FPInnovations

WIRE ROPE INTEGRITY IN WINCH-ASSISTED HARVESTING OPERATIONS

A GUIDE TO WIRE ROPE HANDLING AND INSPECTION FOR MACHINE OPERATORS

Steep Slope Initiative 2017

Definitions

Minimum breaking strength: Minimum load required for the wire rope to fail.

Elastic limit: The load limit at which the wire rope will, when the load is removed, return to its original length without incurring damage. Usually defined as 60 to 65% of the minimum breaking strength. If a strain is applied beyond this limit, the wire rope is damaged immediately, resulting in a permanent reduction of the strength. Cease operations and replace the rope.

Endurance limit: Occurs at 50% of the wire rope's minimum breaking strength. When a rope is repeatedly strained past this limit, its lifespan is reduced and failure may occur even if tension does not reach the elastic limit or breaking strength.

Safe working load: Refers to the maximum weight a wire rope can handle without the rope incurring damage. It is a fraction of the minimum breaking strength divided by the safety factor, and is often specified by the manufacturer.

Strength efficiency: Refers to the breaking strength of an end connector. Usually denoted as a function of the rope's breaking strength.

Lay: Has different definitions in the context of wire rope. (1) The length of wire rope required for one strand to completely spiral around the rope. (2) The direction in which the rope's strands rotate or lay (e.g., right lay vs. left lay). (3) How the strands are assembled in the rope relative to the wires (e.g., regular lay vs. lang lay).

WIRE ROPE INTEGRITY IN WINCH-ASSISTED HARVESTING OPERATIONS

This guide provides machine operators who work in winch-assisted harvesting operations with best practices guidelines for handling wire rope. It offers guidance on damage prevention, inspections, end connectors, storage, and rope management during harvesting operations. Following these best practices is essential in order to maximize the service life of the rope and to prevent accidents.

WIRE ROPE INTEGRITY IN WINCH-ASSISTED HARVESTING OPERATIONS

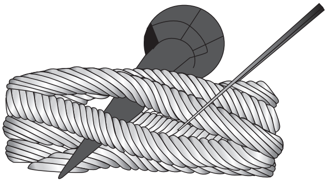
To ensure the safety of workers during winch-assisted harvesting operations, it is essential that operators inspect the wire rope regularly and according to best practices. The objective of an inspection is to determine rates of deterioration and to detect any damage that may affect the rope's integrity.

Best practices regarding wire rope inspections are:

- Schedule periodic, thorough inspections according to the manufacturer's or regulator's recommendations, or at least every 100 hours of operation.If the manufacturer's instructions for inspection and criteria for rope replacement are not available, use the criteria outlined in ISO 4309 (outlined here in Section 2).
- Visually inspect the rope's entire length and all attachment points before every use. If significant changes to the rope condition are observed, conduct a thorough tactile and internal inspection.
- When visually inspecting a rope, check for the following defects:
    - Broken, worn, or abraded wires
    - Reduction in rope diameter
    - Rope stretch

- Corrosion
- Crushed, flattened, or jammed strands
- Other defects: birdcaging, kinking, and core protrusion

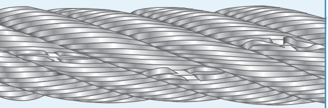
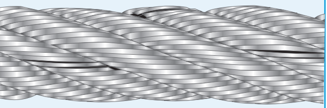
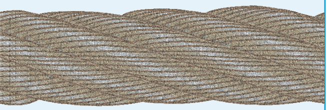
- Visual and tactile inspections provide information about the visible outer wires only, which account for only 20% of the cross-sectional area. To obtain detailed information about the condition of the internal rope, use a marlin spike or an electromagnetic wire rope inspection system.
- Cut off damaged rope sections, if practicable.
- Remove broken wires, to prevent damage to adjacent wires and sheaves. To do this, hold the end with pliers and then bend the wire back and forth until it breaks in the valley between the strands.
- Keep an inspection log. Note the inspection dates and the details of: hours of use; types of inspections; damage; shock-loading incidents; and any wire rope sections or individual wires that have been removed, including their location.

