Arboriculture & Urban Forestry 2012. 38(1): 1–5

Breaking Load of Hitches and Ropes Used in Rigging

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Abstract. The incorporation of hardware like blocks into the rigging system has prompted a change in the types of ropes used as slings to attach blocks to trees. Since large forces can be generated while rigging trees, it is important to determine the breaking load of hitches used to attach a sling to a tree or the rigging rope to a piece of wood. Breaking load and specific strength (the ratio of breaking strength to linear density of the rope) were measured for four common hitches and seven ropes often used in arboricultural rigging. Hitches were tied around a utility pole to simulate field conditions, and tested with a gradually increasing load. Breaking load was similar between all hitches, but varied widely among ropes, while specific strength differed between ropes and hitches. Tying hitches around the utility pole mimicked the arboricultural application of hitches and ropes, but the static application of the load, which did not reflect dynamic loads often generated during rigging, was an important limitation.

Key Words. Breaking Load; Hitch; Rigging; Rope; Specific Strength.

Rigging is one of the most dangerous aspects of arboriculture because large, swinging pieces of wood can generate dynamic loads of great magnitude. Pieces of wood in motion have substantial momentum, and, if uncontrolled, can injure the climber or ground workers and damage property. Introduction of mechanical devices like blocks and lowering devices (e.g., Good Rigging Control System, Hobbs Lowering Device, and the Port-A-Wrap) have led to the incorporation of different types of rigging ropes (e.g., double braids) better suited for use with such devices. In rigging, laid three-strand and single braid (12- and 16-strand construction) polyester ropes have, to some extent, been replaced with double braid ropes. However, double braid ropes are inappropriate for use in natural anchor point rigging (Donzelli and Lilly 2001) because of their relatively loose construction, which is susceptible to snagging and allowing abrasive particles into the core fibers (Smith and Padgett 1996).

In arboricultural rigging, ropes and slings are often tied in hitches, and while spliced eyes are generally the most efficient permanent rope terminations (McKenna et al. 2004), they require special expertise to fashion and are peculiar to a particular rope material and construction (Milne and McLaren 2006). A permanent termination-like a splice is not always useful in arboricultural rigging. Hitches also provide greater flexibility because of the ease with which they can be tied around trunks or branches of varying diameter and the ability to remotely tie off a limb. Some hitches also offer the advantage of being easy to untie after loading.

Many hitches are used in rigging, and technical publications (Donzelli and Lilly 2001; Lilly 2005) describe the appropriate arboricultural uses of each. Cow and timber hitches are commonly used to attach a block or friction device to the tree, and the clove hitch and running bowline are used to attach the lowering rope to the branch or piece of wood being removed. The timber hitch and running bowline offer the advantage of being easy to untie; clove and cow hitches provide a secure attachment to the tree even when not loaded.

Smith and Padgett (1996) note the wealth of information on the efficiency of knots; they also highlight the inherent variability in test results depending on numerous confounding factors (e.g., rope diameter, construction, and material; test method and conditions; person who ties the knot). Simon (2002) noted that there is no theory to quantitatively predict the breaking load of knots, presumably because of the wide array of complicating factors. Aside from one previous study at Samson Rope in 2004 (cited in Detter et al. 2008), testing knots has mostly originated in other disciplines, such as caving (Richards 2005), rock climbing (Brown 2008), and sailing (Milne and McLaren 2006). Such work is informative, but the ropes tested and the testing conditions often differ from arboriculturally relevant ropes and conditions.

Ropes commonly used in rigging include single braid and double braid ropes. Single braid ropes are used for natural anchor point rigging and typically have twelve strands and a hollow core. The strands of single braid ropes provide abrasion resistance and bear loads. In contrast, double braid ropes, which are used when rigging with blocks and lowering devices, consist of a braided sheath of fibers (of varying thickness) that resist abrasion and carry some of the load, around a core of primarily load-bearing fibers (McKenna et al. 2004). In arboricultural applications, single braid and double braid ropes consist primarily of polyester, although small amounts of other fibers are sometimes incorporated into the rope to achieve a specific purpose, such as reduced weight.

