Random Rope and System Testing

September 2, 2009

Abstract-
Though there is a tremendous amount of significant rope and equipment test data available, there were a few items that we could find no research on in the standard texts or on-line. *Engineering Practical Systems* and *CMC Rope Rescue* are both tremendous resources with excellent data and answers to most questions. The internet has a wealth of knowledge to offer as well. Ultimately, we decided to conduct some quick, unscientific testing to find a few of the answers we still lack.

The following questions were tested in varying degrees:
1. Is the Double Beckett secure enough to be used as a life safety anchor with ½" rope?
2. Is a 'Bridged" Prusik (Top Knot Prusik) safe to use in a life safety system and how does it compare to a standard wrap?
3. Will a bar rack hold a load unattended at any point? If not, will the rope slip prior to bar deflection?
4. Does theoretical mechanical advantage equate to real world results in relation to haul team potential.

Disclaimer
None of these results should be considered scientific by any stretch. We provide this purely as information that we garnered from the limited testing we performed. There were no strict controls and much of the testing was on nearly the same section of rope, which would not allow for the stretch factor. As an example we witnessed a catastrophic failure of an in-line figure of eight knot on the ½ rope at 4200#, well below it's tested rating. This same knot had be used on the prior eight pulls in excess of 3000#, a scientific test would have naturally replaced the rope for the series we were testing at the time. Also, we are a technical rescue team in central Indiana. We do not work routinely in high angle environments, mountains, or long hauls. Our direction and inferences may not match that of teams that do work in those complex environments. There are no guarantees in this report other than what we found in these limited tests. Finally, this information is not for publication or reference. We merely want to share it within our team and a few trusted industry associates.

Equipment & Methods
- The rope used in the bar rack test was an unused section of ½" kernmantle, 10' long
- The rope used for all other tests was a well-used section of ½" kernmantle, recently retired to utility rope. This section had not be used since it was replaced as an in-service rescue rope. It had never been shock loaded or used in any method other than training. This rope was in very good condition.

- The bar rack was a CMC Rescue Rack, no defects.
- The Gibbs ascender was well used, in service, no defects.
- The prusik loops were new sections that hadn't been used in life safety.
- One older prusik was used but removed from testing after it's first slip. It was a previously in-service loop but was very soft. In the photos it is the green piece that melted extensively.
- The testing scale was a Dillon 500# dynamometer.
- The load input was either a standard MA rope system or a 12T power winch on the front of Rescue 91 (test dependant).

