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Periodic Revisionof Low Stretch Kernmantel Ropes Used as PPE that is Based on the Change in Rope Diameter

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Abstract: *When working at heights and over free depth, according to legislation, an employer is obliged to take relevant measures to protect employees from falling from a height or into a depth. This protection is ensured by means of collective or individual protection, while arborists and collectors of tree seeds use almost exclusively individual protection equipment, which are ropes and connectors. Prior to commencing any work, the condition and functionality of this equipment must be checked, if necessary, periodically. According to the manufacturers' instructions the ropes are checked visually by inspecting and monitoring the changes in diameter and length. Based on dynamic loading, this article aims to determine, whether, on the basis of the measured values of diameter and length,it is provable to determine further use of lowstretch kernmantel ropes as PPE for protection of person.*
Keywords *-low stretch kernmantel ropes, elongation ropes, examination PPE*

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I. Introduction

The sources of the Czech Statistical Office, the statistics of which also include a fall from a height as the cause of death, indicate that within the monitored period from 2006 to 2015, each year in average 122 people died as a result of a fall (STATISTICAL YEARBOOK OF THE CZECH REPUBLIC 2008 -2017). It includes all falls occurring during work or leisure activities, during which the use of PPE is expected. These are the falls registered under the following codes: W 11 Fall on or from a ladder, W 12 Fall on or from a scaffold, W 13 Fall from a building or structure, or fall through them, W 14 Fall from a tree, W15 Fall from a rock, W 17 Other fall from one level to another.[8-17] According to the assessment of fatal occupational accidents, the work of tree climbers can be assessed as the most hazardous along with the work of mining workers.[6] It is therefore evident that a specific attention should be paid to ensure the safety of people working at heights and above free depth. It is also important to be aware of the fact that the above are very risky workplaces.

When treating trees, the employer chooses personal protective equipment, which is namely protective equipment to prevent the fall. The most frequently usedPPEinclude the following: full body harnesses, lanyards, low stretch kernmantel ropes, energy absorbers, connectors, sit harnesses, etc.[5] The employer is obliged to ensure that the chosen personal protective equipment is regularly inspected and tested [18]. Before using personal protective equipment, the employee is obliged to make sure that they are complete, serviceable and safe. [3] Currently, there are several professional organizations that try to provide training for persons with professional qualifications, and this activityis also legally stipulated for manufacturers. [1] The truth is that most of the trainings of professionally qualified persons for periodic inspection does not differ in terms of individual manufacturers and professional organizations. We can say that the training procedures, proposed examinations and inspection procedures are almost identical. In normal operational practice, both day-to-day checks and periodic inspections are based on the use of relatively simple visual methods. [5]

The question is, however, whether the use of rope‘s length and diameter can be sufficiently proved and justified during the inspections of low stretch kernmantle ropes. Based on the measurements thisis the only assessable data. [3]

II. Materials and Method

The starting point for the formulation of solution methodology is a formulated general hypothesis containing the basic premises:

- A load applied on the rope has an impact on its dimension (diameter-length), and it is possible to determine the limits of its elongation and thinning resulting from tensile stress (impact stress), and thus to determine the moment when the rope has to be discarded.

2.1 Materials

The test was conducted with a low stretch kernmantel type A rope, certified pursuant to ČSN EN 1891.

General rope characteristics:

Rope diameter	11 mm
Number of falls	10
Elongation	3.2%
Strength	22 kN
Min. strength with knots	15 kN
Material used	PES/PA

2.2 Method

Twenty ropes from the same manufacturer were purchased for testing. In order to achieve the most objective testing results, the ropes were purchased from four different vendors to prevent the possibility of having the ropes from a single knitting lot. Two four-meter long samples were taken from each rope; one for testing and the other as a reserve sample in case of the test crisis. The samples were labelled identically to the remains of the parent ropes, and samples A (initially used) and samples B (as backup) were determined. A figure of eight knot was tied at each rope termination so that the length of each sample was exactly 2,500 mm. One termination was attached to a fixed anchor point via a strain gauge sensor. This termination remained fixed throughout the entire period of measurement;it means eleven series of measurements. Data from the strain gauge sensor were recorded, but within the scope of the measurement the data was only used to check the specified load values.

