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

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Outline

- Purpose
- Materials
- Methods
- Results
  - Quantitative
  - Qualitative
- Conclusions
- Discussion
  - Causation
  - Comparison
- Questions

Purpose

- Last year I gave a talk here (ITRS)
  - Science as Applied to Technical Rescue Research
- I issued a personal challenge to everyone
  - Find a way to further technical rescue science
- Put my money where my mouth is…
  - This is my way of furthering technical rescue science
  - Compare my recommendations to what we did
- There are some science goals too…

Purpose Continued…

- Science goals
  - Measure absolute breaking strengths
    - Basket Hitches
    - Wrap Three Pull Two Anchors (W3P2)
  - Measure relative breaking strengths
  - Observe variability in breaking strengths
  - Observe variability in failure mechanisms
  - Determine if both are suitable rescue anchors
    - (as expected)

Materials

- Two spools of new unused one inch tubular PMI webbing
  - Lot number 45105 and loom 514
  - Listed as 3 spools since there was a splice
- Baldwin universal testing machine with DP41 digital load deflection upgrade electronics
  - Internal load cell range of 0 to 200,000 lbs
  - College of Engineering, Montana State University
  - Last calibrated on 3/10/2011 and measurements took place on 6/23/2011-6/24/2011


Load
5690
Actuator Position
4210
DOWN
UP
Do Not
close valve
Tightly

Methods

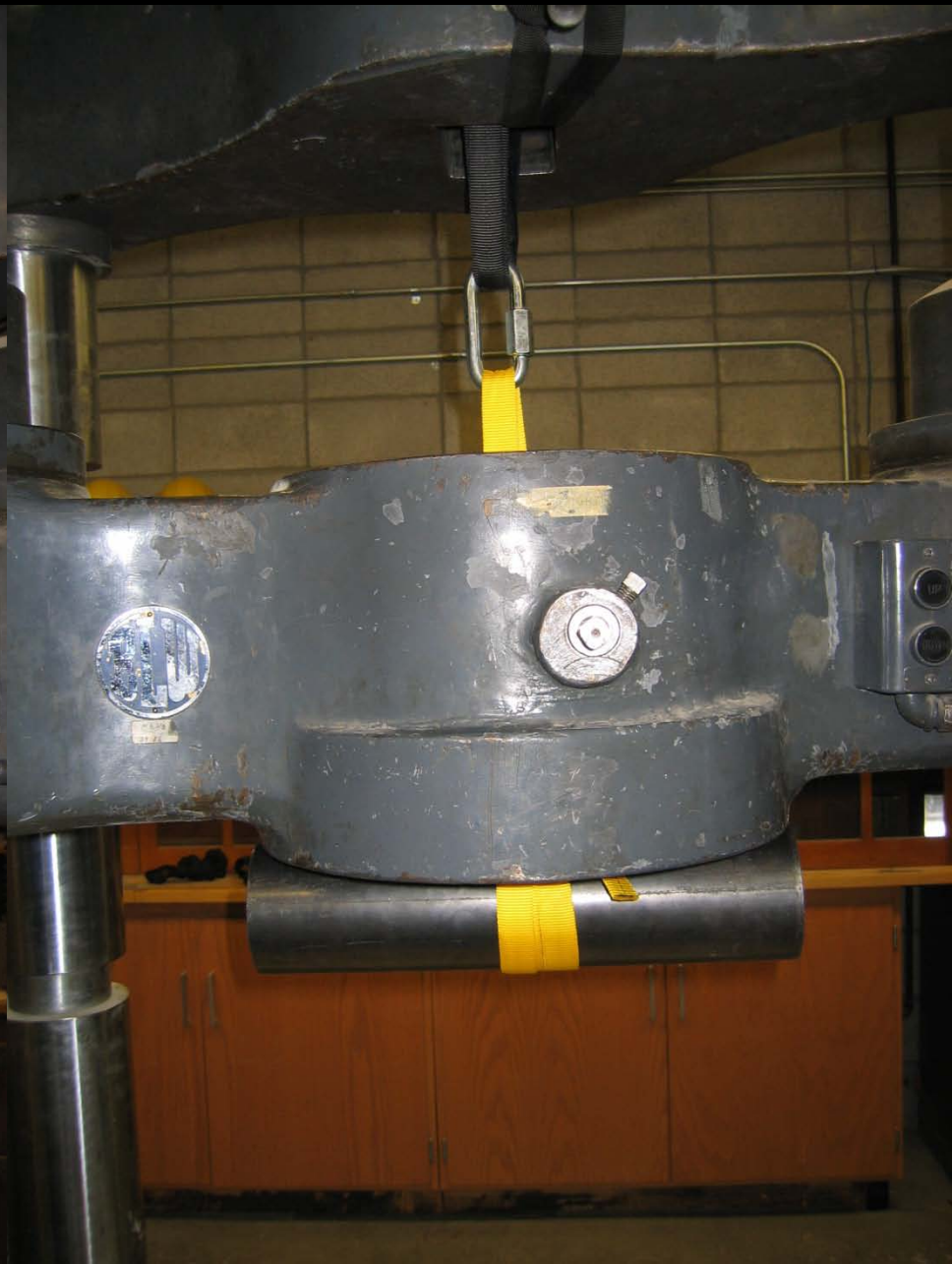
- Basket hitches- 8 feet of webbing
- W3P2 anchors- 9 feet of webbing
- Alternating along length of spool
  - Removes effect of which spool the anchor came from
- All tied by one person (A.S.) to retain consistency

