Drop Testing Versus Slow-Pull Strength Testing

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OBJECTIVE

To compare the results of standard slow-pull strength tests with those from dynamic tests on rescue products. Do the results of slow-pull tests reliably correspond to those from dynamic strength testing?

BACKGROUND AND NEED

Testing standards for carabiners and woven-fiber products such as rope, webbing and harnesses call for Minimum Breaking Strength ratings (MBS) to be determined by slow-pull testing. The setup and procedures for slow-pull tests are repeatable and affordable. However, in practice in the field, critical forces are most commonly experienced from dynamic, rapid events.

We looked at the presentation at ITRS 2005, *"Daisy Chains and Other Lanyards: Some Shocking Results when Shock Loaded" by Mike Gibbs.* Results from these drop tests indicated that high-tech fibers such as Spectra, Technora, Dyneema etc. fail in a dynamic event at forces significantly lower than their slow-pull test results. This motivated us to examine standard slow-pull test methods on rescue and climbing gear.

Then, in the Evans and Stavens presentation at ITRS 2011, *"Empirically Derived Breaking Strengths for Basket Hitches and Wrap Three Pull Two Webbing Anchors", ITRS 2011 Evans and Stavens,*1" tubular nylon webbing was slow-pull tested in both basket hitch and wrap-three-pull-two configurations.

We wondered how the results of this testing would compare to the same tests done with a dynamic drop test. Are slow-pull test results valid data for making safety judgments in field use? What materials other than nylon might react with significant differences between the two methods of applying a force? Our original objective was to duplicate the Evans and Stavens test, but to substitute dynamic drop-tests. We soon discovered that would be too ambitious.

We narrowed the field to basket hitches only. Then, since many products we employ are manufactured from aluminum, we added testing on aluminum carabiners, which are also slow-pull tested for strength ratings. As a result of adding the second material, and due to time and resource constraints, the testing and conclusions are not intended to be comprehensive. The testing does, however, identify potential patterns needing follow-up testing.

TEST COMPONENTS

We searched the country for a drop tower that could generate the potential 50kN+ (11,000lbf+)[1] forces required to consistently break the webbing. We were offered the use of the tower at Yates Gear in Redding, CA. This is a rigid 30 foot tall outdoor tower with a 254Kg (560lb) test mass. John Yates was convinced there would be no problem generating the required forces. He was correct. Everything broke. After two days of dropping a 254Kg mass, we did, however, create a huge crater at the base of the tower. The tower can now be used to test the effects of gear being dropped into a lake.

The webbing used was new PMI 25mm (1") tubular nylon webbing with an 18kN (4000lbf) Minimum Breaking Strength (MBS)[2], and similar webbing from Bally Mills.

The rope was Sterling SuperStatic 7/16" nylon rope with a breaking strength of 30kN (6745lbf). This was new rope but an early version of SuperStatic with a manufacture date of about 2006. It didn't break.

Carabiners were Black Diamond "Oz" wiregate "offset D" carabiners. These are smaller than would normally be used by most SAR teams, but have a low MBS of 20kN. We chose these to facilitate easier breaking.

Connections to the anchor (tower) and load were made with Maillon Rapide 12mm X 100mm (4"x1/2") steel oval screw links from CMC. The links are rated with a Working Load Limit of 1500kg. These simulate the 12mm diameter pins used in standardized testing. These never failed during testing.

[1] Metric conversions are approximate and rounded throughout the document.
[2] Manufacturer's MBS figures are derived from the 3-Sigma Rule (3σ). This identifies the lowest breaking strength found among 99.7% of all test results. It is considered a conservative rating.

