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Dynamic parameters of lowering loads at gradual tree felling

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Abstract: The lowering of loads at gradual tree felling is the riskiest activity performed by tree climbers. During this activity, great forces emerge and act on the felled tree, while the tree climbers use the tree itself to anchor and secure their stance. This research aims to find out whether certain methods of work or the use of certain rigging for lowering loads exhibit positive features in reducing the forces acting on the anchoring point of the rigging system. The work methodology consists of three operations: (*i*) the calculation of the coefficient of shear friction for the combination of 4 ropes and 5 lowering devices – altogether 20 combinations; (*ii*) the mathematical modelling of the maximum forces acting on the lowering loads of known weight; and (*iii*) the verification of mathematical modelling using a series of measured experiments of lowering loads of known weight. The research results present the calculation of the shear friction coefficient for 20 combinations of rigging rope and lowering devices. The maximum magnitudes of the forces which may act on the upper anchoring point of the rigging system at the known load weight were additionally calculated. A total of 240 force values were measured when a load of 12 kg in weight falls according to a predetermined model situation. The results indicate that the greatest influence on decreasing the impact force generated by the falling load is that of the load attachment, reduced load weight, shortened length of the fall or elongation of the total rope length in the rigging system. The differences in the coefficients of shear friction are apparent in the results of measurements, too.

Keywords: arboriculture; friction; rigging; ropes; tree climbing

Trees represent a key element of the urban environment and fulfil not only architectonic and aesthetic functions but also the often-neglected function of providing a microclimate (Bianchini et al. 2020). Their presence in towns, however, brings the danger of their impaired operational safety (Klein et al. 2021). Situations often occur when dangerous trees have to be removed. Buildings, electric lines, etc. under trees in the urban environment force us to use gradual felling (from the tree crown top) while taking obstacles occurring in the zone of the tree fall into account. This can be undertaken using high-lift platforms or tree climbers with rope techniques. The complicated character of urban development, the poor accessibility of platforms in the terrain and their difficult handling, the high cost of their use as well as the author's personal experience result in the opinion that arboriculture in the urban environment will be dominated by a high share of manual work performed by tree climbers even in the future. Adopting the method of tree climbing, operators of manual power chainsaws proceed along the trunk from the butt to the top of the standing tree, delimbing the standing tree. They then cut the top part of the tree and proceed back to the butt so that they can cut trunk sections in order that they can safely throw them down or lower them to the ground suspended on a rope (Ulrich et al. 2020).

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Tree climbing is a very risky activity causing frequent occupational accidents (Longo et al. 2013; Staněk et al. 2022). Tree climbing is characteristically defined by ergonomically inappropriate working positions (Staněk et al. 2023) and work high above the ground with the potential risk of falling (Lim et al. 2020; Kane 2021). Due to the above-mentioned reasons, the method of gradual tree felling while lowering the loads, often from a considerable height, can be considered one of the riskiest types of work from the viewpoint of health protection at work (Ulrich et al. 2020). In spite of the fact that the tree-climbing method of work is physically highly demanding and dangerous, it cannot be satisfactorily replaced by any other currently available technology. Rope techniques allow one to perform operations precisely at the required place. Using ropes, operators can also get, for example, into the central parts of tree crowns where the aerial platform basket cannot get to due to the branches. Previous studies monitoring fatal and less serious injuries in arboriculture indicate that nearly 33% of tree climbing fatalities are caused by falling from heights (Wiatrowski 2005; Buckley et al. 2008; Centers for Disease Control and Prevention 2009). In Great Britain, 83 injuries were recorded in the period 2005–2010 from a total number of 1 000 tree climbers (Robb, Cocking 2014). In the United States, 30 people die every year out of 100 000 workers taking care of greenery (Wiatrowski 2005; Ball, Vosberg 2010). In the Czech Republic, 878 occupational accidents in forestry were recorded in 2016–2018, of which 8 were fatal (Lant 2019).

The lowering of loads consisting of cut branches and trunk sections is possible by means of a rigging system comprising upper and lower anchoring points and rigging rope. The lowered load is controlled by a rope wrapped around the launch anchor (friction brake) which is, at the same time, the lower anchoring point of the rigging system. The upper anchoring point comprises special lowering devices whose primary function is to anchor the rigging rope. However, the passage of the rigging rope through these devices generates friction which affects the magnitude of forces acting within the system. A secondary function of the lowering devices forming the upper anchoring point of the rigging system thus also takes the function of a friction rope brake. If a part of the friction required to control the falling load is transferred from the lower anchoring point to the upper anchoring point, the effect of the combination of forces is eliminated to a certain extent, and the resulting magnitude of the force acting on the upper anchoring point is lower. The magnitude of forces acting on the upper anchoring point of the rigging system is directly associated with the safety of the work performed by the tree climber. The amount of friction generated on the upper anchoring point primarily depends on the so-called coefficient of shear friction. The coefficient of shear friction (μ) is a dimensionless physical quantity specifying the share of frictional force between two bodies (their surfaces). This publication comes into being primarily due to the fact that coefficients of shear friction for combinations of rigging ropes and devices have hitherto not been subject to any research.

The aim of this study was to determine the unknown coefficients of shear friction for the combinations of the surfaces of the individual tested ropes and the individual tested lowering devices used as the upper anchoring point of the rigging system using an original measurement methodology. A partial goal of the research was to determine the potential maximum forces which can affect the upper anchoring point of the rigging system at a known drop height of a load whose weight is known. The series of measurements during which a load of known weight and drop height was lowered under predefined conditions (girding angle of the rigging rope and friction rope brake, type of rigging rope and type of lowering device forming the upper anchoring point of the rigging system) was to define the influence of the predefined shear friction coefficients on the force acting on the upper anchoring point of the rigging system. The influence of the load lowering mode (gradual dynamic lowering of the load; immediate static capture of the load) on the magnitude of the force acting on the upper anchoring point of the rigging system was also one of the studied factors.