Methods

- Anchors tied around a 4 inch diameter smooth steel pipe filled with concrete
- Basket hitch knots were placed behind the metal pipe
- W3P2 knots were placed on the front of the pipe facing the load
- Attachment point was a 3 inch steel hardware screw link

Basket Hitch

W3P2



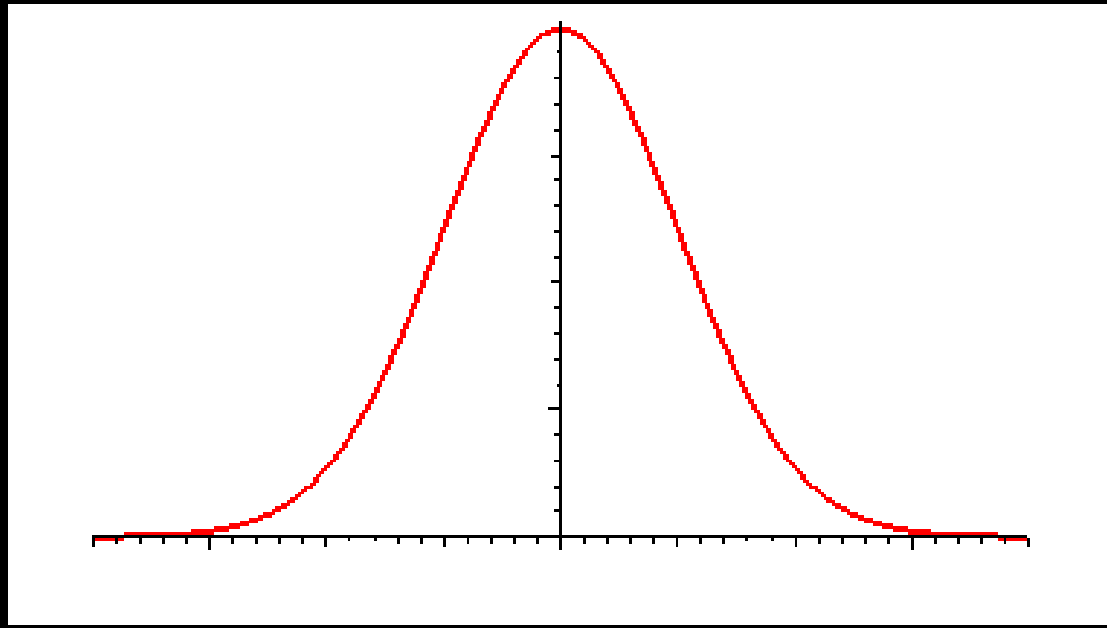
Anchor Assembly

Methods

- Anchors quickly loaded up to ~8000 lbs (~82 lbs per second)
- Rate of loading was decreased (~14 lbs per second) till breakage occurred
- All trials were photographed and recorded
- Anchor internal angles were measured from photographs
- Number and kind of breaks was recorded
- Notes on abnormalities observed during measurement

Methods

- Data scaled by internal angles
- Descriptive Statistics
  - Average (Mean)
  - Maximum
  - Minimum
  - Range
  - Standard Deviation