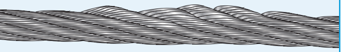
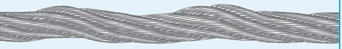
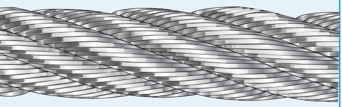


Inspection of a
6-strand rope

COMMON DEFECTS AND DISCARD CRITERIA

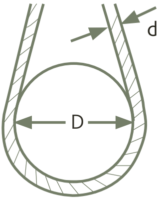
If the wire rope's structure is distorted because of defects such as kinks, birdcaging, or wire/core/strand protrusion, the distorted section must be removed or the entire rope discarded immediately. **Below are some common defects and their discard criteria as outlined in ISO 4309:**

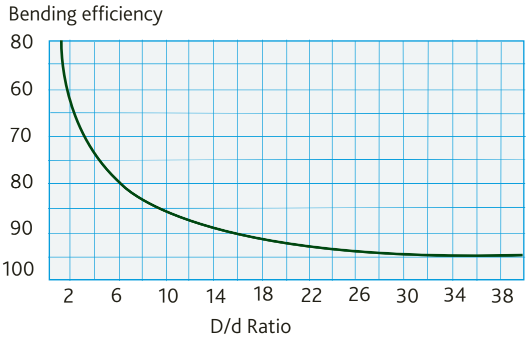
DEFECT	DISCARD CRITERIA
 Breaks: crown wire	Discard or remove section if: • 6 or more randomly occurring wire breaks are found over a lay length, or • 3 or more breaks occur in a single strand in one lay, or • 2 or more wire breaks occur at termination points.
 Breaks: valley wire	Discard or remove section if: • 2 or more valley wire breaks occur over a lay length, or • 2 or more wire breaks occur at termination points.
 Corrosion	Discard rope if wire surface is heavily pitted and slack, and corrosion cannot be wiped away. Perform internal inspection if signs of internal corrosion (such as corrosion debris exuding from between strands) are visible. Discard if internal corrosion is confirmed.

DEFECT	DISCARD CRITERIA
 Flattened portion	Flattened portions wear more quickly. Inspect them more frequently for broken wires and corrosion damage.
 Changes in rope diameter	Discard the rope or remove the section if there is an obvious localized decrease in diameter caused by failure of a core or rope centre, or by a sunken strand. When non-localized changes in diameter are found, discard the rope if the changes in diameter exceed 7.5% of nominal diameter.
 Waviness	Discard the rope or remove the section if the gap (g) between the underside of the rope and a straightedge is 1/10 of rope diameter (d) or greater.
 External wear	External wear will cause the diameter to decrease and will result in broken wires. See discard criteria for wire breaks and changes in diameter, above.

Wire rope in operation is subjected to several kinds of stresses that reduce the rope's strength and service life. The most common stresses are outlined here.

Bending fatigue: The main cause of bending is where a rope passes over a sheave or drum. The difference in the diameters of the inside and outside of a rope passing over a sheave results in uneven stretching of the rope. As the ratio of sheave diameter to rope diameter decreases, wear caused by the bending increases exponentially. This results in broken wires and a reduced rope lifespan.





To prevent and mitigate bending damage to the rope:

- Follow the manufacturer's specified minimum D/d ratio. If the manufacturer's instructions are not available, maintain a minimum ratio of sheave diameter to rope diameter of 16:1.

Sheave/rope diameter ratio[a]	Efficiency of rope (%)
(D/d)	79
12:1	83
14:1	86
16:1	88
18:1	90
20:1	91
24:1	93
30:1	95

[a] Ratios of 10:1 and less will lead to permanent distortions within the rope.

- Keep the bending direction consistent. Once the rope has been cycled, the bending direction is set. Reinstalling the rope in the opposite direction will result in increased wear.
- Keep the rope lubricated according to the manufacturer's specifications.
- A rope made with many smaller outer wires per strand, fibre cores, and/or lang lay is more resistant to bending fatigue.