MATERIAL AND METHODS

An original methodology, consisting of three parts, was designed for this research. The frictional force is calculated using the Euler-Eytelwein formula, as presented in Figure 1 (Konyukhov, Schweizerhof 2013), where F_1 is the force generated due to the action of the gravitational force on the lowered load. The right side of the equation

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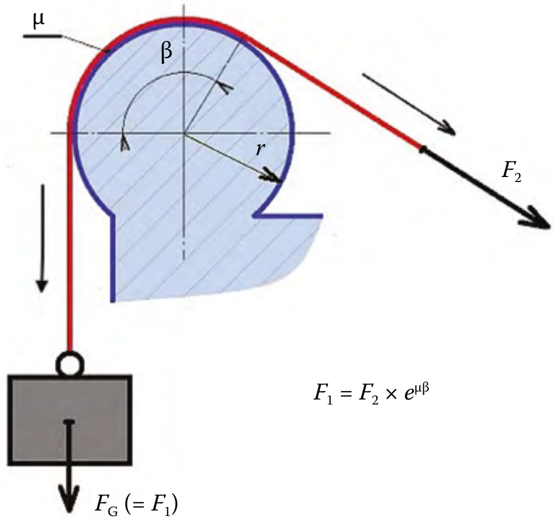

Figure 1. Practical representation of the Euler-Eytelwein formula; the forces in the system are in equilibrium

μ – coefficient of shear friction; β – the angle of the rope girding around the friction rope brake; r – radius; F_1 – force generated due to the action of the gravitational force on the lowered load; F_2 – the human power acting on the free end of the rigging rope; F_G – same as F_1; e – Euler's number (2.71828182846)

Source: https://cs.wikipedia.org/wiki/Vláknové_tření, modified

expresses the magnitude of the emerging frictional force, which depends on a combination of several factors: the human power acting on the free end of the rigging rope (F_2), the angle of the rope girding around the friction rope brake (β) and the mutual properties of the surfaces of the bodies forming the friction brake that appear in the formula as the coefficient of shear friction (μ). Euler's number, the value of which is 2.71828182846 (without unit), also appears on the right side of the equation, which is, however, always constant thus having no influence on the change in the magnitude of the emerging frictional force. It follows from the formula that the magnitude of the frictional force can be best influenced by changing the shear friction coefficient or by changing the angle of the rope girding around the friction brake. The size of the shear friction coefficient is commonly known for combinations that are most frequently used in engineering (steel-steel, rubber-asphalt, etc.). However, shear friction coefficients for the combinations of materials used for lowering loads, which include textile fibres and various kinds of metals of diverse surface treatments are not known.

The first step (Step 1) of the research was to determine the coefficient of shear friction for the combinations of four types of rigging ropes (Table 1, Figure 2) and five types of lowering devices (Table 2, Figure 3) used as the upper anchoring points and one lowering device used as the lower anchoring point. For adding up the shear friction coefficient μ, it was necessary to design the experiment and find out the other measurable quantities appearing in the Euler-Eytelwein formula. Force F_2 was determined based on a laboratory experiment in which a load of known weight (12 kg) suspended on Rope 1 was pulled through Lowering device 1, in which the rope made a known girding angle. The rope was pulled through the device at a constant speed using an electric rope winch. Force F_2 was measured by an electronic force meter EnForcer (Rock Exotica, USA). The measured values of forces were used to calculate the Coefficient of shear friction 1. The experiment was repeated with Rope 1 and Lowering device 2, etc.

The ropes used in the research were both new (unworn surface) and used. The used ropes exhibited considerable wear and tear of both the individual fibres and the entire bundles of fibres. Compared with the new ropes, the surface of the used ropes was much rougher both visually and to the touch. A Tendon Static 11 mm rope was used to ascend the tree climber to the treetop, a Tendon Timber 15 mm rope was used to lower the loads. Both ropes were used in an arborist practice for a year, but not every day. Both ropes showed signs of surface wear and soiling. None of the ropes showed

Table 1. Characteristics of tested lowering ropes

Rope	Made by	Name	Diameter (mm)	Limit load (kN)	Condition
Rope 1	Courant	Maona	12	40	new
Rope 2	Teufelberger	Sirius	14	52	used
Rope 3	Tendon	Static	11	33	new
Rope 4	Tendon	Timber	15	61	used

