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A STUDY OF DAMAGE TO HAULING STEEL WIRE ROPES ON THE EXAMPLE OF TRACTOR WOOD EXTRACTION

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Abstract

The method and partial results of the survey of mechanical damage to steel wire ropes (torn wires and rope deformations), used in tractor wood extraction in the Republic of Slovenia, is described in the article. Ten ropes of three different types were examined in the investigation. It was found out that the number of torn wires increased significantly towards the end of a wire rope (that is towards the load fastening point), while other deformations are more frequent at the first half of the rope.

Key words: steel wire ropes, wood extraction, tractors, skidders

POŠKODBE VLAČILNIH JEKLENIH VRVI

Izvleček

V prispevku je opisana metoda in delni rezultati meritev mehanskih poškodb (raztrgane žice in deformacije) jeklenih vrvi, ki jih uporabljamo pri traktorskem spravilu lesa v R. Sloveniji. Izmerili smo spremembe pri treh različnih tipih vrvi na desetih premerih vrvi. Ugotovili smo, da število raztrganih žic močno narašča proti koncu vrvi (na mestu pripenjanja bremena), medtem ko so ostale deformacije pogostejše in večje v prvi polovici vrvi.

Ključne besede: jeklene žične vrvi, spravilo lesa, traktorji, Slovenija

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1 INTRODUCTION

Wire ropes are constituent parts of the majority of devices used for wood extraction in forestry. They are destined either for the gathering of timber (by winches) or for the hauling, bunching and transport of timber (by cableways; KOŠIR 1990). By cableway wood extraction, different wire ropes are used for different purposes - one for the hauling and transport and another for bunching of timber. Yet there are also devices, by which the same rope is used for the hauling as well as for bunching of timber. By tractor wood extraction, the same rope is actively used only for the gathering of timber.

If used, the ropes wear out rather quickly. In the case of cableway wood extraction, the skylines have to be replaced every 2000 working hours and the main lines every 1200 working hours. By tractor wood extraction, wearing of the ropes is much faster and the winch ropes have to be exchanged every 200 - 300 working hours.

The wearing of a rope depends on several factors: the construction of a device, working conditions (the quantity of rocks, the slope), the load size and the usage (KOŠIR, 1993a).

2 WIRE ROPES IN TIMBER EXTRACTION

Too fast wearing of the ropes is a serious economic problem for foresters. If only the ropes of wood extraction devices that are used in the state forests of Slovenia are taken into consideration (Table 1), it is quite clear that the costs of such rope quantity of represent a great financial burden for forestry enterprises. Steel wire ropes cost 5 - 10 DM per running metre on the average, depending on their thickness and other characteristics.

Therefore, it is important to find out the factors which have influence on the wearing of ropes and - connected to that - on the necessity of their replacing -

because only once these factors are known, the prevention of their damaging effects is possible. For this reason an investigation was started in 1991 to reveal the factors responsible for the shortening of the life of steel wire ropes used for wood extraction. As tractors are most frequently used for extraction of timber - by their number as well as by the quantity of extracted timber (KOŠIR et all. 1991, 1993b) - the investigation started with a study of tractor wood extraction.

Table 1 *The length of wire ropes, used for wood extraction in the state forests of Slovenia (approx. 300 000ha) - an estimation*

Type of a device	Length of hauling lines	Length of skylines	Length of auxiliary/ main lines	Total
Adapted farm tractors	20.500	-	-	20.500
Steering frame skidders	7.000	-	-	7.000
Adapted caterpillars	5.500	-	-	5.500
Tractors together	33.000	-	-	33.000
Single drum gravity cable cranes	20.500	20.500	2.500	43.500
Mobile tower yarders	12.500	12.500	13.500	38.500
Total	66.000	33.000	16.000	115.000

In the last years the number of tractors and cable cranes owned by forestry enterprises has significantly dropped. Despite this fact those machines have remained in forestry and are involved in forest operations, both in private and in the state forests and are managed by contractors.