FAILURE MECHANISMS

Abrasion damage: Abrasion occurs when the rope rubs against an external source such as a rock outcrop, a different section of the rope, or a component of the rigging. To prevent and mitigate damage to the rope due to abrasion:

- Avoid running the rope on the ground, over rocks, or around sharp bends.
- Use a heavy-duty chain segment near the harvesting machine and in other high-wear areas.
- Move the anchor or anchor machine as needed to prevent cable contact at ground breaks.
- Before every use, inspect the wire rope for surface wear, nicks, cuts, broken wires, or changes in diameter. Some types of rope (e.g., swaged) can appear normal even when worn out, so it is important for the operator to know the characteristics of the cable type.
- Lang lay ropes, ropes with fewer larger wires, and ropes with a higher content of carbon content are more resistant to abrasion.

Tensile overload: Tensile overload occurs when the rope experiences an axial load that overwhelms its strength. The result may be a loss of rope strength or even rope failure. To prevent overloading of the rope:

- a tension monitoring and recording system. Review tension log data daily, and whenever shock loading is known or suspected to have occurred.

- Avoid loading the rope above the safe working load specified by the manufacturer. (Note: The wire rope's safe working load must be downrated according to the efficiency rating of the weakest termination type in the system. See Section 5.)
- Cease operations and replace the rope if tension ever exceeds the elastic limit. If tension exceeds the rope's endurance limit, its lifespan will be reduced.

Temperature damage: Wire rope can also be damaged by exposure to extreme temperatures, which can occur when the rope rubs against trees or stumps during operations. For IWRC wire rope, exposure to temperatures of 93°C and above will result in downrating of rope strength. For evidence of heat damage, look for charring of wood where the rope has contacted the tree or stump (charring occurs at 120 to 150°C). WorkSafeBC regulation OHSR 15 defines the temperature exposure limit for wire core rope sling as 205°C.

FAILURE MECHANISMS

It is essential for the operator of a winch-assisted harvesting machine to understand that the rigging system is only as strong as the weakest link. In fact, the weakest part of a winch-assist rigging system may be at the end of the rope, where it connects to another segment such as a length of chain. Because of this, the breaking strength of the rigging system must be downrated according to the strength efficiency of the weakest connector. Section 6 lists the strength efficiency of end connectors.

The most common end connectors used in winch-assisted harvesting operations are:

Spelter socket: Molten zinc or an epoxy compound is poured into the socket to bind the wire rope into the fitting. Spelter sockets are the strongest end connections currently available. However, they must be installed at a workshop, which makes them impractical to replace in the field. Installing with resin can be done in the field by a trained technician, but the process is time consuming because it may take hours for the resin to set.

Wedge socket: The rope is looped around a wedge that is inserted into the socket and held in place by tension. Wedge sockets are common in winch-assist operations because they are fast and easy to install in the field. Incorrect installation can result in uneven loading and a significant reduction in strength.

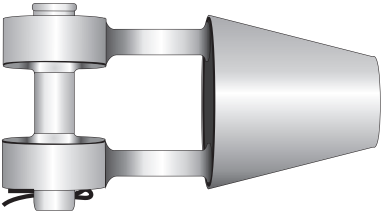
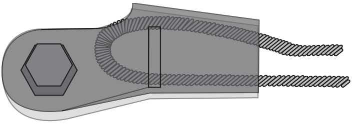
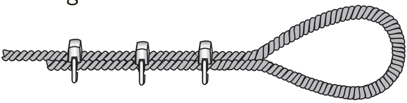
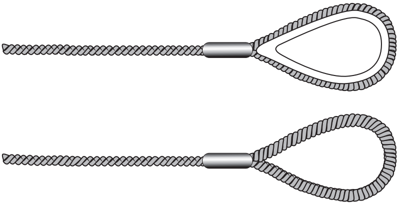
Flemish eye with pressed ferrule: Also called farmer's eye. It has a high strength efficiency (92 to 95%) when fitted with a pressed ferrule, yet this can only be done at a workshop. Without the ferrule, the Flemish eye serves as a quick temporary splice. Thimbles add strength and prevent rope damage.