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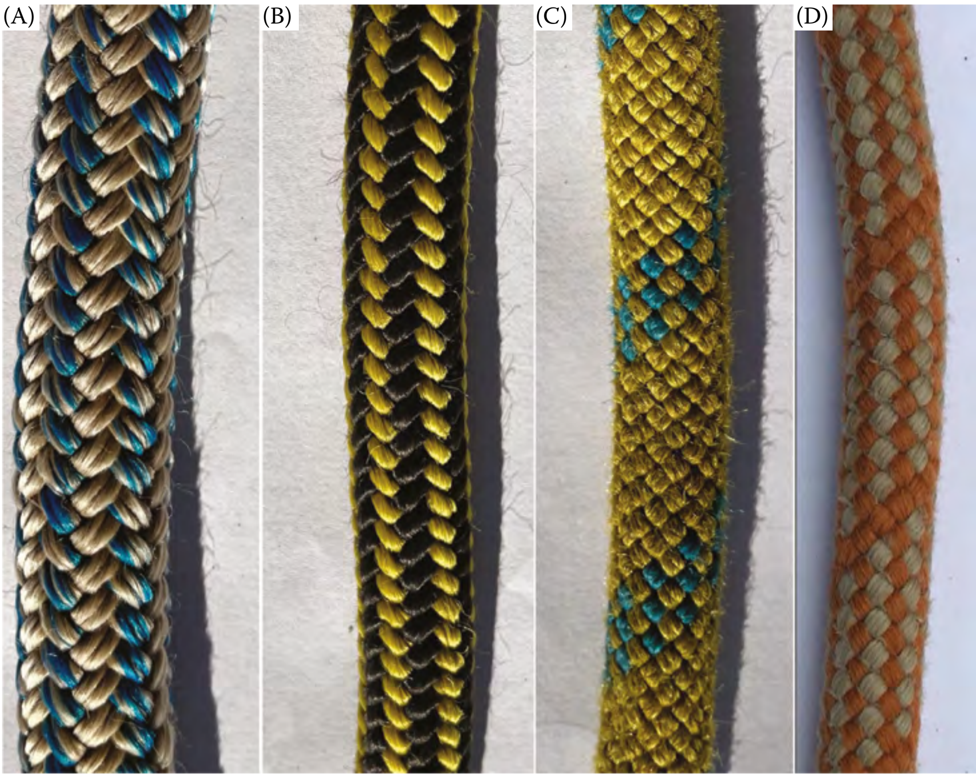

Figure 2. Tested ropes: (A) Courant Maona 12 mm, (B) Tendon Timber 15 mm, (C) Tendon Static 11 mm, (D) Teufelberger Sirius 14 mm

signs that would lead to the rope being retired, such as the extreme thinning of the rope, stiffening of the rope, wear of the braid so that the rope core shows through, or other surface or tangible changes such as heat damage. The used ropes were used in the research to study the influence of the rope condition on the size of the shear friction coefficient.

The second step (Step 2) in the methodological procedure was the mathematical modelling of the maximum forces acting on the upper anchoring point of the rigging system provided that the weight of the lowered load is known. The maximum force was calculated using Equation (1) according to Pavier (1998):

$$F = 2\,m\,g \times \left(1 + \sqrt{1 + \frac{2\,k\,f}{m\,g}}\right) \tag{1}$$

where:
F – maximum force;
m – load weight;
g – gravitational acceleration;
k – the rope's elasticity;
f – the fall factor.

Table 2. Characteristics of tested lowering devices for the upper anchoring point and for the lower anchoring point (last in the table)

Lowering device	Made by	Name	Limit load (kN)	Weight (g)	Material/surface
Anchor ring	Petzl	Ring 48 mm	23	40	dural/elox
Carabiner	Singing Rock	Ovál	30	195	steel/galvanized
Pulley	ISC	Silver Block	100	1 400	stainless steel
Kambium saver	Singing Rock	Jingle II	25	353	steel
Lowering ring	Antal	Rigging Ring L 28 mm	37	120	dural/hard elox
Lowering anchor	Notch	Port-a-wrap	90	1 700	stainless steel

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Figure 3. Tested lowering devices for the upper anchoring point: (A) Singing rock Jingle II, (B) Antal Rigging Ring L 28 mm, (C) Singing Rock Ovál, (D) ISC Silver Block, (E) Petzl Ring 48 mm

Equation (2) applies to the calculation of the rope's elasticity *k* (McLaren 2006):

$$k = P \times \frac{L}{x} \quad (2)$$

where:

k – the rope's elasticity;
P – the force that extends the rope;
x – the rope's extension;
L – the initial length of the rope.

The model situation considered in the determination of maximum forces acting on the anchoring point of the rigging system was negative lowering with the complete immediate static load capture as, in this method of capturing the load, the greatest force emerged acting on the upper anchoring point of the rigging system. The mathematical model assumed that the maximum elongation of ropes would be < 1% of the total length engaged in the system, this value being established experimentally by measuring the rope length before and after the load drop. The mathematical calculation takes the change in the potential kinetic energy of load into account, which changes only due to gravitation from zero potential energy to maximum energy. The maximum energy in the system is recorded at the last moment before the load is caught by the rope. Then, the kinetic energy is transformed into the work energy

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to be performed by the rigging rope. This energy is partly consumed by the rope elongation and partly transformed into thermal energy due to the friction of the rope and lowering devices. The remaining (originally kinetic) energy is transferred onto the upper anchoring point of the rigging system.

The third step (Step 3) in the methodology included a series of measured experiments on the fall of a load of 12 kg in weight. The length of the load drop was 0.4 m and 1.0 m. The total length of the lowering rope in the rigging system was gradually set to 3.0 m, 5.0 m and 10.0 m. The rope length gives a distance between the upper and lower anchoring points. The total rope length further included a rope part leading from the upper anchoring point to the load choker, which was 0.2 m or 0.5 m depending on the situation. The load was secured on Rope 1, and the upper anchoring point of the rigging system was formed by Lowering device 1, in which the rope made the known girding angle ($\beta = \pi$ rad). All the studied combinations of ropes and devices (Rope 1 and Lowering device 2, Rope 1 and Lowering device 3, etc.) were gradually measured. The lower anchoring point of the rigging system consisted of a steel lowering anchor for all the above-characterised combinations of rigging ropes and devices. A model situation of a negative lowering method with a complete immediate static load capture and a model situation of a negative lowering method with the gradual dynamic load lowering were simulated by changing the angle of the rope girding around the friction rope brake. The negative lowering of the load is a situation when the upper anchoring point of the rigging system occurs lower than the lowered load. Thus, the lowered load falls in free fall after having been cut off and an impact force is created when it is caught by the rope. The girding angle used at the complete immediate static capturing of the load was $\beta = 2\pi$ rad, while the girding angle used at the gradual dynamic lowering of the load was $\beta = \pi$ rad. The force generated by the load fall was recorded by a Rock Exotica force meter (Rock Exotica, USA) which formed the connecting link between the tree construction and the lowering device with the rope. The force meter was adjusted to record the greatest force measured in the frequency of 500 measurements per second. During the first installation of the lowering device, a fall was tested without recording the value of the forces. It served to stabilise the system and eliminate any later deviation of measurements caused by the tightening of knots or friction between the anchor loop and the tree trunk. The data obtained from the series of measurements were processed and compared with the model situation from Step 2.

