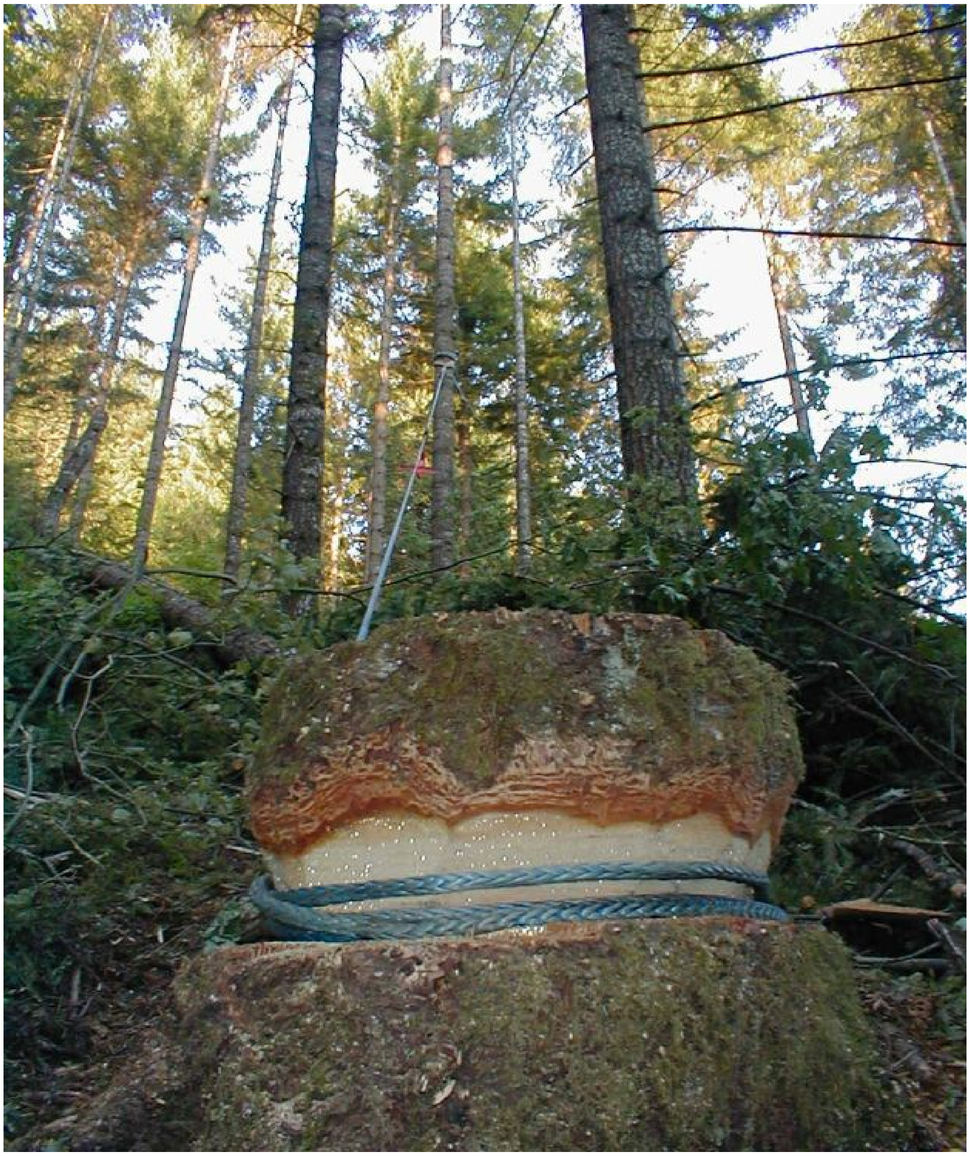
Rigging and Operations Guide: Use of Synthetic Ropes as Alternatives to Steel Wire Ropes in Logging Applications



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I. Introduction

As an outcome of three Oregon Occupational Safety and Health Administration Worksite Redesign Grants, the Synthetic Rope Research Team of Oregon State University's Forest Engineering Department provides this Rigging and Operations Guide: Use of Synthetic Ropes as Alternatives to Steel Wire Ropes in Logging Applications. We have compiled guidance on important applications and share what we have learned while using synthetic rope. Mention of trade names in this report is for identification only and does not constitute an endorsement by Oregon State University or the Oregon Occupational Safety and Health Administration. Whenever Amsteel Blue or ASB is mentioned we are specifically referring to AmSteel®-Blue synthetic rope by Samson Rope Technologies. Sometimes we refer to the synthetic rope by a shorter name of "synrope." Lastly, we cannot assure that this Guide is applicable to all synthetic ropes available.

We offer this guide as a starting point for users not as a final and absolute manual of how to use synthetic rope. Our research basis for this guide is at the beginning stages compared to the years of use and experience with steel wire rope. We expect this guide to be updated and replaced as new information becomes available from user experiences and further research.

Users of this guide should also be aware that additional information on rigging and operations are available in:

- Division 7. Forest Activities Code. Oregon Occupational Safety and Health Administration. Available online at http://www.cbs.state.or.us/external/osha/standards/div_7.htm

- Three Grant Reports and associated documents online at http://www.orosha.org/grants/awarded.htm

    - Using Synthetic Rope to Reduce Workloads in Logging
    - Running Lines and End Connectors for Synthetic Rope to Reduce Logging Workloads
    - Field Testing of Synthetic Rope in Logging Applications to Reduce Workloads

The Division 7. Forest Activities Code (OR-OSHA safety code) covers safety regulations for logging and other forest operations and should be consulted for specific applications. The Grant Reports offer more detailed information on synthetic rope research and developments. Trials that were not successful with synthetic rope are provided in the Grant Reports. Additional materials on splicing are included on the OR-OSHA website that are outcomes of the Grant projects.

We have organized this Guide based on uses so operators can turn to the section of interest. Thus, we list:

I. Introduction
II. Straps
III. End Connectors
IV. Adjustable Line Lengths
V. Guylines
VI. Intermediate Supports and Tail Trees
VII. Connections to Winches and Drums
VIII. Winch Lines on Skidding Machines
IX. Chokers
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XII. Splicing Instructions
XIII. References

The Guide is picture-based to a large extent and will need to shown in color for best understanding by users. A range of applications for synthetic rope is shown in Figure 1 below.

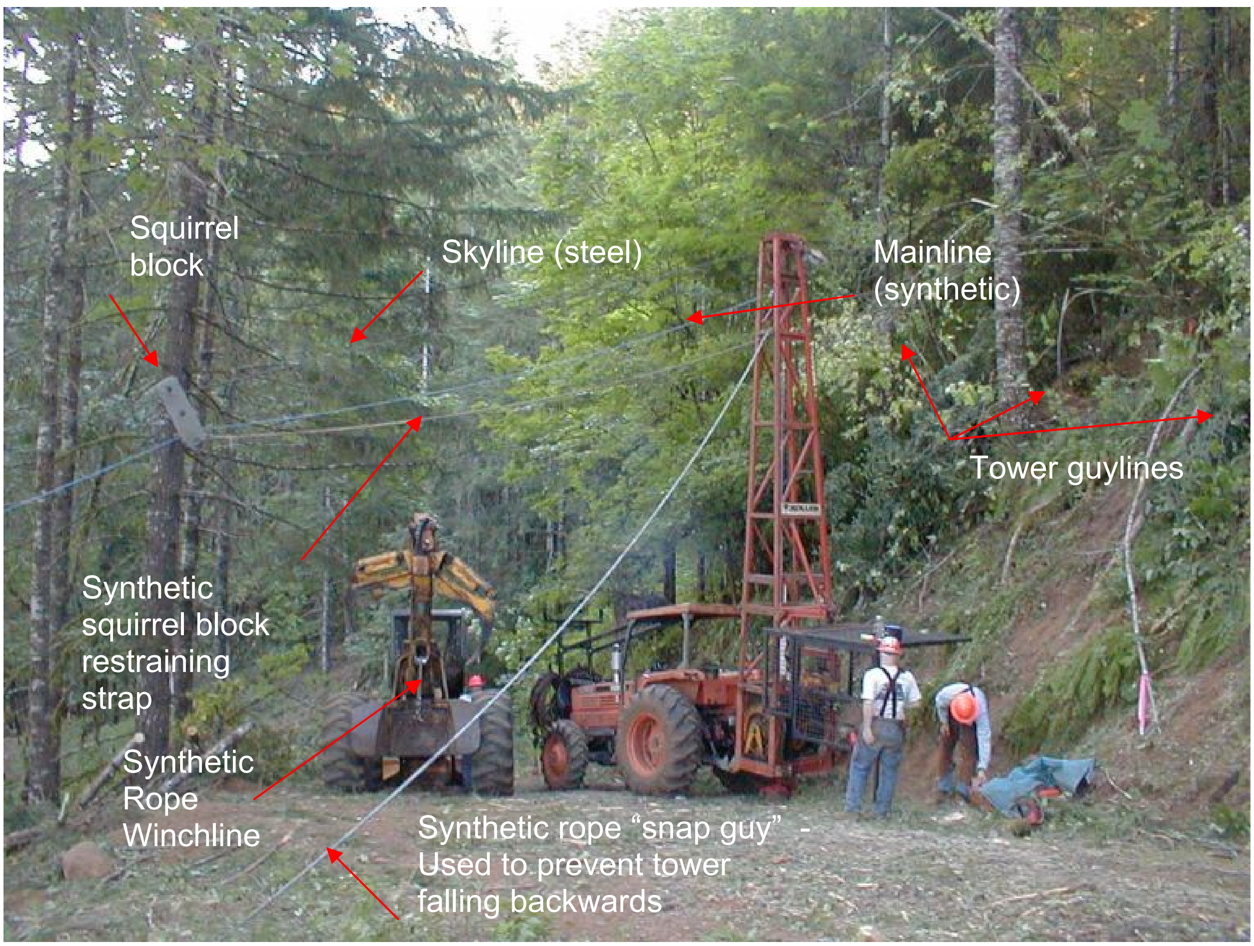

Figure 1. Some potential synthetic rope applications.