- Two tailed Z-test
  - Test null hypothesis that breaking strengths are equal
- Performed Twice
  - On full data set
  - Data without abnormalities during measurement

Results

- Results will be presented:
  - In toto
  - Summaries of
    - All data
    - Truncated Data
  - Visualizations of data
    - All data
    - Truncated data
- If you want the data

Sample Number	Breaking Strength (lbs)	Scaled Breaking Strength (lbs)	Number of Breaks	Breakage Type	Notes/Abnormalities
1-B-1-1	10786	10879	2	Clean	
1-B-3-2	9153	9232	1	Clean	
1-B-5-3	10191	10279	2	Clean	Breaking strength taken from data file not machine
1-B-7-4	10494	10585	2	Clean	
1-B-9-5	9025	9103	1	Clean	
1-B-11-6	10394	10484	1	1/2 inch fray	
1-B-13-7	10396	10486	2	Clean	
1-B-15-8	11148	11244	2	2 inch fray, 4.5 inch fray	Loaded to 9150 lbs before slowing the pull
1-B-17-9	10274	10363	2	Clean, 1 inch fray	Main anchor strand failed
1-B-19-10	9984	10070	2	Clean	Was previously pulled, pulled to failure second time, New Anchor
1-B-21-11	10398	10488	2	Clean, 1 inch fray	
1-B-23-12	9781	9865	2	Clean	Was previously pulled, pulled to failure second time, New Screw Link
1-B-25-13	8826	8902	1	Clean	
1-B-27-14	9704	9788	1	Clean	Other side was half cut with a 2.5 inch fray, but did not fail
1-B-29-15	9240	9320	2	Clean	
1-B-31-16	9713	9797	2	Clean	
1-B-33-17	9556	9638	2	Clean, 2 inch fray	
1-B-35-18	9198	9277	2	Clean	
2-B-2-19	11113	11209	2	Clean, 1 inch fray	
2-B-4-20	9483	9565	2	Clean	
2-B-6-21	9610	9693	2	Clean	
3-B-2-22	9551	9633	1	Clean	Was previously pulled, pulled to failure second time, New Anchor
3-B-4-23	9353	9434	1	Clean	Other side was half cut but did not fail
3-B-6-24	9697	9781	2	Clean	
3-B-8-25	8874	8951	1	8 inch fray	
3-B-10-26	10103	10190	2	Clean	
3-B-12-27	10238	10326	2	Clean	Was previously pulled, pulled to failure second time, New Anchor
3-B-14-28	9734	9818	2	Clean, 2 inch fray	
3-B-16-29	10373	10463	2	Clean	
3-B-18-30	10766	10859	2	Clean	
3-B-20-31	9805	9890	2	Clean	
3-B-22-32	8860	8936	1	Clean	Breaking strength taken from data file not machine
3-B-23-33	10215	10303	2	Clean	
3-B-26-34	9140	9219	1	1 inch fray	

1-W-2-35	10077	10137	2	Clean, partial 2 inch fray	
1-W-4-36	8734	8786	1	Clean	
1-W-6-37	10071	10131	1	1/2 inch fray	
1-W-8-38	10803	10868	2	Clean	
1-W-10-39	9361	9417	1	Clean	One anchor strand broke but the anchor held and was pulled farther
1-W-12-40	9215	9270	1	Clean	
1-W-14-41	10906	10971	2	3 inch fray, 1.5 inch fray	
1-W-16-42	11626	11696	2	2 inch fray, 4 inch fray	
1-W-18-43	9518	9575	1	Clean	
1-W-20-44	10734	10798	2	Clean	Webbing fused together on the side of the pipe
1-W-22-45	9157	9212	1	Clean	
1-W-24-46	11216	11283	2	Clean	
1-W-26-47	9749	9807	2	Clean	
1-W-28-48	8800	8853	1	Clean	
1-W-30-49	9079	9133	1	Clean	
1-W-32-50	10337	10399	2	Clean, 3 inch fray	
1-W-34-51	9184	9239	1	Clean	
2-W-1-52	8951	9005	1	Clean	
2-W-3-53	8691	8743	1	Clean	
2-W-5-54	7401	7445	1	7 inch fray	Never moved to a slower pull, New Anchor and New Screwlink
3-W-1-55	8259	8308	1	Clean	
3-W-3-56	9044	9098	1	Clean	Unbroken strand had 2 inch fray at quicklink location
3-W-5-57	7411	7455	1	Clean	One anchor strand broke but the anchor held and was pulled farther
3-W-7-58	8097	8145	1	Clean	One anchor strand broke but the anchor held and was pulled farther
3-W-9-59	8423	8473	1	Clean	
3-W-11-60	8947	9000	1	Clean	
3-W-13-61	8489	8540	1	Clean	One strand broke but the anchor held and was pulled to >4000 lbs
3-W-15-62	8075	8123	1	Clean	
3-W-17-63	7821	7868	1	Clean	
3-W-19-64	7973	8021	1	Clean	Start of a fray near break
3-W-21-65	7969	8017	1	Clean	
3-W-24-66	8982	9036	1	1.5 inch fray	
3-W-25-67	9043	9097	1	Clean	Was previously pulled, pulled to failure second time, New Anchor
3-W-27-68	8174	8223	1	2 inch fray	
3-W-28-69	8632	8684	1	Clean	

