FUTURE FORESTS RESEARCH

HARVESTING TECHNICAL NOTE

HTN05-12
2013

Simulating Skyline Tensions of Rigging Configurations

Summary

Dynamic forces, sometimes called shock loading, can send large temporary fluctuations in stored elastic energy through the cable system and can pose a serious risk of cable failure. This study used a model yarder to quantify and compare the observed peak skyline tensions in three cable configurations using a fall block, by simulating common situations that are known to cause shock loading. North Bend is the most popular configuration using a fall block in New Zealand. North Bend is different from other fall block configurations such as South Bend and Block in the Bight based only on the main line geometry. Few cable logging crews in New Zealand use the South Bend configuration, and the majority are not familiar with Block in the Bight, so it was useful to compare the performance of these three systems. Results indicated that compared to others, the North Bend configuration had the lowest peak tensions when the load was dropped into full suspension and when bridling. South Bend was found to have the lowest peak tensions during simulated collisions with ground objects. Longer chokers increased the magnitude of shock loading significantly in most cases.

Hunter Harrill and Rien Visser, University of Canterbury

Introduction

There are a number of different rigging configurations which can be used when cable logging, and some are more preferred than others in a given location (Studier and Binkley, 1974; FITEC, 2000; WorkSafeBC, 2006). Deciding which rigging configuration to use can be challenging, and is usually based on the available equipment, the crew, and the site conditions, among many other variables, but it is often chosen based on the experience and comfort of the crew.

A survey in New Zealand found there were approximately 10 different rigging configurations commonly used in cable logging (Harrill and Visser, 2011). The North Bend configuration was the most common, followed by Grabinsky ("scab skyline"), shotgun, and highlead. However, only 20% of crews had tried using any other configurations outside of the four most common in the last five years. This is particularly interesting when considering fall block rigging configurations (i.e., North Bend, South Bend, and Block in the Bight), of which North Bend is most popular. North Bend is different from the others based only on the main line geometry, yet only a few crews surveyed had tried South Bend, and the majority were not familiar with Block in the Bight.

When planning for cable logging operations, payload analysis is often used for determining the most appropriate logging system and its potential productivity. The load carrying capability of the skyline is based on the breaking strength of the cable and the use of a safety factor. The industry uses a safety factor of three when calculating the payload potential for logging skylines (Studier and Binkley 1974; FITEC 2000; WorkSafeBC 2006). A lot of previous work over the period from the 1960s to the 1980s has described static tensions in logging cables and how to calculate them. One researcher developed a computer program to analyse static tensions for the fall block configurations, North Bend, South Bend, and Modified North Bend, but it was never commercialised (Woodruff, 1984).

Safety factors provide room for dynamic forces, sometimes called shock loading, that can send temporary fluctuations in stored elastic energy through the system (Pyles and Womack 1994; Womack *et al.* 1994; Visser 1998). Dynamic forces can be greater than the payload itself, and if not accounted for through the safety factor can lead to wire rope damage (e.g., fatigue and elastic deformation), resulting in skyline or guy line failure, or failure of tail holds or guy line anchors. These failures should be avoided at all costs due to the serious safety hazard which could cause harm or injury to workers, not to mention lost productive time and unnecessary maintenance and repair.

Very few studies, with the exception of Kellogg (1987), have tried to compare various rigging configurations in the same operating conditions. Even less work has been completed in monitoring dynamic forces in cable logging, and none have aimed to compare these tensions between rigging configurations. This study aims to quantify and

compare the observed skyline tensions using a model yarder, by simulating common situations that are known to cause shock loading. The goal is to provide suggestions as to how to minimize these forces in everyday practice and to provide suggestions on where and when to use which configuration.

Objectives

The objectives of the study were to simulate the measured skyline tensions due to dynamic loading (shock loading) for each of the fall block rigging configurations under the following conditions:

1. The load suddenly drops into full suspension.
2. The load collides with a ground object.
3. Bridling to reach stems away from the skyline corridor:
    a. During breakout;
    b. While lateral yarding.

Methods

All simulated yarding tests were performed using the University of Canterbury School of Forestry 1:15 scale model yarder (Figure 1, left). Skyline tensions were measured with the use of a PT Global PT1000 Single Point load cell and custom built mounting bracket along with a PT200M display unit (Figure 1, right). The display unit was connected to a laptop computer which recorded skyline tensions to the nearest gram (force) continuously at 20 readings per second. The laptop computer also recorded video of operation and line tension simultaneously using Snagit video capturing software and the built-in camera in the laptop computer. The video was later used for time study analysis.

