Running Lines and End Connectors for Synthetic Rope to Reduce Logging Workloads

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Oregon Occupational Safety and Health Administration
Worksite Redesign Grant Final Report
July 2004

EXECUTIVE SUMMARY

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In order to realize the ergonomic and efficiency benefits in logging and trucking applications, suitable end connectors must be developed and tested for terminating synthetic rope. At the start of this research and development effort, synthetic rope end connectors were limited to specific splices, knots, and thimble/eye connectors. There is a need to develop synthetic rope terminations to winches, steel wire rope connectors (nubbins, fittings, etc.), and to synrope itself.

We reviewed potential end connectors used for wire rope and worked with the manufacturer on ideas/concepts. We were not successful in working with manufacturers of wire rope end connectors as they viewed synthetic rope as competitive or had unsuccessful prior experiences. We consulted with experts in the chemistry of the rope and epoxies to select potential systems of bonding rope to connectors. Some of our early trials capitalized on the strength of the buried eye splice used by the rope testing standards to establish the strength of the rope.

We have come to realize that the criteria for acceptable end connectors with synthetic rope depend on how they are used. Some terminations need to develop high strength because they are bearing loads while others may be terminations that either are expected to "break away" or simply terminate the rope without having much of a load. Another important criteria is the ease of production or manufacture in the field conditions of a rigging shop or in the woods. Finally, end connectors should be relatively consistent in their performance rather than variable in use. The table below lists the end connectors evaluated.

End connector	**Origin**	**Use**	**Average strength & variability**
Buried eye splice	Manufacturer	Eye to shackle various connectors	Standard 100%, little variation
Long splice	Manufacturer	Connect two ropes	95% , little variation
"Y" splice	Manufacturer	Variable length, eye for tensioning	50-90%, variable, can slip out w/o tension
"Whoopie Sling"	Manufacturer	Variable sling length	85-90%, little variation
Knots—various	Marine industry	Terminations	8-58%, highly variable
Cable clamps (clips)	Wire rope industry	Connect rope to itself	~60%, OK variability tensioning difficult
Pinned nubbin	OSU-Hartter design	Connect to nubbin	~95%, little variation
Knuckle link	Hartter design	Connect to steel housing	~100% little variation
Pressed nubbin	Wire rope industry	Connect to nubbin	~20-25%, little variation

End connector	Origin	Use	Average strength & variability
Butt splice packed into nubbin	OSU Concept	Connect to nubbin	~10-15%, could be variable
Chain link to buried eye splice	Truck wrapper design & others	Connect to chain, T bar, etc.	Wrapper strength w/ reduced pin size
SEFAC	Manufactured end connector	Connect to wire rope or steel end connectors	~40-65%, variable & difficult to produce
Various tested epoxies to steel nubbins	Wire rope industry	Connect synrope to nubbins	~12-36% highly variable & difficult
Twisters	Wire rope industry	Variable length & tensioning device	~80% of double rope strength

Most of the end connectors above were tested in a designed experiment documented in the MS thesis of Joel Hartter (2004) under the grant sponsorship. Other tests were conducted as well. We qualify our recommendations to the AmSteel®-Blue rope we tested and urge caution for users until they have some experience with the connectors themselves. Based on this initial work, we believe that the following list of end connectors will be useful to industry adjusted as needed to meet the strength requirements in use.

- Buried eye splice
- Whoopie Sling
- Long splice
- Rope clamps – in selected applications to low tension terminations
- Knuckle link
- Pinned nubbin
- Pressed nubbin, Butt Splice packed nubbin, drum connectors (various)—For breakaway or drum connections relying on sufficient wraps on drum
- Y-splice – with careful construction and pre-tensioning with mostly rig up conditions
- Twisters—with careful use not to over twist ropes
- Chain link to buried eye splice as in truck wrappers

We further do not recommend the following end connectors at this time:

- Knots as they are variable and can have low strengths including knots as recommended by rope manufacturers
- Epoxy to nubbin connectors as they are extremely difficult to prepare and then are variable in strength
- SEFAC—an industry connector with difficult production requirements & variable results

Our results to document the uses of synthetic rope for running line applications are limited to winching applications in ground skidding, use of synrope on a carriage, and using synthetic rope as mainline on a small yarder. All of the above running line applications have been successful and show promise. We have learned important lessons and identified problems and opportunities on drumline spooling and capacities.

We have documented the potential uses of synthetic rope as a skyline but have not as yet done trials to verify the potentials. We could not incorporate synthetic rope in cable planning analysis programs as yet but offer an approximation approach to see its potentials. We are still working on using synthetic rope with various carriage designs.

We have produced two designs for end connectors that are in the public domain and available to manufacturers or machine shop production: pinned nubbin and knuckle link. We have studied damage and wear to synthetic rope in our project but still rely on the manufacturers' recommendations for replacement.

Acknowledgements

The entire synthetic rope research team would like to thank the Oregon Occupational Safety and Health Administration Worksite Redesign Grant for the funding the project and Mike Lulay of that agency for his assistance. We also thank Milo Clauson and the Wood Science and Engineering Department for his leadership and their lab testing facilities. Many cooperating rigging shops, suppliers, and logging firms helped with our efforts. Samson Rope Technologies has provided assistance in many ways to the project. It has been an interesting and challenging project whose results will continue developing over the years ahead.

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I. Introduction

Earlier research with synthetic rope revealed the importance of end connectors to use the rope effectively (Garland, et al, 2002). With the current Worksite Redevelopment Grant by Oregon Occupational Safety and Health Administration commencing in 2001, our team of researchers in the Forest Engineering Department began investigating end connectors for use with synthetic rope. Other topics were also included in the grant about looking at the use of synthetic rope in running line applications, wear and damage, and planning approaches using synthetic rope.

Both the wire rope industry and marine users of synthetic rope have end connectors that meet many of their needs. However, because of the properties of the AmSteel®-Blue synthetic rope we selected for our studies, we needed to evaluate existing potential end connectors and actually design some new ones for logging applications.

Mr. Joel Hartter, a mechanical engineering graduate, was part of the research team while completing a Master of Science degree with Dr. Garland in Forest Engineering at Oregon State University. His thesis provides full details of the designed experiment for evaluating end connectors for synthetic rope (Hartter, 2004). Summary results are presented here for readers to quickly see the project results; however, the team's publications and Hartter's thesis provide additional information and detailed procedures.

The report is organized as follows:

The report is organized so that readers can use the "Bookmarks" guide to reach the particular topic of interest or click on the chapter title in the Table of Contents. Material from other project documents are included in this report and are so noted by "NB: …" notes at the start and end of the included section. Figure and table numbers are the same as those cited in the included section while the figure and table numbers specific for this report are listed with the prefix “R” to distinguish them (eg, Figure R1 shows…or Table R1. …).

Mention of trade names in this report is for identification only and does not constitute an endorsement by Oregon State University or the Occupational Safety and Health Administration. Whenever Amsteel Blue is mentioned we are specifically referring to AmSteel®-Blue synthetic rope by Samson Rope Technologies.

II. Synthetic Rope End Connectors Evaluated and Designed

The material that follows is abstracted from the thesis of Joel Hartter (2004) while working on the synthetic rope project. We selected three rope sizes for tests based on the most common usage in logging: 3/8”, 9/16”, and 5/8” nominal AmSteel®-Blue 12-strand braided ropes manufactured by Samson Rope Technologies (mention of trade names does not constitute an endorsement by Oregon State University nor the Oregon Occupational Safety and Health Administration).

NB: Hartter information begins here:

1.1 End Connection and Termination Designs Tested

The following subsections describe the end connections for synthetic rope that were tested under this project. All test specimens used new synthetic rope. Table 1 lists the end connections tested under this project. A detailed description of the *spliced*, *adhesives*, and *dry hardware* end connections can be found in the next subsections.

Table 1. End connection designs

	Spliced
1	Buried Eye Splice
2	Whoopie Sling
3	Long Splice
4	Y-Splice
	Adhesives
5	Steel Nubbin w/ Socketfast Blue A-20
6	UHMW-PE Nubbin w/ Socketfast Blue A-20
7	Steel Nubbin w/ Scotchweld DP-8010
8	UHMW-PE Nubbin w/ Scotchweld DP-8011
9	Notched Steel Nubbin w/ Socketfast Blue A-20
10	SEFAC
	Dry Hardware
11	Rope Clamps
12	Pinned Nubbin
13	Knuckle Link
14	Pressed Nubbin
X	Truck Wrappers (for 3/8" diameter only)

1.1.1 Buried Eye Splice

In this project, the buried eye splice is the control treatment, or benchmark. An end connection or termination is needed with the synthetic rope to use it in harvesting systems. The synthetic rope is essentially modified anytime it uses a splice or end connection. The rope manufacturer identifies the buried eye splice as retaining the most breaking strength when the rope is modified compared to any other end connection.

Thus, the buried eye splice becomes the benchmark to compare all end connector concepts. In this project, because the rope in a timber harvesting system is only as strong as its end connection, the breaking strength of the buried eye splice will be the effective 100% breaking strength of the rope. It is a simple splice to construct and is used in all diameter classes, but specifically for 3/8”, 9/16”, and 5/8” nominal diameters in this study. Figure 1 shows the eye of a completed buried eye splice.

Figure 1. Buried eye splice

1.1.2 Whoopie Sling

Loggers do not like to carry more equipment than required for a job. Cable operations are set up on steep slopes and over long spans. Traditionally, heavy cast steel blocks, shackles, and steel wire rope straps would be carried into the brush. Bringing this hardware out to the tailtree or intermediate support tree can be an arduous task. In fact, this equipment can be so heavy and bulky that more than one trip is often required.

Currently, steel wire rope guylines and support lines are the industry standard. Each is constructed to a specific length to meet job requirements. When the length does not meet the jobsite specific attributes, a second rope length is shackled to the guyline or the guyline is wrapped around the tree and terminated with forged steel rope clamps. The more hardware in the woods, the more time and energy are expended to bring it in and out of the woods.

The Whoopie Sling concept has been developed to alleviate such a situation. Not only is the synthetic rope approximately seven times lighter than the steel wire rope guylines of the same diameter and length, but the Whoopie Sling is an adjustable sling. The adjustable strap configuration allows the user to move from one guyline length to another without the addition of hardware or extra slings.

The Whoopie Sling is an adjustable strap concept made out of the same synthetic rope (see Figure 2). One end of the rope has a modified Brummel eye splice that will connect to the anchor point. The main section of rope is used to create a length of the user's discretion. The free end is passed back through the middle of the rope, similar to the Buried Eye Splice procedure. The tail is then terminated with a butt-splice.

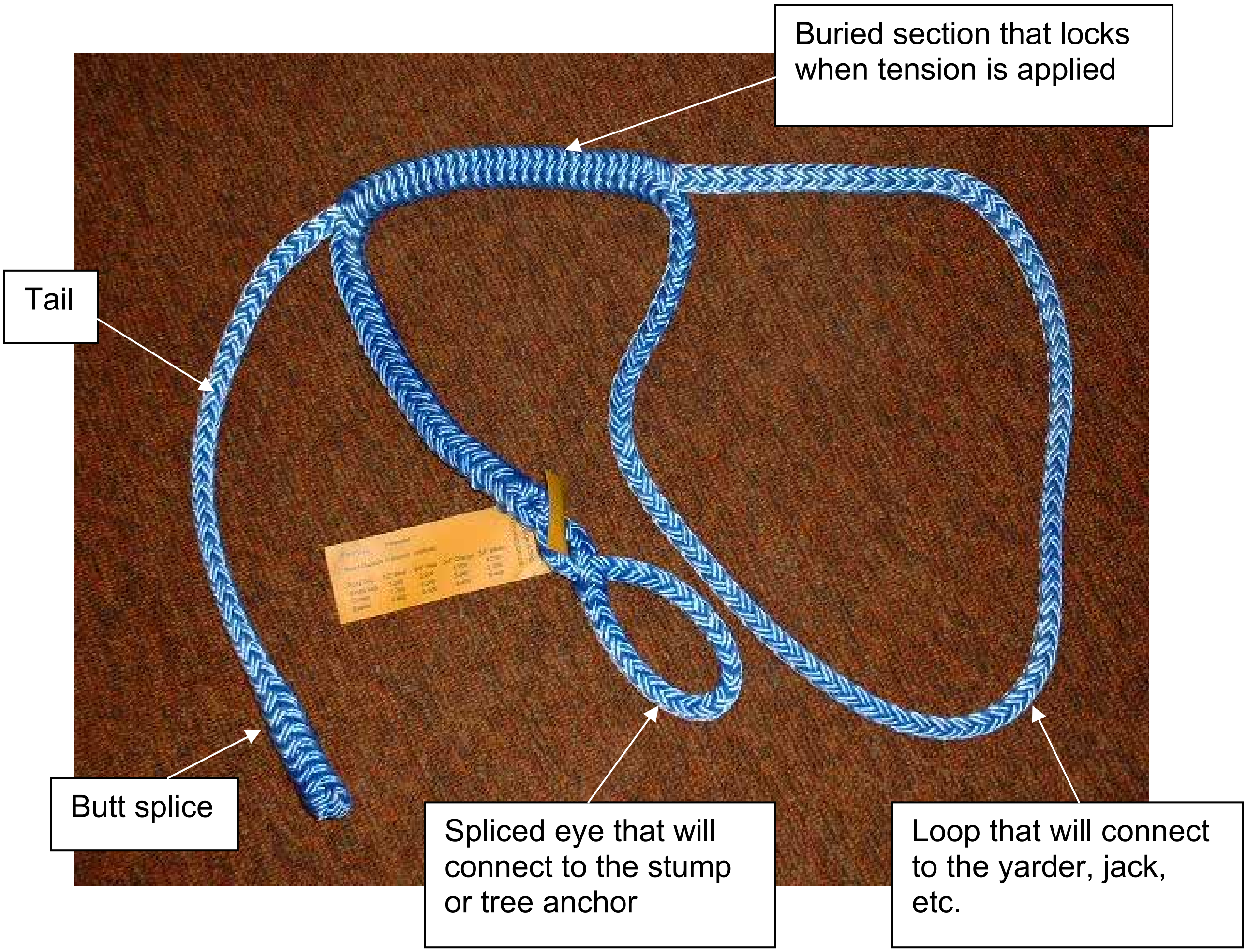

Figure 2. Whoopie Sling

The length of the Whoopie Sling can easily be adjusted. The user must pull on the loop to add length. Conversely, to decrease the length of the Whoopie Sling, the user simply pulls on the tail. The Whoopie Sling concept is based on the same constrictive principle used in the other splices. When tension is applied to the line, the rope constricts and grabs the buried section and the strap is locked into position. When tension is released, the sling is easily adjusted to a new length.

1.1.3 Long Splice

The long splice is used to join two pieces of synthetic rope together by a simple splicing technique. As discussed previously, knots significantly compromise the strength of the rope and thus are not an adequate way to connect two ropes together. In the case of the long splice, the ends of each of the ropes are tapered from 12 strands to six strands in a similar fashion as the buried eye splice (see Figure 3). Then, the end of rope 1 is threaded into a section of rope 2 (Figure 4). Additionally, at the same point, rope 2 is threaded into rope 1 (see Figure 5). Figure 5 shows the finished long splice using new and used rope.

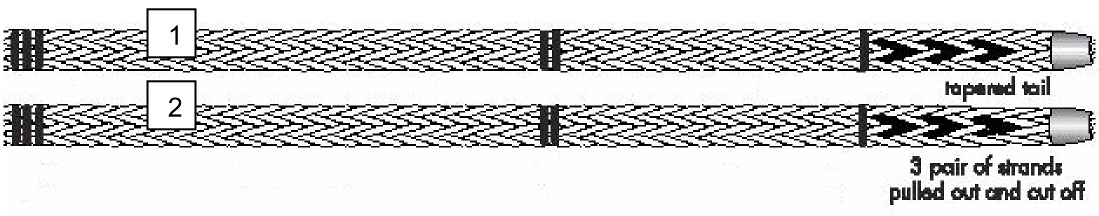

Figure 3. Taper procedure for long splice (Samson Rope Technologies A., 2002)

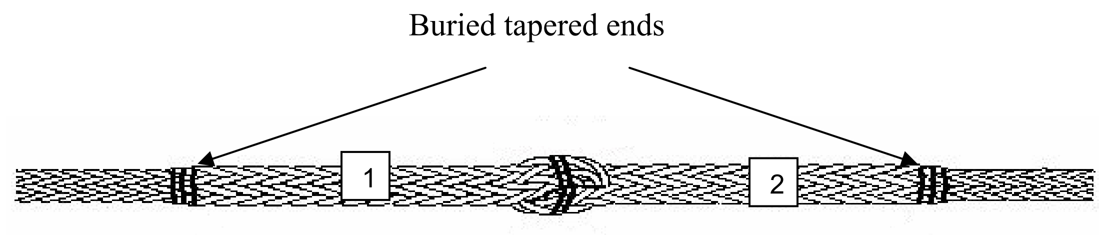

Figure 4. Finished long splice (Samson Rope Technologies A., 2002)

The long splice may be performed on used or new rope. As with the buried eye splice, when tension is applied to either end of the rope, the rope compresses on itself and holds.

Figure 5. Finished long splice

1.1.4 Y-splice

The Y-splice was derived as another solution to the problem of adjustable rope lengths (Figure 10). The Y-splice was created so that the user could bring one long rope with eye splices at each end into the field. Knowing that this length of rope works only for a distinct number of rigging scenarios, a second length of rope can be spliced into the main section of the rope. The separate length of the rope has a buried eye splice at one end. The tapered end can then be inserted at any point on the sling to add or subtract length to fit the particular guyline requirements.

The Y-splice is created similarly to the aforementioned splices. The main section of rope is a buried eye splice at each end. A separate length of rope is created with a buried eye splice at one end. There is a 50% taper from 12 strands to six strands at the free end of the rope. This free end is then inserted into the main section of the rope at a desired point. The main section of rope and the newly connected section of rope form a "Y". Tension on the Y-splice compresses the ropes together for the holding strength.

Figure 6. Y-splice

1.1.5 Steel Nubbins with Two Adhesives

The nubbin (also called a "ferrule") is a common and versatile end connection for use with steel wire rope in logging. It is a quick connection for use with yarders, carriages, and winch drums. An operator can easily insert the nubbin into a "ferrule pocket" on the drum, add tension, and secure the wire rope to the drum.