Our experience with this one rope (AmSteel®-Blue) indicates synthetic ropes of high modulus fibers are appropriate for implementation in logging applications. We believe, based on the variety of applications and resulting wear observed, that an array of different rope types, constructions, and fiber materials now exists or may be created which will fit specific applications to achieve ergonomic and economic benefits.

II. Straps

Many users of synthetic rope find straps for hanging rigging in trees and on the ground most useful. The light weight and strength plus ease of handling while up in a tree make straps of synthetic rope a good first application (Figure 2). Synthetic straps are:

- EASILY SPLICED to desired length using long splice to form looped strap.
- LIGHTER, EASIER to handle than both steel wire rope and other synthetic straps (ballistic nylon).
- FLEXIBLE - No bending resistance like steel wire rope when trying to wrap around stumps, trees, and while up in a lift tree.
- Flops around tree, unlike steel, and with less effort than other synthetic straps.
- Various strap configurations: two eyes or endless loop
- Straps allow for basket, choker, and sling configurations.

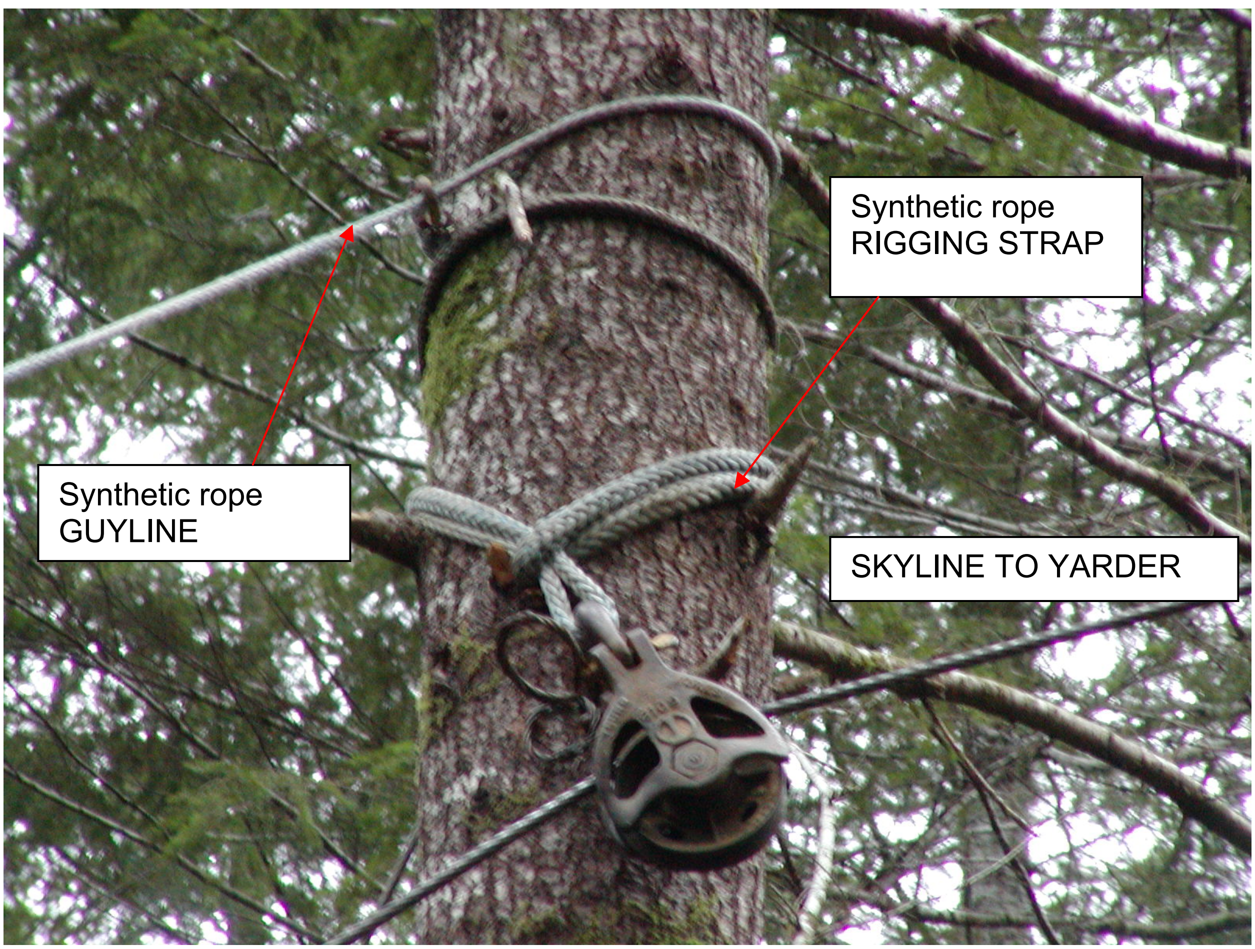

Figure 2. View of tail tree rigged with synthetic rope.

Division 7. Rule 437-007-0645 addresses straps and their uses and provides sizing requirements based on whether the rigging is hung in a single or double eye, whether the strap is in the tree or on the ground and the angles of the lines supported by the block. The endless loop above is equivalent to a block hung in two eyes with shallow angles of the lines entering and leaving the tree.

Figure 3 below shows the endless loop strap of synthetic rope. The larger the line size, the longer the loop will need to be to accommodate the buried sections (essentially a long splice).

Figure 3. Loop strap of synthetic rope with pen showing end for end (long) splice connection.

III. End Connectors

Based on our 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 (Logger's 3-tuck eye)
- Whoopie Sling (adjustable length strap or line)

- End for End splice (Logger's Long splice)
- Rope clamps – in selected applications with 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 chokers, toggles or truck wrappers

We 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

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. Table 1 below lists the end connectors evaluated.

Table 1. Summary of End Connections evaluated.

End connector	**Origin**	**Use**	**Average strength & variability**
Buried eye splice	Manufacturer	Eye to shackle various connectors	Standard 100%, little variation
End for End (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 strap or line length	85-90%, little variation
Knots—various	Marine industry	Terminations	8-58%, highly variable

End connector	Origin	Use	Average strength & variability
Cable clamps (clips)	Wire rope industry	Connect rope to itself	~60%, OK variability tightening difficult
Pinned nubbin	OSU-Hartter design	Connect rope to nubbin	~95%, little variation
Knuckle link	Hartter design	Connect to steel housing	~100% little variation
Pressed nubbin	Wire rope industry	Connect rope to nubbin	~20-25%, little variation
Butt splice packed into nubbin	OSU Concept	Connect rope 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 rope to nubbins	~12-36% highly variable & difficult
Twisters	Wire rope industry	Variable length & tensioning device	~80% of double rope strength

Buried Eye Splice

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.

The buried eye splice will be the effective 100% breaking strength of the rope. Figure 4 shows the eye of a completed buried eye splice. This may be used with standard shackle connections.

Figure 4. Buried eye splice

Whoopie Sling

The Whoopie Sling is an adjustable sling. The adjustable strap configuration allows the user to move from one strap, line, or guyline length to another without the addition of hardware or extra slings (see Figure 5). 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 choosing. 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.

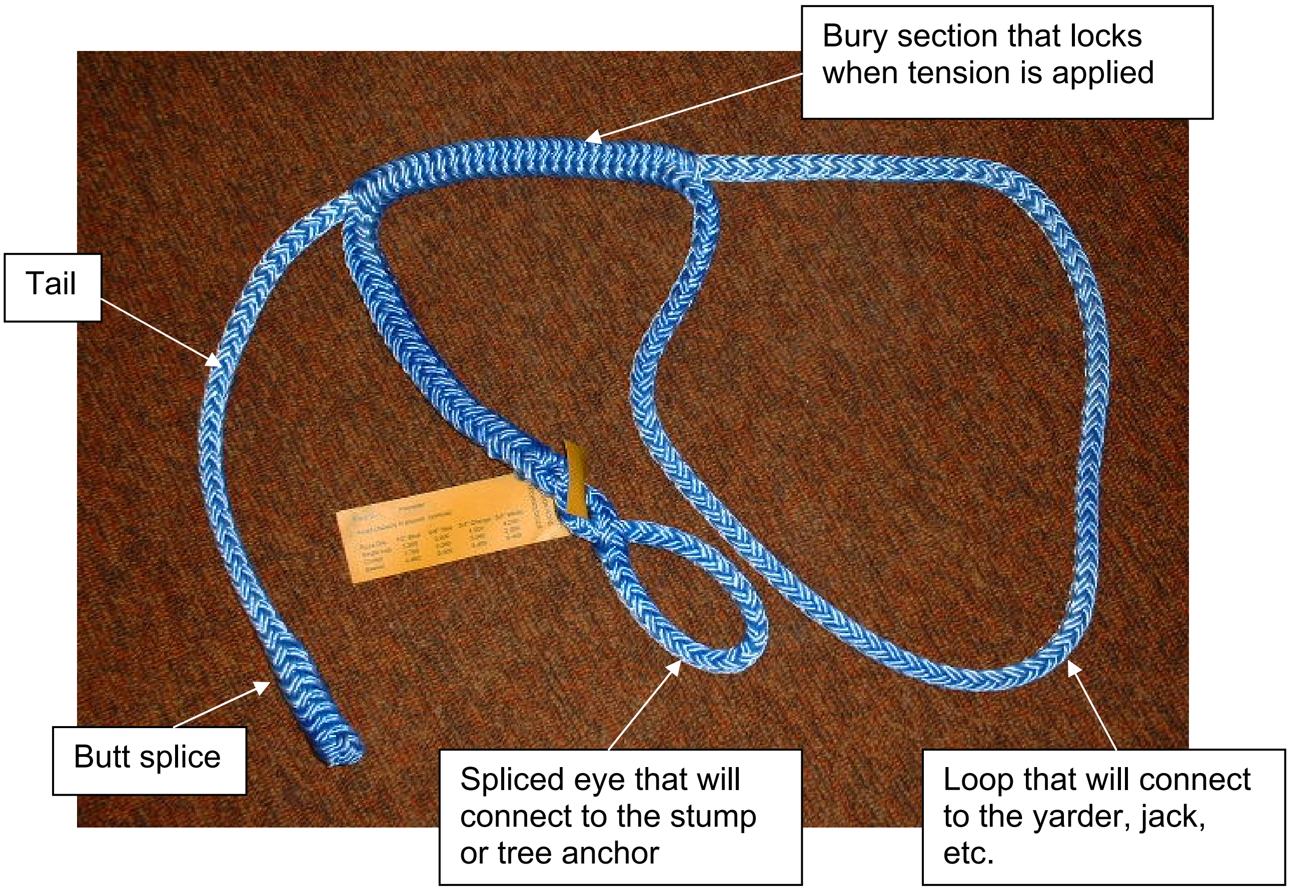

Figure 5. Whoopie Sling

End for End (Long) Splice

The End for End (long) splice is used to join two pieces of synthetic rope together by a simple splicing technique. 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 6). Then, the end of rope 1 is threaded into a section of rope 2 (Figure 7). Additionally, at the same point, rope 2 is threaded into rope 1 (see Figure 7, 8). Figure 8 shows a finished long splice using new and used rope.

