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LINE 6X19 SEALE +FC ZS HYSTERESIS DETERMINATION

Summary. The article presents results of tests carried out on testing machine adapted to test long ropes sections, made at The Research and Supervisory Centre of Underground Mining Co. Ltd. Tests were performed for different rope safety factors. The lines static damping coefficient was specified and characteristics defining the relationship between the elongation and the acting force were developed. It was also shown the existence of the phenomenon of creep in the lines which provides its rheological properties.

WYZNACZANIE HISTEREZY LINY O KONSTRUKCJI 6X19 SEALE +FC ZS

Streszczenie. W artykule przedstawiono wyniki badań, wykonanych w Centrum Badań i Dozoru Górnictwa Podziemnego Sp. z o.o. w oddziale Mysłowice-Brzezinka, na maszynie wytrzymałościowej przystosowanej do badań długich odcinków lin. Badania liny przeprowadzono dla różnych współczynników bezpieczeństwa *m*. Określono współczynnik tłumienia statycznego w linie oraz opracowano charakterystyki, określające zależność pomiędzy wydłużeniem a działającą siłą. Wykazano także istnienie zjawiska pełzania w linie, które świadczy o jej właściwościach reologicznych.

1. INTRODUCTION

Research for lines hysteresis determination was carried out The Research and Supervisory Centre of Underground Mining Co. Ltd The Research and Supervisory Centre of Underground Mining Co. Ltd. Under the terms of tensile tests included in the standard PN-EN ISO 6892-1: 2010 [9], the rope 6x19 SEALE +FC Zs [5, 7] with diameter 12 (mm) was considerate. In fig. 1, 2 and 3 the rope and testing machine is shown.

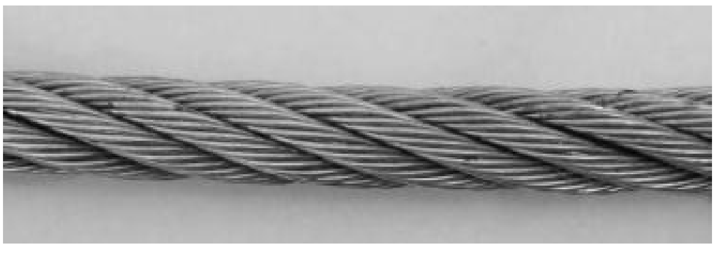


Fig. 1. Sample of tested line
Rys. 1. Odcinek badanej liny

10 line samples with length of 2,5 m were tested. According to the certificate of the rope and wire diameter measurement, the core and strands measurement, basic line parameters were adopted (table 1).

Fig. 2. Testing machine
Rys. 2. Maszyna wytrzymałościowa

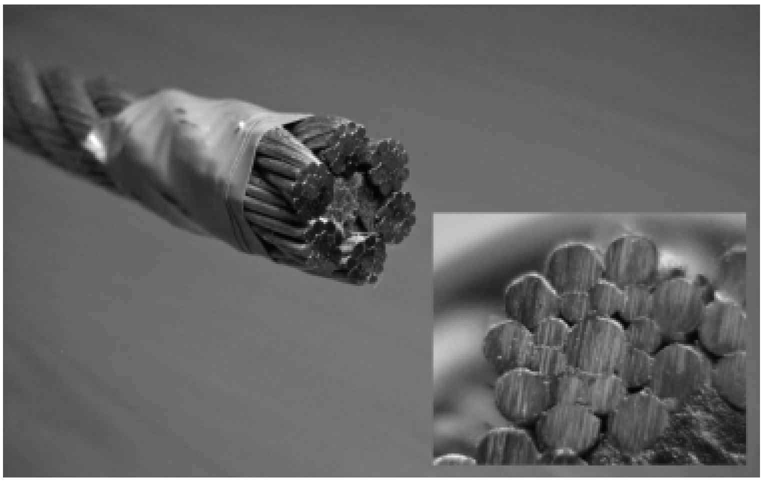


Fig. 3. Cross-section of the tested line, the construction of the strands
Rys. 3. Przekrój badanej liny, budowa splotki

The basic test was to make attempts to break the rope in order to determine the actual breaking load. Samples were prepared according to standard PN-EN ISO 6892-1: 2010, the length of the test section between the handles L greater than 36 diameters [1] and always greater than 1500 (mm). For the line diameter d=12 (mm) Lmin=432 (mm). The length ~2500 mm was assumed.