The nubbin is not only used in running line applications, but also in static line applications. It is used to connect guylines and support lines to additional lengths of rope. For example, a guyline is to be set up using a horizontal distance of 120 feet and there is only 85 feet of guyline. An additional length of rope with a steel nubbin attached can quickly be added to the system by using a double-ender hook (Figure 7).

Figure 7. Double-ender hook showing nubbin connection

This low-tech connection is one of the most widely used connections in logging. Due to its availability and material properties, the ferrule was selected for use with synthetic rope. The steel B-5 wedge nubbin has a tapered inner wall, which produces compressive stresses on the wire rope as a tensile load is applied axially. It is a quick connection that can easily slide into place. The nubbin is locked in place when tension applied to the line.

Due to the lack of heat resistance of the synthetic rope (T_g = 150°F), the conventional method for connecting steel wire rope to the steel nubbin with a zinc compound is not appropriate. The molten zinc would not only melt the UHMW-PE fibers, but it would not bond with them as well. However, a similar concept for the synthetic rope replaced the zinc compound with an adhesive.

Both the 9/16" and 5/8" diameter synthetic rope were used with the tapered wall B-5 nubbin. Using the manufacturer's specifications for steel wire rope, the equivalent nominal diameter synthetic rope was used. The free rope end is fed through the smaller hole of the ferrule. The exposed strands were unraveled and frayed. The fibers inside the nubbin were coated with an adhesive.

This study employed two different adhesives. The Socketfast® Blue A-20 was used to bond the synthetic rope to the steel and UHMW-PE nubbins. The Socketfast® Blue A-20 is a low-viscosity styrene adhesive and did not have a specific applicator or application process. Figure 8 shows the catalyst (left) that came with a pint of resin (right). The two compounds were mixed together and then applied to the test specimens in accordance with the manufacturer's application procedures.

Figure 8. Socketfast® Blue A-20

The second adhesive is a two-part acrylic from 3M Corporation: Scotch-Weld™ DP-8010. This amine adhesive has a significantly higher viscosity than the Phillystran. In addition, the adhesive required a brush- or spray-on primer of 0.0001" thickness for steel surfaces. The specially designed adhesive application system (applicator gun, mixing nozzles, and plunger) provided a simple method for applying the adhesive to the synthetic rope and nubbins. The self-contained application system (Figure 9) omitted user error in mixing. A 10:1 mixing nozzle attached to the spout of the cartridge. A 2-ounce cartridge of the adhesive connected to the front of the gun. The nozzle was trimmed to provide a 1/16" diameter bead size of adhesive.

Figure 9. 3M Scotch-Weld™ DP-8010

Using this bead size of 1/16”, the nozzle could be inserted into the middle of the rope. Adhesive was also applied to the yarns as the strands were opened and frayed out. Moreover, the structural adhesive is granular and viscous (17,000 centipoises for base and 27,000 centipoises for accelerator) enough to collect inside the nubbin and within the rope strands and yarns. Additionally, the manufacturer recommended applying metal primer to the steel nubbins prior to potting.

The two obvious differences in the adhesives are the viscosity of the adhesive and the potting system. The Socketfast® Blue A-20 adhesive was extremely less viscous at only 200-400 centipoises. For this reason and because the catalyst was mixed differently, a different potting technique had to be employed (Phillystran, 1997).

All test specimens were prepared according to the standardized procedures. However, after the samples were pulled from the mold, it was evident that the adhesive coverage was not uniform. Figure 10 shows the differences in potted end connections using the same procedure. Most specimens appeared to have good adhesive coverage down to the fiber level (Figure 10B), but some had discontinuous coverage with differing thicknesses Figure 10A).

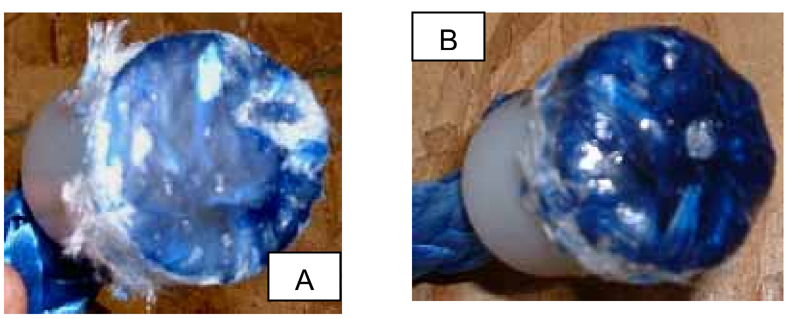

Figure 10. A) UHMW nubbin with less adhesive coverage
B) UHMW nubbin with more adhesive coverage

The work life of the Socketfast® Blue A-20 adhesive quoted by the manufacturer was 20-30 minutes, but experience in the laboratory was that for the first 30-35 minutes, the adhesive was still runny. Work life of the adhesive could be extended by applying the adhesive in a container with limited exposure to air. Air exposure directly reduces work life. However, as the adhesive reaches the terminus of its work life, it quickly coagulates. At this point, it turns into a jelly and should not be used for the end connections.

Due to the low viscosity the Socketfast® Blue A-20 adhesive, the end connections should be potted upside down, otherwise the adhesive will run down exterior and interior strands of the rope. Preliminary potted trials were conducted to determine the best way to pot the test samples. Although plastic zip-ties and molding clay were used to prohibit adhesive from passing through the rope interior, there was still leaking out the bottom of the nubbin. Due to the chemical composition of the Socketfast® Blue A-20 adhesive, care must be taken in determining materials to be used as potting molds because the styrene monomer may melt the mold as it pots.

From the outside, it appeared that there was adequate coverage. As the nubbins were inspected 72 hours following potting, the adhesive was not brittle and felt similar to a solid nylon.

1.1.6 UHMW-PE Nubbin With Adhesives

This test concept is essentially the same as the steel nubbin with adhesive; only the nubbin material has changed. The UHMW-PE nubbin is manufactured with the same dimensions as the steel B-5 version. Both the B-5 and UHMW-PE nubbins were tested with the same adhesives. Figure 11 shows the B-5 steel nubbin with the UHMW-PE nubbin.

Figure 11. B-5 Steel nubbin and UHMW-PE nubbin

1.1.7 Notched Steel Nubbin With Phillystran Adhesive

The nubbin used in this end connection is a modified B-5. A small "step" was made in the tapered wall. The notch was machined into the nubbin to allow for better compression of the rope and a higher breaking strength. In addition, the step also provides an extra lock when tension is applied to the rope. The synthetic rope was threaded through the nubbin, the strands were unraveled and frayed. The adhesive was then poured to fill the nubbin. As the adhesive cures, it bonds to the rope and to the nubbin walls. When straight tension is applied, the wall should provide an additional normal force upward.

Not only does the notch slightly increase the bond area, but also it provides a catch point, a bench, for the hardened epoxy to bond. As tension is applied, this notch makes it more difficult for the rope and adhesive to pull through the nubbin. Unlike with the smooth, continuous taper in the nubbin interior, the rope and adhesive must deform more to pass through the notched nubbin. Therefore, it can hold more load than the B-5 nubbin. Figure 12 shows the machined B-5 notched nubbin and Figure A8 in the Appendix shows the design and dimensions.

Figure 12. Notched nubbin

1.1.8 SEFAC™

The SEFAC™ design was provided by the fiber manufacturer. Various potting techniques had been considered by DSM for synthetic rope terminations. However, conventional designs had not been designed for high modulus fiber ropes with high strength and a low coefficient of friction. The SEFAC™ was designed to combine the strength of a compression fitting with the additional holding capacity of a structural adhesive. It adds two additional coupling collars that compress the rope against tapered walls.

This end termination was a two-piece system and its dimensions depend on the diameter of the rope. It had a steel socket and a tapered steel spike inserted into the center of the rope and into the socket. The initial drawback to this system was that it was a two-part system. In addition to the design, the fiber and rope manufacturer recommended the structural adhesive, Socketfast® A-20. The immediate drawback to this two-part system was that it was difficult to pot. The Socketfast® A-20 initially had the viscosity of a thin syrup.

The socket was potted upside down. The rope is threaded through the socket, the strands are unraveled and frayed. The Phillystran adhesive is then poured into the connection and the spike added. The spike is pushed into the rope to compress the rope to complete the compression fitting. Figure 13 shows the SEFAC™ concept. Although the rope at the end of the socket was tightened with a zip-tie and modeling clay was used to plug the gap between the rope and the socket, the Socketfast® Blue A-20 dripped through the inner strands of the rope. As a result of low viscosity, the adhesive covered as much as 8” below the end connection. The adhesive hardened this section of rope and seemed to make the rope sample brittle and perhaps more susceptible to failure under cyclic loading conditions.

Moreover, as the adhesive dripped out of the bottom of the socket and into the inner fibers and strands of the rope, the amount in the socket decreased. It was impossible to tell how much adhesive remained in the socket. As the adhesive dripped out, there was less bond strength between the adhesive and the socket walls and spike. After 72 hours, the terminations were checked. At this point, all adhesive set up, dried, and the gap at the bottom of the socket between the rope and the socket was plugged. Additional adhesive was poured into the socket until it was full.

Under this potting methodology, it was difficult to cover the internal fibers of the strands with the Socketfast® Blue A-20. The strands had to be frayed in order to increase adhesive coverage, bond area, and therefore bond strength. However, the rope could not be completely frayed inside the socket. It needed to have some form to retain strength of the rope construction. Completely undoing the unique 12-strand braid might weaken the rope under cyclic loading conditions.

Figure 13. SEFAC™

1.1.9 Rope Clamps

The wire rope clamps used in this pilot study were the standard Crosby® Clips used with steel wire rope. The quick connection was specifically designed for in-field installation. Made of forged galvanized steel, each clip is resistant to corrosion and rusting.

Wire rope clamps are u-bolt clips placed in series along the rope. The Synthetic rope is wrapped over itself, leaving enough rope for an eye. The rope that is overlaid on itself is clamped together using the u-bolt clips. The clips are properly spaced according to spacing dimensions found in the Wire Rope Users Manual (Wire Rope Technical Board, 1993) and tightened with a torque wrench to 45 foot-pounds (less than the 90 foot-pounds recommended because higher torque was not feasible). The Oregon OSHA Forest Activities safety code states that improved plow steel wire rope requires the use of three clips for diameters between 3/8" and 5/8", but also requires an extra clip added when "high strength wire rope" is used (OR-OSHA, 2003). In order to better test synthetic rope as a substitute for steel wire rope in forest operations, identical rigging practices were used. Therefore, four clips were used at a spacing of 4". Figure 14 shows a picture of this end connection.

Figure 14. Wire rope clamp

1.1.10 Pinned Nubbin

The pinned nubbin concept was developed using early research by the Synthetic Rope Research Team. The eye splice of the sample was fed into the nubbin and secured with a bolt that was fed through a bored hole in the nubbin. The rope was pulled tight so that the top of the eye was bent around the bolt. Initial trials of the 5/8" diameter rope prior to this study reached 39% of the catalogued minimum breaking strength (unpublished data). The results from further exploratory testing with 9/16" diameter rope in this study with nubbins are found in Table 2 below.

Table 2. Exploratory testing results with bolts

Diameter	End Connection	Breaking Strength (lbs.)	% of Catalogue Minimum	% of Catalogue Average
9/16	B6 Nubbin with 1/2" Grade 8 Bolt	23077	57%	52%
9/16	B5 Nubbin with 1/2" Grade 8 Bolt	28699	71%	64%

The feasibility and breaking strength of this concept warranted further investigation under the scope of this project.

The pinned nubbin connection is a dry end connection, meaning it requires no adhesive only a mechanical means to attach the rope. The buried eye splice achieves the highest breaking strength, but does not work in every timber harvesting application.

To provide more compressive strength than the B-5 nubbin, a new socket was fabricated to use with the 5/8" and 9/16" synthetic rope. Figure 15 shows a diagram of how the eye splice of the rope is tightened, and Figure 16 shows the fabricated piece. Dimensions can be found in the Appendix.

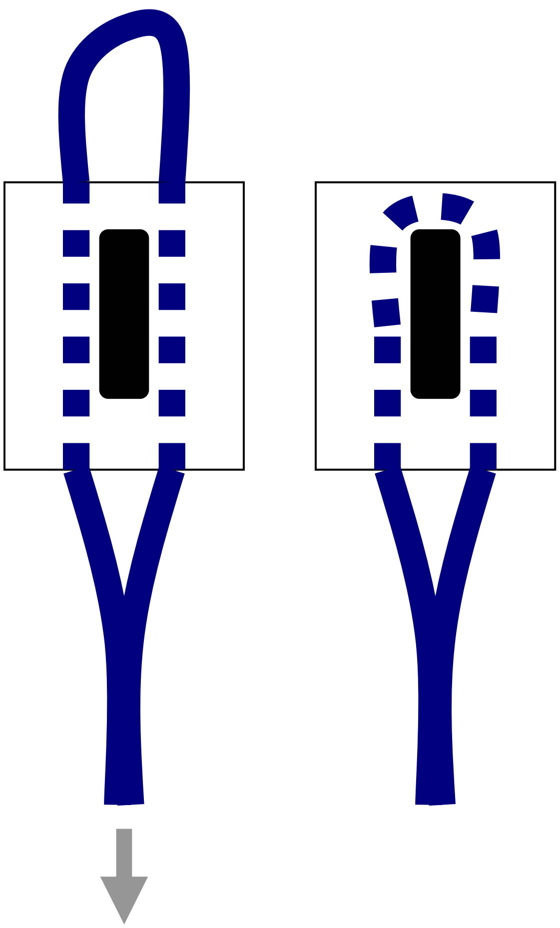

Figure 15. How the pinned nubbin works

Figure 16. Pinned nubbin

In order to keep the new nubbin as close to the B-5 dimensions as possible, this specific design relied heavily on material properties and heat treatment. When a load is applied to the rope, there is a substantial bending stress in the pin. To reduce deflection, a larger pin was needed than earlier bolts tested. As a rule of thumb, the larger the diameter of a pin, the more bending it can withstand. However, a larger pin would fill more of the inside volume of the socket and not allow the rope to fit inside the nubbin. Keeping all of the design constraints in mind, a new pin was designed. At the tested end of the specimen, there will be a buried eye splice. The synthetic rope will be threaded through the nubbin and the eye of the buried eye splice will be locked into the nubbin when the pin slides through the nubbin and through the eye of the rope.

1.1.11 Knuckle Link

The knuckle link was developed from a simple concept. Chain links can have relatively high tensile strength if the cast pieces are hardened through heat treatment. Not only do the chain links have high tensile strength, but also their material properties lend them to having high compressive strength. Using the strength advantages of a buried eye splice coupled with a quick connection, an initial concept was constructed with a small Grade 8 bolt welded across a chain link.

The idea was promising as it yielded approximately 85% breaking strength before the bolt failed. However, a better design was needed. The connection needed to be a single piece as the introduction of additional parts and materials increases tolerances and room for error. In addition, the chain link could not be used because the link was already heat treated. Weld points further weaken the material. Furthermore, the weld and material surrounding it become increasingly weak and prone to cracking when the part is heat treated.

Although the initial concept was not a sound design, it led to the development of the knuckle link (shown in Figure 17). This end connection for both 9/16” and 5/8” diameter synthetic rope was machined from a single piece of stock. The part was machined from A4 steel and then heat treated to a hardness of Rockwell$_C$ 59. Dimensions can be found in the Appendix.

Figure 17. Knuckle link

In addition, the choice of material to be heat treated is important. The initial design concept was modeled after a heat treated chain link with normalized round stock welded to it. However, welding a piece that is already heat treated is difficult and reduces its strength. If the piece is heat treated and then welded together, it cannot be heat treated again to increase strength. The weld is a weak point and it is extremely difficult to heat treat.

The design was modified in order to machine it from a single piece of stock. It was first attempted with solid 4140 Steel stock. 4140 Steel has good compressive and tensile properties. Extrapolating its use in similar applications, the normalized 4140 stock was heat treated. As a result of this heat treatment, the part developed a hairline crack, an obvious point of failure. This result shows that not only is the design important, but the knuckle link needed to be A4 grade steel.

The knuckle link is attached to the synthetic rope using an eye splice. As the rope is being spliced, it is first passed up through one hole, over the bar, and passed back down through the other hole. Then, the eye splice can be constructed with the knuckle link attached.

The knuckle link is a durable quick end connection that was designed to be used for static and running line applications. It is spliced directly into the rope and will not fall off when taken into the woods. It is also lightweight and can fit easily in a pocket. The major drawback with this design is that it leaves the rope exposed. Bending a rope over the bar puts a large stress on the rope and individual strands at that point.

1.1.12 Pressed Nubbin

The pressed nubbin concept was derived directly from steel wire rope applications (Figure 18). A hydraulic press is used to compress the steel nubbin onto the wire rope. Similarly, the same steel nubbins that correspond to 9/16” and 5/8” diameter wire rope were pressed onto the synthetic rope at 1800 psi using a 500-ton Esco hydraulic press (Black, 2004). No lubricants or tape were used on the rope so as to affect the performance of the test specimen during the break test.

Figure 18. Pressed nubbin

1.1.13 Truck Wrappers

The synthetic rope truck wrapper is a design similar to the steel wire rope truck wrappers (Figure 19). In the case of the synthetic rope truck wrapper, 3/8” synthetic rope is substituted for the 3/8” steel wire rope. For our tests, the 12 foot synthetic rope has a buried eye splice connected to a one-foot section of 5/16” chain at both ends.

Figure 19. Truck wrapper

1.1.14 End Connection Fabrication

All spliced end connections were constructed in the test laboratory using the rope manufacturer's procedures. B-5 nubbins, 9/16" and 5/8" rope clamps, and the 5/16" chain for the truck wrappers were purchased from the local rigging shop.

Some end connections required fabrication: SEFAC^{TM}, UHMW-PE nubbin, notched nubbin, pinned nubbin, and knuckle link. These concepts were manufactured within specified tolerances at the machine shop at the Forestry Research Laboratory at Oregon State University. Completed products were then thoroughly inspected for quality.

NB: Hartter thesis material stops here.

Twisters

In addition to the end connectors described above, the OSU Team also tested the "Twister" concept widely used with wire rope to tighten lines. While the rope manufacturers do not recommend twisting rope because it reduces strength, twisters are commonly used as tiebacks for rigged trees or stumps. See Figure R1 below.

Figure R1: Twister used with synthetic rope

Knots with Synthetic Rope

Rope users rely on knots for many applications but logging applications may produce tensions near the ultimate strength of the rope and for that and other reasons, Samson Rope Technologies does not recommend knots for AmSteel®-Blue rope. It addition, knots are not approved as end connectors for logging applications except with wire rope at the end of a winchline in Division 7, Forest Activities, Safety Codes.

