HARVESTING TECHNICAL NOTE

HTN09-06
2017

A Study of Breakout Forces in Cable Logging

Summary

A study was carried out to measure breakout and inhaul forces during two yarding operations. These forces were measured by inserting a wireless load cell between the choker and either the mainline or butt-rigging. This gave a continuous readout, and the maximum force was recorded and compared to a number of operational factors. The study was replicated at two sites, one using a slack-pulling carriage in a shotgun configuration, the other using a North Bend system with butt-rigging. Results showed that across the range of payloads measured, the breakout force was about 0.4 tonnes greater than the weight of the turn, when break out conditions were easy (stem on top of pile with no obstruction). However this additional force increased to 2.1 tonnes above the payload if other stems were on top of the target load. The highest forces measured were 9.1 tonnes and 11.5 tonnes for break-out and inhaul, respectively.

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INTRODUCTION

Steep country forests contribute more than 40% of New Zealand's annual log harvest, and this is forecast to rise to over 60% in coming years (Raymond, 2012). Cable logging systems are expensive compared to ground-based systems, due to higher daily operating costs and lower daily production (Visser, 2016). Classical approaches to improve the economic viability of any logging system include reducing costs, increasing daily productivity, or both (Harrill, 2014).

Productivity is often estimated with the aid of payload analysis techniques. These tools have been available for many decades, and help forest engineers determine the maximum available payloads that can be yarded (Harrill, 2014). However, these calculations are based on static tensions in wire ropes (Carson & Jorgensen, 1978). To ensure the dynamic tensions do not exceed the breaking strain of the wire ropes, a safety factor is applied to account for the dynamic loads, which are unknown.

A feature of cable logging in New Zealand is the reliance on larger yarders of North American design (Visser, 2013). In recent years there has been renewed interest around the use of smaller and lower cost yarders of European design (Visser *et al.* 2011). However, there has been slow uptake to date by industry due to uncertainties over suitable power requirements to yard New Zealand-size trees (Campbell 2016, Evanson & Hill, 2015).

There are many forces involved in cable logging, such as skyline lifting force, skidding force, gravity and friction (Figure 1), and an improved understanding of these forces may aid attempts to become more efficient. The static forces involved with log breakout have been well described (Mifflin, 1982). Dynamic load magnitude (i.e. amplification of tensions) is possibly the most valuable parameter that tension monitoring of logging cables can produce (Pyles *et al.*, 1994).

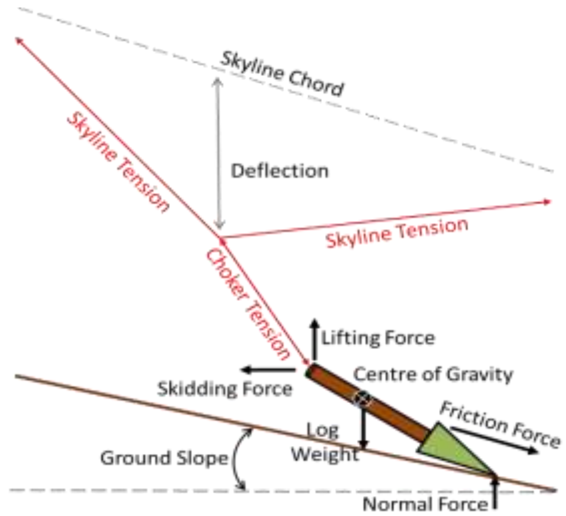

Figure 1: Forces acting on a partially suspended log (adapted from Mifflin, 1982).

Being able to predict the magnitude of the maximum and average forces involved in yarding operations is critical for efficient design and operation of new smaller-sized, lower cost yarders, as the forces dictate the power, line size and transmission requirements (Falk, 1980). Furthermore, amplification factors would allow for a more precise estimate of payload capacity for a given machine and setup, but also help to verify the adequacy of current methods of payload analysis (Harrill 2014).