3 METHODS OF MEASUREMENT

The mechanical damage and changes to steel wire ropes used in tractor wood extraction were studied - among the other goals there was also the intention to test the method with which it would also be possible to evaluate the wearing out and the damage to ropes by diverse wood extraction devices in the further studies. A special record sheet was prepared for the measured data to be filled in. The list of variables, evaluated for each rope separately, is presented in Table 2 and Figure 1.

By counting of the torn wires it was not possible to know whether the same wire was torn several times.

The measurements were carried out in the region of Celje in May and June 1991. The damage was evaluated on three wire ropes (total measured = 10 ropes). Adapted farm tractors and steering frame skidders were included in the investigation (LKT 80, Timberjack, Belt).

The rope no.1 was examined by adapted farm tractors IMT 560 (manufactured by Pančevo - Serbia), the rope no.2 by steering frame skidders Belt (manufactured by Belt Črnomelj - Slovenia) and the rope no.3 by steering frame skidders Timberjack (Table 3 and Table 4). In most cases conifer wood (length 8m) was extracted, either on soft or on hard ground surface.

The results of the measurements were treated according to the normal procedures. Our major interest was to establish, how the deformations and other changes were distributed along the whole length of the rope. Therefore, the most important independent variable was the rope distance (in metres) from the winch drum, on which the changes were evaluated. Because the ropes' lengths were different, this variable was expressed in per cents of the whole length of a rope (0% = by the winch, 100% = by the load). The other independent variables, as for example the ground surface, the age and quantity of extracted timber, were taken into consideration too, yet there were not enough measurements done for the influence of these latter variables to be statistically reliably defined.

Table 2 *The list of variables by measurements of damage to steel wire ropes*

Label of the variable	Description
STA	Duration of the rope usage (days)
KUB	Quantity of timber extracted by a single rope (m^3)
POD	Ground surface (0 = soft, 1 = hard); soft surface = smooth, even terrain, deep soils; hard surface = rocky, uneven terrain
MET	Distance in metres (1 = by the drum)
NSTRGA	Number of torn wires by non-deformed wire rope (torn wires by deformed wire rope are not included); in case of ovalness, the torn wires are taken into consideration as well
NTOCKA	Number of local defects (folded wire ropes)
NZICA1	Number of torn wires by CDEFOB
NZICA2	Number of torn wires by CDEFOD
COVALN	Length of ovalness (cm); the ovalness of rope was taken into consideration if the difference in diameters was more than 15%
CBREZB	Length of deformed - flattened - rope (cm); the rope's core is not deformed (no wires are torn)
CBREZD	Length of deformed - flattened - rope (cm); the core is visibly deformed, but no wires are torn
CDEFOB	Length of deformed - flattened - rope (cm); the core is not deformed, some wires are torn
CDEFOD	Length of deformed - flattened - rope (cm); the core is visibly deformed, some wires are torn
CVTISN	Length of the segment (cm) on which the rope's core is replaced by a pressed-in rope strand