NB: Material from Hartter's thesis starts here.

Knots

Knots are not recommended by the manufacturer for use with synthetic rope. Due to asymmetric loading, bending, and pinching of the strands, knots can significantly reduce rope strength. Table 3 shows the percentage of breaking strength retained when conventional ropes are tied with a bend, hitch, or knot. Although the ultimate tensile load for UHMW-PE rope is much higher than ropes of polyester or nylon construction, knots still are not suitable end connections for UHMW-PE rope. Because the coefficient of friction for UHMW-PE rope is significantly lower than nylon or polyester, there is more slippage. In addition, the long chain molecules of the strands lose strength when they are bent and constricted. Therefore, UHMW-PE rope might have less retained breaking strength with knots, hitches, and bends than reported in ….

NB: Hartter's material ends here.

Tables supplied by rope manufacturers such as Table 3 below are for ropes unlike those tested in the OR-OSHA project. This Table 3 offers percentage breaking strengths for selected knots for ropes that develop far less ultimate strength than what the AmSteel®-Blue rope achieves.

NB: Hartter's material begins here.

Table 3. Percentage of breaking strength retained for common knot, bend, and hitch configurations with conventional ropes **not constructed of high modulus fibers**

Type of knot, bend or hitch	Percentage of Retained Strength
Clove Hitch with Half Hitch	60%
Cow Hitch	85%
Bowline	60-70%
Anchor Bend	
• Over 5/8” diameter ring	55-65%
• Over 4” diameter post	80-90%
Two Half Hitches	
• Over 5/8” diameter ring	60-70%
• Over 4” diameter post	65-75%
Square Knot	43-47%
Sheet Bend	48-58%
Fisherman’s Knot	50-58%
Carrick Bend	55-60%
Timber Hitch	65-70%
Round Turn	65-70%

(Foster et al., 1997), (Samson Rope Technologies A., 2002)

Although not formally part of the designed experiment of this pilot study, some exploratory testing of knots was conducted in the laboratory to better understand the effects of knots specifically with UHMW-PE rope. Table 4. shows the configurations that were tested. Although Table 3 reported a strength retention of 60-70% for the bowline knot, Table 4 reports an average of 32% of the catalogue minimum breaking strength. In addition, the cow hitch tested achieved only an average of 58% of the catalogue minimum. Other configurations were tested, but the cow hitch had the highest breaking strength.

Table 4. Results of exploratory testing of knots with Amsteel®-Blue

Diameter	Knot	Breaking Strength (lbs.)	% of Catalogue Minimum
9/16"	Bowline	12754	32%
9/16"	Bowline	13141	33%
9/16"	Figure 8	13193	33%
9/16"	Taught Line Hitch	15780	39%
9/16"	Blake's Hitch	18685	46%
9/16"	Tarbuck Knot	12730	32%
9/16"	Blood Knot	13414	33%
9/16"	Double Stevedore	19799	49%
9/16"	Improved (tucked) Half Blood Knot	8000	20%
9/16"	Double Stevedore	22307	55%
9/16"	Cow Hitch	24261	60%
9/16"	Cow Hitch	22747	57%
9/16"	Dyneema Fish Knot	21231	40%
3/8"	Double Fisherman's with safety knot	6424	35%

NB: Material from Hartter's thesis stops here.

It should be noted that the testing shown in Hartter's Table 4. above was conducted in a laboratory setting with careful control over the knot tying and having the loose end secured for some knots. In fact, the Cow Hitch tested was in reality two spliced eyes connected together with a Cow Hitch configuration with knot lines fastened to splices rather than loose. For several knots tested, when we did not secure the loose end of the rope forming the knot, it simply pulled through the knot with little holding capacity, eg Improved (tucked) Half Blood Knot and Cow Hitch and Bowline tests not shown above. Some loggers have used the timber hitch for securing tree guyline end connectors but such knot uses are not approved end connections by OR-OSHA Forest Activities, Division 7 rules. When knots were not slowly tightened, they tended to pull out. In addition, some knots place rope sections under high tensions cutting across other rope sections leading to the rope actually cutting itself off in the knot as it tightens.

Selected Connectors used to connect to Winches and Drums

As part of the project, we needed to attach synthetic rope to drums and winches using connections suitable for the winch/drum connections themselves. A number of end connections were tried:

Pressed Nubbin on synthetic rope
Epoxy poured nubbin
Butt Splice packed into nubbin used as an end connector on a winch (see photos below in Figures R2 and R3)
Short loop and locking plates
Buried eye splice on the winch itself

Figure R2

Figure R3

We recognize that the strength of an end connection on a winch/drum is less dependent on the ultimate connection than the number of tensioned wraps prior to the termination. Some winch manufacturers recommend operating with at least 4 full wraps of wire rope before the termination. Samson recommends 8 full wraps on the drum before the termination because the AmSteel®-Blue has such a low coefficient of friction (Samson C, 2003). We were not able to test the tensions in and out after wraps over steel drums or stumps but believe this information should be examined in future research.

III. Results of Laboratory Testing

Under Hartter's thesis project laboratory tests were made of various end connectors for 9/16" and 5/8" AmSteel®-Blue synthetic ropes under an experimental design that used standardized test procedures and eliminated or measured other sources of variation for the break tests of the end connectors (see Hartter, 2004 for full thesis information).

Tests with 5/8" AmSteel®-Blue Rope

Figures 20 and 21 below from Hartter's thesis show the breaking strength of end connectors for the 5/8" AmSteel®-Blue end connectors tested in actual mean values of 5 spools tested and as a percentage of the Samson published catalogue minimum values. Figures 22 and 23 show the actual results by spool for the tested rope as a percent of the Buried eye-splice (set as 100%) and the actual values by spool.

NB: Hartter's graphs are shown below

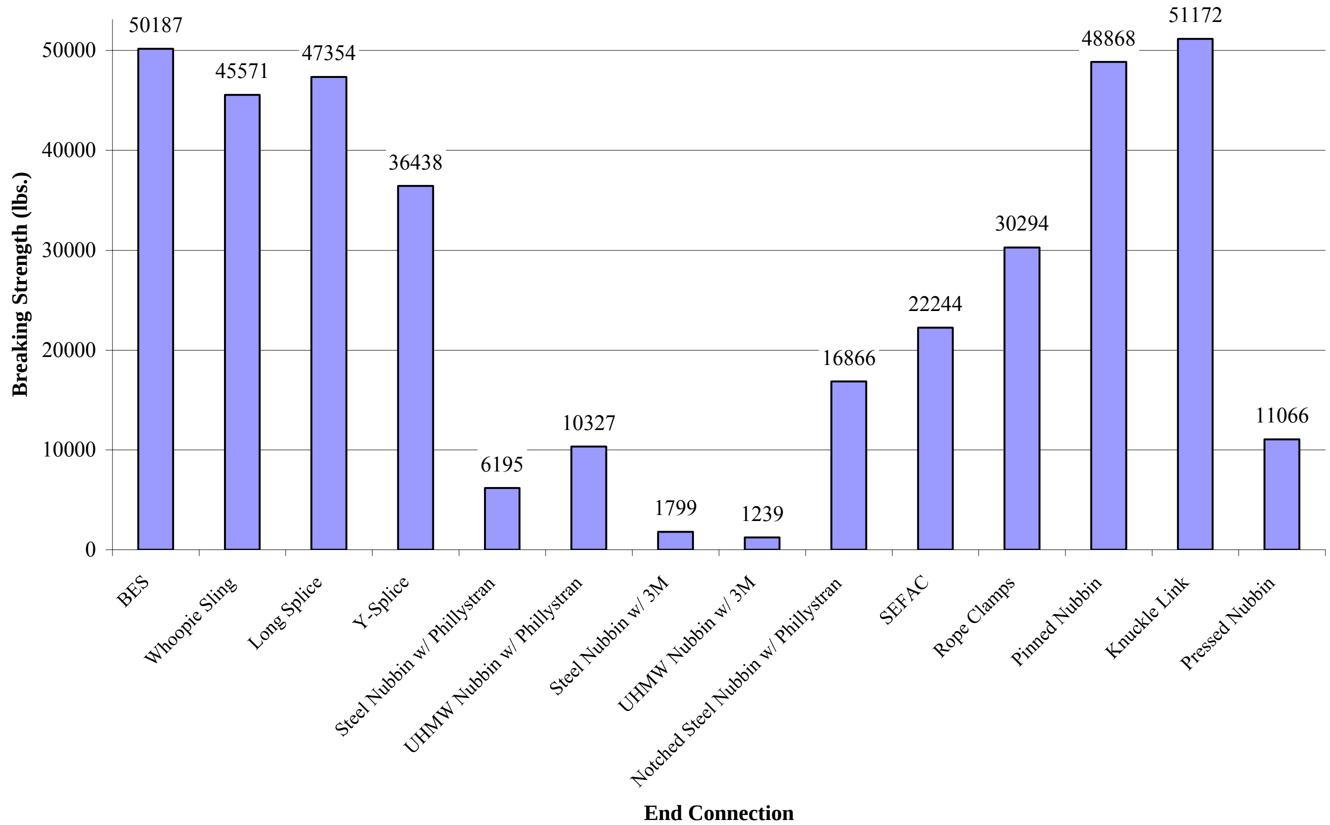

Figure 20. 5/8" synthetic rope end connection mean breaking strengths

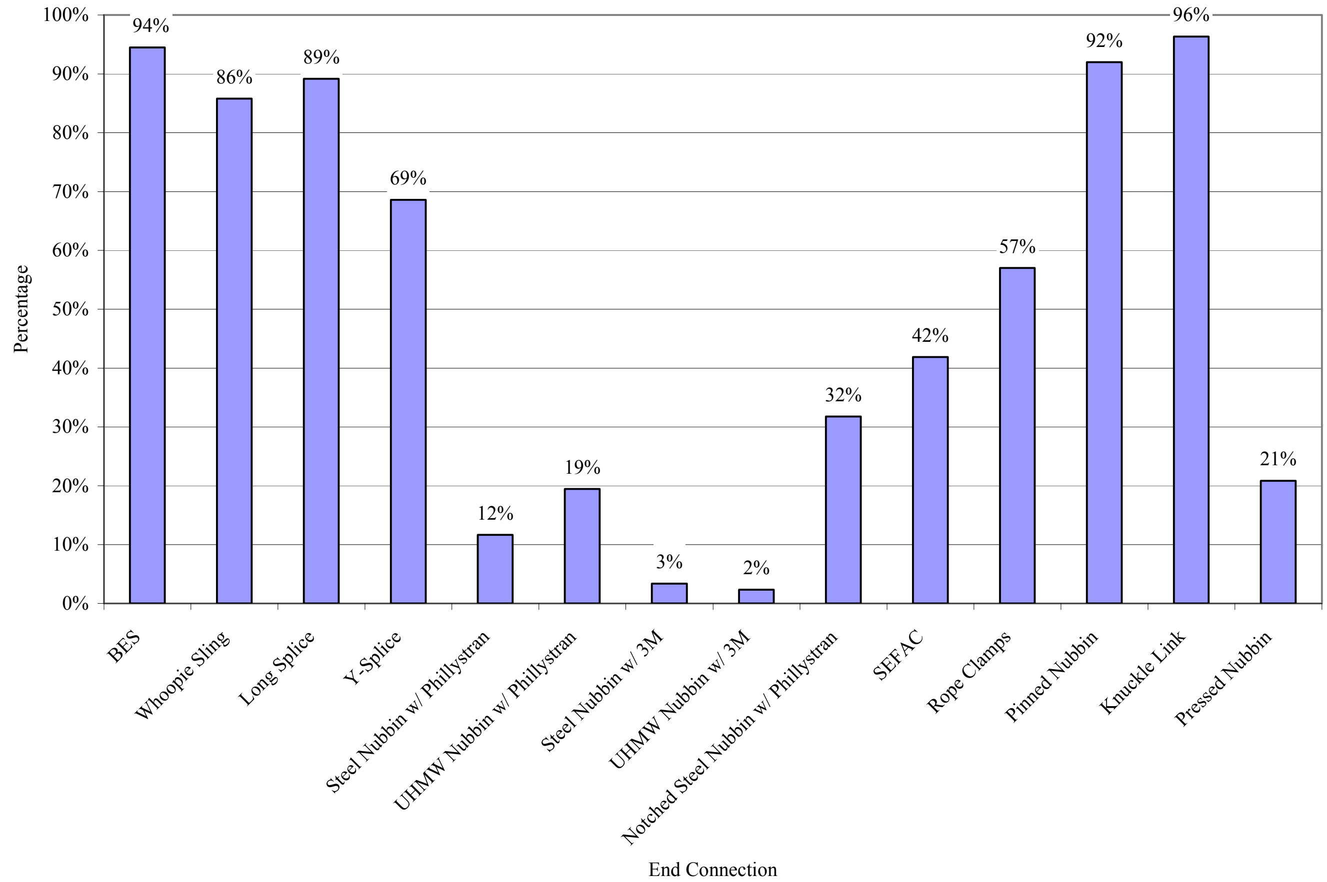

Figure 21. 5/8” diameter end connection breaking Strengths as a percentage of catalogue minimum

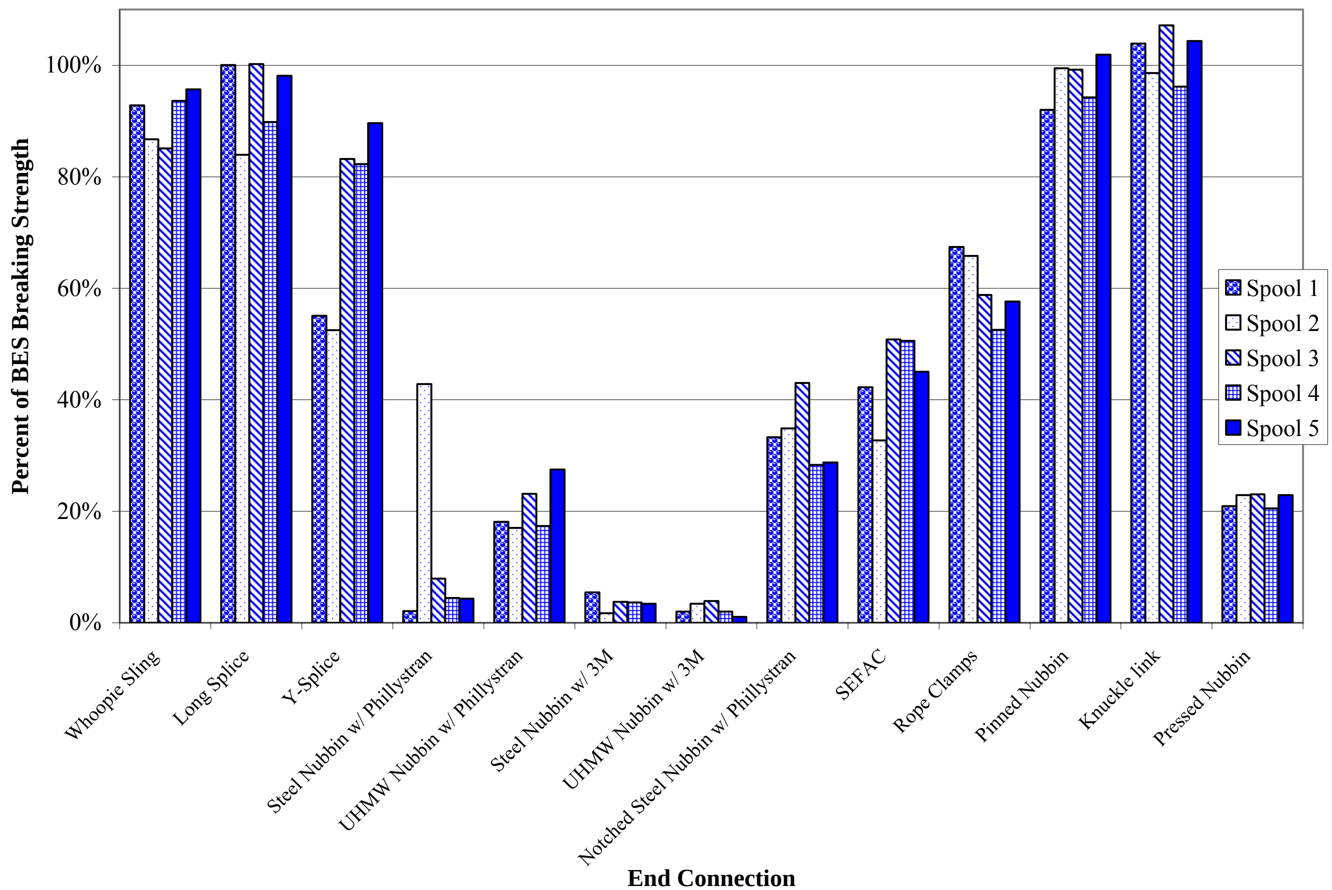

Figure 22. 5/8" diameter breaking strengths relative to the buried eye splice at 100%

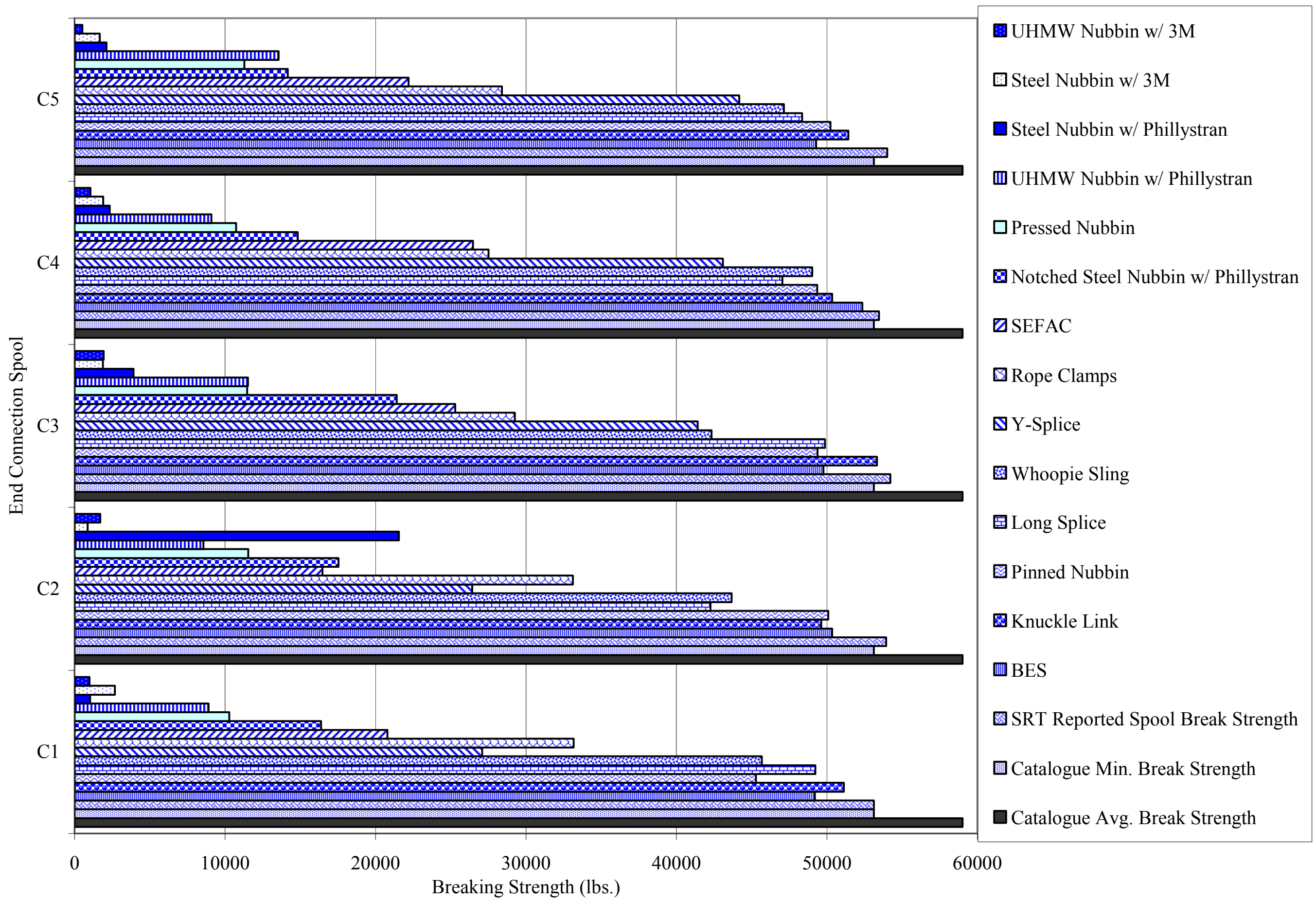

Figure 23. End Connector Breaking Strengths for 5/8" Diameter Synthetic Rope

NB: Hartter's graphs for 5/8" rope stop here

Tests with 9/16” AmSteel®-Blue Rope

Similar to graphs above, the tests with the 9/16” rope are presented below. Figures 24 and 25 show results of average values while Figures 26 and 27 show spool values and variation.

