Do Synthetic Ropes change the design principles of standing skylines?

Abstract:

Cable logging is often the only sound logging technology for sensitive mountainous regions. European cable systems are mainly operating as standing skylines. All design routines estimate or calculate the forces in the cables (especially the skyline) under the presumption of fixed anchor points. The usage of synthetic ropes as guy lines may change this. The flexibility of synthetic ropes may work as shock absorber and reduce the maximum forces in the skylines.

The pattern of forces in the guy lines during typical yarding operations are used to simulate and calculate the movements of a tower yarder and the effect on the forces in the skyline. This paper shows how to simulate the dynamic loads on guy lines for typical ropes (wire vs. synthetic) in the lab. The test bench for this dynamic load is described and the forces in the tested ropes are compared with measurements done on real installations.

The resulting movements of the peak of a tower yarder are calculated and compared. The paper gives an outlook how the usage of synthetic ropes will influence the design procedure of standing skyline systems.

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Background

Cable Logging has a long tradition in many mountainous forest regions around the globe. Important wood resources and valuable ecosystems are located in mountainous forests. In flat or almost flat areas forestry is often competing with other land use types like agriculture, settlement or industrial use. Commercial forest plantations are mainly established in areas with moderate terrain conditions. Main reason for that is to have low priced costs for harvest and other management activities. Nevertheless forests in mountainous conditions are valuable timber resources, which are logged under this specific conditions. The UNEP-WCMC statistics (Tab1.) indicates 3 times the forest area of the USA (FAO) located in mountains. Two third of the forests in mountainous regions are temperate and boreal forests, just 30% are tropical or subtropical forests.

Cable logging has a long history in many regions. European cable logging systems are adapted to the given terrain conditions. The use of intermediate supports is common, but due to cost reasons also European yarding crews try to install single span set-up’s.

Tab. 1: Areas of different forest types occurring in 4 mountain classes (km²)
Source: IREMONGER et al. 1997

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>&gt;=2500</th>
<th>1500-2500m &amp; slope&gt;=2°</th>
<th>1000-1500m &amp; slope &gt;=5° or local elevation range &gt;300</th>
<th>300-1000m &amp; local elevation range &gt;300</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical (&amp; subtropical)</td>
<td>293.093</td>
<td>450.221</td>
<td>589.328</td>
<td>1.541.000</td>
<td>2.873.642</td>
</tr>
<tr>
<td>Temperate and boreal forests</td>
<td>322.415</td>
<td>1.101.058</td>
<td>1.543.647</td>
<td>3.638.428</td>
<td>6.605.548</td>
</tr>
<tr>
<td>TOTAL</td>
<td>615.508</td>
<td>1.551.279</td>
<td>2.132.975</td>
<td>5.179.428</td>
<td>9.479.190</td>
</tr>
</tbody>
</table>

In opposite to installations in the North West, in Europe the sag of the cable is little. That results in flat cable curves with reduced payloads. The topography is one factor, others are the ownership pattern and the need to have a high lateral stability in thinning operations to avoid damages to the residual trees. The traditional long distance cable yarding installations (PESTAL) used the gravity and had just a small engine to pull the carriage uphill. This installations had 2 or more intermediate supports and reached often up to 1000 meters (~0.6 miles).

Beginning 1950, the “new mobile” short distance cable systems where introduced (PESTAL 1962). This mobile tower yarders are mainly running as uphill or downhill systems, most of all as standing skyline systems. Small equipment allows yarding distances up to 300m (~915ft), bigger ones up to 800 m (~2440ft).
Objectives

There is a long list of scientific discussions about the calculation of the exact cable curve (IRVINE 1975). The differences between parabolic curve or catenary are not discussed in this paper.

The traditional design of cable systems for forest logging in Austria used an algorithm developed by PESTAL. This algorithm is based on cable mechanics (CITARY 1962) and made some simplifications for the daily use. The formulas for the calculation are accurate enough and simple to apply. In opposite to cableways and chairlifts the cable is fixed between two anchors. For cableways and chairlifts the forces in the cable are independent from the position of the load, a balancing system keeps the forces constant.

