

Forces Required for Pulling Out a Winch Steel Cable and Physical Load of Choker-Man

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Abstract:

The forces required for pulling out a winch steel cable are essential for evaluating the effect on physical load of choker man. The following parameters have the greatest impact on the size of these forces: diameter and unit weight of steel cable, resistance forces in the winch that occur due to friction in the drum bearings, improper adjustment of winch brake and clutch and also the terrain slope where the rope is pulled. This paper presents the results of in situ measurements:

- ⇒ pulling force of steel cable,
- ⇒ velocity of steel cable pulling,
- ⇒ power consumed in pulling,

carried out on a Hittner 2 x 80 winch mounted on a skidder Ecotrac 120V.

Changes of measurement values are analyzed as a function of:

- ⇒ length of the pulled steel cable, and
- ⇒ terrain slope (5 different inclinations ranging between -19° and $+19^\circ$).

Based on the research results, physical load of choker-man is classified as work under heavy load according to the Directive 90/269/EEC, including the possibility of excessive work loading of healthy workers. During this evaluation, due to specific conditions in the forest, it has been observed that the assessment of physical load of choker-man is not satisfactory according to the applicable regulations.

Keywords: steel cable, forest winch, choker man, pulling forces, physical load.

1 Introduction

In Croatia, in the area of hilly and mountainous forests (terrains with higher or lower slope), (semi)length method is used for wood processing, and large skidders are used for wood skidding in regeneration and selection fellings, and medium (thinning) skidders and adapted farming tractors in thinnings.

Krpan et al. (2003), in analyzing the annual allowable cut of the Croatian forestry by type of felling and terrain condition, determined the volume of 1.4 mil. m³ of wood assortments skidded by large skidders from regeneration and selection fellings in mountainous and hilly areas.

Beuk et al. (2007) outline that in the company Hrvatske šume d.o.o. Zagreb (Croatian Forests Ltd.) more than 70% of wood assortments is skidded annually by forest vehicles equipped with winches and owned by the company, and that almost half (46 %) out of the total volume of skidded wood is skidded by skidders whose mass exceeds 5 t. Most of the skidders (168 pieces) stated by these authors are skidders with the mass of approximately 7 t equipped with double drum winch of the nominal cable pulling force of 80 kN and steel cable diameter of 14 mm. Taking into consideration private entrepreneurs, the total number of skidders engaged in timber skidding in Croatian forestry ranges around 300 pieces.

Physical load of workers engaged in wood harvesting has been the object of research for a very long time and it has been proved that workers engaged in pulling out the steel cable and hooking the logs, the so-called choker-men, are among the most severely loaded workers. Martinić (1994) carried out some of the above mentioned researches and based on the measured average pulse during daily work of workers, he

classified choker-men in the class of medium loaded workers (according to Ronay classification from 1975), while based on the energy consumption in an 8-hour working day, he classified the choker-man work in the class of the most labor-intensive work (according to Kaminski classification from 1971).

Based on measured forces of steel cable pulling and the applicable Croatian „*Regulations on protection at work during manual load transfer*“, Pandur et al. (2008), assess the work of choker-men as the work with high load taking also into account the additional load of choker-men in the form of their mass when pulling the cable uphill. Stampfer et al. (2010) compare the load of choker-men working with forest cables and using radio-controlled hookers with those using traditional mechanical hookers. They measured the heart rate frequency as the indicator of the workload. Ottaviani et al. (2011) determine the difference in the workload caused by the replacement of the steel cable by synthetic rope of larger diameter when pulling the auxiliary rope for setting the new wire line at the distance of 300 m. The results obtained show that the pulling force of the synthetic rope is more than three times lower than the pulling force of the steel cable, that the energy consumption is also almost three times lower in favor of the synthetic rope and that the pulling force of 140 N measured at the end of the cable route is the highest load that a person can endure on such slope.

2 Scope and objectives

The objective of this research was to determine the workload of choker-men according to *Directives 90/269/EEC - manual handling of loads*, which was the basis for the *Regulations of the Republic of Slovenia (Pravilnik o zagotavljanju varnosti in zdravja pri ročnem premeščanju bremen, Ur.I. RS, št. 73/2005)* and for the measured manual forces of pulling out the cable at 5 different terrain slopes. The winch was a Hittner 2 x 80 kN mounted on a skidder Ecotrac 120 V.

