FROM THE LAB TO THE FIELD:
A LOOK AT THE PRECISION AND BIAS OF PRUSIK HITCH TESTING

TRADITIONAL METHODS
• Slow pull
• Small scale
• Test apparatus limitations
QUESTIONS

• Do traditional test methods represent field conditions?
• Are Prusik hitches behaving consistently across various rigging configurations, rope type and diameter?
• Are there any unknowns?

CONSTANT RATE OF ELONGATION (CRE)

• Conventional hydraulic cylinders apply a constant rate of pull / constant rate of elongation. Force becomes the dependent.
• Elongation causes loading
• Possible to have force (load) decrease while elongation increases
• Does not factor inertia in the form strain energy

STRAIN ENERGY

• All static and low-stretch kermantle ropes have strain energy due to percentage of elongation given an applied force.
• Function of stress (load) / strain (elongation), ropes elastic modulus (Young’s modulus).
• Ability for the rope to rebound once load (stress) is removed. (Boing Factor)
CONSTANT RATE OF LOADING (CRL)

• Load constantly applied, elongation is the dependent.
• Loading causes elongation
• Potential to have “inertial runaway”

DOES EITHER TEST METHOD REFLECT FIELD CONDITIONS?

• Overall length of stroke (length of rope used)
• Post & pre tensioned host rope versus non-tensioned rope
• Slow pull versus fast pull
• What is the overall reliability factor of Prusiks?

DOES SCALE MATTER?
OTHER VARIABLES

- Material comparison
- Construction comparison
- Environmental (wet conditioning)
- Age (wear & tear)
- 11mm (7/16") host rope versus 13mm (1/2")

LARGE SCALE TEST CONFIGURATIONS

- Prusik pulling on a post-tensioned rope
- Prusik pulling on a pre-tensioned rope
- Prusik pulling on a non-tensioned rope
- Compare data with slow pull test
- Objective is not to purposely fail the Prusiks but to analyze what happens on the onset of overloading

CMC RESCUE’S NEW CAPSTAN

- Constant rotation
- 800 lbf capacity
- Average rate of pull: 1.4ft/second
- Gripping ability increases according to number of wraps and tension applied on rope
- Tension is maintained on the rope through duration of the test
- Not quite CRE or CRL
**POST-TENSION SET UP**

- Method used for majority of the data set (benchmark)
- Rope tied off to anchorage using a bowline knot
- 9ft (3m) of rope between knot and Prusik.
- Approximately 50ft (16m) of rope in the 3:1 MA system.
- Load cell located inline with 3-wrap Prusik
- Load applied to the system until initial Prusik slip or failure occurs

**PRE-TENSIONED SET UP**

- Similar rope system as post tension.
- System used to lift 600 lb (2.6 kN) mass off the ground.
- Prusik was then reset while system under tension.
- Mass was anchored to the ground. System continued to pull until Prusik slips.

**NON-TENSION SET UP**

- Rope tied off to anchorage using a bowline knot
- 9ft (3m) of rope between knot and Prusik.
- 3:1 MAH system “piggy-backed” on test rope (separate rope)
- Approximately 50ft (16m) of rope in the system.
- Load cell located inline with 3-wrap Prusik
**PRUSIK CORD SPECIFICATIONS**

- 8mm CMC Prusik Cord (sewn loop)
- 8mm PMI Prusik Cord (tied)
- 8mm Sterling Prusik Cord (tied)

All made out of 100% nylon. All 3 manufactures claim compatibility with kernmantle life safety rope (cord designed to be used as Prusik cord)

**ROPE SPECIFICATIONS:**

**CMC LIFELINE**

- 100 % nylon (32 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =
  
  \[
  \text{Elongation} = \frac{\frac{3}{4}" (12.7\text{mm})}{2.6 \text{ kN}} = 4.7% \\
  \frac{7/16" (11\text{mm})}{2.6 \text{ kN}} = 6.7%
  \]

Both ropes manufactured 2nd quarter of 2015

**CMC STATIC-PRO LIFELINE**

- 100 % Polyester (32 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =
  
  \[
  \text{Elongation} = \frac{\frac{3}{4}" (12.7\text{mm})}{2.6 \text{ kN}} = 1.9% \\
  \frac{7/16" (11\text{mm})}{2.6 \text{ kN}} = 2.0%
  \]