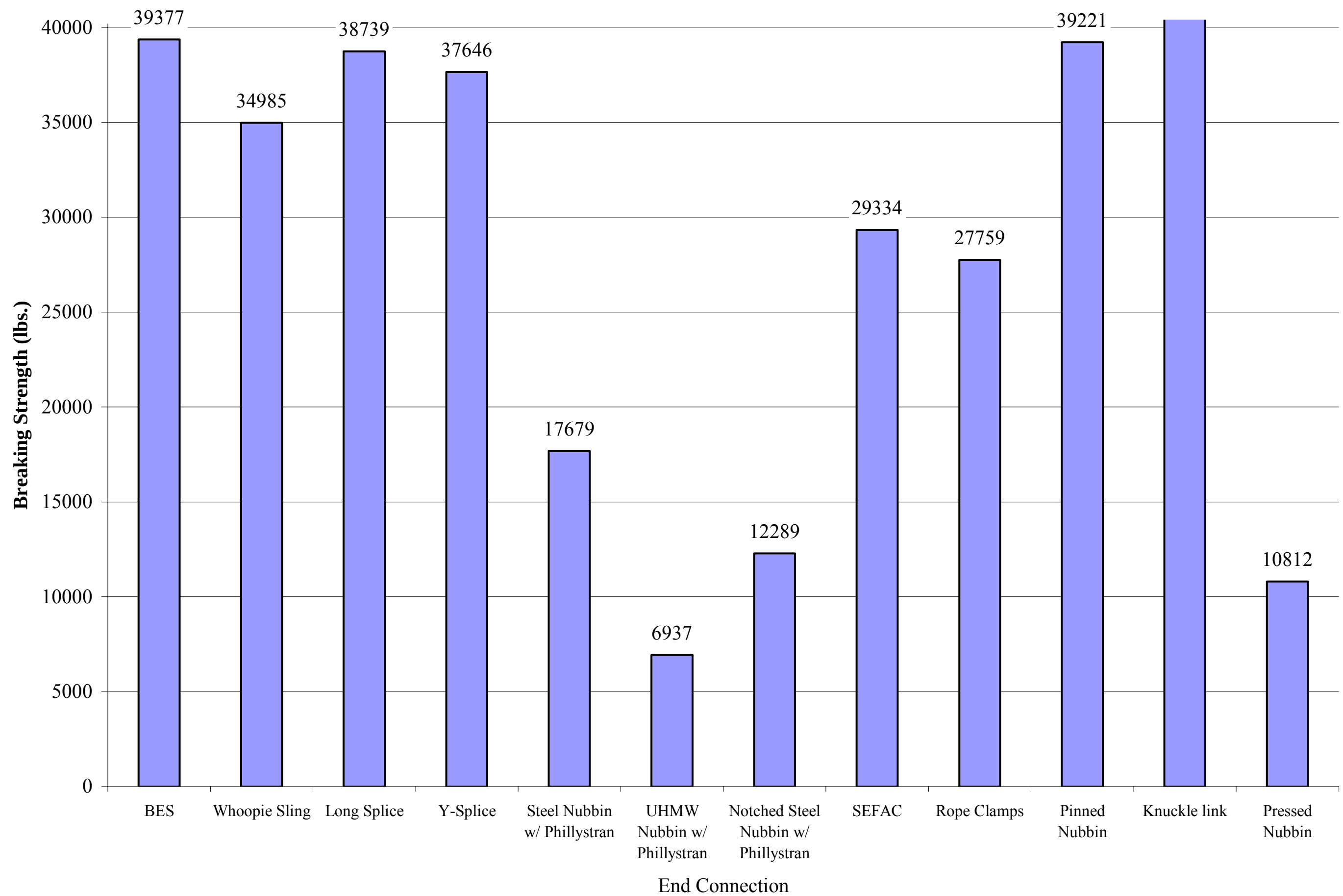

Figure 24. 9/16" diameter synthetic rope end connection mean breaking strengths

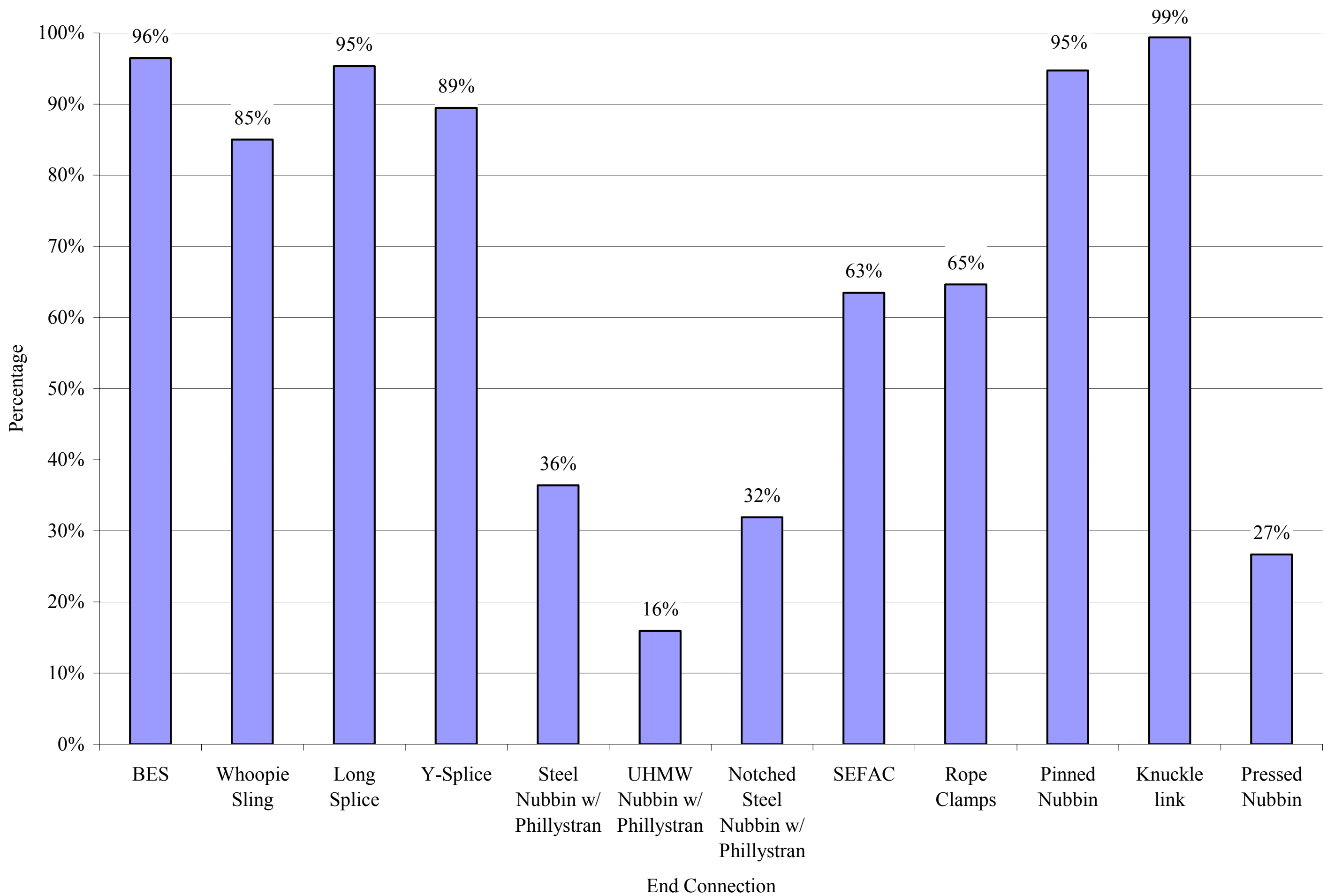

Figure 25. 9/16" Diameter average breaking strength as a percentage of catalogue minimum strength

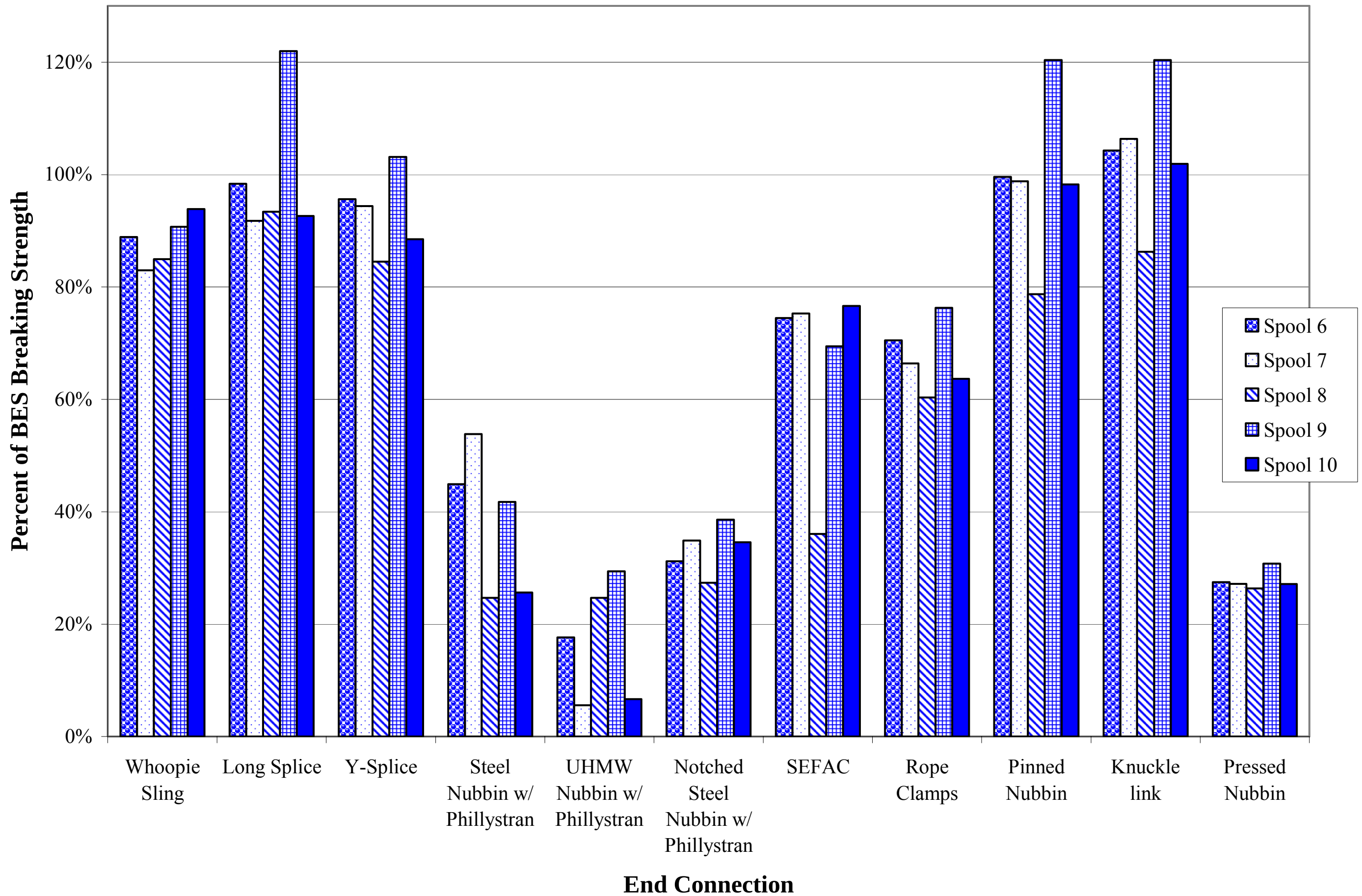

Figure 26. 9/16" Diameter Breaking Strengths Relative to the Buried Eye Splice

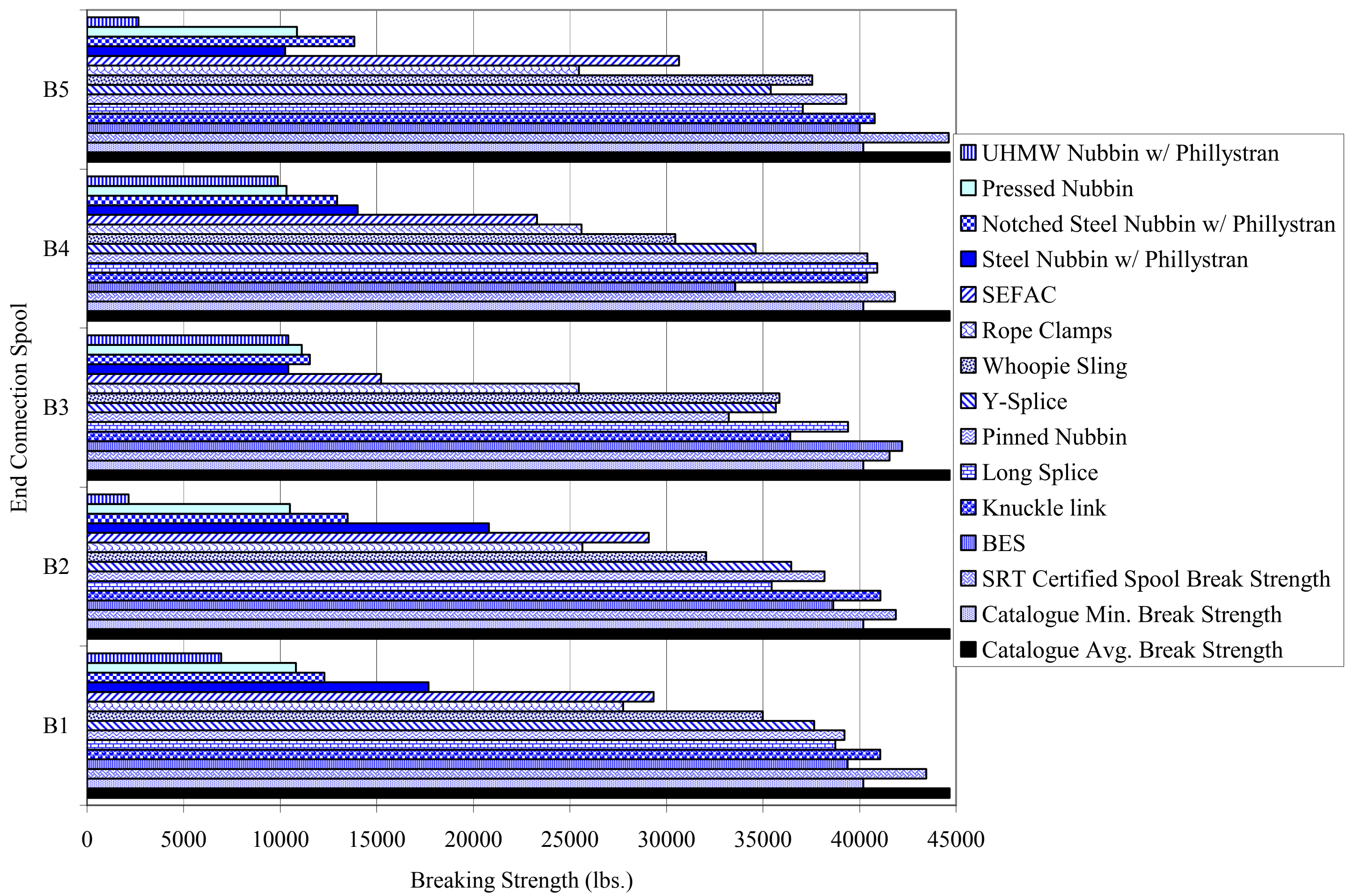

Figure 27. End Connector Breaking Strengths for 9/16" Synthetic Rope

NB: Hartter's graphs from thesis stop here

Discussion of Results for 5/8" & 9/16" AmSteel®-Blue Ropes

From a practical standpoint, there is not a difference in the performance of the of the two rope sizes with respect to the end connectors tested so conclusions about suitability of end connectors can be made for both rope sizes. However, there are some observations that are worth noting in the testing results.