Article 2 of the *Directives* states that “the manual load transfer means any physical work that involves lifting, transferring, lowering, pushing, pulling or carrying of load by human power”. This involves the work of choker-men when pulling out the steel cable. Article 9 of the above said *Regulations* provides the following factors that are significant for the assessment of the safety risk, for endangering the health and especially back injury:

a) Load characteristics:

- ⇒ Its weight, form and size
- ⇒ Grip position
- ⇒ Center of gravity position
- ⇒ Possibility of involuntary and unplanned moving

b) Worker's loads:

- ⇒ Necessary holding or moving (motion) of the body, especially for moving the torso in the spine area and keeping the body bent
- ⇒ Distance of the load from the worker's body
- ⇒ Horizontal and/or vertical distance to which the load is to be transferred
- ⇒ Intensity, frequency and duration of the required body power
- ⇒ Use of suitable personal protection kit
- ⇒ Imposed work rhythm beyond the control of workers
- ⇒ Provide time for break and rest

c) Characteristics of work environment:

- ⇒ Space used by the worker, especially in vertical direction
- ⇒ Height difference between individual levels of walking, accepting and delivering load, as well as temperature, moisture and air flow rate
- ⇒ Workplace illumination

- ⇒ Type of ground surface on which the load is transferred
- ⇒ Characteristics of work clothing and footwear

Attachment I to the *Directive* (Table 1) presents the maximum allowed mass that can be transferred (pulled) considering the sex and age of workers, all in “suitable” work conditions such as ergonomically favorable body position, satisfactory characteristics of the space where workers walk (e.g. flat and non-slippery ground), adequate load grip.

Table 1: Allowed load by age and sex

Age, years	Men (kg)	Women (kg)
15 – 19	35	13
19 – 45	55	30
> 45	45	25
Pregnant women	-	5

Attachment II to the *Directive* describes the assessment method of the total load (UO) of healthy workers according to the equation:

$$UO = T_1 \cdot (T_2 + T_3 + T_4 + T_5 + T_6) \quad (1)$$

where:

- T1 – factor of worker’s time load
- T2 – factor of load weight for acceptance with both hands
- T3 – factor of body and load position during transfer
- T4 – factor of workplace condition
- T5 – factor of work experience
- T6 – factor of work environment temperature

The values of these factors can be read, for different conditions, in related tables. For the work of choker-men, the values of factors can be assessed relatively well, except for the factor T₂, i.e. the factor of load weight. The reason lies in the fact that the load (the weight of steel cable) increases as the worker walks away from the vehicle. The investigation of forces required for pulling out the cable on flat, hard ground (Horvat and Sever 1983, Horvat 1983, Horvat et al. 1999, Horvat et al. 2004) confirmed this expected fact.

3 Materials and methods

The force required for pulling out the cable is a significant ergonomic and technological parameter because, through fatigue and load of the worker who pulls the cable, it also affects the work output. It is an important technical and exploitation characteristics that depends on the cable design, coefficient of friction between the cable and ground, cable length, friction in the drum bearings and terrain slope on which the choker-man moves (Horvat and Sever, 1983).

3.1 Object of research

The object of research was the winch Hittner 2 x 80 kN mounted on the skidder Ecotrac 120 V, which is used in Croatian forestry for skidding timber from hilly regeneration and mountainous selection fellings.

It is a double drum winch of the nominal pulling force of 80 kN per each drum. The diameter of the pulling cable is 14 mm, and its total length per drum is 70 m. The cable is secured on the drum circumference with the possibility of interruption. The safety distance between the height of the circumference of the drum and the height of the cable fully coiled on the drum is 47 cm. The cable of each drum is led through two vertical and one horizontal roller.

The winch is hydraulically driven, and it is equipped with a worm power transmission (41 : 2) for coiling and pulling out the cable, friction clutch and brake. The steering is electro-hydraulic through the steering knob and the switch on the steering knob.

The cable length mass is 0.82 kg/m, the calculated interruption force is 158 kN, while the minimum interruption force is 124 kN. The cable pulling strength is 1770 N/mm².



Figure 1: Winch Hittner 2 x 80 kN

This paper shows the results of measurements of pulling forces of steel cable of both drums of the winch Hittner 2x80, mounted on the skidder Ecotrac 120V. The cable pulling forces were measured at 5 different terrain slopes: -19°, -10°, 0°, +10°, +19° with the cable pulling length up to 42.5 m. The speeds of cable pulling were calculated with the help of the known cable pulling length and time bases, and with the help of the measured force and calculated speed, the power was measured that a choker-man has to use for its pulling, i.e. the total power that also takes into account the choker-man mass of 80 kg, which also affects his workload, especially when moving uphill on higher slopes. The measured forces were used as one of the essential parameters in determining the workload of choker-men in accordance with the applicable Directive 90/269/EEC.

3.2 Site of research

The site for measuring the cable pulling forces was located in the area of Sokolovac Forest Office, Koprivnica Forest Administration, in a mixed stand of sessile oak and hornbeam. The measurement was carried out at five different terrain slopes: -10°, -19°, 0°, +10°, +19° with the maximum length of cable pulling up to 42.5 m. During the measurement at the slope of +19°, the highest length of the pulled cable of the left drum was up to 37.5 m due to excessive pulling resistance and fatigue of the worker who pulled the steel cable.

The terrain path was designated with markers placed at 5 m intervals. Every time the choker-man passed by each marker, it was recorded by an additional (ergo) dynamometer. The path length is significant for the calculation of speed and then based on speed for the power used for pulling the cable. When the path length and time of passing the path during cable pulling are known, the speed can later be easily calculated.