Results: Table Summary

	All Data		Truncated Data	
	Basket	W3P2	Basket	W3P2
Average Breaking Strength	9943.2	9167.3	9928.3	9221.6
Maximum	11244.2	11695.5	11208.9	11695.5
Minimum	8902.2	7445.3	8902.2	7455.3
Range	2342.0	4250.3	2306.7	4240.2
Standard Deviation	642.4	1075.4	627.7	1064.4
N	34	35	27	33
Average Number of Breaks	1.7	1.2	1.7	1.2
Maximum	2	2	2	2
Minimum	1	1	1	1
Range	1.00	1.00	1.00	1.00
Standard Deviation	0.46	0.43	0.47	0.44

- All data is basically the same as truncated data
- Basket Hitch stronger than W3P2
  - 775.9 lbs (full data set), 706.7 lbs (truncated data set)

Results: Salient Points

- All data is basically the same as truncated data
- Basket Hitch stronger than W3P2
  - 775.9 lbs (full data set), 706.7 lbs (truncated data set)
- Range of W3P2 anchors is nearly twice Baskets
  - Means baskets break more consistently than W3P2's
- Standard Deviation of Baskets is smaller
  - Means baskets break more consistently than W3P2's
- Testing the null hypothesis of equal strengths
  - Full: P-value of .000212 (a=.05, critical value 1.959964)
  - Truncated: P-value of .001494 (a=.05, critical value 1.959964)

Figure 1: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (All Data)