TEST PROCEDURES – NYLON WEBBING

TEST #1
Drop test on a Basket Hitch of Nylon Webbing

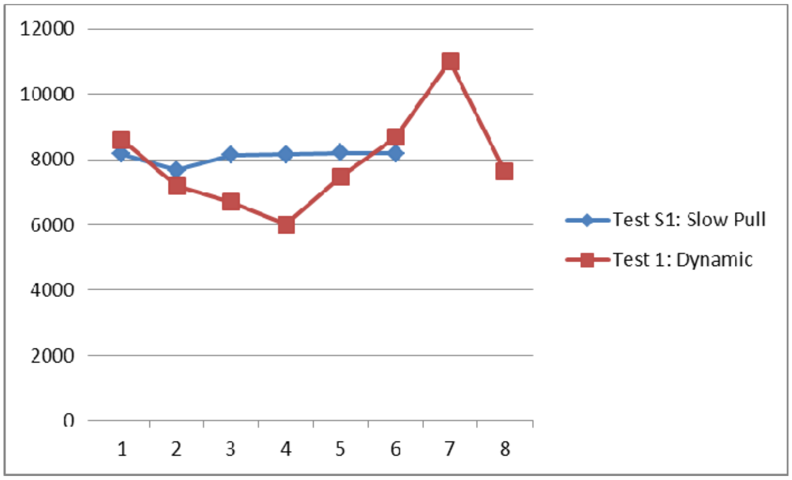
A three meter (10’) length of 25mm webbing was tied into a loop using a water knot. The loop was then configured as a basket hitch around a 30cm (12 inch) bollard attached to the tower, and both ends of the basket hitch were then clipped into a screw link. The interior angle created by the two legs of the basket hitch was approximately 42º. The steel mass (load) was connected to the screw link by a 1.5M (5’) steel cable, and connected to the tower with a Yates Quick Release.

The load was raised 1.5 meters above the screw link for a fall distance of 3 meters, resulting in a fall-factor of 2.

TEST #S1
Slow-pull test on a Basket Hitch of Webbing

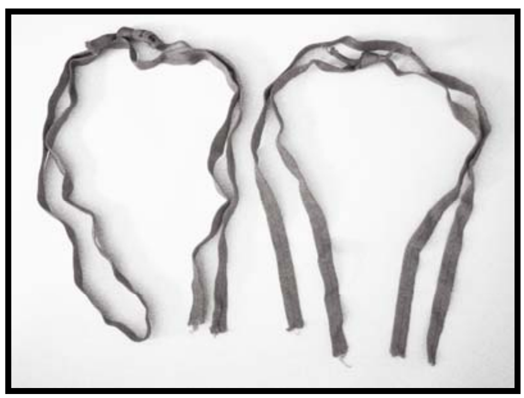
As in Test #1, a three meter length of webbing was tied in a basket hitch around the same 30cm (12”) bollard, and connected with a screw link to an upright hydraulic ram. The ram speed was approximately 50mm (2”) per minute.

TEST #1/S1 DATA



RESULTS
The dynamic testing resulted in a range 6010lbf to 11,000lbf, with an average breaking strength of 7912 (35kN). The slow-pull test results ranged from 7680lbf to 8200lbf, with an average of 8087lbf (36kN). All samples broke at the load side quick-link, and all but one saw both strands fail simultaneously.

CONCLUSIONS
Even with very few samples, the tests on nylon webbing indicated that slow-pull breaking strengths are, on average, similar to dynamic force breaking strengths. Therefore manufacturer's MBS (minimum breaking strength) ratings likely correlate to the breaking strength in a dynamic event, and can probably be relied upon in field use for system analysis.



However, the very large range in the dynamic results should lead to caution when applying a simplistic analysis to determine system strength in the field.

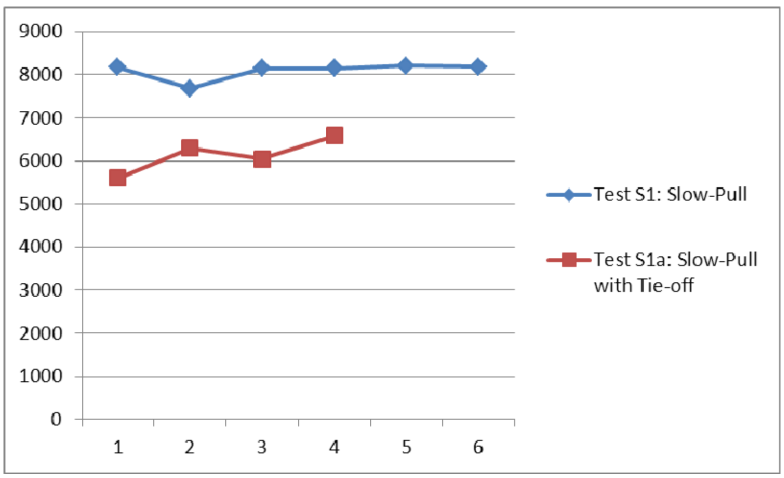
Unlike standardized test methods that are designed to eliminate as many variables as possible, systems in the field are impacted by numerous additional forces and variables, such as shifts in the direction of pull, friction from many sources and so on. A simple analysis of our basket hitch could be:
4 strands of 25mm webbing at the focal point @ 18kN each = 72kN, minus 1/3 for the knot = 48kN. Our results averaged 35kN, and using the 3-Sigma rule would result in an MBS of only 18.5kN! The knot was not the only factor affecting the system's strength. The myriad of unknown variables can be somewhat compensated for by a rescue team employing a conservative safety factor when building their rescue systems.

