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Technical Note

Consideration of the Safety of Bungee Jumping in Relation to Mechanical Properties of the Installation Based on a Jump Accident in Gdynia

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This paper considers a bungee jumping accident that took place in July 2019 in Gdynia, Poland. The authors conducted an investigation to determine the cause of the bungee rope failure. It was based on mechanical tests concerning the strength of the rope as well as the calculation of the force induced in the rope during the jump. Based on the theoretical and experimental results, the rope safety factor was estimated. It appeared to be three-fold lower than it is recommended in Polish regulations concerning ropes dedicated to lifting people for industrial and public purposes. However, no law regulations strictly concerning bungee installation makes it easy for accidents to occur.

Keywords: bungee rope failure; bungee jumping safety; latex rope; mechanical test; safety factor.

1. Introduction

Bungee jumping originated in Vanuatu, a country in Polynesia, where young boys (12-year-old) used to participate in a special passage to manhood ceremony involving such a jumping. Attenborough described the ritual in 1966 [1]. Boys, and grown-up men, climb a dedicated wooden tower approximately 27 m high, take a platform on a selected elevation (the lowest is 10 m) and tie up two vines around their ankles. Then the boy/man jumps down. The length of the vines and the platform construction is prepared to make the jumper land on the ground on his back without any harm. The jumper velocity is slowed down by the platform hinging downwards as the vines stretch to their limits and the thin supports of the platform brake to absorb some of the fall shock. Simultaneously, at this instant, the vines whip tightly around the jumper's ankles. This event is still performed on the island for commercial purposes [2].

Throughout the years, the activity became popular worldwide as entertainment. However, the construction of the platform and the rope significantly differ from the original. A crane is frequently employed to carry a platform for the jumper, and different platform heights above the ground are chosen. The rope is synthetic and made of rubber instead of a vine. In popular bungee jumping, a single rope is used, replacing the original double rope system.

Bungee jumping is a high-risk activity. It was considered one of the issues in assessing safe practices among college students in [3]. Besides the obvious risk of death in the case of bungee jump installation failure, there is also a risk of injury due to body overloading. Human body response in the course of a bungee jump is described in [4]. The authors measured the heart rate, blood pressure and perception of fear among 17 students before, immediately before and after the first bungee jump. These indicators tend to increase just before the jump to stabilize afterward. The authors concluded that several physiological reactions may happen in the human body during such high-adrenaline activities. Other studies concerning jumping-related body injuries are considered in the literature. For example, [5] presents a literature review on ocular injuries related to bungee jumping and discusses a case of redness in both eyes related to a single jump. A case of a thigh break due to a taut bungee cord in the jumping course is discussed in [6]. In the presented literature review (1993–2012), the authors have found 25 case studies of bungee-related body injuries, the most frequent were ocular injuries (13 cases), and a single fatality was reported. The authors summarize that fatalities in bungee jumping are related mostly to equipment malfunction, user error, or pre-existing comorbidity. The scientific literature does not cover all bungee jumping accidents, and some cases can be found on the internet. In 2021 alone two deadly cases were reported online: in Colombia (July 2021) and Kazakhstan (October 2021).

This paper focuses on the bungee rope failure that took place in July 2019 in Gdynia (Poland). The jumper fell off the cord in the final phase of the free flight jump stage. The man survived as he fell on a jump cushion but broke his spin in multiple sections. The authors analyzed the materials secured on the site: bungee rope, cuffs, photos and films. In addition, mechanical tests of the rope and its ending were conducted. The tests made it possible to define the ultimate force of these elements.

On the other hand, the force induced in the rope during the jump course has been theoretically calculated based on the mechanics of a falling mass. Based on the experimental and theoretical results, the rope safety factor has been estimated, which led to a discussion concerning the cause of the rope failure and current legal provisions regarding bungee jumping. In the following sections, the paper covers the course of the accident events, materials and elements used for the jump, possible scenarios concerning the rope failure, theoretical analysis and mechanical tests performed, leading to conclusions.

2. Materials and methods

2.1. The jumping stand and a course of events

In July 2019, during the summer festival in Gdynia (Poland) bungee jumping was provided as extra entertainment. The participants were lifted on the crane-mounted cage to the elevation of 92 meters to make a jump on a rubber rope. One end of the rope was attached to the cage, and the second one to the jumper. Both ends of the rope were finished by a single steel snap hook. The jumper was provided with a pair of cuffs pulled around his ankles. Each cuff was attached to a separate snap hook through a webbing strap, and both hooks were attached to the snap hook of the rope using other webbing straps. The rope end on the jumper's side with its snap hook was covered by a textile sleeve. All elements are shown in Fig. 1.

