Is There A Right Way To Tie A Prusik?

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Abstract:

Attendees at the 2014 International Technical Rescue Symposium raised questions about how prusiks behave when tied with prusik loop bends in different places within the hitch, and how those configurations alter prusik strength and weak points. To answer these questions, forty 7 mm prusiks were slow pulled on 11 mm rope measuring the strength tied with the double fisherman's bend in both limbs of the prusiks, and observing failure locations. Samples tied with the bend farthest from the bowline/"anchor" (N=20) broke at an average strength of 13.9 kN (3127 lbs), with a standard deviation of 0.4 kN (100 lbs), maximum of 14.8 kN (3335 lbs), minimum of 13.1 kN (2938 lbs), and a range of 1.8 kN (397 lbs). Samples tied with the bend closest to the bowline (N=20) broke at an average strength of 13.4 kN (3008 lbs), with a standard deviation of 0.7 kN (160 lbs), maximum of 14.6 kN (3278 lbs), minimum of 11.9 kN (2667 lbs), and a range of 2.7 kN (611 lbs). A two tailed z-test was performed and yielded a ρ-value of 0.004875 with α=0.05, meaning the results are statistically significant. All prusiks that failed broke where the accessory cord entered the prusik hitch (under the bridge), and the strand that broke was always the strand <u>without</u> the bend, regardless of bend position. The differences between the two data sets are small, meaning riggers can decide if the strength difference is large enough to necessitate a change in their rigging. It appears that rope slip out of a tightening knot reduces the force in the limb with the knot, making this strand the least likely to fail.

Introduction:

While attending the 2014 International Technical Rescue Symposium, I presented an article about the strength of prusiks of various diameters on 11mm rope (Evans 2014). After the presentation a number of attendees approached me about the research design and how it may have employed methods that yielded suspect results. One such concern raised was that nearly all the prusiks I observed broke in the same place, where a strand of cord entered the prusik hitch under the bridge (Figure 1). An observer pointed out that it is possible to tie a prusik with the double fisherman's bend in one of two places, either limb of the prusik hitch (Figure 2a,b). The location of the knot in the cord may have altered where the hitches broke, thus systematically altering the results I observed because I tied all the prusiks the same way.

This study was designed to determine if the location of the double fisherman's knot in a prusik altered either the strength of prusiks, or where they failed. To answer these two questions, prusiks were tied in two configurations (towards the anchor/bowline and away from the anchor/bowline) and slow pulled, recording their failure strengths and locations of failure.

Materials and Methods:

New unused rope and cord were donated by Pigeon Mountain Industries (PMI) for testing. They donated hundreds of feet of 11 mm Classic Sport Max (Pit Rope), 11 mm Classic Sport EZ (EZ Bend), and 7 mm accessory cord, which was used for a variety of studies (Evans 2015), so only some of the total donation was used here. I cut the rope into 86.5 cm (34 inch) sections and tied them with a bowline with no backup knot. I cut the cord into 104 cm (41 inch) sections and tied them in loops using double fisherman's knots. All knots were tied by me to maintain consistency. Half of the prusik loops were tied with the double fisherman's knot in the limb closest to the anchor knot (Figure 2a) and half were tied with the double fisherman's knot in the limb farthest from the anchor knot (Figure 2b). Samples were connected to the ram by the bowline with an SMC 45 kN steel carabiner (1/4 inch diameter bar stock), and the prusiks connected to an anchor using a hook and chain (Figure 3).

Prusik breaking strengths were measured by pulling with a hydraulic ram at 8 inches per minute and recording the forces they experienced with an Omega LCCA-15K load cell at 200 measurements a second. After a prusik broke, the location of failure was identified and recorded. Descriptive statistics were calculated in Excel and a two tailed z-test performed to determine if the average strengths of the two configurations were different.