Both one and the other end of the rope section was untwine, then the jute core was removed and wires were bent and flooded with the appropriate alloy according to standard. Tips flooded in the taper samples are shown in fig. 4. By flooding the samples in tapered bushes, rope in the study is subject to pure tension [8, 4]. In order to comply with braking tests the section of rope was fastened in special tapered holders (fig. 5).

Table 1

Line parameters

Line diameter:	12,00	mm
Lines construction:	S6x19+FC	-
Length:	25,00	m
Weight:	13,40	Kg
Lay of a rope	sZ	-
Cord, material:	jute	-
Coverage of the rope:	galvanized, bare	-
Core, maintenance:	soaked	-
Minimal braking force (computational):	84,11	kN
Nominal wires strength:	1 770,00	N/mm^2
Carrying capacity with safety factor 1:5 DOR:	1 714,7	kg
Line standard:	DIN 3058	-
Wire standard:	DIN 2780	-
The standard ropes acceptance tests:	DIN 3051	-
Unit weight:	0,5126	kg/m
Metallically cross-section:	55,29	mm^2
The diameter of the rope core (computational):	8,58	mm
Diameter of strands:	3,88	mm
Diameter of strands core:	1,10	mm
Wire diameter 1^{st} layer:	0,90	mm
Wire diameter 2^{nd} layer:	0,60	mm

Fig. 4. Samples ready for tests
Rys. 4. Próbki lin gotowe do badań

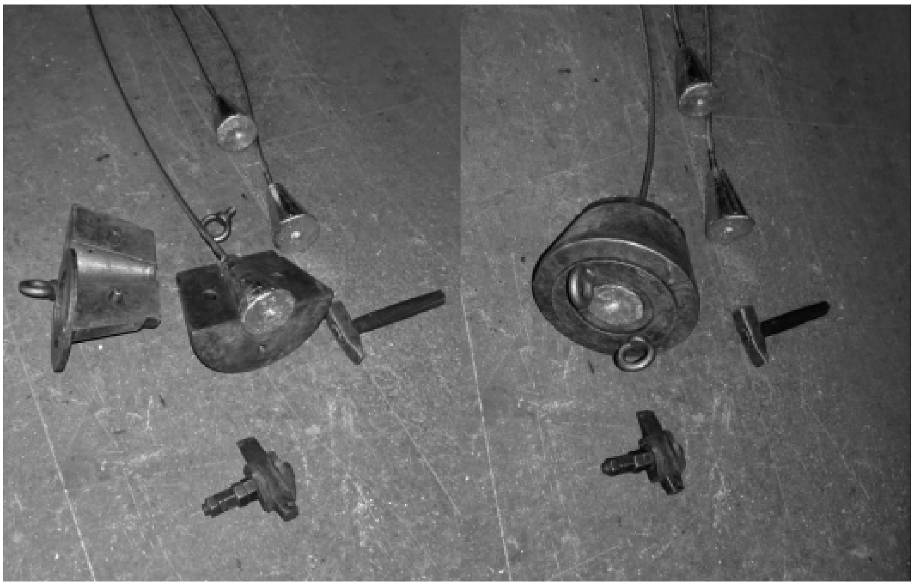


Fig. 5. Special taper holders
Rys. 5. Mocowanie stożków w uchwycie

Before test the sample length, diameter, and the actual rope lead was measured. Samples were fixed in the holder (fig. 5) and attached to the testing machine (fig. 6).