Figure 2: Cable pulling route designated by markers (left) and measurement of cable pulling force (right)

3.3 Measuring equipment

In this research, all forces were measured by tensometry method. The measurements performed with tensometry method of mechanical values of pulling the winch steel cable were made with the measuring equipment of the Laboratory for technical-technological measurements of the Faculty of Forestry in Zagreb, which includes: tensile-pressure dynamometer HBM 20 kN and ergo-dynamometer 1 kN with the pertaining equipment consisting of the measuring amplifier HBM Spider 8 and field computer. The measuring data were recorded by use of the computer program Catman 4.0 (Hottinger Baldwin Messtechnik GmbH), and further mathematical-statistical data processing was carried out by use of the computer program Microsoft Excel.



Figure 3: Dynamometer HBM 20 kN (left) and measuring amplifier Spider 8 with terrain computer (right)

4 Results of research

In accordance with the set objectives, the increasing tendency was determined of the cable pulling force on forest soil of different slopes (-10°, -19°, 0°, 10°, 19°) and the assessment was made of the worker's load in accordance with the factors presented in Attachment II to the *Directive*, and for a start the results were expressed only for one slope.

4.1 Measurement of cable pulling forces

All cable pulling forces were measured in the field depending on time. Simultaneously with the measurement of pulling forces, records were also made of workers passing by markers placed along the cable pulling line at 5 m intervals. The passing of choker-men by markers during cable pulling was additionally recorded by an ergo-dynamometer. In this way, a data basis was obtained, which contained the dependence of cable pulling forces on time and passing of choker-men by markers at each 5 m at the same time, as shown in Figure 4, where the curve in the upper part of the diagram represents the dependence of cable pulling force on time, while the curve in the lower part of the diagram, i.e. the peaks of this curve represent the passing of choker-men by markers.

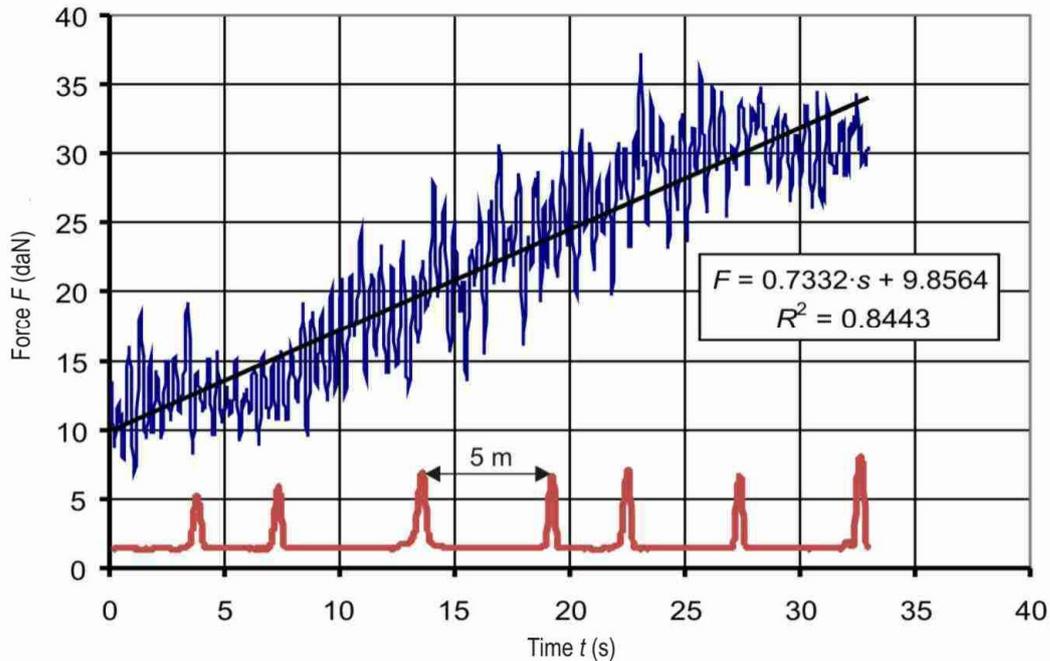


Figure 4: Dependence of cable pulling force on time (upper curve) and passing of choker-men by markers (lower curve) where the peaks represent 5 m distance between markers

By further data processing, dependance was established of cable pulling force on the length of the pulled cable for both winch drums on all researched slopes. All dependances were compared by regression analysis. Fig. 5 shows the diagram of dependance of force on the length of pulled cable for the right winch drum on the skidder Ecotrac 120 V at the terrain slope up to +10°. Apart from good correlation, the increase is observed of manual force ranging from 7 daN at the beginning to 23 daN at the end (42.5 m) of cable pulling. This triplification of force realized by one hand (!) would mean that the factor of load weight ranges between $T_2 = 2$ at the beginning and $T_2 = 8$ at the end of pulling. As shown in Fig. 5 for the slope of 10°, the factor of load weight up to approximately 10 m is $T_2 = 2$, $T_2 = 4$ between 10 and 35 m and over 35 m $T_2 = 8$.

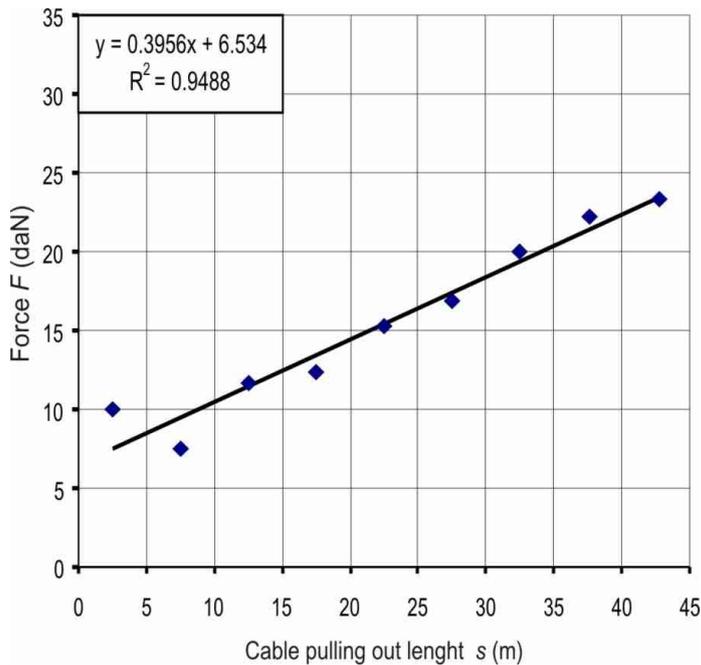


Figure 5: Results of measurement of cable pulling force at the slope of 10° for the right winch drum

4.2 Assessment of the total worker's load

The assessment of the total workload of choker-men was made on the basis of the table given in Attachment II to the *Directive* and equation (1). The factor of the worker's time load is defined in the table in 5 steps for short-term and long-term transfer, where for the assessment of choker-man it is easier to determine the factor value through total cable pulling time in a work day (long-term load) than through the number of cable pullings out (short-term load). In this way, the factor $T_1 = 4$ would be obtained for cable pulling of 1 to 3 hours a day,.

The table showing the factor of body position (T_3) gives graded weights in 4 steps, of which the choker-man work is best described by grade 3 (body deeply bent or very leaned forward; moderately bent, and at the same time the upper part of the body slightly turned around, the load far away from the body or at the height of shoulders, standing or sitting position with factor $T_3 = 4$).

The factor of workplace condition is graded into three grades, and the choker-man work corresponds best to the medium grade with factor $T_4 = 1$ due to non-ergonomic conditions and irregular, slope or slippery terrain.

The factor of work experience is only graded in two steps and namely $T_5 = 0$ for the work experience of more than 12 months.

The factor of work environment temperature ranges between $T_6 = 10$ for the temperature below -10°C and above 30°C , and for average conditions $T_6 = 0$, for the temperature from -1 to 21°C . In this assessment, the factor of average conditions was applied.

Based on factors selected in this way, the total workload of the choker-men would be:

For pulling the cable up to 10 meters :

$$\Rightarrow \text{UO} = T_1 (T_2 + T_3 + T_4 + T_5 + T_6) = 4 (2+4+1+0+0) = 28$$

For pulling the cable from 10 to 35 meters:

$$\Rightarrow UO = T1 (T2 + T3 + T4 + T5 + T6) = 4 (4+4+1+0+0) = 36$$

For pulling the cable over 35 meters:

$$\Rightarrow UO = T1 (T2 + T3 + T4 + T5 + T6) = 4 (8+4+1+0+0) = 42$$

The value of the total load achieved in this way should be compared to the recommendation of the Directive to make the final assessment. For the load between 26 and 50, the *Directive* states that this is »high load - possibility of excessive load with healthy workers. It is necessary to investigate the possibility of lowering the load due to manual load transfer«.

Since the total load over 50 is considered »very high load – big possibility of inducing health issues due to manual load transfer. It is necessary to use suitable equipment or other work methods for reducing the body load«, the above calculation should be emphasized – high worker's load, along with the fact that the factor value of temperature outside the range from -1 to 21 °C increases considerably.

4.3 Determination of cable pulling speed

The experimental measurement was carried out at the slope of 10° and it is interesting to see its effect on the worker movement, especially his speed. By measuring the moments of his passing by markers, placed at 5 m intervals, which were recorded by the additional ergonomic diagram, the passed path was determined (the length of pulled out cable), and with computer time, the speed of the choker-man movement was calculated, as shown in Figure 6. With the satisfactory correlation, decrease of the choker-man movement speed can be observed from approximately 1.6 m/s at the beginning to 1.1 m/s at the end of cable pulling.

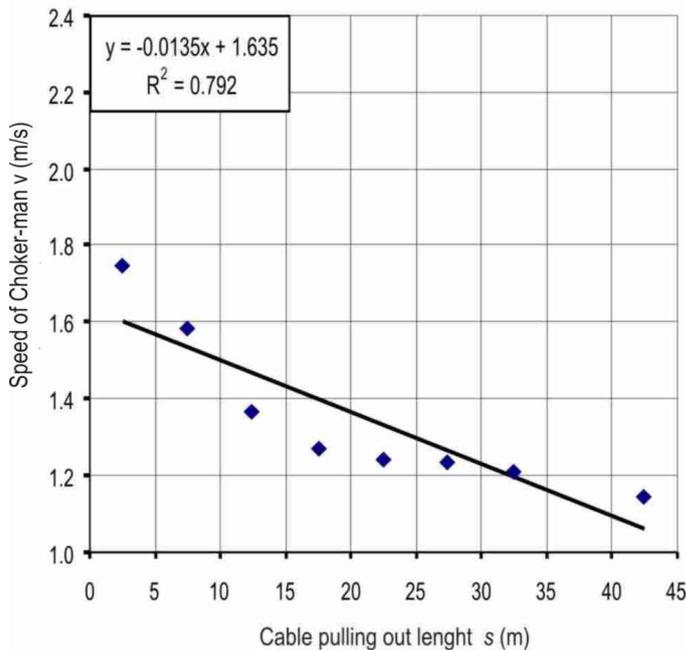


Figure 6: Choker-man speed at the slope of 10° for the right winch drum

4.4 Worker power

The calculation of the achieved energy (power), whose dependence on cable pulling length is shown in Fig. 7, can be used for assessing the input energy during cable pulling. Fig. 7 shows, with good correlation, continuous increase of output power (and hence also input power), which is doubled at the end of pulling. With a continuous increase of force, which is three times higher than the starting force at 40 m of cable pulling and with a 30% drop of speed, the input power is still doubled.

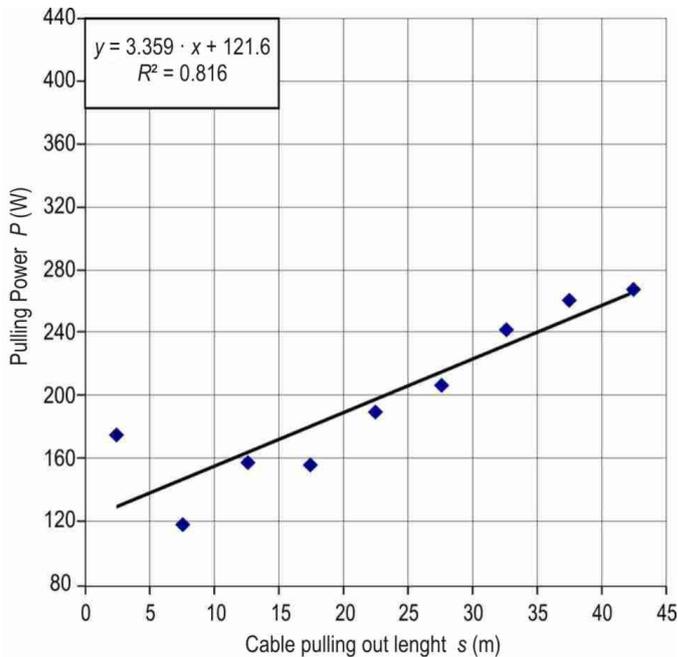


Figure 7: Worker power achieved at the slope of 10° for the right winch drum

4.5 Effect of terrain slope

In the above survey of experiment results of measurement, cable pulling up the slope of 10° was intentionally selected so as to enable the analysis of its impact on the worker's load. Indeed, the slope has no significant effect on back load, this being one of the basic assumptions of the *Directive*, and however it affects strongly the movement resistance and hence also the worker's energy load. When moving uphill, along with the pulling force, the worker has to move his own weight up the slope. As shown in Fig. 8, when moving downhill, the worker moves with greater ease with his weight.

If analyzing the load of a choker-man of 80 kg moving up the slope of 10°, Figure 9 presents the total force he overcomes and the power achieved depending on the pulling length. If the flow of forces is compared with the diagram in Fig. 5, a considerable increase of forces or resistance to the choker-man movement can be observed. When moving uphill, the increase of resistance is lowered at the end of pulling from threefold (Fig. 5) to 50% (Fig. 9).

Based on the values of this total resistance and speed from the diagram of its change shown in Fig. 6, the power achieved, or work performed, can be calculated.