Of the 5 spools tested in each rope size, none of the 5/8" line was reported by Samson's certified test data did meet the Catalogue Average strength and only one in 5 spools of the 9/16" line was certified to meet the Catalogue Average strength by Samson.

None of the 5/8" spools tested met the Certified Strength by Samson and 2 of 5 spools in 9/16" rope met the Certified Strength by Samson by our testing using the same procedure as Samson for the Buried Eye Splice test per the Cordage Institute and Samson Rope Technologies.

All of the 5/8" spools and 3 of the 9/16" spools tested failed to meet the Catalogue Minimum Breaking Strength for the Buried Eye Splice test per the Cordage Institute and Samson Rope Technologies.

However, the ropes were sufficiently strong for logging applications and testing end connectors. Published values for "average and minimum" values as well as "certified" values may not be the exact numbers seen by tests by purchasers. Caution should be made applying published values at the breaking strength of the ropes.

Based on Hartter's tests of breaking strength alone and a criteria that the end connector must achieve at least 50% of the Catalogue Minimum value, the following end connectors are seen as having the strength needed in logging.

NB: Hartter's materials starts here

Overall suitability of end connections

Breaking was the primary factor in determining overall suitability of end connections for use with current timber harvesting systems. A cut-off value was established to judge quantitatively whether the end connections were suitable. This cut-off value was set at 50% of the catalogue minimum breaking strength. The 50% values used were:

- 5/8" diameter = 26,557 pounds.
- 9/16" diameter = 20,097 pounds.
- 3/8" diameter = 9200 pounds.

Those end connections whose mean breaking strength was 50% of the catalogue minimum for each diameter class is shown in the table below. In addition to breaking strengths relative to the catalogue minimum, Table 5 also shows the breaking strength relative to the average and the buried eye splice.

Table 5. End connections that achieved a breaking strength of at least 50% of the catalogue minimum

Diameter		End Connection	Mean Breaking Strength (lbs.)	Percent of Buried Eye Splice	Percent of Catalogue Minimum	Percent of Catalogue Average
3/8"	1	Buried Eye Splice	18766	100.0%	102.0%	91.8%
3/8"	2	Truck Wrappers	15310	81.6%	83.2%	74.9%
9/16"	1	Buried Eye Splice	38757	100.0%	96.4%	86.8%
9/16"	2	Whoopie Sling	34177	88.2%	85.0%	76.5%
9/16"	3	Long Splice	38314	98.9%	95.3%	85.8%
9/16"	4	Y-Splice	35956	92.8%	89.5%	80.5%
9/16"	10	SEFAC	25519	65.8%	63.5%	57.1%
9/16"	11	Rope Clamps	25985	67.0%	64.6%	58.2%
9/16"	12	Pinned Nubbin	38067	98.2%	94.7%	85.2%
9/16"	13	Knuckle Link	39944	103.1%	99.4%	89.4%
5/8"	1	Buried Eye Splice	50187	100.0%	94.5%	85.0%
5/8"	2	Whoopie Sling	45571	90.8%	85.8%	77.2%
5/8"	3	Long Splice	47354	94.4%	89.2%	80.2%
5/8"	4	Y-Splice	36438	72.6%	68.6%	61.7%
5/8"	11	Rope Clamps	30294	60.4%	57.0%	51.3%
5/8"	12	Pinned Nubbin	48868	97.4%	92.0%	82.8%
5/8"	13	Knuckle Link	51172	102.0%	96.3%	86.7%

Due to the variance in the breaking strengths for each connection, an accepted and published value was identified as the cut-off. For example, the Y-splice's breaking strength is not only dependent on splice construction, but it is also dependent on preloading conditions and lock-stitching. The breaking strength performance can therefore be inconsistent and the mean strength relative to the buried eye splice can be misrepresentative. The catalogue minimum represents an independent cut-off value that the end connections must be measured against.

NB: Hartter's material ends here

In addition, the variability of the end connectors needs to be considered because a highly variable value may mean that an end connector could fail at lower values for unknown reasons. Hartter looked at the variation of end connectors tested and produced the Tables 6 and 7 below.

NB: Hartter's tables start here

Table 6. Breaking strength and standard deviation for 5/8” diameter

	End Connection (n = 5) for all	***Average Breaking Strength***	***Standard Deviation (lbs.)***	***Standard Deviation (% of mean)***	***Variance***
1	Buried Eye Splice	50187	1291	2.6%	1333708
2	Whoopie Sling	45571	2672	5.9%	5709876
3	Long Splice	47354	3037	6.4%	7379565
4	Y-Splice	36438	8893	24.4%	63270888
5	Steel Nubbin w/ Socketfast Blue A-20	6195	8648	139.6%	59830976
6	UHMW-PE Nubbin w/ Socketfast Blue A-20	10327	2149	20.8%	3693395
7	Steel Nubbin w/ Scotchweld DP-8010	1799	651	36.2%	339213
8	UHMW-PE Nubbin w/ Scotchweld DP-8011	1239	575	46.4%	264161
9	Notched Steel Nubbin w/ Socketfast Blue A-20	16866	2864	17.0%	6561020
10	SEFAC	22244	3957	17.8%	12525497
11	Rope Clamps	30294	2674	8.8%	5720263
12	Pinned Nubbin	48868	2043	4.2%	3339707
13	Knuckle Link	51172	1393	2.7%	1551940
14	Pressed Nubbin	11066	537	4.9%	230899

Table 7. Breaking strength and standard deviation for 9/16” diameter

	End Connection (n = 5) for all	***Average Breaking Strength***	***Standard Deviation (lbs.)***	***Standard Deviation (% of mean)***	***Variance***
1	Buried Eye Splice	38757	3196	8.2%	8171647
2	Whoopie Sling	34177	2882	8.4%	6645409
3	Long Splice	38314	2118	5.5%	3589451
4	Y-Splice	35956	1153	3.2%	1064439
5	Steel Nubbin w/ Socketfast Blue A-20	14630	4601	31.5%	16936661
6	UHMW-PE Nubbin w/ Socketfast Blue A-20	6407	3891	60.7%	12109433
7	Steel Nubbin w/ Scotchweld DP-8010	N/A	N/A	N/A	N/A
8	UHMW-PE Nubbin w/ Scotchweld DP-8011	N/A	N/A	N/A	N/A
9	Notched Steel Nubbin w/ Socketfast Blue A-20	12819	922	7.2%	679977
10	SEFAC	25519	6413	25.1%	32901142
11	Rope Clamps	25985	995	3.8%	791518
12	Pinned Nubbin	38067	2815	7.4%	6340816
13	Knuckle Link	39944	1997	5.0%	3189926
14	Pressed Nubbin	10724	313	2.9%	78027

NB: Hartter’s tables stop here

Applying an additional criteria that the consistency of the rope end connections is important along with the strength, then the list below shows suitable end connectors from laboratory testing.

Buried Eye Splice
Whoopie Sling
Long Splice
Rope Clamps
Pinned Nubbin
Knuckle Link
Pressed Nubbin

Other epoxy based and manufactured dry end connectors are too inconsistent to recommend for logging applications at present. The Y Splice met the criteria for strength in both line sizes but was variable in the 5/8" line size and pulled out during tensioning in the test procedures. This leads to a qualified judgment that the Y Splice may be suitable during rig up and other interim uses but should not be left as a termination in working rope applications.

Discussion of Results for 3/8" AmSteel®-Blue used for Truck Wrappers

Besides the 14 end connectors tested for logging applications, the use of synthetic rope for log truck wrappers is being tested. We tested the wrappers configured per the photo and discussion around Figure 19 shown earlier. Results of Hartters' tests are shown below from his thesis.

NB: Hartter material begins here.

3/8" Results

Break Test Results

Only two end connections were tested with the 3/8" diameter synthetic rope. As with the 9/16" and 5/8" diameter classes, the buried eye splice was also tested. In addition, truck wrappers were tested. Figure 28 shows the mean breaking strength for both end connections.

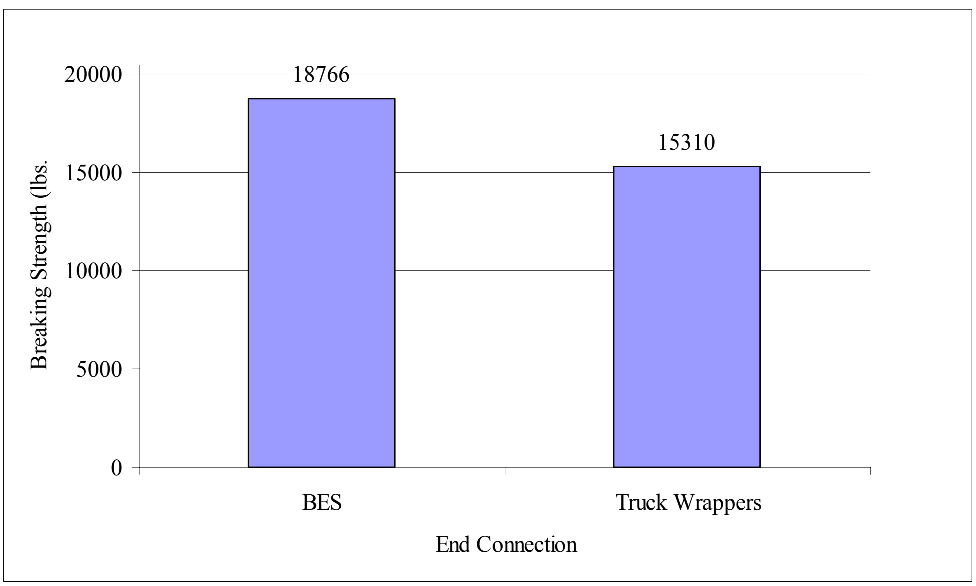

Figure 28. 3/8" diameter mean breaking strengths

The average ultimate loads are shown in Table 8. Figure 29 shows the breaking strength of the end connections as a percentage of the catalogue minimum value of 18,401 pounds. The buried eye splice had a relative mean breaking strength of 102%, while the wrappers had a relative mean breaking strength of 83% of the catalogue minimum.

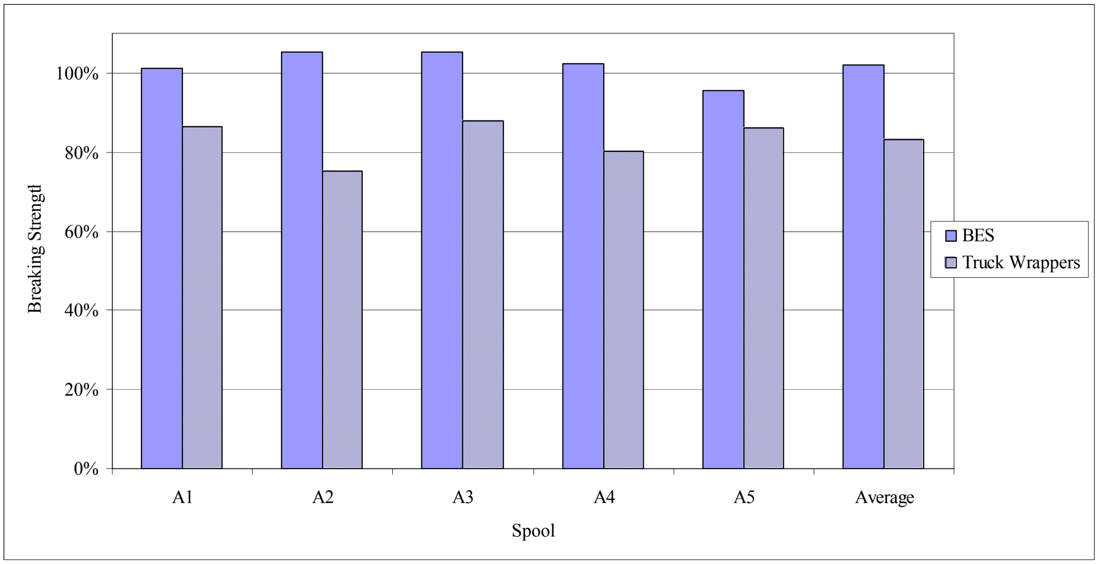

Figure 29. 3/8" Breaking strength as a percentage of catalogue minimum

The second end connection tested was the truck wrapper. The truck wrappers had breaking strengths that ranged from 13,847 pounds to 16,186 pounds with a standard deviation of 979 pounds. However, the average breaking strength of the truck wrappers was 15,310 pounds. The range of values for the truck wrappers may be a small cause for concern. Although the 5 samples did exceed the minimum OR-OSHA requirement of 15,000 pounds with an average of 15,310 pounds breaking strength, the standard deviation was 979 pounds. The breaking strengths were as low as 13,847 pounds, which is significantly lower than the required 15,000 pounds.

Table 8. Breaking Strength and standard deviation for 3/8" diameter

End Connection	*(n = 5) for all*	*Average Breaking Strength*	*Standard Deviation (lbs.)*	*Standard Deviation (% of mean)*
1 Buried Eye Splice		18766	738	3.9%
2 Wrappers		15310	979	6.4%

Figure 30 shows the ultimate loads for both end connections from each spool. This figure plots these breaking strengths with the catalogue minimum, catalogue average, and peak loads reported from the certified Samson Rope Technologies break test report for each spool. The average breaking strength for the buried eye splice was 18,766 pounds.

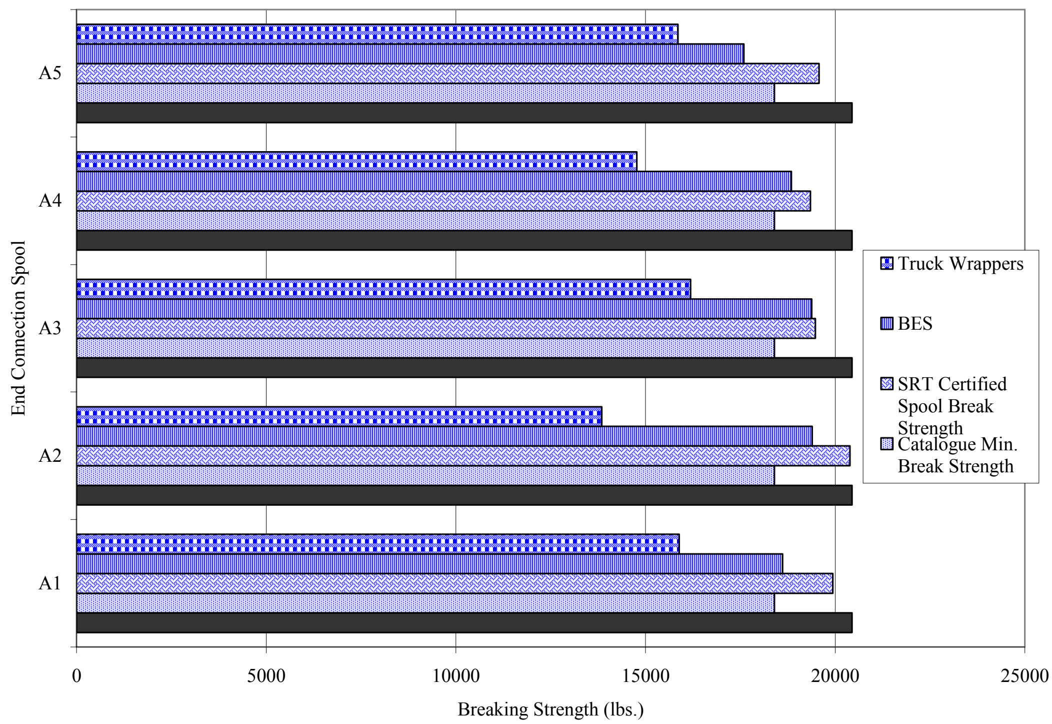

Figure 30. End connector breaking strengths for 3/8" synthetic rope

NB: Hartter material ends here.

Looking at Figure 30 some observations can be made.

- None of the 5 sample spools met the Catalogue Average Value
- Samson Certified values did meet the Catalogue Minimum Value and one nearly met the Average value
- Only one of the OSU Buried Eye Splice tests failed to meet the Catalogue Minimum Value.
- Average of 5 tests of 3/8" wrappers met the 15,000 pound OR-OSHA Div 7 requirement but two did not fully meet the value.

Discussion of Twisters

In a test of a twister, we found that twisting synthetic rope could generate up to 8,000+ pounds of tension in a line. Because two sections of rope are used to make a twister, when pulled to failure, the twister reached approximately 80% of the double strength of the rope. Twisters have their best application in line tightening and for tying back support stumps and trees.

IV. Overall Results and Recommendations for End Connector Usage

Based on the total project experience and Hartter's testing in the thesis, criteria useful to selecting end connectors for use in logging applications are:

- Strength- sufficient for the application, considering the ultimate loads expected on the end connector (eg, modified by wraps on drum/stump before termination)

- Consistency of performance- highly variable end connectors should not be used in critical situations or their use limited or monitored
- Ease of construction or fabrication- complicated end connectors involving epoxies or hardware are not recommended for field applications

Taking all of the above into consideration, the project team believes the following end connectors to be suitable for applications in logging but with some of the precautions noted below and with careful use and monitoring. Additional research and testing should be done as the experience grows with the use of the end connectors listed:

Buried Eye Splice
Whoopie Sling
Long Splice
Rope Clamps
Pinned Nubbin
Knuckle Link
Pressed Nubbin
Twisters
Chain link to Buried Eye Splice as used in truck wrappers
Various drum/winch connectors, eg butt splice packed into nubbin, etc, provided sufficient wraps are on the drum/stump prior to the termination

We believe, that as additional experience with synthetic rope in logging applications continue, other end connectors will be developed that will need testing and evaluation.

Hartter has made some additional recommendations in his thesis that merit examination and are reproduced below.

NB: Hartter's material starts here

Use Guidelines and Recommendations

Along with selecting suitable end connections for timber harvesting applications, recommendations for use of synthetic rope with end connections follow from this pilot study.

1. End connections and termination concepts have been developed through controlled laboratory testing and engineering analysis. Materials selection and fabrication for the hardware is essential not only for the strength of the end connection, but also for the safety of the workers. Furthermore, when fabricating connectors, one should know the material properties and the effects of welding and heat treating. In summary, it is not advisable to inappropriately use any material available, weld a bolt on, and put it into use in the field. Such actions jeopardize the safety of the entire crew.