Fig. 6. Samples in testing machine
Rys. 6. Proces osadzenia próbki w maszynie

2. EXPERIMENTAL PROCEDURES

To established research program it was adopted, in accordance with the standard, that the rate of stretching is going to be small, causing increases in the stress range from 10 [MPa/s] to 20 [MPa/s], for line under consideration [1, 6, 9]:

$$\Delta\sigma < 10\left(\frac{MPa}{s}\right) \rightarrow \Delta F_i < 10 \cdot A\left(\frac{N}{s}\right) \quad (1)$$

where:

A – lines metallically cross-section;
ΔF_i – unit increase in force;

The first sample was treated as a test where a series of proofing tests were made and then the rope was stretched to breaking up in order to determine the actual breaking force. Tensile testing graph is shown in fig. 7.

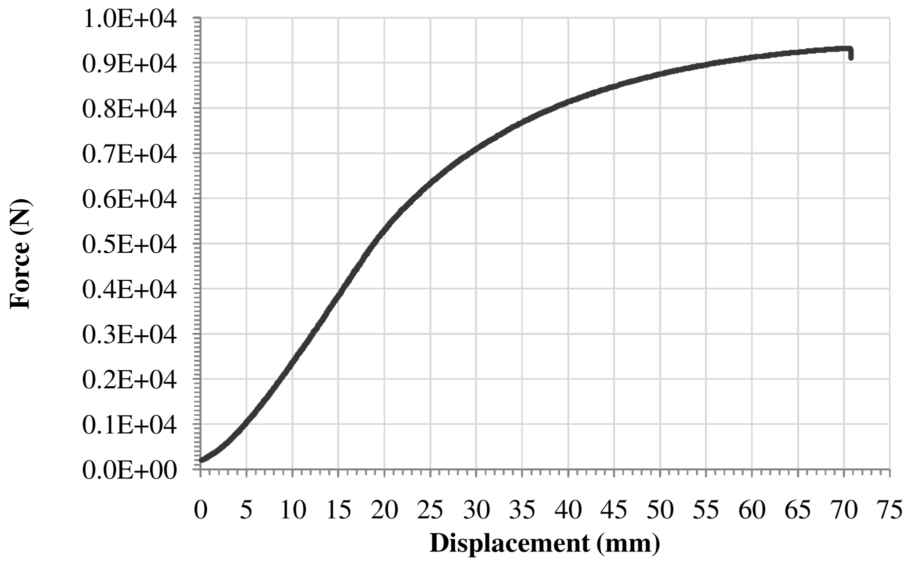


Fig. 7. Rope elongation graph stretched until breaking
Rys. 7. Wykres maszynowy rozciąganej liny aż do zerwania

As follows from fig. 7, the force at break is approximately 93 (kN). Next, the initial force P_0 necessary for further investigations was determinate in accordance with the formula (2). Figure 8 shows a fragment of the rope after the break, where place of the break were wires in a strand placed exactly in the center of the sample.

$$P_0 = \frac{1}{50} P_c = \frac{93}{50}(kN) = 1.86(kN) \quad (2)$$

where: P_c – Real load breaking the line.

Fig. 8. A break of wires in a strand during the tensile test
Rys. 8. Zerwanie drutów w splotce podczas próby rozciągania

The next step was to conduct a series of 90 tests involving pre-tension from force P_0 to the value specified by the selected factors of safety and relief. Then, loading and unloading for 10 cycles for each of the 9 samples.

3. TEST RESULTS

While performing tests on a test sample, the sample was treated with a tensile force and after reaching the designated value of the force specified by a safety factor, holding the rope in position by the time of 10 s followed, then the force was reduced to 0 kN.

