Knot Break Strength vs Rope Break Strength

All knots reduce the breaking strength of rope. The question is, has been, and will always be, how much. The general rule has been a knot reduces strength approximately 50%. That is almost true.

In early 2004 I asked and received permission from the Cordage Institute Technical Committee to conduct a study on knot efficiency. The Institute solicited donors of many types of ropes to be tested.

In the climbing and rescue sector we chose 3 types of ropes; 7mm Acc. Cord, 10.5mm Dynamic, and 12.5mm Static ropes, with conventional fibers i.e. nylon and polyester. With help from knowledgeable people in the industry 8 knots were chosen; bowline, fig. 8 end, fig. 8 bight, butterfly, fisherman's knot, double fisherman's knot, sheet bend, and double sheet bend.

To remove as many variables as possible, it was decided to break 5 specimens of each size to establish a benchmark. Then we conducted 5 breaks for each knot. All the knots were tied by the same person and the test were conducted in a relative controlled environment. The data was collected on an Excel Spread sheet for the various graphs and charts.

This paper discusses the methods, procedures, mistakes, and successes and will display the findings. There are still many more tests to conduct. This is a work in progress and may not ever be complete.

About the Presenter

Dave Richards is currently the Technical Director of the Cordage Institute with thirty-five years of experience in the rope and cordage industry. He has worked for 2 rope manufacturers and 2 rigging shops. In 1985 he started Southwest Ocean Services, a full service, fiber rope rigging shop. Since 1998 he has been a consulting and expert witness in cases involving fiber rope accidents. He is co-author of a fiber rope rigging patent and author of "The Splice Book".

Member of: Cordage Institute, American Society of Mechanical Engineers (B30.9 Sling Sub-committee) ASTM (D13.16 Fiber Rope Sub-committee Chair), Marine Technology Society, and American Boat and Yacht Council.

Married, 6 children, 13 grand children, 1 great-grandchild

Knot Break Strength vs Rope Break Strength

Testing of fiber rope is always a challenge. There are many variables in any test, but fiber ropes with knots have even more. The key to good tests is the repeatability. First priority was to select the types and sizes of rope to be tested. This was done with the advice of the industry. Three types and sizes were selected, Static Life Safety 12.5mm, Dynamic Climbing 10.5 mm, and Accessory Cord 7mm. The next was to select the knots to be tested. Again we went to those with the knowledge of what is being used. Eight knots were selected; Bowline, Fig. 8 end, Fig. 8 bight, Butterfly, Fisherman's knot, Double Fisherman's knot, Sheet Bend, and Double Sheet Bend. The next decision was quantity of tests. There are two factors involved, amount of rope, and time available to do the tests. Since this was strictly an all-volunteer project, we decided to keep the quantity of rope to 300 ft. of each size and type. This allowed 5 breaks of each type and size to establish a benchmark, and 5 breaks for each knot. This will give an average strength and a standard deviation to work with. PMI provided all the rope used in this segment of testing. The next segment includes ¼" and ½" diameter ropes of various constructions and fibers.

Equipment

The test equipment is a standard hydraulic ram pull against a fixed load cell. Ram length is 36" with a pulling speed of approximately 39"/minute. The load is recorded and peak load retained with a digital readout. The clevis has a 1" diameter pin. This can be used to hold the rope or the 4" diameter bollards.

The overall length of the test bed is six feet with ram extended providing nine feet of usable bed length. The fixed end is moveable thus allowing shorter lengths to be tested. The load cell is calibrated to ASTM E-4 Standard annually. This is an open test frame with protection for the operator. It is possible to observe the reaction of the knots as tension is applied.

Method

This type of testing is to determine the percentage of the knot strength vs. rope strength. The first step is to determine the average of each type rope with five breaks in accordance with CI-1801. The ropes were tested and the mean and standard deviation was determined. Each of the knots was tested and the break strength recorded. The Bowline, Fig. 8 end and bight, and the Butterfly knot had one end on the bollard. Bollards on both ends held the Fisherman's, and Sheet Bend knots. The mean and standard deviation were determined. This was then compared to break strength of the rope and percent of break strength determined. In all testing there is some variation, to eliminate as much of this as possible all the knots were tied by the same person using the same procedures. The data was then recorded on Excel and the various graphs and charts were compiled.