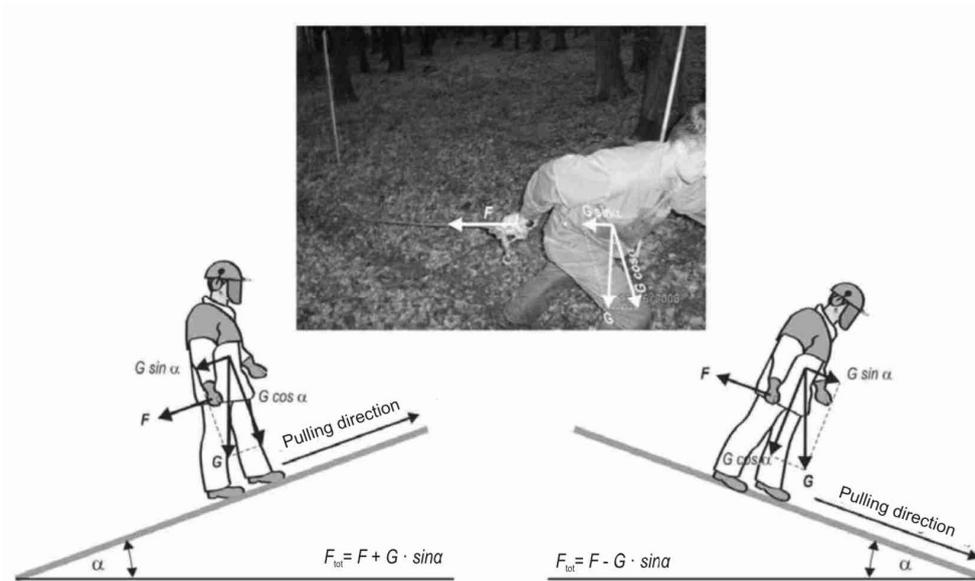


Figure 8: Forces affecting the worker walking on the slope

The diagram of power in Fig. 9 shows some significant characteristics:

- ⇒ achieved (input) human power is much higher than the power required for overcoming the resistance of cable pulling,
- ⇒ achieved power increases only slightly with the increase of the pulling length.

Such trend of power in the dependence of the cable pulling length shows that the worker did not increase the input power as it seemed to be based on Fig. 7, and that instead he continuously achieved the power of approximately 370 W during the whole process of cable pulling.

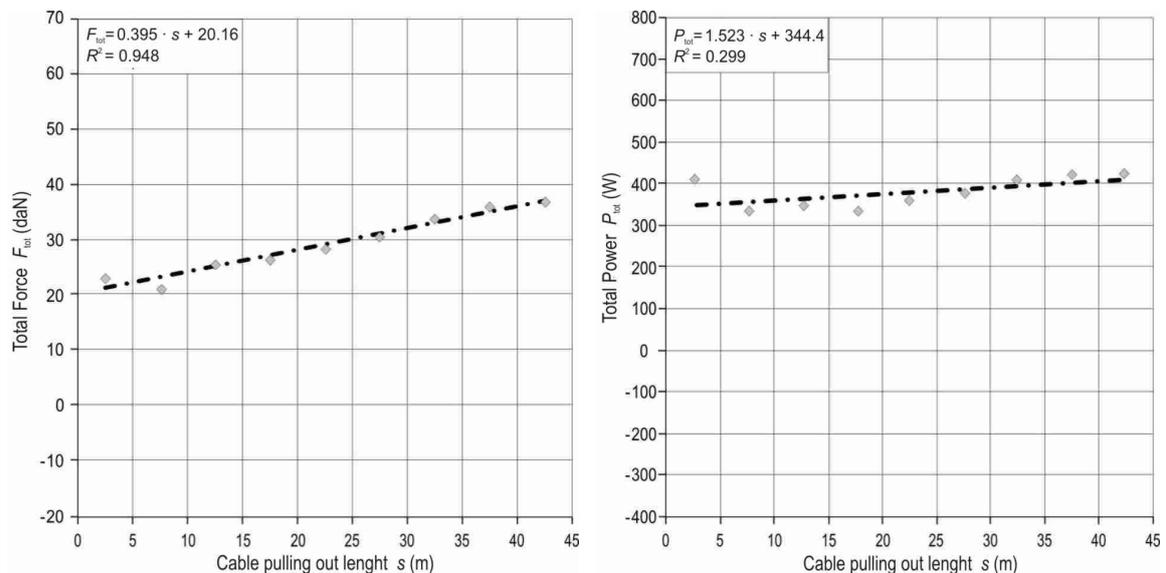


Figure 9: Total force and achieved power in moving uphill on the slope of 10° for the right winch drum

4.6 Analysis of overall results of research

Overall results of research involve the trend of cable pulling force, speed changes and achieved power depending on the pulling length for both winch drums and movement of the choker-man on 5 slopes. The results are shown in Fig. 10.

The diagram in Fig. 10 shows as follows:

⇒ For forces:

- a) It can be read from the diagram that there is a difference in the starting force up to 7 daN. Higher starting forces were measured on the right drum. Lower forces were measured on the left drum than on the right drum, except on the slope of 19°, where a sudden increase was recorded of the cable pulling force that exceeded 30 daN at the distance of 30 m.
- b) The increase of force at the end of cable pulling compared to the beginning of cable pulling is higher when moving uphill.
- c) Realized forces with both drums when moving uphill (10° and 19°) exceed 20 daN near the end of cable pulling, and in this case the factor value of the load is $T_2=8$.

⇒ For speed:

- d) With the increase of the cable pulling distance, the choker-man starts moving more slowly, except on the highest slope, where constant speed (1.65 m/s) was observed on the right drum, while on the left drum even an increase of speed was observed.
- e) With the right drum, the highest drop of speed was observed in moving uphill on the slope of 10° and 19°. On the left drum, a drop of speed of the choker-man movement was observed on all slopes except on the slope of -19°.
- f) The choker-man moves most slowly on the slope of 10° (right drum), i.e. on the slope of 19° (left drum).