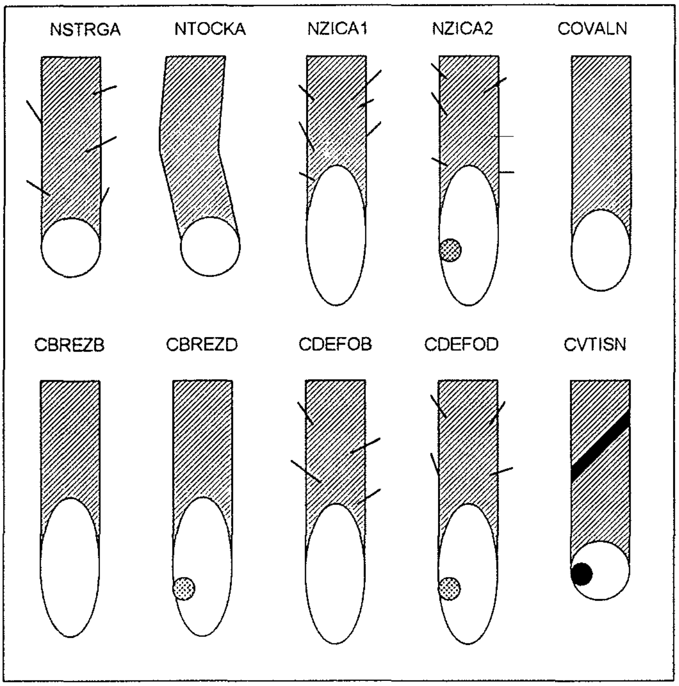

Figure 1 *Schematic display of the measured variables*

Table 3 *Characteristics of the examined wire ropes*

Wire rope	Diameter (mm)	Construction	Manufacturer	Supplier	Date of delivery	Weight (kg/m)	Breaking force (kN)	Twist-ing
1	12	6x37+FC	NFK,YU	UNIOR, ŠMARJE	1,1988	0,498	91,1	sZ
2	14	6x19+FC Seale	NFK,YU	RUDAR, ZAGREB	7,1987 9,1989	0,730	134,0	sZ
3	16	6x37+FC	NFK,YU	RUDAR, ZAGREB	7,1987	0,886	162,0	sZ

Table 4 *The data about the examined ropes and the tractors*

Type of a tractor	Type of a winch	Pulling force (kN)	Safety factor	Rope no.
IMT 560	Igland Compact	2 x 50	1,8	1
	GV 50 2H	2 x 50		
Belt GV 70	Igland	2 x 80	1,7	2
LKT 81	Original	2 x 60	2,2	2
Timberjack	Hercules original	80	2,0	3

Among the dependent variables, the sum of all torn wires (NSUM) and the sum of all deformations in cm per 1m (CSUM) were the most important . The length of non-deformed rope per rope segments of 1m was expressed as the difference between the CSUM value and 100cm.

4 RESULTS OF THE TRIAL

One of the purposes of the investigation was also the testing of the method of rope damage evaluation. Because of this, the amount of various ropes used in different working conditions was not great enough for a reliable evaluation of the influence of ground surface on rope damage (Appendix 2). A special problem is the relation of the duration of rope use, which is in high correlation with the quantity of extracted timber (Appendix 2), to damage to ropes.

This relation could be the most accurately evaluated if the same rope was observed and examined for a longer period of time or a sufficient amount of ropes of different ages were measured. The second possibility was chosen but not enough data were gathered for the rope no.3. The results for the ropes no. 1 and no. 2 were well comparable - considering the age of the ropes and the quantity of transported timber (Table 5). Anyway, the results of the measurements for the rope no. 3 are presented too - although only one measurement was done.

Table 5 Average values of some variables

Variable	Label	Unit	Rope no.1	Rope no.2	Rope no.3
Quantity of wood	KUB	m^3	505	644	35
Duration of use	STA	day	144	145	62
Rope length	MAX	m	57,58	53,74	62,87
Number of examined ropes			4	5	1

The dependent variables have been classified into two groups (see also Appendix 1). In the first group, the variables representing the number of torn wires and in the second one there are those related to the various rope deformations. The mean values for both groups are presented in Table 6 and Table 7. In the first group (torn wires), the number of torn wires where rope is not significantly deformed (only the ovalness is possible) is the most frequent rope damage. The torn wires in the segments of badly deformed rope represent less than a fifth of the whole amount of torn wires.

Table 6 The average number of torn wires per 1m of rope

Variable	Label	Rope no.1	Rope no.2	Rope no.3
Number of torn wires by non-deformed wire rope per m	NSTRGA	6,43	7,59	2,97
Number of torn wires by length of deformed - flattened - rope (cm); the core is not deformed, some wires are torn per m	NZICA1	0,69	0,48	0,02
Number of torn wires by length of deformed - flattened - rope (cm); the core is visibly deformed, some wires are torn per m	NZICA2	0,53	0,72	0,14
Total number of torn wires per m	NSUM	7,66	8,79	3,13

Among deformations, ovalness is the most frequent form, and the second one is the flatness of rope without the deformation of its core. If damage was expressed in per cents, ovalness would represent 18% - 34% of deformations and diverse flatness the additional 6% - 12%. It is evident from Table 7, that on the average only 54% - 76% of rope remain non-deformed.

