CASE STUDY: DETERIORATION OF WIRE ROPES USED IN CABLE ASSIST HARVESTING SYSTEMS

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2. ABSTRACT

The introduction of cable assist harvesting systems in NZ forestry has the aim of improving forest worker safety by getting more staff off the ground and out of harm's way. The wire rope used to tether the felling machine back to the winch machine is an integral part of the system whose condition must be monitored for safe machine operation. At present inspections of these ropes is generally conducted by the operator to standards that vary based on management requirements and experience of the operator. Up until this point no formal research has been conducted using electromagnetic non-destructive testing (NDT). This project was carried out with Hancock Forest Management, six of their harvesting contractors and with scanning provided by Shaw's Wire Ropes.

The ropes used in all systems were subjected to an electromagnetic NDT scan measuring prevalence of wire breaks, loss of metallic area and internal corrosion with the ropes being assessed against ISO standard 4309 of 2010. Alongside the NDT scans a questionnaire about the machinery, the rope(s), the operator and the operating practice was put to the crew foremen and machine operators. The questionnaire results and wire rope certificates from the NDT testing was then analysed to assess the wear and deterioration of the wire ropes of the six systems.

Cable assist ropes were found to be wearing well given the harsh conditions they work in. NDT failure resulted from instances of mechanical damage and valley breaks in the rope. Other need for rope replacement was found to be largely a result of loss of length of the rope from damaged sections being removed and regular replacement of the rigging at the working end of the rope. Longer term deterioration patterns were not detected to a significant degree and are thought not to be developing due to the short rope lifespan. Abrasive wear is minimal, corrosion is minimal and internal wear and bending fatigue were not found to be prevalent. Instances of drum crushing were found on the longer rope winch systems and could become more of an issue in future with longer ropes now being installed on these machines.

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3. INTRODUCTION

3.1 The Problem

Tree falling is one of the most dangerous tasks within the NZ's forest industry, with faller deaths accounting for around 41% of all historic deaths in the industry. The last few years have seen the introduction of tethered harvesting machines keeping falling workers out of harm's way.

These systems are generally composed of a felling machine as would be used on terrain up to around 50% slope that is 'tethered' by a wire rope and winch to an anchored bulldozer or excavator further up slope. The winch assistance allows the felling machines to climb back uphill more easily on steeper terrain, providing access. It is generally considered that cable assisted machines should be able to operate up into the range of 75%-85% slope (Cavalli R. , 2015)

One of the most important parts of this system is the wire rope or ropes that are used to connect the felling machine to the winch machine. These wire ropes are currently the same ropes as would be used on cable haulers as mainlines or skylines. The issue with their use in the winch assist operation is that very little is known about the deterioration of the ropes being used, and therefore their expected lifespan. The implications of this are twofold: firstly, the contractors and people operating the machines need to know what types of rope failure are expected so they can pick up on these and replace the ropes as necessary, and secondly, new health and safety law in NZ requires everyone in the chain of supply and use of these ropes to have some knowledge of how these ropes should perform in their end use. The New Zealand Approved Code of Practice for production forestry also requires machine and wire rope inspection and maintenance routines. (Ministry of Business, Innovation and Employment New Zealand, 2012)

The biggest issue here is with health and safety. These ropes are being used in conditions they were not directly designed for. The ropes are being dragged through mud and dirt, pulled around trees and rocks, and spend most of their time outside in the weather. Trees and rocks are far from being ideal sheaves for a rope to be worked over, and there are no rope lifespan models in literature for anything other than a running sheave in ideal conditions.

The wire rope as used in this application is considered a consumable, it is something that wears over time and will be replaced once worn out. In other industries, ropes last much longer than in this application. 12 months for a cable assist machine is considered a reasonable life, whereas 30 years can be had from a ski lift rope but the price difference is more substantial too. A 500m cable assist rope costs around $10,000 but a ski lift rope can cost $150,000.

This dissertation aims to give a description of how wire ropes are wearing in this use. This report considers the reasons wire ropes are failing NDT inspections and also aims to determine where the main wear on the ropes is occurring.

At this point in time there has been no direct investigation into the deterioration of wire ropes used in this context by means of non-destructive testing (NDT). Research exists for the loads imposed on the ropes, the extent of maximum slope for these machines, and their effect on productivity for harvesting operations. With more knowledge about the types and extent of deterioration of wire ropes still in service, it would be possible to better direct future inspection schemes and further research in this area.

3.2 Existing Information

Research has been conducted around the tensions being experienced by cable assist winch cables in use, and has highlighted that the tension within the rope can exceed the safe working load (SWL) + 25% of the rope (Schaare, Harrill, & Visser, 2016). This equates to roughly 42% of the ultimate strength of the rope. The exact magnitude of the tension spikes in this range is unknown as the equipment was not calibrated for such high loads, but it is still concerning for rope condition. At a load of 50% of the ultimate breaking load (UBL), the rope reaches its endurance limit, where loading above this will cause accelerated deterioration of the rope. Shock loading in this case is very different from the definition in hoisting systems, where even the acceleration of a load off the ground is considered a shock load (Peterka, et al., 2015).

The New Zealand ACoP states that there needs to be best practice guidelines for wire rope inspection in these cable assist machines. In use visual inspection of wire ropes is at times considered an unreliable way of determining wire rope condition, however it remains the most common inspection method used in forestry in NZ. Visual inspections for instance do not easily pick up internal wear and damage. In lab and field tests of 8000 ropes in the late 1980s, it was found that 10% of tested in use ropes were in an unacceptable condition, and 70% of discarded ropes still were still at nearly their initial advertised breaking strength (Weischedel & Ramsey, 1989).