2. Potted end connectors are not recommended.

   Potted terminations are not recommended for a number of reasons. When potting, it is difficult to ensure even coverage of the adhesive at the strand and or at the fiber level. Two different methods have been attempted in this pilot study, but both procedures yielded nubbins with inconsistent breaking strengths. In addition, there can be extreme variability with potting environment and techniques. A worker in a rigging shop or worker in the field might construct the end terminations in different environments, e.g. different temperature, humidity, etc. Moreover, each person may be unfamiliar with potting techniques or may hasten the potting time in order to put the rope back into service. Such practices only increase the chance of failure and unsafe working conditions. Potted terminations' breaking strength performance are inconsistence even in a controlled environment. Finally, bond strength with certain materials is quite weak. Currently there is no potted termination recommended by the manufacturer due to synthetic rope properties.

Wire rope clip construction must be considered in this evaluation. Due to the forging process to create the bracket in which the rope sits, the steel is has rough edges with grooves. In addition, use with wire rope can tool the forged steel and create jagged edges that can cut the rope. As the rope is compressed by the u-bolt and tensioned axially, fibers and strands can be damaged.

As a result, four recommendations should be made when using the wire rope clip concept with synthetic rope.

3. Do not use wire rope clips that have been used previously with steel wire rope. Additionally, the bracket should be checked for sharp edges and grooves that the rope can catch on.

4. The u-bolt and bracket should be free of any abrasive surface. However, smoothing the steel also reduces the coefficient of friction and can increase slip. The use of a rubberized plastic coating for these pieces is suggested. The coating is commercially available and can easily be applied and used approximately 24 hours later. The rough forged steel surface will be covered but not induce slippage.

5. Try a different compression fitting that would offset the strands instead of compressing the together. Both the u-bolt and fist-grip wire rope clip configurations compress the rope together to form the eye. If each piece of rope could be compressed individually, slippage might be reduced.

6. Static lines using wire rope clips should not be load bearing. In other words, wraps should be taken on a tree or stump to hold the load and then the rope secured using the clips. As tension increases, rope diameter decreases to the nominal diameter. Thus, the compression and holding forces of the clips decrease causing the end connectors to slip.

In addition, recommendations can be made regarding the spliced end connections.

7. The breaking strength of splices depend on construction. The manufacturer's splicing instructions should be carefully and completely followed. Fids should be properly sized and tails should be the appropriate length and taper. The size of the eye should be the only aspect of the construction that will vary from instructions.

8. Splices can be completed in a matter of minutes. The distinct advantage of the spliced end connections is that they can be used immediately. However, care must be taken

when installing the splice into the new rigging system. When being carried into the woods and rigging configurations are set up, the tail of the splice can slip out. The tail remains in place only when tension is applied. Therefore, it is advisable to lock-stitch all splices prior to use with the appropriate material.

Finally, overall recommendations regarding general use of synthetic rope are made.

9. Synthetic rope cannot take the abuse that steel wire rope can. Operators and loggers should be careful not to step on the rope, run it over with equipment, sever its strands, or drag it over abrasive or sharp surfaces. Synthetic rope has many advantages to steel wire rope, but these can only be realized with proper rope care. Consult the manufacturer's catalogue for general care and handling.

10. The new synthetic rope must be pre-tensioned slowly.

11. New rope must be spooled on a drum with some tension on it. As a rule of thumb, the new rope that has not had the construction stretch taken out of it should be spooled using 2-5% breaking strength of the rope. The rope must be pre-tensioned in order to receive the full breaking strength of the rope. Otherwise, there will be some pretension stretch.

12. Avoid operational situations with excessive heat and heat build-up. The synthetic rope has a critical temperature of 70°C (158°F) and temperatures at or above this level will seriously affect rope properties. It also presents a major safety hazard.

13. Inspect the rope often for severed strands and fibers, creep, and other damage. Consult the manufacturer's rope inspection and retirement guidelines.

14. Good judgment should be used when using the synthetic rope in forest operations. According to the rope manufacturer, normal working loads should not exceed 20% of the minimum breaking strength (Samson Rope Technologies, 2001). Working loads are loads that a rope is subjected to in everyday activity. If normal operations consistently require large working loads, a larger diameter synthetic rope with a higher breaking strength rating should be considered.

NB: Hartter's material ends here

Pinned Nubbin and Knuckle Link End Connectors

Two of the recommended end connectors were specially developed for this project. Based on the project teams' early trials with the pinned nubbin concept, Hartter designed a pinned nubbin for testing in the project. In addition, Hartter saw opportunities to capitalize on the strength of the buried eye splice and designed a knuckle link end connector. Both designs are protected by being in the public domain but any manufacturer or shop could build such end connections for use in logging. The designs are provided as a separate part of this research outcome and are cited separately in Appendices 1 and 2.

The project team recognizes there will be temptations to modify these designs to lower cost or improve upon them. We must advise caution in the selection of materials for strength, construction practices for these end connectors, and uses beyond the straight in-line loadings we tested. Weak materials or sharp edges on an end connector could cause premature failure and perhaps cause injuries.

V. Running Line Applications, Drum Connections and Spooling, Carriage Uses

Running Line Applications

Our experience with running line applications is limited to using AmSteel®-Blue rope as winch lines on skidding machines and as a mainline on the yarder for the Student Logging Crew. The use for winch lines on skidding machines has been documented in various project reports (Garland, et al, 2004). We have documented the use as a yarder mainline in Pilkerton, et al 2003)

NB: Material from Pilkerton, et al 2003 starts here

The mainline trial has been successful to date. One rope failure has been encountered near the load hook. A "strand interchange" (knotting of old and new spool for a strand) during manufacturing was located near the break and suspected to be the failure mechanism. While our early lateral pulls are not substantially different (due to minor differences in unit line weight with 3/8-inch steel rope), there is a noted difference in the reduced sag which develops with the synthetic mainline. This reduces the pulling effort required. Spooling capacity increased on the drum due to better layering of the synthetic line. The Koller K300 mainline drum capacity is rated at 1150 feet of steel line. We installed approximately 1300 feet of synthetic rope and still have additional drum capacity.

NB: Material from Pilkerton, et al 2003 ends here

We believe a trial with a skyline application of synthetic rope would be useful. A test situation should first confirm that running steel sheaves over the line does not damage the rope or put workers at risk. We also have available sheaves for the Koller carriage made out of the same material as the rope which could also be tested to see about damage levels, if any.

Drum Connections and Spooling

Our experience with attaching synthetic rope to drums and winches shows there are a number of suitable end connections for the final termination on the drum/winch but all depend for strength of the remaining wraps taking the tension and not the termination. In addition, we found spooling capacity, tensioning during initial winding and unspooling line from shipping reels to be important considerations.

Spooling Capacity

Based on operational installations and compared with the manufacturer's spool capacity equation, it is possible to spool approximately 35 percent more synthetic rope due to its ability to reduce the volume of voids associated with less malleable steel wire rope. These observations were made over a range of winch types and sizes as shown in Table R1.

Table R1. Spool capacity with steel and synthetic: calculated and actual

Drum	line size inch	Manuf. spool capacity	wire rope equation capacity	Samson Equation capacity	OSU-FE Equation capacity	TENSIONED SPOOLED ACTUAL spooled capacity	ACTUAL to EQUATION RATIO	% Difference ACTUAL to OSU-FE
Lewis	1/8	250		276				
	3/16	150		123				
	1/4			69	88	92	1.33	5%
	3/8			31	39			
Skidder	9/16		150	149	190	223	1.50	17%
	5/8		121	120	154	162	1.35	5%
	3/4		84	84	106	112	1.33	6%

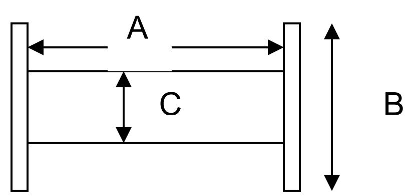

Figure R4. Dimensions for drum/winch capacity equations

Equations typically use the dimensions of the drum/winch as shown in Figure R4 above for determining the length of rope that will fit on a winch drum.

Samson Rope Technologies uses the following formula:

$L = [A * (B^2 – C^2)] / [15.3 * (d^2)]$

Where:

L = the length of line to be stored on the drum, (feet)
A = the width of the barrel between flanges, (inches)
B = the flange diameter, (inches)
C = the barrel diameter, (inches)
d = the diameter of the rope to be spooled, (inches)

For steel wire rope, the following formula is used to determine the length of rope that will fit on a drum:

$$L = 0.2618 * A * [(C/2 + n*d)^2 – (C/2)^2] / (d^2)$$

Where:

L = the length of line to be stored on the drum, (feet)
A = the width of the barrel between flanges, (inches)
B = the flange diameter, (inches)
C = the barrel diameter, (inches)
d = the diameter of the rope to be spooled, (inches)
n = number of layers on the drum, = (B/2 – C/2) / d
and 0.2618 = Pi / 12, Pi = 3.14159..

The Samson equation and the steel wire rope equations result in the same length, L, for spooling capacity. Observational experience of length actually spooled on a drum found these equations to be conservative.

Analysis of the derivation of the synthetic rope equation showed the assumed cross sectional area of the rope on a drum is a square with the side length of d, the rope diameter. This seems like an appropriate approach for steel wire rope where its cross sectional area is rigid, resulting in a stacking or block volume with voids (neglecting the ability to partially fill valleys formed in the lower layer). A modified equation was developed where the cross sectional area of the rope is circular and recognizing the ability of synthetic rope to fill a greater amount of the drum volume through packing of the interspatial voids of the square cross sectional area derivation.

The modified equation for L then becomes:

$$L = [A * (B^2 – C^2)] / [12 * (d^2)]$$

Where:

L = the length of line to be stored on the drum, (feet)
A = the width of the barrel between flanges, (inches)
B = the flange diameter, (inches)
C = the barrel diameter, (inches)
d = the diameter of the rope to be spooled, (inches)

The length L may also be determined by using the Samson equation and dividing that result by (Pi/4) or 0.78540 which is the area ratio of a circle of diameter d to a square with side length d.

This equation produces a projected length which is five (5) percent less than observed actual compared to 35 percent less than observed with the Samson equation.

Winding rope on a Winch/Drum

Samson Rope Technologies Industrial Rope Catalog (2003 C) recommends “The first layer (wrap) around the winch drum should be put on closely and tightly. Initial winding tension (load) should be approximately fifty pounds. This will prevent subsequent wraps from slipping down between turns when tension is applied. Samson winch lines will tend to self-level.” **Important note: Due to their low coefficient of friction and high strength, AmSteel and AmSteel-Blue lines must be worked with at least eight (8) wraps on the drum.**

Our experience with winching on skidder drums and on the mainline drum of the Koller K300 yarder confirms the “self leveling” ability of the line when spooling on the winch. However, we have not confirmed that as little as 50 pounds tension will prevent “diving” of the line at working tensions. It is our recommendation that the entire length to be spooled onto the working drum have a tension significantly greater than 50 pounds. Our practice has been to winch a pickup truck or the skidder with some braking resistance during spooling of the winch line.

Removing Rope from Shipping Reels

Samson recommends “Synthetic-fiber ropes are normally shipped on reels for maximum protection in transit. The rope should be removed from the reel by pulling it off the top while reel is free to rotate. This can be accomplished by passing a pipe through the center of the reel and jacking it up until the reel is free from the deck. Rope should never be taken from a reel lying on its side.”

Ropes with 12-strand construction, such as the ASB synthetic ropes trialed in the research, are non-rotational in construction and do not have a twist or lay associated with them. This facilitates coiling and reeling compared with steel wire rope.

Carriage Uses

The carriages used on skyline systems are important elements of the cable system. Two general types of carriages can be identified:

- Carriages that pull the mainline from the yarder through the carriage to serve as a skidding line by a slackpulling action that can be manual or mechanized (motorized or use stored energy).
- Carriages that have a separate drum in the carriage spooling skidding line powered by a motor or with lines from the yarder.

In addition, carriages are held in place on the skyline during operations either by lines from the yarder or by some device placed on the skyline to hold the carriage, eg a stopping mechanism or clamps to hold the carriage in place.

Finally, carriages that use steel wire rope may have some line clamping device that aids in pulling slack in the mainline for the skidding operation and are referred to as “slackpulling carriages.” Clamping synthetic rope is not recommended at present.

NB: Material from Pilkerton, et al 2003 starts here

The carriage dropline trial provided information on the failure modes. Sharp edges on the used carriage cut the trial rope on a low deflection corridor with perpendicular lateral pulls. The adage “you can’t push a rope” was confirmed in application of this winch design for spooling off the skidding line. The two-speed winch created back-spooling hang-ups on the drum. When the rigging crew applied minimal, constant pulling tension during lateral slackpulling, the back-spooling was eliminated. The rope failed once on the drum as the yarder engineer spooled and unspooled the drum to release the dropline. In spite of the problems, the owner would like to again try the rope in the near future.

NB: Material from Pilkerton, et al 2003 ends here

VI. Wear and Damage Evaluations

Our project did not last sufficiently long enough to fully assess wear and damage criteria for the AmSteel®-Blue synthetic rope. We were able to distinguish between expendable rope sections that are “expected” to break or be replaced and those rope sections that should last for long periods of use. For example, steel winch lines suffer damage from use (called pig tailing from the way it looks) which distorts the wire rope and makes it unusable for sliders or ring/pear chokers. Users often cut 10 feet or so off the wire rope winch line and continue to do so periodically until the winch line is so short as to need replacement. While synthetic rope does not pig tail, it can be damaged near the end of the winch line and need replacing. However, a new section of synthetic winch line can easily be long-spliced to replace the damaged line. Chokers, whether of steel or synthetic rope, are expendable items expected to break. We were able to make some laboratory tests and visually examine broken synthetic ropes for the wear and damage.

One of our first tests was to assess how new rope reacted to damage by cutting individual strands of the 12 strand braided AmSteel®-Blue synthetic rope. We found that 9/16” size rope with a Catalogue Minimum Breaking Strength of 40,194 pounds broke according to Table R2 below.

Table R2. Breaking strength after strands of synthetic rope are cut.

Cut Strands	Breaking Strength	Percent of Minimum BS
0	40,194	100%
1	35,034	87.2%
2	31,375	78.1%
3	24,924	62.0%

If we consider that the predicted strength for 11 of 12, 10 of 12, and 9 of 12 remaining strands would be 91.7%, 83.3% and 75% of the 12 of 12 100% strength, test values show strength roughly proportional to remaining strands until 3 strands are cut. Cutting even one strand of a 12 strand rope is far more damage than that allowed for steel wire rope in Division 7, Forest Activities Code. New synthetic rope has considerable strength even when one full strand is cut.

We also received Amsteel Grey (lower fiber strength rope w/o UV protection) guylines of 9/16" size that were used at least 3.5 years by a Washington Contractor. In cooperation with Samson Rope Technologies (to aid in splicing eyes for testing), we found that the guylines had 68% and 65% remaining strength of their Catalogue Minimum. The guylines showed considerable wear and a chainsaw had cut one strand of the rope in one sample tested.

We observed that the AmSteel®-Blue synthetic rope changed after use. It became "fuzzy" as surface strands were lightly abraded and its diameter increased when not tensioned. Looking closely at the rope that had been used for short duration, shows the differences below but little material has been removed from the rope and the UV protection is still intact on the individual strands within the rope (See Figure R5).

Figure R5. Gradation of color with normal use. Shown is the 3/8-inch ASB synthetic rope mainline for a Koller K300 yarder.

Because the wear and damage evidence for steel wire rope is more common to loggers, we first list below a brief comparison for steel wire rope and synthetic rope from Pilkerton, et al, 2003.

NB: material from Pilkerton, 2003, starts here

Our efforts to put the synthetic rope in the hands of the users have provided significant information on failure and wear mechanisms. Treating synthetic rope as steel rope has provided future operational changes and/or rope configuration and materials changes for improvement. None of the failures were so different than similar steel wire rope failures as to give concern about using synthetic rope. In fact, some synthetic rope failures were similar to "expendable" failures in steel wire rope winch lines.

Wear and Replacement Issues: Wire rope and synthetic rope are most often evaluated for replacement by visual indicators or simple measures on the rope itself (element counts, diameter measurement, etc.). While wire rope standards may exist for allowable wire breaks for some industries (elevators, material lifts over personnel, etc.), they do not apply to logging where work practices call for personnel to be in the clear when loads are on the lines. Some rope elements in logging are considered "expendables" because of the wear they receive such as chokers or the end sections of winch lines and drop lines. Similarly, existing retirement guidelines for arborists' use of synthetic ropes are not applicable to logging applications. Visual evidence from abrasion, corrosion, crushing, diameter reductions, stranding, bending and shock loading for wire and synthetic ropes differ as follows.

Abrasion -- Abrasion in wire rope causes broken wires and replacement is based on a specified number of broken wires. Synthetic rope initially fuzzes up from broken filaments that produce a protective cushion but when braided rope is worn 25% from abrasion it should be replaced. Powder inside the rope indicates internal abrasion.

Corrosion – With wire rope, pitted wire surfaces and breaks indicate corrosion and corrosion is difficult to assess for interior damage. AmSteel Blue synthetic rope is not affected by corrosion for the chemicals typically encountered on logging operations.

Crushing – With wire rope, flattening of strands from poor spooling and other causes damages it and reduces its strength. Synthetic rope may flatten and glaze due to tension around pins and sheaves but will return to a round shape when worked by hand.

Diameter reductions -- Wire rope diameter reduction is a critical retirement factor due to excessive abrasion, loss of core support, inner wire failure and so forth. Synthetic ropes may actually increase in apparent diameter from abraded filaments and material inside the rope itself. Localized diameter reductions, flat areas, and lumps and bumps in the synthetic rope are of concern for replacement as well as ropes built up with dirt and debris.

Stranding -- Wire rope stranding occurs from various causes including kinking, twisting, or tight grooves leading to broken wires and "jaggers" (exposed broken wires) to such a degree the rope is unusable. Synthetic rope will have broken filaments and strands but no jaggers.

Bending – Wire rope manufacturers' recommended ratios of bending to rope diameters have seldom been met for wire rope in logging. Synthetic rope ratio recommendations are also slightly larger than those found in logging practice.

Shock Loading – In wire rope, birdcaging (core protrusion) is evidence of shock loading and seriously degrades rope strength. Synthetic rope is less subject to shock loading but fibers may have memory and may retain effects of shock loading during normal loads. We are continuing to assess wear criteria for synthetic ropes.