Table 7 The average length of deformations (cm) per 1m of rope

Variable	Label	Rope no.1	Rope no.2	Rope no.3
Length of deformed - flattened - rope (cm/m); the rope's core is not deformed (no wires are torn)	CBREZB	3,55	5,21	7,43
Length of deformed - flattened - rope (cm/m); the core is visibly deformed, but no wires are torn	CBREZD	1,28	3,99	1,90
Length of deformed - flattened - rope (cm/m); the core is not deformed, some wires are torn	CDEFOB	1,21	1,32	0,16
Length of deformed - flattened - rope (cm/m); the core is visibly deformed, some wires are torn	CDEFOD	0,36	2,13	1,03
Length of ovalness (cm/m); the ovalness of rope was taken into consideration if the difference in diameters was more than 15%	COVALN	17,66	18,24	33,62
Length of the segment (cm/m) in which the rope's core is replaced by a pressed-in rope strand	CVTISN	0,18	1,30	1,52
Total deformations (cm/m)	CSUM	24,24	32,19	45,67

An analysis of local deformations (Table 8), among which the restraightened slings are the most frequent, shows that local deformations are more numerous in the closer parts of the ropes. This can well be undrestood since slings emerge, when there is too much rope unwound, so that it curves and twists uncontrollably. As the rope no. 3 had only been used for a short period, the mentioned characteristic had not been evident with it yet . If the ropes no.1 and no. 2 are compared, it could be establish, that the thicker rope no. 2 has less local deformations. Most probably that is due to the fact that the thicker rope does not twist so easily as the thinner ropes do.

Table 8 The average number of local deformations (NTOCKA) per meter of a rope with regard to the position in the rope (% of the rope length)

Position in the rope	Comment	Rope no.1	Rope no.2	Rope no.3
0% - 20%	Near the winch	0,19	0,36	0
21% - 40%		0,50	0,29	0,08
41% - 60%		0,43	0,27	0
61% - 80%	Use of chokers	0,39	0,20	0
81% - 100%	Near the load	0,24	0,13	0
Average value		0,35	0,25	0,02

The dependencies of the number of torn wires (NSUM) and the sum of lengths of all deformations (CSUM) were also treated by regression equations to evaluate the shares of explained variability (Table 9).

Table 9 Regression dependence of rope damage on the distance from the winch (M - %)

Independent variable M (%)	Regression coefficient b_i	Dependent variable					
		Rope no.1		Rope no.2		Rope no.3	
		Total number of torn wires per m	Total lengths of deformed rope cm/m	Total number of torn wires per m	Total lengths of deformed rope cm/m	Total number of torn wires per m	Total lengths of deformed rope cm/m
		NSUM	CSUM	NSUM	CSUM	NSUM	CSUM
M	b1			0,253			
M^2	b2		-0,0142				
M^3	b3				-7,61E-05	1,17E-05	
M^4	b4						-1,59E-06
M^5	b5		1,50E-08	-1,68E-09			
M^8	b6				2,44E-15		
M^{10}	b7	6,54E-19					
M^{12}	b8		-6,70E-23				1,12E-22
1/M	b9		-315,45		-70,78		-714,47
$1/M^2$	b10		361,80				921,25
Constant	a	0,40	63,57	-0,92	53,21	0,09	93,58
Explained var.	R^2	0,40	0,22	0,05	0,26	0,47	0,36
N of cases		229	229	258	258	63	63
The equation: NSUM (or CSUM) = a + b1*M + b2*M^2 + b3*M^3 +...+ b10/M^2							

It was found out that the entire number of torn wires (NSUM) normally increases towards the end of the rope (M = % of rope length, 0 = near the winch). This is quite evident with the ropes no.1 and no.3, while in case of rope no.2 the maximum number of torn wires exists at 75% of the rope length. This maximum is obviously the consequence of too great wearing of the rope, which was most probably caused by incautious work (Figure 2).