Figure 1: UC Model Yarder and load cell with custom built mounting bracket for measuring skyline tension.

The setup specifications used during simulated yarding tests using the University of Canterbury School of Forestry scale model yarder are given in Table 1. The same log, carriage, butt rigging and skyline corridor were used for every yarding test, and the log was retrieved from the same starting position for each repetition.

Table 1: UC Model Yarder and setup specifications used during simulated yarding tests.

Description	Value	Units
Tower height	2.32	m
Tail height	2.05	m
Span	12.0	m
Deflection	1.2	m
Deflection	10	%
Skyline diameter	4.0	mm
Skyline weight	0.014	kg/m
Mainline diameter	3.0	mm
Mainline weight	0.006	kg/m
Haulback diameter	3.0	mm
Haulback weight	0.006	kg/m
Carriage weight	0.229	kg
Fall block weight	0.137	kg
Butt Rigging and Chokers	0.036	kg
Log weight	4.92	kg

Operations Description

Three tests were performed to simulate common causes of shock loading during cable yarding operations (Figure 2). Each test was repeated 10 times for each of the three rigging configurations (e.g. North Bend, South Bend, and Block in the Bight), five of which used long choker lengths (55 mm) and the other five used short choker lengths (32 mm). For each repetition, the log was retrieved from the same starting position. The haul back block was placed directly in line with the skyline at a height of 1.15 m from the ground except during the bridling test. The skyline was set at 10% mid-span loaded deflection for each test, measured using a laser level. The yarder's motor was set to the desired speed level (30 rpm) and audible signals were used to annotate operational procedures. The operator took special effort to control the drag as consistently as possible for each test, in an attempt to minimize variability due to the operator.

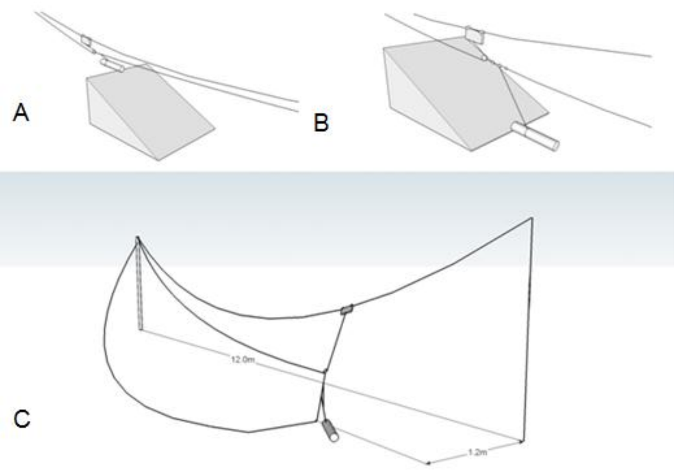

Figure 2: Diagram of the North Bend configuration performing the three tests (A) Drop, (B) Impact, and (C) Bridling.

Drop Test

The drop test best represents shock loading that may be experienced when yarding logs over a rock bluff where they are fully suspended thereafter. The drop test (Figure 2A) started with the log at mid span (6 m) resting on the ground. The main line was pulled in with brake applied to the haul back until slack was taken out of the line and the log began to move. Brake pressure was reduced to the haul back to allow the log to be yarded forward and up the ramp. The log was then pulled over the end of the ramp into full suspension generating a shock load, and then continued along the skyline corridor until it reached the tower, where it was lowered to the ground.

Impact Test

The impact test best represents shock loading that may be experienced when logs collide with a ground object such as a stump, causing a hang-up. The impact test (Figure 2B) started in the same position as the drop test. The log was then yarded forward 45 cm until it collided with the bottom of the ramp where it initially stopped until slack in the ropes was taken up and enough force was generated to dislodge the log, generating a shock load. The log continued to be yarded to the tower and then lowered as in the drop test. The haul back and main ropes were operated in the same manner, only this time less brake pressure was applied to the haul back in order to maintain ground leading of the log to ensure a collision with the ramp edge.

Bridling Test

The bridling test represents dynamic loading that may be experienced due to introduction of a third plane of lateral forces when logs are located away from the skyline corridor. The bridling test (Figure 2C) started with the log resting on the ground at 10.35 m from the tower and offset to one side of the skyline by 1.20 m where it would normally be too far away to reach with either size of chokers, thus requiring the practice of bridling. The tail block was offset 1.20 m from the skyline and placed directly behind the log at ground level. The mainline was pulled in while applying pressure to the haul back brake until partial suspension was generated. Brake pressure was then decreased to allow the log to be yarded laterally back under the skyline corridor, and eventually along the corridor until mid-span where it was lowered to the ground.