Modern electromagnetic testing equipment can assess wire ropes in a non-destructive manner. The testing equipment can pick up broken wires (local fractures, LF) within a rope, the continuous change in cross sectional metallic area (loss of metallic area, LMA), and the aggregate surface roughness (wire rope roughness, WRR) of the wires within the rope (Ramsey, 1989). The location and number of fractures is only indicative of rope condition, but is good for spotting discrete flaws within the rope. The LMA is a good basis for discard criteria of wire ropes as it gives the area of available steel for strength within the rope and how much the rope has worn mechanically. The WRR is used for determining if there has been any corrosion or pitting within the rope.

Performing tensile tests of used wire ropes does not always give a good indication of the rope condition. In a test performed in 1989 on a mine elevator rope the tensile test suggested a 14% reduction in the advertised tensile strength of the rope, but the rope had lost 28% of its metallic cross sectional area in that section (Weischedel & Ramsey, 1989). This is further complicated by the fact that ropes get stronger with use, plastic deformation of the rope causes work hardening and a corresponding strength increase with time (Chaplin C. R., 1995).

Multi-layer winding of ropes on winch drums causes the outer layers to be supported by intermittent contacts with the rope layers beneath resulting in very high contact stresses (Chaplin C. , 1995). Since in some cases in these machines there are several layers of rope on a drum there is possibility for damage of rope on the drum. Backslip can also occur as the rope is paid onto the drum at high tension and released at low tension, causing the rope to slip by contraction as it unwinds off the drum unloaded. Backslipping can cause accelerated wear of the rope at the drum end (Chaplin C. , 1995).

Bending fatigue becomes an issue for ropes bent over small sheaves, their service life can be shortened drastically if the sheave size is too small. Ideally the sheave to rope diameter ratio should be above 20:1, however a 1 1/8-inch rope on a 40 cm DBH tree has a ratio of 14:1. Wear experienced in these small ratios also tends to be more internal to the rope rather than by external breakages as would normally be experienced with rope bending fatigue (Nabijou & Hobbs, 1994). It is obvious that an external visual inspection is very unlikely to pick up on this type of deterioration. 14:1 D/d ratio also imposes an approximate 5% reduction in the UBL of the system (Casar Wire Ropes, 2004).

Contact length between the rope and sheave is also a contributing factor. Ideally once one lay length or rope is in contact with the sheave the strands are bound together contacting the sheave twice and cannot slip. However, if one lay length is not in contact, interstrand movement is still occurring, and at high bearing stresses which accelerates the rate of wear in the rope (Feyrer, 2015). For a 1 1/8-inch rope bending on a 35cm tree, a bend of 47 degrees is required to reach full bending.

In other lab testing accompanied with NDT testing, higher than normal rope loading at 50% of ultimate breaking load (UBL) as opposed to 30% UBL has highlighted that degradation is primarily in the form of broken wires and fatigue rather than in LMA. It was also found that as the number of bending cycles increases, the rate of deterioration increases at an accelerating rate (Bartels, McKewan, & Miscoe, 1992).

Service life also varies depending on the material that the rope is working on. Zhang, et al. (2013) found that ropes working on softer nylon pulleys last up to two times as long as steel ropes for the same loading. The nylon pulleys were found to wear the external wires less, internal fretting wear area was found to be larger and service life was ultimately longer as the fretting surface (internal contact between adjacent wires) is smoother so wear rate is slower.

Grit and contamination between ropes and sheaves also has a detrimental effect on rope life. Nabijou (1994) found that sand and mud being placed between rope sheave interfaces can reduce life by up to 80%. Sands, muds and other contaminants are regularly encountered by the winch assist ropes as they are being run along the ground surface, so this may affect deterioration if the grit makes it back into the winch drum or the running sheaves or feed rollers prior to the drum.

Peterka et al. used regular NDT inspections to determine a fracture growth development curve on a wire rope used in a cableway which was then used to determine a rope replacement date. The rope considered was a 6x19 fibre core rope, 26.5mm in diameter, very similar to the 6x26 ropes being used in this forestry application. Rope diameter loss was most extreme in the last year of operation, with 1.9mm diameter loss over the 10-year period of testing. At this location, LMA was found to be 5.38% not including wire breakages, and 7% including. The growth of fractures in the rope was found to be exponential in nature. The rope life was extended safely from 6 years to 13. 6 years with the aid of the NDT testing (Peterka, et al., 2015).

4. METHODOLOGY

The research conducted consisted of two parts, a questionnaire related to the use of the system and an electromagnetic non-destructive scan of the ropes.

4.1 Questionnaire

Before each electromagnetic test, a questionnaire about the machinery being used and the operating practice was carried out with the crew foremen and machine operators. A copy of the questionnaire is given in Appendix 1. The questionnaire had four main sections; the machinery, the rope(s), the operator and the operating practice.

The machinery information will give an indication of how the ropes are being used. Not all the systems work in the same way with regards to rope tension control and slack pulling.

The rope information was captured to see if there would be any links between rope wear and the amount of work each rope has done. Rope hours was one of the major links, as well as the total amount of wood felled on the rope were recorded. Notes were also taken on the operators' inspections of the rope and the criteria for discard.

Information about the operator(s) was recorded to see if there might be a connection between the number of operators, operator experience, and the number of operators who have learnt to operate the tethered system.

Lastly the operating practice was recorded. This was conducted to ascertain if certain practices affect rope life. For instance, length of rope run out might highlight sections of rope that are more worn than those that stay on the winch, this can help indicate relative rates of wear.

4.2 Non-destructive Test

Non-destructive electromagnetic tests were carried out on the ropes of the 6 systems, to assess them for further use in this application. Allowed wire breakage rates are three adjacent wires in a single strand, six breaks in six wire diameters and 14 breaks in 30 rope diameters. The NDT gives information in the location and prominence of broken wires in the wire rope, and an indication of the actual wear of the rope by giving a percentage of the loss in metallic area from the most worn section relative to that of the best section.