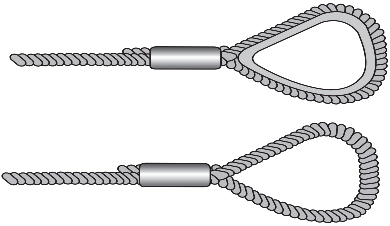
Soft eye with pressed ferrule: A soft eye is often fitted on the wire rope by the supplier. It provides a strong connection (90 to 95%). However it must be fitted at a workshop, so it is not practical to replace in the field. Ferrules also tend to fail more frequently if dragged on the ground, due to their material composition. Thimbles add strength and prevent rope damage.

Spliced eye: Also called logger's splice. It is the most common end connector in winch-assisted harvesting operations due to its ease of preparation in the field and its popularity in cable-harvesting operations. It also pulls easily through the block and is easy to inspect. However, the sliced eye is not the strongest connector (~80% efficiency). Using a thimble adds strength and prevents eye deformation.

Split wedge ferrule: This connector is commonly used in winch-assisted harvesting operations because it can be installed quickly (in minutes) and because of its popularity in cable-harvesting operations (most loggers are familiar with this connector). It is lightweight and easy to handle; however, knowledge of its strength is limited. If not fitted correctly, overloading of one strand may occur and in turn cause frequent wire breaks or rope failure. A split wedge ferrule must not be used with swaged rope.

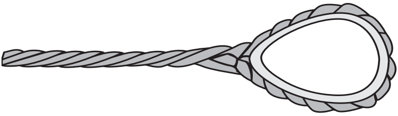
STRENGTH EFFICIENCY OF END CONNECTORS

ATTACHMENT OR SPLICE	Efficiency (% of rope strength)
 Spelter and swaged socket	100
 Wedge socket	70 to 90
 Cable clips	80
 Flemish eye with pressed ferrule	92 to 95 (+6 with thimble)



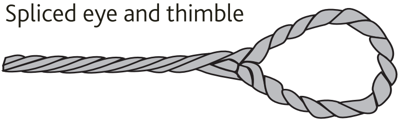
Soft eye with pressed ferrule

90 to 95
(+6 with thimble)