Results

Let us first consider the skyline tension without shock loading, when the carriage and load are fully suspended but stationary and forces have come to equilibrium at mid span. Static skyline tension at mid span for any operation can be calculated using a very simple equation (WorkSafeBC 2006):

$$T = \frac{L * S}{4D} + \frac{WS^2}{8D} \qquad \text{Eq. 1}$$

Where T= skyline tension (kg), L= weight (kg) of the load (carriage, logs, and haul back line), S= span length (m), D= deflection (m), W= weight of skyline (kg/m)

Using Equation 1 and the model yarder specifications from Table 1, the calculated static skyline tension at mid span when fully suspended would be 13.51 kg. This is surprisingly close to the measured static skyline tension at mid-span of 13.06 kg. However, the static skyline tension at mid-span differs when the fall block configurations are used. The difference is due to how the load achieves suspension and the function of the cables. The calculation used in Equation 1 assumes the use of a standing skyline system where the skyline suspends the load and the haul back is used to transport the carriage, whereas to achieve lift with the fall block configurations, brake pressure has to be applied to the haul back while the main line is pulled onto the corresponding drum. The “tug-of-war” between the main line and the haul back eventually results in enough vertical force to lift the

log off the ground after which the majority of the load is transferred to the skyline. However, the main line and haul back still share a portion of the load because if the brakes on one or both of these drums were to be released the load would plummet to the ground. The fall block configurations therefore result in decreased skyline tension compared to what was calculated in Equation 1 and that observed.

The actual static skyline tension at mid-span was 10.07 kg, 11.61 kg and 11.76 kg for North Bend, South Bend and Block in the Bight respectively (Figure 3). Dynamic loading will be compared to the static tension in terms of its proportional increase. Amplification due to shock loading during breakout of logs in this study will be calculated using an equation from Pyles and Womack (1994) for breakout tension amplification:

$$\mathit{Load\ Amplification\ Factor} = \frac{\mathit{peak\ breakout\ tension} - \mathit{skyline\ pretension}}{\mathit{Skyline\ pretension}} \qquad \text{Eq. 2}$$

Equation 2 can also be used to calculate the amplification of shock loading during drop tests, by substituting the fully suspended static skyline tension for skyline pretension.

Drop Test

The drop test indicated that both the variable of choker length and rigging configuration were statistically significant with P-value<0.01 and P-value<0.00; α = 0.05 respectively. North Bend with short chokers produced the lowest recorded average peak skyline tension (11,501 g) and was 1.14 times greater than the static skyline tension at mid-span (Table 2). The greatest tension recorded was for Block and the Bight with long chokers (14,380 g) and was 1.19 times greater than the static tension at mid-span. Average peak tensions were consistent within treatments and longer chokers produced higher tensions; which can be explained by the log having to fall further and build up greater velocity (Figure 4).

Using longer chokers than short chokers produced dynamic tensions that were 1.19 times greater than the static load (additional 491 g) for North Bend, compared to 1.19 (additional 922 g) and 1.19 (additional 979 g) for South Bend and Block in the Bight respectively. South Bend behaved quite similarly to Block in the Bight, and both were found to be significantly different from North Bend (P-value<0.01; α = 0.05), but not from each other.

Figure 3: Static skyline tension observed at mid-span for the North Bend configuration.

Table 2: Maximum skyline tensions observed during various shock loading tests.

Test	Cycle Component	Configuration	Choker Length	Average (g)	SD (g)	Amplification
Drop	Full Suspension	North Bend	Short	11501	713	1.1
		North Bend	Long	11992	1737	1.2
		South Bend	Short	12923	224	1.1
		South Bend	Long	13845	523	1.2
		Block in the Bight	Short	13053	242	1.1
		Block in the Bight	Long	14032	401	1.2
Impact	In haul	North Bend	Short	10671	3070	7.6
		North Bend	Long	12402	1225	8.8
		South Bend	Short	9010	887	6.2
		South Bend	Long	10833	381	7.1
		Block in the Bight	Short	11482	1643	7.4
		Block in the Bight	Long	10997	822	7.3
Bridling	Breakout	North Bend	Short	4103	887	2.7
		North Bend	Long	7020	2503	5.2
		South Bend	Short	4619	598	3.4
		South Bend	Long	6246	2136	4.7
		Block in the Bight	Short	4740	256	3.1
		Block in the Bight	Long	10231	3791	8.1
Bridling	Lateral yarding	North Bend	Short	11068	699	n/a
		North Bend	Long	12432	528	n/a
		South Bend	Short	11446	595	n/a
		South Bend	Long	14258	2073	n/a
		Block in the Bight	Short	11376	606	n/a
		Block in the Bight	Long	13185	2141	n/a