The non-destructive testing is a very simple procedure. The NDT equipment is taken to site for the inspection, and consists of three parts; the magnet which is used to magnetise the rope and contains the sensors that pick up the electromagnetic signals, a signal converter, and a computer that is used to collect and process all the NDT data. Figure 1 shows the NDT electromagnet prior to one of the tests.

Figure 1: The NDT electromagnet prior to one of the tests

Before the test, the rope is magnetised, a procedure that only has to be conducted once per rope. For each system in this investigation, this was the first inspection and so the magnetisation was performed before each test. The NDT machine is placed around the rope at the winch machine end, and the full length of the rope is paid out though the NDT tester by walking the felling machine away from the winch machine. The test itself is then performed as the rope is drawn back on to the winch.

Not the entire length of every rope was tested. In all cases a given number of wraps need to be left on the winch drum, leaving a small length that runs from the drum out to the winch fairlead where the testing is run.

5. RESULTS: CASE STUDIES

Each study is presented individually, the description of the system and operating practice is given first, followed by the results of the NDT test. In each case machine weights are including a winch where applicable.

5.1 System 1

System Description

The first system tested consisted of a 39 tonne Sumitomo SH330 anchor machine, the winch is mounted at the on the back of the machine above the engine and pays rope out over the boom of the excavator to the 39 tonne Tigercat LS855C self-levelling felling machine. The winch in this system is limited to 22 tonne pull, it theoretically should not pull greater than this load and should slip if the felling machine pulls a load greater than 22 tonne on the rope.

The end connector between the rope and chains to the machine was a spliced eye going through a bow shackle onto the chain connected to the felling machine. Wedged sockets were used initially but were changed to spliced eyes as this was the contractors' preference. Figure 2 shows the end connection at the day of the test.

Figure 2: Spliced eye rope end connection used by system 1

A 1 1/8 inch 6x26 IWRC steel core swaged wire rope was used in this system. The rope had been in service for 10 months at the time of the test, and in that time had accrued approximately 1500 hours. The initial length of the rope was 440m, and there was 260m at the time of the test. Some of this loss of length is attributed to routine replacement of the splice at the end of the rope due to wear and damage, however a 100m length section was removed due to the rope getting caught in the fairlead and being damaged. The rope had not been end for ended during its life.

70-80% of the crews 400m^3/day target was being felled using the tether. The machine works approximately 8 PMH per day. That puts the rope at having felled approximately 80,000m^3 of wood in its service life so far.

The operator interviewed was the sole operator of the machine and he had learnt to operate the tethered machine on this rope. His experience consisted of three years felling before being moved to the tether.

Felling is only conducted for the crew that owns this machine. Initially the machine would be caught on steep slopes by the rope as it slipped or the rope did not pay out at the same speed as the felling machine resulting in shock loads. Turning up the overspeed on the winch has eliminated this issue alongside more experience being gained by the machine operator with time.

Typically, the maximum length of rope being paid out was the full 240m allowed by the electronics controlling the winch. Trees are used all of the time to change the direction of pull of the wire rope. The operator commented on the importance of knowing where the rope is being run, so that he can know whether there is possibility of a tree or stump falling over and thus whether to expect a jolt being passed through the rope. The time the felling machine is spending over 35 degrees was unknown, but they are at times checking the slope the machine is working on. Comment was made that they had recently checked a slope they thought to be very steep, and turned out to be 23 degrees.

The rope in this system was planned to be replaced sometime soon after the testing, the wear itself is of no issue, the rope was in good condition but in practice the reduced length was too short to enable effective use of the tethered system.

Overall the impression gained from the operator and the foreman was that they were taking particular care in looking after their equipment. They were recording all information about rope installation, dates splices are changed, and machine calibration. The operator is regularly inspecting the rope for damage and removing damaged sections as required.

Rope Condition

The condition of this rope for the amount of work it had done was surprising. The NDT indicated only 3 wire breaks in the entire length of the rope, one each at 48m, 142m, and 146m. These breaks were all in the long working section of the rope, and there were no breaks in the last 100m of rope. This is likely because the first 150m is doing more work than the remaining 100m. The wear as stated in the NDT certification was normal/ medium. There was slight corrosion, and no kinks or bending. Some slight flattening at the drum end of the rope was observed.

This rope was in very good condition and was by far the rope with the highest number of work hours. The need for replacement was apparent in that they were running out to the full length of the rope and greater length was required. Based on the observed condition of the rope, it could be used for many more hours.

Analysis

This rope was one of the best tested even for the hours it had worked. The rope condition is likely to be good as they are taking good care of their equipment, regular rope inspections are removing damaged sections that would otherwise fail it in a NDT inspection. They are also averse to pushing the machine to its limits, with the steepest of slopes still being felled manually.

5.2 System 2

System Description

The second system tested consisted of a 35 tonne Caterpillar 329 excavator winch machine working with a 41 tonne Caterpillar 552 self-levelling felling machine. The winch system was twin drum having the winches mounted on the back of the anchor machine and the ropes paying out over its boom.

In this system two 7/8 inch IWRC steel core power swaged ropes were being used and connect independently to the chains on the felling machine. The tension in the two ropes is intended to be kept even by controlling hydraulic pressure on the winches through the winches electronics. The rope installed was 300m long in November of 2015. There was approximately 600 hours on this rope and at the time of testing the rope had not been end for ended. Connection from the rope to the chains on the felling machine are again by means of a spliced eye.

The timber the machine was felling was 40-year-old pine, so very large. There was also comment that the soils in this area were weak on top, especially so in the wet winter conditions prior to testing. The machine was reported to be slipping quite often and shock loading the rope. It was also stated that due to the weakness of the soil and the steep slopes that the felling machine was having difficulty climbing back up slopes to the anchor even with the winch assistance.

Shovelling as an extraction method is used infrequently, only in cases where wood is blind to the hauler in any given setting. Most of the time trees and stumps are used to change the direction of pull of the wire ropes.

