Empirically Derived Breaking Strengths for Basket Hitches and Wrap Three Pull Two Webbing Anchors

Thomas Evans[a] and Aaron Stavens[b]
[a]Montana State University, Department of Earth Sciences, PO Box 173480, Bozeman, MT 59717-3480, cavertevans@gmail.com
[b]aaron.stavens@caves.org

Introduction and Background:

All rope rescue systems have an anchor, and if the system is designed conservatively, the anchor should be stronger than the rest of the system (ideally the rope is the weakest point in the system). Consequently it is important to know the strengths of our anchors, as well as the relative strength of the anchors in different configurations. Copious pull tests and dynamic tests of anchors have been performed in the past however few of these testing programs have been published for a wider audience, and rarely are the conditions of the tests reported in sufficient detail for others to independently determine the validity and rigor of the testing programs. In addition, statistically significant numbers of tests are usually absent, meaning that the variability in anchor performance is nearly entirely unknown. The research program presented here is designed to measure the absolute breaking strength of two anchor types (basket hitches and wrap three pull two anchors (W3P2)), observe their relative strengths, the variability in breaking strengths and breakage patterns, and ultimately to ascertain if both are acceptable rescue anchors as expected.

Materials:

Two spools of new unused one inch PMI tubular webbing were used from lot number 45105 and loom 514. One of the two spools had a splice, and the splice point was not included in any of the anchors measured, though both sections of webbing on the full spool were given their own spool designation when sample numbers were assigned to each anchor. Measurements of breaking strengths were conducted on a Baldwin universal testing machine with DP41 digital load deflection upgrade electronics with an internal load cell range of 0 to 200,000 lbs, at the College of Engineering, Montana State University. The universal testing machine was last calibrated on 3/10/2011 and measurements took place on 6/23/2011–6/24/2011.

Methods:

Eight feet of webbing was used to tie basket hitches and nine feet was used for W3P2 anchors. To ensure no effect was observed due to the spool of webbing used, lengths of webbing were cut from each spool alternating between basket hitches and W3P2 anchors. Samples were given a unique sample number consisting of four parts; the spool number the webbing came from; type of anchor tied; the number of the piece of webbing along the length of a spool, and finally the test number. For example 3-B-14-28 corresponds to webbing from spool number three, a basket hitch was tied with it, it was the fourteenth length of webbing cut from spool three, and it was the twenty-eighth measurement performed. All anchors were tied by one person (A.S.) to retain consistency. Anchors were tied around a 4 inch diameter smooth steel pipe filled with concrete and the attachment point was a half inch diameter, four inch tall steel screw link purchased from a hardware store. Basket hitch knots were placed behind the metal pipe while the W3P2 knots were placed on the front of the pipe facing the load.

Each anchor was built and quickly loaded up to ~8000 lbs (~82 lbs per second) then the rate of loading was decreased (~14 lbs per second) till breakage occurred. All trials were photographed prior to initiation and recorded to create a permanent record of qualitative observations. The anchor internal angle was measured from anchor photographs. The number of breaks each anchor experienced, as well as the kind of break (clean or a fray) was recorded in addition to any notes or abnormalities observed during measurement.

The measured raw breaking strengths were multiplied by the force multiplier determined by the internal angle of the anchor to calculate the load experienced by the anchor. This scaled data was used for all statistics. Descriptive statistics (average, maximum, minimum, range, and standard deviation) were calculated for all trials as well as a subset of those trails in which no abnormalities were observed. To test the null hypothesis that the two anchors had the same breaking strength a two-tailed Z-test was performed for all the data as well as the subset of tests in which no abnormalities were observed.

All anchors broken were saved and archived for later study and can be accessed by contacting the authors. In addition, copies of the electronic data (photographs, videos, and Excel files) can be provided upon request.