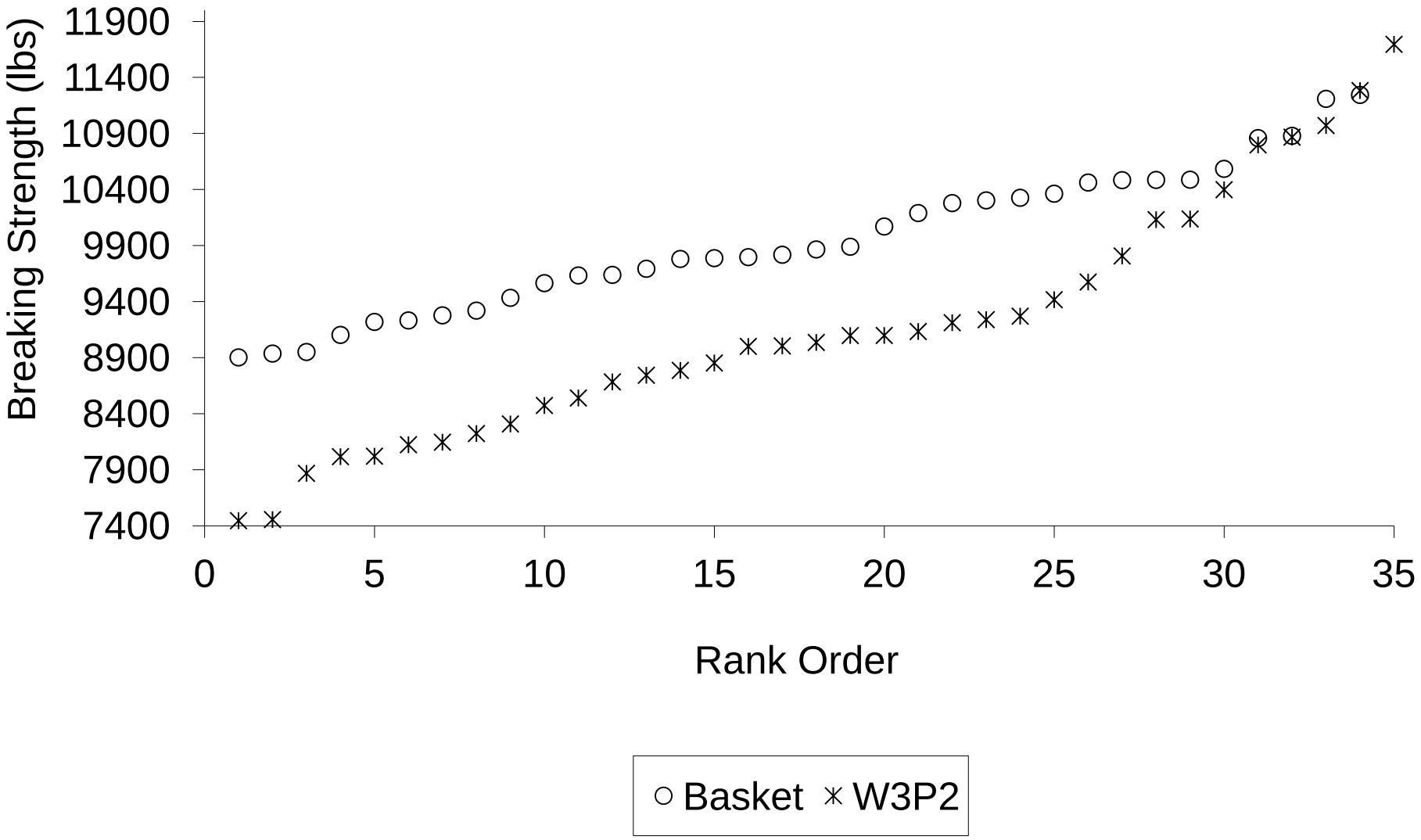
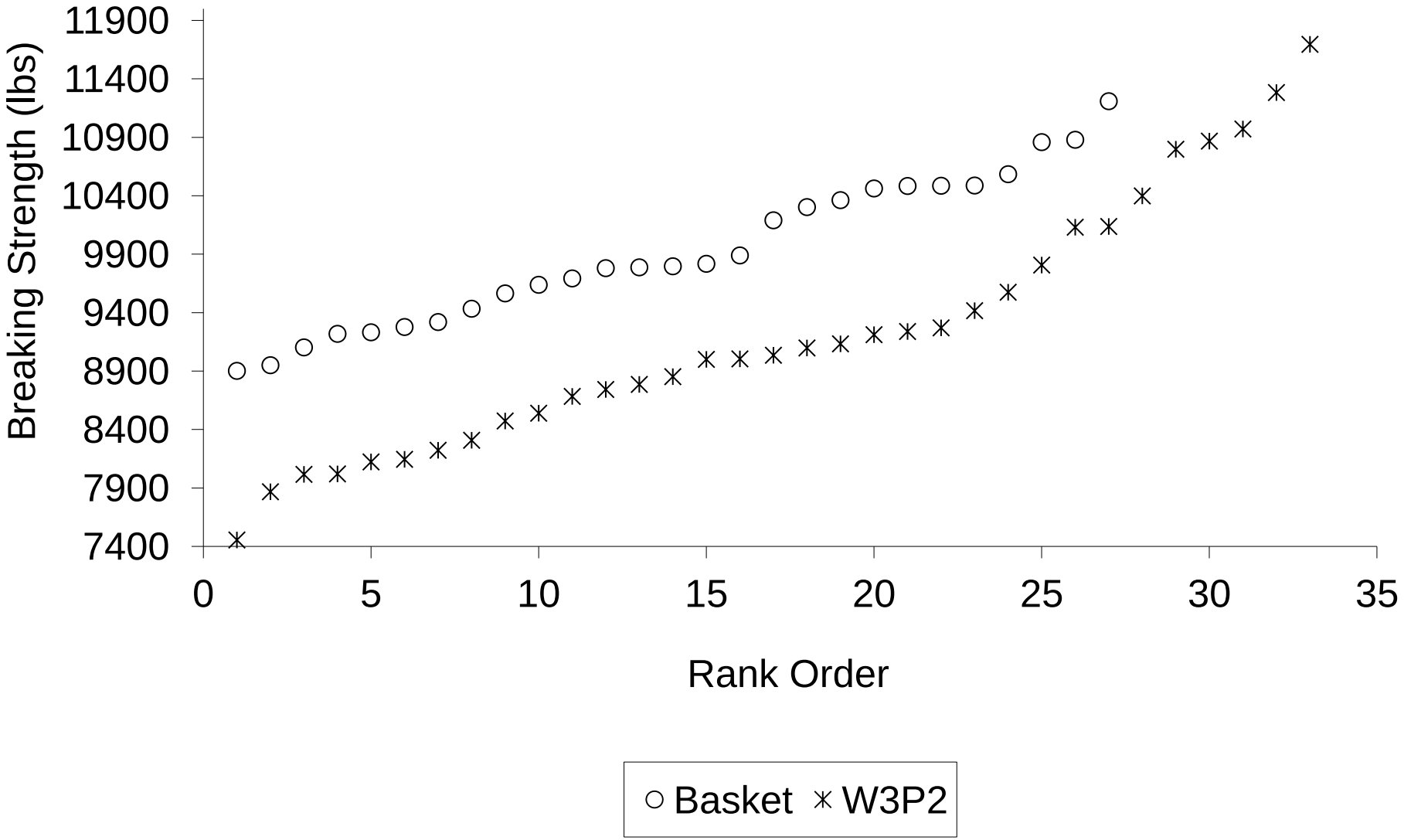