Data

Normally there are three categories referring to types of configurations in the end or joining of rope. Knots, Bends, and Hitches. However for simplicity and clarity in this paper we will divide this data into two categories; End line knots and joining knots. The Bowline, Figure 8 end and bight, and Butterfly are end line knots that

are to hold on to something. Sheet Bend and Fisherman's Knot are to joining two ropes of the same size and type together. To determine the consistency we used the Standard Deviation divided into the mean break strength. Standard Deviation is the square root of (the sum of the squared deviations from the mean, divided by the sample size minus one) In formulae it is often represented by the letters SD or the symbol (Greek letter) sigma. The lower the percentage the more consistent the knot. It was necessary to add backup knots, as noted, to get the rope to break.

12.5 mm Static Life Safety Rope Data

	Brk. Str.	Bowline	Fig. 8 end	Fig. 8 bight	Butterfly	Sheet Bend	Fish knot	Dbl Sheet Bnd	Dbl Fish Knot
Brk 1	10,102.0	6,414.0	7,299.0	7,798.0	8,028.0	5,219.0	5,149.0	5,440.0	7,756.0
Brk 2	9,984.0	6,240.0	7,548.0	7,562.0	8,078.0	4,962.0	5,515.0	5,372.0	7,705.0
Brk 3	9,967.0	6,271.0	7,641.0	7,536.0	8,069.0	5,065.0	5,371.0	5,402.0	7,818.0
Brk 4	9,773.0	6,170.0	7,446.0	7,773.0	8,069.0	5,175.0	5,195.0	5,585.0	7,749.0
Brk 5	9,820.0	6,315.0	7,453.0	7,788.0	7,779.0	4,984.0	5,147.0	5,363.0	7,800.0
Mean	9,929.2	6,282.0	7,477.4	7,691.4	8,004.6	5,081.0	5,275	5,432.4	7,765.6
Std. Dev.	132.9	90.7	127.6	130.6	127.6	113.7	162.4	90.5	44.6
% Of Brk	100%	63.3%	75.3%	77.5%	80.6%	51.1%	53.1%	54.7%	78.2%
% Of Brk	1.3%	1.4%	1.7%	1.7%	1.6%	2.2%	3.0%	1.7%	0.05%

Note: Fish Knot has a tendency to slip @4400 lbs. without 2 half hitches on both sides

Note: Double Sheet Bend pulled out at 3,705 lbs. included a an Overhand knot on bend back side to achieve breaks.

Fig. 1

10.5 mm Dynamic Climbing Rope Data

	Brk. Str.	Bowline	Fig. 8 end	Fig. 8 bight	Butterfly	Sheet Bend	Fish knot	Dbl Sheet Bnd	Dbl Fish Knot
Brk 1	4,994.0	3,112.0	3,289.0	3,492.0	3,544.0	2,576.0	3,109.0	2,632.0	3,445.0
Brk 2	4,963.0	3,051.0	3,633.0	3,643.0	3,407.0	2,575.0	3,000.0	2,795.0	3,727.0
Brk 3	4,959.0	3,223.0	3,470.0	3,507.0	3,663.0	2,520.0	2,946.0	2,873.0	3,640.0
Brk 4	5,250.0	3,233.0	3,489.0	3,535.0	3,519.0	2,427.0	3,066.0	2,712.0	3,925.0
Brk 5	5,015.0	3,276.0	3,588.0	3,440.0	3,688.0	2,483.0	3,064.0	2,734.0	3,766.0
Mean	5,036.2	3,179.0	3,493.8	3,523.4	3,564.2	2,516.2	3,037.0	2,749.2	3,700.6
Std. Dev.	121.7	93.7	133.0	75.2	114.3	63.4	64.0	90.5	176.3
% of Brk	100%	63.1%	69.4%	69.9%	70.8%	49.9%	60.3%	54.6%	73.4%
% of Brk	2.4%	2.9%	3.8%	2.1%	3.2%	2.5%	2.1%	3.3%	4.7%

Note: Sheet Bend slips without 2 half hitches on the bend back line and overhand knot on turn thru line. With 8" tail pulled to 912 lbs. resulting in 4" tails @ 1600 lbs. the knot pulled out. Recommend always taking half hitches and overhand knot.