The current operator has two years' experience in mechanical felling, and is one of two that operate the machine. Both of the operators have learnt to work on the tethered machine on this rope. In the process of learning the felling machine has been caught by the rope after sliding on the hill, with experience however the operator learns to manage the equipment in such a way that the ropes stay fairly taut and this jolting is eliminated.

During normal operations, the rope is paid out to a length between 150m to 200m, it was stated that the full length of the rope was rarely let out. It was estimated by the operator that around 5% of the working day would be on slopes greater than 35%.

Comment was made that there is definitely the potential for the wire rope to run over rock at this site. The operator said that he often could not predict when it was going to be an issue, but that the rock is soft and porous. It was also observed that the ropes would twist the chains as torsion is built up on the rope as it is loaded, there was no use of swivel releasing this torque.

Rope Condition

The front winch rope was of a 263m test length. There was medium to heavy wear on the rope itself, slight corrosion, some kinks and bending, but no doglegs or mechanical damage. Most damage was in the first 100m and almost all within the first 150m. 10 breaks overall were indicated by the NDT, first there were two breaks found at 7m both in the same strand. Next there was an internal break at 14m, then 2 valley breaks at 64m, 2 more broken wires at 114m, 2 further internal breaks at 134m and a single broken wire at 264m. Most of the damage can be seen in the first 150m of rope that is working the hardest. Valley breaks are a failure as per the test standard, and this rope failed its inspection and needs to be discarded.

The rear winch rope fared slightly better, there was still medium to heavy wear on the rope but fewer broken wires. The NDT indicated one break at 9m, two outer wire breakages at 20m, a single outer wire breakage at 70m and one inner and one outer at 98m, giving six breakages in total. There was slight corrosion, and kinking, but no bending, doglegging or mechanical damage. This rope failed its inspection also needs to be replaced as per the first.

Analysis

These ropes were in the worst condition of the test set and there could be several reasons for this. Two operators have learnt to work on the tether on this rope, it is not unlikely that the rope would be shock loaded as the operator is learning as the operator has not yet had time to find ways to pay the rope in and out smoothly.

The timber being felled in the blocks this rope has been working is very large. If the felling machine is rocking as it works it could be sending catenary whips that act as shock loads up the rope more frequently than if it were in smaller timber.

Another very important factor is the soil type. The soils at the test site were very weak and as such the felling machine was requiring more winch pull and was slipping on the slope enough to be shock loading the rope regularly. The combination of spending more time at high load and being shock loaded is expected to be the cause of the relatively poor rope condition.

5.3 System 3

System Description

This system consisted of a 36 tonne (estimated) Terex 82-40 bulldozer twin winch anchor machine, and a 37 tonne John Deere 909MH self-levelling felling machine. The twin ropes here were wound onto two ex-hauler drums and rotated together on a common shaft. Each rope terminated at a wedged socket end connector onto a short line that ran through an equaliser block connected to twin chains that connected to the felling machine. Tension in the two ropes should in theory remain constant through the working of the equaliser block. To avoid the two ropes rotating a swivel was used at each end of each working rope. Figures 3 and 4 show the end connection arrangement.

Figure 3: Wedged sockets, hammerlock and swivel system connecting working rope to equaliser section

Figure 4: Equaliser block and hammerlock system used for the rope end connection of system 3

Both ropes were 1 inch IWRC swaged wire ropes. They were first certified in June of 2015 and were of 400m in initial length. The best estimate of the total hours on the rope came from estimating the number of hours from the length of time the machine has been in service. It was estimated by the operator that 20% of the falling is being conducted on the tether. This machine works 8 PMH per day, and in that time the target is to fell 410 – 440m^3. This rope has then likely worked around 12 months, so that comes to 20% of 2000 hours, being around 400 hours. This equates to approximately 22,000m^3 of wood in total. The ropes had not been end for ended at the time of testing and 380m of rope was tested.

This machine has had two operators. The first operator has operated tethered excavators in a civil application and the current one has ten years' steep slope harvesting experience and has had a few months' experience on another tethered machine before starting at this crew. Neither of the operators had learnt to operate the tethered machine on this rope.

The ropes were more worn up to around 300m where there was fairly well lubricated 'fresh' rope between there and the drum. Trees and stumps are rarely used to change the direction of pull of the rope. The steepest felling is still being carried out manually, and it was stated that they thought they were not often over 35 degrees in slope. At the time of the test, this rope was heavily coated in mud and soil. Figure 4 shows how heavily coated in mud the rigging system and equaliser rope was.

Rope Condition

First, the right hand winch rope was tested. There was medium wear on this rope with some slight surface corrosion. There were no kinks, bending or doglegs. There were some small instances of mechanical damage seen on the ropes as seen in the form of minor distortion of the rope strands. Four wire breaks indicated, each individual at 116m, 176m, 256m, and 291m. The mechanical damage was around 245m.

The left hand winch was worn a little more with medium to heavy wear. Again there was some corrosion at the front end, but no kinks, bending or doglegs. No mechanical damage was seen on this rope. Some flattening caused by crushing at the inside of the drum was seen for the end 20 – 40m. There were 4 breaks indicated in this rope, one each at 150m and 211m and two breaks in separate strands at 197m.

Analysis

These ropes were reasonably worn for the number of hours they had worked. The estimate of worked hours is approximate and should not be taken as absolute. The distortion of the strands is likely due to the ropes not feeding onto the winch drum well and at high load. The rope is then being pinched slightly at the beginning of each new layer on the drum.

The wear on these ropes could come from a couple of sources. The winch pull cannot be altered and as such the winch pulls at one load all the time, the result is that the ropes are much more likely to be at a higher load more of the time compared to the other machines tested where line pull is adjustable. The operator made comment that the winch machine can drag the 37 tonne felling machine along level ground without the feller walking its tracks, this implies a substantial load can be placed on the ropes. Winch damage has been seen and poor feeding could also be responsible for the wear. Worth noting is that the left hand winch utilises a left handed drum but runs a right hand lay rope which will wear the rope faster, explaining the accelerated wear on the left hand rope.

5.4 System 4

System Description

The fourth system is the same winch system to the first system. The anchor machine was a Hitachi Zaxis 330 that had a single drum winch, with a total weight of around 38 tonne (estimated). The felling machine was a Hitachi Zaxis 290 excavator converted for forest operations.

The rope used was a single 1 1/8 inch IWRC swaged rope that had 470 recorded hours on it. Crew production was 220t/day and the operator estimated that 75% of this is felled by this system. This puts the rope at having harvested approximately 12,500m^3 of wood in total. The rope at the time of the test had not been end for ended.

Wedged sockets were used initially to connect the rope to the felling machine, but with the difficulty of resetting them spliced eyes are now used. Some reasonable wear has also been found to be occurring between the connections with the chain to the machine. Hammerlocks are wearing reasonably heavily against shackles and both need to be replaced fairly frequently. Figures 5 shows the end connector arrangement, and Figure 6 shows some significant wear between the hammerlock and the felling machine in this system.

Figure 5: Spliced eye end connection and splice of system 4

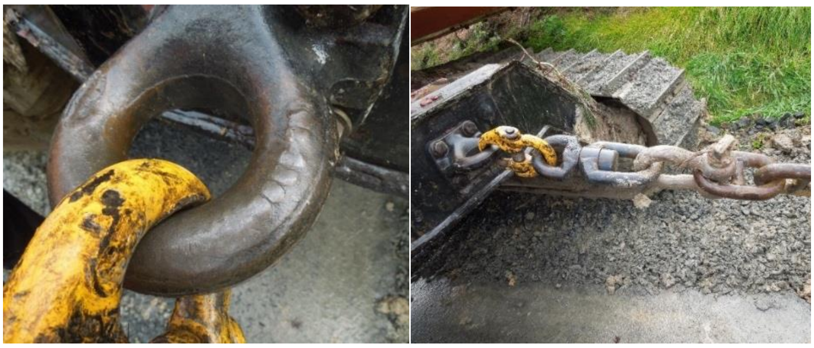

Figure 6: Example of wear between hammerlock and towing eye, and its attachment to the chain on system 4

The operator has 4 years of falling experience and had put all the hours on this machine, he had been operating this tethered machine for 18 months. The operator interviewed predominantly operates this machine, but at occasionally there is another. Two operators have learnt to operate the tethered machine on this rope.

There has never been an instance of the machine slipping on the slope and it being caught by the rope. Generally, 200-300m is the maximum distance of rope being paid out, it only needs to be half of a yarder corridor length as there is approach from both ridges of any given setting at this site. The rope is bent around trees to change the direction of pull all the time as all faces are felled in a herringbone style.

The chains and shackles on this machine are checked daily, and the rope is inspected whenever the full length is run out and the machine is turned off. Both operators walk the length of the rope when it is inspected. This machine was also unusual in that it had an hour clock for the winch itself, that being separate from the winch machines engine hour clock.

Rope Condition

The rope as tested was in good condition, it appeared new even though it had a reasonable number of hours on it. A length of 453m was tested, the wear was normal/medium, there was no corrosion, kinks, bending, doglegs, or mechanical damage. The NDT indicated two broken wires, one at 365m and the other at 418m. There were also some broken wires in the area of the splice, but these would be eliminated with replacement of the splice. Figure 4 shows a cleaned section of the rope at the time of the test.

Figure 7: Cleaned section of rope from system 4. Note lack of discernible wear

Analysis

This is another example of a good condition rope. It still has relatively few hours on it at 470, and with only two wire breaks it is still in very good condition. The rope appeared to be almost new, there was no obvious discernible external wear on the rope itself.

The operator was well aware how this machine is being operated, he knew all the power settings he runs the winch at, and always keeps it at the lowest setting required to pull the machine back up the slope.

5.5 System 5

System Description

This system consisted of another twin rope system the same as that in the second test. The anchor machine was a Hitachi Zaxis 240, with a transport weight of 34 tonne. The felling machine was a Tigercat LS855C self-leveller weighing 39 tonne.

The winch system was an independent twin drum system, with each rope running to its own chain that connects to the felling machine. Both ropes were 7/8 inch IWRC power swaged ropes. The length of the rope at the test was 260m. This was not the full length, the electronics controlling the feed out were limited to 260m and the owner did not know how to reset this limit. The ropes had been installed in April of 2016, giving 80 days at 6 PMH per day to an estimated total of approximately 500 hours. 500-700t/day is felled by this machine as it works fulltime for two crews. The rope had not been end for ended at the time of the test.

Figure 8: And connection between rope, chains and machine on system 5

The operator has 15 years' experience in machine operation and 12 months on this tethered machine. The operator interviewed was the main operator, but at times there is a second. No operators have learnt to work the system on this rope, this is the second set of ropes on this machine for this contractor.

The full length up to the 260m limit is being run out in this system. They are now trying to avoid using trees to change the direction of pull of the rope, it was commonplace in the previous rope. It was estimated that around 30% of the time this machine is running on a slope over 35 degrees. The felling machine has never slipped in the cutover in such a way that it was caught by the rope.

This crew was unusual in the respect that they had pre-determined intervals for splice replacement and rope inspection. The splices are replaced every 4 weeks or 160 hours, whichever occurs first. As the machine is felling for two crews, the equipment needs moved every two weeks, at each shift the full length of the rope is laid out on the ground and two people take a quick visual inspection of the ropes by walking the length of the rope. The operator also laid logs in the ground at crests on the slope to prevent the rope running along or into the soil on the slope.

Rope Condition

The back winch was tested first and was found to be in reasonable condition, the wear was medium, the there was some slight corrosion. There were no instances of kinks, bending, doglegs or mechanical damage. No wire breaks were found in the test length of 260m.

The front winch rope was in exactly the same condition as the back winch, with the exception of having a single broken wire indicated at 247m.

Analysis

This is another instance of a machine with fairly low hours, and again the rope is in good used condition. The crew is taking very good care of the machinery and it shows in the condition of the rope.

5.6 System 6

System Description

The last system tested was of another different design, the anchor machine was a Liebherr 734 bulldozer twin winch system, including winches this machine weighs around 27 tonne. The felling machine was a John Deere 909K with an operating weight around 40 tonne.

The two winch system consisted of two independently operated winches mounted either side at the back of the bulldozer. The ropes ran through fairleads at the top corners of the blade into a twin rope equaliser block that connects to the felling machine with two chains. Both ropes were 7/8 inch IWRC power swaged ropes, the test length was 350m. The ropes had done exactly 190 hours at the time of the test. The machine fells approximately 700t/day in 7-8 PMH per day. The rope had not been end for ended at the time of the test, however they were aiming to get around 1000 hours out of the rope before end for ending. The rope will be scrutinised beyond 700 hours to determine if it should be end for ended early. As different from all other machines tested, the winches in this system are set to a maximum pull of 18 tonne as opposed to the combined SWL of 22 tonne for these ropes.

The end connection was by means of an equaliser block similar to the third system. Each working rope terminates at a swivel, connected to two equaliser ropes. The two equaliser ropes run from one rope end through the equaliser block to the other ropes end.

Figure 9: Equaliser block arrangement of system 6

The operator has 3 years' experience in tethered felling machines, and had one-year steep terrain felling prior to that. The operator interviewed is the sole operator of this machine. This was the third rope to be put on this machine so no operators had learnt to operate the tether on this rope.

The machine fells for between 2 and 3 crews depending on the requirements of the other crews. The rope in this system is always kept tight by the operator, so the felling machine never slips in a way that it shock loads the rope. Typically, 200m of rope is thought to be paid out, but on occasion 350 – 450m is paid out. The operator estimated that approximately 50% of the time the machine is operating at slopes greater than 35 degrees.

The previous ropes on this system ran a total of 1400 hours, being end for ended at 1020 hours. The operator thought that the end for end was too late at 1020 hours, hence the decision to begin reviewing rope condition beyond 700 hours on this rope.

Record keeping was excellent in this system. A maintenance book is kept in the felling machine and the machine hours at any major work is taken down. This includes rope replacement, when ends are reset and how much rope is removed.

Rope Condition

The right hand rope was in new condition, with medium wear. There was no corrosion, kinks, bending, doglegs or mechanical damage on the rope. There were also no broken wires found.

The left hand rope was in new condition, with little to no wear, no kinks, bending or doglegs. There was however an instance of mechanical damage on the rope, this was at 54m from the free end, and caused the rope to fail its inspection. The damage consisted of three broken wires in a single valley in the rope.

Analysis

The damage on this rope was known by the operator before the test, and needed to be removed before the system could be used again. The damage was an accident and caused mechanically by being pinched between cleats of the dozer tracks. It was not known by the operator if the damage would be a rope failure so was not removed prior to the test. These ropes were in as new condition which would be expected having only worked 190 hours. Figure 10 shows the damage in the rope that resulted in the failure of the left hand rope.

The maximum tension allowed on the rope system has been lowered and the operator also aims to keep tensions as low as reasonably required. This system was different in that the anchor machine weight was over ten tonne lighter than the felling machine, reinforcing that these machines are cable 'assist'.

Figure 10: The mechanical damage resulting in failure of the LH rope in system 6

5.7 Summary of Studies and Rope Condition

Tables 1 and 2 give a summary of the main data recorded in the study.

On the whole, the ropes are considered to be wearing well in this application. Broken wires in and of themselves are not cause for concern. Due to the large radial stresses in a loaded rope, stresses from a broken wire are passed on to adjacent wires through the length of contact before the breakage.

Valley breaks can be serious as they are as sign of internal wear in the rope and an indication that there might be a large number of internal wire breakages, as well as a significant point weakness hence their being a cause for immediate discard. All the ropes that failed inspection failed for from mechanical damage or damage in the valleys between the strands. This is damage that should be able to be picked up in a visual inspection if the ropes were not coated in soil and debris. Most of the ropes tested were coated with mud and dirt from the rope working in the cutover. Although visual inspections can be carried out, the entire length of the rope would need to be cleaned for a thorough inspection.

All ropes tested had corroded to some degree, this occurs when the ropes are sitting unused. In all cases the corrosion was only minor but it was evident which ropes had been sitting for longer than others.

Table 1: Summary of main recorded variables for tests 1, 2, and 3.

	System 1	**System 2**		**System 3**	
Anchor machine	Sumitomo SH330, 39 tonne est.	Cat 329 35 tonne		Terex 82-40 40 tonne approx.	
Make of winch	DC Repairs, single drum	EMS Twin drum		Custom made twin drum	
Tethered machine	Tigercat LS855C, 39 tonne	Cat 552, 38 tonne		John Deere 909H 37 tonne	
Rope type	Single 1 1/8” Swaged	2x 7/8” Power Swaged		2x 1" Swaged	
Initial length (m)	440	300		400	
Length at test (m)	260	260		380	
Hours on rope	1500	580		400	
Operator experience	3 years felling	2 years felling		10 years’ steel slope harvesting	
No of operators on machine	1	2		2	
Operators learnt on this rope	1	2		0	
Is tethered machine ever caught by winch	Initially frequent, not anymore	Initially while learning		No	
Maximum distance of rope fed out	240m	150 - 200m		100-200m	
Bending around stumps	All the time	Most of the time		Minimal	
		Front Winch	**Back Winch**	**RH Winch**	**LH Winch**
Rope diameter	28.6mm	22.2mm	22.2mm	25.42mm	25.45mm
Rope length (m)	241	263	263	380	380
Rope condition	Used	Well Used	Well Used	Used	Used
Type of end connector	Spliced eye	Spliced eye	Spliced eye	Wedged socket	Wedged socket
Wear	Normal/Medium	Medium to Heavy	Medium to Heavy	Medium	Medium to Heavy
No. broken wires	3	10	6	5	4
Locations (m)	48, 142, 146	7, 14, 64, 114, 134, 264	9, 20, 70, 98	116, 176, 245, 256, 291	150, 197, 211
Result	PASS	FAIL	FAIL	PASS	PASS
Reason		Valley Breaks cause for failure			
Notes				Dry at front end	40m flattening at back end

Table 2: Summary of main recorded variables for tests 4, 5, and 6

	System 4	System 5		System 6	
Anchor machine	Hitachi Zaxis 330	Hitachi Zaxis 240, 34 tonne		Liebherr 734, 27 tonne	
Make of winch	DC Repairs, 470 hours	EMS twin drum		ROB Twin drum	
Tethered machine	Hitachi Zaxis 290, 34 tonne	Tigercat LS855C, 39 tonne		John Deere 909K, 40 tonne	
Rope type	Single 1 1/8” Swaged	2x 7/8” Power Swaged		2x 7/8” Power Swaged	
Initial length (m)	500	400		500	
Length at test (m)	450	260		500	
Hours on rope	470	480		190	
Operator experience	4 years falling	15 years’ machine operation, 1 year on tether		1-year felling, 3 years tethered felling	
No of operators on machine	2	2		1	
Operators learnt on this rope	0	0		0	
Is tethered machine ever caught by winch	no, never	never occurred on this rope		never	
Maximum distance of rope fed out	200-300m	300m		200m in this block	
Bending around stumps	All the time	trying to avoid		all the time	
		Back Winch	**Front Winch**	**LH Winch**	**LH Winch**
Rope diameter	29.04mm	22.81mm	22.69mm	22.49mm	22.21mm
Rope length	453	260	260	350	348
Rope Condition	Good	Good, Used	Good, Used	Good	New with mechanical damage
Type of end connector	Splice	Spliced eye	Spliced eye	Wedged socket	Wedged socket
Wear	Normal/Medium	Medium	Medium	Medium	Nil
No. Broken wires	2	0	1	0	3
Locations	365, 418		247.5		54
Result	PASS	PASS	PASS	PASS	FAIL
Reason					Mechanical damage at 54m

6. DISCUSSION

Bending around trees does not seem to be detrimental to rope life, there was no discernible difference in condition between the ropes that had been bent around stumps and those that had not. Systems 1, 2, 4, and 6 are regularly using trees to change rope directions and apart from system 2 all the ropes subject to tree bending were in no worse condition than those that are not subject to tree bending. There was also no evidence of discoloration due to heat from friction. Bending around trees does pose other operational risks which are not considered in this study.

Control over working rope tension appears to affect wear to some extent. The machines that can work the ropes at the minimum tension required to assist the felling machine up slope tended to have ropes in better condition. System 3 maintains a consistent and reasonably high tension on the ropes due to the winch design, and soils at the site of system 2 being weak are requiring greater tensions to pull the felling machine back upslope. Both systems 2 and 3 exhibited more wear than the other machines tested for the same hours.

There is a variation in the rope knowledge of the operators. When asked, no contractor could give an exact decision criterion for rope replacement. This has also been highlighted in the fact that not all contractors are performing regular inspections of the full rope length and not all instances of mechanical damage were known to the operators.

Tight radius bending does not appear to be affecting rope life in this application. The ropes only go through a small number of bending cycles per day as they are not running as much or as fast as a crane rope for instance. If it takes 30 mins to clear a single swath downhill and the rope runs around 3 trees and the 3 sheaves in the winch system, then it runs through 12 bending cycles every 30 mins. For a rope at 1500 hours this is 36,000 bending cycles in the entire rope life. A crane rope however is expected to last for hundreds of thousands of bending cycles over a much longer time period.

Rope length loss from mechanical damage and end connector replacement is more of a cause for replacement than that of simply wearing a rope out as indicated by the NDT testing. Rope damage in valley breaks was the only cause for rope failure in a certificate, not excessive wear of the rope. No rope failed solely due to a significant loss of metallic area, or development of wire breakages. The greatest loss of metallic area on any rope was 2%, which although not insignificant is still only minor.

Winches that hold a large amount of rope on the winch drum have shown some signs of drum crushing on the innermost wraps. This can be mediated by end for ending the rope before the winch crushing and rope distortion gets excessive.

Longer term deteriorations seen in other industries have not been detected to a significant extent in this test set. There is little to no evidence of bending fatigue and only slight corrosion was picked up on four of the six systems but was not developed enough to be considered a risk to accelerating abrasive wear or compromising rope strength. Very little abrasive wear was spotted on any of the ropes tested, however only one rope was close to the end of its life. External wear is minimal, all ropes appeared to be in good condition externally, and only diameter measurements taken throughout the rope life can quantify this properly.

6.1 Limitations of the Study

Limitations here come in two forms. The accuracy of the NDT data is excellent; the NDT machine is sensitive enough to pick up welds/ joins in individual wires in the rope. The LMA trace is not always perfect, it can fluctuate if the rope is not magnetised well in the initial magnetisation run, or if the machine is disturbed by a rope jumping during the test. The NDT finds internal wear well, and is more accurate than simply taking a diameter measurement with Vernier callipers.

Information from the contractors was variable. Only three operators could give the rope hours confidently to within 50 hours of actual work time, either by an hour clock specifically for the winch or the winch machines hour clock. One other estimated it knowing the hours on the winch machine at rope installation, and two had to be estimated back from machine output and the number of PMH per day. The questionnaire also regularly asks for estimations from the contractors, this is usually information that would be impossible to capture otherwise but the quality of it is easily disputed.