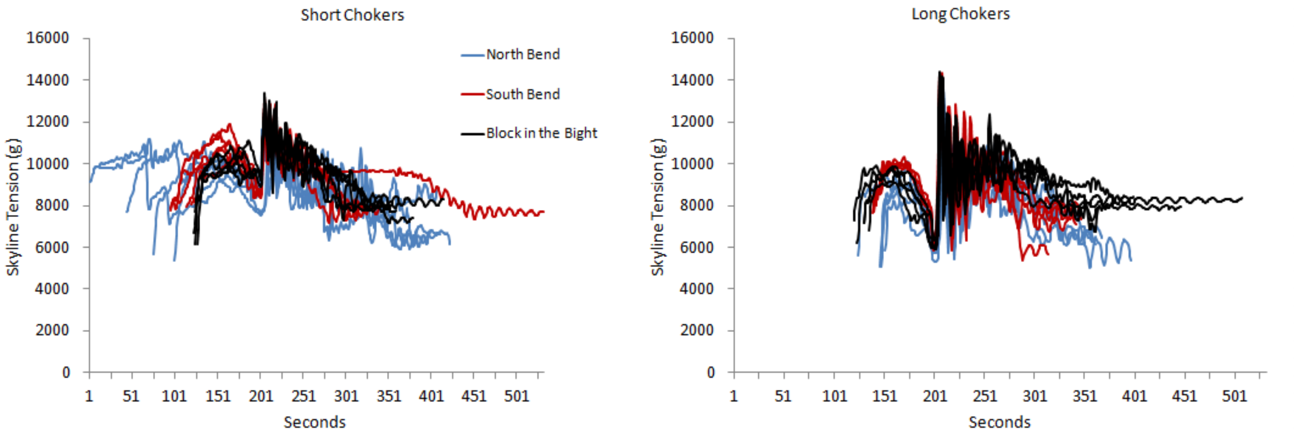

Figure 4: Drop test comparison between short and long chokers and vertical line indicating point when log dropped into full suspension.

Impact Test

No statistical significance was detected in either rigging configuration or choker length for the impact test. What is interesting to note however, is how similar tensions were between the long and short chokers when the Block and the Bight rigging configuration was used as compared to others (Table 2). In fact it's the only configuration where longer chokers produced lower tensions. South Bend with short chokers produced the lowest tensions, which can be attributed in part to the more upward lift generated by the purchase of the main rope and fall block used. It was also observed that this configuration performed very well at avoiding the ground object, as several cycles were repeated since the log avoided collision altogether. Interestingly, Woodruff (1984) found that South Bend was introduced one year after North Bend as an alternative for down-hill yarding due to its ability to avoid hang-ups and reduced brake wear to the haulback.

Bridling

Bridling test results indicated that only choker length was statistically significant (p-value<0.00, α = 0.05). During bridling, the maximum tensions recorded during the initial breakout and subsequent lateral yarding components of the yarding cycle were somewhat similar between rigging configurations with short chokers (Table 2; Figure 5).

When long chokers were used, tensions were highly variable (Figure 5), especially for Block in the Bight during breakout, which had the greatest average peak tensions for the cycle component (10,231 g). The resulting tension was 87% of static tension at mid-span and 2.2 times greater than observed with short chokers (4,740 g), and highlights the difference in amplification of 8.1 and 3.1 for long and short chokers respectively. The video footage shows the skyline in this setup deflecting into view of the camera lens, when other configurations did not. This can be somewhat explained by how more mainline had to be pulled onto the drum than with short chokers, which put more tension on the mainline and haulback to attain the same amount of desired lift, thus allowing the coefficient of friction to be reduced and allowing the log to move forward. The increased tension in mainline and haulback is partially transferred to the skyline, and in this case is exaggerated by the geometry of the mainline and the purchase in the fall block, where the terminal end is connected to the skyline carriage.