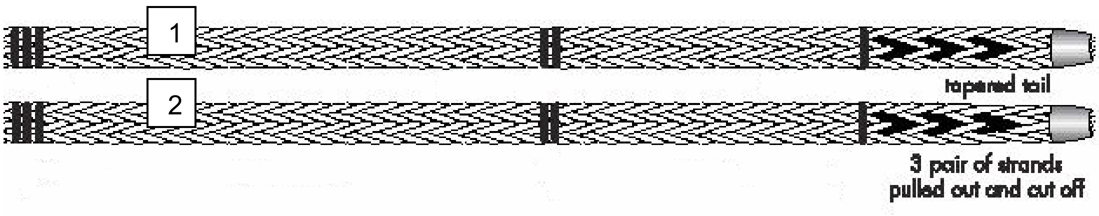

Figure 6. Taper procedure for long splice (Samson Rope Technologies A., 2002)

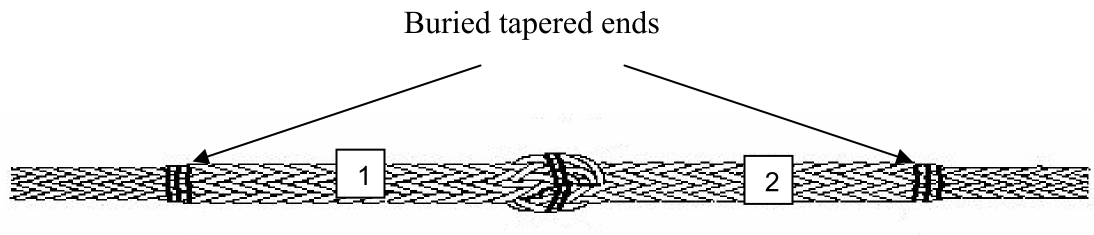

Figure 7. Finished long splice (Samson Rope Technologies A., 2002)

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 8. Finished long splice

Y-splice

The Y-splice was derived as another solution to the problem of adjustable rope lengths (Figure 9). 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 main section to create the length to fit the particular guyline requirements.

The main section of rope has 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 main section compresses the ropes together for the holding strength.

Figure 9. Y-splice

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 to form 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 Div. 7. Code and tightened with a torque wrench to 45 foot-pounds (less than the 90 foot-pounds recommended by the Manufacturer because higher torque was not achievable). The Oregon OSHA Division 7. 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. Figure 10 shows a picture of this end connection.

Figure 10. Wire rope clamps

Three recommendations help when using the wire rope clip concept with synthetic rope:

1. Avoid using wire rope clips that have been used previously with steel wire rope. Additionally, the bracket (saddle) should be checked for sharp edges and grooves that the rope can catch on.

2. 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.

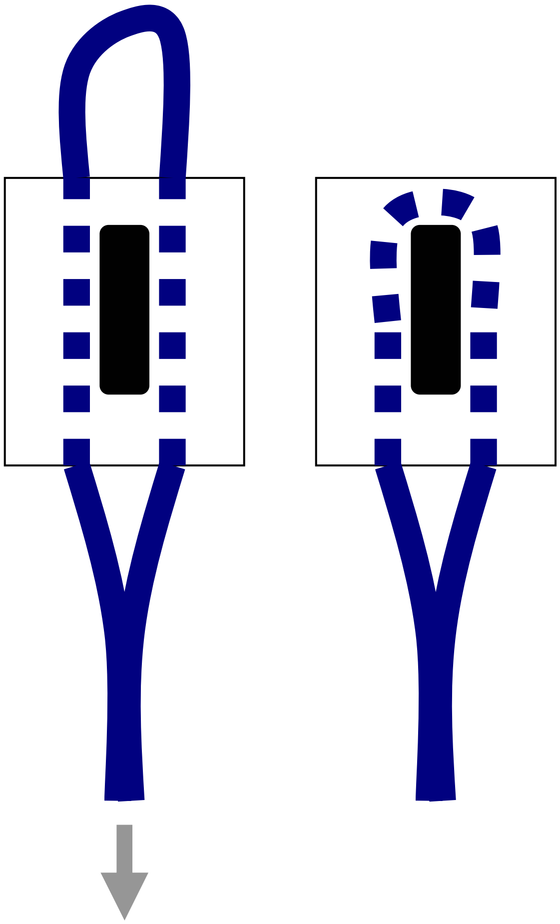

Figure 11. How the pinned nubbin works

3. 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 free rope end wrapped on another tree or stump and 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 clamp connectors to slip.

Pinned Nubbin

The pinned nubbin concept was developed using early research by the Synthetic Rope Research Team. The pinned nubbin connection is a dry end connection, meaning it requires no adhesive, only a mechanical means to attach the rope. The pinned nubbin is a designed and engineered end connection and users need to follow fabrication instructions in Hartter, 2004.

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 11 shows a diagram of how the eye splice of the rope is tightened, and Figure 12 shows the fabricated piece.

Figure 12. Pinned nubbin

In order to keep the new nubbin as close to the B-5 external 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. 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 the eye of the rope.

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. The developed knuckle link is shown in Figure 13.

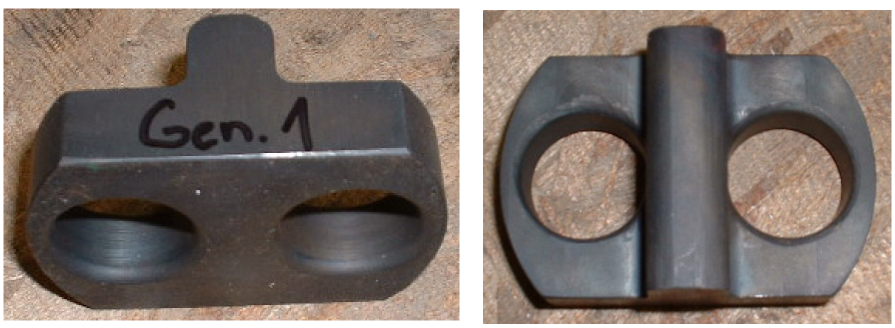

Figure 13. Knuckle link

In addition, the choice of material to be heat treated is important. 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 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. The major drawback with this design is that it leaves the rope exposed. Bending a rope over the bar increases stress on the rope and individual strands at that point.

Pressed Nubbin

The pressed nubbin concept was derived directly from steel wire rope applications (Figure 14). 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. No lubricants or tape were used on the rope so as to affect the performance of the test specimen during the break test.

Figure 14. Pressed nubbin

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 and to tie back anchors. 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 15 below.

Figure 15: Twister used with synthetic rope

Chain Link to Buried Eye Splice

For some end connections, a buried eye splice can be attached to a chain link to form a connection as for a log truck wrapper in Figure 16 below. The strength of the buried eye splice is reduced somewhat because of the small diameter of the chain link. However this connection has proven to be satisfactory for a variety of applications.

Figure 16. Truck wrapper

Knots with Synthetic Rope

Many 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 winch line in Division 7, Forest Activities, Safety Codes.

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.

IV. Adjustable Line Lengths

The length of a rigging strap, guyline, or intermediate support line is rarely the required length to complete the necessary rigging. It may be too long-- which may require extra wraps or tying to another anchor to take up the slack prior to securing the end. It may be too short-- requiring the use of an additional length of rope and connections.

Synthetic rope, especially the hollow braid design used in the research, has the ability to be configured to create a strap or line of adjustable length. This application could reduce the number of various length straps and lines required.

One configuration is the Samson Rope Technologies “Whoopie Sling”. This application is used primarily in the arborist profession. We adapted the idea to create straps and lines with a larger loop that provides for a range of possible lengths.

The length of the adjustable strap or line can easily be adjusted. The user must pull on the loop to add length. Conversely, to decrease the length, the user simply pulls on the tail. The Whoopie Sling concept is based on the same constrictive principle used in 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 constrictive section can be bunched together to allow the buried section to slide easily through the bunched bury section and thus adjust to a new length. Figures 17 and 18 demonstrate the tightening of an adjustable length guyline.

Figure 17. Adjustable guyline extension (slack) using “whoopie sling” technique with synthetic rope.