In forest yarding systems the skyline is fixed between two anchors (this is similar to cables for suspension bridges). The forces are dependent to the position of the load, maximum forces appear when the load is in the middle of the span. Due to the rough operating conditions (carriages with 2 or 4 rollers, discrete movements, immediate stops, load touches the ground) the forces in the different cables show a high variation. This kind of strain to the cable is often visible by jumping carriages along the cableway. Fig. 1 shows a typical diagram of the forces in the guy lines and the skyline of a K-300 mobile yarder. On the right half of the diagram the unloaded phase of the yarding cycle shows moderate frequencies at a low level of forces.

Between second 53 and ~ 85 the lateral hauling shows partial stronger forces in all cables and beginning with second 85 the part of the in-hauling with high amplitudes is recorded. This high amplitudes are not very dangerous because the energy content is low related to the short time the peak's occurs. Nevertheless it is a stress to the cable which may reduce the durability of the cable (FEYRER 1991).
Figure 1: Forces in cables of a typical K-300 setup (PERTLIK 1993)

The traditional setup with the same type of cables for the skyline and the guy lines gives no chance to absorb the peaks of the forces resulting from the turbulent uphill running carriage. By introducing synthetic ropes this changed. Today the usage of synthetic ropes as skyline is not accepted. The main reason is the not solved problem of protection against abrasion. This problem don’t happen with guy lines. This lines are shorter, not pulled over the ground and it’s easier to inspect the surface for damages. Several forest enterprises use now synthetic ropes for their mobile yarders as guy lines. Under European conditions, fully equipped mobile yarders are often on the limits of the road traffic regulations. The save of weight by using synthetic ropes (weight ratio: steel / synthetic rope= 1/7) helps to fulfill the road traffic regulations. The ergonomic benefit for the crew’s, by handling lighter cables should contribute to a more convenient working environment.

Test bench

The test bench (picture 1) installed at the premises of the Forest engineering institute is a simple 2-way hydraulic cylinder to stretch out a cable by forth and back movements of the cylinder. A proportional directional control valve allows smooth switching and expect positioning procedures. The built in displacement transducer gives full control on the volume flow and reduces the hysteresis considerably (< 1.5 %). The valve is controlled by an programmable process control unit (SIEMENS LOGO!SoftComfort V6.1). The maximum frequency of the cylinder is 0.75 Hz (45 strokes/minute, +/- 100mm) with an maximum payload of 500 kN (150 bar). The cylinder have a maximum slideway of 800mm. The maximum volume flow of the hydraulic aggregate is 460 l/min and an external cooling circuit allow sustained continuous operation.

Picture 1: 50 kN cylinder, hydraulic aggregate and manual control unit
The process control unit controls the valve and can simulate the typical sequences of the forces in the cables of a mobile yader (out-haul, lateral hauling, in-haul).

The Forces in the cable are measured with load cells. The actual position of the cylinder is also measured with an displacement transducer. All this is processed with an 8 channel amplifier (HBM Quantum), online displayed and stored for further analysis. Because of the risk of cable failures, nobody should be present during the tests. The room is equipped with a video monitoring system and the amplifier is integrated in the computer network of the university.

**Absorber effect**

In taut cable systems with both ends fix anchored, the most critical situation (PESTAL 1961) occurs in single span layout’s. Therefore PESTAL advise to reduce the set-up force in such situations to 50% of the maximum design force. This results in high deflections and crews tend to ignore this recommendation to avoid intermediate supports. In multiple span layouts not specified cable length will glide into the loaded span and soften the increment of the forces, comparable to weight based tensioning systems used for chairlifts (ERNST 1959).

For the critical single span layout the values in Tab. 2 show for common length of guy lines the elongation effect under an increase of the forces in the skyline. The better absorbing effect of longer guy lines, compared to short ones is obvious (Remark: Short guy lines may under specific terrain conditions also have the effect to increase the pressure on the tower of the yarder due to inappropriate angles between the cables).

Following the well known formula’s (1), (2) and (3) the additional elongation of the guy line can be calculated as a result of the oscillating forces in the skyline.

\[
\begin{align*}
\sigma &= \frac{F}{A} \text{ respectively } \Delta \sigma = \frac{\Delta F}{A} \\
\varepsilon &= \frac{\Delta l}{l_0} \\
\sigma &= E \cdot \varepsilon
\end{align*}
\]

For the linear range the elongation in (3) is replace with the term of (2). For steel cables a module of elasticity is calculated with 180 kN/mm² whereas carbon fiber based synthetic ropes will have one of 120 - 140 kN7mm². For the calculations in Tab. 2 a module of elasticity of 130 was assumed.

\[
\begin{align*}
\Delta \sigma &= E \cdot \varepsilon \\
\Delta l &= \frac{\Delta \sigma \cdot l_0}{E}
\end{align*}
\]

Symbols:
- \(F\) force applied to the cable
- \(A\) cross sectional area
$\sigma$  tension
$\varepsilon$  elongation
$\Delta l$  additional length
$l_0$  reference length
$E$  module of elasticity
Tab. 2: Elongation of guy lines in meters under increasing forces in the skyline  
\((E = 130 \text{ kN/mm}^2)\)

<table>
<thead>
<tr>
<th>guyline length [m]</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>55</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0,04</td>
<td>0,09</td>
<td>0,13</td>
<td>0,17</td>
<td>0,22</td>
<td>0,26</td>
<td>0,30</td>
<td>0,35</td>
<td>0,48</td>
<td>0,52</td>
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<td>25</td>
<td>0,05</td>
<td>0,11</td>
<td>0,16</td>
<td>0,22</td>
<td>0,27</td>
<td>0,32</td>
<td>0,38</td>
<td>0,43</td>
<td>0,59</td>
<td>0,65</td>
</tr>
<tr>
<td>30</td>
<td>0,06</td>
<td>0,13</td>
<td>0,19</td>
<td>0,26</td>
<td>0,32</td>
<td>0,39</td>
<td>0,45</td>
<td>0,52</td>
<td>0,71</td>
<td>0,78</td>
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<tr>
<td>35</td>
<td>0,08</td>
<td>0,15</td>
<td>0,23</td>
<td>0,30</td>
<td>0,38</td>
<td>0,45</td>
<td>0,53</td>
<td>0,61</td>
<td>0,83</td>
<td>0,91</td>
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<tr>
<td>40</td>
<td>0,09</td>
<td>0,17</td>
<td>0,26</td>
<td>0,35</td>
<td>0,43</td>
<td>0,52</td>
<td>0,61</td>
<td>0,69</td>
<td>0,95</td>
<td>1,04</td>
</tr>
</tbody>
</table>

Having the reference length as a linear element in formula’s (4) and (5) the absorbing effect to the skyline is roughly the ratio of the guy line length to the length of the span. For an exact calculation the angles between the skyline and the guy lines have to be accounted. On closer inspection that have to be solved as a spherical problem.

For common layouts this will be a value of 1/10 to 1/5 and reduce the amplitude of the forces in the skyline in a range of 10 to 20 %. The marked area in Tab. 2 shows for common situations the possible movements of the top of the tower, especially during the lateral hauling, when the elongation of the skyline increases the lateral deflection and is not balancing the elongation of the guy lines. That underlines also the necessity to set up the yarder following Euler buckling mode 1 (both ends pinned - hinged, free to rotate). As a result of the lower modulus of elasticity the movements of the top of the tower will increase. This absorption will lower the average and peak stress in cables and contribute to safer operations. It will be of interest if the elasticity of synthetic ropes will change during the lifetime or stay stable.

Summary

Cable yarding is the logging method for significant forest areas located in mountainous regions. The specific design with fixed anchors on both ends results in non-standard strains. The systems are not comparable to cableways or chairlifts.

A test bench to stress cables with oscillating forces is described.

The consideration of the elongation effects to the top of the tower of a cable yarder demonstrates the absorbing effect of the guy lines in general. The difference in the modulus of elasticity is boosting this effect and should find reflection in the design rules.
Synthetic ropes will be an opportunity to make the work easier but will also contribute to some safety aspects.

References


FAO, Global Forest Resources Assessment 2005. (FAO Website)


PESTAL, E. 1961, Seilbahnen und Seilkran für Holz und Materialtransport; Verlag Georg Fromme & Co. Wien und München