Fig. 2

7 mm Accessory Cord Data

	Brk. Str.	Bowline	Fig. 8 end	Fig. 8 bight	Butterfly	Sheet Bend	Fish knot	Dbl Sheet Bnd	Dbl Fish Knot
Brk 1	2,433.0	1,620.0	1,851.0	1,816.0	1,739.0	1,521.0	1,480.0	1,477.0	1,985.0
Brk 2	2,420.0	1,704.0	1,794.0	1,815.0	1,799.0	1,420.0	1,445.0	1,355.0	1,949.0
Brk 3	2,468.0	1,600.0	1,792.0	1,899.0	1,754.0	1,521.0	1,430.0	1,332.0	2,015.0
Brk 4	2,455.0	1,694.0	1,790.0	1,799.0	1,739.0	1,443.0	1,487.0	1,489.0	1,927.0
Brk 5	2,460.0	1,597.0	1,742.0	1,819.0	1,785.0	1,568.0	1,466.0	1,357.0	2,041.0
Mean	2,447.2	1,643.0	1,793.8	1,829.6	1,763.2	1,494.6	1,461.6	1,402.0	1,983.4
Std. Dev.	19.9	52.0	38.6	39.5	27.4	61.3	23.9	74.7	46.6
% of Brk	100.0%	67.1%	73.3%	74.7%	72.0%	61.1%	59.7%	57%	81.0%
% of Brk	0.08%	3.2%	2.2%	2.1%	1.6%	4.1%	1.6%	5.3%	2.3%

NOTE 1: Sheet Bend with back up knots 2 half hitches on bend back side and overhand knot on pass thru side.

NOTE 2: Double Sheet bend had a lot of slipping 4 of 5 knots broke cover first - Double Sheet Bend with 2 half hitches on bend back side broke same as Note 1