Spliced eye and thimble

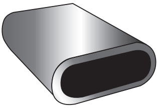
80 to 88



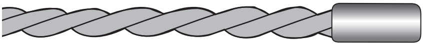
Spliced eye without thimble

<80

Swaged ferrule



80 to 90



Split wedge ferrule

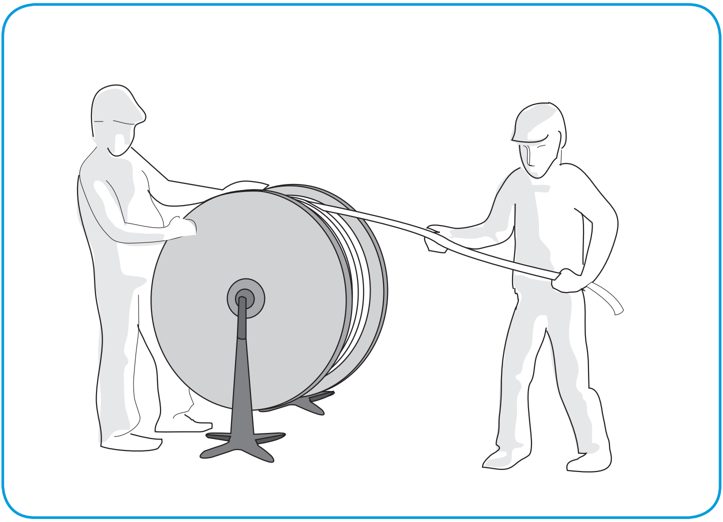
Unknown

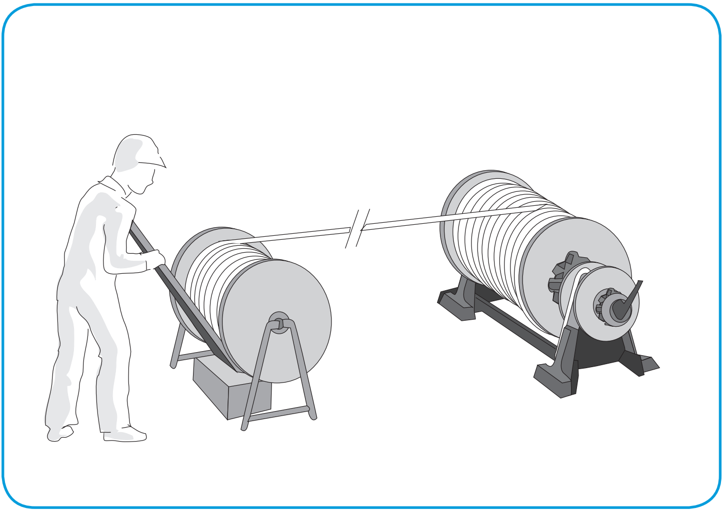
STRENGTH EFFICIENCY OF END CONNECTORS

STORAGE AND HANDLING

The service life of wire rope used in winch-assisted harvesting operations can range from 1500 to 2000 hours. Best practices for spooling, storage, and handling of wire rope in order to maximize service life are:

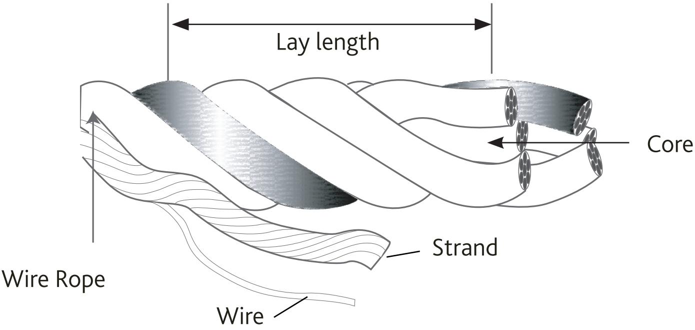
- Keep the wire rope lubricated. Use the manufacturer's recommended method and lubricant.
- Before lubricating a wire rope, clean it with a wire brush to remove fine particles and dirt.
- Keep the wire rope off the ground to avoid it coming into contact with fine particles and other contaminants.
- Store wire rope in a clean, ventilated, dry place without exposure to chemical fumes, corrosive agents, acid, or ocean spray.
- Keep wire rope away from heat, such as steam or hot water.
- Periodically "upend" the wire rope (switch it end-for-end), in order to distribute wear evenly.
- Rotate the reel occasionally in order to distribute the lubricant.
- When uncoiling or installing a wire rope, position the reel so that the rope is spooled top-to-top or bottom-to-bottom, in order to keep bending direction consistent.
- When uncoiling or installing a wire rope, pay out the rope in a straight line with minimal slack to avoid causing turn in the rope, which can result in kinks, loops, or bends.