Results:

Basket hitches were tied with an internal angle of 15 degrees, yielding a force multiplier of 0.008628961, while W3P2 anchors had an internal angle of 12.5 degrees, yielding a force multiplier of 0.005979200. Table 1 displays the raw breaking strengths, scaled breaking strengths, number of breaks, breakage types (clean or fray), and notes and observations made during measurements.

Basket hitches (N=34) broke at an average load of 9943.2 lbs with a standard deviation of 642.4 lbs, with a maximum load of 11244.2 lbs, and a minimum of 8902.2 lbs. W3P2 anchors (N=35) broke at an average load of 9167.3 lbs with a standard deviation of 1075.4 lbs, with a maximum load of 11695.5 lbs, and a minimum of 7445.3 lbs. To test the null hypothesis that the two anchors broke at the same average strength, a two-tailed Z-test was performed yielding a P-value of .000212 (α=.05, critical value 1.959964), suggesting there is a statistically significant difference between the breaking strengths of the two anchor types. Figure 1 shows the breaking strengths of both basket hitches and W3P2 anchors versus rank order (lowest breaking strength to highest). The difference between the average breaking strengths between the two anchor types is visually observed through the gap between the two trends in breaking strengths.

All measurements shaded in grey in Table 1 had some abnormality during measurement, and were omitted to remove any effect the abnormalities may have had during data analysis. The same general trends were observed with this truncated (more conservative) data set. Basket hitches (N=27) broke at an average load of 9928.3 lbs with a standard deviation of 627.7 lbs, with a maximum load of 11208.9 lbs, and a minimum of 8902.2 lbs. W3P2 anchors (N=33) broke at an average load of 9221.6 lbs with a standard deviation of 1064.4 lbs, with a maximum load of 11695.5 lbs, and a minimum of 7455.3 lbs. The two-tailed Z-test yielded a P-value of .001494 (α=.05, critical value 1.959964), also suggesting there is a statistically significant difference between the breaking strengths of the two anchor types. Figure 2 shows the breaking strengths of both basket hitches and W3P2 anchors versus rank order (lowest breaking strength to highest). The difference between the average breaking strengths between the two anchor types is visually observed through the gap between the two trends in breaking strengths. Both Figures 1 and 2 show basically the same trends.

Observations

In all trials the anchors broke at the screw link and not at the knot, suggesting that the knots are not the weak point in the anchors in the configuration tested. Basket hitches tended to break at two locations simultaneously (24 times or 71%), while W3P2 anchors broke in two locations less frequently (8 times or 23%). In 4 trials (11%) one strand of a W3P2 anchor broke, however the anchor held until pulled further since the loaded webbing held the anchor in place even with the severed strand. In addition, the W3P2 anchors made many more noises during loading than the basket hitches.

Figures 3 and 4 depict the breaking strengths of both basket hitches and W3P2 anchors versus rank order (lowest breaking strength to highest) with the spool of origin indicated for each test. Basket hitches show a roughly even distribution of spools throughout the rank order breaking strengths suggesting there is no effect due to the spool of origin in the breaking strengths. The opposite is true of W3P2 anchors with spool 3 anchors breaking at lower strengths than spool 1 anchors. Since statistically significant numbers of anchors of both types could not be made with each spool of webbing it is impossible to determine if this effect is real or a function of chance. Here we simply note that there appears to be a difference in the breaking strengths of W3P2 anchors between spools and acknowledge an insufficient sample size to determine if this effect is a function of chance or not.

<u>Sources of Error:</u>

All measurements have an associated error, in this case the error inherent in the Baldwin universal testing machine was as low as can be expected since it had been recently calibrated. More importantly, the error is on the order of plus or minus a few pounds. The error in cutting the lengths of webbing was on the order of a millimeter or two. The variability in tying hitches and their internal angles are the largest source of error in this suite of measurements. This variability was small enough that, when measured, the internal angles for each anchor type (basket hitch or W3P2) were consistently the same. Internal angle measurement error was on the order of half a degree. In toto the sources of error are small enough that the conclusions reached are not affected by their inherent uncertainty in measurement (error bar).