RESULTS

Figure 4 shows six groups with four values of the shear friction coefficient. Each of the six groups

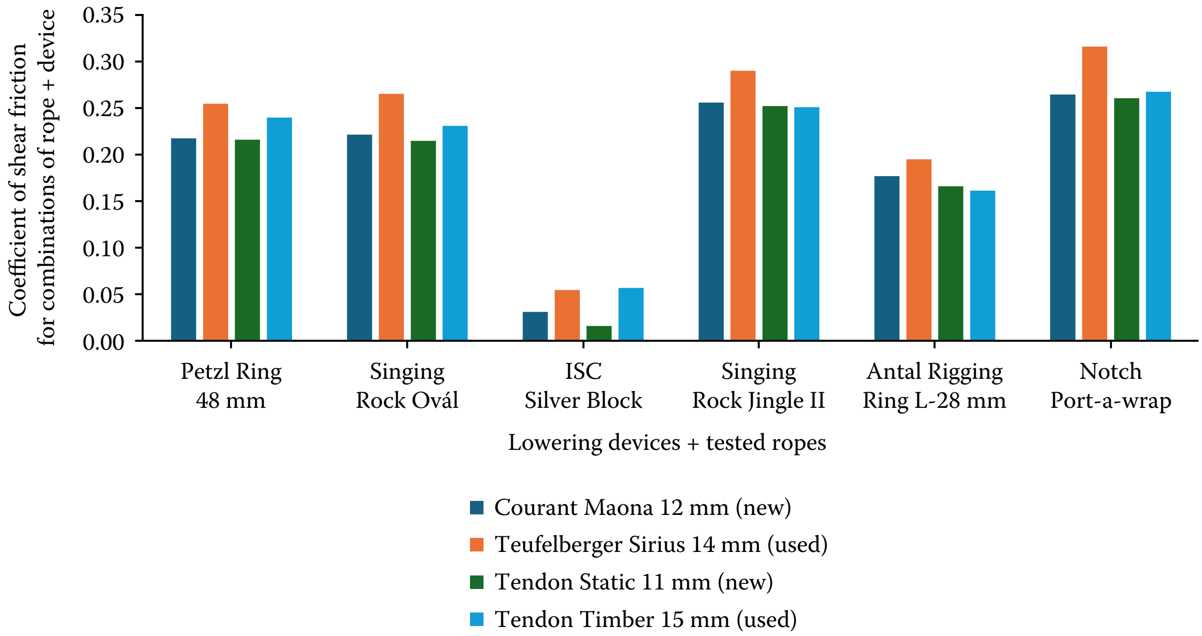

Figure 4. Size of shear friction coefficient

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represents one lowering device. Five lowering devices always formed the upper anchoring point of the rigging system, and the steel friction rope brake formed, in all cases, the lower anchoring point of the rigging system. Each of the four colours plotted in Figure 4 represents one type of rigging rope. The highest shear friction coefficient values in the five lowering devices were recorded in combination with the rope Teufelberger Sirius 14 mm, which exhibited considerable wear and tear already before the measurement. Another rope exhibited higher values in one case only; it was the Tendon Timber 15 mm in combination with the pulley ISC Silver Block 100 kN. The highest of all the coefficients of shear friction was recorded in the combination of the Teufelberger Sirius 14 mm rope (considerably worn) and the steel friction rope brake. On the other hand, the lowest values were recorded in the new Tendon Static 11 mm rope with five out of six devices. The only exception when the Tendon Static 11 mm did not exhibit the lowest coefficient of shear friction was the combination with the steel friction rope brake. In this combination, the coefficient of shear friction was lower in the Courant Maona 12 mm (new) rope. The overall lowest coefficient of shear friction was recorded in the combination of the Tendon Static 11 mm (new) rope and the ISC Silver Block 100 kN pulley. Here, the calculated shear friction coefficient values are, in some cases, even 15 times lower than with the use of the same rope and another lowering device.

Table 3 presents the results from the mathematical calculations of the maximum forces which can affect the upper anchoring point in the rigging system upon the fall of a load of 12 kg in weight.

Table 4 presents values of maximum forces which can develop during the fall of a load of 100 kg in weight according to the scenario described in Step 2 of the methodology. The values in the table show that if a load of 100 kg in weight falls 0.4 m in free fall, it is able to generate a force of up to 19 797 N onto the upper anchoring point at the immediate static capture. This mathematical model illustrates the magnitude of the forces that can be generated when loads are lowered under extreme conditions. Extreme conditions are, for example, the immediate static capture of the falling load, a rope with extremely low elongation, the potential poor skills of the person operating the rigging system and the inappropriate use of lowering devices.