Both ropes manufactured 2nd quarter of 2015
ROPE SPECIFICATIONS:
NEW ENGLAND ROPES KMIII

- Polyester Sheath / Nylon Core (32 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =
  $\frac{1}{2}''$ (12.7mm) = 4.6%
  7/16'' (11mm) = 5.1%

Both ropes manufactured 2nd quarter of 2015

ROPE SPECIFICATIONS:
PMI CLASSIC PROFESSIONAL

- 100% Nylon (16 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =
  $\frac{1}{2}''$ (12.7mm) = 2.9%

Rope manufactured 3rd quarter of 2014

ROPE SPECIFICATIONS:
STERLING ROPE HTP™

- 100% Polyester (48 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =
  $\frac{1}{2}''$ (12.7mm) = 1.6%

Rope manufactured 3rd quarter of 2013
POST-TENSION DATA SET USING 8MM CMC PRUSIK CORD

Mean values across all rope types: 1,884 lbf
Standard deviation across all rope types: 123
Confidence interval across all rope types: 341

TYPICAL POST-TENSION GRAPH PROFILE

- Load cell located inline with the Prusik hitch (reflects load applied on Prusik)
- Load applied until noticeable Prusik hitch “clutching” was observed

POST-TENSION DATA SET USING CMC ROPE & CORD RETURNED FROM THE FIELD*

Mean values across all rope types: 1,581 lbf
Std deviation across all rope types: 144
Confidence interval across all rope types: 400

* Ropes and Prusiks returned from CMC Rescue School.
Moderate amount of wear & tear. Ropes were 5-8 years old, Prusiks approximately 3 years old.
**POST-TENSION DATA SET USING WET**

CMC PRUSIK CORD & ROPE

<table>
<thead>
<tr>
<th>Rope Type</th>
<th>Sample #1</th>
<th>Sample #2</th>
<th>Sample #3</th>
<th>Sample 4</th>
<th>Sample 5</th>
<th>Average (mean)</th>
<th>Standard Deviation</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC Lifeline</td>
<td>1,541 lbf</td>
<td>1,426 lbf</td>
<td>1,519 lbf</td>
<td>1,528 lbf</td>
<td>1,771 lbf</td>
<td>1,557 lbf</td>
<td>128</td>
<td>355</td>
</tr>
<tr>
<td>CMC Static Pro</td>
<td>1,842 lbf</td>
<td>1,393 lbf</td>
<td>1,979 lbf</td>
<td>1,657 lbf</td>
<td>1,933 lbf</td>
<td>1,881 lbf</td>
<td>138</td>
<td>384</td>
</tr>
<tr>
<td>NER KMIII</td>
<td>1,658 lbf</td>
<td>1,334 lbf</td>
<td>1,759 lbf</td>
<td>1,401 lbf</td>
<td>1,340 lbf</td>
<td>1,390 lbf</td>
<td>136</td>
<td>377</td>
</tr>
</tbody>
</table>

Mean values across all rope types: 1,609 lbf
Std deviation across all rope types: 134
Confidence interval across all rope types: 372

*Ropes and cord immersed in tap water for 1hr.

**POST-TENSION DATA SET USING 8MM CMC PRUSIK CORD**

<table>
<thead>
<tr>
<th>Rope Type</th>
<th>Sample #1</th>
<th>Sample #2</th>
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<th>Standard Deviation</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC Lifeline</td>
<td>1,006 lbf</td>
<td>1,256 lbf</td>
<td>1,357 lbf</td>
<td>1,208 lbf</td>
<td>1,290 lbf</td>
<td>1,223 lbf</td>
<td>133</td>
<td>369</td>
</tr>
<tr>
<td>CMC Static Pro</td>
<td>1,421 lbf</td>
<td>1,290 lbf</td>
<td>1,358 lbf</td>
<td>1,293 lbf</td>
<td>1,300 lbf</td>
<td>1,341 lbf</td>
<td>52</td>
<td>144</td>
</tr>
<tr>
<td>NER KMIII</td>
<td>1,290 lbf</td>
<td>1,143 lbf</td>
<td>1,166 lbf</td>
<td>943 lbf</td>
<td>1,077 lbf</td>
<td>1,124 lbf</td>
<td>127</td>
<td>352</td>
</tr>
</tbody>
</table>

Mean values across all rope types: 1,231 lbf
Std. deviation across all rope types: 104
Confidence interval across all rope types: 289

**POST-TENSION DATA COMPARISON SUMMARY:**

**DRY TO WET (MEAN VALUES)**

- CMC Lifeline: - 19%
- CMC Static Pro: -11%
- NER KMIII: - 18%
Post-Tension Data Comparison Summary: New to Used (Mean Values)

- CMC Lifeline: +0.7%
- CMC Static Pro: -27%
- NER KMIII: -30%

Post-Tension Data Comparison Summary: 13MM Versus 11MM (Mean Values)

- CMC Lifeline: -35%
- CMC Static Pro: -34%
- NER KMIII: -32%

<table>
<thead>
<tr>
<th>Product / Prusik Cording</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Average (Mean)</th>
<th>Std Deviation</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC Prusik on PMI Classic Pro</td>
<td>1,506 lbf</td>
<td>1,512 lbf</td>
<td>1,637 lbf</td>
<td>1,707 lbf</td>
<td>1,708 lbf</td>
<td>261 lbf</td>
<td>1,657 lbf - 1,759 lbf</td>
</tr>
<tr>
<td>PMI Prusik on PMI Classic Pro</td>
<td>2,554 lbf</td>
<td>2,458 lbf</td>
<td>2,748 lbf</td>
<td>2,814 lbf</td>
<td>2,620 lbf</td>
<td>153 lbf</td>
<td>2,327 lbf - 2,914 lbf</td>
</tr>
<tr>
<td>CMC Prusik on Sterling HTP</td>
<td>1,621 lbf</td>
<td>1,584 lbf</td>
<td>1,788 lbf</td>
<td>1,795 lbf</td>
<td>1,735 lbf</td>
<td>128 lbf</td>
<td>1,618 lbf - 1,842 lbf</td>
</tr>
<tr>
<td>Sterling Prusik on Sterling HTP</td>
<td>1,911 lbf</td>
<td>1,871 lbf</td>
<td>2,167 lbf</td>
<td>2,087 lbf</td>
<td>1,975 lbf</td>
<td>144 lbf</td>
<td>1,831 lbf - 2,120 lbf</td>
</tr>
</tbody>
</table>
### PRE-TENSION DATA SET USING 8MM CMC PRUSIK CORD

<table>
<thead>
<tr>
<th>Rope Type</th>
<th>Sample # 1</th>
<th>Sample # 2</th>
<th>Sample # 3</th>
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<th>Standard Deviation</th>
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</tr>
</thead>
<tbody>
<tr>
<td>CMC Lifeline</td>
<td>2,199 lbf</td>
<td>2,183 lbf</td>
<td>2,100 lbf</td>
<td>2,070 lbf</td>
<td>2,010 lbf</td>
<td>2,135 lbf</td>
<td>214</td>
<td>805</td>
</tr>
<tr>
<td>CMC Static Pro</td>
<td>2,016 lbf</td>
<td>2,001 lbf</td>
<td>1,995 lbf</td>
<td>1,963 lbf</td>
<td>1,999 lbf</td>
<td>2,023 lbf</td>
<td>22</td>
<td>59</td>
</tr>
<tr>
<td>NER KMIII</td>
<td>1,562 lbf</td>
<td>1,587 lbf</td>
<td>1,605 lbf</td>
<td>1,605 lbf</td>
<td>1,669 lbf</td>
<td>1,610 lbf</td>
<td>74</td>
<td>206</td>
</tr>
</tbody>
</table>

Mean values across all rope types: 1,986 lbf
Std deviation across all rope types: 103
Confidence interval across all rope types: 286

### TYPICAL PRE-TENSION GRAPH PROFILE

![Graph](image)

### DATA COMPARISON SUMMARY POST-TENSION VERSUS PRE-TENSION (MEAN VALUES)

- CMC Lifeline: +17%
- CMC Static Pro: +5%
- NER KMIII: +0.2%

Difference in mean values: +6%
Difference in Standard deviation: -17%
### NON-TENSION, LARGE SCALE, FAST PULL DATA SET USING 8MM CMC PRUSIK CORD