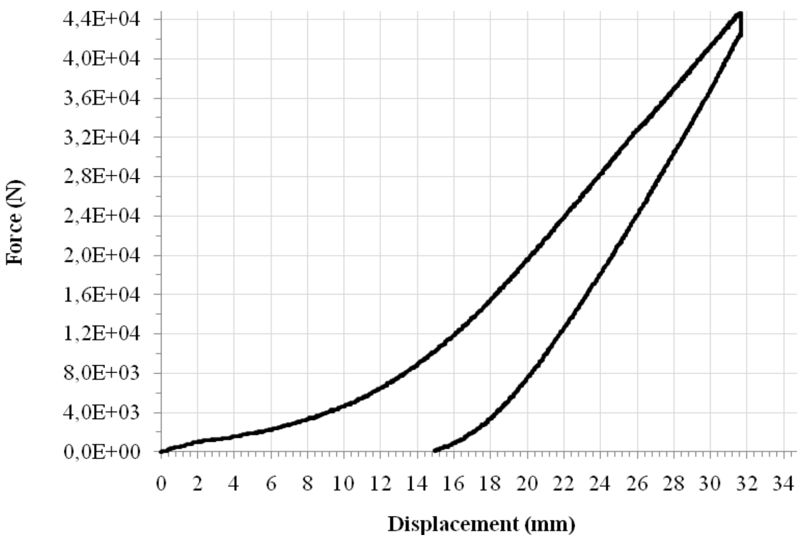


Fig. 9. Pre-tension of brand new rope
Rys. 9. Wstępne rozciąganie liny fabrycznie nowej

Figure 9 shows the graph for the test pre-tensioning (rope brand new). It can be seen that at holding the rope in position by the time of 10 s, despite the lack of change of the force from the machine, the strength of the line decreases, reflecting the rheological properties of the rope – its creeping [6].

After a series of 90 loading/unloading tests plots determining the relationship between force and displacement were obtained. The plots shows that the for rope brand new the relationship is not linear, and the courses for the ropes loading and relieving are different.

During the first loading called pre-tension, line becomes considerably permanent set. On subsequent loading cycles, elongation values are minor and are stabilizing, but the loading and unloading curves continue to be non-linear. Obtained loading/unloading characteristics point out that the steel ropes have visco-elastic (elastic-plastic) characteristics [1].

During each cycle of loading and unloading there is a dissipation of strain energy, which measure are the hysteresis loops [1, 3] (fig. 10).