The vertical axes in Figures 5 and 6 show the values of the forces obtained by the measurements in which a load (12 kg) was put into the state of free fall and then captured by the rope. The horizontal axes in Figures 5 and 7 are divided into two parts with different lengths of load fall: 0.4 m (left) and 1.0 m (right). The left and right parts of the two figures are further divided into two zones. Zone π shows the values of the gradual dynamic load capture and Zone 2π shows the values of the immediate static load capture. The values measured using specific lowering devices (specified in the figures' legend) are distinguished by different colours.

Figures 5 and 6 show a striking difference between the forces recorded during the dynamic lowering of the load (π) and during the static load capture (2π). Although the higher values of the forces at the immediate static load capture were expected as a matter of course, the difference in the case of e.g. Courant Maona 12 mm + Antal Rigging Ring L 28 mm (fall length 1 m) was more than 3.7 times. The highest of all the values acting on the anchoring point for the same combination of rope and device was 2 138 N. The values in Figure 6 are, on average, 78 N lower than those presented in Figure 5. This fact is given by the different properties of the tested ropes, such as modulus of elasticity or coefficient of shear friction in combination with the lowering device.

Figure 7 shows a model situation when a load of 12 kg in weight was gradually captured by the

Table 3. Maximum forces that can emerge upon the action of load (12 kg) in the above-described model situation

Total rope length (m)	Drop height (m)	
	0.4	1
3.2 and 3.5	1 662 N	2 375 N
5.2 and 5.5	1 364 N	1 948 N
10.2 and 10.5	1 057 N	1 485 N

Table 4. Maximum forces that can emerge upon the action of load (100 kg) in the above-described model situation

Total rope length (m)	Drop height (m)	
	0.4	1
3.2 and 3.5	13 850 N	19 797 N
5.2 and 5.5	11 366 N	16 238 N
10.2 and 10.5	8 816 N	12 382 N

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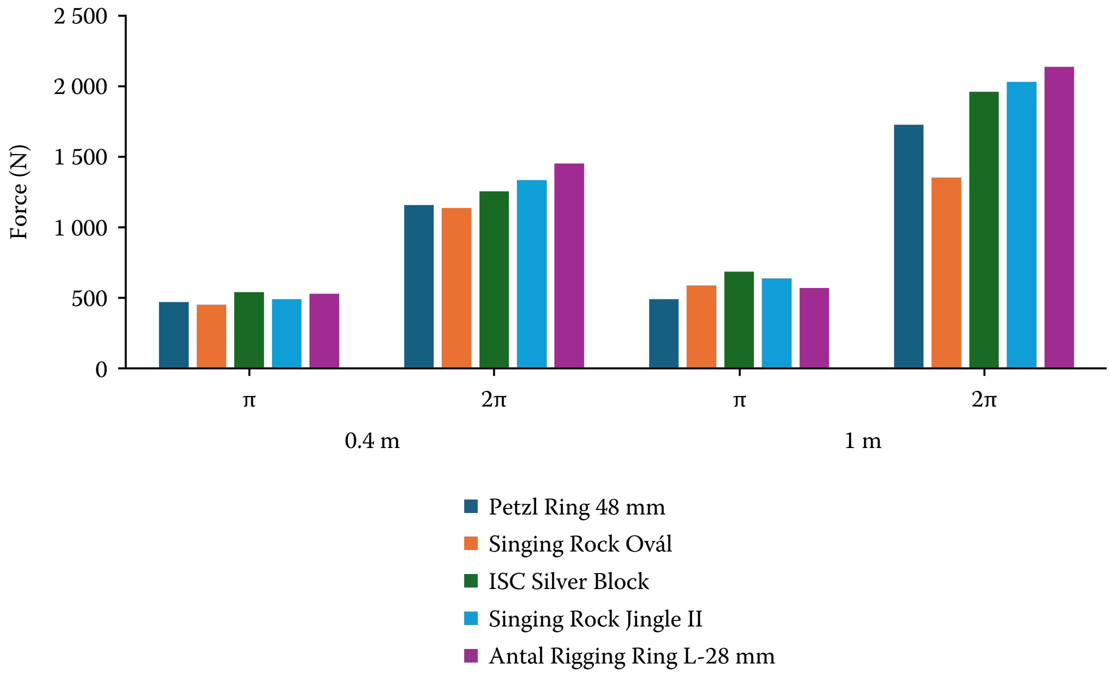

Figure 5. Values of forces measured for the rope Courant Maona 12 mm according to the scenario described in Step 2 of the methodology (rope lengths 3.2 m and 3.5 m)

operator lowering it so that the impact force generated by the free fall of this load (length 1 m) would be minimised. The overall rope length in the system was 10.5 m, and the girding angle of the lower anchoring point was π rad. The figure shows five groups of values, each group represents one lowering device, and each colour in the legend represents a specific type of rigging rope. The highest values are recorded in the group of the ISC Silver Block pulley. This corresponds with the values in Figure 4 where the ISC Silver Block pulley features the lowest coefficient of shear friction out of all the tested devices. On the other hand, the lowest values of impact forces were measured for