In light of the scarcity of robust data to describe arboriculturally-relevant ropes and hitches, the objectives of this study were to determine a) the breaking load of hitches commonly used in arboricultural practice, and b) whether the breaking load differed among ropes commonly used for rigging.

METHODS AND MATERIALS

Seven single and double braid ropes were selected from three rope manufacturers for testing (Table 1). Ropes were selected based on their frequency of use in rigging as judged by the author and three ISA Certified Arborists who have extensive backgrounds in rigging and training. All ropes were nominally 12.7 mm in diameter, but had a range of breaking loads as rated by the manufacturer (Table 1). Ropes were hitched to a utility pole that was 20 cm in diameter and 2.5 m long. The pole was secured into the tensile testing machine at Yale Cordage (Saco, Maine, U.S.). Four different poles were used throughout the tests. Surface roughness of the poles was not quantified, but visually appeared similar when testing began. One end of the rope was secured to the hydraulic ram of the testing machine with four wraps around a bollard (10.2 cm in diameter) and a bowline around a steel bolt (2.54 cm in diameter). Ropes were precut to lengths of 4.6 m (when testing the running bowline and timber hitch) and 5.5 m (when testing the clove and cow hitches) to ensure the same length for the standing part of rope for each hitch.

Approximately 2.1 m from the bollard, one of four common hitches was tied to the utility pole: clove hitch, cow hitch (Figure 1), running bowline, and timber hitch (Figure 2). Clove and cow hitches were finished with a half hitch around the standing part of the rope, and a stopper knot in the tag end of the rope to prevent it from pulling through the hitch. Finishing hitches in this way was not necessary when the running bowline and timber hitch were tied. Hitches were initially tied to be 30 cm from the end of the pole and parallel to its long axis (Figure 3). As testing continued, ropes began to damage the end of the poles, and so subsequent tests were moved farther away from the end (up to 50 cm) to maintain a reasonably comparable pole surface for all tests. Each hitch was consistently tied, dressed, and set by one of three ISA Certified Arborists who have extensive rigging experience. Testing was conducted in a randomized complete block design.

Hitches were pre-loaded to 0.889 kN for 60 seconds to ensure similar alignment of the hitch and its orientation relative to the pole. The speed of the hydraulic ram on the test machine was 6.5 mm/s, a rate typical for testing synthetic ropes (pers. comm.: K. Buzzell, 07/23/2010). Hitches slipped off the end of the pole prior to failure three times; these tests were not included in the analysis.

In addition to the breaking load, specific strength (or tenacity) of the rope was calculated as the ratio of breaking load to linear density of the rope (kg/100 m). This is a common measurement in fiber rope engineering (McKenna et al. 2004). Another common measurement, efficiency, was not calculated because there was insufficient time and material to determine the unknotted breaking load of ropes considered in the study.

A two-way analysis of variance (ANOVA) was used to determine whether breaking load and specific strength differed among hitches, ropes, and their interaction. A small sample of Double Esterlon™ ropes measuring 15.9 mm in diameter was also tested with the clove hitch and running bowline. Greater breaking loads of such ropes began to damage poles, which limited the number of such tests. A separate two-way ANOVA was used to investigate whether breaking load and specific strength of Double Esterlon ropes differed among rope diameter, hitches, and their interaction. General linear models (PROC GLM) were used to analyze least squared means because of unequal sample sizes in each ANOVA. Tukey's honestly significant difference test was used for multiple comparisons within significant ($P < 0.05$) effects. All analyses were conducted in SAS (v. 9.2, SAS Institute, Cary, North Carolina, U.S.).

RESULTS

Hitches sometimes rotated circumferentially or slid axially on the pole depending on the type of knot that was tested. Neither of these motions was quantified, but rotation of clove and cow hitches was more common. On many tests involving those hitches, the hitch rotated clockwise (as viewed from the moving bollard on the testing machine) approximately 90 degrees from its original position. Rotations appeared to be more common on single braid ropes, but it was not possible to confirm this observation due to changes in the surface roughness of the poles over time. The location of failure was always at the first bend in the standing part of the rope where it entered the hitch and cinched around the pole (Figure 3). For running bowlines and timber hitches, the location of failure coincided with the location of the eye through which the standing part of the rope passed before cinching around the pole. Failure of clove and cow hitches occurred where the half hitch that finished each hitch took a bight on the standing part of the rope.

