Mooring Lines With Reduced Recoil Properties- Design, Analysis And Standardization

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***Abstract* – A horizontal synthetic rope testing machine, with a 500,000 kg capacity, was constructed for Samson Rope Technologies by Satec. The testing machine was designed to accommodate the characteristics of synthetic rope that are different than wire rope – such as higher elongation. With its high crosshead speed capability and elongation measurement capability, this machine can be used to study both the dynamic and static behaviors of high performance ropes.**

A patented 12-strand HMPE rope was developed to exhibit reduced recoil properties. This paper discusses the design, testing and analysis of this technology. Comparison of rope testing standards and analysis of energy absorption and rope recoil are presented and the effects of rope length are discussed.

Development of the Cordage Institute testing procedure CI1502 is also presented to summarize the collective efforts in the cordage industry to standardize the testing and performance requirements of a reduced recoil rope.

I. INTRODUCTION

A systematic study of recoil behavior of ropes was studied in 1966, comparing ropes made of synthetic vs. natural fiber [1]. It was concluded that the rope with higher energy absorption capability would tend to recoil more, since more energy would be stored in the rope when it broke. As more synthetic ropes were used, rope manufacturers started to address this issue, by designing synthetic ropes with lower recoil/backlash tendencies [2]. The basic principle behind the then new design was to combine the correct proportion of "high stretch" and "low stretch" components, where the "low stretch" component would break before the "high stretch component" did. Some design and testing of reduced recoil ropes using the same or other principles were also discussed [3, 4].

CID A-A-50435B [5] was developed in 1992 to provide specifications of reduced recoil rope, but it only applies to 4 strand Aramid ropes. The basic premise is that there is enough warning time for people to respond when a rope breaks so even if it recoils the damage is minimum.

To develop a standard which can be used for all ropes, a standard testing procedure would need to be developed to assure consistent testing and data reporting. A Cordage Institute technical committee, "The Reduced Recoil Risk Rope, CI1502", has been working on a standard testing procedure for several years. The group has examined and discussed all aspects of defining and identifying the recoil properties of a rope. Significant discussion was focused on the effect of the length of the rope on the rope's recoil property. It was agreed that a longer rope tends to recoil more as there is more energy stored in it. A prototype testing procedure was proposed to standardize the sample preparation such as rope length requirement and limitation of splicing length as well as testing details [6]. The focus of CI1502, instead of the warning time, is to quantify the "warning time stretch" a rope has after the first break (the first separation of at least one load carrying component in the rope), which is defined as "the stretch from the point of first break to the point at which the last design component breaks". The "warning time stretch" can later be converted to the true "warning time" when the loading rate of the rope is known. This is an important improvement in comparison to CID A-A-505435B as the real warning time can now be estimated properly based on rope size and loading rate.

The CI1502 testing standard is expected to be completed soon to provide a good testing guide for recoil property determination. Table I compares CID A-A-50435B standard and the current CI 1502 revision 12, listing the major difference between the two.

Table I
Comparison between CID A-A-50435B
and CI 1502 revision 12

	A-A-50435B	CI 1502 (revision 12)
Fiber	Aramid	Any
Construction	4-strand	Any
Strength	Specified	Per Manufacturer
Elongation at break	< 6%	To be determined
Warning time	10 sec	Implied/Specified by warning time stretch
Test Length	50 ft between splice ends (= 50 ft for 1" dia)	(600 x dia) overall length (= 50 ft for 1" dia)
Note	Performance spec	Testing standard, no performance requirements defined

A. Energy Absorption

The stored energy of a rope can be easily computed by integrating the area under load vs. elongation curve as shown in Figure 1. When presented as strength (N or any force unit) vs. elongation (% of stretch), the area represents the energy storage capability per unit length of the rope.

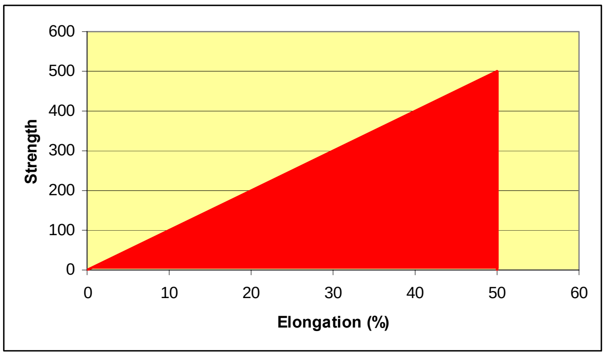

Fig. 1. Energy Storage of a Rope under load, per unit length of rope.

The concept of having a stretchy component, capable of absorbing enough energy released by the rope, in this sense, is shown below, in Fig. 2.

