Austro2011/FORMEC´11: Pushing the boundaries with research and innovation in forest engineering October 9 – 12, 2011, Graz and Rein – Austria

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*, *piegai@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

Cable yarders

- 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; Tcar = Tscar + ΔT (tension increment due to the load) – (Tcar must be < Tmax)
- TI: tension increment index - TI= $\Delta T/P$

Variables

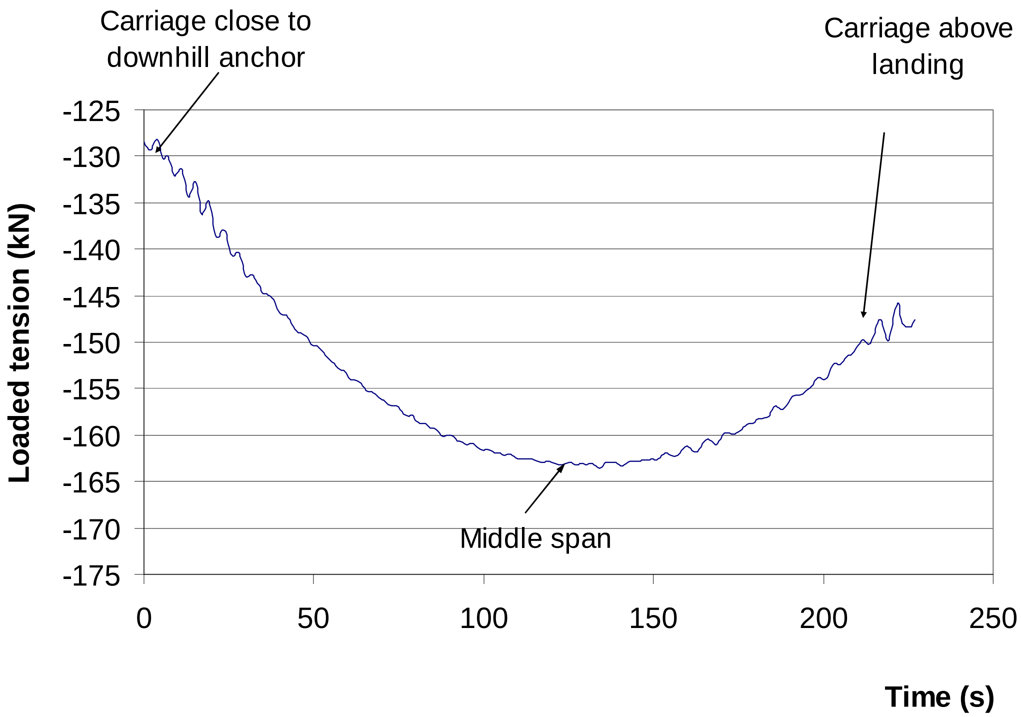
- Multiple linear regression was applied to find the relationship between Tcar and the other parameters (for single and multi-span lines)
- Dependent variable: Tcar
- Independent variables: Tscar, P, SL (span length), span slope
- The variables were indexed dividing them by the breaking strength (CR)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

