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Loading experienced by a tie-in point during ascents

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ABSTRACT

Working in trees is an inherently dangerous profession, with a higher than average fatality rate. Climbers secure themselves with a rope and harness to a tie-in point to ascend into and work in a tree, but it can be difficult—if not impossible—to assess the safety of a tie-in point from the ground. Very little experimental work has described the loads associated with ascending into and working in trees, but it is critical to understand them to assess safety. We measured loads induced by competitors in the ascent event at the International Tree Climbing Competition and analyzed their amplitude and frequency. We also measured the sway frequency of a small sample of tie-in points. Load time histories revealed repeated cycling between maximal and minimal impulse loads at a particular frequency as competitors ascended. After accounting for competitors' weight, ascending using a single foot ascender induced greater loads than footlocking or using two foot ascenders. Footlocking induced loads at a lower frequency than using two foot ascenders. Although the loading frequency for all techniques was higher than the first natural sway frequency of tie-in points, the atypically large tie-in point used during the ascent event precludes extrapolation to tie-in points of typical size. Since there are very few data to quantify loads during an ascent, and many other relevant aspects to quantify in order to estimate the likelihood of failure of a tie-in point, the results will be useful to future studies.

1. Introduction

Working in trees is an inherently dangerous profession because climbers work at height and use sharp tools that can easily sever climbing gear or body parts. The fatality rate per 100,000 workers involved in tree work was 14.1, much greater than the overall fatality rate of 4.0 per 100,000 workers (Wiatrowski, 2005), although fatalities do not necessarily involve trained arborists. Of the 1,285 arboriculture worker fatalities between 1992 and 2007, 44% occurred while pruning or trimming trees, and 34% involved a fall (Castillo and Menéndez, 2009). To address the likelihood of falling, the Center for Disease Control's National Institute for Occupational Safety and Health (NIOSH) explicitly recommended, "checking the condition of tree branches before…climbing," (Castillo and Menéndez, 2009). While obvious to qualified arborists, this advice presents three challenges: (i) one cannot carefully inspect a branch from a distance, even with binoculars; (ii) assessing the severity of defects often requires careful measurements, analysis, or sophisticated measuring devices; and (iii) robust data quantifying climber-induced loads and branch responses are sparse.

Cetrangolo et al. (2018) presented a method for analyzing the safety factors associated with an unorthodox ascent technique. Safety factor is the ratio of the load-bearing capacity of a structure to the expected loading; for many engineered civil structures, it is between 1.67 and 3.00 (Salmon and Johnson, 1990). Cetrangolo et al. (2018) reported safety factors as low as 3 during an ascent and 1.2 during a simulated fall—dangerously low values considering the uncertainty associated with the finite element model (FEM) developed to calculate them. During a simulated fall, results of the FEM demonstrated the importance of both the amplitude and period of loading. When the rope arrests a falling climber, the impulse load (which depends on the climber's mass, the fall distance, and the rope's stiffness—the combination of rope elasticity and the length of rope in the system) induces a dynamic stress on the tie-in point, so the period of loading is important with respect to the natural sway period of the part of the tree that serves as the tie-in point. Analogously, cyclic loading during an ascent induces a dynamic stress on the tie-in point. If the loading frequency approaches or equals one of the natural sway frequencies associated with the tie-in point, dynamic amplification may occur.

While sophisticated and useful, Cetrangolo et al.'s (2018) FEM was limited to the modeled branch. And the loads included in the FEM were limited to (i) calculated loads of a climber who falls (assuming certain masses, fall distances, and rope properties) and (ii) loads measured during ascents by two climbers using two ascent techniques (ascenders on a single, stationary rope and footlocking a double stationary rope). Calculations of the arrest of a falling climber were used instead of empirical measurements to avoid injury.

To improve the understanding of how ascending into a tree loads

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the tie-in point, the primary objective of this paper was to determine the amplitude and frequency of loading associated with different ascent techniques. A secondary objective was to illustrate the measurement of sway frequency of a typical tie-in point, which is necessary to predict the likelihood of failure of the tie-in point during an ascent. A better understanding of these parameters will improve the assessment of safety factors at tie-in points.

2. Methods

2.1. Loads during an ascent

In July 2017, during the International Tree Climbing Competition at the United States National Arboretum in Washington, D.C., we measured loads during the ascent event < http://www.itcc-isa.com/Portals/0/docs/AscentEvent_Online.pdf > , starting when the competitor's foot left the ground (when their time started) through the point when they rang a bell signaling the end of their ascent. The duration of the ascent was measured as the time elapsed between the starting and stopping times. We measured loads accurate to 44.5 N at 200 Hz using a load shackle (StraightPoint LLC, Camarillo, CA) fixed between the haul rope (KMIII Max, Teufelberger, Fall River, MA, USA, 11.1 mm diameter, 1.00% elastic elongation, 35.1 kN minimum breaking strength) used to lower competitors in case of an emergency and the large rigging hub (DMM, Wales, UK, 45 kN minimum breaking strength) to which competitors' ropes were attached (Fig. 1). The haul rope ran over a 25-cm diameter branch in a scarlet oak (*Quercus coccinea* Münchh), and the rigging hub was suspended 18.1 m above the ground. We zeroed the load shackle between ascents to tare rope weight.

We obtained informed consent from 66 of 68 competitors, and asked competitors to report their weight and years of experience climbing and competing. During the competition, we recorded loads for 59 of the 66 ascents (both the laptop battery and a backup battery expired after 10 h of nearly continuous data collection). Since it was not convenient to explicitly obtain competitors' weight during the event, for a random sample of twelve competitors, we also measured loads during the "setup" part of the event. During the setup, competitors load tested their ascent system, including a brief interval with the competitor suspended from the rope. During that interval, we recorded the competitors' weight as the median load value for the interval (usually between two and three seconds) that the climber was suspended.

We classified each competitor's ascent according to the number of ropes ascended (one or two), whether the rope(s) were moving or stationary, and the ascent technique (a single foot ascender, two foot ascenders, or footlocking). We also recorded the type of rope used so that we could determine rope elongation at 10% of minimum breaking strength from manufacturers' data.

2.2. Tie-in point frequency

In August 2017, we measured the free vibration response of six tie-in points to determine their natural sway frequency. We selected six trees (three individuals each) of two species (*Platanus* × *hispanica* Mill. ex Münchh., *Styphnolobium japonicum* (L.) Schott) on the University of Massachusetts campus in Amherst, MA, USA (USDA hardiness zone 5a) and a climber set his rope in an appropriate branch union for a safe ascent. Within 10 cm of the tie-in point, he attached a tri-axial accelerometer (Lord MicroStrain, Williston, VT, USA) that recorded accelerations for 31.25 s at 128 Hz. The climber descended from the tree, leaving his rope around the tie-in point. At the start of a data collection session, the climber loaded the tie-in point with his weight (778 N) and quickly let go of the rope, allowing the tie-in point to sway freely for

Fig. 1. Views of the load shackle incorporated into the event setup from the side (left) and front (right) show (from top to bottom in each image) the haul rope, the load shackle, and the rigging hub. The bottom of the left-hand image also shows two carabiners connecting ascent lines to the hub.