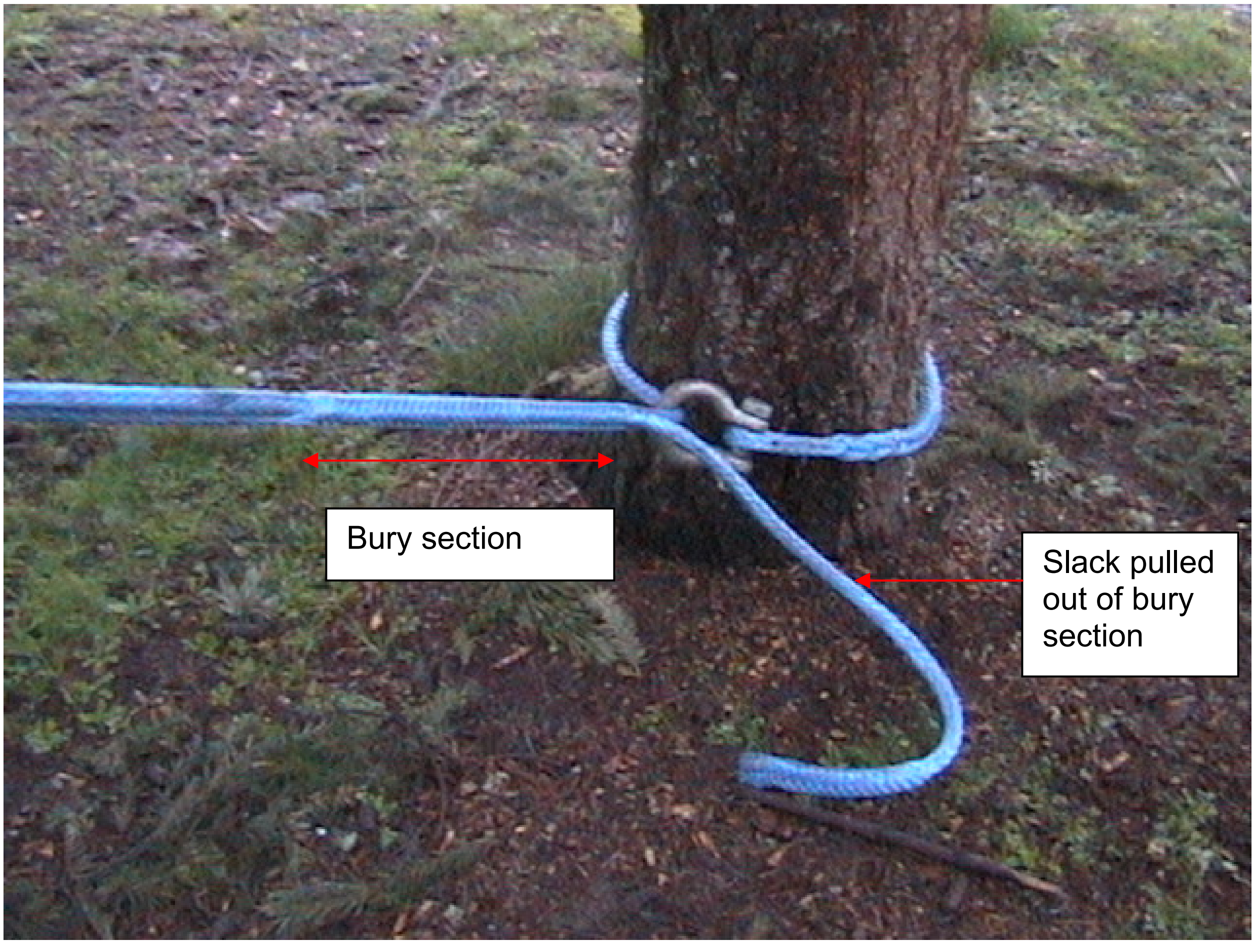

Figure 18. Adjustable guyline extension tightened into position.

There still is a need to tighten synthetic rope guylines and support lines. Experience has shown one or two workers can easily tension a synthetic line. There is little "belly" or sag in the line, a marked improvement over steel lines when tensioned by manual effort.

It is possible to use a rigging chain and come-along system to tension a line if additional tension is desired (Figure 19). One cooperator places a single wire rope clamp on the line to be tightened and hooks the come-along hook above the rope clamp to create a temporary connection for tightening the line.

Figure 19. Rigging chain wrapped around synthetic rope guyline for tensioning with come-along. Note the use of a grab hook and the direction of wrap to prevent rigging chain from sliding along the synthetic rope.

Tiebacks And Twisters

Synthetic ropes, with their ease of use, lightweight, and high strength offer additional rigging practices to secure marginal tailholds, anchor stumps, or guy trees with tiebacks and twisters. While synthetic rope Manufacturers do not advise twisting ropes, we found them to be effective twisters while maintaining sufficient strength. See Figure 20 below.

Figure 20. Twister shown made with 3/8 – inch diameter synthetic rope.

V. Guylines

Guylines are one of the attractive uses of synthetic rope (Figure 21). They are strong, light and easy to work with up a tree. However, the termination of the guyline can be a bit of a problem when it is necessary to use up extra length. One option is shown below In Figures 22, 23, and 24.

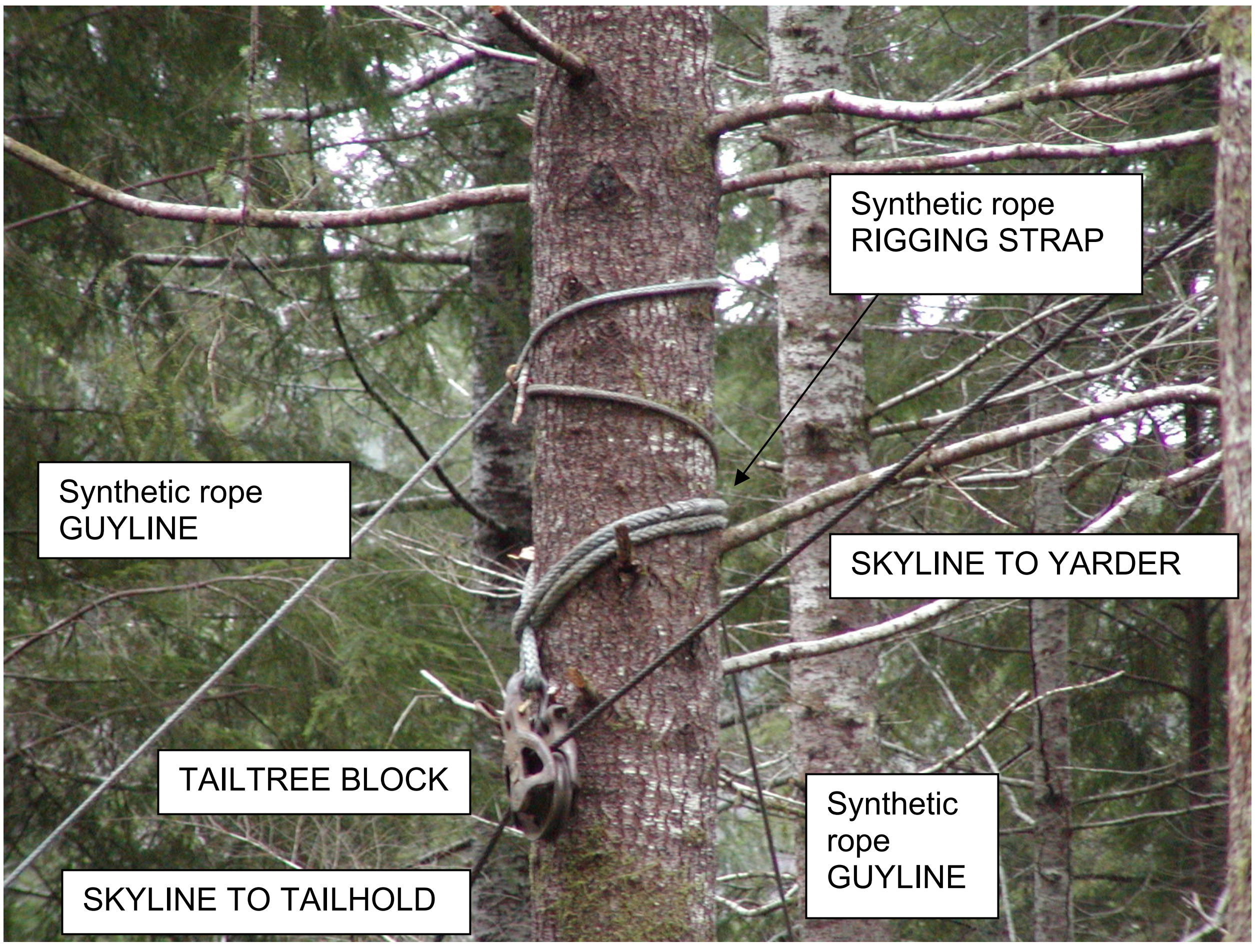

Figure 21. View of tail tree rigged with synthetic rope guylines and rigging strap.