NB: Material from Pilkerton, 2003 ends here

Wear and replacement for synthetic rope (AmSteel®-Blue)

An objective of the research grant was to help establish wear and replacement criteria for synthetic rope use in logging conditions. Because knowledge was lacking for synthetic ropes and with the brief duration of the field trials, we first looked to the manufacturer's guidelines (Samson Rope Technologies C, 2003: Rope usage information, inspection, and retirement). We also provide our own suggestions based on observations, experience, and tempered with safety considerations in logging.

Manufacturer's Guidelines and Project Experience

"It can be expected that strengths will decrease as soon as rope is put into use. Because of the wide range of rope use, changes in conditions, exposure to the many factors affecting rope behavior, and the possibility of risk to life and property, it is impossible to cover all aspects of rope applications or to make blanket recommendations as to working loads." (Samson, 2003 C)

The manufacturer promotes a normal working load of 20 percent of published strengths. Current OR-OSHA Division 7 Forest Activities safety rules require equivalent strengths for synthetic use as an alternative to steel. As with steel wire rope applications in logging, the loadings on synthetic rope must be within safe working loads and workers should be in a position "in the clear" avoid the "potential failure zone" as recommended in Division 7, Forest Activities Code.

"A higher working load may be selected only with expert knowledge of conditions and professional estimates of risk, if the rope has been inspected and found to be in good condition, and if the rope has not been subject to dynamic loading (such as sudden drops, snubs or pickups), excessive use, elevated temperatures, or extended periods under load." (Samson, 2003 C)

These same caveats apply to logging with steel wire rope. It is incumbent upon the contractor or designated person to monitor, assess, and act accordingly.

"Normal working loads are not applicable when rope has been subject to dynamic loading. Whenever a load is picked up, stopped, moved or swung there is an increased force due to dynamic loading. The more rapidly or suddenly such actions occur, the greater the increase will be." (Samson, 2003 C)

Logging, especially cable logging, is by its nature subject to dynamic loads. "Dynamic effects are greater on low elongation ropes" such as the AmSteel®-Blue ropes (UHMWPE ropes) we tested. "Dynamic effects are also greater on a short rope than a long one." (Samson, 2003 C)

Summary of manufacturer's and research findings with respect to wear and replacement

Rope Inspection:

"No type of visual inspection can be guaranteed to accurately and precisely determine the actual residual strength. When fibers show wear in any given area, the rope should be re-spliced, downgraded, or replaced. Check the line regularly for frayed strands and broken yarns. Pulled strands should be re-threaded into the rope if possible. A pulled strand can snag on a foreign object during rope operation." (Samson, 2003 C)

Surface Abrasion:

"When the rope is first put into service the outer filaments of the rope will quickly fuzz up. This is the result of these filaments breaking and this 'roughened' surface actually forms a protective cushion and shield for the fibers underneath. This condition should stabilize, not progress. If the surface roughness increases, excessive abrasion is taking place and strength is being lost." (Samson, 2003 C)

Research findings are consistent with this statement. In static line applications such as guylines, support jack lift lines, and rigging straps, "fuzzing" was observed and appeared stable over time. With the skidder winch line applications, a gradation of "fuzziness" was observed. It was greatest at the working end (where choker sliders settled for inhaul) (Figure R6) and decreased up the line (Figure R7). Occasional failures of the winch lines were experienced in our trials. These occurred near the tail end of the Buried Eye Splice segment, similar to the experience with lab strength tests of new rope. Operators were able to cut the rope to create a clean tail and install a buried eye splice in the rope.

Figure R8 shows accumulation of cut filaments from a strand into a tuft. The manufacturer's recommendation for retirement from service is based on a 25 percent strand volume reduction due to abrasion. It is estimated this section shown has less than a 10 percent volume reduction.

Figure R6. Rope appearance. Fuzzed filaments and tufts (local accumulation of fuzzed filaments) on the end of a skidder winch line. Continuous abrasion by the ring sliders created this condition. Rope failures have occurred near the buried tail of this eye splice, but not in the splice section itself. This is considered an acceptable wear condition for this application as the skidder winch line. Synthetic winch lines which experience cut strands that are not taken out of service or repaired (spliced) should be used with appropriate clearance from the probable failure zone. OR-OSHA 437-007-0605 exempts skidder winch lines from the out of service requirement because of expected failure and operator protection.

Figure R7. Section of skidder winch line from Figure R6 located away from the working end. Note reduction in quantity and quality of tufts. Also note residual blue coating on the internal portion of the strands.

Figure R8. Section of a 3/8-inch ASB synthetic rope wrapper with accumulation of cut filaments.

Cut Strands:

The manufacturer recommends retiring a rope or cutting and re-splicing a section when two (2) or more adjacent strands are cut (Samson, 2003 C). Our research showed a strength reduction of approximately 10, 20 and 40 percent with 1, 2, and 3 cut strands, respectively. Figure R9 shows a section of a winch line which incurred a localized severe abrasion resulting in effectively severing one strand. On lines which are critical to the overall system and safety of the employees, a more conservative standard should be applied. Figure R10 shows a tail tree guyline which has several partially severed, but non-adjacent, strands. A long splice should be performed to eliminate this potential failure spot.

Pulled Strands

“Pulled strands should be re-threaded into the rope if possible. A pulled strand can snag on a foreign object during rope operation.” (Samson, 2003 C). This applies to yarns (groupings of filaments which make up strands). Figure R11 shows a pulled yarn. Strands are easier to re-thread than yarns. One may consider pulling a strand to facilitate resetting a pulled yarn.

Compression:

Compressive loading of fibers around a pin, shackle, or drum barrel may result in a fiber set on the section which may have a slight sheen or glaze to it (Figure R12). The fiber set should be readily eliminated by flexing the rope. If so, then no permanent damage has occurred and the rope may be placed back in service.

Discoloration:

“With use, all ropes get dirty. Be on the lookout for areas of discoloration which could be caused by chemical contamination. Determine the cause of the discoloration and replace the rope if it is brittle or stiff.” (Samson, 2003 C)

Figure R9. Severe abrasion in a section of 7/8-inch ASB synthetic winch line. Pen is inserted underneath the intact remnants of a strand. Manufacturer's recommendation is to retire a rope or cut and re-splice the remaining rope when 2 or more adjacent strands are cut.

Figure R10. Tail tree guyline with partial cuts in a couple of non-adjacent strands. While this situation does not exceed manufacturer's out of service criteria, removal and re-splicing (long splice) of this section would be a prudent action by the operator.

Figure R11. Pulled yarn (collection of filaments) from a single strand of a 12 strand ASB synthetic rope. Pulled yarns and strands should be re-threaded to prevent snagging and further malformation of the rope structure during operation.

Figure R12. Fiber set due to compressive loading around the barrel of a drum winch. Note slightly glazed appearance. Flexing of the rope should eliminate this appearance and allow for continued use of the rope.

End for Ending or Upending Working Ropes

Samson recommends: “It is recommended that every winch line be rotated end-for-end on a periodic basis. This will vary high stress and wear points and extend useful life. Recommended end-for-ending period is six (6) months, at which time visual inspection and washing can be programmed.” (Samson, 2003 C)

In the duration of our experience, while exceeding six months, we have not changed the ends or upended our skidder winch line or Koller yarder mainline. For the skidder, the few breaks which occurred near the working end have been easily repaired. A section of previously used winch line was recently long spliced (end for end splice) onto the winch line to extend its length. It is not clear that end for ending is a necessary practice with a skidder winch line. On longer lines, such as the yarder mainline, we have not performed this operation yet. It is likely a valuable practice given the gradation of wear in our spooled line.

Avoiding Severe Abuse of Synthetic Rope

It is clear that synthetic rope is not as resistant to abuse as is wire rope. Operators simply cannot assume that synthetic rope can be treated like wire rope. In fact, to achieve the ergonomic benefits of the lighter weight of the synthetic rope, users will need to avoid the kind of abuse shown on the winch line of the skidder used by the Student Logging Crew at OSU (Figure R13).

Figure R13. Grooves shown are cut in ½-inch steel plate by wire rope under improper operation of fairlead arch. Abrasive surfaces such as this must be dressed smoothly prior to use of synthetics. Synthetic rope will not stand the abuses that steel wire rope will. Continued operation in this mode will create undue shortening of operational life of synthetic rope due to fraying of fibers and resultant reduction in rope strength.

During operations, synthetic rope users will need to plan ahead to avoid pulling the rope across sharp objects, rocks, equipment edges, and abrasive materials. In Figure R14 below, short duration abrasion would not be a problem but planning should avoid abusive rope circumstances.

Figure R14. Rubbing on log shows sources of abrasion in operation and need for planning of extraction to prevent abrasive locations and to plan the lead to avoid rubbing on standing timber or over stumps.

VII. Planning Approach with Synthetic Rope

There are various computer programs to aid in planning cable operations with steel wire rope, eg, LoggerPC, PLANEX, and others. These programs help determine feasible of skyline loads on selected terrain profiles under consideration. The programs take into account the behavior of wire rope when it hangs unloaded in the shape of a special curve called a "catenary." Loggers refer to this effect as a line with a "belly in the line." The weight of the wire rope is a large consideration in making the computations of what loads the cables can support. In fact, without sufficient belly in the line or "deflection," cables can carry only small loads in proportion to their breaking strength. A number of loggers make the assessment of planning feasibility using these programs and public agencies use these programs in their timber sale planning activities. It would be helpful to use synthetic rope as either standing skylines, running skylines or as mainlines for cable yarding and thus reduce the weight in the cables themselves. Modifications to existing planning software or new programs for synthetic rope would help cable planners if the synthetic rope has applications for skylines or running lines.

Our research was only able to assess the use of AmSteel®-Blue synthetic rope as a mainline on a Koller K-300 Yarder and that usage is effective and evaluations are still ongoing after 2 seasons of cable logging with the OSU Student Logging Crew. We hope to test the use of synthetic rope as a skyline in future research and perhaps develop new programs to plan for cable operations with lightweight but strong synthetic rope. One indication of the potential gains for synthetic rope are seen in the ratio of rope weight to breaking strength for a typical skyline length of 1500 feet compared for steel wire rope and AmSteel®-Blue in the table R3 below.

Table R3. Ratios of weight to breaking strength of steel and synthetic ropes

Line size	Steel wt.	EIPS steel BS	Ratio BS/wt.	AmSteel ®-Blue wt.	AmSteel ®-Blue BS	Ratio BS/wt	Actual Rope Weight Difference
5/8	1080	41200	38	159	53114	334	921
3/4	1560	58800	38	200	62640	314	1360
7/8	2130	79600	37	294	88479	301	1836
1	2775	103400	37	351	104400	297	2424
1 1/8	3510	130000	37	478	133110	279	3032
1 1/4	4335	159800	37	543	148770	274	3792

The potential increase in available load could be seen as the weight difference but skyline payloads are affected by the available deflection on the terrain. Using a specific example, payload differences are seen from Pilkerton, et al (2001) below.

NB: Material from Pilkerton, et al 2001 starts here

The light weight and high strength of synthetic rope provides the potential to increase skyline payloads. The benefits will be greatest at low deflections where the ratio of total line weight to net payload is greatest. Table 2 illustrates the potential benefits of using synthetic rope (AmSteel®-Blue) and wire rope (independent wire rope core, EIPS). Two rope diameters are compared for a 1500-ft span, zero chord slope, where a load is fully suspended at midspan. The maximum payload that brings each rope up to its design load (1/3 of breaking strength) is calculated. At low deflection (4%) the synthetic rope provides a 67% increase over the fully suspended payload for the 5/8-inch wire rope and 31% for the 1-inch rope. The percentage increase declines as the deflection increases.

Table 2. Percent increase in maximum midspan payload at 4, 8 and 12 percent deflection for 5/8-inch and 1-inch diameter ropes, EIPS steel wire rope and AmSteel®-Blue synthetic rope.

	5/8-inch diameter rope			1-inch diameter rope		
Deflection (percent)	Steel Payload (pounds)	Synthetic Payload (pounds)	Percent Increase	Steel Payload (pounds)	Synthetic Payload (pounds)	Percent Increase
4	1645	2743	67	4096	5373	31
8	3779	5512	46	9450	10814	14
12	5824	8177	40	14581	16052	10

NB: Material from Pilkerton, et al, 2001 ends here

The planning models for steel wire rope have used simplifying assumptions to make calculations easier for analyzing load potentials. Two assumptions used are the rigid link assumption which assumes loaded wire rope is virtually straight when loaded, and the weightless line assumption which assumes the weight of the rope is low compared to the weight of the line or load. For steel wire rope, these assumptions can lead to errors under many circumstances. However, for synthetic rope these same assumptions are much more realistic for the way synthetic rope behaves (see table above). Thus, simplified calculations may be sufficiently accurate for skyline analyses.

Other programs or calculations are often made for guyline loadings where the shape of the guyline as a rigid link or a catenary is important to balance the forces on a tower or tailtree. In our estimation, it is possible to pull synthetic rope guylines virtually straight with the tensions found in guylines; thus, the same rigid link and weightless line assumptions can be useful for guyline analysis in cable operations. Future research and detailed comparisons should validate these initial observations and findings.

VIII. Future Research and Developments Needed

For someone who can see potential uses for synthetic rope in logging, making a list of needs and opportunities is both easy and difficult. The easy part is that a long list of needs comes easy but the hard part is what can be most important in that list. The research team's list is provided below and a list from Hartter's Thesis is also provided.

- Extended study to help provide wear and damage criteria for AmSteel®-Blue synthetic rope in logging
- Research on a variety of different rope types and manufacturers for uses in logging
- Study of synthetic rope used for rigging applications in cable logging, ergonomic benefits used as haywire or strawline, and development of connectors
- Research and development for use of synthetic rope as a skyline

- Research and development for use of synthetic rope with a traction carriage to eliminate use of an expensive yarder
- Investigate the use of “sling choker hooks” for synthetic choker bells.
- Tension of lines in and out of wraps around steel drum surface, notched stump, tree bark, and other surfaces.
- Insertion of pencil size lead (or other material) into synrope for pressed nubbin connection- possible strength increase and stiffener for choker use?
- Use of Prusick knot as a replacement for steel rigging chain, tests of knots against steel connectors, use of knuckle link as a butt plate/bang plate
- Economics of synthetic rope use in various applications
- Environmental benefits from using synthetic rope in harvesting
- Use of synthetic rope in other forest operations: silvicultural operations, planting, even fire fighting
- Complete system of synthetic blocks, rigging and ropes for logging applications.

The list could continue but Hartter’s Thesis ideas are also presented below.

NB: Hartter material starts here

Future Research and Testing

Although this particular study is concluded, it is just the beginning for formalized end connection and termination research for synthetic rope. This project was a pilot study. As the first extensive investigation of end connections for UHMW-PE rope for use in timber harvesting applications, many concepts were identified and designed. Some concepts were adapted from hardware or techniques already in use with steel wire rope or from other synthetic rope applications. The idea of this project was to begin formal research and select which concepts would warrant further attention. Now that the breaking strength of selected end connections has been quantified, work can be done to modify or refine these designs.

As a pilot study, a number of end connections were developed and tested, but only five replications were conducted. Now that suitable end connections have been identified, larger sample sizes could be chosen. End connections could be adapted and tested on more rope diameters. Although 3/8”, 9/16”, and 5/8” diameters are commonly used rope sizes, larger diameters up to 1 ½” could be tested.

Another concept of interest is a synthetic rope choker design. Although the choker was not developed under this project, demand for it exists. The choker is extensively used in cable, skidder, and helicopter logging. It is an essential piece of rigging that connects the logs to the dropline, winchline, or dropline to bring the logs to the landing. Synthetic chokers will not only decrease weight, but more importantly, they will reduce the safety hazards and hardships of carrying them into the brush.

Furthermore, the choker is considered expendable; it is the first to fail if a load is too large. A choker must be strong enough to hold loads, must not detach or slip off during transport to the landing, must release quickly, and must break before the winchline or dropline fails. A synthetic rope design would be extremely useful in logging applications. Unlike a steel choker that is much stiffer, the new design must consider the difficulty of pushing the synthetic rope under a log.

There are additional rope manufacturers around the world that produce UHMW-PE braided rope from Dyneema® or Spectra® fibers. This project chose one particular product, but this does not mean that this research is not applicable to other 12-strand braided ropes. It was chosen to be a general representation of UHMW-PE rope and to test its applicability in forest operations. Other synthetic ropes offer slightly different characteristics such as increased strength, decreased weight, or an additional protective coating. Other products should be investigated and tested for specific use criteria.

Furthermore, additional rope constructions exist due to demand by industries and their operational requirements. Tech 12™ produced with Technora® fibers, for example, is a stiffer rope with more abrasion resistance than the AmSteel®-Blue, but with a lower breaking strength and reduced the number of cycles to failure. Plasma® produced by Puget Sound Rope is constructed from Spectra® 1000 fiber. Through a proprietary recrystallization process that heats the fibers and draws them further to eliminate stretch, a stronger 12-strand braided rope with better abrasion resistance is constructed (Puget Sound Rope, 2004). With the elimination of some of the stretch however, the number of cycles to failure are reduced.

In the end, different rope manufacturers, constructions, and materials may be more suitable for specific operational conditions in other forest operations. However, it is important to consider that ropes designed for lower creep, increased abrasion resistance, less stretch, or more rigidity may sacrifice breaking strength and the number of cycles to failure. Ropes designed for specific site requirements should be tested accordingly.

Research could also investigate the operational performance of synthetic rope with other lightweight materials, such as UHMW-PE or nylon sheaves. These materials offer the advantage of a decreased coefficient of friction. Similar to UHMW-PE rope, UHMW-PE and nylon have a stronger compressive strength to weight ratio than that of steel. Because of its inherent material properties, steel sheaves are good heat conductors. Synthetic sheaves could reduce heat build-up as the rope passes through and reduce operational hazards from heat or damaged UHMW-PE rope.

UHMW-PE is advantageous in many cases. It has a low coefficient of friction, good wear properties, is readily available, and has relatively low critical and melting temperatures. Other engineered plastics on the market have greater tensile strength due to glass fiber reinforcement. In addition, these materials have higher melting temperatures. Some of these plastics' properties are compared to UHMW-PE in Table **9**. Such materials could be better than UHMW-PE as in the case of the nubbin. As discussed earlier, the UHMW-PE nubbins had little hoop strength and consequently deformed quite heavily. New plastics are lighter than conventional end connections and their temperature ranges should withstand operational conditions. However, their performance with adhesives or other end connection designs is not known and should be investigated.