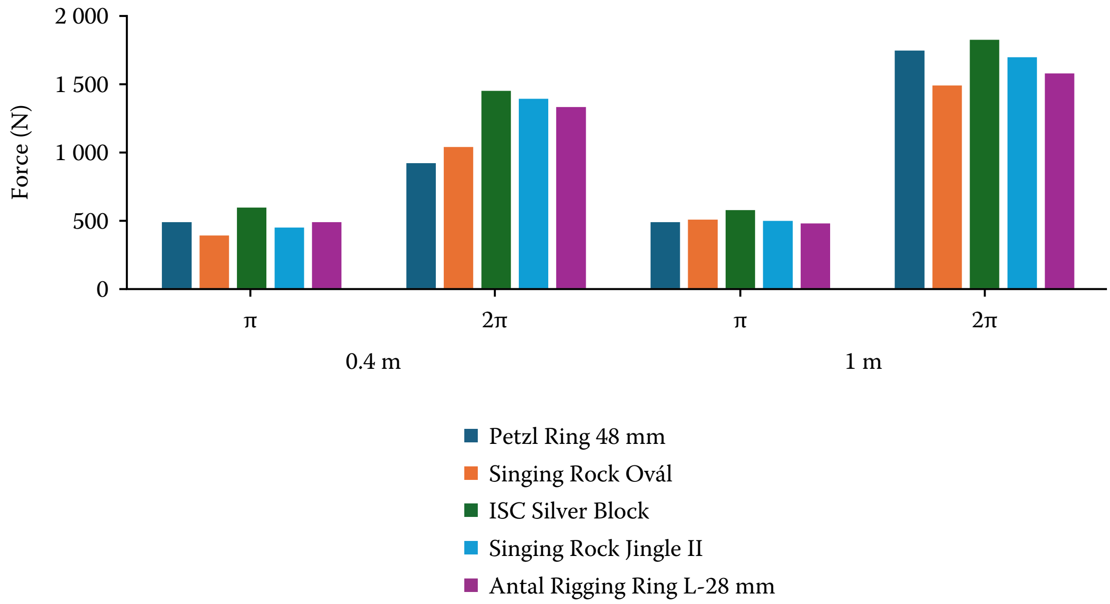

Figure 6. Values of forces measured for the rope Tendon Static 11 mm according to the scenario described in Step 2 of the methodology (rope lengths 3.2 m and 3.5 m)

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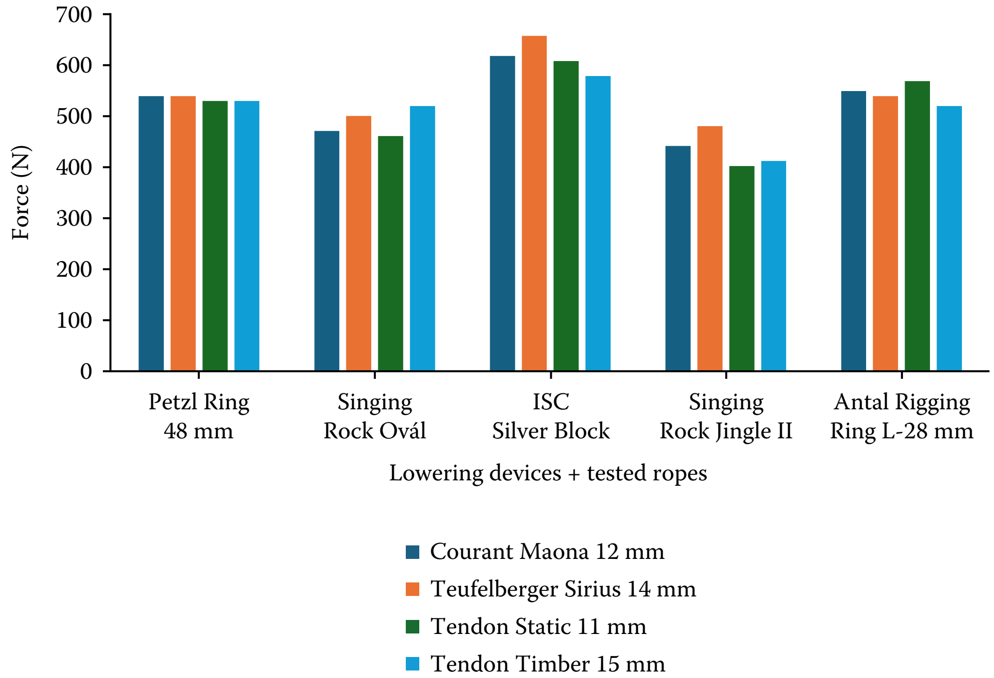

Figure 7. Negative gradual lowering of load, drop height 1 m, rope length 10.5 m

the cambium saver Singing Rock Jingle II where lower values could be expected than in the other lowering devices thanks to the fact that the coefficient of shear friction was known, which was the highest out of all the devices used on the upper anchoring point.

Figure 8 shows the values of the forces measured upon the complete immediate static capture of the load of 12 kg in weight and a drop height of 1 m. The overall rope length in the system was 10.5 m, the girding angle of the lower anchoring point was 2π rad. The model situation in Figure 8 differs from the situation in Figure 7 only by the method of load capture. The other parameters of the load fall are identical.