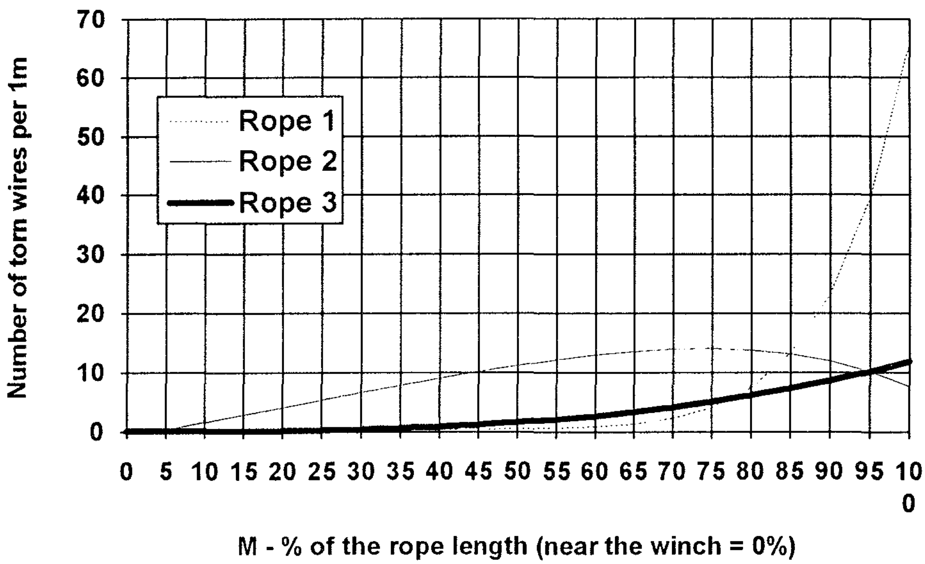

Figure 2 *Dependence of the number of torn wires upon the place of rope measurement*

Different longitudinal rope deformations (CSUM) show that ropes are most deformed somewhere between 20% and 40% of their length (the winch is considered the starting point = 0%) and the least deformed at the very beginning (where the rope is the least deformed in general) and at the very end of the rope (where normally torn wires are prevailing - Figure 3).

The deformations most probably result from unsuitable rope winding on the drum, which is with the majority of tractors not properly solved. In Slovenia, tractors are mainly used for wood gathering at the distances of 10m - 30m. That corresponds to the position of rope deformations, resulting from its winding to a drum when it is heavily loaded by hauled timber.

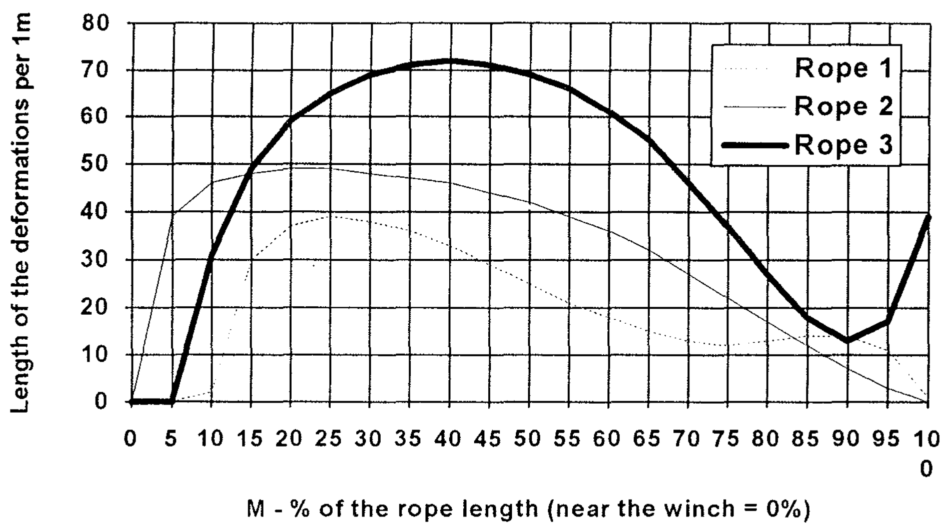

Figure 3 *Dependence of the length of rope deformation upon the position of rope measurement*

A further analysis of the total damages (NSUM + CSUM) of the rope per 1m showed that the cumulative distribution could be divided into three parts (Figure 4). The first part of the rope length lies near the winch drum (up to the 20% of the rope length) where the inclination of the cumulative curve is rather great with a digressive tendency. The structure of rope damage shows the prevailing share of longitudinal deformations over broken wires per 1m.