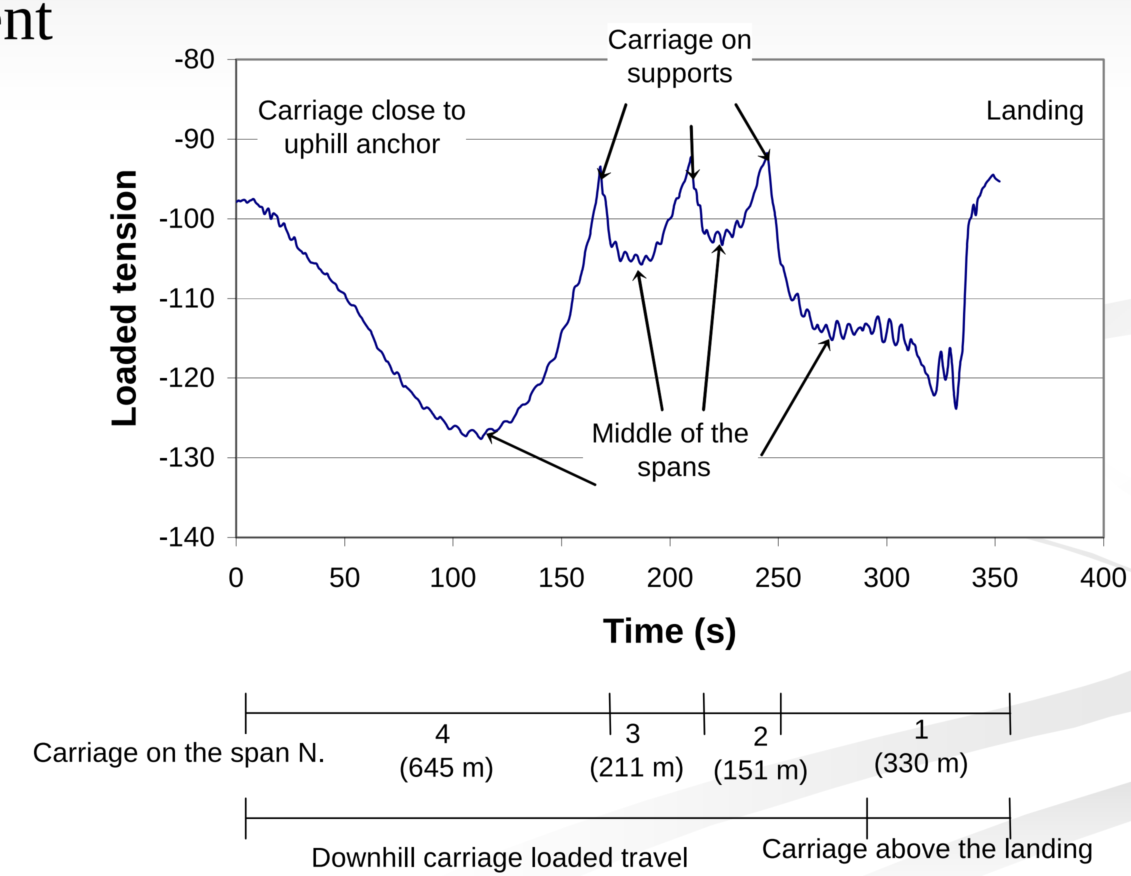


Single span line

- Higher the span length, higher the skyline tension increment ($\Delta T = Tcar - Tscar$) (equal Tscar and P)
- The tension increment decreases when Tscar increases (equal SL and P)
- ΔT raises when P increases (equal Tscar). This response is higher when low Tscar are applied (Tscar=1/3.5 Tmax)
- Usually the TI value varies between 3 and 4
- The higher Tscar the higher Tcar (P equal), even though the higher Tscar the lower ΔT 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



Multi span line

- Carriage on the supports, the loaded skyline tension gets closer to the value of Tscar
- (Equal Tscar and P), Tcar is lower than Tcar recorded in single-span lines (resilience given by supports)
- (Equal Tscar and P), the higher the span length, the higher ΔT
- For the same P value, the higher Tscar, the lower ΔT
- For the same Tscar, the higher P, the higher ΔT (especially in case of low Tscar)
- TI (with high and low Tscar) 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) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR)
2) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR) + (d×SL)
3) **Tcar/CR = a + (b×Tscar/CR) + (c×P/CR) + (d×SL) + (e×Slope)**

Output of the regression analyses for single-span lines – uphill anchor – N.=114,
R^2 = coefficient of determination; S.E. = Standard error

Function	Factors a cost	b x TS/CR	c x P/CR	d x SL	e x Slope	R^2	S.E.	Predicted/Observed Max difference (%) +	-
1	0.04220	0.79888	3.47109			0.970	0.0083	5.3	-5.9
2	0.04555	0.75152	3.43653	0.00003		0.985	0.0057	5.9	-5.1
3	**0.04954**	**0.75036**	**3.53831**	**0.00004**	**-0.02059**	**0.989**	**0.0051**	**6.1**	**-3.4**

- Statistical significant relationship between the variables ($p<0.001$)
- All the models explain more than 97% of the Tcar/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) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR)

5) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR) + (dxSL)

6) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR) + (e×Span%)

7) Tcar/CR = a + (b×Tscar/CR) + (c×P/CR) + (d×SL) + (e×Span%)

Output of the regression analyses for multi-span lines – uphill anchor – data related to the longest span
N.= 587, R^2 = coefficient of determination; S.E. = Standard error

Function	Factors					R^2	S.E.	Predicted/Observed Max difference (%)	
	a cost	b TS/CR	c P/CR	d Span%	E SL			+	-
4	0.03451	0.79589	3.09188			0.922	0.0190	19.0	-10.3
5	0.03089	0.78088	2.91798		0.00004	0.954	0.0145	15.5	-10.8
6	-0.02472	0.85139	2.86113	0.08345		0.979	0.0099	9.9	-9.3
7	-0.01850	0.84105	2.84614	0.07344	0.00001	0.980	0.0097	10.2	-9.2

- 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 3/5÷2/3 Tmax
- the load weight should vary between 1/9 - 1/11 Tmax (Z=3) and between 1/6-1/7 Tmax (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 Tscar 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 Tscar = 2/3 Tmax, higher P are permitted P=1/9 Tmax)
- Higher Tscar (3/4 Tmax) 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 Tscar are permitted (4/5 Tmax) – P=1/9 Tmax
- 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!!!!

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*, *piegai@unifi.it*

Austro2011/FORMEC´11: Pushing the boundaries with research and innovation in forest engineering October 9 – 12, 2011, Graz and Rein – Austria