The breaking load of knotted ropes varied primarily among ropes (which explained 88% of the model's variance). The range of values (16.6 kN) between ropes was much larger than the range of values between hitches (1.45 kN), for which values were statistically similar (Table 2). Breaking load was greatest for Double Esterlon, which was greater than the other double braid ropes (Table 2). Breaking load was least for ArborPlex and XTC-12 (Table 2). Breaking load of True-Blue was greater than the other single braid ropes (Table 2).

There were fewer differences between ropes for specific strength: all of the single braid ropes had similar values, which were less than values for the double braids (Table 2). The type of rope was again a more robust explanatory variable than the

Table 1. Ropes used in testing, including their construction, manufacturer, material, nominal diameter (mm), rated breaking load (kN), and linear density (kg/100 m). The latter four values were obtained from manufacturers' literature.

Rope	Braid	Manufacturer	Material	Diameter	Breaking load	Density
ArborPlex	Single	Samson	Polyester/polyolefin	12.7	26.69	10.1
Double Esterlon	Double	Yale	Polyester	12.7	48.04	12.1
Double Esterlon	Double	Yale	Polyester	15.9	75.57	14.3
Industrial Poly DB	Double	New England	Polyester	12.7	44.04	10.4
Safety Pro-12	Single	New England	Polyester/polyolefin	12.7	29.36	11.6
Stable Braid	Double	Samson	Polyester	12.7	46.26	12.2
True-Blue	Single	Samson	Polyester	12.7	32.47	13.1
XTC-12	Single	Yale	Polyester/polyolefin	12.7	26.69	10.0

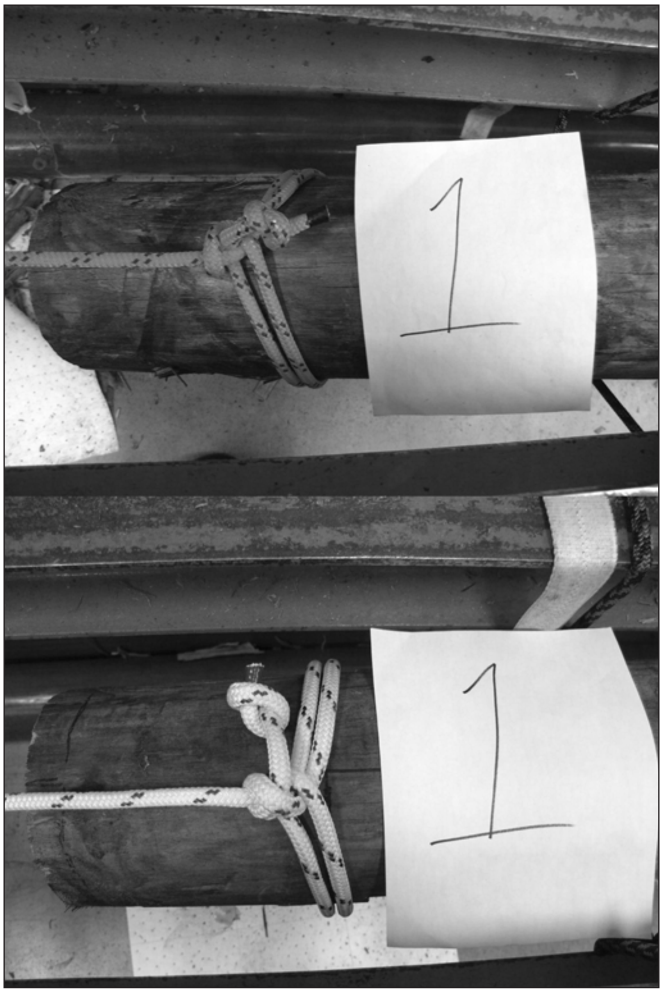

Figure 1. Clove (top) and cow hitches including the half hitch and stopper knot that was needed to prevent the tag end of the rope pulling through during the test.