<u>Conclusions:</u>

1. Webbing anchors broke at lower strengths than expected. Assuming a ~4000 lb breaking strength for each strand, a 16,000 lb breaking strength estimate was generated.
2. As tied the weakest point in the anchors is not the knot but the webbing itself.
3. Webbing anchors can break in more than one location simultaneously during failure.
4. Basket hitches break, on average, at a higher strength and with less variability (smaller standard deviation) than W3P2 anchors.
5. Basket hitches appear to be between 705 to 775 lbs stronger than W3P2 anchors in the configuration tested.
6. The most common failure mechanism of basket hitches is breaking of webbing at two locations simultaneously while the most common failure mode of W3P2 anchors is the failure of one strand.
7. There is variability in the breaking strength of anchors between spools of webbing as well as within a spool of webbing.
8. Both basket hitches and W3P2 anchors are stronger than 11mm nylon rope (~6000 lbs) so both are acceptable rescue anchors when tied in the configuration tested here.
9. Developing and implementing a testing program is easier than expected and is possible for many individuals who live in proximity to a university with testing facilities.

<u>Discussion:</u>

When interpreting the findings presented here it is important to keep in mind that these results apply to anchors tied in the configuration tested. Our results have no bearing on basket hitches and W3P2 anchors with knots located in different places, a variable that should be investigated in the future.

Both anchor types demonstrated they are adequate for rescue systems however, both have strengths and weaknesses. Basket hitches are stronger, are tied faster, and use less webbing, however, they slip and move around more easily than a W3P2 anchor. W3P2 anchors are weaker (but strong enough), are slower to tie, use more webbing, but stay in place far better than basket hitches. Ultimately both anchor types are effective and useful in a rigger's tool belt of techniques to apply to different problems. Both should be used in rescue systems when their strengths are needed and their weaknesses can be mitigated.

The observations and measurements presented here are consistent with an inference of the mechanism of loading and failure that explains the relative strength difference between the two anchor types. This inference forms the core of a hypothesis (testable causal explanation) of how anchors load and break, however, this inference should be tested prior to being used as an explanation of how anchors work.

Inference of loading and breakage mechanism: As anchors are loaded each limb takes weight more or less equally until the material starts to stretch. At this point the limbs are weighted unequally since some limbs were shorter than others (even if it is only a small difference). If the difference between the forces applied to limbs is greater than the static friction of the webbing against the object it is wrapped around the anchor will slip and equalize the force on the limbs. Basket hitches have far less friction between the webbing and the object it is wrapped around since there is less contact between the two objects. Consequently basket hitches are able to distribute the load faster and at a lower threshold than W3P2 anchors. When basket hitches finally fail they fail simultaneously at two locations since the breaking strength of the webbing has been reached at essentially the same time throughout the anchor since it is approximately equally loaded. W3P2 anchors have far more friction between the webbing and the object they are wrapped around making it harder for the limbs to equalize. This creates an anchor that has unequally weighted limbs, and the limb with the greatest loading fails first, creating a break in only one place. This causal mechanism also explains the observation of hearing more sounds from W3P2 anchors during loading. The greater friction caused the W3P2 anchors to shift small distances more frequently during loading producing noises, ultimately yielding an anchor that was probably not fully equalized. To test this hypothesis the same suite of measurements could be performed, however, the steel pipe used could be covered with a coarse sand paper introducing more friction to the system. If this causal mechanism is correct, the breaking strengths of the basket hitches should be reduced and we would expect to see basket hitches breaking more frequently at one location and not two. W3P2 anchors should also break at a lower value, though the loss should be smaller than basket hitches, and they should fail at one location more frequently. In addition W3P2 anchors should make less noise during measurements than when broken using a smooth pipe.

This research program has demonstrated the value of utilizing statistically significant samples since the variability in breaking behavior and strength has suggested properties of how the materials are behaving during use. This information directly suggests hypotheses that can be tested in the future, as well as provides users with information that can be used to select anchors more appropriately for the rigging challenges they face.