The rope was continuously loaded with a weight of 10 kg for a period of 60 seconds. After this loading period, with the load still applied, the rope diameters were measured at three levels. The first level was 150 mm above the upper knot, the second level in the middle between the two knots and the last level 150 mm below the lower knot. The measurements were takenwith an unmodifiedslide gauge, and two independent measurements were performed at each level. All six measured values were added up and divided by six. The result was an

$$\mathrm{Pr} = \frac{\mathrm{Lb}\,.\,100}{\mathrm{L}a} \qquad [\%] \qquad (1)$$

arithmetic mean that represented the measured rope diameter. The rope sample was loaded with a 50 kg mass for 300 seconds. After this loading period, with the load still applied, two marks 1,000 mm apart were made, and in the following calculations this value isexpressed as the distance value La. Afterwards, the load was increased to 150 kg. After the elapse of 300 seconds, the distances between the indicated marks were measured again and recorded as the distance Lb. The resultant elongation Pr was then expressed in formula 1. This calculation shows the total elongation of the rope, that means, a percentage of the rope elongation.

The next step in the test cycle was the dynamic performance test. At the free rope termination into a figure eight knot, a weight of 80 kg was suspended. Consequently, the anchoring circle of the weight,into which the figure eight knot was connected, was lifted to the same height as the anchor point at a distance of 80 mm horizontally from that point. The weight was anchored with a cord that was briskly cut off in order to release the mass immediately. Subsequently, the whole test cycle was repeated nine times. Contrary to EN 1891, the mass of 80 kg was chosen instead of 100 kg, as required by the standard for type A ropes. In the test, it was considered that during the fall the rope is loaded by tree climbers who only exceptionally have a body weight of over 80 kg. [5] It is therefore advisable to test the deformation of the rope and its characteristics when a dynamic performance load of 80 kg is applied.

III. Results

The measured values were statistically evaluated. Tobe able to use theinspection methods for rope tests, which are based on the knowledge of changes in rope diameters and rope lengths that can be used to determine if to retain the ropes or discard them, statistical hypotheses were established in advance. A null hypothesis was determined in such way that in case of the absence of a sufficient statistical prove proving its invalidity, it would be possible, on the basis of its wording, to apply it in working practice during the revision of ropes.

3.1 Results of Rope Diameter Changes as a Consequence of Impact Load

The determination of null hypothesis was based on the assumption that when a dynamic loadis applied on the rope, it becomes thinner. Following ČSN EN 1891, which stipulates that the rope elongation must not reach values higher than 5%, a reduction in the rope diameter by more than 5% was observed when determining the thinning of the rope. Therefore, the hypothesis H_0: $\mu \leq 95\%$ (in our case H_0: $\mu \leq 10.45$ mm) was determined. In contrast to the fact that, according to the manufacturer's specifications, the rope must withstand at least 10 falls of a100 kg mass without compromising its integrity, in our test the thinning value of the rope was evaluated already after five falls of a 80 kg mass. The alternative hypothesis was determined H_1: $\mu > 95\%$. Therefore, theobjective is to perform a statistical verification, whether it is possible to determine the value of rope thinning in percentage already after five falls, and thus to determine when it will be reasonable to discard the rope. [4]

To verify the possibility of monitoring the dynamic loading of the rope through the changein the rope diameter, the null hypothesis was formulated; in which the rope diameter before the start of the dynamic loading and after five dynamic loads is equal. To reject the null hypothesis, an F-test of equality of variances of both sets was chosen. If the F-test does not recommend rejecting this null hypothesis, consequently the two-sampleT-test of equality of variances will be used. [4]

By comparing the test criterion with the critical value, the null hypothesis cannot be rejected (the test criterion of 8.6093E-24 is higher than the critical value of 0.4612). This fact is evident from the box plot 1. By comparing the calculated probability and the determined confidence level the null hypothesis must be rejected (P; 0 <α; 0.05).