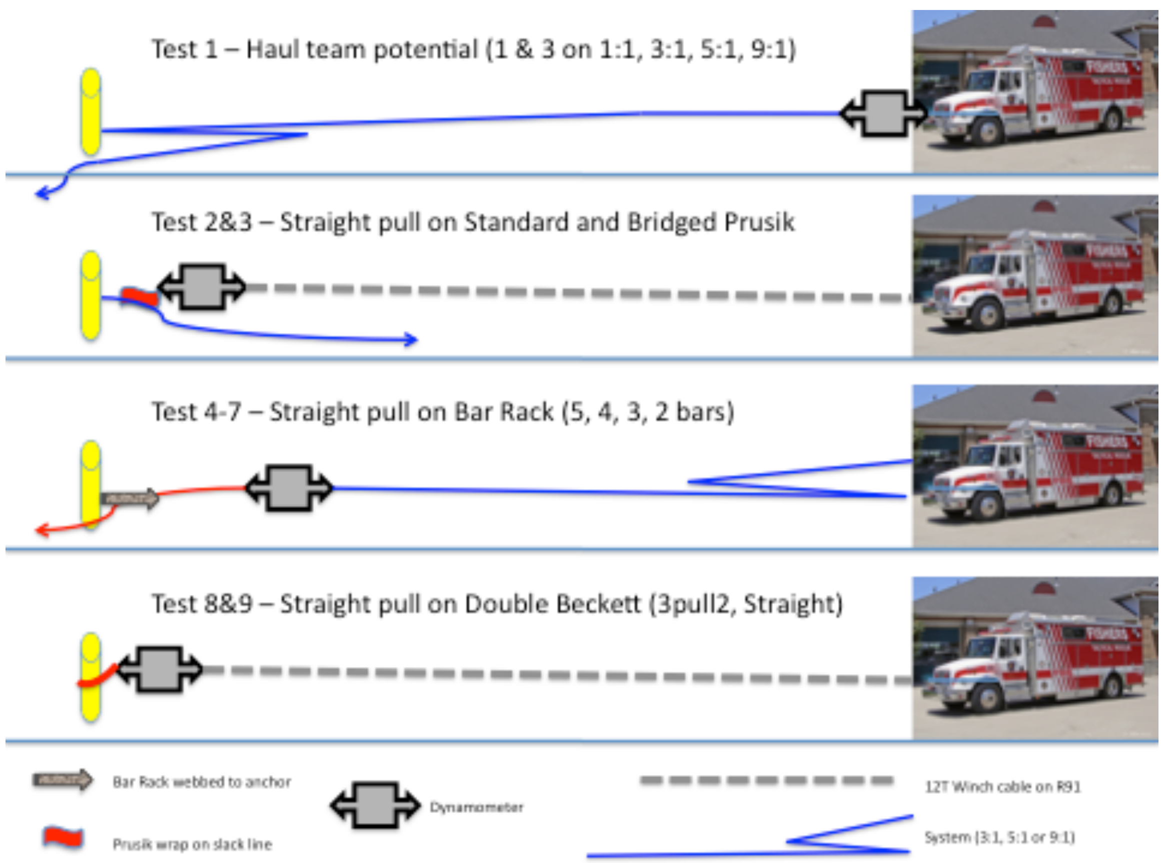


Figure 1.1 – Test layouts

Test #1 – Haul Team Potential

Brief: CMC testing concluded, through detailed and exhaustive research, that an average haul potential for a three person team, on hard surface, pulling a ½ line was 444 pounds. Given that number, a quick calculation indicates that the same team could generate 1,332# with a 3:1 MA system, 2,220# on a 5:1 MA system, and 3,996# on a 9:1 MA system. Naturally this doesn't account for friction loss and other associated factors. We wanted to see how close the actual pull potential were to the theoretical, both for curiosity and to evaluate the potential for damage when using a 9:1 system. We performed 18 individual test pulls in varying configurations. Each test was conducted at least 3 times and the average is listed below.

Data:

- 1 person, 1:1 pull = 160 (equals CMC results)
- 3 person, 1:1 pull = 550 (relatively close to the CMC average of 444#)
- 1 person, 3:1 MA = 240
- 3 person, 3:1 MA = 1080 (approx 80% of the theoretical potential)
- 3 person, 5:1 MA = 1760 (approx 79% of the theoretical potential)
- 3 person, 9:1 MA = 2317 (only 58% of the theoretical potential)

Result: While the 3:1 and 5:1 systems produce pull values that are generally consistent with the theoretical values, the 9:1 was far less. As a result, one could conclude that the 9:1 wouldn't generate system-failure forces in normal use. This also raised many more questions for us in the area of physics and testing in general as this was far below the expected result.


Figure 1.2, 1.3 – Haul Team Testing

Test 2-3 – Prusik Loop Testing

Brief: We were recently made aware of an article written by Jim Segerstrom that discussed what he referred to as a "FLP hitch" or funny looking prusik. Essentially, it was a bridged prusik where the knot is left setting on the top of the wrap. In the article there was anecdotal evidence of successful usage but no evidence of actual testing. Our intent was to test this knot and compare it to a standard triple wrap prusik. The initial test (on the oldest and softest loop) produced visible melting and failure at about the point expected. We then switched to newer, unused loops to continue testing.

Figure 2.1 – "FLP" or Bridged Prusik Loop

Testing results from several texts (Including Mike Brown, et al) indicates that a prusik should slip anywhere from 1500# to 3000# (or the break point of the prusik itself), which makes it an ideal safety fuse in any system as it will indicate excessive loads (double the standard life safety load) without failure. The prusik will slip and then re-grab the rope, keeping the system safe while alerting the team to a dangerous load or problem. The 8mm cord we tested has a rated break strength of 2,875#, the double fishermen knot reduces this to 2,271#. On our first test we saw initial slippage at 1250# with visible melting of the loop, after switching to the better loops we continued testing. Loops #1 and #2 were of the same age and history, the older green loops. Loops #3-8 were from brand new sections and are red in the photos.

Figure 2.2, 2.3 – Old prusik loop failure with melting and residual on haul line

Data:

Weight given is the reading on the dynamometer at the point of slippage

Loop #	Standard Wrap	Bridged Wrap	Loop Stretch
1	1400#, 1600#		
2		2000#, 1800#	
3	850#, 1800#		2”
4		1000#, 1800#	1”
5	1000#		
6	1750# (manually pre-tensioned)		
7		1400#	
8		1950# (manually pre-tensioned)	

Result: While clearly a limited and unscientific test sample, we were impressed and the capacity of the bridged loop. It is important that the prusik continue to slip at a safe point to provide the visual indication of potential system problems and the bridged loop continued to slip below 2000# on average. Every hitch performed better on the second (and third though not included) tests after the cord had been stretched. Clearly, a prusik/haul line that has been loaded to the point of slippage should be removed from life safety service due to the visible damage to all surfaces and obvious stretch and melting.

The advantages to the bridged prusik are identified in the article by Segerstrom:

1. Easier to tie, simply grab the mid-point and wrap, no need to offset or adjust the knot.
2. Faster setup for a less-experienced technician

3. Keeps the double fisherman out of tension to allow for unlocking later if needed.
4. Easily visualized due to the layout and positioning.
5. Much easier to grab in a gloved hand (ideal in cold weather).

While the benefits certainly don't mandate a wholesale change in operations to the bridged prusik, the results do allow us to comfortably include it in our rope systems toolbox. As a follow-up to this test we did run a single test on a tandem prusik set. The tandems shared the load (one slipped and the other held and vice versa) and didn't show measurable slippage until 3,300#. This should still be the fuse in the system but is a good bit higher than the single loop.

Figure 2.4, 2.5 – Sample tests of the standard and bridged prusik loop

Test 3a – Gibbs Ascender

Brief: Given the tools available, one of the technicians requested to see what the Gibbs ascender would do in similar testing. We have all read of the potential for failure in the older ascender models and their ability to cut rope when shock loaded at certain points. We had long ago switched to all soft-cam systems but we keep a few of the new style Gibbs ascender in our spare bag for personal ascending, litter tending, etc.

Data: Only three tests were performed due to the rapid degradation of the test rope and the need to move on to other tests.

- Test 3a(1) – The rope outer sheath was torn and melted when the ascender slipped at 5000#
- Test 3a(2) – Moving to a new, undamaged section of the rope when saw slippage followed immediately by complete de-sheathing at 3200#
- Test 3a(3) – Following test 3a(2) we found that the torn rope was still held in the Gibbs at 2000#, we decided to reload the line to see if it would continue to hold or fail. At 3250#, on the same section, the inner core ripped catastrophically and the test was concluded.

Figure 3a.1 – Montage of Gibbs Ascender failures

Test 4 – Bar Rack Testing

Brief: The curiosity behind this test was regarding the holding capacity of an unattended bar rack. Generally speaking, we all have experienced the ability to hold a rescuer on a decent with very little effort on the bar rack. The test was to see how much weight the bar rack would hold during a 'whistle test' with no belay. Naturally, the rack will slow any descent, with increasing friction based on the number of bars. As we attempted several configurations we found that the rack, as simply will not hold any load if it is unattended. Our attendant was able to hold about 1000# without slippage on a full 5 bar rack with one handed pressure on the rack (holding the rope toward the load in stopping fashion). We then locked the rack off with a single overhand to see if the rope would slip prior to locking down the safety knot. What we found was a complete deflection on the rack at 1400#, rendering the rack useless and out of service.
While the rack did hold at 1400#, it was obvious that increased loading was going to lead to individual bars popping out of the rack arm.

Result: We were impressed at the fact that a single rescuer can hold nearly twice the standard rescue load with very little effort. While most bar racks are rated at 8000#-10000# breaking strength, we were surprised to see how the rack bent under the load we placed on it. Other published tests also indicate potential failure in the 1200#-1500# range but we were still surprised at the amount of damage. While the bar rack would only be used in lowering, it still must be locked off and depended on to hold loads. Clearly, between the prusik and the bar rack, a 2:1 safety margin is not uncommon in most rescue systems (not accounting for belays, backups, etc.)

Figure 4.1 – Bar rack deflection

Test 8-9 – Double Beckett Testing

Brief: We recently took interest in a knot used to readily adjust a section of rope while allowing for locking it in place. The Double Beckett (or double sheet bend) is generally used to connect two ropes of differing sizes. With a simple follow through on the final loop, this knot works excellent on connecting a loop of 1/2 " rope that can be adjusted. Originally, we saw this as an anchor for a tripod while training with the infamous Pritzes at SBFD. Other potential applications that were discussed were for a large wrap anchor using a wrap 3 pull 2 loop, allowing for an additional leg of rope to become the extended anchor.

Result: We tested this knot twice up to the maximum 5000# on the meter. We noticed no slippage and it appeared that the stretch was away from the knot. While we tested it in a straight loop configuration, we feel that a wrap 3 pull 2 would be the only prudent way to utilize this knot in a life safety system Additionally, an overhand safety could be added to the end of the knot once it is adjusted and set. We felt the testing proved that this knot can be considered in the system toolbox for certain anchor situations and should be readily used in non-system applications (edge protection, edgeman safety, tripod securing, etc). Immediately after testing this loop we tested a used section of 1" tubular webbing that failed at around 4800# at the water knot, as expected. In a second set of tests we attempted to break this knot without the dynamometer involved. Our test rope first failed at the in-line 8 used to connect it to the winch. We tried again with an 8 on a bight, that knot also failed while the Double Beckett held tight (though with tremendous tightening and stretch).

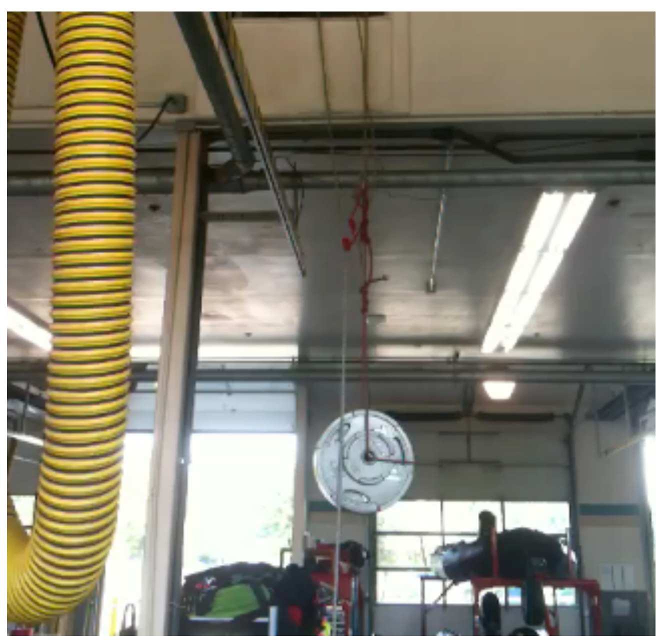
Figure 8.1, 8.2 – Double Beckett, 8.3 – Failed webbing at water knot

Figure 8.4 – Double Beckett after several load tests, Figure 8.5 – Failed Figure 8 on bight

Test 10 – Drop Testing of Bridged Prusik

Brief: After the initial testing of the bridged prusik we felt confident in it's inclusion in our system options. Realizing we had not actually tested it in a shock-load trial we decided to attempt some drop tests. Only three tests were performed but we saw absolutely no evidence to the contrary of our initial estimation of the wrap's performance.

Data: The test was performed by dropping a 200# load a distance of approximately 4 feet. The securing line was held by a web fuse that was cut to create an instant drop. Test #1 was a standard wrap prusik, #2 was a bridged prusik, and #3 was a bridged prusik with the dynamometer in the link for impact load calculation.



Results: In all three tests the prusik loops locked and grabbed without any movement on the line. Each was set loosely and marked with a tape, upon release there was no noticeable movement from the tape on any of the three tests. The dynamometer showed a 750# impact load on the third test, which indicated that a 600# rescue load would, of course, have dramatically high impact forces in a belay situation. Again, we felt the bridged prusik performed just as well as the standard wrap.

<u>Summary</u>

Though the testing used only limited samples and very little in the way of strict controls, we felt we learned a great deal about several components in our systems. Some of the important take home points are as follows:

1. The MA is at best theoretical, do not assume that your haul team can lift 4,500 pounds just because you built a 9:1 system.
2. The bridged prusik is a valuable tool and should be considered. It has several advantages and compared excellently in drop testing. Prusik hitches in the system are the best indicator of system overload and a very valuable component in the life safety application.
3. The Gibbs ascender should never be loaded to the point of rope destruction in any life safety application. Nevertheless, it was quite impressive to see what soft-cam failure means next to hard-cam failure. Careful consideration must be given if a system is being used to lift a heavy object to remove an entrapment. The 9000# rated rope will only hold as much as the brakes in the system will allow.
4. A bar rack may be rated at 10,000# break strength but the brake will fail well before that point. The damage we witnessed at 1400# shows that this component remains ideal in life safety applications but has limited use in heavy lifting systems.
5. The Double Beckett knot is very effective for it's applications and can easily be incorporated into system use. Using a wrap 3 pull 2 will nearly eliminate the knot from the equation, though the knot is proven to at least 5000#.
6. As a curiosity we also 'set' a few of the prusik wraps in a fashion similar to testing a system before use. A three person team shock-pulled the rope, setting the knots, three times. The dynamometer showed this force to be about 500#.