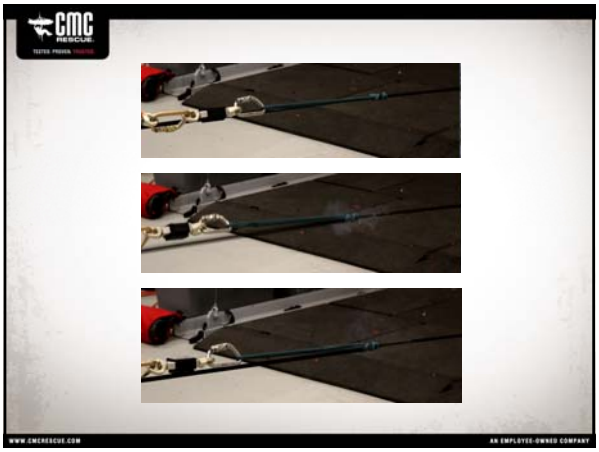


TRADITIONAL METHODS

- Slow pull
- Small scale
- Test apparatus limitations

QUESTIONS

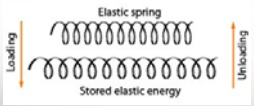
- Do traditional test methods represent field conditions?
- Are Prusik hitches behaving consistently across various rigging configurations, rope type and diameter?
- Are there any unknowns?

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?

DOES SCALE MATTER?

- 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?

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) =

  ½" (12.7mm) = 4.7%

  7/16" (11mm) = 6.7%

Both ropes manufactured 2nd quarter of 2015

ROPE SPECIFICATIONS:
CMC STATIC-PRO LIFELINE

- 100 % Polyester (32 carrier sheath)
- Elongation @ 2.6 kN (600 lbf) =

  ½" (12.7mm) = 1.9%

  7/16" (11mm) = 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) =

  ½" (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) =

  ½" (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) =

  ½" (12.7mm) = 1.6%

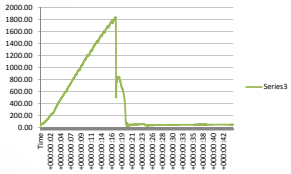
  rope manufactured 3rd quarter of 2013

POST-TENSION DATA SET USING 8MM CMC PRUSIK CORD

Rope Type (13mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	1,835 lbf	1,647 lbf	1,833 lbf	1,983 lbf	2,109 lbf	1,881 lbf	174	484
CMC Static Pro	2,073 lbf	2,154 lbf	2,041 lbf	2,165 lbf	2,094 lbf	2,105 lbf	53	147
NER KMIII	1,576 lbf	1,531 lbf	1,861 lbf	1,770 lbf	1,591 lbf	1,666 lbf	142	392

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*

Rope Type (13mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	1,763 lbf	1,910 lbf	1,702 lbf	2,082 lbf	1,883 lbf	1,868 lbf	147	408
CMC Static Pro	1,621 lbf	1,591 lbf	1,479 lbf	1,493 lbf	1,834 lbf	1,604 lbf	143	395
NER KMIII	1,419 lbf	1,364 lbf	1,126 lbf	1,184 lbf	-	1,273 lbf	141	389

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

Rope Type (13mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	1,541 lbf	1,426 lbf	1,519 lbf	1,528 lbf	1,771 lbf	1,557 lbf	128	355
CMC Static Pro	1,842 lbf	1,993 lbf	1,979 lbf	1,657 lbf	1,933 lbf	1,881 lbf	138	384
NER KMIII	1,616 lbf	1,334 lbf	1,259 lbf	1,401 lbf	1,340 lbf	1,390 lbf	136	377

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

Rope Type (11mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	1,006 lbf	1,256 lbf	1,357 lbf	1,208 lbf	1,290 lbf	1,223 lbf	133	369
CMC Static Pro	1,421 lbf	1,350 lbf	1,358 lbf	1,293 lbf	1,300 lbf	1,344 lbf	52	144
NER KMIII	1,290 lbf	1,143 lbf	1,166 lbf	943 lbf	1,077 lbf	1,124 lbf	127	352

Mean values across all rope types: 1,231 lbf
Standard 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 11 MM (MEAN VALUES)