Strength

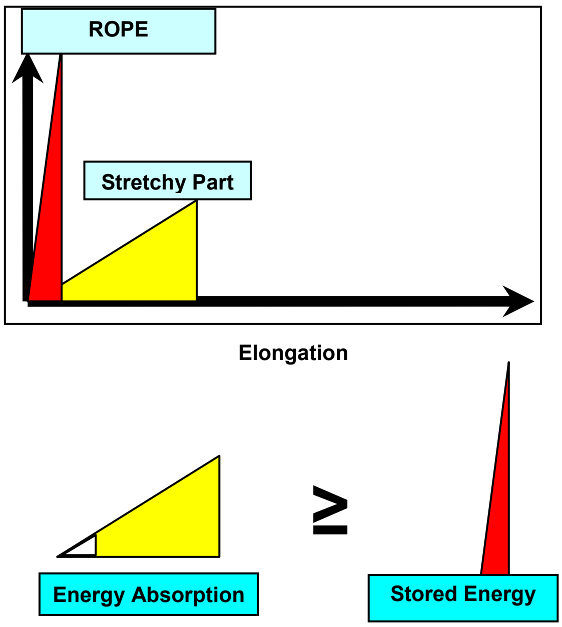

Fig. 2. Energy absorption of the rope needs to be larger than the energy stored in the rope to prevent rope recoil.

B. Product Design

Figure 3 shows Mooring Defender, a 12 strand construction HMPE rope with the energy absorption components.

Figure 3. Mooring Defender

Although this study focused on reduced recoil behavior of a rope, other performance characteristics were also considered.

HMPE fiber is used as the strength member of the rope based on the following considerations:

1. high strength and low weight
2. superior fatigue resistance
3. superior abrasion resistance
4. superior weather resistance
5. flexibility
6. elongation characteristics similar to wire

A 12 strand single braid rope was constructed to accomplish the following important rope performance requirements:

1. easy to splice
2. capability to incorporate energy absorption in the rope design easily
3. torque balance
4. easy to inspect
5. flexibility

In addition to the above considered factors, the surface of the Mooring Defender is also modified with Polyester and a proprietary coating to increase its coefficient of friction to enhance the surface characteristics.

II. SCOPE

The reduced recoil behavior is tested following the current CI 1502 revision. This study only covers the specially designed 12 strand braided rope. Performance and behavior of 4 strand ropes are not studied or compared in this study.

III. PROCEDURE

A. Tester

Samson Rope Technologies has a state of the art horizontal tester specifically designed for synthetic rope testing, shown in Fig. 4.

The machine is calibrated from 1,820 kg to 500,000 kg and has a 15.2 m sample bed length with 4.9 m of stroke. The test machine is computer controlled for precise data logging of elongation and tensile measurements. The hydraulic ram can reach a maximum speed of 3.7 m/min at loads up to 45,450 kg, up to 3.1 m/min at loads up to almost 136,400 kg, and up to 0.6 m/min at loads up to 500,000 kg.

Fig. 4. Samson's Rope Testing Machine

B. Reduced Recoil property determination

The sample is prepared following prototype testing procedure per CI1502 revision 12. The rope sample size is 1 in (24 mm) diameter and the overall length is 600 in (15,240 mm) with a total spliced length of approximately 65 in (1,651mm), thereby satisfying the maximum (240 x rope diameter) limitation specified by CI1502.

The rope samples were cycled 10 times to 50% of the expected strength before the final break, following the guideline of CI 1500 and CI1502.

After the first break, the test continued and the "warning time" is recorded as the time difference between the first break and the last break.

Crosshead speed is set such that the rope reaches 50% of its breaking strength in not less than 5 seconds and not more than 50 seconds. For the 24 mm (1 in) dia. rope test, the average loading rate is 0.6 m/min and reaches 50% of its break strength in approximately 30 seconds.

Two different rope designs were tested for comparison. One is with a high stretch component and the other one is with an intermediate stretch component as the energy absorption mechanism.

Individual strands of each energy absorption component were tested for their breaking strength and elongation. The data are used to compare and compute the energy absorption capability of these strands.

IV. TESTING RESULTS AND DISCUSSION

A. Recoil Properties

Fig. 5 shows the testing results of Mooring Defender, presented as load vs. stretch. Several events are marked on the curve, 1st break (breaking strength), residual stretch, 2nd break, etc. The series of strength vs stretch loops at the left portion of the curves shows the 10 cycles to 50% of the breaking strength before the final break.