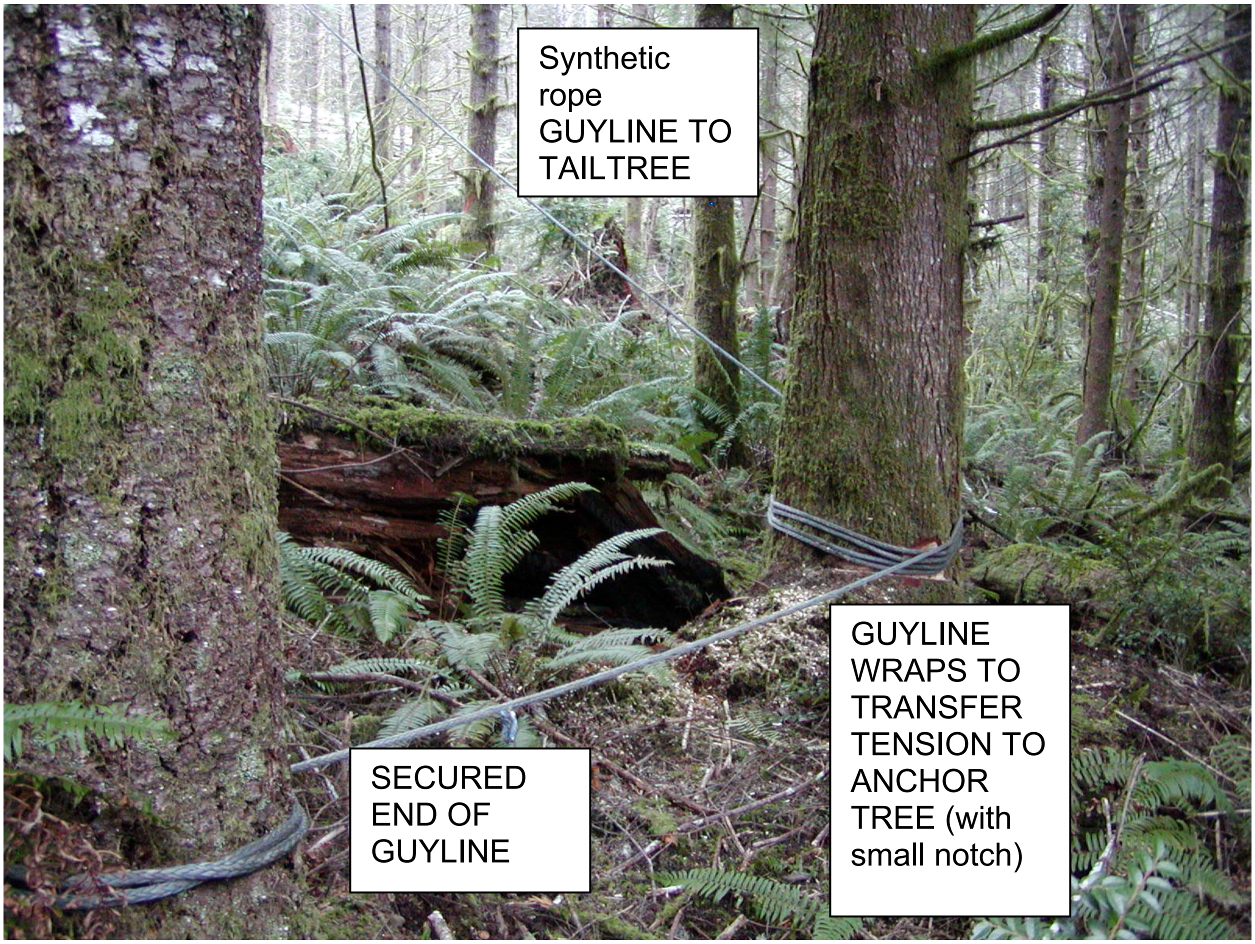

Figure 22. Guyline anchoring : In this example, first to anchor tree (in guying zone), wrapped to transfer tension load, notched to keep guyline from slipping up bark. Extra length run to another tree, wrapped twice, and secured with shackle. Based on conversations with OR-OSHA personnel, this “out of lead” securement is permissible where the line tension in the extra length section is not needed to secure the initial anchor, nor creates a block purchase effect on the initial anchor.

Figure 23. Guyline end secured to second tree (or stump), shackle end connected to eye splice (buried eye splice) and back onto extra length of guyline reaching between initial anchor (in foreground) and terminal anchor.

Figure 24. Close up of shackle connected to buried eye splice (yellow end) and locked back on the tail of the eye splice. Extra wraps around secondary section of guyline (to right of photo) used take up short length of slack (slack length insufficient to complete an additional wrap). If eye and shackle had just reached the guyline (to right of photo), no extra wraps would be required – just shackle the eye onto the secondary guyline section.

Another option for securing a synthetic rope guyline with extra length is to wrap the load bearing line around the anchor tree or stump a sufficient number of times to take the load off the unsecured end or tail. Then, wrap the tail around another termination stump or tree and secure with cable clamps. Cable clamps should not be used on lines with load because the synthetic line will change diameter as it is loaded and thus render the cable clamps ineffective.

For guylines connected to stumps, it is important that the stump be properly notched without leaving saw kerf cuts and sharp edges (Figure 25). Synthetic rope can be pulled into saw kerf cuts and damaged when the line is tightened. Another improvement is to use a piece of fire hose to protect the guyline from wear and abrasion as in Figure 26 below.

Figure 25. Stump notched with a minimum of saw kerf cuts remaining that could damage synthetic rope guylines.

Figure 26. Guyline with fire hose to protect synthetic rope from wear and damage.

VI. Intermediate Supports and Tail Trees

Intermediate supports are used to provide height for the skyline to allow carriage clearance, log lift, and suspension of the logs (Figure 27). A rigged tail tree accomplishes these objectives at the back end of a unit (Figure 2, previously). Proper use of lift trees (intermediate supports, tail trees) improves yarding productivity and reduces wear and tear on yarding equipment. Inadequate suspension leads to "brute force" techniques to bring logs to the landing. Intermediate supports reduce the environmental impacts of scarred trees, gouging and soil damage.

Rigging lift trees with steel wire rope is difficult and thus, they may not be used as often as they should be. Lighter lift lines and guylines reduce the physical burden of properly rigging lift trees. Implementation of the required rigging (especially guylines) under OR-OSHA Division 7 is more likely to occur with synthetic lines than steel wire rope. Oregon OSHA Division 7 safety code (Forest Activities) now permits the use of synthetic ropes, which meet strength requirements.

Intermediate supports generally consist of a rigging strap to hang a block in the tree, one or two guylines (as prescribed), the support line for the intermediate support jack, and the skyline support jack itself (Figure 28). Tail trees require the rigging strap, block, and required number of guylines.

Synthetic ropes of prescribed strength may be used in place of steel for the rigging strap, the guyline(s), and the lift/support line. This could amount to 450 feet of rope to rig and guy the support tree. The difference in weight between steel and synthetic ropes could be a reduction by nearly a factor of ten.

Cooperators have been able to load all required rigging (blocks, shackles, lines) onto a pack frame and make one trip across the unit to rig the next intermediate support.

Securing the intermediate support line once it is lifted into position may be achieved with the use of a shackle, wire rope clamps, or an adjustable length strap in the same way as for guylines (See Figure 29).

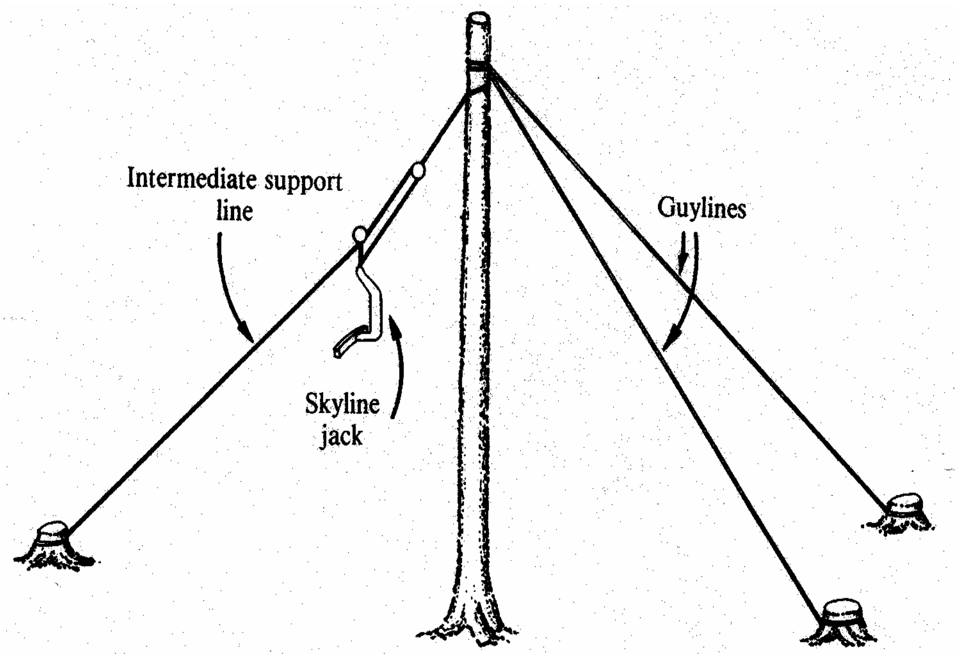

Figure 27. Schematic of Single Tree Intermediate Support rigged

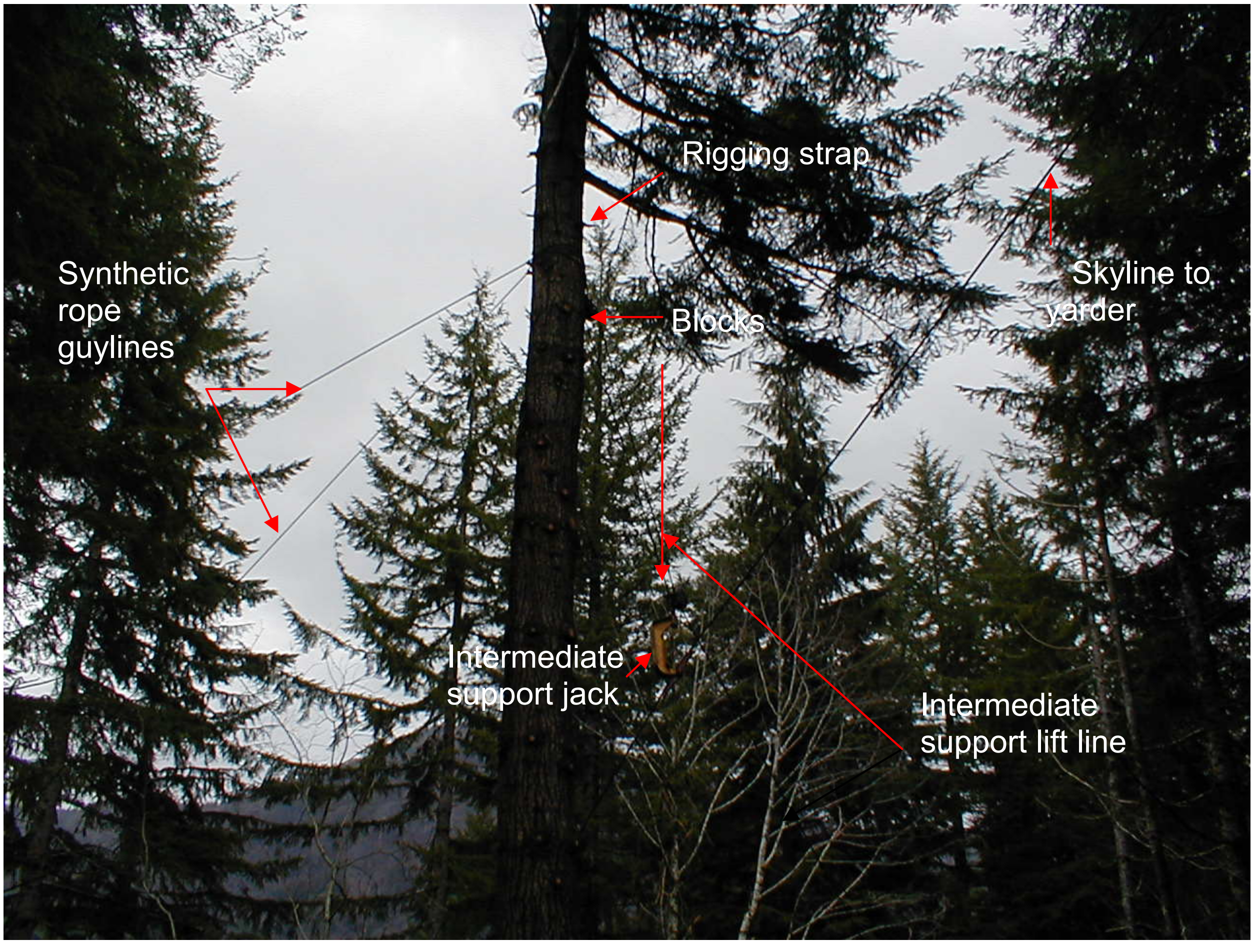

Figure 28. Intermediate support tree rigged with synthetic rope for guylines (2), a rigging strap, and 1 intermediate support lift line. Intermediate support lift line runs from the anchor up through the block at top of jack (yellow “C”), up to and through the block secured in the tree with the rigging strap, and back down to the top of jack.