Some research has attempted to monitor the tensions in actual logging operations, but little is known about the tension increases due to loads. Several researchers have noted that the highest dynamic tensions observed in cable logging are during breakout of logs just before, or during, carriage inhaul,

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depending on conditions (Carson & Jorgensen 1978, Falk 1980, Harrill & Visser 2013, Harrill 2014, Henshaw 1977, Peters & Biller 1984, Pyles *et al.* 1994). Some of these studies were conducted with models or by measuring the skyline tension only. Additionally, not all of the studies had the objective of quantifying amplifications. As such there were no studies investigating breakout forces in chokers in actual cable logging operations under New Zealand conditions.

OBJECTIVES

The primary objective of this study was to assess the force required to both move (breakout) and pull a stem during extraction (inhaul) using a cable yarder; in order to determine the minimum requirements to yard New Zealand-size trees.

METHODS

Study Sites & Systems Description

The first study took place with Gillion Logging Ltd. working in Otago's Herbert Forest (Study Site 1; Port Blakely) on Monday 3rd April 2017. The merchantable tree size in this stand was 2.3 m³ with an average height of 38 m. The site had been felled by a winch-assisted machine and mainly pre-bunched into large surge piles (Figure 2).

Figure 2: Study Site 1 conditions showing large surge piles from which stems were yarded.

The crew utilised a Madill 071 yarder operating in the shotgun rigging configuration with an Acme motorised slack-pulling carriage. The skyline was rigged with a tail spar to provide lift / deflection.

The second study took place with Bundi Road Logging Ltd. in Nemona Forest south of Greymouth (Study Site 2; PF Olsen) on Thursday 8th June 2017. The merchantable tree size in this stand was 2.9 m³ with an average height of 41 m.

Figure 3: Study Site 2 conditions with mechanically felled stems.

The site had been felled by both a winch-assisted machine and motor-manually, whereby most stems extracted during the study were machine felled (Figure 3). The crew utilised a Berger C19 yarder operating in the North Bend rigging configuration during the study.

Data Collection

A wireless load-shackle (WLS) rated to 12 tonnes was connected to a swivel dee at the end of the mainline (in Study Site 1) and to the swivel on the butt rigging (in Study Site 2). For the duration of the study only one choker was attached (Figure 4). This was to avoid the risk of entanglement that might pull off or damage the wireless aerial and battery housing on the side of the load-shackle.

A field computer, for which a USB aerial was supplied with the load-shackle, was used to record the data. The data logging software continuously recorded the choker tension at a rate of 10 Hz. By analysing the data, the maximum tension at breakout (MaxT BO) was identified and recorded for each hauler cycle, and during the initial part of the inhaul the maximum inhaul tension (MaxT Inhaul) was recorded.

Figure 4: Wireless Load Shackle attached to choker and mainline swivel dee at Study Site 1.

The choker-setter pulled the mainline/shackle/choker laterally and set the choker on a selected stem, or in some cases two or three stems were hooked ("stropped") using the single choker.

The following factors were recorded using callipers, a Nikon Forestry Pro laser range finder, inclinometer and a compass:

- Number of logs for turn (n);
- Stem DBH (cm) and length (m)
- Distance of skyline carriage (m) and angle to carriage (°)
- Lead Angle (°) of stem to skyline.
    - 1 = < 30°
    - 2 = 30 < 60°
    - 3 = 60 < 90°
    - 4 = > 90°
- Terrain slope (%)

A subjective difficulty rating was applied which attempted to relate to the true difficulty of breakout where:

- 0 = easy break out, stem on top of pile / top of ground, no obstruction
- 1 = stem needed to push past other stems to break-out
- 2 = other stems on top of target load

RESULTS

In total 60 complete cycles were recorded at the two study sites. A typical tension sequence during breakout and inhaul is shown in Figure 5. The maximum values are identified from the chart and used for the maximum tension analyses.

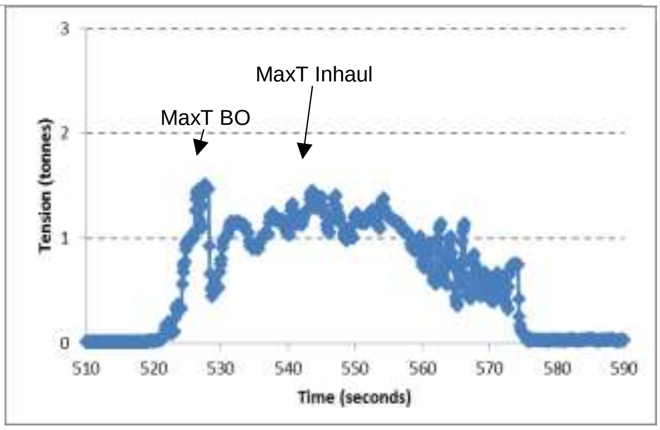

Figure 5: Typical cycle showing tensions measured during breakout and inhaul phases.

The maximum breakout tension (MaxT BO), maximum inhaul tension (MaxT Inhaul) and an amplification factor of the turn volume for each was calculated based on the assumption of 1 m³ = 1 tonne. A summary of the average and range of breakout and inhaul forces measured during each study and average results of both studies is presented (Table 1).

Table 1: Summary of breakout and inhaul forces measured during the study.

Study Site	1	2	Average
Turn Volume (m^3)	2.1 (0.8-4.4)	3.6 (1.7-6.4)	2.6
MaxT BO (tonnes)	3.0 (1.1-8.6)	4.6 (2.7-9.1)	3.6
BO Ampl. Factor	1.5 (0.6-3.6)	1.3 (1.0-2.1)	1.4
MaxT Inhaul (tonnes)	3.0 (1.0-7.0)	5.3 (2.5-11.5)	3.8
Inhaul Ampl. Factor	1.5 (0.8-5.1)	1.5 (1.0-2.5)	1.5

Overall the average MaxT BO was 3.6 tonnes, which equated to an average amplification factor (MaxT BO divided by the volume of the turn) of 1.4.

The average MaxT Inhaul was 3.8 tonnes with an amplification factor of 1.5. In 20 of the 60 cycles recorded (33% of cycles) the MaxT BO was greater than MaxT Inhaul (i.e. no clear trend).

Figure 6 shows the chart relating breakout force (MaxT BO, in red) and the max inhaul force (MaxT Inhaul, in blue) to the turn volume.

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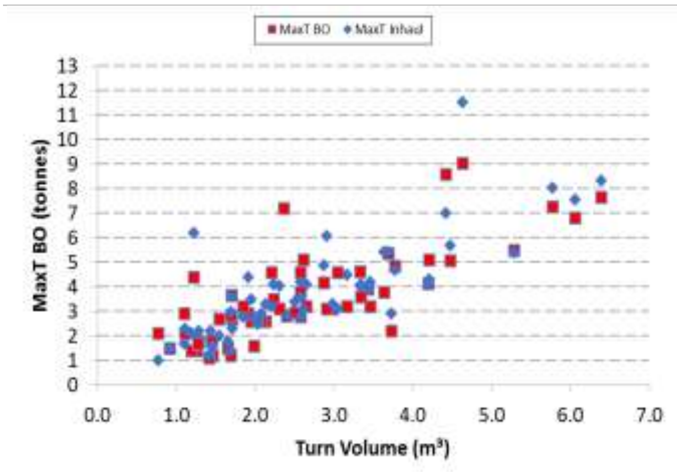

Figure 6: Relationship between maximum tension during breakout and inhaul, and turn volume.

Examples of breakout and inhaul tensions

Some examples of breakout and inhaul tensions recorded during the study are presented in the following tension charts.

Figure 7 shows a medium-sized stem (2.6 m^3) at Site 1, that was difficult to break out (5.1 tonnes tension, amplification factor = 2.0), but then smooth inhaul with low recorded tensions (3.1 tonnes).

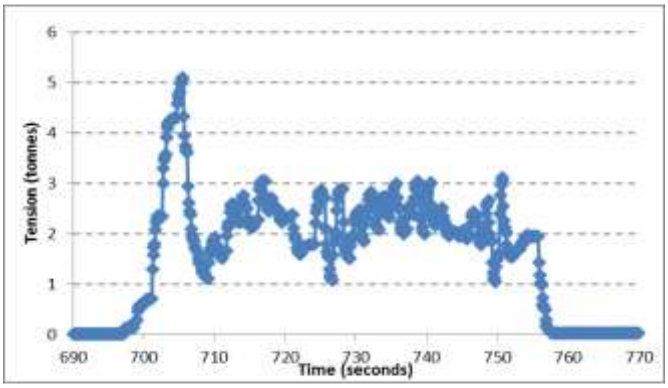

Figure 7: Higher breakout force but smooth inhaul.

Figure 8 shows a small stem that was easy to break out (1.4 tonnes) with low tensions during inhaul (1.7 tonnes), both as expected, but clamping the carriage to the skyline and releasing the mainline to drop the stem at the landing caused a 2.2 tonne shock load.

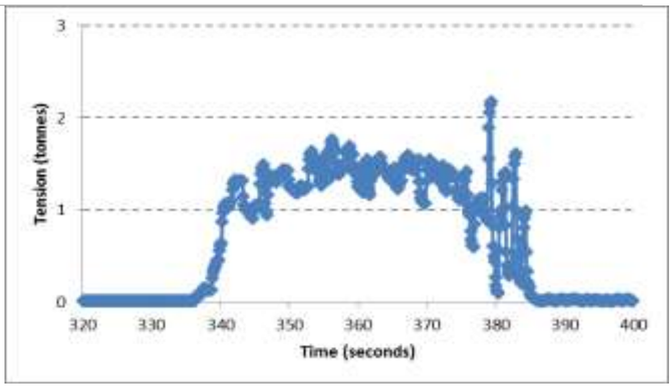

Figure 8: Easy break-out and in-haul, but data shows shock loading event up at landing.

Figure 9 is an example of where the largest MaxT BO and MaxT Inhaul at Site 2 occurred. The three stems (volume of 4.6 m^3) were initially pulled at just under 7 tonne force but did not move. The operator then tried two more attempts at breakout of just over 8 and 9 tonnes force, to finally break out the stems which were lodged/pinched between other stems in a pile (difficulty rating 2).

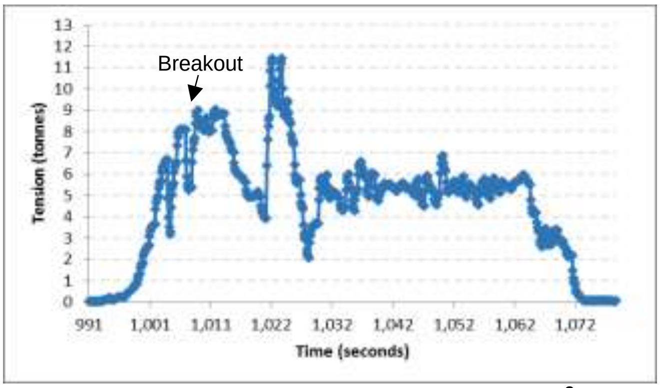

Figure 9: Breaking out larger payload (4.6 m^3) out of pile with high difficulty rating.

However, once broken out the stems got hung-up on the way in to the landing, which produced a peak inhaul tension of 11.5 tonnes (resulting in a 7 tonne shock load).

DISCUSSION

The maximum tensions recorded at breakout for the two studies were 8.6 tonnes and 9.1 tonnes respectively. Very few of the hauler cycles in either study recorded maximum breakout tensions beyond 6.0 tonnes (Figure 6). Interestingly, the average breakout amplification factors of 1.3-1.5 and maximum tensions relative to turn volumes recorded were similar to the other studies that have measured mainline/choker tension. Henshaw (1977) reported break out amplifications ranging from 1.23 to 4.5. Falk (1980) found breakout amplifications ranging from 0.8 to 4.0 for a 1-tonne log. Peters & Billers (1984) developed a regression equation from field studies yarding hardwood logs (0.5-2.0 tonnes piece size), which yielded an average amplification factor of 1.24.