Fig. 3

Comparison Charts

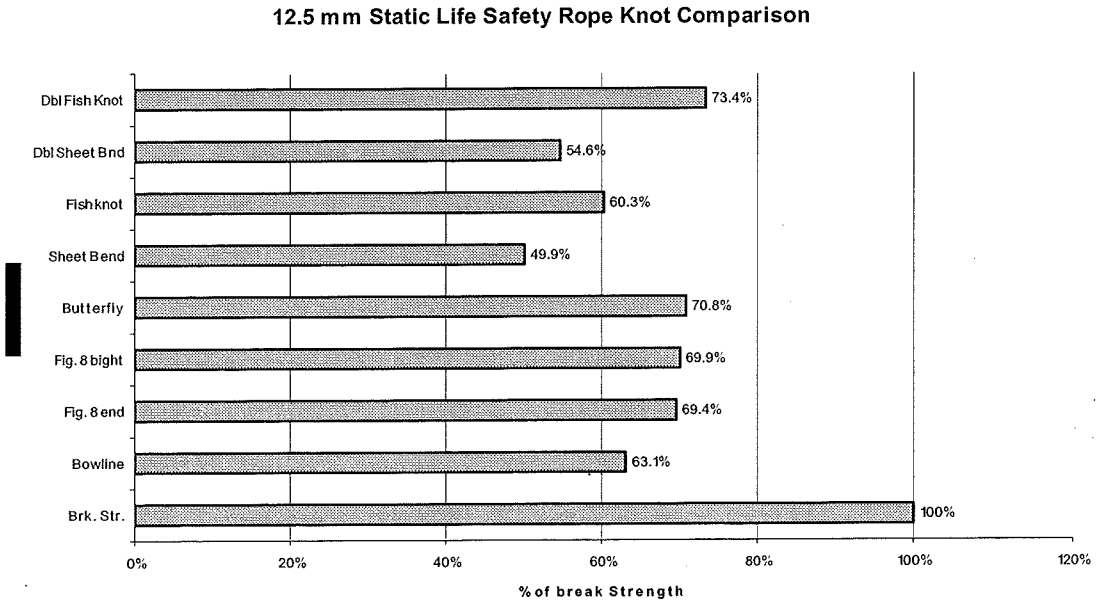

Fig. 4

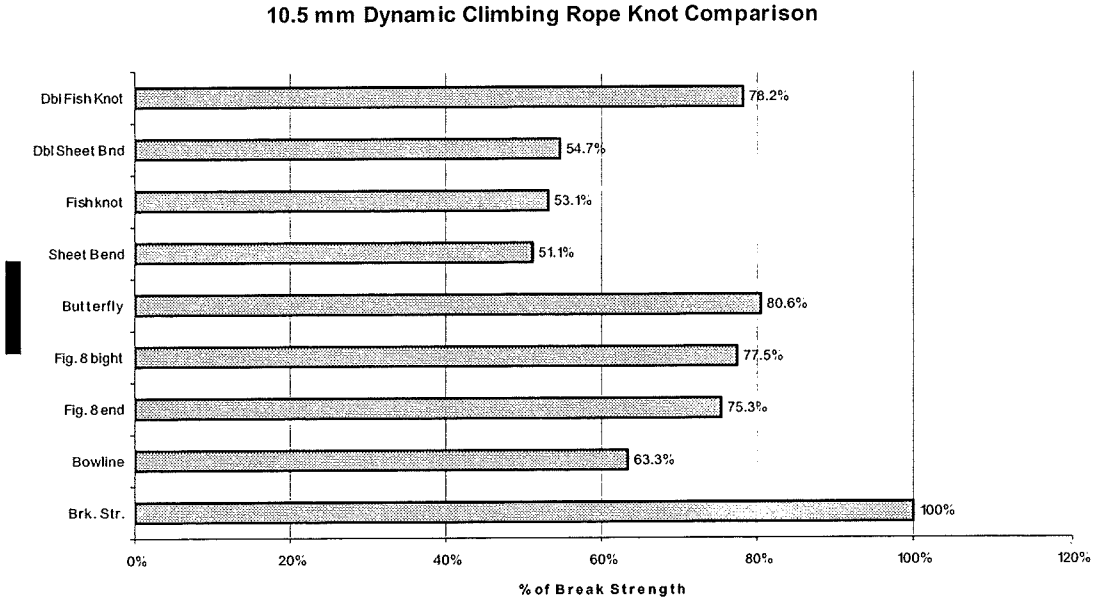

Fig. 5

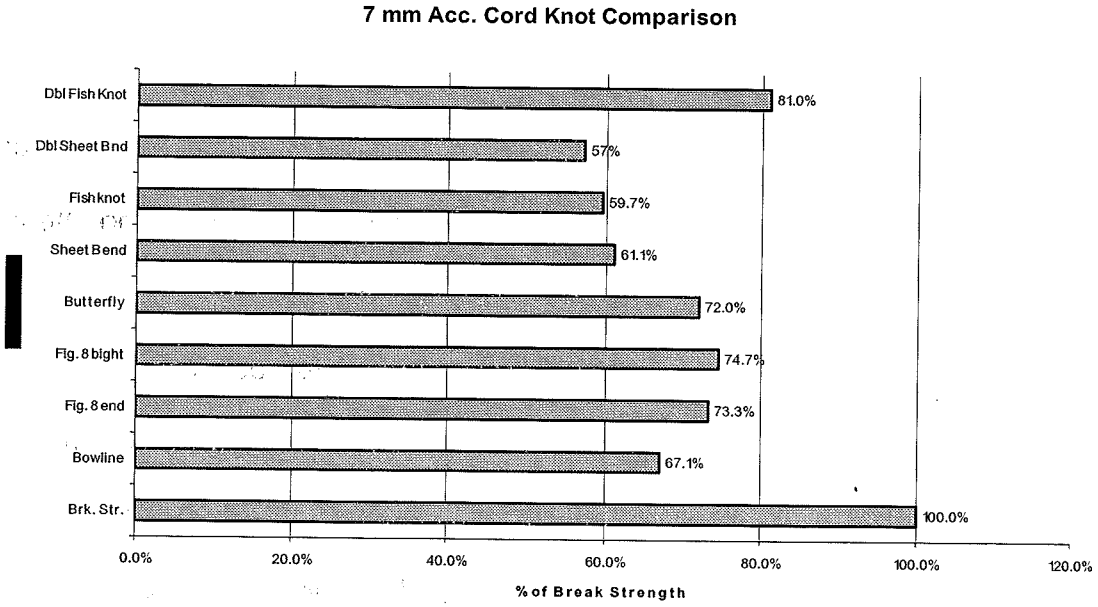
7 mm Acc. Cord Knot Comparison
Dbl Fish Knot
Dbl Sheet Bnd
Fish knot
Sheet Bend
Butterfly
Fig. 8 bight
Fig. 8 end
Bowline
Brk. Str.
81.0%
57%
59.7%
61.1%
72.0%
74.7%
73.3%
67.1%
100.0%
0.0%
20.0%
40.0%
60.0%
80.0%
100.0%
120.0%
% of Break Strength