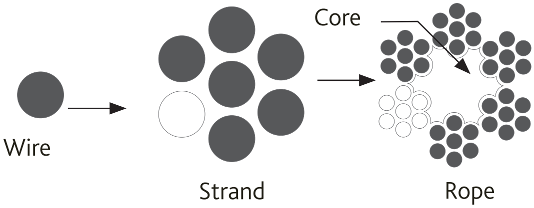




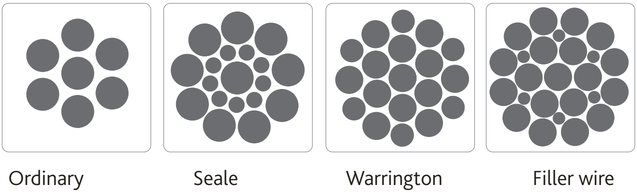
Correct spooling techniques

The three structural components of wire rope are: wires, strands, and a core

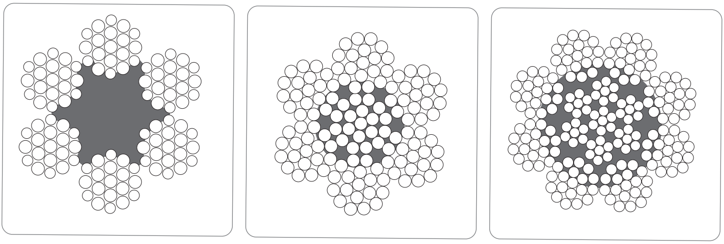




Rope construction refers to the combination and arrangement of wires around the core. Common constructions include ordinary, Seale (S), Warrington (W), Warrington Seale (WS), and filler wire (Fi). Cores can be constructed from fibre (FC), wire strand (WS), or independent wire rope (IWR).



Common wire rope constructions



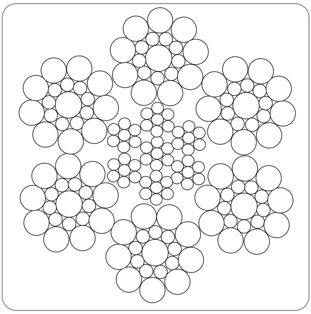
Fibre

Wire strand

Independent wire rope

Types of wire rope cores

Rope nomenclature follows this format: number of strands, number of wires per strand, rope construction, and type of core. **For example:**



6x19S + IWRC

- 6 strands
- 19 wires per strand
- Seale construction
- Independent wire core rope

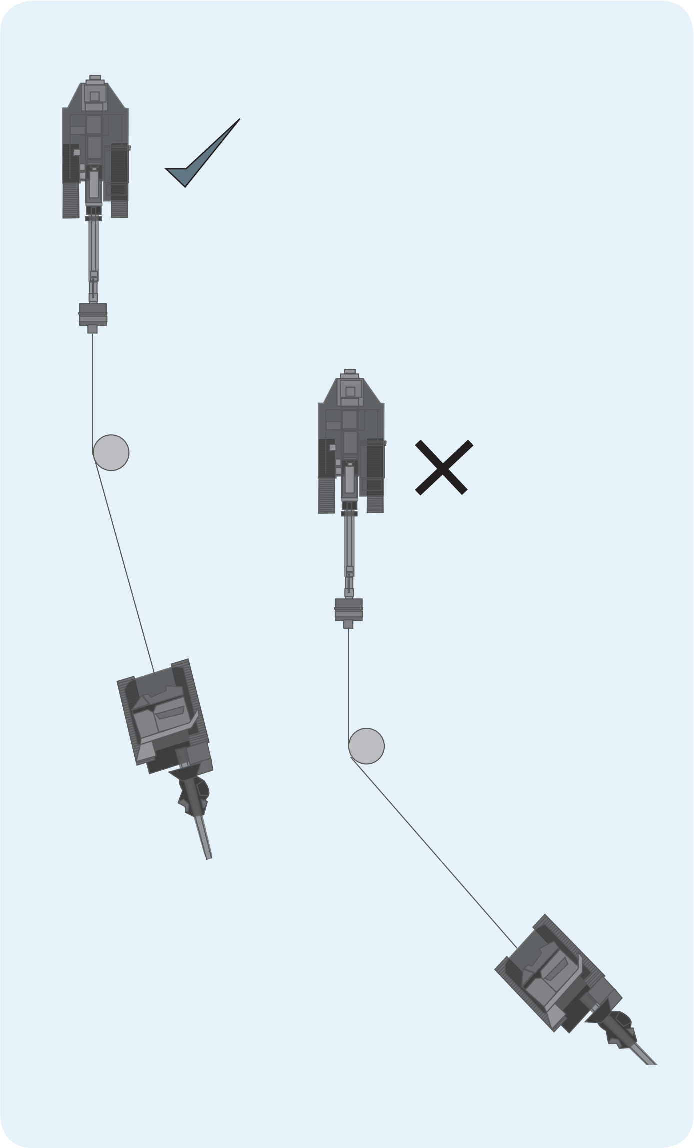
Each construction has unique strengths, so wire rope selection becomes a compromise between attributes. For example, there is an inverse relationship between bending fatigue resistance and abrasion resistance: ropes with many smaller wires are resistant to bending but are susceptible to abrasion, while the opposite is true for ropes with fewer bigger wires.