Most ropes tested in this study were also near midlife, no ropes were tested in a severely degraded condition or at particularly high hours, the results could be quite different if all ropes were tested at 1500+ hours or at disregard for instance. Four out of the six ropes were between 400 and 600 hours. It did prove difficult to find machines that had ropes at very high hours such as the first, this is either a result of population available to sample or a result of few ropes making it to these high hours before replacement.

6.2 Validity of the Findings

Pinpointing any specific causes for wear or damage is extremely difficult as there are so many variables in these systems. The information captured in the questionnaire is also only an indication of what is really happening to the ropes.

Cable assist logging being so new is a changing environment. Current ropes on the sixth system are 100m longer than the previous set, and the new set was replaced with larger capacity drums. Likewise, on the first system, the intention was to replace the now short high hour rope with a rope that will be initially longer than the last was initially. With this additional length comes more risk of drum crushing as has been seen on the third system. New twin rope systems are also changing in their operation, currently the load is shared evenly between the two ropes, but current machines are being programmed to carry 66% load on a main rope and 33% load on the second. As a result, the wear development of the differently loaded ropes has the potential be quite different.

Anecdotal evidence also indicates that ropes in this application are failing. Although this study indicates that these ropes should not fail from being worn, in practical terms they do fail and the causes are still unknown. Rope forensics therefore should be conducted on failed sections to determine the most likely causes of failure.

6.3 Going Forward

At present it appears that the ropes are getting damaged mechanically or running out of length before some of the longer term deterioration types are being seen. High rates of internal wear from small diameter bending, or bending fatigue from short contact areas or tight radius bending has not been detected, but it is likely still possible. Corrosion is only minor but has the potential to accelerate abrasive wear over a long time. Ropes being installed on machines are currently longer than those that were being installed in the past. If an ‘old’ rope started life at 400m and loses 150m over 12 months, it is not useful at 250m and gets replaced even though it has not had a chance to wear out. If this rope is replaced as 500m it is then 350m at the end of the 12 months and is still useful, this should result in a longer rope life which in turn gives the rope more time to develop more complex deterioration and wear, that is assuming it is not damaged mechanically and disregarded beforehand.

Causes of mechanical damage are unknown and cannot be proven with the NDT system. It should not be forgotten that there is likelihood of damage to chains and ropes near the felling machine. In all cases the end rigging needs to be handled by the grapple of the felling machine to be connected as the chains are too heavy to be reasonably manoeuvred by hand, this significantly increases the chances of mechanical damage by the grapple.

The process of visiting sites and speaking to contractors has highlighted that there is room for training for the operators working these ropes. Three of the six contractors visited were taking records of rope and machine maintenance which has aided this study, however few of the contractors spoken to knew how to conduct a detailed rope inspection. Training and education to operators and contractors will allow for better understanding of what needs to be looked for in a rope inspection. Regular and correct inspections will allow for better safety by better managing the risks associated with running ropes in these conditions.

7. CONCLUSION

NDT examination of 6 wire rope systems shows that wire ropes are wearing well considering the conditions they are subjected to. Most ropes are getting damaged mechanically or running out of usefulness by gradual loss of length with damage at the free end and replacement of the rigging at the end of the rope. Longer term deterioration patters are not being observed. Abrasive wear is minimal, corrosion is minimal both externally and internally, and internal wear and bending fatigue are not observed to any significant extent. Instances of drum crushing have been observed and could possibly become an issue in future as new rope lengths are increasing.

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9. APPENDIX

9.1 Appendix 1 Research Questionnaire

Non-destructive Testing of Ropes used in Cable-Assist Operations.

Hancock FM, Shaw's Wire Rope and University of Canterbury

Mick Theobald, Bertus Marks, James Byron & Rien Visser

Objective: The goal is to carry out a series of case studies of the condition of ropes that are currently in use with cable assist operations. There are two parts to each test: (1) the actual physical test of the rope, (2) capture of information through this questionnaire that will help support the analyses of the findings.

The Machines

1. What is the anchor / winch machine – make/ model – weight? How many hours are on it?

2. What is the winch design (make model - Single / double drum?) How many hours are on it?

3. What is the make, model and operating weight of the current tethered machine? And how many hours are on it?

The Rope

4. What is the rope type & size, what is the length on the drum, and when was this rope installed?

5. How many hours has the rope been in service? (Note - based on machine hours – or #weeks x typical operating hours?)

6. Do you know how much (m3) has been felled using this rope? – or what percent of your harvest is felled with this system?

7. Typically, how much wood is extracted per day (i.e. target), and how many hours worked per day?

8. Do you regularly shovel (as in extract, not just bunching) the felled trees (most of the time, some of the time, as little as possible, never)

9. Has the rope been end-for-ended? – also, if not would you do this as standard practice in the future – and if so what is your criteria for deciding when to end for end.

10. What would be your criteria for rope discard / rope replacement.

11. Is the rope left wound back onto the winch at the end of every day, if not, how often would the rope be being left out between shifts?

The Operator

12. How much experience does the machine operator have; how many hours approximately in this application, and how many years' experience harvesting on steep terrain untethered?

13. How many different operators does the felling machine have under normal use?

14. How many different operators have learnt to operate the tethered machine on this rope?

Operating Practice

15. Does this machine fell for more than one crew?

16. Roughly how many times a week does the falling machine slide on the slope in such a way that it is 'caught' by the winch machine if at all?

17. What is the typical maximum distance of rope used during operations?

18. How regularly are trees (/stumps) used to change direction of the pull of the winch rope? (most of the time, some of the time, as little as possible, never)

19. Approximately what percentage of the time is the felling machine spending on slopes greater than 35°? (If known)

Other comments or questions: