SKYLINE TENSION ANALYSIS IN YARDING OPERATION: CASE STUDIES IN ITALY

Fabio Fabiano, Enrico Marchi, Francesco Neri*, Franco Piegai

University of Florence - Department of Agricultural and Forest Economics, Engineering, Sciences and Technologies, Florence (Italy)

fabio.fabiano@unifi.it, emarchi@unifi.it, *francesco.neri@unifi.it, piedai@unifi.it
Introduction – Cable yarding

- Key role in steep terrain logging for an efficient forest management and for reducing environmental impact
- Initial skyline tension (unloaded) determination and the maximum log load (load weight) in relation to avoiding overloads
- Tensions must be within allowable limits when the carriage is located anywhere on the line
- Often, in Italy, many cableways are just based on the operators’ experience and no calculation of the tension in skylines is carried out
- Analytical methods to determine the maximum payload
- Low level of accuracy - high variability of the factors involved (supports elasticity)
- Information on skyline tension increments is still limited

The study:
- Summary of a-decade investigations on skyline tensions - gravitational system
- 69 lines (single and multi) were tested in experimental fields or forest yards
The best functions to describe the skyline behaviour were determined (different line designs, loads and initial tensioning)

Practical instructions to increase work safety with cable cranes
- Tension measurements were carried out on several ropes
- Ropes diameter between 6 - 34 mm
- Seale, Warrington-Seale and Warrington
- Core mainly fiber
- 44 single-span lines
  - Length between 105-680 m
  - Slope varied from 10 to 50%
- 25 multi-span lines
  - Length between 105-1079 m
  - Slope varied from 10 to 57%
**Tensions measurement**

- Load cells were placed between skyline and anchors (both at uphill and downhill)
- Cells were connected to digital strain meters
- Data loggers recorded the data at a sampling interval of 1 second
- Tensions were measured varying:
  - The initial tensioning (Tscar)
  - The load (P)
- The maximum tension values of loaded skyline (Tcar), recorded for each line at different Tscar and P, were used in the data analysis
Descriptive analysis

- **Tmax**: maximum skyline tension (ratio between the breaking strength (CR) of the rope and the safety factor $Z = 2.5 - 3$)
- **Tscar**: initial tensioning
- **Pmax**: maximum load

- **Tcar**: loaded skyline tension; $T_{car} = T_{scar} + \Delta T$ (tension increment due to the load) – *(Tcar must be < Tmax)*
- **TI**: tension increment index - $TI = \Delta T/P$
Variables

- Multiple linear regression was applied to find the relationship between Tcar and the other parameters (for single and multi-span lines)
- Dependent variable: Tcar
- Independent variables: Tscar, P, SL (span length), span slope
- The variables were indexed dividing them by the breaking strength (CR) of the rope
- Regression analyses were carried out by the Statgraphics 5.1 software
Results

- Tensions in skyline ropes depend on:
  - Initial tensioning (Tscar) related to the rope specifications
  - Load weight (P)
  - Geometrical features of the line

Single-span line

- Tension increases when the loaded carriage moves from the anchors to the middle of the span

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### Chart Details

- **X-axis (Time, s):** 0 to 250
- **Y-axis (Loaded tension, kN):** -175 to -125
- **Points of Interest:**
  - Carriage close to downhill anchor
  - Carriage above landing
  - Middle span

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<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Loaded tension (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-175</td>
</tr>
<tr>
<td>50</td>
<td>-135</td>
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<tr>
<td>100</td>
<td>-130</td>
</tr>
<tr>
<td>150</td>
<td>-125</td>
</tr>
<tr>
<td>200</td>
<td>-120</td>
</tr>
<tr>
<td>250</td>
<td>-115</td>
</tr>
</tbody>
</table>
Higher the span length, higher the skyline tension increment ($\Delta T = T_{car} - T_{scar}$) (equal $T_{scar}$ and $P$)

- The tension increment decreases when $T_{scar}$ increases (equal $SL$ and $P$)

- $\Delta T$ raises when $P$ increases (equal $T_{scar}$). This response is higher when low $T_{scar}$ are applied ($T_{scar} = 1/3.5 \ T_{max}$)

- Usually the TI value varies between 3 and 4

- The higher $T_{scar}$ the higher $T_{car}$ ($P$ equal), even though the higher $T_{scar}$ the lower $\Delta T$ and TI
Multi span line

- Tensions depend on the SL – tensions peak when the load is on the middle of the longest span of the line
- The longest span location on the line does not affect the tension increment

![Graph showing tension over time and carriage positions on the spans.](image-url)
Multi span line

- Carriage on the supports, the loaded skyline tension gets closer to the value of $T_{scar}$
- (Equal $T_{scar}$ and $P$), $T_{car}$ is lower than $T_{car}$ recorded in single-span lines (resilience given by supports)
- (Equal $T_{scar}$ and $P$), the higher the span length, the higher $\Delta T$
- For the same $P$ value, the higher $T_{scar}$, the lower $\Delta T$
- For the same $T_{scar}$, the higher $P$, the higher $\Delta T$ (especially in case of low $T_{scar}$)
- TI (with high and low $T_{scar}$) are lower in multi span lines
- The TI values were between 2.5 and 3 (2 span) and between 2 and 2.5 (3 or more span)
Regression analysis – single span

- Multiple linear regression models were applied to uphill/downhill anchors data (Tscar/CR; P/CR; SL and Slope - independent variables)

1) $T_{car}/CR = a + (b \times T_{scar}/CR) + (c \times P/CR)$
2) $T_{car}/CR = a + (b \times T_{scar}/CR) + (c \times P/CR) + (d \times SL)$
3) $T_{car}/CR = a + (b \times T_{scar}/CR) + (c \times P/CR) + (d \times SL) + (e \times Slope)$

- Statistical significant relationship between the variables ($p<0.001$)
- All the models explain more than 97% of the $T_{car}/CR$ variability
- Lower errors for the uphill anchor
Regression analysis – multi span

- Tcar/CR was measured when the load was in the longest span (max TI)
- (Tscar/CR; P/CR; SL; Span% - independent variables)

4) \( \text{Tcar/CR} = a + (b \times \text{Tscar/CR}) + (c \times P/CR) \)
5) \( \text{Tcar/CR} = a + (b \times \text{Tscar/CR}) + (c \times P/CR) + (dxSL) \)
6) \( \text{Tcar/CR} = a + (b \times \text{Tscar/CR}) + (c \times P/CR) + (e \times \text{Span%}) \)
7) \( \text{Tcar/CR} = a + (b \times \text{Tscar/CR}) + (c \times P/CR) + (d \times SL) + (e \times \text{Span%}) \)

Statistical significant relationship between the variables (p<0.001)
All the models explain more than 92% of the Tcar/CR variability
Discussion

■ Multi-span lines show lower skyline tension increment (Equal Tscar and P)

■ Multi-span similar to single-span lines when the longest span reaches almost the total length of the line

■ In single-span lines the application of regression models highlighted that:
  • initial tensioning should vary between $\frac{3}{5} \div \frac{2}{3} T_{max}$
  • the load weight should vary between $\frac{1}{9} - \frac{1}{11} T_{max}$ ($Z=3$) and between $\frac{1}{6}-\frac{1}{7} T_{max}$ ($Z=2.5$)
  • long lines permit lower load than short lines
Discussion

- In multi-span lines:
  - \((Z=2.5 – 3)\), multi-span lines permit higher \(T_{scar}\) and \(P\) than single-span lines
  - If the main span length is \(2/3\) of the total length of the line, tension increments are very similar to the values recorded in single-span lines (with similar \(T_{scar} = 2/3 \ T_{max}\), higher \(P\) are permitted \(P=1/9 \ T_{max}\))
  - Higher \(T_{scar} (3/4 \ T_{max})\) and \(P\) are permitted in case of two equal-length spans on the line
  - In case of 3 or more spans on the line higher \(T_{scar}\) are permitted \((4/5 \ T_{max}) – P=1/9 \ T_{max}\)
- High mounting tension are suggested to avoid skyline deflections on supports and troubles with the carriage on the saddles
Conclusion

- The linear regressions models allowed to suggest rules for a safer use of standing skyline, on the basis of field measurements.

- A safety factor equal to 2.5 is recommended (usually adopted in forest operation).

- Tension monitoring systems or self-regulating mechanisms (adjustable skyline brakes or tensioning devices) are recommended.
Thank you for your attention!!!!!