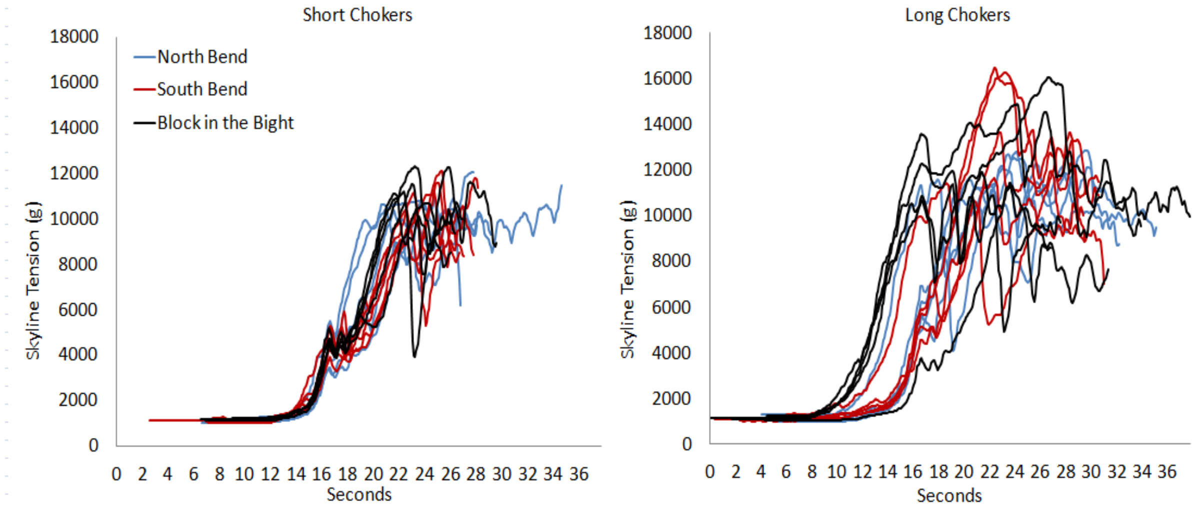

Figure 5: Bridling test comparison between short and long chokers.

Conclusion

The simulation study results using the model yarder showed that there were differences in skyline tensions between the three rigging configurations and varying choker lengths for the same application. However, statistical analysis showed that in all tests, with the exception of the drop test, there was no significant difference in maximum skyline tensions generated based on which rigging configuration was used. There was no significant difference in skyline tension between any of the treatments when the log had a collision with a ground object, although South Bend yielded the smallest tension and performed best in avoiding collision. In both the initial breakout and lateral yarding components of a cycle during bridling, choker length was the only variable found to be statistically significant. Longer chokers produced higher and more variable skyline tensions and amplifications, especially when using Block in the Bight during breakout, and while lateral yarding with South Bend or Block in the Bight.

The results from this study have provided some insight into dynamic forces between rigging configurations. The results, however, should be used with caution. There are other ropes involved in these configurations which are subject to shock loading, such as the haul back line and especially the mainline, and on some occasions the mainline tension can limit the allowable payload. Monitoring tensions on these operating ropes requires a load cell that allows the moving ropes to pass through the device. Monitoring of the mainline and haulback were outside the scope of this research, but warrant further investigation. It is also important to note that tensions and amplifications from shock loading in this study will differ from the real situation due to scale issues, especially with respect to rope weight, for example where a common 28-mm skyline weighs approximately 3.12 kg/m and can account for a large portion of vertical forces, compared to 13.7 g/m used with the model yarder.

Recommendations

- Use North Bend for expected drops into full suspension and where possible shorten choker length.

Results suggest that in some cases one configuration might be more preferred than another based on potential skyline tension. For instance, North Bend proved to be much better in minimizing peak tensions than others during the simulated drop tests. Perhaps choosing North Bend over the other fall block configurations when encountering a sudden drop into full suspension is a good choice, due to the pendulum effect observed that dampens the loading. Using longer chokers during drop tests resulted in tensions that were 1.19 times greater than the static skyline tension at mid-span. If the static tension at mid-span were to be equal to the safe working load of the rope, this could pose a concern, as dynamic tensions would then approach the rope's endurance and elastic limits (50-60% breaking strength).

- South Bend may be an appropriate configuration when risk of collision with ground objects is high.

Although it is not statistically significant, we can see that South Bend performed well in the simulated impact test, resulting in the lowest recorded peak tensions, which confirms the findings of Woodruff (1984) on the historical use of the configuration.

- Use shorter chokers when bridling when possible and avoid the combination of long chokers with Block in the Bight.

Bridling is a common practice to reach logs offset from the skyline. Tests results indicated that using longer chokers which are preferred to reach logs can contribute to larger and more variable tensions during breakout and lateral yarding, and provide less control over the drag. The combination of Block and the Bight and long chokers while bridling produced severe amplifications (8.1 compared to 3.1 for short chokers) of skyline tension and should not be advised.

Acknowledgements

The authors would like to thank Future Forests Research (FFR) Rotorua, New Zealand for supporting the development of this research project. In particular we acknowledge Keith Raymond of FFR for his input into developing the research direction. Special thanks also go to Nigel Pink from the University of Canterbury for his help in the construction of the load cell mounting bracket.

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