Fig. 6

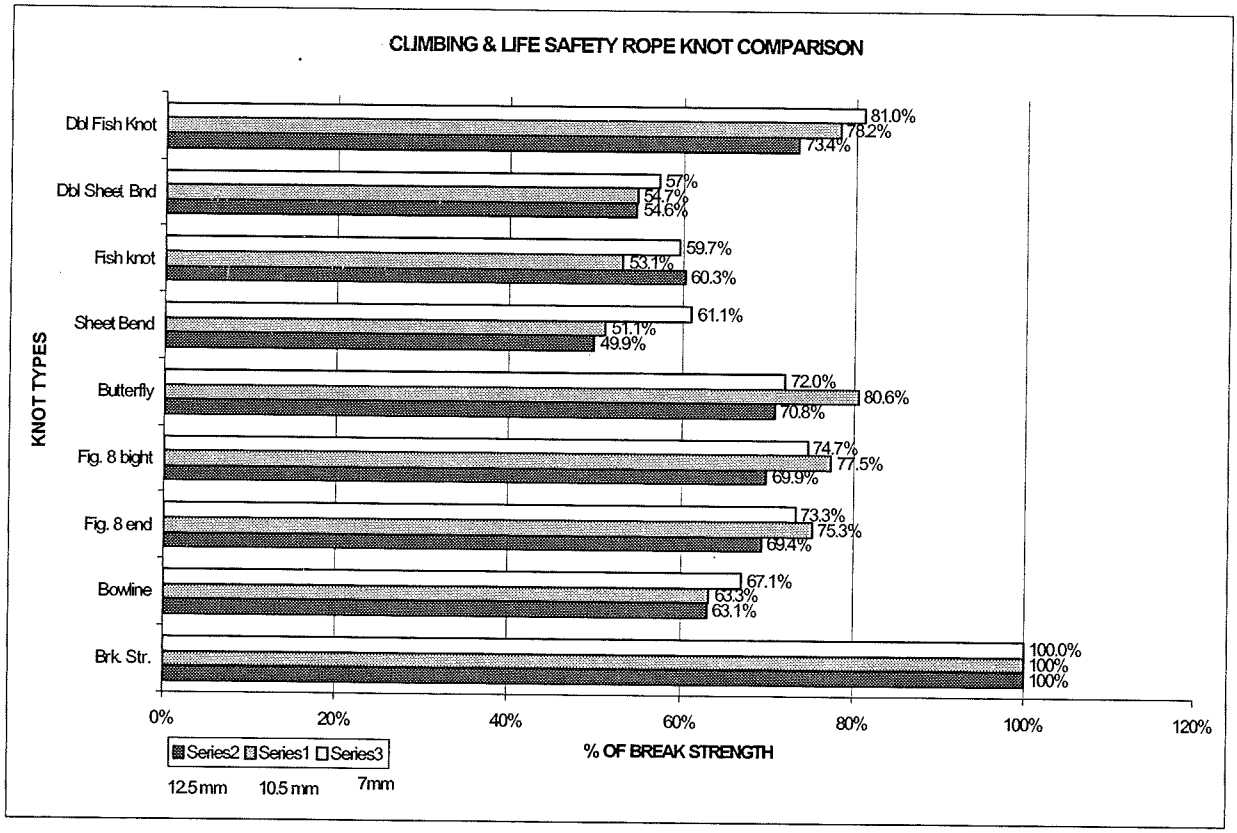
CLIMBING & LIFE SAFETY ROPE KNOT COMPARISON
KNOT TYPES
Dbl Fish Knot
Dbl Sheet Bnd
Fish knot
Sheet Bend
Butterfly
Fig. 8 bight
Fig. 8 end
Bowline
Brk. Str.
81.0%
78.2%
73.4%
57%
54.7%
54.6%
59.7%
53.1%
60.3%
61.1%
51.1%
49.9%
72.0%
80.6%
70.8%
74.7%
77.5%
69.9%
73.3%
75.3%
69.4%
67.1%
63.3%
63.1%
100.0%
100%
100%
0%
20%
40%
60%
80%
100%
120%
% OF BREAK STRENGTH
Series2 Series1 Series3
12.5mm
10.5 mm
7mm

Fig. 7

Comments

The answer to the question of strength loss is "it depends". In the testing process it was very obvious that it was important to tie the knot carefully, paying attention to detail. By observing the knot tighten down any malfunction became very obvious quickly and resulted in low break strength or a pull out. The joining knots seemed to be the most susceptible. The speed of the ram used was 39"/min., faster or slower speeds may result in slightly different values. It was also found that size and material have a minor influence on the efficiency of the knot. A Bowline in the 2 larger sizes 12.5mm Static and 10.5mm Dynamic were almost the same, 7mm Acc. Cord was approximately 4% higher. The Figure 8 knots were slightly more efficient with the 10.5mm a little better than the 7mm with the 12.5mm the least. A Butterfly knot had the highest efficiency in the 10.5mm at over 80%. The Double Fisherman's Knot seemed to be the best joining knot. Most all of the joining knots required backup knots.

The most efficient end line knots Butterfly and Figure 8 knots have a disadvantage of being almost impossible to untie after a significant load of about 1,000 lbs. was applied.

The standard Bowline was selected for the test, but the Cowboy or Dutch Bowline was tested to see if there was a difference. The numbers were almost identical.

There are many other knots and variations of knots that could be tested. It has also been suggested that pre-cycling the knots to a lower load prior to break may have an effect. As stated in the beginning this is a work in progress and may never be complete.