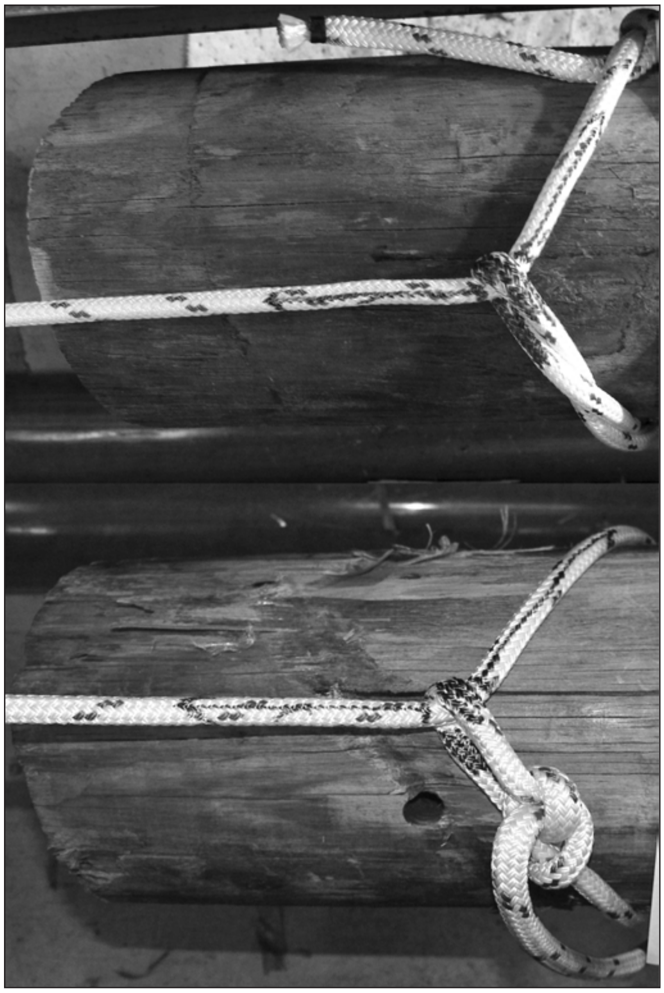

Figure 2. Timber hitch (top) and running bowline; in the former, a loop (crossing parts of rope) was formed around the standing part of the rope; in the latter, a bight (parallel parts of rope) was formed around the standing part of the rope.

type of hitch, explaining 83% of the model's variance. The running bowline had greater specific strength than the timber hitch, but there were no other differences between hitches (Table 2).

The effect of hitches was consistent for all ropes because the interaction of rope and hitch was not significant for breaking load ($P = 0.29$) or specific strength ($P = 0.21$).

The breaking load of Double Esterlon ropes that were 15.9 mm in diameter was greater than Double Esterlon ropes measuring 12.7 mm in diameter, but specific strength did not differ between ropes of each diameter (Table 3). There were no differences in breaking load or specific strength between hitches when Double Esterlon ropes of each diameter were tested (Table 3), and the interaction of rope diameter and hitch was not significant ($P > 0.20$) for either response variable.

DISCUSSION

The common location of failure for all tests, regardless of the type of rope and hitch, was consistent with the similarity of breaking load for all hitches. When running bowlines were preceded by a butt hitch or half hitch around the log during previous tests at Samson Rope, the first bend in the rope at the butt hitch was always the point of failure (Detter et al. 2008). Rotation of many

Figure 3. Rope tied in a running bowline under the pre-load of 0.889 kN. The black line on the utility pole normal to the rope indicates the location where the hitch was tied (30 cm from the end of the pole). The white arrow indicates the point of failure for all ropes and hitches.

Table 2. Least squares means (standard error) for breaking load (P_{MAX} in kN) and specific strength (kN/(kg/100 m)) classified by knot and rope.