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

POST-TENSION DATA SET PRUSIK CORD COMPARISON

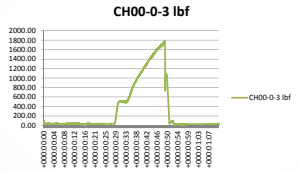
Rope / Prusik Combo	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average (mean)	Std deviation	95% Confidence Interval
CMC Prusik on PMI Classic Pro	1,506 lbf	1,512 lbf	1,637 lbf	1,707 lbf	2,143 lbf	1,701 lbf	261	724
PMI Prusik on PMI Classic Pro	2,554 lbf	2,458 lbf	2,748 lbf	2,814 lbf	2,528 lbf	2,620 lbf	153	422
CMC Prusik on Sterling HTP	1,621 lbf	1,584 lbf	1,788 lbf	1,795 lbf	1,889 lbf	1,735 lbf	128	355
Sterling Prusik on Sterling HTP	1,911 lbf	1,871 lbf	2,167 lbf	2,087 lbf	1,838 lbf	1,975 lbf	144	400

PRE-TENSION DATA SET USING 8MM CMC PRUSIK CORD

Rope Type (13mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	2,199 lbf	2,183 lbf	2,100 lbf	2,070 lbf	2,610 lbf	2,231 lbf	214	605
CMC Static Pro	2,016 lbf	2,014 lbf	2,005 lbf	1,995 lbf	1,963 lbf	1,999 lbf	22	59
NER KMIII	1,592 lbf	1,787 lbf	1,624 lbf	1,682 lbf	1,660 lbf	1,669 lbf	74	206

Mean values across all rope types: 1,996 lbf
Std deviation across all rope types: 103
Confidence interval across all rope types: 286

TYPICAL PRE-TENSION GRAPH PROFILE



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

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

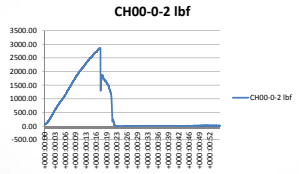
Difference in mean values: + 6%
Difference in Standard deviation: - 17%

NON-TENSION, LARGE SCALE, FAST PULL DATA SET USING 8MM CMC PRUSIK CORD

Rope Type	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	3,108 lbf	2,867 lbf	2,681 lbf	3,011 lbf	2,290 lbf	2,791 lbf	323	897
CMC Static Pro	2,411 lbf	2,087 lbf	2,539 lbf	2,206 lbf	2,460 lbf	2,341 lbf	188	521
NER KMIII	2,030 lbf	2,086 lbf	2,544 lbf	2,184 lbf	1,830 lbf	2,135 lbf	263	729

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

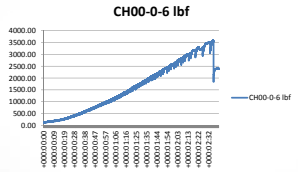
- Fixed rate of pull (1ft/min)
- Rope wrapped around bollard
- Traditional method used for testing Prusik hitch effectiveness.

NON-TENSION, SMALL SCALE, SLOW PULL DATA SET USING 8MM CMC PRUSIK CORD

Rope Type (13mm)	Sample # 1	Sample # 2	Sample # 3	Sample #4	Sample #5	Average (mean)	Standard Deviation	95% Confidence Interval
CMC Lifeline	3,226 lbf	3,254 lbf	3,291 lbf	3,596 lbf	4,097 lbf	3,492 lbf	369	1024
CMC Static Pro	2,766 lbf	2,421 lbf	2,636 lbf	2,645 lbf	2,160 lbf	2,526 lbf	239	662
NER KMIII	2,416 lbf	2,304 lbf	2,570 lbf	2,890 lbf	2,684 lbf	2,574 lbf	230	636

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



NON-TENSION DATA COMPARISON SUMMARY, FAST LARGE SCALE PULL VERSUS SMALL SCALE SLOW PULL

- 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

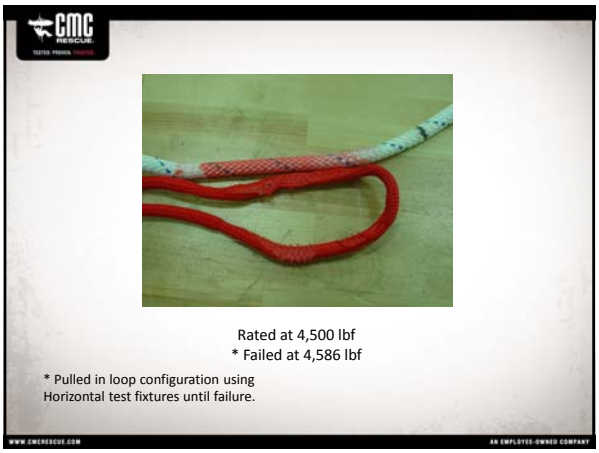
*Pulled in loop configuration using Horizontal test fixtures until failure.

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