Acknowledgements:

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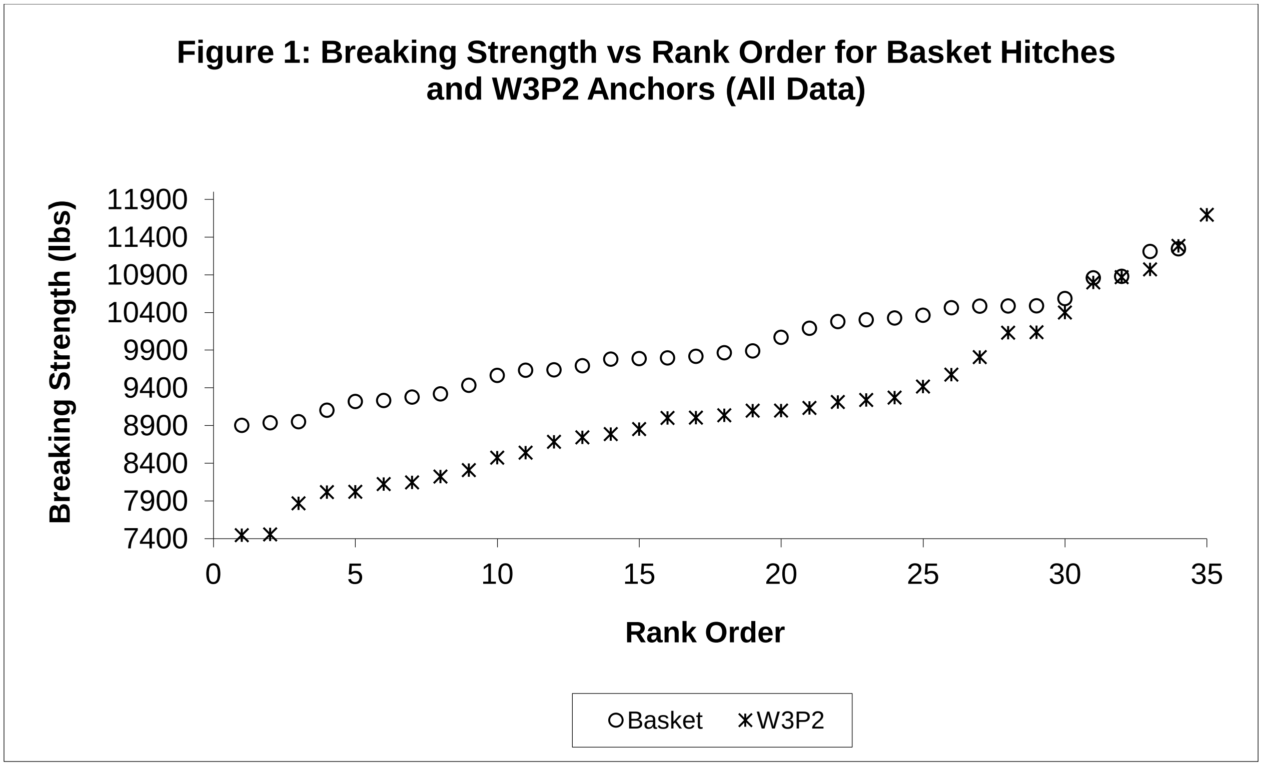
Figure 1: Breaking Strength vs Rank Order for Basket Hitches
and W3P2 Anchors (All Data)
Breaking Strength (lbs)
11900
11400
10900
10400
9900
9400
8900
8400
7900
7400
0
5
10
15
20
25
30
35
Rank Order
Basket
W3P2