AND WAIT! THERE'S MORE…

TEST #S1a
Slow-Pull with Basket Hitch Tied-off at Load

While we had the ram setup, we decided to try one additional test: a slow pull on a basket hitch of 25mm webbing as before, but with an overhand tie-off in the webbing at the quick-link connected to the load. The hypothesis being "multiple knots do not reduce the webbing's strength more than a single knot."

TEST #S1a Data



RESULTS
The tests with an overhand tie-off at the load resulted in breaking strengths about 25% weaker than the tests without the tie-off. Without the tie-off, the average strength was 8087lbf. With the tie-off the average breaking strength was 6127lbf.

CONCLUSIONS
Even with a sample size of only four, the results were surprising. Every sample broke right at the tie-off knot. While the overhand knot is essentially the same knot as the water knot, in the figure 8 force is applied to all four strands while the water knot sees a force on only two strands. Would the results have been much different with a figure 8 or other knot instead of the overhand? We can't comfortably reach conclusions with this sample size, but more testing would be illuminating.

TEST PROCEDURES – ALUMINUM CARABINERS

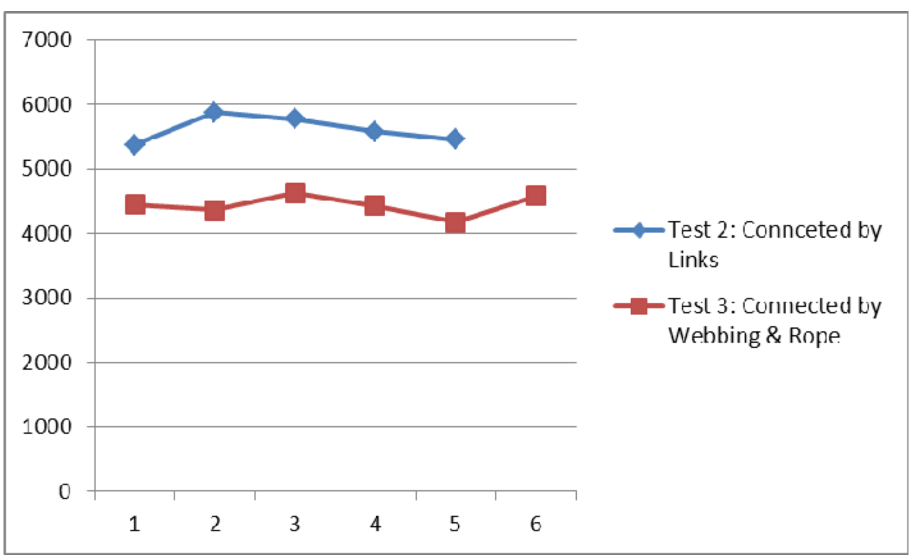
TEST #2
Drop Test on Offset-D Aluminum Carabiner

The carabiner was connected to the anchor and the load with 12mm diameter screw links. These are the same diameter as the pins used in standardized testing by manufacturers. The same mass, drop distance and procedure as in test #1 was employed: a 254Kg mass dropped 3 meters on a 1.5 meter cable. Both links self-positioned against the carabiner's spine.

TEST #3
Drop Test on Offset-D Carabiner Connected by Rope and Webbing

The carabiner was connected to the anchor with a 1 meter loop of 25mm webbing tied with a water knot and configured as a basket hitch. The carabiner was connected to the load with 1.4 meters of 11mm static rope tied in a loop by a double fisherman's knot. The same mass and drop as above was employed.

TEST #2/3 Data



RESULTS

Test #2 samples ranged in breaking strength from 5377lbf to 5875lbf with an average of 5611lbf (25kN). Test #3, with webbing and rope connecting the carabiner had a range of 4173lbf to 4625lbf and an average of 4435lbf (19.7kN).

Carabiners left exactly as they landed

In test #2, all the sample carabiners broke at the small radius and exhibited substantial elongation. Test #3 samples all broke at the large radius – where the webbing was connected.