Figure 9 shows a model situation of the measuring impact force at a negative immediate static capture of the load (12 kg) with a drop height of 1 m

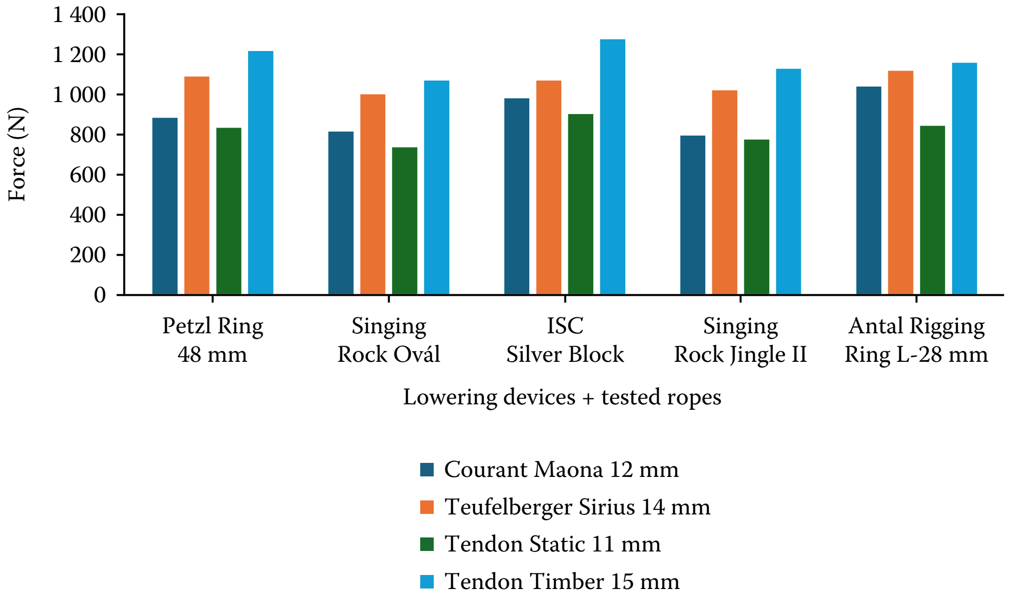

Figure 8. Negative complete immediate static capture of the load, drop height 1 m, rope length 10.5 m

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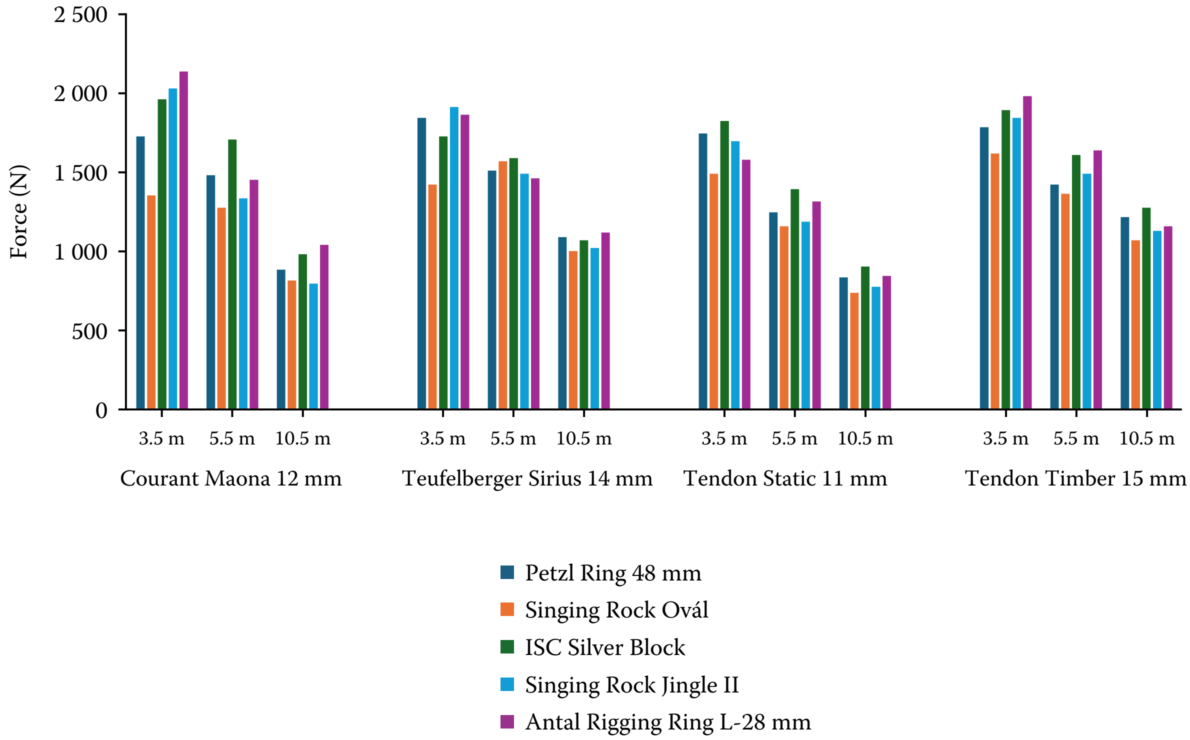

Figure 9. Comparison of the four types of tested ropes (drop height 1 m, immediate static capture)

and an overall rope length 3.5 m, 5.5 m and 10.5 m. The figure compares the measured values of the forces for all the tested rigging ropes (above each group), five tested lowering devices (colour legend below the figure) and three different overall rope lengths in the rigging system (for each rope 3.5 m, 5.5 m and 10.5 m from the left). The values of the forces in the figure clearly demonstrate the role which the overall rope length in the system plays in the magnitude of the impact force. The overall rope length in the system of 3.5 m gives up to double impact force values than the overall rope length in the system of 10.5 m. This difference in the values is caused by the rope's capacity to absorb a part of the impact energy created by the load.

The differences in the coefficients of shear friction presented in Figure 4 are primarily given by the design of the lowering devices (rotating pulley roll), their material properties and the material properties of the rigging ropes. The potential forces that can act in the rigging system can be up to 19 times greater than the load weight (Table 3 and Table 4). The magnitude of the force acting on the upper anchoring point of the rigging system depends on the load weight, load drop height, overall rope length in the rigging system and method of load capture. Compared to the dynamic load lowering, the measured forces are nearly two times greater when the load capture is static. At the gradual dynamic lowering of the load, the coefficient of shear friction significantly affects the magnitude of the force acting on the upper anchoring point. The overall rope length in the rigging system can considerably reduce the magnitude of the force acting on the upper anchoring point of the rigging system (Figure 9).