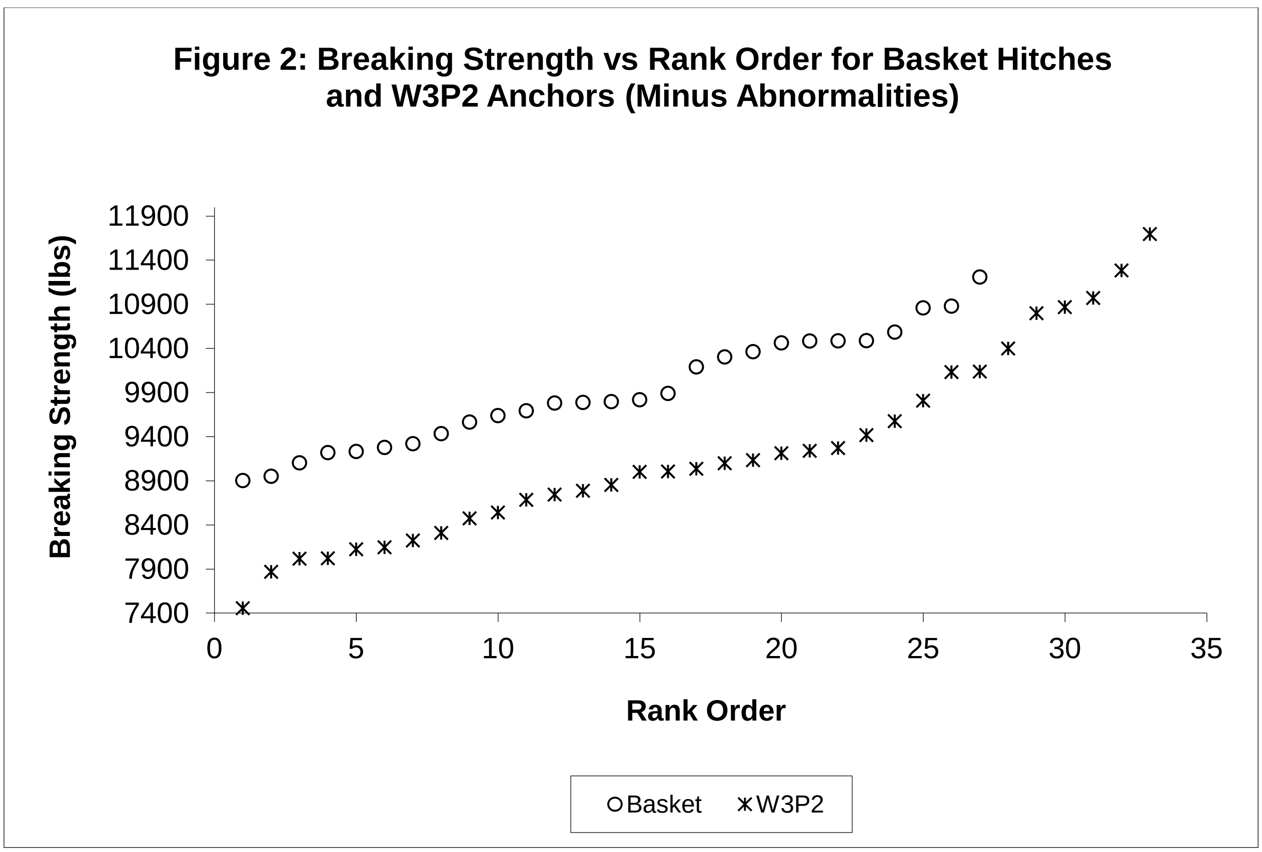
Figure 2: Breaking Strength vs Rank Order for Basket Hitches
and W3P2 Anchors (Minus Abnormalities)
Breaking Strength (lbs)
11900
11400
10900
10400
9900
9400
8900
8400
7900
7400
0
5
10
15
20
25
30
35
Rank Order
Basket
W3P2

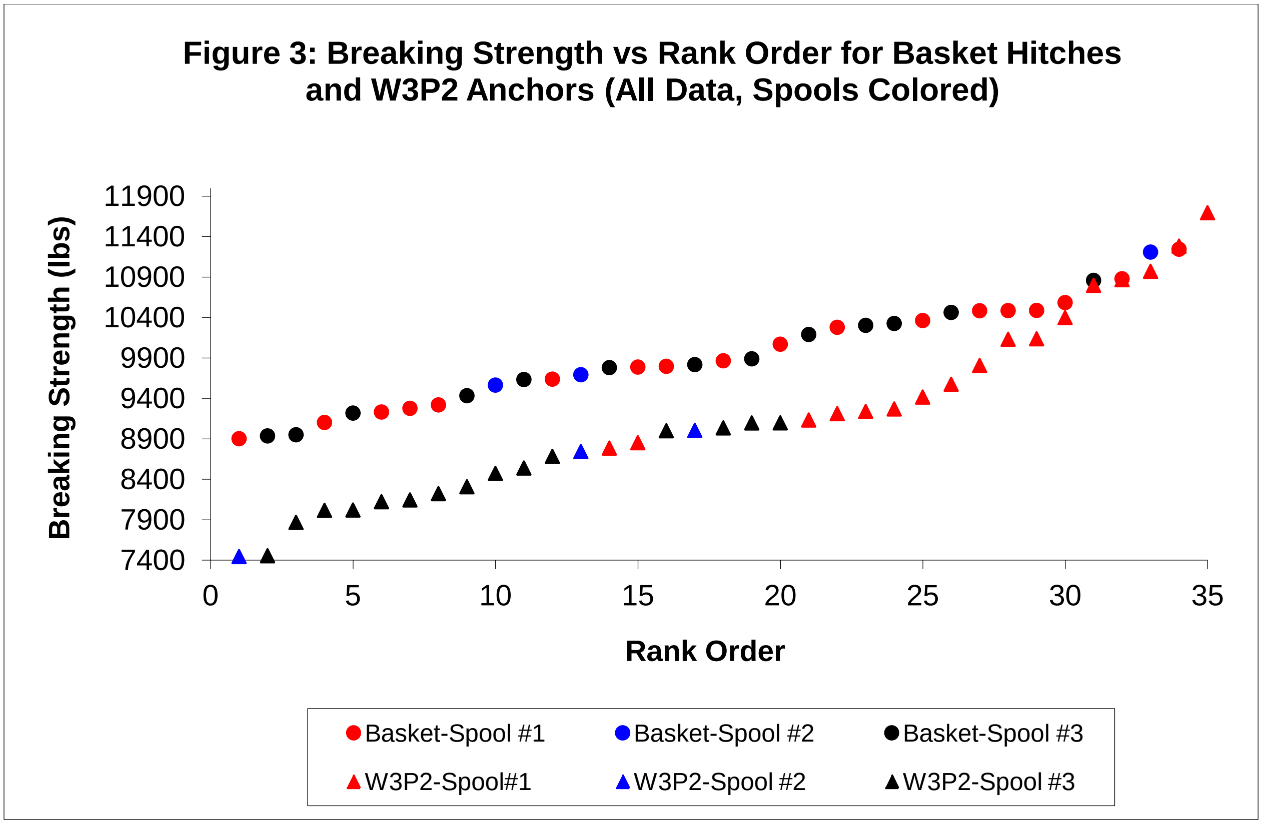
Figure 3: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (All Data, Spools Colored)
Breaking Strength (lbs)
11900
11400
10900
10400
9900
9400
8900
8400
7900
7400
0
5
10
15
20
25
30
35
Rank Order
Basket-Spool #1
Basket-Spool #2
Basket-Spool #3
W3P2-Spool#1
W3P2-Spool #2
W3P2-Spool #3