ROPE MANAGEMENT DURING OPERATIONS: CATCHING AROUND STUMPS

The practice of using a stump or a tree to change the direction of the tethered machine is known as catching. Catching the wire rope around an object helps maintain a proper lead angle. And, catching can help the base machine cover more ground and therefore avoid changing the location of the anchor machine. However, catching presents many hazards: the stump or tree used for catching may move, potentially causing uncontrolled movement of the machine, shock loading of the cable, and machine upset. Catching can also lead to rope tension being different above and below the stump, which can result in inaccurate tension readings. The abrasion and high temperatures resulting from friction around a stump will result in increased wear of the wire rope. In some cases, the rope may even cut into the stump and become wedged.

Some manufacturers' guidelines allow catching but with restrictions. To mitigate hazards associated with catching:

- Keep deflection angles as wide as possible (see picture below).
- Do not catch around any objects that may move during operations.
- Avoid using trees for catching because they can be more unstable than stumps.
- Check a catched stump frequently, to confirm its stability.
- Ensure the diameter of the catched stump is large enough to avoid distortions in the rope due to bending (see Section 3).
- Position the rope to avoid unintentional catching.
- Note that catching may result in inaccurate tension readings, which means shock-loading events may go undetected.
- Avoid catching during periods of high fire hazard.



ROPE MANAGEMENT DURING OPERATIONS: CATCHING AROUND STUMPS

Typically an excavator or bulldozer is modified to act as an anchor for the winch system's base machine, but other objects such as stumps, trees, deadmen, and rocks may be used as anchors.

Machine anchors:

- Use an anchor machine with a low centre of gravity and a low cable-exit point to prevent overturning.
- Position the machine on level or upsloping ground whenever possible.
- Position and secure the machine to prevent any sideways rotation or downslope movement.
- To ensure stability, apply the anchor machine's track brakes; place the machine's s blade or bucket against a tree or stump, or dig it into the ground; and use guylines to anchor the machine to one or more stumps on the uphill side. Ensure the guylines are tight and forces are equally distributed.
- A longer rope deployment may add extra ground friction resistance to the anchor system and help improve the anchor's resistance to movement.
- Install and use a tension monitor that relays information to the operator of the base machine.
- Install and use video cameras to provide the base machine operator with a live feed of cable spooling on winch drum.
- Install and use an anchor movement alarm (break-away switch) that signals the operator and applies the winch break if the anchor machine moves.

Stumps and trees:

- Use appropriately sized stumps and trees. See the Cable Yarding Systems Handbook (WorkSafeBC, 2006).
- If using multiple stumps or trees, follow the accepted tie-back procedures described in the Cable Yarding Systems Handbook (WorkSafeBC, 2006).
- Where necessary, notch stumps as per standard cable-harvesting methods.

- Anchor straps must match or exceed the safe working load of the wire rope.
- Use caution if rigging a block purchase to redirect the rope's force, because forces on the anchor can become large, depending on the angles involved.
- Deadmen and rock anchors:
- Instructions for selecting and installing deadmen and rock anchors are in the Cable Yarding Systems Handbook (WorkSafeBC, 2006).

For more information on the Steep Slope Initiative program go to:
http://steepslopeinitiative.fpinnovations.ca

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About FPInnovations' Steep Slope Initiative (SSI)

The Steep Slope Initiative is a five-year plan (2015 to 2020) to engage forest industry members, equipment manufacturers and distributors, regulators, and other stakeholders in building a common vision and strategy for overcoming the challenges of harvesting on steep slopes.

FPInnovations' Steep Slope Initiative is centred on three goals:

Improve worker safety

Increase operating margin

Increase access to currently unavailable fibre

REFERENCES

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maintenance, inspection and discard.

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Harrill, H & Visser, R. 2017. Wire rope end connectors for winch-assisted machines. Harvesting Technical Note HTN09-05. Future Forests Research Ltd. Rotorua New Zealand.

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