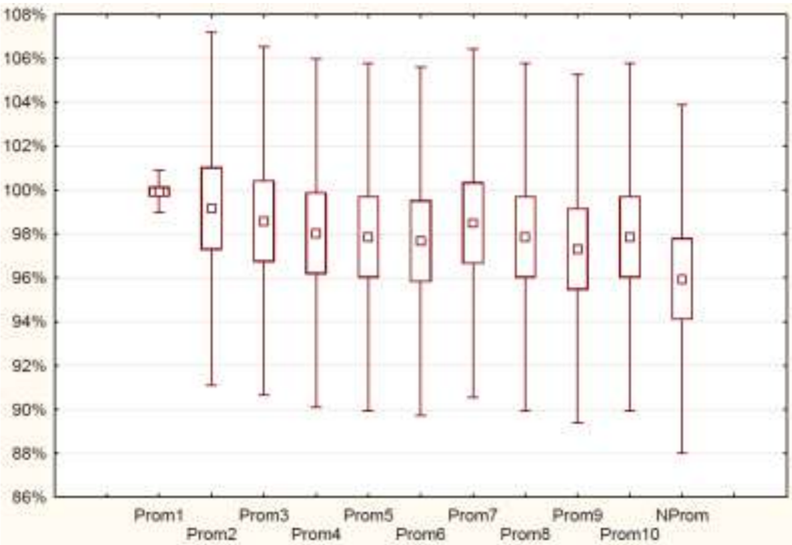

Chart 1:Box plotshowing the rope diameter change in %.

		Number of impact loads										
		0	1	2	3	4	5	6	7	8	9	10
Sample number	1	11.00	11.20	10.56	10.50	10.48	10.46	10.55	10.48	10.42	10.48	10.27
	2	10.95	10.67	11.04	10.98	10.96	10.94	10.75	10.96	10.62	10.96	10.75
	3	11.04	10.69	11.11	11.05	11.03	11.01	10.75	11.03	10.62	11.03	10.82
	4	11.01	10.59	11.18	11.12	11.10	11.08	10.75	11.10	10.62	11.10	10.89
	5	10.96	10.73	10.99	10.93	10.91	10.89	10.75	10.91	10.62	10.91	10.70
	6	10.98	10.63	11.11	11.05	11.03	11.01	10.75	11.03	10.62	11.03	10.82
	7	11.07	11.60	10.23	10.17	10.15	10.13	10.75	10.15	10.62	10.15	9.94
	8	11.09	11.90	9.95	9.89	9.87	9.85	10.74	9.87	10.62	9.87	9.66
	9	11.08	10.50	11.34	11.28	11.26	11.24	10.75	11.26	10.62	11.26	11.05
	10	11.06	10.30	11.52	11.46	11.44	11.42	10.75	11.44	10.62	11.44	11.23
	11	11.00	10.91	10.85	10.79	10.77	10.75	10.75	10.77	10.62	10.77	10.56
	12	11.01	10.93	10.84	10.78	10.76	10.74	10.75	10.76	10.62	10.76	10.55
	13	10.98	10.69	11.05	10.99	10.97	10.95	10.75	10.97	10.62	10.97	10.76
	14	10.96	10.97	10.75	10.69	10.67	10.65	10.75	10.67	10.62	10.67	10.46
	15	10.92	10.64	11.04	10.98	10.96	10.94	10.75	10.96	10.62	10.96	10.75
	16	10.96	10.99	10.73	10.67	10.65	10.63	10.75	10.65	10.62	10.65	10.44
	17	10.97	11.40	10.33	10.27	10.25	10.23	10.75	10.25	10.62	10.25	10.04
	18	10.93	11.60	10.09	10.03	10.01	9.99	10.75	10.01	10.62	10.01	9.80
	19	10.94	10.23	11.47	11.41	11.39	11.37	10.75	11.39	10.62	11.39	11.18
	20	10.93	10.98	10.71	10.65	10.63	10.61	10.75	10.63	10.62	10.63	10.42

Table1:The measured values of rope diameter D (mm) when determining the influence of the number of massfalls

Sample number	Number of impact loads										
	0	1	2	3	4	5	6	7	8	9	10
1	100.00%	101.82%	96.00%	95.45%	95.27%	95.09%	95.91%	95.27%	94.73%	95.27%	93.36%
2	99.55%	97.00%	100.36%	99.82%	99.64%	99.45%	97.71%	99.64%	96.55%	99.64%	97.73%
3	100.36%	97.18%	101.00%	100.45%	100.27%	100.09%	97.71%	100.27%	96.55%	100.27%	98.36%
4	100.09%	96.27%	101.64%	101.09%	100.91%	100.73%	97.71%	100.91%	96.55%	100.91%	99.00%
5	99.64%	97.55%	99.91%	99.36%	99.18%	99.00%	97.71%	99.18%	96.55%	99.18%	97.27%
6	99.82%	96.64%	101.00%	100.45%	100.27%	100.09%	97.71%	100.27%	96.55%	100.27%	98.36%
7	100.64%	105.45%	93.00%	92.45%	92.27%	92.09%	97.71%	92.27%	96.55%	92.27%	90.36%
8	100.82%	108.18%	90.45%	89.91%	89.73%	89.55%	97.64%	89.73%	96.55%	89.73%	87.82%
9	100.73%	95.45%	103.09%	102.55%	102.36%	102.18%	97.71%	102.36%	96.55%	102.36%	100.45%
10	100.55%	93.64%	104.73%	104.18%	104.00%	103.82%	97.71%	104.00%	96.55%	104.00%	102.09%
11	100.00%	99.18%	98.64%	98.09%	97.91%	97.73%	97.71%	97.91%	96.55%	97.91%	96.00%
12	100.09%	99.36%	98.55%	98.00%	97.82%	97.64%	97.71%	97.82%	96.55%	97.82%	95.91%
13	99.82%	97.18%	100.45%	99.91%	99.73%	99.55%	97.71%	99.73%	96.55%	99.73%	97.82%
14	99.64%	99.73%	97.73%	97.18%	97.00%	96.82%	97.71%	97.00%	96.55%	97.00%	95.09%
15	99.27%	96.73%	100.36%	99.82%	99.64%	99.45%	97.71%	99.64%	96.55%	99.64%	97.73%
16	99.64%	99.91%	97.55%	97.00%	96.82%	96.64%	97.71%	96.82%	96.55%	96.82%	94.91%
17	99.73%	103.64%	93.91%	93.36%	93.18%	93.00%	97.71%	93.18%	96.55%	93.18%	91.27%
18	99.36%	105.45%	91.73%	91.18%	91.00%	90.82%	97.71%	91.00%	96.55%	91.00%	89.09%
19	99.45%	93.00%	104.27%	103.73%	103.55%	103.36%	97.71%	103.55%	96.55%	103.55%	101.64%
20	99.36%	99.82%	97.36%	96.82%	96.64%	96.45%	97.71%	96.64%	96.55%	96.64%	94.73%

Table2:The measured values when determining the influence of the number of mass falls on the diameters of twenty rope samples.The values are expressed in percentage.

3.2 Evaluation of Rope Elongation as a Result of Impact Load

The determination of null hypothesis was based on the assumption that when a dynamic load is applied on the rope, it elongates. Under the ČSN EN 1891 a rope elongation must not exceed 5%. Therefore, the hypothesis H_0: $\mu \leq 105\%$ (in our case H_0: $\mu \leq 1{,}050$ mm) was determined. As the rope, according to the manufacturer's specifications, is expected to withstand a minimum of 10 falls (in contrary to our 100 kg weight drop test), this value will be compared with the value measured after five falls. The alternative hypothesis was determined as H_1: $\mu < 105\%$. Therefore, the objective is to perform a statistical verification, whether it is possible to determine the value in percentage after five falls, and thus to determine when it will be reasonable to discard the rope. [4]

To verify the possibility of monitoring the dynamic loading of the rope through the change in its elongation, the null hypothesis was formulated; in which the rope elongation before the start of the dynamic loading and after five dynamic loads is equal. To reject the null hypothesis, an F-test of the equality of variances of both sets was chosen. If the F-test does not recommend rejecting this null hypothesis, consequently the two-samplet-test of equality of variances will be used. [4]

By comparing the test criterion with the critical value, it was decided not to reject the null hypothesis (the test criterion of 0.62173 is lower than the critical value of 2.168252). This is evident from the box plot. By comparing the calculated probability and the established confidence level the null hypothesis cannot be rejected as well (P; 1.23E-13 <α; 0.05).

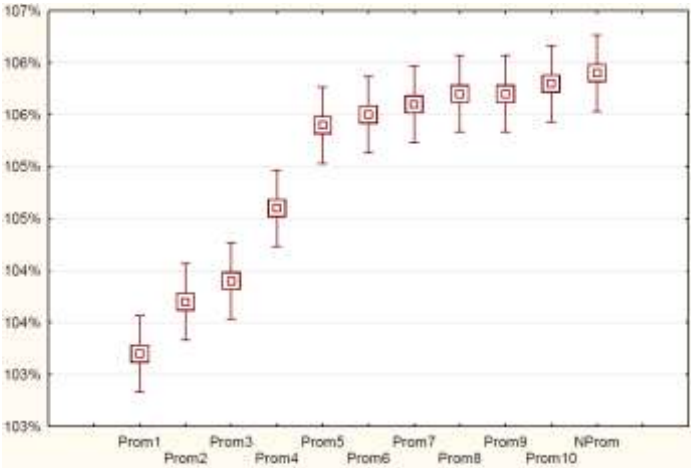

Chart1-2:Box plot showing the rope elongation in %.

		Number of impact loads										
		0	1	2	3	4	5	6	7	8	9	10
Sample number	1	1.032	1.036	1.04	1.046	1.053	1.056	1.058	1.057	1.058	1.06	1.058
	2	1.032	1.037	1.038	1.046	1.054	1.054	1.054	1.059	1.056	1.059	1.059
	3	1.037	1.037	1.039	1.048	1.052	1.055	1.055	1.058	1.057	1.059	1.057
	4	1.028	1.037	1.037	1.047	1.053	1.053	1.057	1.058	1.055	1.057	1.058
	5	1.031	1.042	1.038	1.047	1.054	1.054	1.056	1.056	1.056	1.058	1.059
	6	1.032	1.033	1.039	1.045	1.054	1.055	1.056	1.057	1.057	1.056	1.059
	7	1.034	1.036	1.039	1.046	1.054	1.055	1.058	1.055	1.057	1.057	1.059
	8	1.030	1.037	1.039	1.044	1.059	1.055	1.057	1.056	1.057	1.058	1.064
	9	1.031	1.039	1.044	1.045	1.050	1.060	1.057	1.057	1.062	1.058	1.055
	10	1.033	1.035	1.035	1.046	1.053	1.051	1.055	1.057	1.053	1.058	1.058
	11	1.032	1.036	1.038	1.046	1.054	1.054	1.056	1.057	1.056	1.063	1.059
	12	1.032	1.038	1.039	1.046	1.056	1.055	1.054	1.062	1.057	1.054	1.061
	13	1.034	1.037	1.041	1.051	1.052	1.057	1.055	1.053	1.059	1.057	1.057
	14	1.033	1.037	1.037	1.042	1.053	1.053	1.056	1.056	1.055	1.058	1.058
	15	1.033	1.039	1.038	1.045	1.055	1.054	1.056	1.057	1.056	1.060	1.060
	16	1.031	1.038	1.040	1.046	1.054	1.056	1.056	1.059	1.058	1.056	1.059
	17	1.032	1.038	1.039	1.048	1.054	1.055	1.061	1.055	1.057	1.057	1.059
	18	1.030	1.036	1.039	1.044	1.056	1.055	1.052	1.056	1.057	1.059	1.061
	19	1.031	1.037	1.041	1.045	1.055	1.057	1.055	1.058	1.059	1.058	1.060
	20	1.032	1.035	1.040	1.047	1.055	1.056	1.056	1.057	1.058	1.058	1.060

Table3:The measured values when determining the influence of the number of mass falls on the length of twenty rope samples. The values are expressed in metres.

	Number of impact loads										
Sample number	0	1	2	3	4	5	6	7	8	9	10
1	103.2%	103.6%	104.0%	104.6%	105.3%	105.6%	105.8%	105.7%	105.8%	106.0%	105.8%
2	103.2%	103.7%	103.8%	104.6%	105.4%	105.4%	105.4%	105.9%	105.6%	105.9%	105.9%
3	103.7%	103.7%	103.9%	104.8%	105.2%	105.5%	105.5%	105.8%	105.7%	105.9%	105.7%
4	102.8%	103.7%	103.7%	104.7%	105.3%	105.3%	105.7%	105.8%	105.5%	105.7%	105.8%
5	103.1%	104.2%	103.8%	104.7%	105.4%	105.4%	105.6%	105.6%	105.6%	105.8%	105.9%
6	103.2%	103.3%	103.9%	104.5%	105.4%	105.5%	105.6%	105.7%	105.7%	105.6%	105.9%
7	103.4%	103.6%	103.9%	104.6%	105.4%	105.5%	105.8%	105.5%	105.7%	105.7%	105.9%
8	103.0%	103.7%	103.9%	104.4%	105.9%	105.5%	105.7%	105.6%	105.7%	105.8%	106.4%
9	103.1%	103.9%	104.4%	104.5%	105.0%	106.0%	105.7%	105.7%	106.2%	105.8%	105.5%
10	103.3%	103.5%	103.5%	104.6%	105.3%	105.1%	105.5%	105.7%	105.3%	105.8%	105.8%
11	103.2%	103.6%	103.8%	104.6%	105.4%	105.4%	105.6%	105.7%	105.6%	106.3%	105.9%
12	103.2%	103.8%	103.9%	104.6%	105.6%	105.5%	105.4%	106.2%	105.7%	105.4%	106.1%
13	103.4%	103.7%	104.1%	105.1%	105.2%	105.7%	105.5%	105.3%	105.9%	105.7%	105.7%
14	103.3%	103.7%	103.7%	104.2%	105.3%	105.3%	105.6%	105.6%	105.5%	105.8%	105.8%
15	103.3%	103.9%	103.8%	104.5%	105.5%	105.4%	105.6%	105.7%	105.6%	106.0%	106.0%
16	103.1%	103.8%	104.0%	104.6%	105.4%	105.6%	105.6%	105.9%	105.8%	105.6%	105.9%
17	103.2%	103.8%	103.9%	104.8%	105.4%	105.5%	106.1%	105.5%	105.7%	105.7%	105.9%
18	103.0%	103.6%	103.9%	104.4%	105.6%	105.5%	105.2%	105.6%	105.7%	105.9%	106.1%
19	103.1%	103.7%	104.1%	104.5%	105.5%	105.7%	105.5%	105.8%	105.9%	105.8%	106.0%
20	103.2%	103.5%	104.0%	104.7%	105.5%	105.6%	105.6%	105.7%	105.8%	105.8%	106.0%

Table 4:The measured values when determining the influence of number of mass falls on the diameter of twenty rope samples. The values are expressed inpercentage.

IV. Conclusion

When determining the appropriateness of using rope characteristics such as length and diameter for rope revisions, it has been identified that a special attention must be paid to the measurement of the rope length. During the measurements, based on the fact that the rope must withstand at least 10 falls of a 100 kg mass without compromising its integrity, the rope thinning value has already been evaluated after five falls of an 80 kg mass during testing. In contrast to ČSN EN 1891 the measurement procedure was determined on the basis of two factors. The body mass of most workers working at heights is far below 100 kg; and it is at the utmost limit to detect the elongation of the rope only when the full number of ten falls is tested. Therefore, it was verified whether the rope elongation stipulated by ČSN EN 1891, which must not reach values higher than 5%, could be observed already after five falls of a body weighing 80 kg. The resulting measurement values, which are summarized in Tables 3 and 4, clearly indicate that the rope is always proposed to be rejected after four falls. Manufacturers recommend discarding the rope even after one fall, but it can be proven from the test results that if the rope elongation does not exceed 5%, a minimum of five consequent falls can be safely restrained.

Based on the test results, however, it is not possible to recommend the rope diameter measurements for rope inspections. Here, it was assumed that the reduction of the rope diameter also results in the reduction of the load bearing cross-section of the rope (thinning of individual fibres). Thus, the diameter measurement could be used to determine the need to discard the rope as well as in case of monitoring its elongation. As the rope is thinned, the circular profile is not uniformly maintained, and the rope cross-section is elliptical or has a different shape, and therefore it can be difficult to determine the precise diameter. Thus, when adding up two perpendicular measurements, the result of the cross-sectional area is distorted. This fact can be reasonably derived from the results, which are clearly shown in Tables 1 and 2. Therefore, it is not possible to make evaluationof the rope inspectionusing the reduction in rope diameter.

According to the above measurements, it is therefore possible to recommend manufacturersthat they should also include precise measurements of the rope lengths into the existing inspection procedures; and then based on the evaluation of the measurements it will be possible to make decisions whether the measured ropes should still be used as a part of PPE.

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