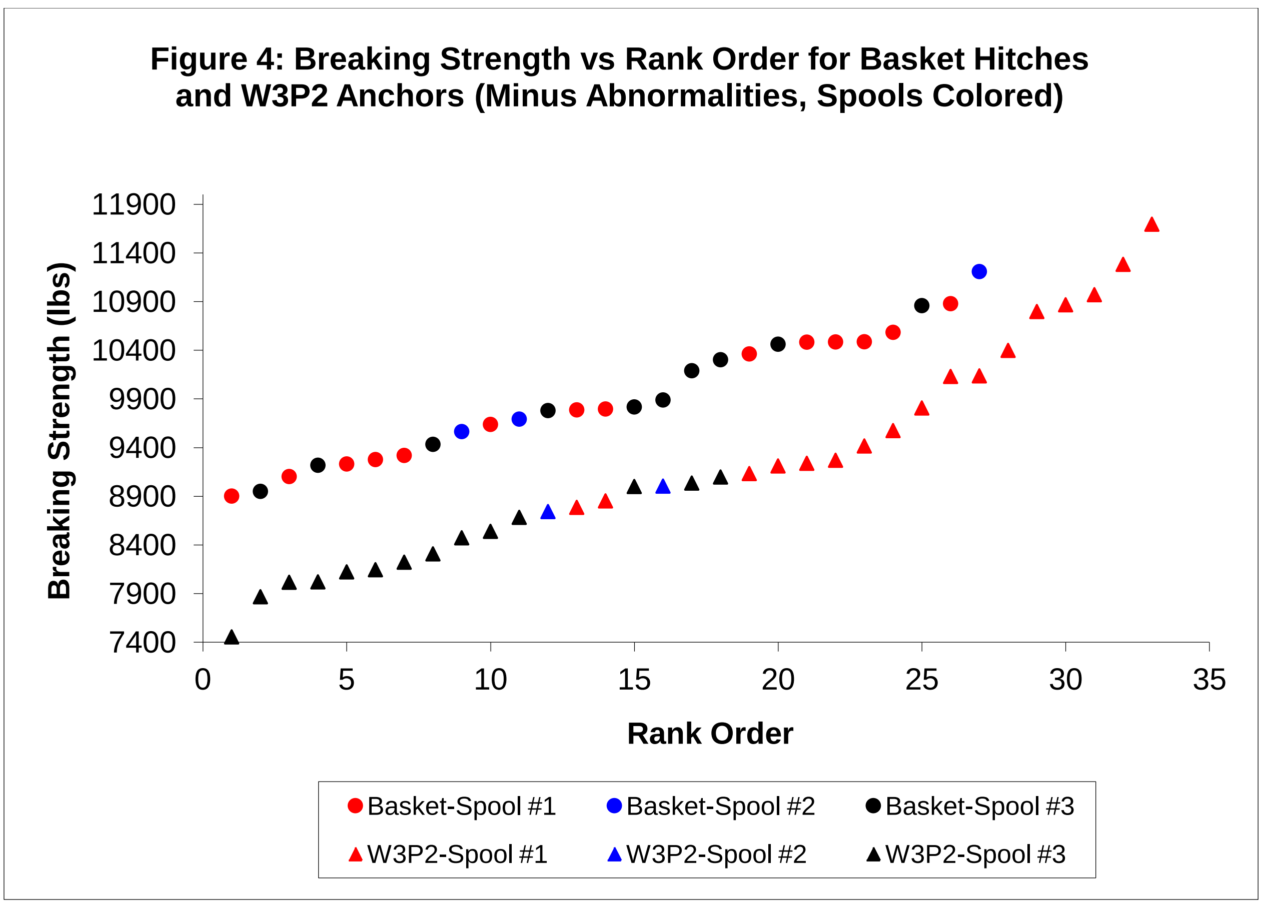
Figure 4: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (Minus Abnormalities, Spools Colored)
Breaking Strength (lbs)
11900
11400
10900
10400
9900
9400
8900
8400
7900
7400
0
5
10
15
20
25
30
35
Rank Order
Basket-Spool #1
Basket-Spool #2
Basket-Spool #3
W3P2-Spool #1
W3P2-Spool #2
W3P2-Spool #3