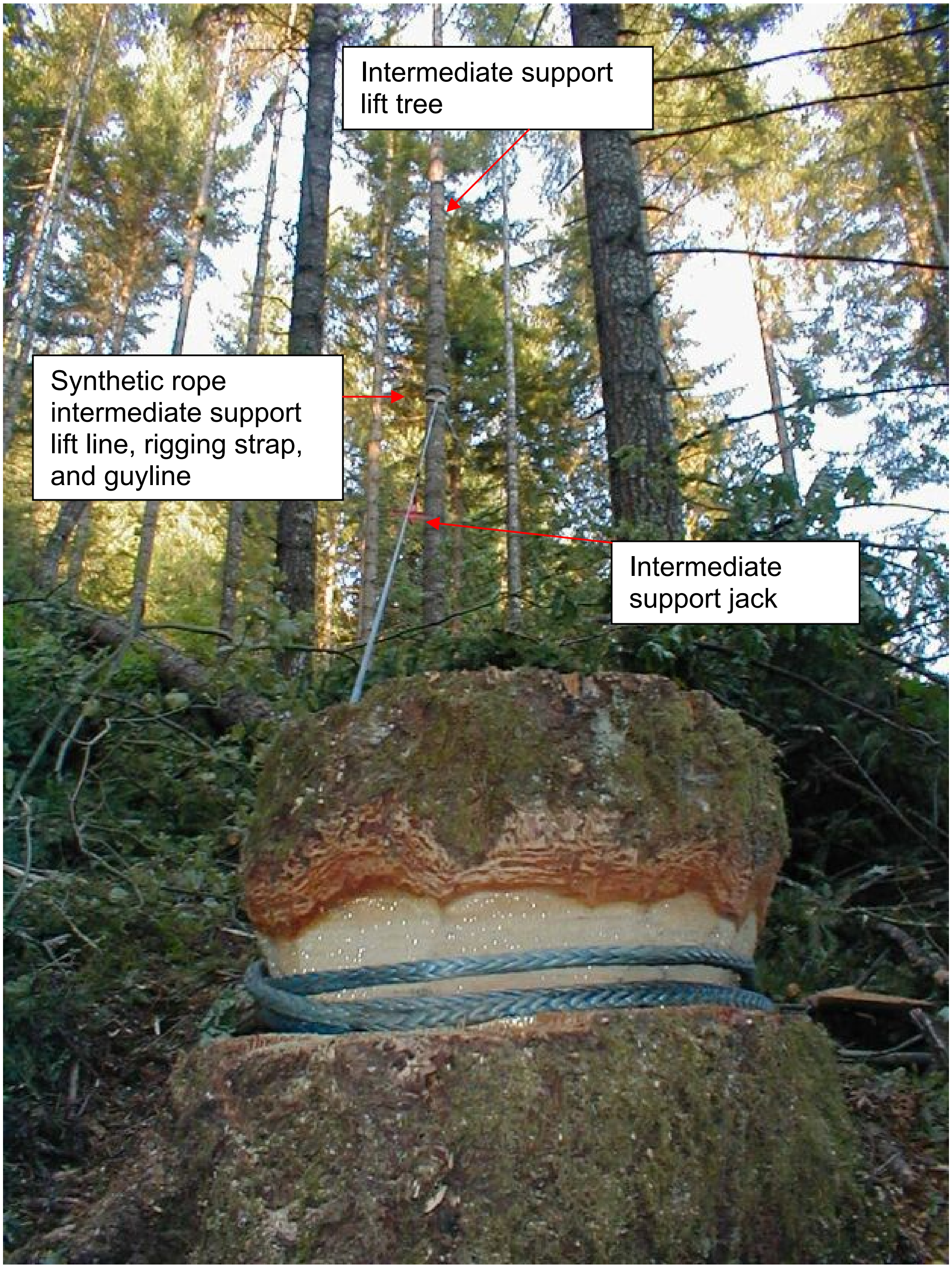

Figure 29. Stump anchor for an intermediate support lift line (used to raise and lower jack) supporting the skyline for a multispan skyline system. It is important to create smooth profile stump notches and avoid creation of pinch points (chainsaw grooves) on anchor stumps.

VII. Connections to Winches and Drums

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 itself. See Figures 30, 31, and 32 below.

Figure 30. Packed butt splice nubbin used as a breakaway attachment to the drum.

Figure 31. Attaching the packed butt splice nubbin end connector to the drum barrel.

Figure 32. Short buried eye splice to connect the synthetic winch line to the skidder drum.

We recognize that the strength of an end connection on a winch/drum is less dependent on the ultimate strength of the 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 rope has such a low coefficient of friction (Samson, 2003).

Spooling the initial wraps and line on a drum under tension is critically important to keeping the line from diving into the loose packed rope (Figure 33). The tension can be provided by simply pulling the skidding machine with braking by the winch itself or by attaching a load to the line of at least 500 to 1000 pounds.

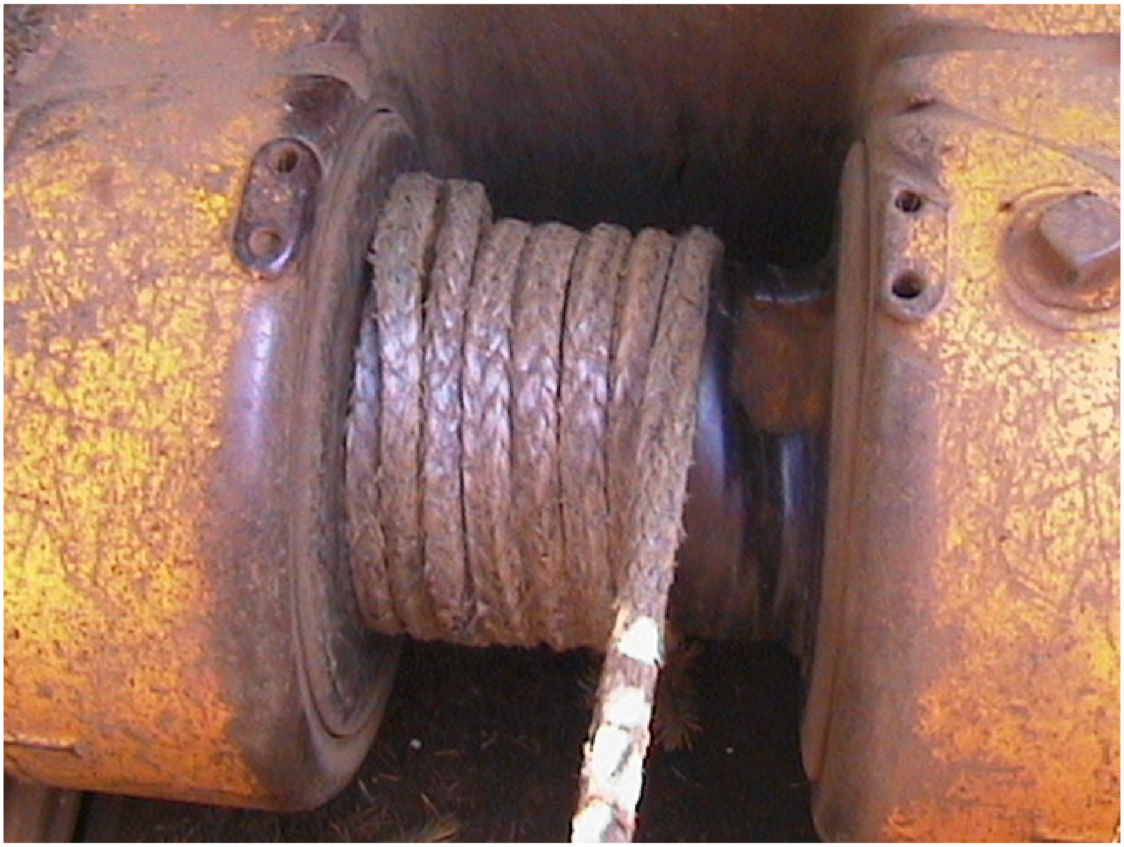

Figure 33. Spooling the winch line on the drum under tension by pulling the machine with the winch.

Adjustment Needed to Skidding Drum Winch

Synthetic rope requires practices to be modified compared to steel. One such modification is the need for adjusting the “free spool tension” on the drum. With the stored torsional energy in steel wire rope, the “free spool” adjustment is set to minimize “spronging” of the wire rope upon drum release. With synthetic rope there is no “spronging” effect, thus the free spool adjustment may be set for minimum resistance for easier line pulling. This adjustment has been recommended to all operators installing a synthetic winch line.