Figure 2: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (Minus Abnormalities)



Observations

- All anchors broke at the quicklink
  - Knots are not the weakest part of the anchor in this configuration
- Baskets broke in 2 places at once (24 times or 71%)
- W3P2 anchors broke in two locations less frequently (8 times or 23%)
- In 4 trials (11%) one strand of a W3P2 anchor broke
  - The anchor held until pulled further
  - Loaded webbing held the anchor in place even with the severed strand

Observations

- W3P2 anchors made many more noises during loading than basket hitches
- Basket hitches have even distribution of breakage between spools
  - No effect due to spool
- W3P2 anchors: spool 3 breaking at lower strengths than spool 1 anchors.
  - Not statistically significant, interesting to note

Figure 3: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (All Data, Spools Colored)

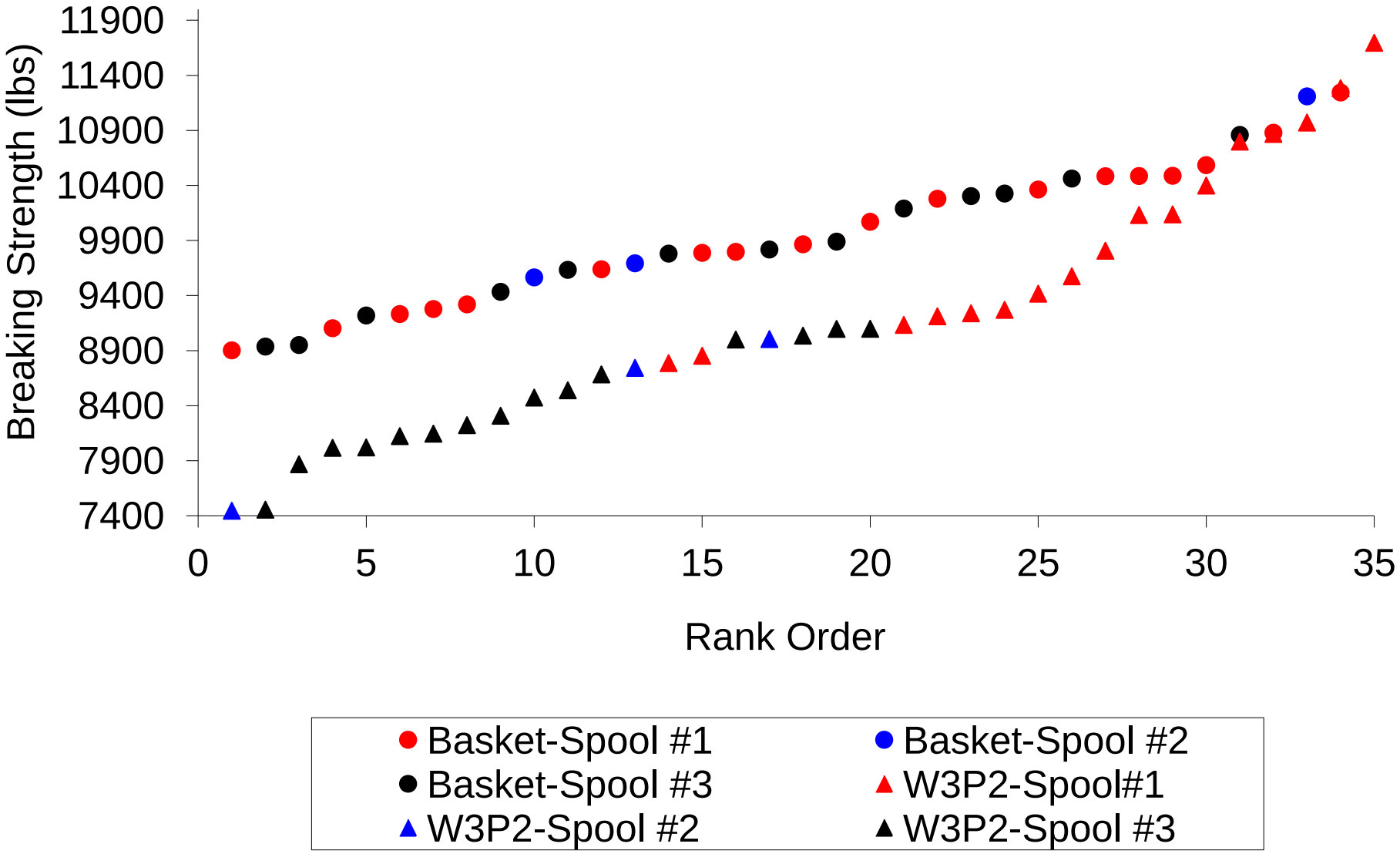
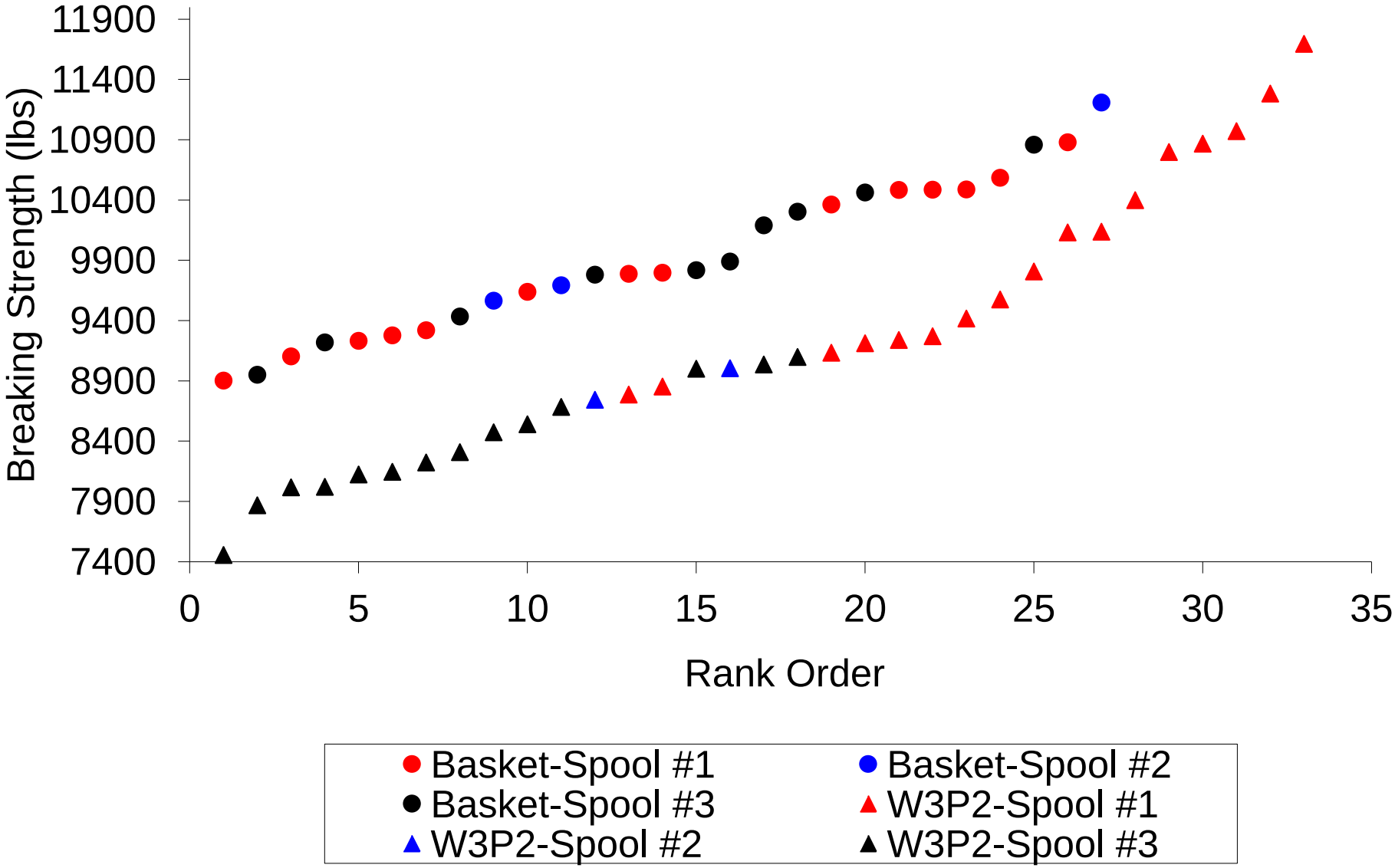