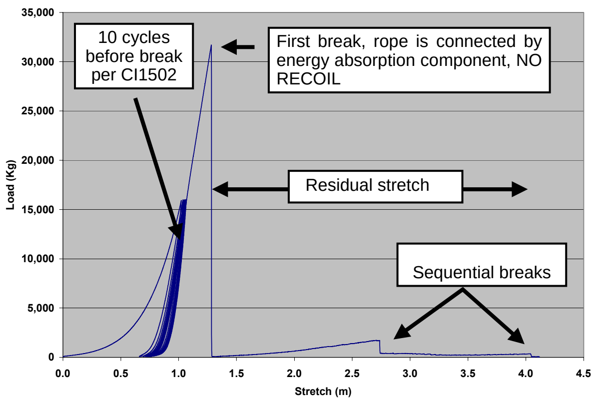

Fig. 5. Strength vs. stretch of 1 inch diameter mooring defender

As the load vs. stretch curve shows, the rope is still connected together, as shown in Fig. 6, by the stretchy component after the 1st break. It continues to stretch until one of the stretchy components breaks at the first peak marked as the "sequential breaks", followed by additional stretch till the whole rope separates into two pieces.

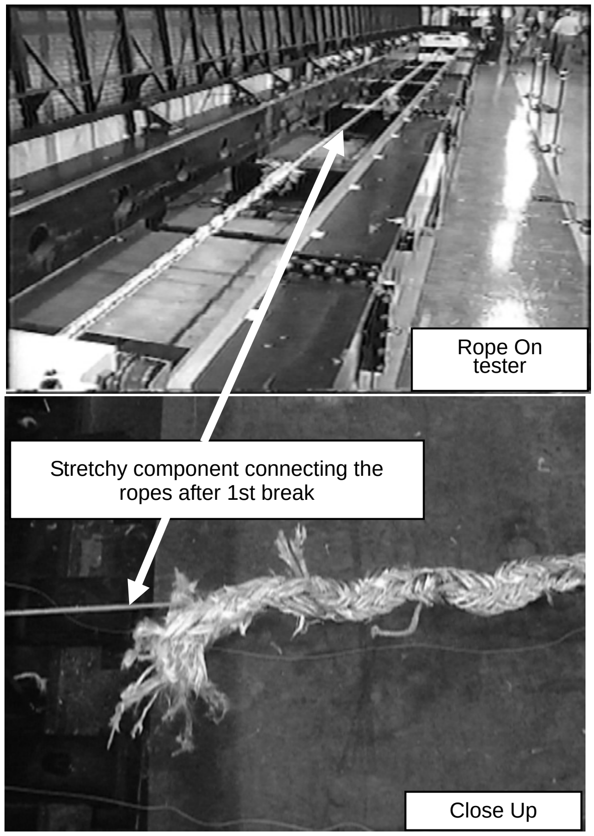

Fig. 6 Rope does not recoil after the 1st break, held together by the stretchy component.

The warning time stretch, between the first break and the last break is approximately 2.8m. The warning time can be computed using the following equation:

Warning time = warning time stretch / loading rate (1)

During the test, the loading rate is 0.6 m/min, which means that if the rope breaks at this speed the last break will not occur until 260 seconds after the 1st break. Using the CID-A-A50435B load rate, Mooring Defender would have a CID warning time in excess of 18 minutes, which grossly exceeds the 10 second warning time.

It is also important to note that the 2nd break, which breaks the energy absorption component, is very low, only about 7% of the original strength of the rope. This strength level further enhances the safety of the rope as the recoil of the 2nd break, if it occurs, will be very low so the rope remains safe even beyond the warning time.

B. Energy dissipation analysis

As discussed earlier, the energy stored in the rope, before it breaks, is the area under the strength vs. elongation curve, as shown in Figures 1 and 2.

The analysis, when expressed in mathematical form, is shown below:

$$\frac{F_s \varepsilon_s}{2} - \frac{F_s \varepsilon_r^2}{2\varepsilon_s} \geq \frac{F_r \varepsilon_r}{2} \qquad (2)$$

where

F_r is the load at the breaking point of the rope

F_s is the load at the breaking point of the stretchy member

ε_r is the elongation at the breaking point of the strength member and;

ε_s is the elongation at the breaking point of the stretchy member

Rearranging the equation we can find that following simple equation to present the criteria of energy dissipation to prevent rope recoil:

$$\frac{\varepsilon_s}{\varepsilon_r} - \frac{\varepsilon_r}{\varepsilon_s} \geq \frac{F_r}{F_s} \qquad (3)$$

The individual strands' strength vs. elongation data are shown in Fig. 6.