Table 9. Material properties of selected engineered plastics

Material	Hardness	Tensile Modulus	Tensile Strength	Flexural Modulus	Melting Temperature
UHMW-PE	50-70 Rockwell R	29,000-174,000	3,000-6,000 psi	77,000 psi	270 F
Ultem® 1010	109 Rockwell M	520,000	16,000 psi	510,000 psi	660-750 F
Ultem® 2300 R	114 Rockwell M	1,350,000	24,500 psi	2,100,000 psi	660-750 F
Verton® FR-700-10 EM HS		287,000	41,000 psi	2,290,000 psi	535-565 F

(GE Plastics A., 2004), (GE Plastics B., 2004), (LNP Engineering Plastics, 2004), (www.ultrapoly.com, 2002)

Along with other engineered materials, better potting procedures and adhesives could be investigated. Although the amine structural adhesive (Scotch-Weld™ DP-8010) had a lower bond strength, it has some properties that warrant further examination. The Phillystran Socketfast® Blue A-20 was a styrene monomer compound. When it potted, it became glassy and brittle. During break tests, the Phillystran adhesive broke apart in small sharp pieces. It was too brittle to withstand the cycling of the rope. In the case of the UHMW-PE nubbin, the nubbin deformed, but the glassy Phillystran adhesive did not and it simply shattered. The 3M adhesive on the other hand was less brittle. It was softer and flexible. These properties are attractive to withstand normal operating conditions of variable tensions and cycling.

Further research of the SEFAC™ connection could yield greater consistency and breaking strengths. For example, more tufting of the rope strands could allow better adhesive coverage and increase the bond strength. The geometry of the socket and spike in the SEFAC™ design could be changed. The current design was constructed purely from the recommendation by the fiber manufacturer. Initial tests used a socket length to spike length ratio of less than 1:1. Initial testing has shown that increasing the ratio to 1:1, increases breaking strength by approximately 5%. Furthermore, the socket was designed to account the unstretched diameter of the rope, not the stretched or nominal diameter.

Although the SEFAC™ does show some promise with an average of over 50% breaking strength, further research is necessary to reduce the variability in breaking strength. However, it is not within this project to further manipulate and modify SEFAC™ design constraints and test them.

End connections and terminations in this particular project were tested solely at controlled ambient conditions. Although the Samson Rope Technologies reports that AmSteel®-Blue is unaffected by the cold, heat, or water, these environmental conditions may have an adverse interaction between the synthetic rope and end connections. Freezing conditions could be simulated and laboratory tested. Logging is a year-round occupation and harvesting operations in many countries are conducted in cold conditions. Research could determine whether cold and dry or cold and wet conditions adversely affect UHMW-PE and end connector performance. Forest operations are also conducted in hot environments. Simulated warm, moist and warm, dry conditions could also be tested in the laboratory. Controlled ambient conditions can test the effects of different end connections on breaking strength of the synthetic rope. However, environmental conditions such as extremely hot and cold temperatures are possible on work sites and should be field tested for suitability and safety.

In addition to varying work site conditions, the breaking strength, creep, or other mechanical properties of synthetic rope could be affected by radiation heat. On a hot summer day, when a yarder or carriage is exposed to direct sunlight, heat can build up. In addition, combustion engines create heat and even with the heat dissipated through natural convection, water coolers, or air blowers, the engine housings still trap some of the hot air and radiate heat. The synthetic rope on the yarder or carriage spool can be subjected to higher temperatures. With a critical temperature of 150°F for AmSteel®-Blue, it is imperative to quantify the amount of heat generated in this case. A test could be set up to determine localized heat effects.

Finally, with all of the additional environmental conditions, a more thorough standardized testing procedure should be defined. As stated earlier, test procedures for this pilot study followed Samson Rope Technology's own SRT Test Method-001-02 protocol that was derived from the Cordage Institute's CI 1500-99 Test Methods for Fiber Rope. The SRT test protocol implies testing only dry ropes. Section 10 in the document briefly describes the conditions under which "wet testing" should occur (i.e. soak the sample for 24 hours and perform the test described in SRT Test Method -001-02). There is no discussion about testing under freezing or localized heat conditions in current synthetic rope testing documents.

NB: Hartter's material stops here

IX. Conclusions

This project has documented end connectors and terminations for use of synthetic rope for logging applications. Even without new developments, existing and proven synthetic rope splices (Buried Eye Splice and Long Splice) would serve many applications to replace wire rope connections to shackles, pins, and other terminations. Our research confirms the strength and usefulness of these splices.

Our experience with knots confirms the Manufacturer's advice not to use knots with AmSteel®-Blue synthetic rope. We re-affirm that high tension ropes cannot depend on knots for terminations. That strongly said, we think some knots may be useful in rigging/climbing applications but future research should verify uses for logging.

We developed the pinned nubbin to take advantage of the buried eye splice strength within the commonly used steel nubbins for terminations. Hartter's design has proven strengths but users must follow the design and material requirements shown in the Appendix.

The knuckle link also provides expanded options to connect with steel connections, machines, and for use as a bang plate connection. Again, materials and designs must be followed to achieve its strength. Users who gain confidence in the knuckle link concept can apply their imaginations to particular problems of synthetic rope end connections.

We also developed some end connections that have the feature of meeting a "breakaway" connection in some applications. The pressed nubbin and various drum connections described above meet this unusual application.

Our experience is that a number of end connections may be suitable for terminating synthetic rope if the terminal rope tension is reduced by wrapping the lines around drums or stumps/trees at least 8 times or so. We need to verify the coefficient of friction for synthetic rope so guidelines can be developed for logging applications.

Synthetic rope manufacturers generally recommend against compression fittings against the ropes because of damage and failures. We tried standard wire rope clamps (clips) and found that they could have uses for terminations for ropes not under high tension or having diameter changes with tension (as with wraps prior to the end connection). Because clamping steel ropes is a common application, additional research with modified clamps should be considered.

Our research started with some optimism about the epoxy fittings and AmSteel®-Blue but our trials showed much more development is needed before this class of fittings can be recommended for logging applications. We are uncertain how this research can be funded.

The tests of wrappers shows that there are suitable end connections with the buried eye splice on the chain ends of the wrappers. The rope strength must be clarified as soon as possible.

In summary, we believe suitable end connectors exist already, can be produced using our designs or recommendations or can be adapted for use of AmSteel®-Blue synthetic rope in logging.

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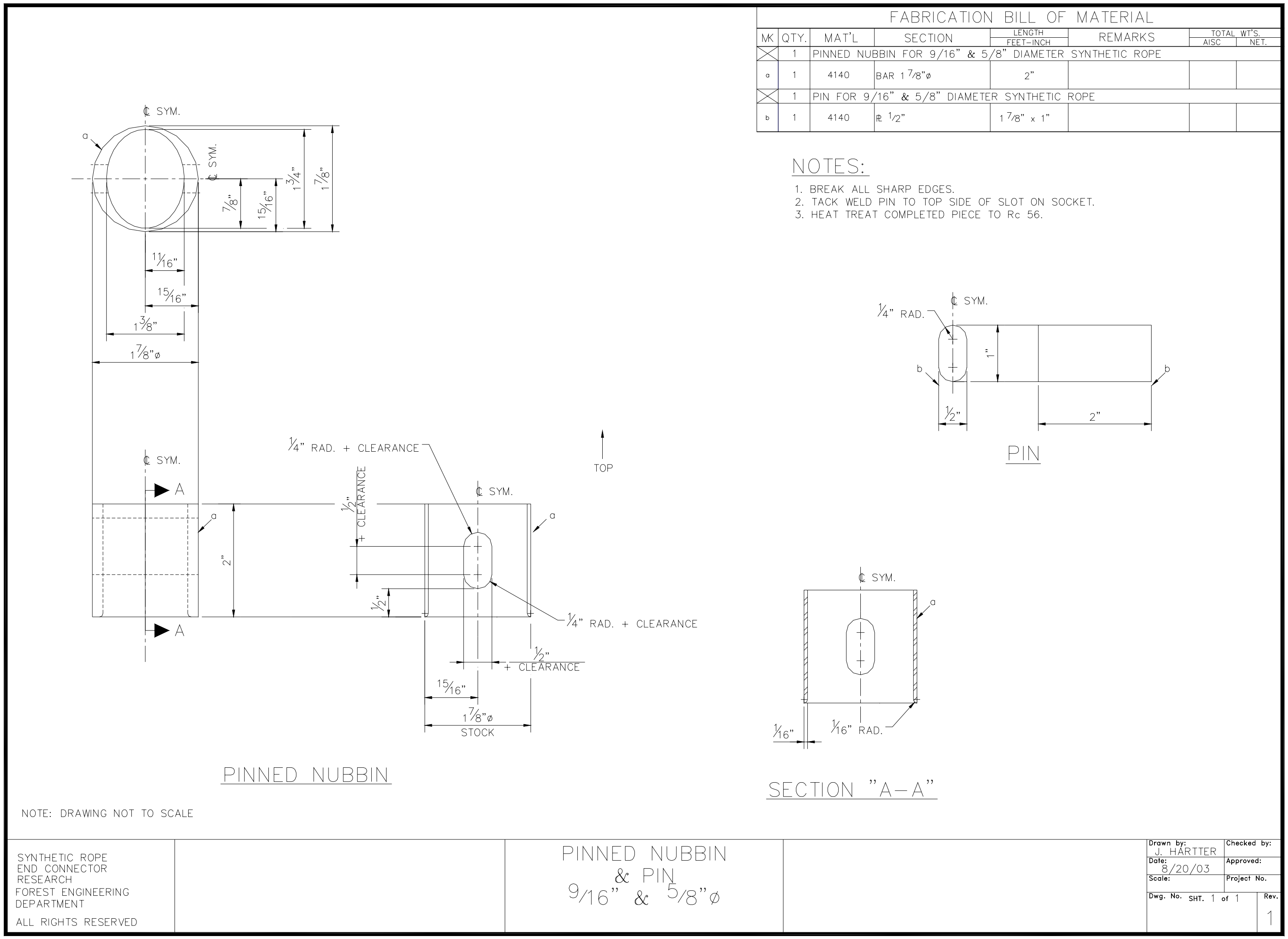
XI. APPENDICES

Appendix 1: Details of Pinned Nubbin Design

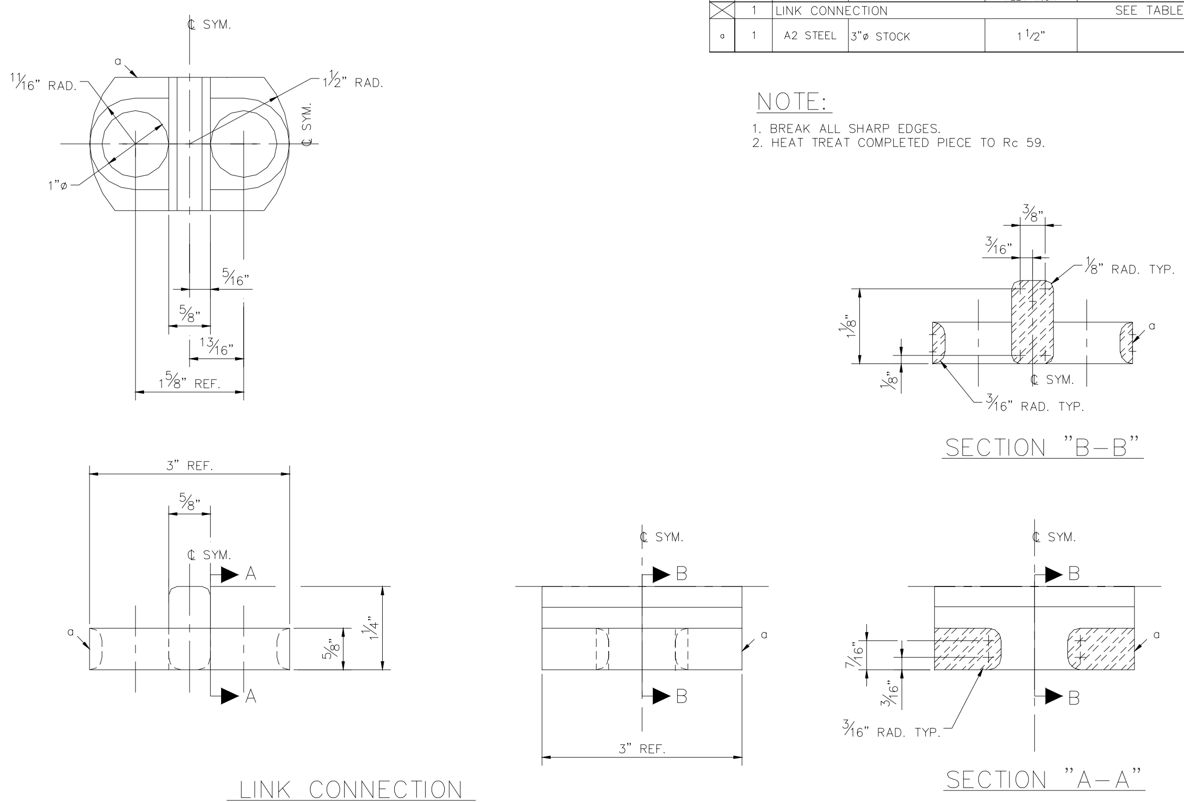


MK	QTY.	MAT'L	SECTION	LENGTH FEET–INCH	REMARKS	TOTAL WT'S. AISC	NET.
X	1	PINNED NUBBIN FOR 9/16" & 5/8" DIAMETER SYNTHETIC ROPE					
a	1	4140	BAR 1 7/8"ø	2"			
X	1	PIN FOR 9/16" & 5/8" DIAMETER SYNTHETIC ROPE					
b	1	4140	℞ 1/2"	1 7/8" x 1"			

Appendix 2: Knuckle Link Details

FABRICATION BILL OF MATERIAL							
MK	QTY.	MAT'L	SECTION	LENGTH FEET–INCH	REMARKS	TOTAL WT'S. AISC	NET.
	1	LINK CONNECTION			SEE TABLE FOR P.N. & WEIGHTS		
a	1	A2 STEEL	3"ø STOCK	1 1/2"			

NOTE:
1. BREAK ALL SHARP EDGES.
2. HEAT TREAT COMPLETED PIECE TO Rc 59.



NOTE: DRAWING NOT TO SCALE

SYNTHETIC ROPE
END CONNECTOR
RESEARCH
FOREST ENGINEERING
DEPARTMENT

KNUCKLE LINK
9/16" & 5/8"ø

Drawn by: J. HARTTER
Checked by:
Date: 9/17/03
Approved:
Scale:
Project No.
Dwg. No. SHT. 1 of 1
Rev. 1

Synthetic Rope End Connections and Terminations in Timber Harvesting Applications

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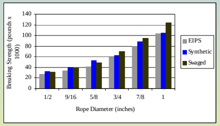
"Why change what works?"

Currently, wire rope is used universally in timber harvesting for skylines, guylines, winch lines, support lines, running lines, chokers, and truck wrappers. It has contributed to the advancement of cable logging. Wire rope is used around the world in quantities of thousands of miles annually. It is the all-purpose, durable, strong solution to meet the demands of logging. Although steel wire rope is the industry standard, it has less than desirable characteristics. It is heavy, difficult to manually handle, susceptible to bending fatigue and contributes to user fatigue.

Ultra-high molecular weight polyethylene (UHMW-PE) braided rope has potential to replace steel wire rope. It has been utilized in the offshore mooring and shipping industries for years. Characteristics such as high flexibility, low stretch, and high strength make the synthetic rope useful. At equivalent diameters, synthetic rope has an equal or greater breaking strength to that Of steel wire rope, but at 1/7 the weight.

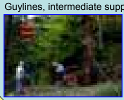
Synthetic Rope Characteristics

- 7 times lighter than steel wire rope
- As strong as steel wire rope at equivalent diameters
- Floats (specific gravity = 0.98)
- UV resistant
- Resistant to chemicals and acids
- Melting temperature of 291 F
- Easy to handle and splice
- No jaggers!



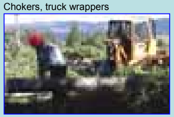
"Where could synthetic rope be utilized within forest operations?"

Static Lines:
Guylines, intermediate support lines, tree straps



Running Lines:
Skidder winch lines, carriage droplines, mainlines

Other Applications:
Chokers, truck wrappers



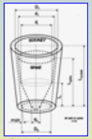
Research Questions

- Can end connections for synthetic rope be conceived that retain adequate breaking strength?
- How are end connections attached to the rope and are these connections feasible in the field?
- In what applications of timber harvesting can these end connections be utilized?

Research Objectives

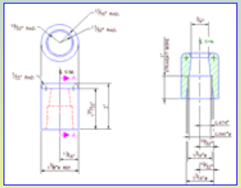
- Quantify breaking strengths of modified or newly developed synthetic rope end connections for further research and development.
- Assess the usability of the synthetic rope end connections for timber harvesting applications.

End Connector Concepts



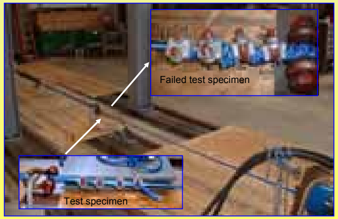
SEFAC

Buried Eye Splice



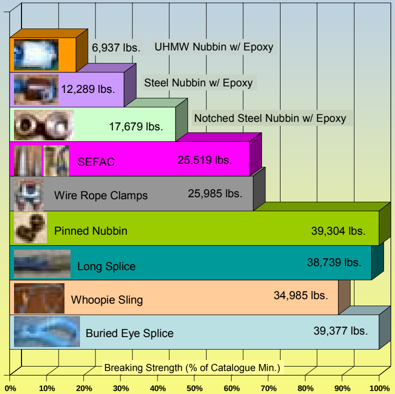
Notched Ferrule

Strength Testing



Example Results and Future Outcomes

- Low coefficient of friction makes compression fittings difficult.
- Knots may be unsuitable end connections for synthetic rope.
- Handling of adhesives is messy, time consuming, and difficult to maintain a uniform bond thickness.
- Adapted technology from steel wire rope has potential merits with synthetic rope.
- New end connections will be developed and steel wire rope connections will be modified to meet strength and usability criteria for timber harvesting.
- U.S. and international design and/or application patents will be pursued for end connection designs.
- Further research in end terminations and connections needed.



"Where does the research go from here?"

- Continued testing with new end connector concepts.
- Continued data analysis.
- Examination and investigation of failure modes
- Statistical analysis of end connection performance.
- Provide guidance to end users.
- Further reporting of findings and recommendations.
- Determine the feasibility and compatibility of synthetic rope end connections concepts for timber harvesting systems.