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</tr>
</thead>
<tbody>
<tr>
<td>CMC Lifeline</td>
<td>3,108 lbf</td>
<td>2,807 lbf</td>
<td>2,681 lbf</td>
<td>3,013 lbf</td>
<td>2,290 lbf</td>
<td>2,791 lbf</td>
<td>323</td>
<td>897</td>
</tr>
<tr>
<td>CMC Static Pro</td>
<td>2,411 lbf</td>
<td>2,087 lbf</td>
<td>2,339 lbf</td>
<td>2,106 lbf</td>
<td>1,940 lbf</td>
<td>2,245 lbf</td>
<td>188</td>
<td>521</td>
</tr>
<tr>
<td>NER KMIII</td>
<td>2,935 lbf</td>
<td>2,836 lbf</td>
<td>2,544 lbf</td>
<td>2,184 lbf</td>
<td>2,830 lbf</td>
<td>2,335 lbf</td>
<td>263</td>
<td>729</td>
</tr>
</tbody>
</table>

Mean values across all rope types: 2,422 lbf  
Standard deviation across all rope types: 68  
95% Confidence interval across all rope types: 189

### TYPICAL NON-TENSION, LARGE SCALE, FAST PULL GRAPH PROFILE

- **SLOW PULL**
  - Fixed rate of pull (1ft/min)
  - Rope wrapped around bollard
  - Traditional method used for testing Prusik hitch effectiveness.
NON-TENSION, SMALL SCALE, SLOW PULL DATA SET USING 8MM CMC PRUSIK CORD

<table>
<thead>
<tr>
<th>Rope Type</th>
<th>Sample #1</th>
<th>Sample #2</th>
<th>Sample #3</th>
<th>Sample #4</th>
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<th>Standard Deviation</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC Lifeline</td>
<td>2,750 lbf</td>
<td>2,548 lbf</td>
<td>2,693 lbf</td>
<td>2,590 lbf</td>
<td>2,607 lbf</td>
<td>2,691 lbf</td>
<td>369 lbf</td>
<td>369 462</td>
</tr>
<tr>
<td>CMC Static Pro</td>
<td>2,774 lbf</td>
<td>2,531 lbf</td>
<td>2,430 lbf</td>
<td>2,407 lbf</td>
<td>2,507 lbf</td>
<td>2,526 lbf</td>
<td>339 lbf</td>
<td>339 442</td>
</tr>
<tr>
<td>NER KMIII</td>
<td>2,155 lbf</td>
<td>2,001 lbf</td>
<td>2,160 lbf</td>
<td>2,090 lbf</td>
<td>2,069 lbf</td>
<td>2,174 lbf</td>
<td>230 lbf</td>
<td>230 366</td>
</tr>
</tbody>
</table>

Mean values across all rope types: 2,871 lbf
Standard deviation across all rope types: 69
Confidence interval across all rope types: 191

TYPICAL SLOW-PULL GRAPH PROFILE

• CMC Lifeline: 23%
• CMC Static Pro: 7.5%
• NER KMIII: 18.5%
DAMAGE & MATERIAL TRANSFER TYPICAL FROM ALL THE TESTS

Rated at 4,500 lbf
* Failed at 4,314 lbf

*Pulled in loop configuration using Horizontal test fixtures until failure.

Rated at 4,500 lbf
* Failed at 1,876 lbf

*Pulled in loop configuration using Horizontal test fixtures until failure.

Rated at 4,500 lbf
* Failed at 4,986 lbf

*Pulled in loop configuration using Horizontal test fixtures until failure.
IN CONCLUSION

• No Prusik hitches failed during any of the tests
• “Boing factor” did not appear to be significant
• Differences in Prusik cord construction and host rope construction and material composition will yield different results.
• Prusik hitch behavior may change with cord and/or host rope wear & tear.
• 8mm Prusiks will generally slip at a lower threshold on 11mm ropes than 13mm ropes.
• Pulling a Prusik along a non-tensioned rope at a slow rate may yield higher slip thresholds
• Pre-loading the system versus post-loading the system did not appear to have a statically significant effect
• Wet Prusik hitches have more difficulty grabbing on wet rope

For more information, please contact:

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