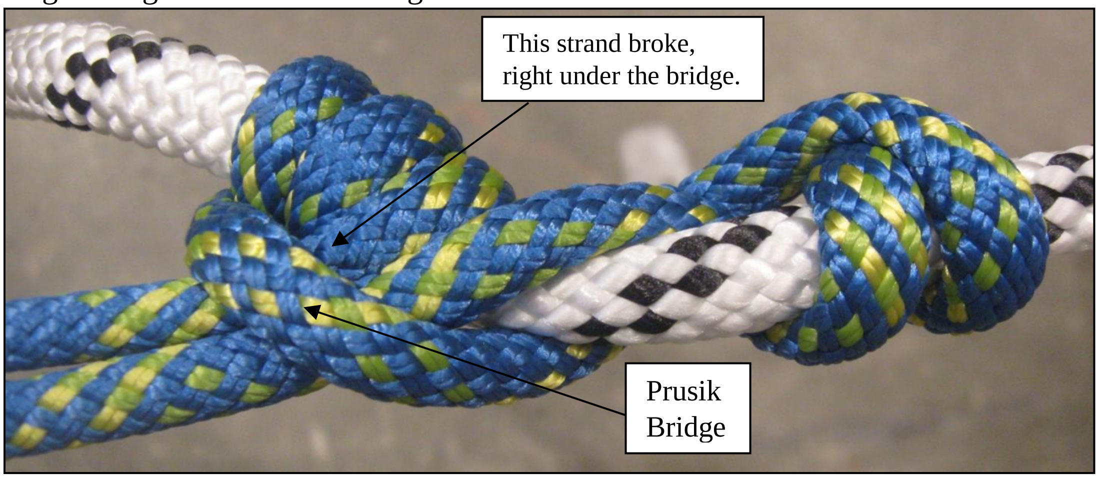

Figure 1: Breakage location for the vast majority of prusiks observed in Evans (2014), the strand closest to the load under the bridge (gently loaded 8 mm prusik on 11 mm EZ Bend rope depicted here). Figure reproduced from Evans (2014, Figure 4).

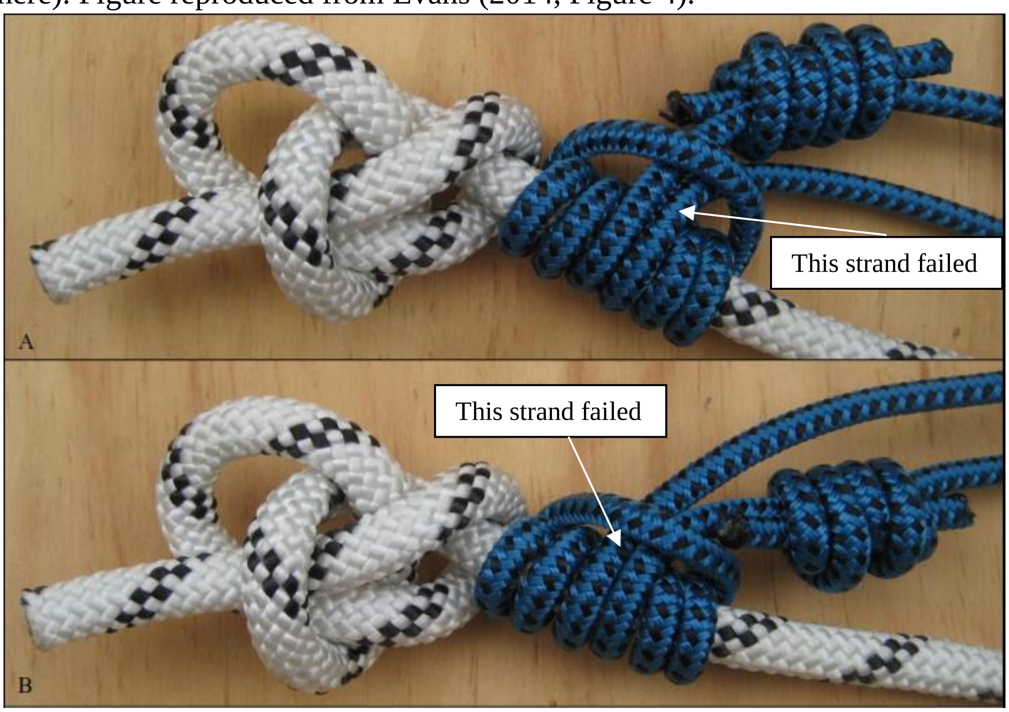

Figure 2: Two possible locations for the fisherman's bend; **A)** in the limb closest the anchor knot, **B)** in the limb farthest from the anchor knot. (Depicted here is 5 mm PMI accessory cord on 11 mm PMI EZ Bend rope; during testing 7 mm cord was used)

Figure 3: Pull test configuration. An SMC 45kN steel carabiner (1/4 inch bar stock), a bowline without a safety in 11 mm PMI EZ Bend rope, a three wrap prusik in 7 mm PMI accessorv cord.

Results:

Table 1a lists the breaking strengths of all samples with the double fisherman's knot in the limb closest to the bowline (Figure 2a) as well as their failure location. Table 1b lists the breaking strengths of all samples with the double fisherman's knot in the limb farthest from the bowline (Figure 2b) as well as their failure location.

Samples tied with the bend farthest from the bowline (N=20) broke at an average strength of 13.9 kN (3127 lbs), with a standard deviation of 0.4 kN (100 lbs), maximum of 14.8 kN (3335 lbs), minimum of 13.1 kN (2938 lbs), and a range of 1.8 kN (397 lbs). Samples tied with the bend closest to the bowline (N=20) broke at an average strength of 13.4 kN (3008 lbs), with a standard deviation of 0.7 kN (160 lbs), maximum of 14.6 kN (3278 lbs), minimum of 11.9 kN (2667 lbs), and a range of 2.7 kN (611 lbs). Visual inspection of both suites of descriptive statistics (bottom of Table 1) shows that all values are quite close, but there is a difference which can uncovered with secondary statistics.

To tease apart the differences between the two populations a two tailed z-test was performed and yielded a ρ-value of 0.004875 with α=0.05. This indicates that given the sample sizes (N=20 for each group), method used, and variances in the two data sets, there is a statistically significant difference between the average breaking strengths between the two treatments. So one configuration is, on average, stronger than the other by ~0.53 kN (~120 lbs).

All prusiks that failed broke where the accessory cord entered the prusik hitch (under the bridge), and the strand that broke was always the strand without the knot in it. One prusik did not fail, but broke the mantle of the rope.

During pulling the double fisherman's bends did not run into the hook used to affix the pruik to the ground, so knots jamming into a connector was not a confounding variable here, although Figure 3 might mislead readers to think this was the case.

Discussion and Conclusions:

These results can be difficult to interpret because the results between the two treatments are so similar. To make comparisons easier, Figure 4 shows a box and whisker plot of both data sets. Comparing the two directly suggests the data set on the right has a lower average, lower quartiles, and a wider range than the data set on the left. This indicates that prusiks tied with the bend in the limb closest to the rigging knot were, on average, weaker, by about 0.53 kN (120 lbs), though with substantial overlap in the results from both data sets. This difference is statistically, but perhaps not practically significant.

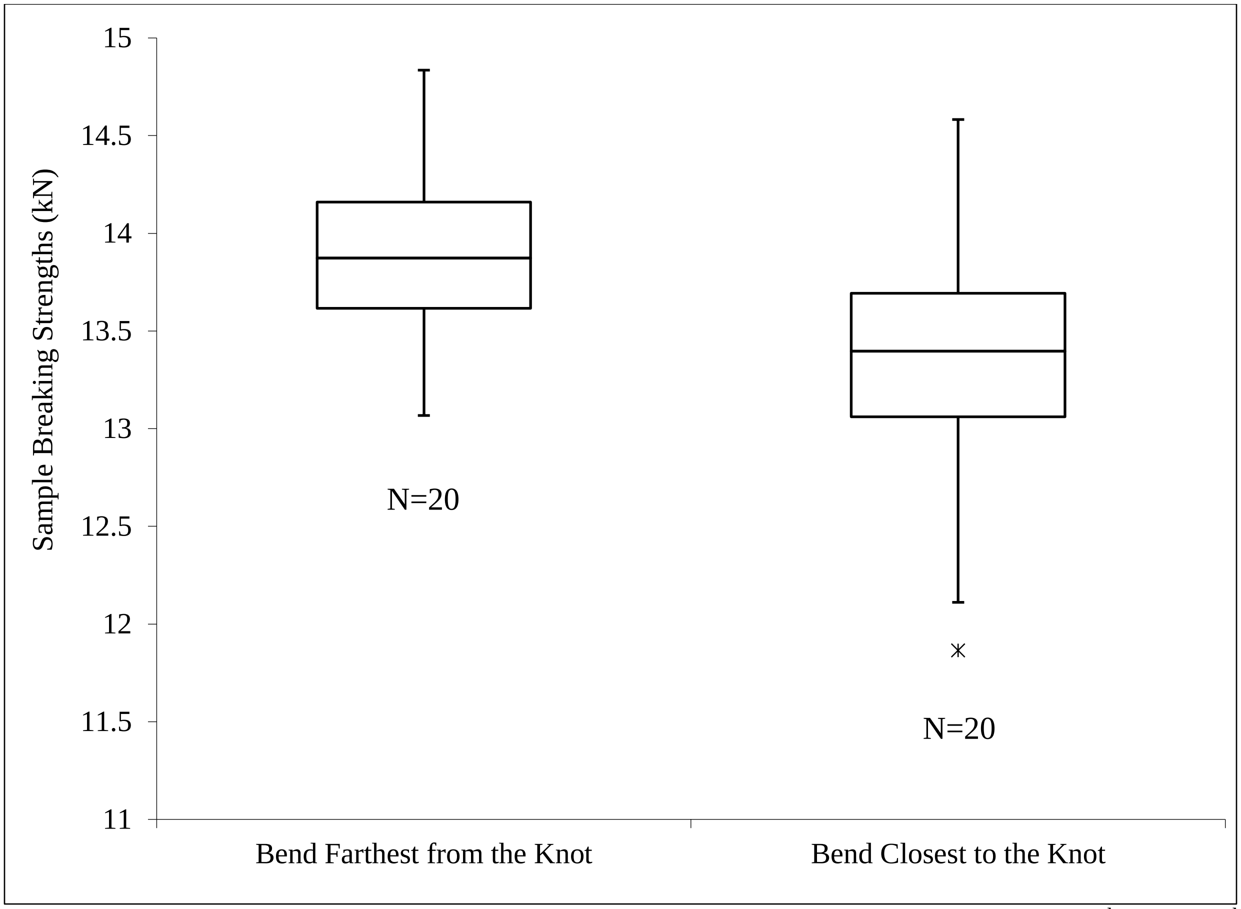

Figure 4: A box and whisker plot depicting the data set averages (horizontal line), 3/4^{ths} and 1/4th quartiles (box upper and lower bounds respectively), ranges (vertical lines), and outliers (*). "Bend farthest from the knot" is the lower photo in Figure 2, and "Bend closest to the knot" is the upper photo in Figure 2.

This simple result indicates that the data reported in Evans (2014) should represent conservative lower estimates of prusik strength, because all of the prusiks tied in that study were tied with the prusik bend in the limb closest to the rigging knot (the weaker configuration). Therefore, using the numbers from Evans (2014) for rigging will provide conservative estimates for new, unused equipment for the rope and cordage combinations tested.

What does this strength difference mean for rigging? This is a practical question each rigger has to determine for his or herself, because the presence of a statistical difference in strength may not have a real world significance. For example, Evans and Stavens (2011) demonstrated that basket hitch webbing anchors are stronger than wrap 3 pull 2 anchors with strong statistical support. However, because both anchors are stronger than the rope (and most common carabiners!), the difference is not of practical interest; both anchors are strong enough for the applications and equipment they are built with and for. Similarly, prusiks tied in both configurations were right around 13 kN or more. The question becomes: is it worth the possibility of an extra hundred pounds of strength to require prusiks tied in a particular configuration? Ultimately if an extra hundred pounds of strength makes or breaks the rigging, then it may be wise to re-rig in a configuration in which such a small difference in strength makes no difference.

A clear result from the data presented here is that the location of where the cordage bend is located within a prusik hitch does alter the weak point. The weakest strand is the one without the double fisherman's knot (Figure 2), regardless of relative position to the anchor. This can be explained by the knot tightening, the strand with the knot lengthening, and the transfer of more load to the limb without the knot. This same effect was observed by Gibbs (2012) when measuring the forces on limbs of multipoint anchors. He observed that anchor limbs with knots in them held less load because they extended as the knots tightened down. While knot tightening in a prusik and lengthening one limb is an interesting observation, it may have no practical application given that altering where the knot is in the hitch has such a small effect on the breaking strength.

Previous research ("Prusik Knot Testing" & " Rope system testing at Unofficial Swiftwater Rescue Instructor meet, Norway") suggests that placing the cord bend in the bridge of the prusik both reduces the ability for the prusik to grab the rope, and the prusik strength. Given that these results are based on sample sizes of 1 in each configuration, the results should be considered with skepticism. Clearly more testing is needed.

Ultimately these observations add to our understanding of how the systems and equipment we are using function, even if the results do not alter how we rig. This is important because recent research has frequently indicated that the systems we are using are not as strong as we think, or are not behaving as expected. While it is clear the systems are safe and strong enough, understanding how they behave in real life is important so we know what we should do to strengthen systems if needed.

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Literature Cited:

Evans, Thomas, Stavens, Aaron, 2011, Empirically Derived Breaking Strengths for Basket Hitches and Wrap Three Pull Two Webbing Anchors, Proceedings of the International Technical Rescue Symposium, Fort Collins, Colorado, November 3-6, 2011

Evans, Thomas, 2014, Empirical Breaking Strengths of Single Prusiks of Four Diameters on 11 mm Static Rope, International Technical Rescue Symposium, Denver, Colorado, November 6-9, 2014

Evans, Thomas, 2015, Response of Some 3:1 Haul Systems to Excessive Loading, International Technical Rescue Symposium, Portland, Oregon, November 5-8, 2015

Gibbs, Mike, 2012, Tying it all Together: Considerations for equalizing multi-point anchor systems, Proceedings of the International Technical Rescue Symposium, Seattle, Washington, November 1-4, 2012

Unknown Author, Unknown Date, Prussik Knot Testing (http://www.swiftwaterrescue.at/content/info/prussik.html)

Unknown Author, 2010, Rope system testing at Unofficial Swiftwater Rescue Instructor meet, Norway, July 2010 (http://www.kajakksenteret.no/files/Rope%20system%20testing%202010.pdf)

Table 1a: Breaking strengths and failure locations for samples with the double fisherman's bend in the strand farthest from the knot (Figure 2b).

Sample #	Breaking Strength (lbs)	Breaking Strength (kN)	Failure Location
5L	3062	13.6	Samples broke where the cord entered the prusik, just under the bridge, in the strand without the knot.
6L	3032	13.5	
7L	3186	14.2	
8L	3335	14.8	
9L	3271	14.6	
10L	3058	13.6	
11L	3200	14.2	
12L	3020	13.4	
13L	3094	13.8	
14L	3094	13.8	
15L	3169	14.1	
16L	2938	13.1	
17L	3183	14.2	
18L	3255	14.5	
19L	2970	13.2	
20L	3180	14.1	
21L	3287	14.6	Rope mantle failed
22L	3117	13.9	Samples broke where the cord entered the prusik, just under the bridge, in the strand without the knot.
23L	3120	13.9	
24L	3092	13.8	
25L	3158	14.0	
Average	3127	13.9	Sample 21L was removed from calculations of descriptive statistics because it displayed a different failure mode.
Std. Dev.	100	0.4	
Maximum	3335	14.8	
Minimum	2938	13.1	
Range	397	1.8	

Table1b: Breaking strengths and failure locations for samples with the double fisherman's bend in the strand closest to the knot (Figure 2a).

Sample #	Breaking Strength (lbs)	Breaking Strength (kN)	Failure Location
26K	3099	13.8	All samples broke where the cord entered the prusik, just under the bridge, in the strand without the knot.
27K	3278	14.6	
28K	2737	12.2	
29K	3054	13.6	
30K	2977	13.2	
31K	3008	13.4	
32K	3243	14.4	
33K	3015	13.4	
34K	3052	13.6	
35K	2936	13.1	
36K	2816	12.5	
37K	2950	13.1	
38K	3068	13.6	
39K	3120	13.9	
40K	2936	13.1	
41K	2939	13.1	
42K	2667	11.9	
43K	2917	13.0	
44K	3273	14.6	
45K	3072	13.7	
Average	3008	13.4	
Std. Dev.	160	0.7	
Maximum	3278	14.6	
Minimum	2667	11.9	
Range	611	2.7	