Rescue Knot Efficiency Revisited

By John McKently

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<u>OCCUPATION / AGENCIES</u>

1. Senior Instructor: California State Fire Training
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4. Member: Montrose (CA) Search and Rescue Team, Los Angeles County Sheriff's Department
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In 1987 personnel from CMC Rescue performed tests on a variety of knots commonly used in rescue systems to determine their efficiency. The purpose of testing was as preparation for the First Edition of the <u>CMC Rope Rescue Manual</u> and for presentations at various industry events. Prior to this time there had been similar testing on climbing knots, but the rope used was three-strand laid rope (Goldline) and there were no details of the testing conditions or methods used, so the results were not considered repeatable or of unknown value to rescuers using low stretch ropes.

Our testing was done at Wellington Puritan, a large rope manufacturer in Georgia, but no details were given about their test machine. There wasn't any Cordage Institute #1801 standard for test methodology at the time, though the report does state that Federal Test 191A Method 6016 was used. In the cases where there was a loop created by the knot, it was attached to the test apparatus with a ½" steel carabiner which had an MBS ±15,000 lbf, well above that of the sample rope or the test knot.

Tests were performed on 18 knots in rope and eight in webbing. Some were the same knot but purposely tied incorrectly. For example: a bowline with the tail on both the inside and outside of the loop. Five samples were tested of each knot and the point of break was noted. Most tests show breaking at the jaws of the test machine or in the knot. Our experience with the 2014 tests was that in most cases the rope broke at the first turn where it entered or exited the knot.

1987 Tests ½" Rhino Rescue Rope (100% Nylon)

Double Fisherman	21%	strength loss	equals	79% Efficiency
Figure 8 Bend	19%			81%
Figure 8 Loop	20%			80%
Double Figure 8 Loop	18%			82%
Bowline	33%			67%

1" Tubular Webbing (100% Nylon)

Water Knot	36%	64%
Overhand Loop	35%	65%

These and similar test results are referred to or copied directly in <u>On Rope</u> (Smith and Padgett), <u>Confined Space and Structural Rope Rescue</u> (Roop, Wright and Vines), and many other state and local fire training manuals.

From a quick glance at those test results, many of us determined that you could expect about a 20% strength loss. In the "Figure 8 family of knots," and those were much stronger than the more traditional Bowline, with the added advantage of the Figure 8's being an inherently safe knots.

In High Angle Rescue Techniques 3rd Edition (Hudson and Vines) four samples each were tested with the following results:

Bowline in 7/16"	74%	Bowline in ½"	73%
Figure 8	78%	Figure 8	80%

In this case no information was given as to the test methodology, environmental conditions or rope used for the test. While the results are not exactly the same, they are close enough to show a pattern confirming our earlier work. In that manual they also include the following caveat, "***Test results may vary, depending on a number of factors such as the design of the rope, the manufacturer and the test conditions.***" Truer words were never written and that statement is applicable to all of the tests described in this report.

During the process of revising the CMC Rope Rescue Manual in 2008 we thought it would be interesting to revisit the tests, and if possible repeat them to see how the results compared. For those tests we used CMC Lifeline, a 100% nylon product, which is similar in construction to the Wellington Puritan Rhino except that it is manufactured by New England Rope. The list of knots tested was reduced, but the other significant difference was the test machine. For the first time the force measuring was done by an electronic load cell and not a mechanical dynamometer so the readings were more precise.

As time went on 100% polyester rope was introduced. Polyester has a higher chemical resistance than nylon, but the main reason for its acceptance by the technical rescue community is that it has less elongation than nylon. Another property of polyester is that it is has less surface friction or is "slipperier" than nylon sheathed ropes. We wondered if that characteristic would allow the rope fibers within the knot to better adjust to the compression and tensioning that occurs during loading and maybe even be more efficient.

For consistency we tested the same knots used during our 2008 testing. We followed the Cordage Institute standard test method but there were some differences. The person tying the knots was different than the earlier tests. The test machine was different. Even with the longer pull distance(60" vs. 48") we had to pretension the samples beyond hand- tight for the series of tests using Rescue Lifeline. We assume that was done during the earlier tests but the notes did not indicate that. The testing was also done on a vertical axis where the previous testing was done horizontally. We do not think that would have a bearing on the results, but it should be noted. In the case of the loop knots-Alpine Butterfly, Figure 8 on a Bight, Double Figure 8 Loop and Inline Figure 8, there was no load in the loop during the end-to-end tests. We wanted to do that, and plan to do so in the future, but logistically it became very complicated and was compounded by the constant need to adjust the load as the sample elongates during the testing.

CMC Tests:

3/2008 ½" CMC Rescue Lifeline (100% Nylon)

9/2014 ½" Static Pro (100% Polyester)

	CMC Lifeline			CMC Static-Pro Lifeline		
	kN	Lbf	Efficiency	kN	Lbf	Efficiency
Control A	**42.7949**	9620		40.8792	**9190**	
Control B	**46.97152**	10,559			(10 samples)	
Average	**44.8832**	10,090				
Alpine Butterfly						
End to End	**29.5851**	6651	66%	24.1894	**5438**	60%
Loop to End	**34.342**	7720	77%	24.7944	**5574**	61%
Bowline	**30.4932**	6855	75%	23.3621	**5252**	58%
Figure 8 Loop						
End to End*	33.0147	**7422**	74%	22.1877	**4988**	54%
Loop to End	**33.5487**	7542	77%	28.4108	**6387**	70%
Double Loop Figure 8	**32.8681**	7389	75%	27.0363	**6078**	66%
Figure 8 Bend	**25.47428**	5727	57%	27.0363	**6078**	66%
Double Fisherman	**35.5987**	8003	79%	32.8234	**7379**	80%
Inline figure 8						
End to End	**23.0918**	5191	51%	19.6834	**4425**	49%
Loop to End	**32.7848**	7370	73%	25.5639	**5747**	63%
Scaffold Knot	**36.5106**	8208	81%	28.0149	**6298**	69%

*Tests conducted 10/15/13 on samples from the same spools of rope as other tests

Values in **BOLD** type are as originally recorded. The other values are calculated from those.

Same samples as above submerged in Goleta, CA tap water for 1 hour

	CMC Rescue Lifeline (3/2008)			CMC Static Pro (9/2014)		
	kN	lbf	% Efficiency	kN	lbf	% Efficiency
Control	44.0107	**9894**	98	42.7608	**9613**	105
Bowline	28.1261	**6623**	67	23.7268	**5334**	58
Figure 8 Loop	37.9789	**8538**	91	27.7213	**6232**	68

Comparison of selected knot efficiency

Knot	Rhino Rescue-1987	Nylon Lifeline-2008	Polyester Lifeline-2014
Bowline	67%	75%	58%
Butterfly		77%	61%
Figure 8 on a Bight	80%	77%	70%
Double Loop Figure 8	82%	75%	66%
Figure 8 Bend	81%	57%	66%
Double Fisherman	79%	79%	80%
In line Figure 8		73%	63%
Scaffold Knot		81%	69%

These tests provide an estimate of what you can expect. There are numerous variables that can affect the efficiency of the knot.

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