Spooling Capacity

Based on operational installations and compared with the manufacturer’s spool capacity equation, it is possible to spool approximately 25 percent more synthetic rope due to its ability to occupy the volume of voids compared to steel wire rope. These observations were made over a range of winch types and sizes. Table 2 shows the results for one skidder.

Table 2. Comparison of formula for spooled line lengths and actual spooled line lengths on a skidder drum.

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
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%

Equations typically use the dimensions of the drum/winch as follows:

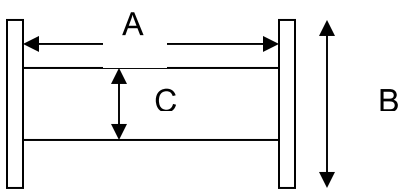

Figure 34. Dimensions used in drum / winch spooling capacity equations.

Spooling Capacity of a Drum

Samson Rope Technologies uses the following formula (see Figure 34 above) for determining the length of rope that will fit on a winch drum. It also approximates the length of steel line that may be fully spooled on a drum.

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)

We found the line length actually spooled on a drum determined by this equation to be conservative.

The Samson Rope Technologies equation assumed the cross sectional area of the rope to be 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).

OSU modified the equation where the cross sectional area of the rope is circular and allowing the 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 OSU 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. This value is the area ratio of a circle with diameter d to a square with side length d.

The OSU equation produces an estimated length that is about five (5) percent less than actually spooled compared to 35 percent less than actually spooled with the Samson equation.

VIII. Winch Lines on Skidding Machines

There are a number of guiding points for using synthetic rope as winch lines on skidding machines. The first deals with the type of connection to use with the chokers. A typical steel winch line may use sliders with a termination of a wire rope knot sucked into the final slider bell. A number of applications have been used by Cooperators in our research. The end connections to the working end of the winch line include:

- T-bar toggle with short chain eye spliced (see Figure 35) used with ring or pear chokers
- Buried eye splice on small ring to stop sliders (could have been a knuckle link used as a bang plate)
- Knot sucked into the final slider used with sliders and cat chokers
- Eye splice to a Cat hook and chokers with eyes

The benefits of winch synthetic rope winch lines include:

- Lightweight, easy to pull to logs, especially uphill
- Faster cycle times (on outhaul) may lead to more daily production

- Physically less strenuous as measured by heart rate.
- No jaggers !!
- No spronged spool (cat's ass) on winch release (NOTE: Winch free spool setting should be adjusted to minimum setting)
- Little to no diving (line buried between wraps on drums). The rare occurrence of a stuck rope can be removed by manually pulling upwards.
- Allows for "long-lining" short corners with skidder instead of cable yarder.
- Achieving skid trail spacing meeting environmental recommendations
- Setting several chokers with sliders or pear/ring and toggle (Figure 36).

Figure 35. Working end of winch line termination is a function of hardware. Shown is ring and T-bar toggle set-up commonly used for presetting chokers with quick off-on of empty and set chokers. Connection of steel hardware to synthetic rope is created with the simple Buried eye splice.

Figure 36. Operator pulling synthetic rope off of crawler tractor winch. Pear-ring choker slid up against “T-bar toggle” and two more chokers on winch line.

Another benefit of using synthetic rope as a winch line is that it can be easily long spliced to add a section of new line to a used line to maintain or extend the winch line. Figure 37 below shows the old and new winch lines spliced together.

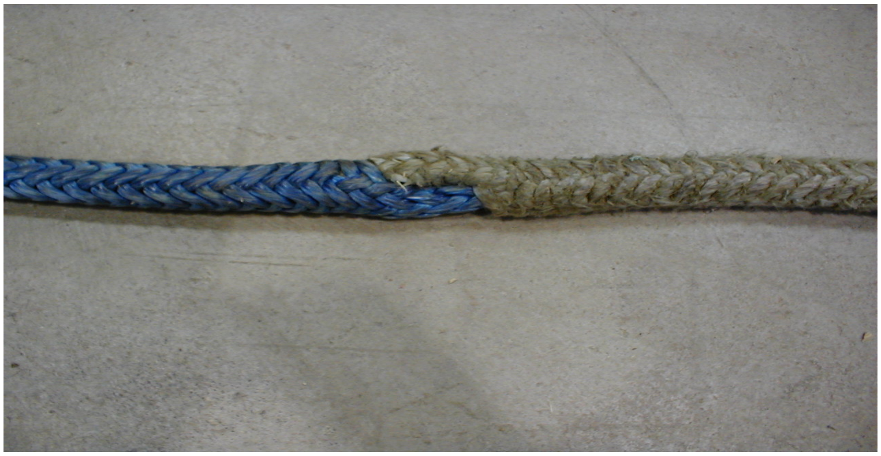

Figure 37. New and old winch lines spliced together.

Alternately, the damaged section of a winch line can be removed and the line re-spliced as in Figure 38 below.

Figure 38. Synthetic ropes may be quickly and cleanly long spliced to repair a damage section or lengthen an existing line.   The duct tape section identifies the crossover point of the long splice.   The operator's finger and the grapple arm are the approximate terminations of the buried tail to create the entire long splice in this 3/4-inch diameter synthetic winch line.

When steel winch lines dive into loose wraps on the drum, the operator must hook a stump and pull the line from the drum. Usually the line is damaged by such actions and may not easily pass a slider or ring. When synthetic rope dives into the drum it can be easily removed by hand from a situation shown in Figure 39.

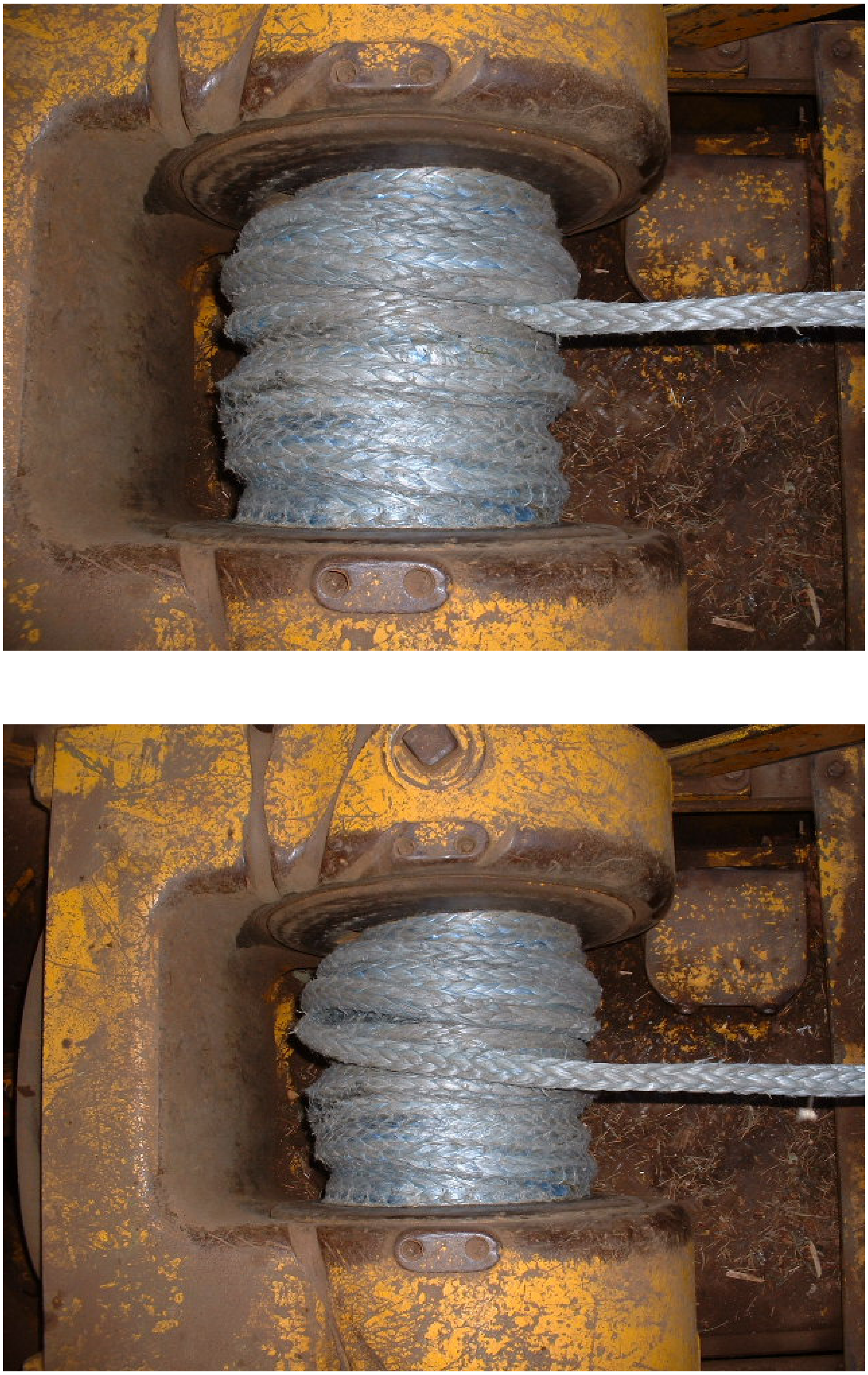

Figure 39. Top: Diving of the tensioned rope is a rare occurrence when the rope is initially installed under tension (tension spooling). Bottom: The rope was pulled free from the hang-up with one hand.

IX. Chokers

The use of synthetic rope as a choker has generated a lot of interest. The steel wire rope choker, with its pressed nubbin and bell, is a simple system that works quite well. However, synthetic rope's light weight, flexibility, non-kinking and non-jaggering characteristics spark interest.

Two designs appear to be workable in practice. The first design was created by a north coast logging contractor and rigging shop. It uses a steel eye bolt with an eye splice connection to create a nubbin end. A nut is welded onto the end of the eye bolt and ground to a round surface for ease of use with the standard bell. The standard steel bell slides as usual on the synthetic rope.