DISCUSSION

The research results indicate that the overall length of the rope in the system can considerably affect the magnitude of forces acting on the anchoring points of the rigging system. The longer the overall rope length in the system is, the more energy the rope can absorb by its fibre friction and the lower the force acts on the upper anchoring point of the rigging system. The same result was published by Donzelli (1999) who claims that the overall rope length in the rigging system is very important for the development and magnitude of forces.

The values in Figure 5 show the role played in the magnitude of the force acting on the upper anchoring point of the rigging system by the load drop

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height. The measurements demonstrated that the greater the drop height of the load, the greater the impact force is developed at its capture. Kane et al. (2009) and Centrangolo et al. (2018) claim that the most secure way to reduce the potential energy of the lowered load is either to reduce the load weight or to reduce the length of its fall. Very similar values for the dynamic load lowering designated as π for both drop heights (0.4 m and 1 m) are shown in Figure 5 as well as in Figure 6. The similar values for the two drop heights demonstrate that the emerging impact force can be considerably affected by the dynamic lowering of the load. When the load is lowered dynamically, i.e. over a longer time interval, the transformation of the potential load energy into impact energy is distributed in time, too. Kane (2017) supports this statement by saying that 'letting the piece run' is another possibility how to reduce the magnitude of impact energy. Although the ISC Silver Block pulley has up to a 15 times lower coefficient of shear friction (Figure 4), in Figure 7, we find the values of measured forces on average only 17% higher than in the other lowering devices. The values presented in Figure 7 are again to demonstrate the significance of the dynamic load lowering for the development of the forces acting on the upper anchoring point of the rigging system. The forces recorded during the dynamic load lowering were, on average, 47% lower than at the immediate static load capture. Detter et al. (2008) found out in some previous studies that dynamic lowering can reduce the magnitude of the force acting on the upper anchoring point by up to half.

The finding that the values in Figure 6 are, on average, 8 kg lower than in Figure 5 confirms the correctness of the calculation of the shear friction coefficient. The value of the shear friction coefficient for the Tendon Static 11 mm rope is lower in most combinations with the lowering devices than the value of the shear friction coefficient for the combinations of lowering devices and the Courant Maona 12 mm rope. At the same time, the other outputs of the measurements indicate that the modulus of elasticity of the Tendon Static 11 mm rope is larger than the modulus of elasticity of the Courant Maona 12 mm rope, which means, in practice, that the Tendon Static 11 mm rope can absorb a greater volume of impact energy and thus reduce the magnitude of impact force measured on the upper anchoring point.

The comparison of values presented in Figures 7 and 8 appears to be interesting, too. The model situation of the load fall differs only in the dynamic lowering of the load (Figure 7) and the static load capture (Figure 8). The differences in the values of these two figures demonstrate, once again, the positive influence of dynamic load lowering on the reduction of the magnitude of the impact force acting on the upper anchoring point. At the same time, the values presented in Figure 7 demonstrate that the differences given by the shear friction coefficients of the individual ropes and devices, as well as differences given by the modules of elasticity of the individual ropes, can be, to a certain extent, eliminated by the dynamic lowering of the load.

Figure 9 shows, among other things, that impact force values are up to 2 times greater with the overall length of the rope in the system of 3.5 m than when the overall rope length in the system is 10.5 m. The difference in the values is caused by the rope's capacity to absorb a part of the impact energy created by the load upon the fall. When the load is falling, the rope is elongated, shrinking its original cross-section diameter and friction occurs in the fibres inside the rope. Due to fibre friction, the originally kinetic energy of the load transforms into thermal energy or, if the force is sufficiently high, also into deformation energy when damage to the individual rope fibres occurs. This capacity to absorb energy then increases with the growing rope length. This property of the rope is widely used in mountaineering, where special dynamic ropes are used to secure climbers, whose capacity to absorb fall energy is many times higher than in the static ropes used in our research. On the other hand, the great elongation of dynamic ropes under load makes their use for security and lowering of loads impossible during the gradual felling of trees. The measured values of the forces in Figure 9 demonstrate that a higher coefficient of shear friction (Figure 4) is shown in the reduced forces acting on the upper anchoring point in Figure 9. The difference is most visible in the Singing Rock Ovál lowering device. The correctness of the measurement results is also supported by Donzelli and Lilly (2001) who claim that reducing the rope friction in the arboriculture block (upper anchoring point) results in an increased reaction force carried by the block or by the loop anchoring the block.

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CONCLUSION

The practical measurements confirmed the correct calculation of the shear friction coefficients. It was demonstrated that the dynamic lowering of loads has a positive influence on the decrease in the forces acting upon the upper anchoring point of the rigging system. The statement that the size of the shear friction coefficient affects the size of impact force appeared to be true. The research demonstrated that the overall length of the rope in the system has an essential influence on the size of the impact force. The results obtained from this work can help tree climbers better understand the action of the forces when lowering loads. Active tree climbers will be able to better estimate what forces will be generated in their rigging systems after the free fall of the loads of specific weights. Understanding the origin and effect of friction on the top anchor point can lead to the selection of tree-felling equipment that will reduce the forces acting on the top anchor point. The reduction of the forces acting on the tree structure will then lead to an increase in the safety of the worker performing the felling.

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