Fig. 1. Failed end of the rope along with a view of leg cuffs and a sleeve covering the rope end.

Several people jumped that day, using three different ropes, which should be selected according to their weight. The last jumper broke down from the rope and fell. The man was ordinarily attached to the rope, and jumped using the same technique as the previous participants. However, the rope broke down in the final phase of the free fall, corresponding to a small rope force, and the man fell almost freely from 92 m. Just before his detachment from the rope, a cloud of talc appeared around the rope in the broken area. No backward movement or speed reduction of the man is observed in films; thus, the movement was not considerably slowed down. The man survived due to an inflatable jumping cushion on the ground below the crane's platform. However, he broke his spine at several points, and thus permanently lost his health.

2.2. *Construction of the rope*

The rope was manufactured by the bungee jumping organizer. It was made from talcum-coated latex threads produced by Rubberflex Sdn Bhd company (Kuala Lumpur, Malaysia). The company produces natural latex extracted from rubber trees. Approximately 1540 latex threads parallel to the rope axis were used to form the rope core. The core was wrapped by some layers of coating made from the same kind of threads (see Figs. 2, 3a, and 3b). All threads were covered by talcum powder, which reduces friction between the threads and thus it reduces the friction-induced secondary tensile stresses [7]. The total diameter of the rope was about 4 cm; however, it was wider at both endings, reaching 5.9 cm on the crane side and 5.1 cm on the jumper side. The larger diameter results from the solution of the rope attachment to snap hooks. The connection was made by threading latex threads through the hooks and fixing these threads on a rope by a second layer of wrapping (see scheme in Fig. 2 and photo in Fig. 3c). The entire rope was approximately 20 m long. The rope had not passed any mechanical tests before its use, so there was no data concerning its mechanical properties such as stress or strain limits.

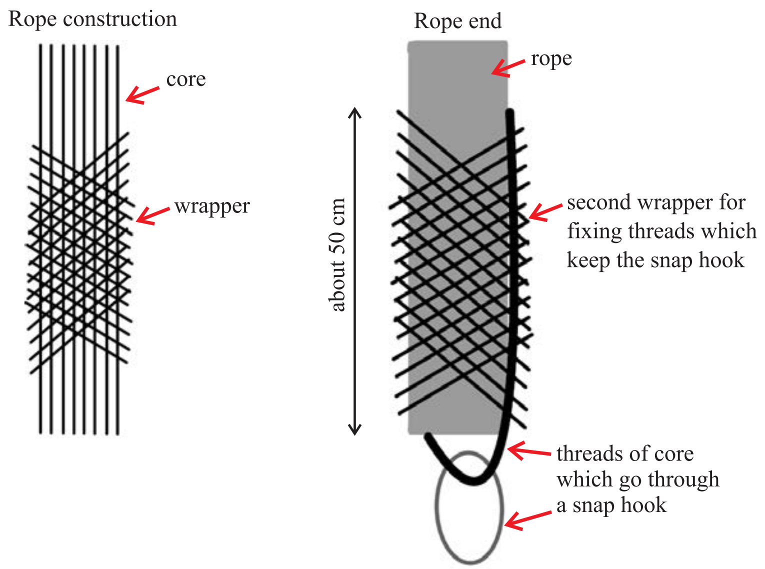

Fig. 2. Scheme of the rope and its ending construction.

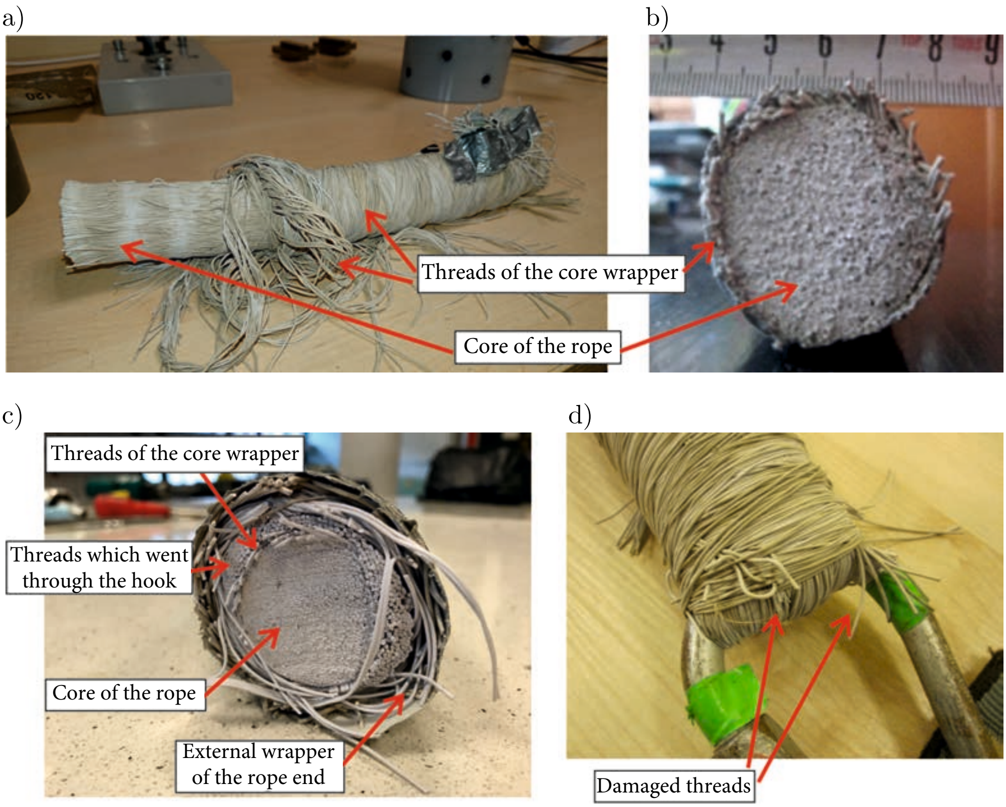

FIG. 3. Rope construction: a) general view of rope fragment, b) cross-section of rope core (units [cm]), c) cross-section of rope end (crane side), d) rope fixation on a snap hook on the crane side.

2.3. Considered scenarios of the rope failure

In the beginning, the possibility of deliberate rope cutting was ruled out by comparing the rope threads sections cut by a knife or torn off by the authors to the ends of the threads broken in an accident. It was found that there is a significant difference between the end cut by the knife and the ends of destroyed rope threads. That means that hypothesis of rope cut can be neglected. Next, the reason for the rope failure was considered. In the fatal jump, the rope mounting in a snap hook was so weak that the fixation failed during the first tension of the rope. The question is: whether the rope was constructed to work at its limit stress and broke without any pre-damage (scenario 1), or whether some safety factor was ommited and the existence of pre-damage caused the failure (scenario 2). To answer this question, mechanical tests of the rope and its mounting to the snap hook, which stayed 'healthy' on the crane side, were provided. The observations made during the tests, as well as the comparison of the rope strength to the theoretical force induced in the rope during the jump (and thus estimation of a safety factor), lead us to the conclusion on the failure cause.

2.4. Calculation of the maximum force in the rope in the jump course

Force arrested by the rope can be estimated based on the energy consideration of the system. The necessary data can be obtained from measurements of the load-extension relation, as made for a bungee rope in [8] or a ropeway in [9]. In this paper, the advantage is taken from film recordings of two jumps: the fatal one and the preceding, safe one. The exact moments of certain phases of jumps, which are: the beginning of free fall, end of free fall and end of rope extension, could be specified from the frame analysis of the films. Thus, a maximum force in the rope in the jump course is calculated based on physical relations concerning the free fall of a given mass (the bodyweight of both jumpers is also known). The following two films are considered:

a) FILM 1 – a successful jump of a man with a body mass equal $m_1 = 95$ kg, which took place just before the accident ('S' jumper), see Fig. 4,
b) FILM 2 – an accident jump of a man with a body mass equal $m_2 = 80$ kg ('A' jumper), see Fig. 5.

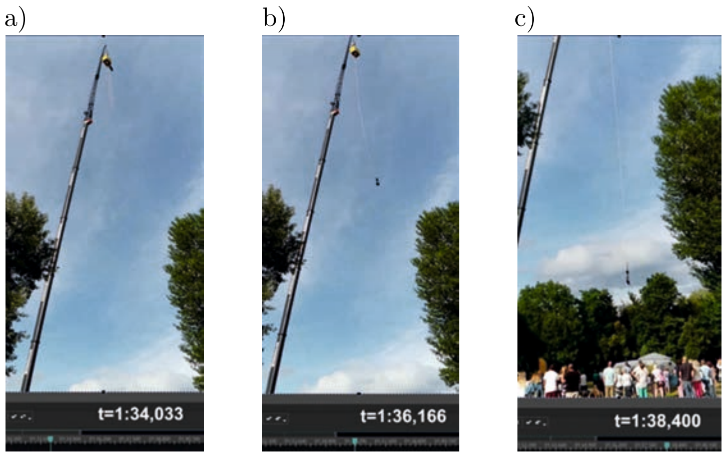

Fig. 4. Successful jump: a) beginning of free fall, b) end of free fall, c) end of rope extension. Specific moments are indicated.

In the frame analysis of the accident jump (see Fig. 5b), it can be noticed that the rope damage appeared just in a moment when it began to be straight. The body position of the jumper was still horizontal at this moment, which means that the full body weight of the jumper was not applied to the rope at the moment of the rope failure.

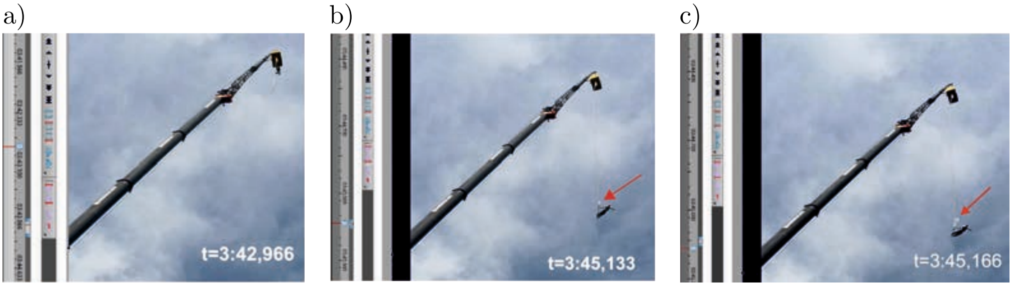

FIG. 5. Accident jump: a) beginning of free fall, b) end of free fall, c) visible rope damage. A cloud of talc is marked by an arrow.

2.5. Mechanical tests of the rope

To observe the rope's behavior during rupture and determine its ultimate strength, three types of tests were performed:

- tensile test of short-length latex threads applied to the rope,
- tensile test of the undamaged rope's part,
- tensile test of the rope's ending on the crane side.

All tests were conducted with the maximum traverse speed for the machines used, which, unfortunately, can be lower than the speed during the accident.

The tests on the mechanical properties of elastomer or latex (rubber) yarns are described in several national standards [10–14]. The producers of testing equipment propose different testing machines with different grips systems and different measurement techniques, see, e.g., [15]. The most important factors in the tests are the gripping system, maximum elongation and the range of applied forces. Generally, the gripping systems for yarns can be divided into two main groups: flat grips or different types of curved grips, including capstan grips. The flat grips enable the usage of short samples, which is important when large elongations are predicted. In this solution, the initial working length of the specimen is equal to the distance between grips because the influence of the shear stress in the yarns' gripping can be neglected. Thus, it is not necessary to use an extensometer in such a setup. The disadvantage of this solution is that samples break close to grips in the tests, which slightly reduces the ultimate force. The second solution, with curved grips, protects the specimen from close to grips breaks. That enables the more exact determination of the ultimate force, but due to the not specified initial working length of the specimen, the calculation of its elasticity requires an extensometer usage. Moreover, in this solution length of the specimen is considerably bigger. That poses a problem in the case of very elastic material because its total elongation is large and usage of universal testing machines becomes questionable.

The above-mentioned standards do not describe what gripping system is preferable. Considering all issues mentioned above, flat grips were used in this study. The tests conducted and the results are discussed in the following subsections.

2.5.1. Short-length latex threads tests. The first test type was performed on the Zwick Roell Z020 testing machine, equipped with a 20 kN load cell. The specimens were made of ten pieces of latex threads taken from the rope's undamaged region while the rope's external coating layer was removed. Due to the large deformation of threads, the working part of the specimens was 30 mm long. To ensure proper fixation of the threads in the machine grips and their uniform deformation, the ends of a specimen were treated with glue tape. The specimens were fixed in the flat grips of the testing machine (Fig. 6). An initial load of 10 N was applied and the main test was performed with the machine's traverse rate of 200 mm/min until the specimen rupture. The test was aimed at approximate values of the ultimate force of the rope and its ultimate extension determination. It was assumed that the ultimate force occurs when the first thread is broken. Additionally, the elasticity of the rope material was calculated. The values obtained in these tests made it possible to select a machine for the entire rope segment and the rope end testing and determine the length of these specimens.

FIG. 6. Latex threads specimen in the Zwick Roell Z020 machine grips.

2.5.2. Tensile tests of the fragment of not damaged rope. This test was aimed at determining the method of rope fixation in the machine grips. The method then was applied to test the rope's free end. Based on the estimated ultimate force in the rope, the Z400 Zwick Roell testing machine was selected for the tests. The machine's capacity was 400 kN and it showed a large traverse motion range. The specimen's total length was stated as 380 mm, and the working length was 250 mm.

Before cutting out the specimens from the rope, the cutting area was banded with glue tape to avoid the destruction of the specimen wrapping. As the rope threads were covered by talcum powder, it was a high obstacle to fix a specimen in machine grips, so that it would not slip out of grips during load application. Thus, several precautions were included to prevent this. Both clamping areas of the specimens were provided with three clamping metal rings firmly tightened around the rope. Additionally, a steel wedge nail was inserted into the core of the rope in the clamping area to produce support for the machine grips. Finally, a pressure of 400 bars was applied in hydraulic grips to fix the sample in the machine. As the diameter of the rope during large deformations was reduced, the clamping pressure was adopted to its initial value when it dropped more than 50 bars. The rope specimen and its location in machine grips are presented in Figs. 7a, 7b, and its situation just before the break is presented in Figs. 7c, 7d.

a)


b)


c)


d)


FIG. 7. a) Rope specimen prepared for the test on Z400 testing machine, b) sample placement in the machine, c) and d) rope specimen just before the break.

The specimen was subjected to the initial load of 100 N and the main test was performed, with traverse movement of 250 mm/min up to rupture. The problems with specimen clamping and the restricted length of rope for testing made it possible to perform only one successful test.

2.5.3. Tensile test on the rope end on the crane side. The rope end, which provided a hook junction to the bungee jumper, was destroyed during the accident. Therefore, it was not possible to specify its loading capacity. The decision was made to investigate the opposite end of the rope (fastening the rope to the crane platform), which was of similar construction, so a similar load-carrying capacity of both ends was assumed. The specimen cut from this end is presented in Fig. 8a. The snap hook in this specimen was originally installed during rope manufacturing. Before the test, the cut section of the rope was prepared to be fixed in the machine the same way as the pure rope specimen. To fix the end with the snap hook in the machine grips, a bolt was inserted through the hook. This bolt was compressed by the grip pressure of 400 bars (Fig. 8b). The test procedure was identical to the test of a pure rope specimen. The sample overview just before rupture is shown in Fig. 8c.

a) b) c)

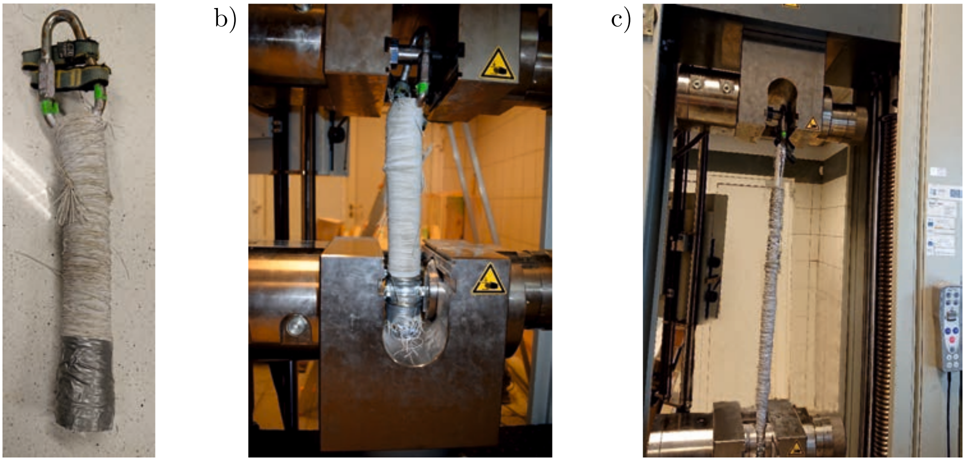

Fig. 8. a) Rope end with the original snap hook, b) sample mounted in the machine grips, c) sample view just before the break – snap hook was torn from the rope.

3. Results

3.1. Calculation of theoretical maximum force in the rope in the jump course

3.1.1. Estimation of the jumper's maximal velocity. The frame analysis of the films made it possible to state the time of the free fall, equal $\Delta t_1 = 2.133$ s for the 'S' jumper (see Fig. 4) and $\Delta t_2 = 2.137$ s for the 'A' jumper (see Fig. 5).

Alternatively, the time Δt of a free fall is a function of the fall distance (related to the rope length, measured as $h = 20$ m) and gravity acceleration g

$$\Delta t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \cdot 20}{9.81}} = 2.019 \text{ s.} \tag{3.1}$$

Neglecting air resistance, the maximum velocity of the free fall, according to Eq. (3.1) is:

$$v = g \cdot \Delta t = 9.81 \cdot 2.019 = 19.81 \text{ m/s.} \tag{3.2}$$

The periods of free fall are taken from the film frame analysis, so they read

$$v_1 = g \cdot \Delta t_1 = 9.81 \cdot 2.133 = 20.92 \text{ m/s (estimation for “S” jumper),}$$

$$v_2 = g \cdot \Delta t_2 = 9.81 \cdot 2.137 = 20.96 \text{ m/s (estimation for “A” jumper).}$$

As the time increments Δt_1, Δt_2 are considered approximate, the velocity v given by the formula (3.2) is taken for further analysis. Thus, it can be assumed that the maximum velocity of free fall was close to $v_{\max} = 20$ m/s.

3.1.2. Estimation of the maximum force acting on a rope during two jumps made. At the moment in which the rope begins to stretch, two kinds of forces occur in the rope. The first force F_1 is necessary to stop the jumper from falling within a certain time Δt_s, measured between the moment of the beginning of the rope tension and its full extension. This force can be estimated based on the “S” jumper jump (here it was $\Delta t_s = 2.234$ s, see Figs. 4b, 4c and $m = 95$ kg). The second force F_2 results from the body weight acting on the rope. To calculate the maximum value of F_1, the law of momentum conservation can be used

$$\int_0^{\Delta t_s} F_1(t)\,\mathrm{d}t = \int_{v_{\max}}^{0} m\,\mathrm{d}v, \tag{3.3}$$

where m stands for the body mass of a jumper and Δt_s denotes the time between the beginning of the rope loading and the moment of its maximum extension.

The time function of the rope force $F_1(t)$ relates to the oscillating, damped movement of a mass attached to the rope. It changes according to the equation of rope elongation in the harmonic damped vibration. An exact description of $F_1(t)$ demands knowledge of the rope stiffness and damping coefficient of the jumper's movement. The experiments on rope specimens described in the previous section can not be the source of rope stiffness calculation due to the artificial construction of the rope ends compared to real construction and the lack of strain measurements by some extensometer. Thus, it was decided to approximate $F_1(t)$ by linear time function with zero value at the beginning (approximation of the first loading cycle of the rope). This approximation poses some limitation to the study; however, examples of linearization of the nonlinear function of loading can be found in the literature [16–18] and similar approximations of the other mechanical functions in [19]:

$$F_1(t) = at, \tag{3.4}$$

where a is the proportionality coefficient. Then after integration

$$\int_0^{\Delta t_s} at\,\mathrm{d}t = m \int_{v_{\max}}^{0} \mathrm{d}v \Rightarrow F_{1\max} = \left| -\frac{2mv_{\max}}{\Delta t_s} \right| = \frac{2 \cdot 95 \cdot 20}{2.234} = 1701 \text{ N}. \tag{3.5}$$

The force F_2 for the 'S' jumper follows the second Newton's law of motion:

$$F_2 = m \cdot g = 95 \cdot 9.81 = 931.9 \text{ N}. \tag{3.6}$$

Finally, the approximate value of the maximum force in the rope during the jump of the 'S' jumper is:

$$F^S_{\max} = F_{1\max} + F_2 = 1701 + 931.9 = 2832.9 \text{ N}. \tag{3.7}$$

Taking the same time Δt_s for the man who performed the accidental jump, the maximum force in the rope is estimated as follows:

$$F^A_{\max} = \frac{2 \cdot 80 \cdot 20}{2.234} + 80 \cdot 9.81 = 2217.2 \text{ N}. \tag{3.8}$$

3.2. Mechanical tests of the rope

3.2.1. Short-length latex threads tests. Ten specimens were tested. The obtained stress-strain relations are presented in Fig. 9. Table 1 presents the mechanical parameters of the specimens, such as ultimate force as well as initial (E_1) and secondary (E_2) elasticity parameters of the material. Equivalent ultimate rope force is estimated by multiplying the result obtained for 10 threads by 154, as the counted number of threads in the rope core is $n = 1540$. This estimation omits the influence of the rope wrapping.

The average ultimate force in the rope reached the value of 12 226 N. The performed experiments' results fulfill the normality requirements according to the Shapiro-Wilk test [20] ($SW = 0.911$, $P = 0.286$). The elongation of specimens was between 311÷500%, and 385.3% on average. The influence of the rope wrapping was omitted in the analysis, so the elongation of the entire rope specimens is intended to be lower.

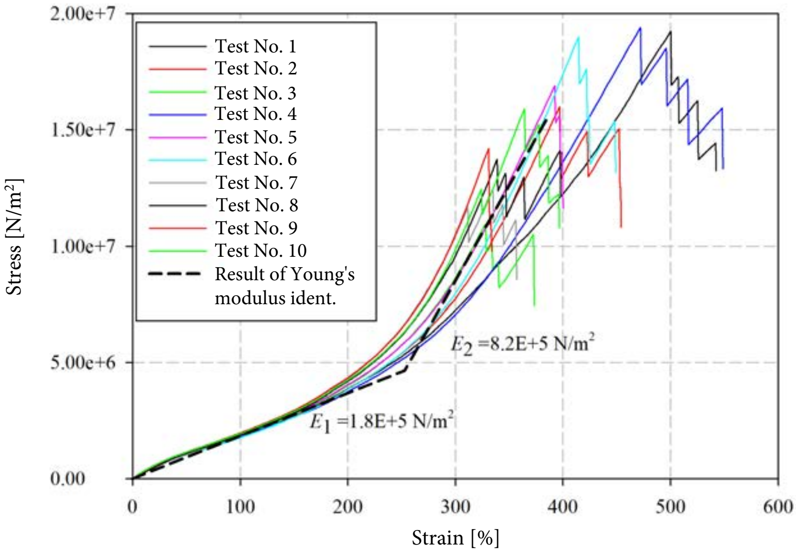

FIG. 9. Stress-strain relations obtained for latex threads specimens.

Table 1. Results of tensile tests of latex threads, rope and the rope's end.

Test number	Ultimate force [N]	Estimated equivalent ultimate rope's force [N]	E_1 [N/m^2]	ε_{1-2} [%]	E_2 [N/m^2]	$\varepsilon_{\mathrm{rup}}$ [%]
1	98.9	15230	17845.2	267.8	58529.2	500.0
2	82.6	12770	17148.9	266.0	81745.9	397.0
3	57.3	8824	18203.3	234.5	66705.8	327.0
4	99.7	15353	16969.8	279.7	73290.8	472.0
5	87.1	13413	18163.5	262.8	91255.4	392.0
6	97.8	15061	17427.4	273.3	97820.6	413.0
7	60.8	9363	19775.0	229.6	83934.3	311.0
8	71.3	10980	19217.9	238.4	84610.8	339.0
9	73.6	11334	19775.0	238.4	96567.3	338.0
10	64.8	9979	19158.3	236.9	84670.4	364.0
Average value	79.4	12226	18368.4 ≈ 18000.0	252.7	81913.0 ≈ 82000.0	385.3
Standard deviation	16.2	2487	998.6	17.8	11943.5	59.5
Ultimate rope force [N]		6715				
Ultimate force of rope's end [N]		6306				

3.2.2. Tensile tests of the fragment of undamaged rope and the rope's end on the crane side. The force-elongation diagrams obtained in both tests are presented in Fig. 10. The first symptoms of the rope sample destruction (sound of breaking latex threads and drops at the diagram) were recorded at the load level of 6303 N. The maximum applied force was equal to 6715 N. As the rope began to tear, a cloud of talc appeared in the location of damage, as it was observed in the bungee accident. The maximum force to make the snap hook tear from the rope was 6306 N. Both results are shown in Table 1.

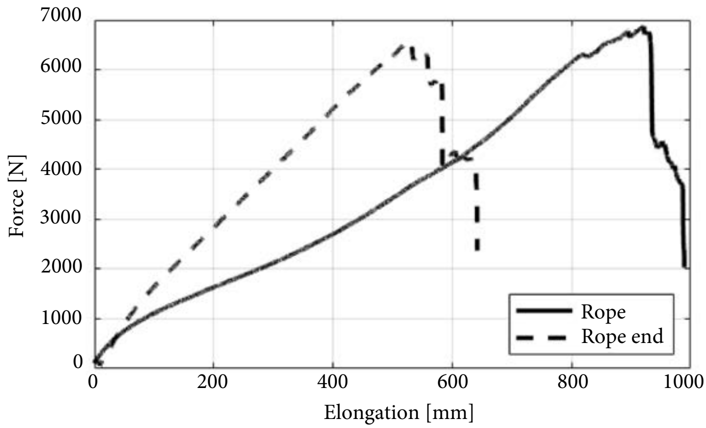

Fig. 10. Force-elongation relations recorded for a typical rope segment and for its end.

4. Discussion

Comparing the maximum force $F_{\max} = 2832.9$ N (see Eq. (3.7)) to the ultimate force achieved in the laboratory (about 6300 N), the safety factor of the rope reads approximately 2.22. If the experiments are performed with a higher speed, the experimental force value could be even reduced. This value confirms scenario 2 of the failure, in which the pre-damage of the rope mounting to the snap hook is considered. If the value equals c.a. 1, sudden failure would be possible, as assumed in scenario 1, without any pre-damage. Secondly, the existence of the pre-damage of the failed rope section is confirmed by a talc cloud appearing around this section during the accident jump (see Fig. 5). The laboratory tensile tests prove that such a talc cloud accompanies the rope rupture. In this accident, the cloud indicates the rope rupture appeared at the end of the free-fall stage, while the force in the rope is still small. Next, the pre-damage occurrence was possible because the failed rope section was covered by a textile sleeve and the eyewitnesses of the accident claim that the rope inspection was not provided before each jump. Finally, scenario 2 is pre-confirmed by inspection of the second end of the rope having the originally mounted snap hook. Some ruptured threads are already visible in this construction as well (see Fig. 3d).

This case prompts us to consider what the safety index should be in general. There are no law regulations for bungee jumping in Poland. In the United Kingdom, sporting organizations and government agencies have established codes for this activity practice [21, 22]. However, in [8], the author points out the drawbacks of these regulations, which are empirical, and do not consider the strength of the components used for the jump concerning forces generated throughout the jump. Nevertheless, the British experience could be followed by the countries without relevant regulations. The accident studied by Jones involved a three-core rope that ended with two snap hooks on the crane side and two webbing straps on the jumper side [8]. This system prevents the jumper from falling in case one hook or one core of the rope breaks.

On the other hand, there are law regulations in Poland concerning hoists, and they emphasize the cases of lifting people. The Regulation of the Minister of Economy of December 28, 2001 [23] on the technical conditions of technical inspection to be met by the jacks reads that in the hoists allowing the people to climb onto the load-bearing element, or staying under it, the minimum rope safety factor should be marked with the coefficient $X = 10$ (§26 of the above-mentioned Regulation). Moreover, in the Directive [24] of the European Parliament and of the Council of May 17, 2006, on machinery, Official Journal of the European Union 9.6.2006 L.157/24-86 paragraph 4.1.2.4, reads that the safety factor for entire ropes and their ends must be selected to ensure an adequate safety level. This coefficient usually equals 5 [24]. The same paragraph states that to verify the correctness of the safety factor, the manufacturer or his authorized representative is obliged to conduct appropriate tests for each type of chain and rope applied to lift the load, including the ends of the ropes.

Further paragraph 6.1.1 reads that the safety factors for the components specified in section 4.1.2.4 are inadequate for machinery intended for lifting persons and bound to be doubled. The machinery intended for lifting persons or persons and goods must be fitted with a suspending or supporting system for the load base, designed and constructed to ensure an adequate overall safety level and prevent the risk of the load base falling. While applying ropes or chains to suspend the load base, at least two independent ropes or chains are required, each leg provided with a separate attachment.

The 2.22 value of the safety factor estimated for the considered rope is much smaller than the value of 10 required for hoists according to the above-mentioned regulations. Although in Poland, there are no regulations concerning the safety factor of bungee jumping installation, one may refer to the above-discussed regulations concerning hoists. Moreover, the paper [25] confirms that a safety factor of 10 should be set for bungee cord manufacturing. Such safety factors can be obtained not only by the rope but by the whole bungee jumping installation.

Finally, some remarks can be made on the force-extension relation measured for the rope. The relation recorded in the study substantially differs from the one presented in [8]. Contrary to that result, no significant stiffening of the sample due to extension was observed in the study. This difference in the rope performance is probably caused by the rope construction and weaving method. We also do not know the kind of rubber used for the rope described in [8]. On the other hand, in the present study, a major difference between results obtained for threads alone and the whole rope segment is observed. The average ultimate force for the rope estimated based on the threads testing is approximately twice higher than obtained in the whole rope segment testing. There can be several reasons for that. One very important is the influence of wrapper layers reducing the deformation of the main threads. Therefore, the mechanical properties of the rope cannot be estimated based on the properties of the threads.

5. Conclusion

There are several studies on the use of a bungee jumper's harness attached directly to the rope. In the authors' opinion, this would be meaningless in the presented case, as the rope was the failed element. However, as a safety measure, all elements of jumping installation should be at least doubled, as in the example described in [8] and recommended by British standards [21, 22]. This means that a multiple-core rope should be used and the cores should be attached separately to the jumper and the jumping platform. Moreover, the bungee rope and all other elements of bungee installation should be mechanically tested before using or having a suitable certification. The necessary safety factor of the whole installation should be specified by law. Finally, a visual inspection of the entire rope before each jump is mandatory.

Declaration of interest

Both authors report a relationship with District Prosecutor's Office in Gdynia, Poland, including paid expert testimony.

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