Figure 4: Breaking Strength vs Rank Order for Basket Hitches and W3P2 Anchors (Minus Abnormalities, Spools Colored)



Conclusions

- Webbing anchors broke at lower strengths than expected
  - Assume ~4000 lbs for each strand, ~16,000 lb breaking strength estimate
- As tied the weakest point in the anchors is not the knot but the webbing itself.
- Webbing anchors can break in more than one location simultaneously during failure.
- Basket hitches break, on average, at a higher strength and with less variability (smaller standard deviation and range) than W3P2 anchors.
- Basket hitches appear to be between 705 to 775 lbs stronger than W3P2 anchors in the configuration tested.

Conclusions Continued

- 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.
- There is variability in the breaking strength of anchors between spools of webbing as well as within a spool of webbing.
- 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.
- Developing and implementing a testing program is easier than expected and is practical for many individuals who live in proximity to a university with testing facilities.

Discussion

Basket Hitches

- Stronger
- Faster
- Less material
- Slip/move around
  - Can double wrap…
  - Uses more material
  - Might behave like a W3P2

W3P2 Anchors

- Weaker (strong enough!)
- Slower
- More material
- Do not move around much

Both have strengths/weaknesses
Use them for strengths when weaknesses minimized

Discussion Continued

- Observations are consistent with causal mechanism
  - Inferred, so a hypothesis, needs to be tested!!
- Loading occurs until static friction overcome
- Baskets have less static friction, so they equalize
- W3P2's have more static friction, so they equalize less
- So baskets reach near equal loading and break at the webbing strength in 2 places at one time
- W3P2's are unequally loaded so they break when one limb is stressed to failure

Discussion: Research Comparison

- Research Group Size
  - Two people- only partially successful
- Experiment Design
  - Not an experiment, empirical-robust design- successful
- Develop and explicitly state multiple hypotheses, then test them
  - Chose empiricism, so no hypotheses state before research
- Quantification
  - Optional, we chose to quantify our results

Discussion: Research Comparison

- Sample Size
  - As designed, 34 and 35- entirely successful
  - What happened- 27 and 33- partially successful
- Statistics
  - Correctly used and applied- entirely successful
- Replication
  - Repeated work of others- entirely successful
- Communicate results
  - Oral and written communication (archived)- entirely successful

Discussion: You can do it too!

- Budget
  - Webbing $180
  - Shipping $23.92
  - Pipe $24.60
  - Concrete $5.45
  - Screw Links $12.87
  - Total $246.84
- Research is cheap/affordable
- Expensive equipment can be borrowed!

Acknowledgments

- Dr. Mike Berry
  - Provided access to testing equipment and lab space
- Kate McDevitt
  - Taught us to use the equipment and collect data digitally
- Cathy Lash
  - Helped cut and label webbing, provided food and logistical support throughout
- Bob Osburn
  - Converted (T.E.) to caving and rope use

Questions?