CONCLUSIONS

Aluminum carabiner testing generated more complicated results than the webbing tests. The manufacturer's testing provided a 3 Sigma MBS rating of 20kN (4500lbf). Our dynamic test #2 with 12mm screw links against the carabiner's spine resulted in an average breaking strength of 25kN (5600lbf), resulting in a 3-Sigma of 22.4kN. This is comparable to the manufacturer's test results. There is probably little or no difference in breaking strengths for aluminum carabiners when test procedures follow standard testing protocols.

However, when the carabiners were connected to the anchor and load with webbing and rope, the average breaking force was 19.7kN (4435lbf), with a 3-Sigma result of 17.8kN. Given the small sample size, this is significantly lower than the manufacturer's rating.

We surmise the reduction in breaking strength of about 20% was due to the point of force being shifting away from the spine of the carabiner toward the gate. The substitution of wide webbing in place of the narrow pins that sit right at the spine, and the acute inside angle of the carabiner may have moved the focus of force as much as 20mm (4/5") away from the spine and toward the gate. Was the difference in breaking strength exaggerated beyond reality by the use of very small carabiners?

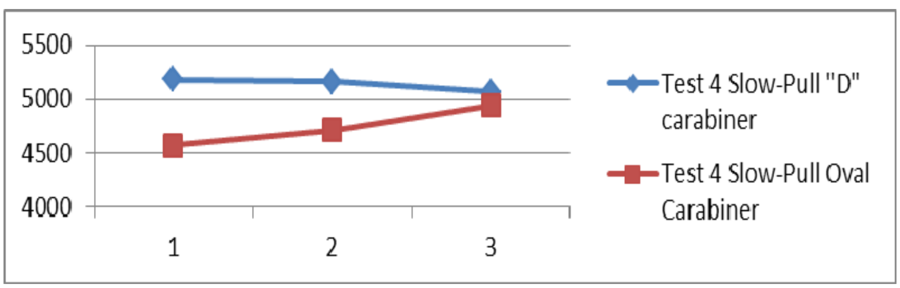
To follow up to this question, one more test was conducted.

TEST #4
Slow-pull Test on a Rescue-Size Carabiner Connected by Webbing and Rope

Full size CMC "D" locking carabiners (MBS rating of 27kN) and CMC Oval carabiners (MBS rating of 21kN) were connected to the "anchor" with the same 25mm webbing and 11mm rope as in test #3.

The same procedure was followed as in previous slow-pull tests.

TEST #4 Data



RESULTS
Oval carabiners broke in a range of 4570lbf to 4940lbf, with an average of 4740lbf (21kN) with a 3-Sigma of 19kN, compared to their manufacturer's 3-Sigma rating of 21kN.
D carabiners ranged from 5070lbf to 5180lbf averaging 5136lbf (23kN)n and resulting in a 3-Sigma of 22kN compared to the manufacturer's 3-Sigma of 27kN.

CONCLUSIONS
The sample size is tiny, but we can suggest that the D carabiners broke well below their manufacturer's ratings because of the shift in force toward the gate, compared to the standard testing method using pins at the spine. When the oval carabiners are tested by the manufacturer, the pins locate themselves away from the spine at the center of the carabiner's curve – about the same location as the center of force during our test with webbing.

SUMMARY

Webbing
Based on our limited testing, we believe nylon webbing MBS figures from manufacturers can be relied on to correlate closely to dynamic situations. We would encourage further investigation in the static vs. dynamic comparison of other elements introduced into a field system such as stitching, buckles and knots. This conclusion does not apply to high-tech fibers as addressed in the Gibb's presentation in 2005. Much more testing needs to be done, and as soon as we can fill in the crater at the base of the Yates tower, we're ready to break more stuff.

Aluminum Carabiners
We cannot conclude that aluminum carabiners react differently with a dynamic force compared to a slow-pull. We can conclude that the standard method for determining the MBS of carabiners does not relate to actual usage in the field. We can also conclude that the actual breaking strength of an aluminum carabiner in most field use will be lower than the manufacturer's MBS rating and we suggest teams de-rate all carabiners except ovals. This conclusion does not necessarily apply to steel carabiners. We hope someone will do dynamic testing on steel.

Our findings emphasized the need for rescue personnel to be knowledgeable in the physics of rescue (science), the MBS of each piece of equipment employed (math), and to have the ability to analyze a rescue system for many factors and in a variety of situations (art).

Many thanks to all who supported this study: