strength of the material in which it is tied. This is called the "knot efficiency". We were not too surprised to find that the deficit caused by the knot varies wildly depending on the material. A figure eight follow through, for instance, is often cited as having 80% of the strength of the rope. In our tests this ranged from 100% – it did not fail at the knot in climbing ropes in about a quarter of cases, including in a UIAA fall test that we observed – to near 50% in 5.5 Spectra/Titan cord. My recommendation is to avoid using knot efficiencies as a teaching tool and instead make recommendations to students regarding which knot to use based on overall strength and ease of tying and untying compared to other knots in the same material.

Which knots to use to make loops out of stuff

Stick to the tried and true: when joining ropes to make loops as in cordelettes the double fisherman is your best choice. In 5.5 Spectra the triple fisherman provides an increase in strength and changes the failure mode of the material. This is true of all the small diameter/high strength cords. When using 1" webbing to form temporary loops the ring bend is your best choice but the flat eight is a good choice, too (see below). To form permanent loops of webbing buy sewn slings. When tying into the rope there's a reason the figure eight knot has been the knot of choice for years. Strong, simple, easy to untie and nearly as strong as the rope, there is no better knot for connecting the climber to the system. Anchoring with big static ropes? If you can figure out how to tie the bowline first time, every time this is a good knot to use with thick static lines but with smaller diameter ropes and cords, high strength/small diameter cord, and webbing you're much better sticking to the afore mentioned knots. More detail on other knots in other configurations is provided below.

Use of flat knots
Take the tails of two ropes. Hold the ropes together and use the tails to tie first an overhand then take that all apart and do the same thing but with an eight knot. Load the rope so that the knot is getting pulled from either side and the tails are not loaded. That's a flat knot. The first is a flat overhand, the other a flat eight. Oft debated (and oft tested) as a rappel knot, we performed tests on 7 and 8mm, static caving/anchoring rope, and two different climbing ropes plus most of the permutations with these materials. If you choose to use the flat overhand knot to tie rappel ropes together for its advantages of clean profile and ease of untying, use it with confidence. Failures with like ropes were always 2,300lbf (pounds of force) or more; with a 10.5/8mm rope combination failure was 1,700lbf or more. A flat eight added some 800lbf of strength in 10.5 rope compared to the flat overhand.

As a means of creating a cordelette loop I would *not* use flat overhand knots if the loop was to be used as a one loop anchor – the double fisherman knot is much stronger. – and flat overhand knots should not be used at all in Spectra, and I assume but did not test, in other small diameter, high strength cords. Flat overhand knots were about half strength compared to the triple fisherman knot in Spectra and flat eights in this material were in between (1,800lbf avg. with flat oh vs 2,980 lfb avg with flat eight vs 3,900lfb avg. with triple fisherman). In 7mm in a loop average failure was 2,900lbf in the flat overhand compared with 4,100lbf with a double fisherman. A flat eight provided nearly the same strength as a double fisherman, breaking at an average of 3,690lbf in 7mm and a bit higher in 8mm. The double fisherman breaks at the test pin while the flat knots break at the knot. If you choose to use a flat knot to make a temporary loop out of a cordelette make it an eight if you have the slack to spare. Keep in mind that flat knots don't stay tied very well for permanent loop making and carrying. We observed very little pulling through of the tails, or inverting within the knot in dozens of tests in slow pull configurations. The tails should be a common sense length of six to eight inches and the knot should be tightened down before use (a loose knot does affect the strength and failure mode). Finally, in BlueWaters "Climb-spec" 1" webbing a loop tied with a ring bend yielded an average failure of an amazing 6,200 lfb, with a flat overhand 4,125 lbf and 5,145 lbf with the flat eight. The flat eight in BlueWater's 1" webbing is a good, convenient choice for anchoring with large, long pieces of webbing, as is often done in top rope anchors.

Myths about backup knots and neatness of knots
We were not surprised to discover that the knot often tied above a person's figure eight follow-through tie-in and called a "back-up" adds nothing to the strength of the knot. Nor does it matter if the eight knot is "sloppy" or "neat". In fact we tested quite a few figure eight knots, in a variety of ropes, that were improperly tied so that the last pass of the "follow-through" was not made. Did it matter? Drum roll please: sometimes it tested stronger than the "correct" eight and in a third of our tests it did not break at the knot. You do not need a backup knot behind a figure eight tie-in knot nor should students be taught that "messy" knots are weaker than "correct" knots. At least in static pull tests so-

called backup knots and knot neatness contribute nothing to the strength of the knot and can lead a student to have a misdirected concern when the back up inevitably falls apart while they are mid climb. Of course a "correct" knot is easier for an instructor to check and that may be the best reason to do it "right" the first time and to teach that this is the "right" way. It would be interesting to perform a few of these "messy knot" tests on UIAA drop tests and see how they perform in dynamic loading situations.

Girth hitches and conventional wisdom

A wide variety of materials were tested in a multitude of configurations. All tests were conducted on 2" diameter test pins to eliminate the carabiner bend as the weak link. We tested like material to like material and every permutation in 7 and 8mm, spectra, spectra webbing, 9/16" and 1" webbing and all the above on wired stopper cable (the medium diameter cable). Like many knots there are so many configurations available it is not possible to give a constant percentage knot efficiency with the girth hitch. In all tests involving girthing a cable, except with 9/16" webbing which broke lower, the cable broke at or above its rated strength of 2,000lbf. In girthing any of the above materials to any of the above materials, in any combination, you can assume a minimum strength of 2,000lbf and usually higher, except in 9/16" webbing. BW 7mm prussic cord girthed to the same averaged a breaking point of 3,570lbf, 1" webbing to the same was well over 4,000lbf and a BW Spectra sling girthed onto 7mm consistently broke at 3,800lbf. Quite a range of numbers but if you always assumed a girth hitch was the strength of a medium wired stopper you would be giving yourself quite a bit of margin. If you must use a girth hitch due to some other issue in your anchor, as long as you recognize the strength deficit, you may do so guilt free. Just pretend the piece you're girthing is a bomber 3/4" wired Stopper.

Use of 9/16" webbing

9/16" webbing did not perform well in any of our tests. As emergency webbing for rappels there is much lighter material available. For slings there is much stronger available. We are now recommending to our students that 9/16" webbing not be used, at least not for anchoring purposes.

The bowline

We teach this knot on our Top Rope Site Manager courses due to its utility in areas that have an abundance of natural anchors. This can be a difficult knot to learn and we are often presented with "variations" that aren't quite text-book right. We saw consistency between our tests but only tested three different ropes when we asked: does it matter if the working end of the rope is on the "inside" or the "outside" of the loop forming the bowline. It didn't matter in these tests. Also, this is another knot where a back-up knot added nothing to the strength in static pulls. Of course if there is some issue that may move the knot around, cause it to rotate or flip, or if your rope is stiff and slippery, a back up is advised until testing is done on these configurations.

We are frequently asked if the bowline works in webbing or materials other than thick static rope. We tested the bowline in 1" (1,925lbf) and 9/16" webbing, 7mm and 8mm cord, and 5.5 Spectra (1,300lbf). **Don't** use the bowline with these materials. You can expect a strength deficit of about 50% with the bowline, and the percentage deficit increases as the diameter of the cord decreases. Finally, when using the bowline to tie off a boulder or tree don't be tempted to think of the loop that the rope forms as it goes around the tree or boulder as anchor strength; it's nowhere near and should be used only to keep track of an errant rope tail, not as an anchor.

Retiring slings and cords

More work needs to be done in this area but our limited testing on our own used 7mm cordelettes and used webbing indicated a significant reduction in strength as the material wore. BW 7mm static cord that was 18 months old and well used but appeared to be in good condition failed consistently at 60% of the same cord in new condition. Tested three times the used stuff was failing at 2,600lbf in a single loop configuration and the new cord failed at 4,200lbf. Well used 1" webbing failed at 70% of its original tensile strength. Obviously some reduction in strength over time is to be expected. It would be interesting to quantify appearance, use, and time in this context and do more research on this topic. It was surprising how much strength 7mm cordelettes that appeared to be in "good" shape had lost. For now the recommendation of replacing cords and slings that get heavily used every year seems to make sense.

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You may e mail Todd Vogel with questions about these tests at todd@sierramountaincenter.com.