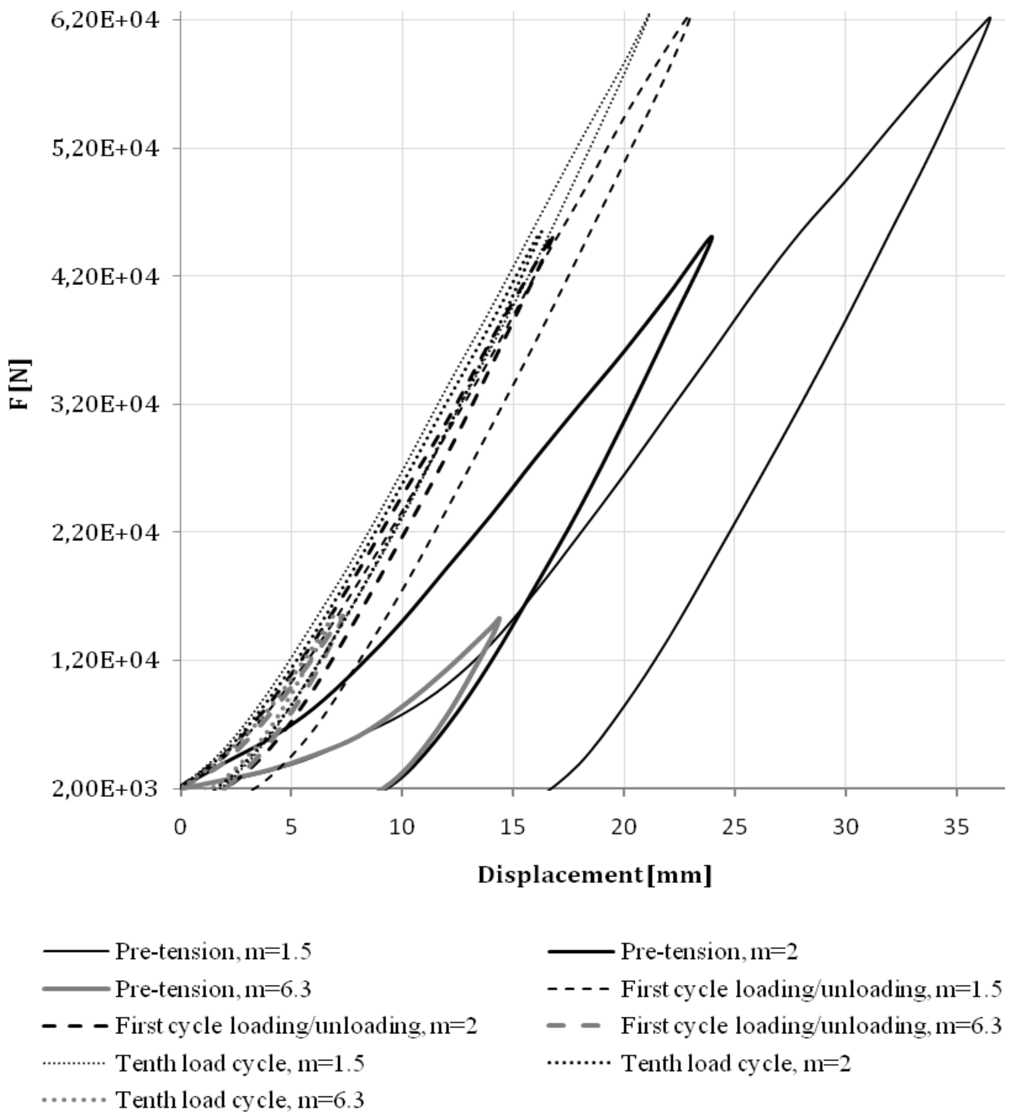


Fig. 10. Loading and unloading characteristics of the factory new rope, depending on the value of safety factor *m*

Rys. 10. Krzywe obciążenia i odciążenia liny fabrycznie nowej w zależności od wartości współczynnika bezpieczeństwa *m*

Established existence of the hysteresis loop in the steel lines indicates, that each cycle of tension is followed by energy dissipation due to internal friction between the strands and wires and the core. In the case of static hysteresis loops (fig. 10), a measure of internal friction is called coefficient of relative energy dissipation:

$$\psi_t = \frac{\Delta W}{W} \tag{3}$$

where: ΔW – loss of strain energy during one cycle, proportional to the area of the loop;
W – energy corresponding to one loading cycle.

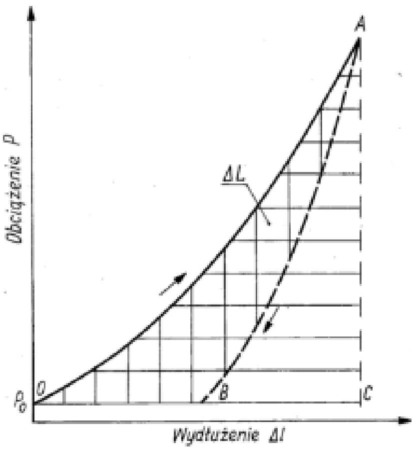


Fig. 11. Loading characteristics of the factory new rope: OAC – work inserted during loading, BAC – work returned during unloading, ΔL – loss of work, P - force, Δl – elongation [1]
Rys. 11. Krzywa obciążenia i odciążenia liny fabrycznie nowej: OAC - praca włożona podczas obciążania, BAC - praca zwrócona podczas odciążania, ΔL - praca stracona, P - siła, Δl – wydłużenie [1]

Due to the fact that the rope is significantly and permanently extended, the strain hysteresis loops are not closed and therefore the coefficient of dissipation is also called the static damping coefficient [2].

The work of ropes deformation W is an area under the characteristics (fig. 11). Due to the absorption of energy by internal friction between the strands, wires, and core, the loading line 0A (fig. 11) does not coincide with the unloading line AB, creating a hysteresis loop. Damping coefficient characterizes the ability of ropes to dissipate energy. It represents the ratio of energy dissipated ΔW to the strain energy W. With the increase of damping coefficient the ability of vibration damping increases. Thus [1]:

$$\psi_t = \frac{\Delta L}{L} = \frac{L_{OAC} - L_{BAC}}{L_{OAC}} \tag{4}$$

where:

L_{OAC} – work inserted during loading;
L_{BAC} – work returned during unloading;
ΔL – loss of work.

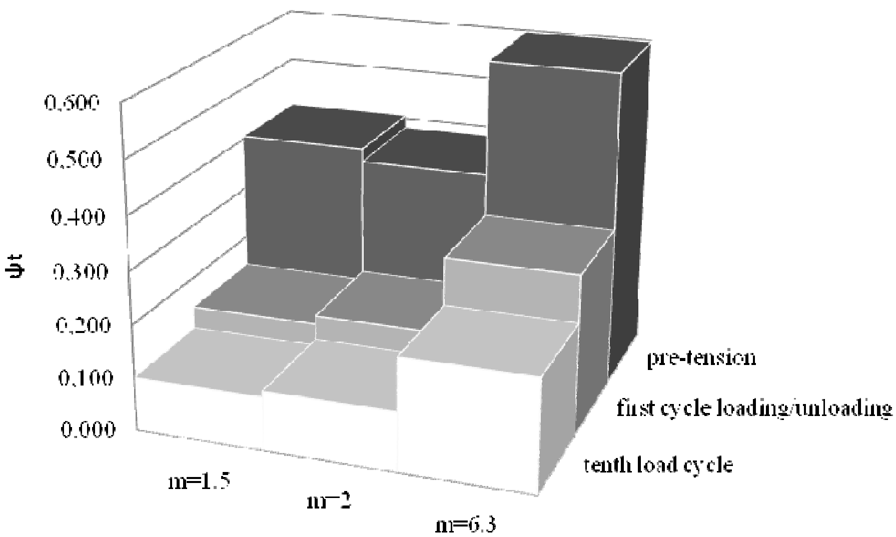
Static damping coefficient values were determined for ten subsequent cycles of loading/unloading, with different loads corresponding to the safety coefficients m = 6.3, 2, 1.5. Table 2 shows results obtained for 1st, 5th and 10th loading/unloading cycle.

Table 2

Static values of damping coefficient

m=1.5	ψ_t	m=2	ψ_t	m=6.3	ψ_t
Pre-stretch (sample 1,2,3)	0,397	Pre-stretch (sample 4,5,6)	0,381	Pre-stretch (sample 7,8,9)	0,562
	0,409		0,369		0,569
	0,408		0,391		0,657
01 – loading cycle (sample 1,2,3)	0,101	01 – loading cycle (sample 4,5,6)	0,137	01 – loading cycle (sample 7,8,9)	0,282
	0,159		0,172		0,300
	0,167		0,165		0,320
10 – loading cycle (sample 1,2,3)	0,102	10 – loading cycle (sample 4,5,6)	0,111	10 – loading cycle (sample 7,8,9)	0,195
	0,100		0,115		0,207
	0,100		0,110		0,234

Static damping coefficient show a dependence on the value of the load and its cycle. At first loading (pre-tension) damping coefficient is much higher than in subsequent cycles. As noticed, when the loading/unloading cycles takes place for the same safety factor values, the values decrease with the number of cycles, where the highest value reaches for the brand new ropes, due to the large clearance between the strands and lack of strands deposition of the core (fig. 12).



	m=1.5	m=2	m=6.3
tenth load cycle	0.101	0.112	0.212
first cycle loading/unloading	0.142	0.158	0.301
pre-tension	0.405	0.380	0.596

Fig. 12. Static damping factor dependence from the cycle and load values - average values
Rys. 12. Zależność współczynnika tłumienia statycznego od cyklu i wartości obciążenia – wartości średnie

The research was only preliminary studies, where the obtained characteristics of the test rope 6x19 SEALE +FC Zs will be used in further studies and simulations of lifting crane. The next stage of research will estimating parameters of Bouc-Wen model [10], to reflect the phenomenon of hysteresis in the lines.

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