Effect	Level	n	P_{MAX}[z]	Specific strength[z]
Rope	ArborPlex	20	21.58 (0.49)a	2.13 (0.04)a
	Double Esterlon	27	38.16 (0.43)f	3.16 (0.04)c
	Industrial Poly DB	12	31.06 (0.64)d	2.98 (0.05)bc
	Safety Pro-12	17	25.64 (0.49)b	2.29 (0.04)a
	Stable Braid	22	35.49 (0.55)e	2.90 (0.05)b
	True-Blue	20	27.89 (0.48)c	2.12 (0.04)a
	XTC-12	20	22.87 (0.49)a	2.29 (0.04)a
Hitch	Clove hitch	37	28.85 (0.38)a	2.55 (0.03)ab
	Cow hitch	34	28.98 (0.39)a	2.55 (0.03)ab
	Running bowline	35	29.72 (0.39)a	2.62 (0.03)a
	Timber hitch	32	28.27 (0.40)a	2.49 (0.03)b

[z] Read down a column within each effect, least squares means followed by the same letter are not significantly different ($P > 0.05$) by Tukey's Honestly Significant Difference test.

Table 3. Least squares means (standard error) for breaking load (P_{MAX} in kN) and specific strength (kN/(kg/100 m)) of Double Esterlon ropes 15.9 mm in diameter and 12.7 mm in diameter.

Effect	Level	n	P_{MAX}[z]	Specific strength[z]
Diameter	12.7 mm	15	38.67 (0.85)a	3.20 (0.07)a
	15.9 mm	9	60.82 (1.06)b	3.03 (0.08)a
Hitch	Clove hitch	13	48.75 (0.97)a	3.05 (0.08)a
	Running bowline	11	50.73 (0.96)a	3.18 (0.08)a

[z] Read down a column within each effect, least squares means followed by the same letter are not significantly different ($P > 0.05$) by Tukey's Honestly Significant Difference test.

clove and cow hitches did not affect the location of failure, nor did it adversely affect breaking load. Rotation of clove and cow hitches presumably was related to the way they were tied. Rotations appeared to begin to untie clove and cow hitches, which was consistent with the need to tie a half hitch and stopper knot to avoid the hitches untying before breaking the rope. Rotations did not consistently cause clove or cow hitches to slip off the pole. A more careful study of the rotation of clove and cow hitches may illuminate some performance deficiencies. In previous field tests, a cow hitch with a half hitch was exclusively used to attach a block to the trunk while removing the top and up to four additional pieces from each of 24 red pines (*Pinus resinosa*) (Kane et al. 2009; Kane, unpublished data). The hitch experienced impact loads up to approximately 18 kN, but it was never observed to rotate, even though—on a few tests—the impact load caused the sling to slide nearly 0.5 m down the trunk, de-barking it.

The common location of failure was also consistent with differences in breaking load between ropes, which have inherently different breaking loads. The breaking load of an untied rope depends on many factors, including its material and construction, as well as the manufacturing process. The location of failure made mechanical sense because the rope would have experienced tensile stress due to the load plus stresses due to contact and friction (Milne and McLaren 2006) from the loop or bight through which the standing part of the rope passed as it cinched around the pole. The common location of failure suggested the importance of rope-on-rope abrasion at that location.

Changes in the surface roughness of poles observed during testing did not appear to alter test results for two reasons. First, at the point of failure, video footage of several tests revealed that the part of the rope that failed was not in contact with the surface of the pole. Although video evidence was not available for every test, it was intuitive that contact between the pole and the part of the rope that failed was minimal considering that for all hitches, another part of the rope was wedged between the pole and the part that failed. Second, the magnitude of variability for breaking load and specific strength was small: the coefficient of variation of both variables for all ropes was less than 10% with the exception of True-Blue (10.4%).

The analysis of specific strength highlighted differences between hitches as well as between the two rope constructions. Rope construction was clearly important in explaining differences in specific strength, since double braids had greater values than single braids. This difference was likely due to the abrasion resistance provided by the outer jacket of fibers on double braids, which presumably protected the load-bearing inner fibers from rope-on-rope abrasion. The outer fibers on double braid ropes were also coated with urethane to reduce abrasion, which may have enhanced abrasion resistance. On single braids, load-bearing fibers would have been immediately abraded at the point where ropes ultimately failed.