Regression analysis was carried out using all the parameters available for predicting MaxT BO. Both turn volume (m^3) and difficulty were highly significant. The site was also a significant factor, with Site1 (2.3m^3 tree size) having an average MaxT BO that was 0.73 tonnes less than Site 2 (2.9m^3 tree size). This is possibly related to the smaller tree size in Site 1 (explaining an additional 2% of the variability in the data). For practical purposes however, site as a factor was excluded from the model.

The final model developed to predict the maximum tension at breakout (r^2 = 0.71) was:

MaxT BO (t) = 0.31 + 1.02 x TurnVol (m^3) + 0.691 (where Difficulty = 1) + 1.745 (if Difficulty = 2)

It is important to note that difficulty rating was subjective and may not have been entirely representative of the true difficulty of breakout. For example, at Study Site 2, one of the turns was assigned a high difficulty rating because it had a stem lying on top of the two stems to be extracted (total volume = 5.3 m^3), which resulted in a breakout tension of only 5.5 tonnes. The low amplification of breakout tension was observed to be due to the stems sliding out from underneath the one on top; which could have been facilitated by the angle of pull and the steepness of the slope (65%).

It was found that site conditions and specific rigging configuration geometry could influence breakout and inhaul tensions. The two study sites had different terrain, soil type, and tree sizes; they also utilised two completely different rigging configurations which behaved differently during breakout. Henshaw (1977) found the coefficient of friction can have a large influence on choker tension. It was possible that the large surge piles at Site 1, where stems slid off the top of other stems rather than the soil itself, provided a lower coefficient of friction as in Study Site 2. The angle from the choker to the carriage may also have a strong influence on choker tension, both in theory (Mifflin, 1982) and in the study findings of Falk (1980). The more vertical angles at Study Site 2 could have resulted in higher choker tensions due to a greater component of vertical (lifting) force compared to Study Site 1.

CONCLUSION

The studies at the two sites showed that, due to large variation in results, it was not possible to accurately predict the magnitude of the maximum breakout force, even when measuring all physical parameters of the stem, turn volume, rigging and carriage.

However, it was possible to make a reasonable prediction of the maximum tension at breakout for the sites studied, by using the turn volume (estimated from the known tree size) and by applying a difficulty rating. This method explained 71% of the variability in maximum breakout force between cycles.

If the carriage, the rigging, and the yarder have a mainline pull limit (for example 8 tonnes-force of main line pull for the Koller K702) it is possible to establish an estimated pragmatic turn volume limit, by combining this with an assessment of the difficulty of breakout. In this example the maximum turn volume where the stem needs to push past other stems to break-out (difficulty factor 1) should be around 6.8 m^3. Where other stems are on top of the stem being extracted (difficulty factor 2) the maximum turn volume should be less than 5.8 m^3.

This finding suggests that smaller and lower cost yarders of European design (such as the Koller K702 and the Valentini V1500 yarder) may have suitable power requirements to breakout New Zealand-size trees. This explains why smaller machines, like the Koller K602H yarder (with ≈ 5 tonnes mainline pull) that was trialled in New Zealand, was able to breakout and yard payloads of 2.6 m3 (expected MaxT BO = 2.9 - 4.0 tonnes, depending on the difficulty factor).

While the mainline may develop enough tension to break out the load, inhaul may not be at a productive speed. Depending on many factors, such as log suspension, where the load is located along the span, and the rigging configuration used, the haul back braking force or skyline lifting force could still be a limiting factor.

ACKNOWLEDGEMENTS

The authors would like to thank the logging crews Bundi Road Logging Ltd. and Gillion Logging Ltd. for their participation and help. We also appreciate the assistance of the forest management companies Port Blakely Ltd. NZ Forestry, and PF Olsen Ltd.

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