⇒ For power:

- g) Higher starting power required for cable pulling was observed on the right drum on the slopes of 0°, -19° and 19°. On the left drum, lower starting power was measured on all terrain slopes.
- h) With the increase of the cable pulling length, the power required for its pulling is also increased. The highest increase of the required power was observed with the left drum on the slope of 19°, while the lowest increase was observed on the same slope downhill (-19°).
- i) The power ranged between 110 W and 320 W on the right drum and between 90 W and 410 W on the left drum, respectively.

Based on the analysis of the overall results in all conditions of terrain slope and for both drums, it can be said that the total worker load has been estimated as high load according to the *Directive*.

By comparing diagrams of the left and right drum, it can be said that there are differences in all three measurements. Cable pulling of the left drum required much more power and force than the right drum, and however for both drums, the achieved power and force are more regularly distributed in the range of moving downhill and uphill. When moving downhill on the highest slope, the worker did not slow down and instead he increased the speed, but also achieved higher power and force, because during his moving downhill, additional power and force must be used for braking, which increases the risk of falling on slippery and irregular ground. For moving uphill, it is necessary to use some more power and force than on flat terrain, because terrain resistance has to be overcome, so that the moving speed is also considerably lower.

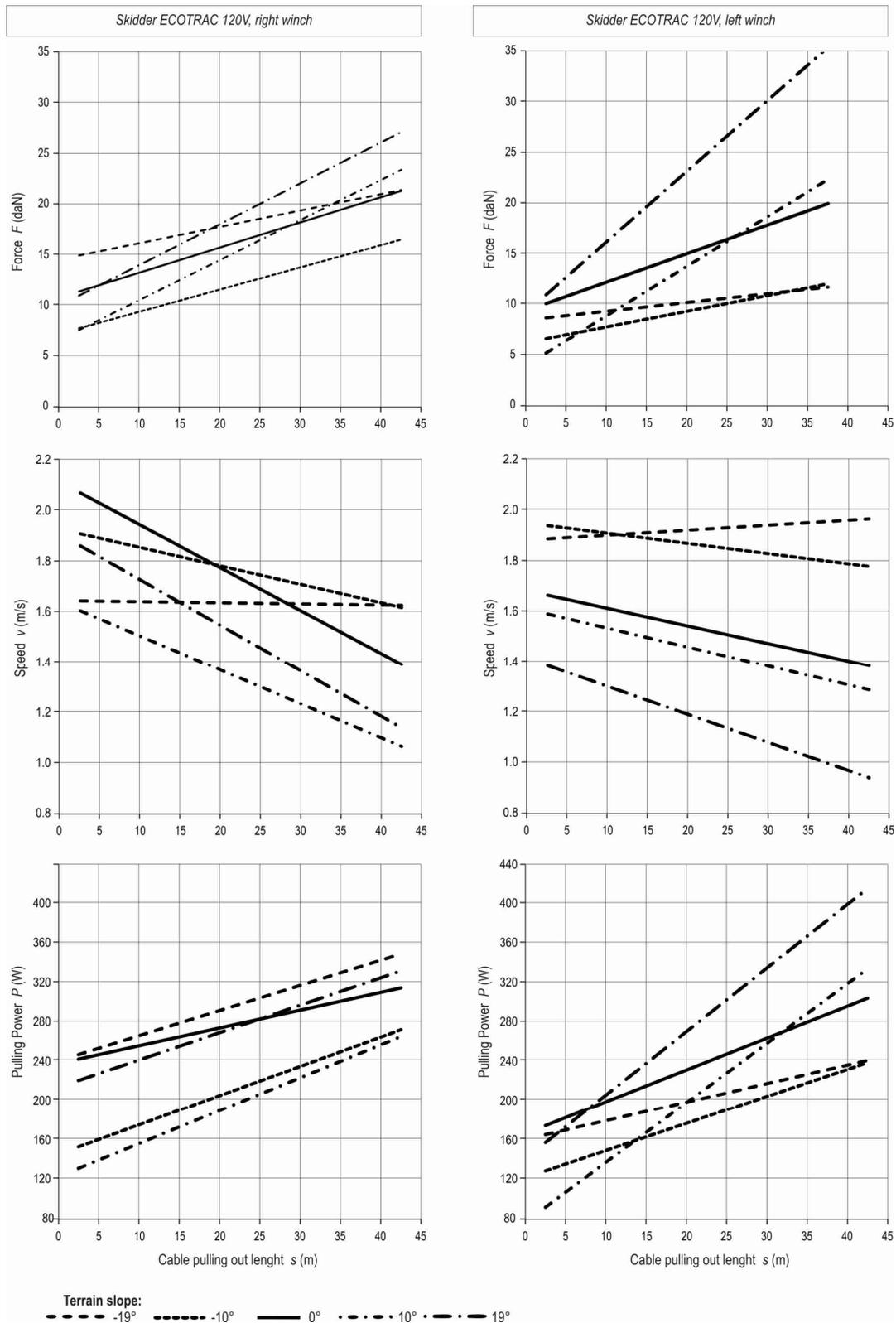


Figure 10: Overall results of research – regression curves

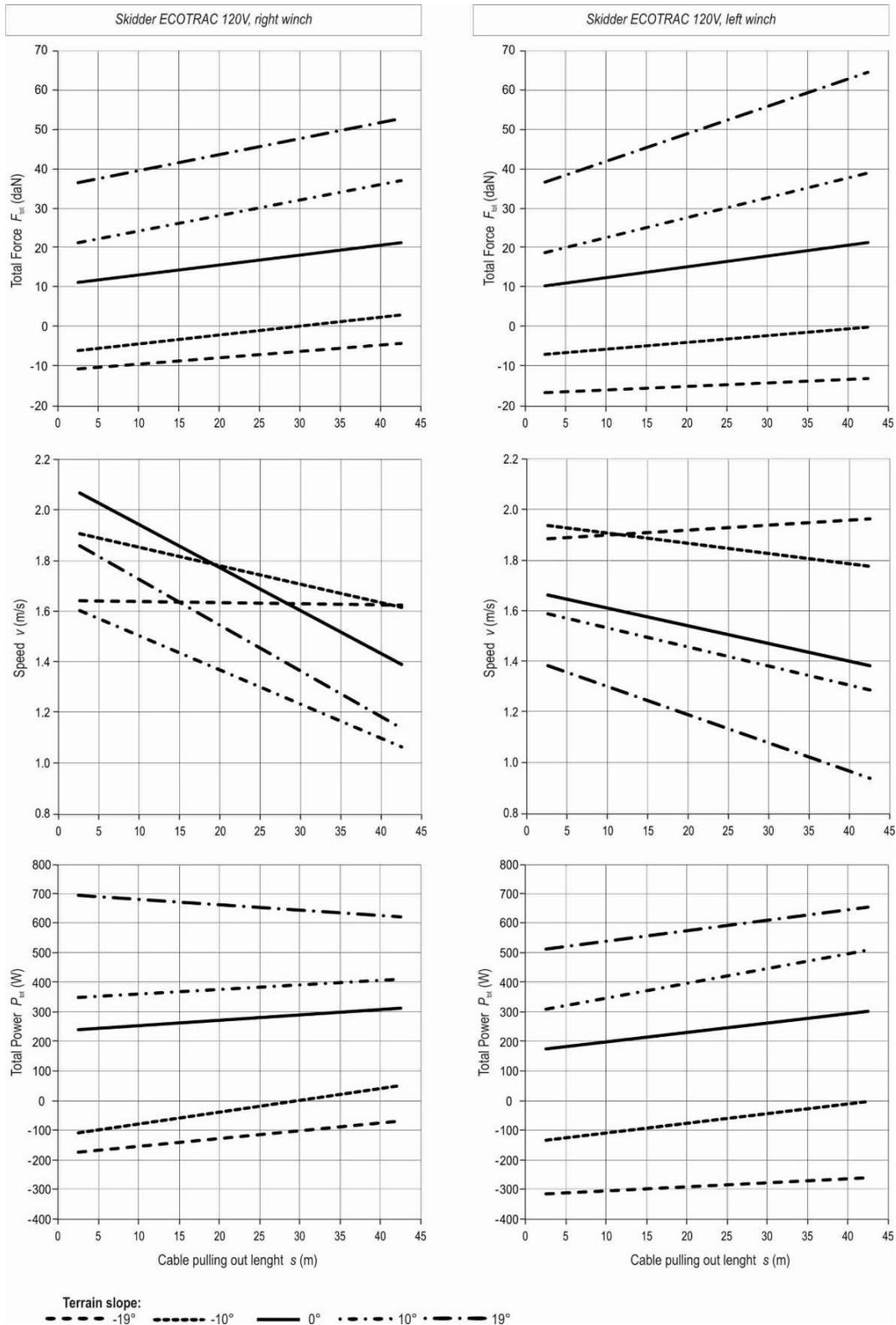


Figure 11: Overall results of research with the effect of choker-man mass – regression curves

5 Conclusions

Since the choker-man moves in specific forest conditions, where the ground on which he walks is mostly slippery and full of numerous obstacles such as stones, branches and similar, an annex should be added to the applicable *Directive* (or new *Regulations* should be made), by which the choker-man workload could be determined more reliably.

According to diagrams in Fig. 11, the choker-man uses approximately the same total power with only slight increase with the increase of cable pulling length regardless of terrain slope. The reason lies in the fact that with the increase of the cable pulling length, total force also increases, and at the same time the speed of cable pulling is lowered.

According to Figure 10 and 11, the difference can be observed in measured (calculated) forces on right and left winch drums, which directly affects speed and ultimately the power used for cable pulling. In order to get the resistance of cable pulling as low as possible, the winch should be properly maintained, i.e. special care should be taken of the right adjustment of the winch brake and clutch.

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