It was unclear why the running bowline had a greater specific strength than the timber hitch. Perhaps the loop (crossing rope parts) formed by the timber hitch around the standing part of the rope reduced rope strength more than the bight (parallel rope parts) that the running bowline formed around the standing part of the rope (Figure 2). Milne and McLaren (2006) also observed that knots with more crossing parts were weaker. The loop formed by the timber hitch around the standing part of the rope could have induced an additional torque, or it could have caused the scissoring effect that Leech (2003) described for rope fibers. While statistically significant, the difference in specific strength between the running bowline and timber hitch has less practical relevance for two reasons: 1) the difference is much smaller than between different ropes, and 2) the hitches are typically used in different applications. The timber hitch is used to attach a sling to the tree, as an anchor point for a friction device or block; the running bowline is used to tie off pieces of wood to be rigged (Lilly 2005).

CONCLUSIONS

Breaking load and specific strength were more closely tied to differences between ropes than between hitches. But consistent performance of hitches across many ropes is reassuring for practitioners. In the absence of data from dynamic loading tests, the results of this study provide a helpful baseline because tests on the utility pole better mimicked loading conditions in arboricultural rigging than previous tests. Practitioners can use results, with caution, to estimate the knotted strength of a rope that they typically use. However, arborists are strongly discouraged from choosing a rope or sling based simply on its breaking load or specific strength. The choice of a rope or sling must also include consideration of its expected use (natural anchor point versus blocks and friction devices), range of loads, frequency of use, and cost. If rigging involves dynamic loading (which is usually true), the rope or sling's ability to absorb energy is a critical point of consideration. Breaking loads measured in a static test cannot be easily applied to situations involving dynamic loads. An important next step should focus on the performance of ropes and hitches subjected to dynamic loads. It would also be helpful to investigate the "grip" of different ropes and hitches on the bark of various species. A final caution: although knotted strength of even the weakest ropes exceeded the breaking loads recorded while removing red pines (Kane et al. 2009), practitioners should always consider the structural integrity of the tree and avoid making the tree the weak link in a rigging system.

Acknowledgments. The author gratefully acknowledges Ed Carpenter, Odis Sisk, Michael Tain (North American Training Solutions), and Kyle McCabe (University of Massachusetts-Amherst) for collecting data; Keith Buzzell, Jamie Goddard, Bill Putnam, Chris Yale, and Tom Yale (Yale Cordage) for donating ropes and their testing facility; Jimmy Cass (Samson Ropes) for donating ropes; Chris Rooney (National Grid) for donating utility poles; and Wes Autio (University of Massachusetts-Amherst) for analytical assistance. The author thanks Keith Buzzell, Tom Yale, and three anonymous reviewers for their thoughtful and constructive criticism on previous drafts of the manuscript. This study was funded in part by a John Z. Duling grant from the TREE Fund.

TREE FUND
Tree Research & Education Endowment Fund

LITERATURE CITED

Brown, A. 2008. The strength of knots in dynamic climbing rope. M.Eng. Technical Report. University of Strathclyde. Glasgow, Scotland.

Detter, A., C. Cowell, L. McKeown, and P. Howard. 2008. Evaluation of current rigging and dismantling practices use in arboriculture. Health and Safety Executive RR668, London.

Donzelli, P.S., and S.J. Lilly. 2001. The Art and Science of Practical Rigging. International Society of Arboriculture, Champaign, Illinois, U.S.

Kane, B., S. Brena, and W. Autio. 2009. Forces and stresses generated during rigging operations. Arboriculture & Urban Forestry 35:68–74.

Leech, C.M. 2003. The modelling and analysis of splices used in synthetic ropes. Proc. R. Soc. London, England. A 459:1641–1659.

Lilly, S.J. 2005. Tree Climbers' Guide. 3rd Edition. International Society of Arboriculture, Champaign, Illinois, U.S.

McKenna, H.A., J.W.S. Hearle, and N. O'Hear. 2004. Handbook of Fibre Rope Technology. Woodhead Publishing Ltd., Cambridge, England.

Milne, K.A., and A.J. McLaren. 2006. An assessment of the strength of knots and splices used as eye terminations in a sailing environment. Sports Engineering 9:1–13.

Richards, D. 2005. Knot break strength vs. rope break strength. Nylon Highway #50. Accessed July 2010 <www.caves.org/section/vertical/nh/50/knotrope.html>

Simon, J. 2002. Physical knots. In: J.A. Calvo, K.C. Millett, and E.J. Rawdon (Eds.). Contemporary Mathematics Physical Knots: Knotting, Linking, and Folding Geometric Objects in R^3. April 2001, Las Vegas, Nevada, U.S. American Mathematical Society, Providence, Rhode Island, U.S. pp. 1–30.

Smith, B., and A. Padgett. 1996. On Rope. Revised Edition. National Speleological Society, Huntsville, Alabama, U.S.

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Résumé. L'incorporation de pièces de quincaillerie, comme par exemple des blocs, dans le système d'attache a forcé des changements quant au type de corde à employer, telles les élingues, afin d'attacher les blocs aux arbres. Étant donné que des forces importantes peuvent être générées lorsqu'on s'attache aux arbres, il est important de déterminer la charge en rupture des nœuds utilisés pour attacher une élingue à un arbre ou de celle d'une corde à une pièce de bois. La charge en rupture et la tension spécifique (ratio entre la tension en rupture et la densité linéaire d'une corde) ont été mesurées pour quatre types communs de nœuds et sept types de cordes souvent utilisés en arboriculture dans des systèmes de gréage. Les nœuds ont été attachés autour d'un poteau de bois afin de simuler les conditions sur le terrain, et ils ont été testés avec une charge augmentant graduellement. Le point de rupture était similaire entre les différents nœuds mais il variait beaucoup selon les cordes employées, tandis que la résistance spécifique variait à la fois entre les types de nœuds et de cordes. Attacher les nœuds autour d'un poteau permettait d'imiter l'emploi des nœuds et des cordes en arboriculture, mais l'application d'une charge statique constituait une importante limitation dans ce test car les charges statiques ne reflètent pas la réalité où c'est plutôt des charges dynamiques qui sont généralement générées dans les systèmes de gréage en arboriculture.

Zusammenfassung. Das Einarbeiten von Hardware wie z. B. Rollen in die Abseiltechnik hat einen Wechsel bei der Art der verwendeten Seile angestoßen, die dazu verwendet werden, Umlenkrollen am Baum zu befestigen. Da während des Abseilens große Kräfte entstehen können, ist es wichtig, die Versagenslast der Haken zu bestimmen, welche dazu verwendet werden, eine Schlinge am Baum oder das Abseil-Seil an dem Holzstück zu befestigen. Die Reißkraft und die spezifische Kraft (das Verhältnis zwischen Reißkraft zur linearen Dichte des Seiles) wurden bei vier populären Haken und sieben Seilen, die oft in der Arboristik verwendet werden, gemessen. Die Haken wurden um einen Masten gebunden, um eine Feldsituation zu simulieren und einer zunehmenden Kraft ausgesetzt. Die Reißlast war bei allen, getesteten Haken gleich, aber bei den Seilen gab es große Unterschiede, während die spezifische Kraft zwischen Seil und Haken differierte. Das Binden von Haken um einen festen Ankerpunkt entspricht der arboristischen Anwendung von Seilen und Haken, aber der simulierte, statische Lasteintrag reflektierte nicht die dynamischen Kräfte, die oft in der Praxis auftreten, was eine wichtige Einschränkung des Testes darstellt.

Resumen. La incorporación de cuadernales en los sistemas de cordaje ha impuesto un cambio en los tipos de cuerdas usadas como eslingas para sujetarlas a los árboles. Debido a las grandes fuerzas que se generan es importante determinar la carga de rotura de los nudos usados para atar una eslinga al árbol o la cuerda de cordaje a la pieza de madera. Se midió la carga y la resistencia específica (relación de resistencia a la densidad lineal de la cuerda) para cuatro nudos comunes y siete cuerdas usadas con frecuencia en cordaje arboricultural. Los nudos fueron elaborados alrededor de un poste de servicios para simular las condiciones de campo y se probaron con un incremento gradual en la carga. La carga de falla fue similar entre todos los nudos, pero varió ampliamente entre las cuerdas, mientras la resistencia específica difirió entre cuerdas y nudos. La sujeción de los nudos alrededor del poste imitó la aplicación arboricultural de nudos y cuerdas, pero la aplicación estática de la carga, la cual no reflejó las cargas dinámicas generadas con frecuencia durante el cordaje, fue una limitación importante.