In the second part of the rope (say: between 20 and 80% of the rope length) the inclination of the cumulative curve is more or less zero and the total probability of damage is close to 0,10. The structure in this part emphasizes the growing share of the number of torn wires per 1m of the rope, with decreasing importance of longitudinal deformations.

The third part of the rope, which is near the load, represents the part where chokers are sliding along the rope during timber bunching. This is the cause of the rapidly growing share of torn wires with very little longitudinal deformations. The inclination of the cumulative curve in this part is similar as in the first part - steep but with a progressive tendency.

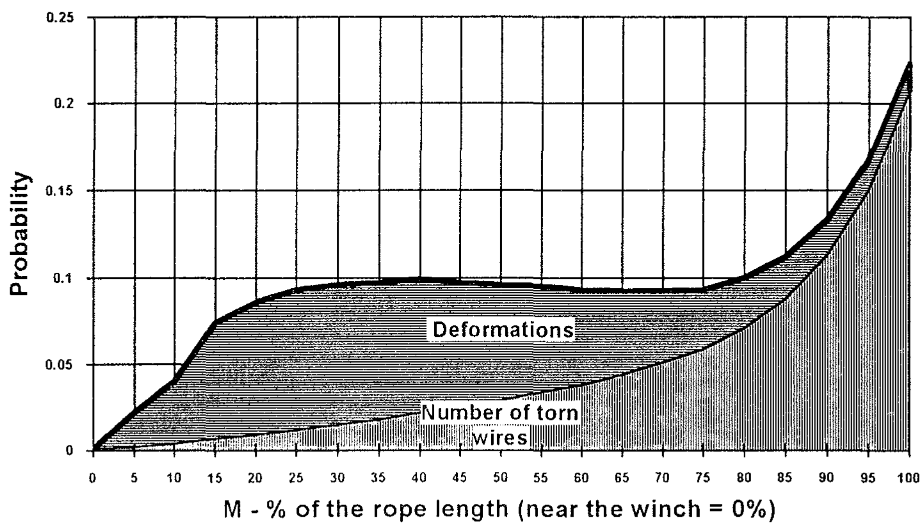

Figure 4 *Probability of the longitudinal deformations and number of torn wires per 1m along the rope length*

Related to this there is the question of the safety factor along the wire rope. It is obviously that the safety factor decreases from around 2 at the beginning of the rope toward 1 at a certain point where the rope is to be broken. It is also clear that the real distribution of safety factor values along the rope length is only possible to measure with mechanical testing of the breaking force at every meter of the rope. On the basis of the results of this paper however, the worst work safety could be expected in the last quarter of the rope, though we could expect breakage also in the first parts due to local deformations, whose influence on the safety factor is fully unknown.

5 DISCUSSION

The survey of the wearing out of ropes by tractor wood extraction showed that ropes were most liable to mechanical deformations at the parts of load fastening and at the parts of slider gathering. These are the parts of the ropes that slide over the ground and different obstacles and are also at the same time through sliders burdened by heavy timber. Consequently due to the improperly solved rope winding, the rope deformations as ovalness, flatness and the like emerge. In these segments of ropes (between 20% and 40% from the drum), the number of torn wires is relatively small.

There are several signs indicating that the ground surface on which the wood is gathered has a significant influence on the wearing out of ropes and damage to them. Yet in this - initial stage of the investigation, this influence could not be reliably evaluated yet. The situation as to the duration of rope usage, which has influence on the quantity of extracted timber, is rather similar. The loading of a rope within its life period is, without any doubt an important factor, which has great influence on the wearing out and the damage to ropes; yet up to now, the extent of this influence has not been studied yet. The wire ropes that are used in tractor skidding today are not resistant enough to such heavy wear because of mechanical influences. The wire ropes in the future will have to have strong steel core to be resistant against external forces, on the other hand thicker wires in the outside layer are an important characteristic too.