The other design incorporates a European design winch line slider and chain end connection as a bell and nubbin system (Figure 40). The slider functions as a standard bell. However, the flexibility of the chain and synthetic rope does not lend itself to shoving under a log. Where chain is used in other countries, a short hook is shoved under a log and the chain is pulled back through. An alternative now being tried adds a short piece of steel rod to the last chain link to aid in feeding the choker under the log and hooking into the bell (Figure 41).

Figure 40. Prototype synthetic choker made with 3/8-inch diameter ASB synthetic rope. A Farmi winch line keyhole slider is used as a choker bell with a chain end to act as the nubbin. The other chain end is for connecting the hooked log to the winch line slider.

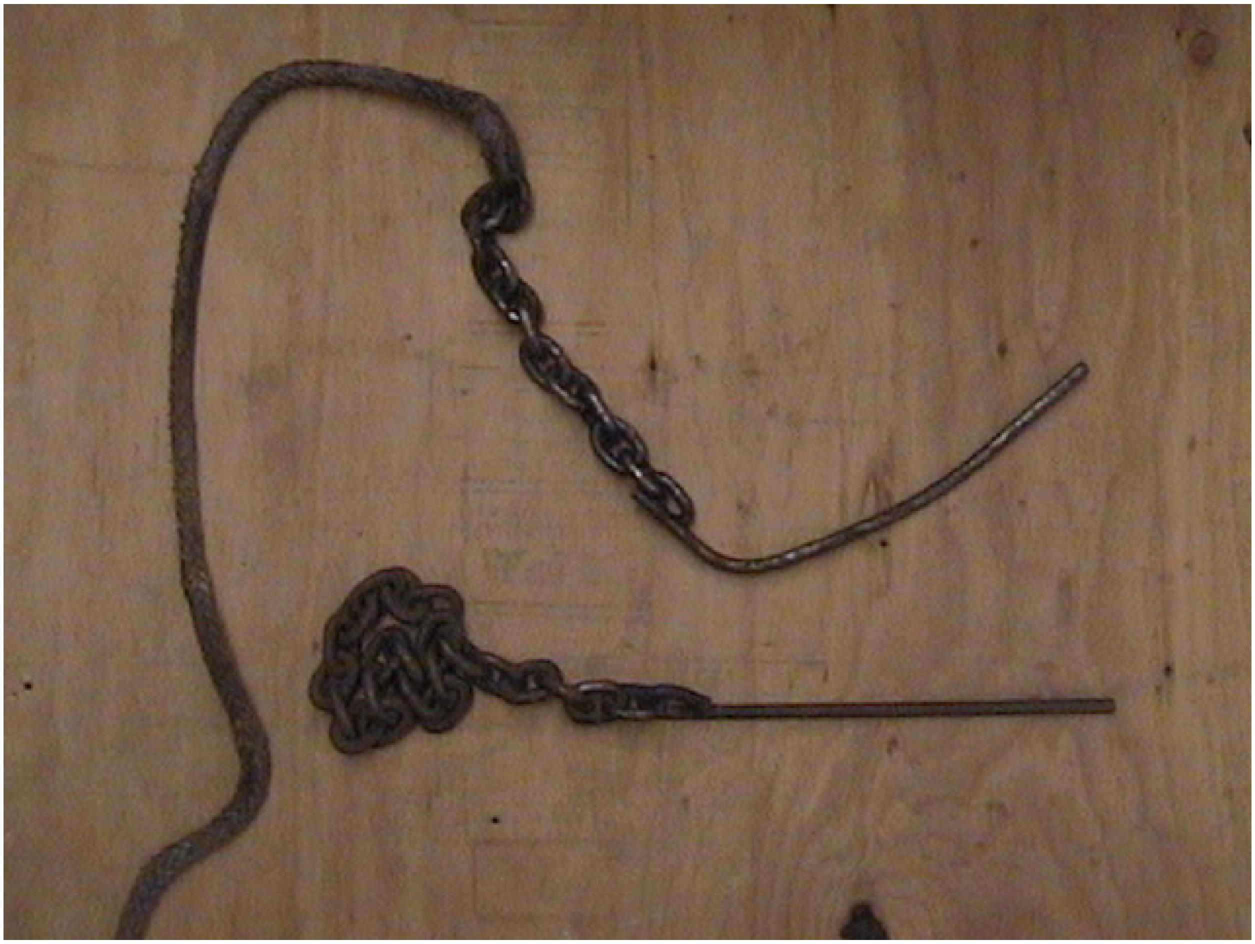

Figure 41. A short length of 5/16-inch diameter steel rod was added to the end of one chain to facilitate feeding the synthetic choker under a log and feeding the chain into the Farmi slider (see Fig. 40). The rod was heated, fed through the chain, looped closed and welded shut. With use, the rod tends to form a curve that aids in feeding it through the choker hole.

X. Handling of Synthetic Rope

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 of the reel with it 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. Rope should never be taken from a reel lying on its side.”

Ropes with 12-strand construction, such as the synthetic ropes 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.

There will be numerous ways to handle synthetic rope but some current users simply coil the rope like an electrical drop cord. Some just throw the rope coils in a back pack. Others have devised ways to pack the rope as in Figure 42.

Figure 42. Synthetic rope guyline coiled for ease of carrying (not possible with steel guylines). This technique is adapted from rock climbing.

Various methods of packing rope for transport are possible. While coils do not stay as neatly circular as steel wire rope, it can be coiled in this fashion. It may also be “flaked” or “flaked out” by creating a FIGURE 8 pattern. This figure 8 coil can be carried across the shoulders by placing an arm in each loop of the “8”. The practice of halving the rope length by bringing the ends (eyes) together prior to coiling or stuffing helps prevent tangles and knots.

Finally, we have found some operational improvements using synthetic rope:

- Safety is improved with lighter loads. Balance is improved. Lighter loads will likely reduce trip and fall hazards and their severity.

- Fewer trips for road change and rigging. All required lines and rigging can be moved with one trip across the hillside at times.

- Synthetic rope does not produce jaggers, avoiding laceration and puncture wounds.

- Faster and easier rigging of tail and intermediate support trees. Rigging straps and guylines can be attached to climbing belt on the ground, and raised with the climbing motion.

- Guylines can be pulled “tight” with 1-2 workers, without come-alongs or powered winch. Little to no “belly” resulting in the guyline when rigged. Guyed tree are less likely to move compared to those guyed with steel guylines when a skyline load is applied to the tail or lift tree.

- Work load as measured by heart rates is reduced for logging tasks using synthetic versus steel wire rope.

XI. Wear and Damage Evaluations

It is clear that synthetic rope will not suffer the same abuse as steel wire rope. Changes in operating practices are needed to achieve the benefits of synthetic rope while protecting it from abuse.

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 3 below.

Table 3. 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 synthetic 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 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 43).

Figure 43. Gradation of color with normal use. Shown is the 3/8-inch diameter 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.

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.

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, 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.”

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)

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)

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)

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)

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)

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 44) and decreased up the line (Figure 45). 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 46 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 44. 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 45. Section of skidder winch line from Figure 44 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 46. Section of a 3/8-inch diameter 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). Our research showed a strength reduction of approximately 10, 20 and 40 percent with 1, 2, and 3 cut strands, respectively. Figure 47 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 48 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). This applies to yarns (groupings of filaments which make up strands). Figure 49 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 50). 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)

Figure 47. Severe abrasion in a section of 7/8-inch diameter 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 48. 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 of this section would be a prudent action by the operator.

Figure 49. 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 50. 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.

Avoiding Severe Abuse of Synthetic Rope

It is clear that synthetic rope is not as resistant to abuse as is steel wire rope. Operators simply cannot assume that synthetic rope can be treated like steel wire rope. In fact, to achieve the ergonomic benefits with 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 51).

Figure 51. Grooves shown are cut in ½-inch steel plate by steel 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 strands, with a 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.

XII. Splicing Instructions

Splicing of synthetic ropes for creation of eyes and long splices typically used in logging operations is significantly easier and faster than with steel wire rope. The process involves burying a tail section either into itself (eye) or into another rope (long splice). An aluminum needle with a hollow end called a “fid” is used for splicing synthetic ropes. The Manufacturer uses the fid as a measuring device to assist in splicing. As shown in Table 4 below, the fid lengths can be related to actual measurements in inches. Following the Manufacturers guidance on splicing can help assure that splices will achieve desired strengths. We cannot assure that deviations from the recommendations will be successful.

Table 4. Lengths of buried tail and bury sections for various diameters of synthetic rope required to construct buried eye and long splices.

LENGTHS OF BURIED TAIL and BURY SECTION for SYNTHETIC ROPE SPLICING
(APPLICABLE TO EYE AND LONG SPLICES)

ROPE DIAMETER	SPLICING FID LENGTH		Length of Buried Tail Tapered tail			Length of Bury Section For inserting Buried taper tail	
(inches)	(inches)		Fids	Inches		Fids	Inches
3/8	8		3	24		3.5	28
7/16	9		3	27		3.5	32
1/2	11		3	33		3.5	39
9/16	12		3	36		3.5	42
5/8	13		3	39		3.5	46
3/4	16		3	48		3.5	56
7/8	18		3	54		3.5	63
1	21		3	63		3.5	74

NOTE: Based on splicing instructions for Samson Rope Technologies AmSteel®-Blue ropes.
Lengths may vary by rope manufacturer, rope construction, and rope fiber.
Mention of trade names is not an endorsement by OSU or OR-OSHA.

Splicing Guides

Specific splicing guides have been prepared with the help of Mike Lulay of OR-OSHA and are available at the agency website for the Buried Eye Splice and Long Splice.

http://www.cbs.state.or.us/external/osha/pdf/education/7g_eyesplice12strand.pdf

In addition, Samson Rope Technologies provides splicing guides on their website at:

http://www.samsonrope.com

Splicing is easy and can be performed by an individual quickly. The Loggers 3 tuck eye splice (steel) is replaced with the Buried Eye Splice (synthetic). The Loggers Long Splice (steel) is even easier with the End for End splice (synthetic). Neither of the synthetic splices has exposed tails like steel splices which are potential injury (lacerations and puncture wounds) mechanisms. Used and declining condition synthetic ropes do not develop JAGGERS -- a source of lacerations and puncture wounds.

XIII. References

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