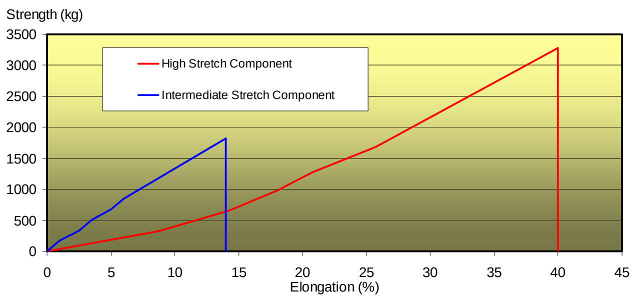

FIG. 6. Strength vs. Elongation of the two stretchy components.

Table II lists the data obtained from Fig. 6, showing the strength/elongation characteristics of the different stretch components used in this study

Table II
Data for Energy dissipation analysis
for 24 mm diameter Mooring Defender

Component	Rope spec	High stretch member	Intermediate stretch member
Strength,kg	29,700	3,280*	1,800**
Elongation	4.5%	40%	14%

*4 strands of 820 kg strength each

** 4 strands of 455 kg strength each

Table III lists the numbers computed using (3) based on data in Table II, comparing the testing results against the prediction from the analysis.

Table III
Recoil tendency analysis based on strength and elongation data

Rope Design	$(\varepsilon_s/\varepsilon_r) - (\varepsilon_r/\varepsilon_s)$	(F_r/F_s)	Recoil
High stretch member	9	9	No
Intermediate stretch member	3	16	Yes

The analysis shows that the energy analysis can be a good tool to understand and predict the recoil behavior of a rope.

C. Fatigue Study

To understand how fatigue would affect the reduced recoil property of the rope, we conducted a fatigue test to load the rope to 50% of its breaking strength for 1000 cycles, followed by breaking the rope per the CI 1502 procedure. The test results are presented in Table IV, comparing a standard CI1502 test on a new rope.

Table IV
Rope strength After fatigue at 50% of its breaking strength
Spec Strength = 29,700 Kg

Number of cycles	Strength, kg	Recoil
10	31,715	No
1000	30,000	No

It is clear that fatigue to the tested level did not affect the recoil. A modeling study is in progress to understand the effect of even longer fatigue exposure to the recoil properties of the rope.

D. Other mechanisms

Other than the designed energy absorption components in the rope, there are also other possible mechanism that dissipate the stored energy when rope breaks:

1. Heat to raise rope temperature
2. Heat to melt polyethylene
3. Sound

Table V estimates the relative contribution of each factor in energy dissipation, including the energy absorption component factor. It is clear that the selection of the energy absorption component is critical for the rope to exhibit reduced recoil property. It also shows a good correlation between the analysis and lab observation.

Table V. Energy dissipation comparison among different possible mechanisms for a 24 mm dia Mooring Defender of 15.24 m length.
(Line potential energy = 1168 kJ)

Energy dissipation mechanisms	Energy dissipated, kJ	% of energy dissipation	Note and Assumptions
Melting of HMPE	23	1	25% of 0.5 m of line melted.
Heat up of the fibers	14	2	50% of 1 m of line heated.
Energy absorption from the stretchy component	1158	92	No Splices
Sound	58	5	5% of the total Stored Energy
Total Energy Absorption Capacity	1253	100	

V. CONCLUSIONS

The tests and analysis show that the energy absorption component needs to have enough energy storage capability to dissipate the energy released from the strength members to reduce the rope recoil. Mooring Defender, designed based on this principle, is proven to be a good reduced recoil rope with other important rope performance attributes. Lab testing also demonstrated that the reduced recoil property of Mooring Defender is not affected by tensile fatigue up to 1000 cycles loading to 50% of the breaking strength of the rope.

"Warning time stretch", as CI1502 specifies, being a rope property, can be used to estimate the true "warning time" considering both the rope and the loading condition, is a better parameter to determine the reduced recoil requirement.

REFERENCES

[1]. Coast Guard Baltimore ND Field Testing and Development Center, "Recoil Properties of Rope", Report No. 449, Project 3973/01/01, Nov 1966.

[2]. R. L. Stanton, "Reduced backlash for synthetic fiber ropes" Safety, July 1983, pp. 51-52.

[3]. Coast Guard Research and Development Center, "A Snapback Evaluation Technique for Synthetic Lines," May, 1982.

[4]. Elizabeth Whitehill and A. Simeon Whitehill, "Continued Development and testing of Reduced snap Back Rope," Proceedings of Oceans'95, MTS/IEEE, October 9-12, 1995, San Diego, California.

[5]. CID A-A-50435B, Commercial Item Description: Ropes (Aramid).

[6]. CI1502 revision 12a, 2004.