In future, the method of measurement here introduced will also be used for the surveys of cableway wood extraction. There, the results will also help to elucidate the safety demands, which are much better defined for cableway wood extraction. Theoretical safety factors are very low in tractor skidding - below 2, while during practical work their values are completely unknown. This is also the field for further investigations, either under controlled conditions or during practical field operations.

6 SUMMARY

The wearing out and damage to ropes by wood extraction are responsible for the frequent replacing of ropes, which is a great financial burden for foresters. In the trial, a method of evaluation of damage to ropes by tractor wood extraction was tested. The rope changes were classified into two groups: torn wires and different deformations as for example ovalness and flatness of rope. Ten tractor ropes were examined; the results of measurements were later treated separately, with consideration to the characteristics of the ropes (rope no.1 = 12mm, rope no.2 = 14mm, rope no.3 = 16mm). It was found out that the distance of the measured part of a rope from the drum expressed in per cents of the rope length (%) was the best indicator of the measured changes. The duration of rope usage and its loading, expressed by the quantity of extracted timber, was evaluated as well. In the analysis, it was not possible to define a reliable and comparable influence of these two factors on the rope wearing out. Most probably the ground surface also has significant influence on the variability of the rope deformations, yet that was not studied separately in this study.

It was found out that the number of torn wires increased significantly towards the end of the rope (where the load is fastened), while the longitudinal deformations were most frequent between 20% and 40% of the rope length (nearer to the winch drum), that is at the section, where the loading of a rope by its winding is the greatest.

The method, introduced in this study, will be further tested in the investigations of rope condition with cable cranes.

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8 APPENDICES

Appendix 1 Mean values of the measured variables

Variable	Mean	Std Dev	Variance	Minimum	Maximum
KUB	516,37	401,83	161469,74	35	1140
STA	135,07	89,73	8051,10	28	271
CBREZB	4,77	11,36	129,13	0	80
CBREZD	2,63	7,51	56,38	0	72
CDEFOB	1,14	4,65	21,65	0	48
CDEFOD	1,27	5,02	25,24	0	43
COVALN	19,76	24,61	605,58	0	99
CVTISN	0,86	5,61	31,46	0	99
CSUM	30,43	32,50	1056,14	0,00	110,00
NSTRGA	6,58	20,01	400,60	0	182
NZICA1	0,52	4,61	21,24	0	99
NZICA2	0,58	4,72	22,28	0	99
NSUM	7,67	21,77	474,03	0,00	192,00
NTOCKA	0,27	0,55	0,30	0	3

Number of valid observations = 550

Appendix 2 Correlation matrix of the most important variables

Correlation	NSUM	CSUM	M (%)	KUB	STA	POD
NSUM	1					
CSUM	-0,1393*	1				
M (%)	0,2787**	-0,3114**	1			
KUB	0,2142**	0,0725		1		
STA	0,1249*	0,1082		0,9095**	1	
POD	-0,0938	-0,0441				1
2 - tailed significance: * = 0,01, ** = 0,001, ... = no significance						

Number of valid observations = 550

COMMENT: This investigation was a part of the research project, entitled "Extraction of wood in the forests with an emphasized protective role in Alpine conditions", which was financed by the Ministry of Science and Technology and the Ministry of Agriculture, Forestry and Nutrition of the Republic of Slovenia. The field measurements were with great personal endeavour and exactness executed by a forest engineer, Ms. Andreja RATAJC and colleagues (The Forestry Enterprise of Celje), during the training at the Institute of Forest and Wood Economy in Ljubljana (now called: Slovenian Forestry Institute), under the menthorship of Dr. B. KOSIR. The results of the measurements were further treated in the Department of Forestry Techniques and Economics. These results have already been presented at the 2. Internationaler Workshop: Seilbringung im Gebirge in Ort/Gmunden, 1992 in Ort, Austria, and later published in the proceedings of the workshop. A slightly changed and revised text has been published here owing to the interest shown by production managers in forestry today.