Comparison of Fixed Length and Sliding Anchor Rigging for Recreational Climbing Systems

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Abstract

The anchor in a recreational climbing system must be unquestionably strong and secure, able to withstand the force of high factor falls. In constructing a multi-point anchor, climbers may generally elect a sliding or fixed length rigging system, resulting in a classic tradeoff between extension and load distribution, respectively. This study explored the effects of sliding and fixed length rigging in anchors experiencing failure of an anchor component. In keeping with prior research, the results indicate that the extension endemic in sliding anchor systems increases peak forces on the remaining anchor component relative to fixed length systems. The increase in peak force appears to be positively correlated with the length of extension subsequent to component failure. Given this limitation of sliding rigging systems, the author concludes with a discussion of considerations for employing sliding rigging systems.

Introduction

In recreational climbing systems, whether on rock, snow, or ice, the anchor must be of unquestionable strength and security. For the purposes of this paper, the "anchor" is the portion of a climbing rope system upon which all other elements of the system may solely depend such that failure would be catastrophic and likely result in the death of the entire party. "Protection" will mean any individual connection point between a party (member) and the climbing medium, whether removable protection (cams, stoppers, ice screws, etc.), in situ protection (bolts, pitons, etc.), or natural protection (trees, rock horns, etc.). A "component" is a point of protection employed as part of an anchor. In many cases, an anchor is constructed by connecting more than one component via some form of rigging.

In U.S. climbing, the merits of various rigging methods for recreational climbing anchors remain an open question. Specifically, debate continues regarding the relative importance of "extension" in determining the security of an anchor rigging. Extension may occur when a component of an anchor system fails, resulting in the rigging shifting such that the load is redistributed among the remaining components. Extension is characterized by a load shift such that additional fall distance is added to the rope system. Should extension occur, a "shock load" typically results on the remaining anchor components. Shock loading is poorly defined among climbers. In this paper a shock load is defined as a high impulse applied to an anchor and/or its components as a result of extension, which occurs rapidly following a prior high impulse.

A shock load is of particular concern in climbing rope systems as a dynamic climbing rope is typically employed as the dampener through which energy is dissipated and peak forces are reduced. Should a shock load occur, the dynamic rope may be unable to compensate for the second loading event as the rope will not have had sufficient time to relax (i.e. recede in length to its rested state thereby restoring its ability to dissipate energy) between loading events. American climbers frequently posit that the presence of a climbing rope in the system relegates concerns regarding extension and shock loading to a secondary position behind that of distributing the load between anchor components. These two ideas represent the fundamental tension present in the dominant U.S. paradigm of anchor rigging: extension vs. distribution (also referred to as "equalization"). Unfortunately, rigging methodologies to date present a tradeoff between distribution and extension such that the most reliable distribution of the load among anchor components comes at the expense of potential extension.

The classic examples presented are the "pre-equalized" or pre-distributed rigging with fixed length legs secured with a bight knot (sometimes called a "ponytail" anchor) and the "sliding-x" rigging which features variable length legs that adjust as load to the anchor changes direction (see Figure 1). The classic sliding- x system fails to create a fully redundant anchor as cutting the rigging material (such as from rockfall) in one location causes complete anchor failure. Consequently, a sliding-x is commonly built with "limiter knots" which achieve redundancy while minimizing the potential extension but also the range of possible loading directions accommodated by the rigging.

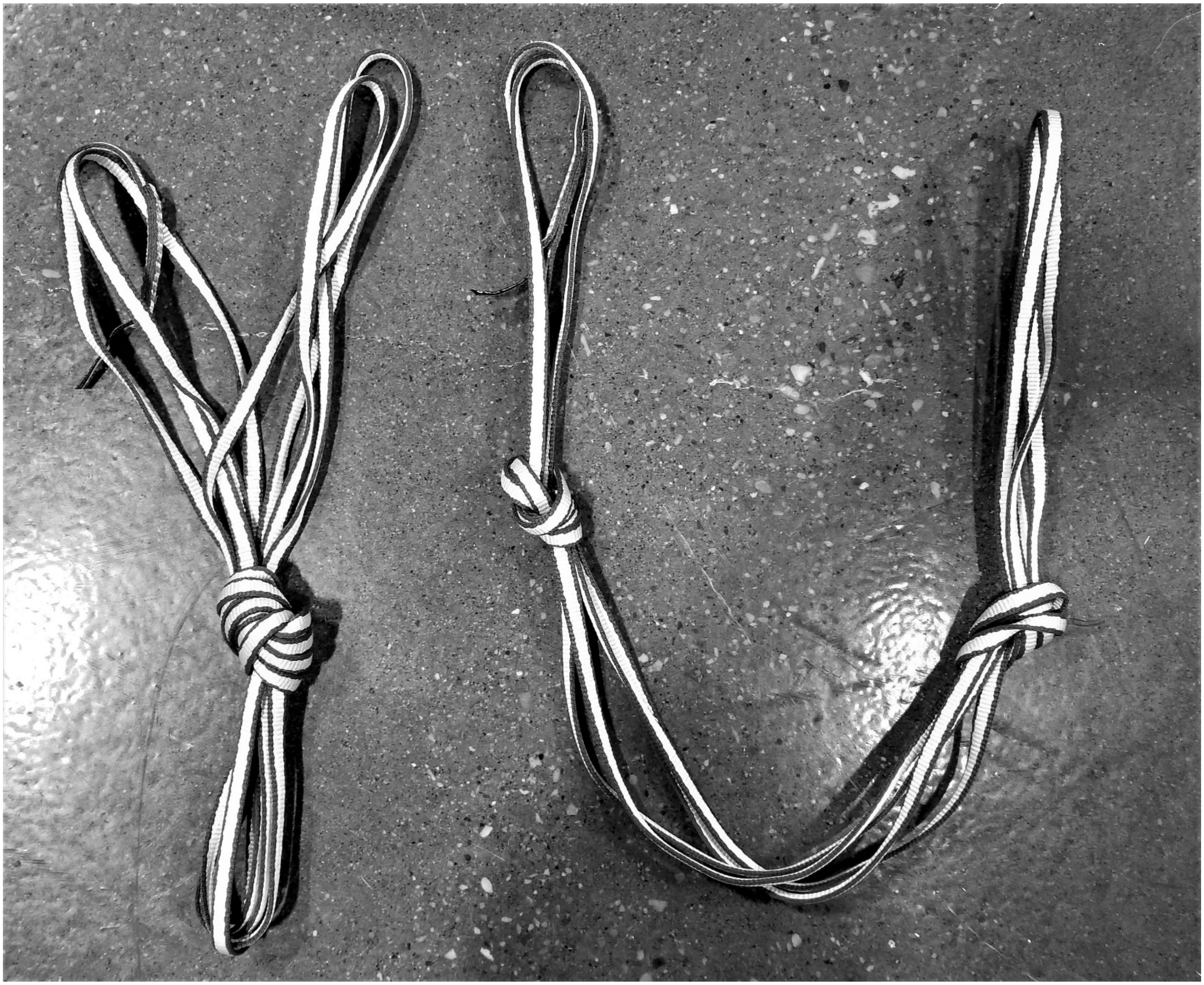


Figure 1: Pontyail (left) and quad anchor rigging using 240cm HMPE slings.

John Long and Bob Gaines’ 2006 text *Climbing Anchors* (2nd ed.) attempted to address the concerns of extension and distribution by introducing a new rigging method called the equalette. Over time, climbers found the most useful version of the equalette to be the quad, which is effectively a sliding-x variant that features double the normal number of strands of material in the rigging (four strands vs. two strands, hence the “quad” moniker; see Figure 1). Since then, the quad has increased significantly in popularity and use. The rigging is particularly noted for its ease of pre-rigging, offering two advantages:

1) If the limiter knots are not untied and have sufficient spacing the quad can readily be used with a variety of component configurations.
2) Two masterpoints are available—isolating any two of the four strands creates a redundant attachment point that affords some small additional convenience and comfort at cramped stances on multipitch routes.

Despite the possibility of extension and attendant shock loading, the distribution of the load among individual anchor components should justify the tradeoff. If the distribution of load is effective, individual components should be less likely to fail, thereby reducing the possibility of extension occurring at all. Indeed, the data offered in Long and Gaines' book support this thesis, indicating distribution between two components as close as a 60/40 split of the load, better distribution than other rigging options such as a classic ponytail.

A significant conclusion from Long and Gaines' research was that the presence of a dynamic rope in the climbing system significantly reduces the forces that might be experienced during extension and subsequent shock load. However, their test cases employed a fall factor of 1. Unfortunately, fall factor 1 does not necessarily allow for inference about fall factor 2 or similarly severe cases. As fall factor 2 represents the most severe falls possible in recreational climbing, addressing this case is relevant for any anchor rigging.

The available evidence suggests that predictable distribution of an anchor load to its individual components is unreliable despite rigging methods that would generally suggest the possibility of distribution. While distribution of the load may be achievable in slow-pull testing (or the related slingshot top rope system), drop testing, which is much more akin to the potential fall factor 2 in multipitch climbing, does not bear this out. Testing by Tom Evans (2016) indicates that distribution is often better with pre-distributed systems than with a sliding system. Similarly, drop tests by British equipment manufacturer DMM indicate lower forces on anchor components with pre-distributed systems (Bransby, 2013). Though these test cases do not represent real-world forces as dynamic climbing rope is not present in the test cases and rigid drop masses are used, the comparative results between tests are still valid. French equipment manufacturer Petzl tested extension in sliding-x rigging systems and found unacceptably high impact forces with large amounts of extension (Batoux, 2017). Further, at least anecdotal evidence from German bolt manufacturer and researcher Jim Titt (2017a & 2017b) exists where distribution among anchor components is not achieved. Consequently, considerable doubt remains about the advisability of trading the serious concern of extension for the uncertain gain of distribution. Indeed, the Deutscher Alpenverein (German Alpine Club) specifically recommends against rigging systems with the possibility of extension (Semmel, 2012). All of this research is predicated upon prior work by the Italian and German Alpine Clubs, which found less than ideal load distribution with sliding systems and significant increases in force with extension (Bedogni, Bressan, Malchiorri, & Zanantoni, n.d. a, n.d. b, n.d. c, 2014; Semmel & Hellberg 2009, CAI & UIAA 2006).

The gestalt of the above results indicates that distribution of load among anchor components may not be achievable in the field, despite rigging systems explicitly designed to achieve this aim. Even if distribution could be achieved, David Coley makes a compelling argument regarding the appropriate application for systems such as the sliding-x, which are quite limited given the logic applied (Coley, 2014). Therefore, as has always been the case, climbers are strongly urged to focus on the strength of individual anchor components, recognizing that no rigging system can compensate for the inadequacy of anchor components.

If a quad or other sliding system is still desired, the amount of possible extension must be addressed. In cases of large amounts of extension, forces are significant on remaining anchor components, and are greater than similar component failure with pre-distributed systems. Theoretical explorations of potential energy bear this out, as does a climber’s intuition. However, with sufficiently small amounts of extension, a variety of factors (rope stretch, knot tightening, etc.) may serve to dissipate energy in such a way that differences between sliding and pre-distributed systems are negligible from a practical perspective. This study aimed to explore whether a significant difference exists between the effects of anchor component failure between pre-distributed and sliding rigging methods as they are typically employed by climbers in the field. Common recommendations for sliding systems allow for very limited extension, which may limit the effects of extension sufficiently to eliminate any practical difference between rigging methods.

Methods

Three sets of tests were conducted using the drop-test gantry at Rock Exotica/Thompson Manufacturing in Layton, Utah. Tests were conducted using rigid 80kg masses. Test cases were designed to simulate high-factor falls where the leader has not yet placed protection. In some cases, falls were true factor 2 falls directly onto the belayer mass. In other cases, falls were high-factor falls where the lead climber mass was clipped through a redirect point on one component of the anchor. In all cases, the belay device was a munter hitch secured to the belayer mass with an overhand slip hitch. The rope from the climber mass to the belayer mass was adjusted to eliminate slack but provide no tension.

Test cases used two anchor points in a horizontal configuration on the drop-test gantry rigged with new 240cm HMPE slings in either pre-distributed (ponytail) or quad systems. In order to induce extension and subsequent shock load, the looker's right anchor point was rigged with a fuse made from 550 cord to ensure the anchor component would fail upon loading. Three sample fuses were slow pull tested to determine an average breaking strength of 4.17kN (4.3kN, 4.0kN, 4.2kN). During drop tests, fuses failed with an average breaking strength of 3.44kN. Both the climber and belayer masses were secured to the rope with figure 8 knots; the belayer mass was secured to the masterpoint of the anchor rigging with a clove hitch. All tests were conducted with fresh sections of used 9.4mm dynamic rope. Load cells were applied at each anchor component. See Figures 2 thru 6 for rigging diagrams and photos.

First Test Set: Quad and Ponytail

The first set of tests was designed as a direct comparison between ponytail and quad anchor rigging as they might be employed in the field. The quad was constructed with a 240cm HPME sling with a distance of 45cm from the anchor components to the nadir of the quad and 38cm between the limiting knots, allowing for approximately 19cm of extension. The ponytail was constructed using an identical 240cm HPME sling with a distance of 42cm from the anchor components to the masterpoint.

For each anchor rigging, there was approximately 30cm between the figure 8 of the belayer mass and the clove hitch securing it to the anchor, a distance similar to that which might be employed by a climber at a hanging or semi-hanging anchor stance. This placed the belayer mass approximately 100cm below the anchor components. The climber mass was placed approximately 120cm above the anchor components. A belay rope ran from a munter hitch secured with an overhand slip hitch on the belayer mass, through a redirect carabiner on the looker's right anchor component (which featured the 3-4kN fuse), and terminated in a figure 8 knot at the climber mass (see Figure 2). A single test was conducted initially with the fuse absent to ensure that subsequent drop tests would result in failure of the fuse. This test resulted in a peak fore of 6.4kN on the redirect anchor component, indicating that the fuse would indeed break during subsequent testing. Three drop tests were conducted for each of the two rigging methods.

Second Test Set: Fall Factor 2

A second set of tests was conducted to compare the effects of a belay system with a redirect point to a fall factor 2 directly onto the belayer. A few drops were conducted using the same test parameters in the first set of tests. Unfortunately, the constraints of the testing facility forced a change to the test parameters as the climber mass came to rest on the floor of the test facility after the factor 2 fall. Therefore, reliable data could not be gathered with these fall distances.

For each anchor rigging in the second and third test sets, there was approximately 5cm between the figure 8 of the belayer mass and the clove hitch securing it to the anchor. This placed the belayer mass approximately 71cm below the anchor components. The climber mass was placed approximately 80cm above the anchor components. These distances were selected to be small enough to keep the climber mass off the floor. In the redirect case, a belay rope ran from a munter hitch secured with an overhand slip hitch on the belayer mass, through a redirect carabiner on the looker's right anchor component (which featured a 3-4kN fuse), and terminated in a figure 8 knot at the climber mass. In the fall factor 2 case, a belay rope ran from a munter hitch secured with an overhand slip hitch on the belayer mass directly to a figure 8 knot at the climber mass, without passing through a redirect carabiner (see Figure 3).

Third Test Set: Variable Extension

A third set of tests was conducted which varied the amount of extension in the quad, to compare forces on the remaining anchor component in the event of failure of one component (simulated by the fuse). Three lengths of extension were tested:

1) 10cm; an amount which might be present in a very conservative rigging
2) 19cm; a "typical" amount that might be employed by a party leaving the limiter knots in place as the rigging is changed between various anchors
3) 39cm; the maximum amount possible using a 240cm sling that would still accommodate the carabiners connecting the rigging to the anchor components

All other parameters were similar to the second set of tests as the increased amount of extension would otherwise result in the climber mass hitting the floor (see Figure 4). Test 2, with 19cm of extension, is an equivalent amount of extension as those in the first set of tests.

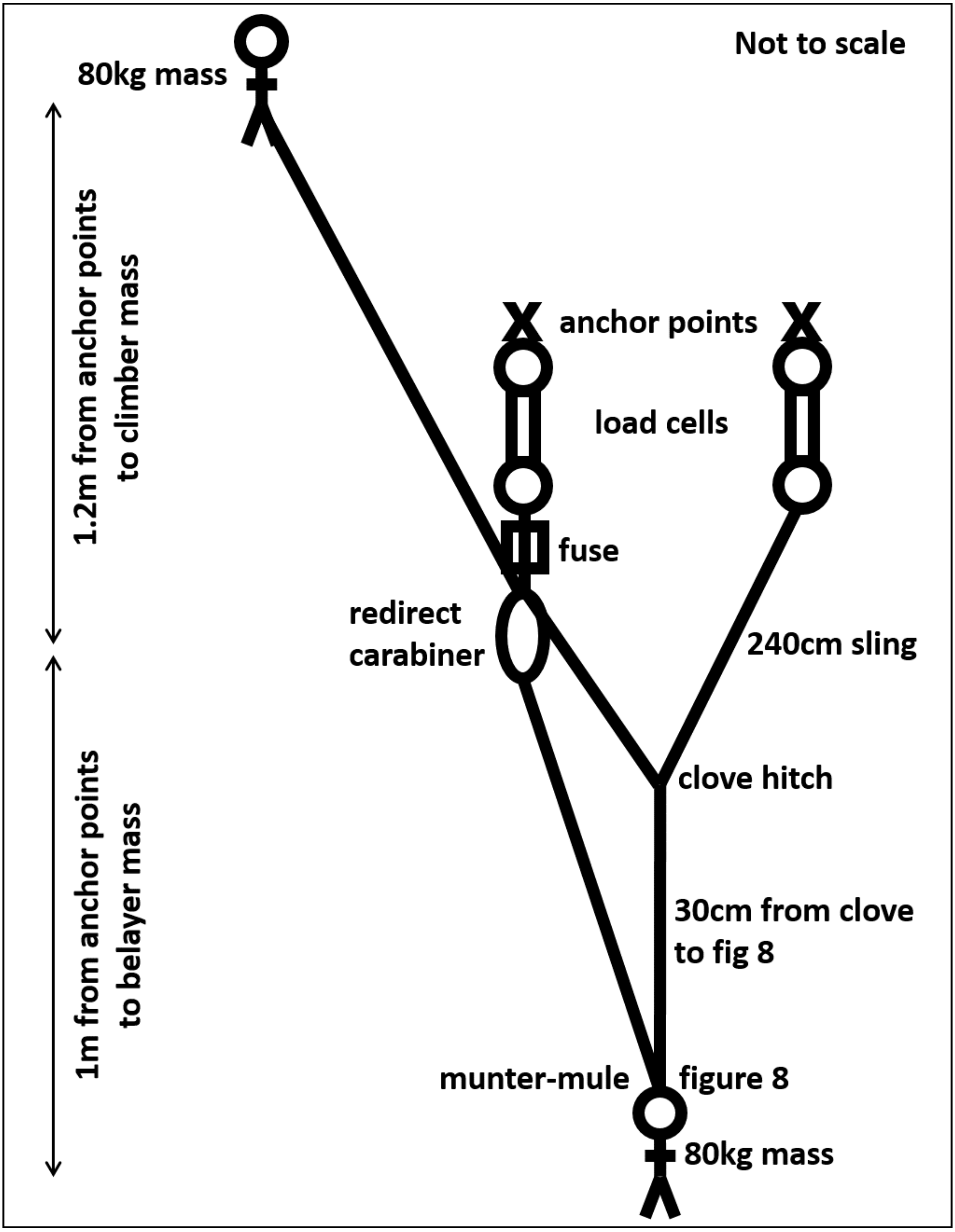
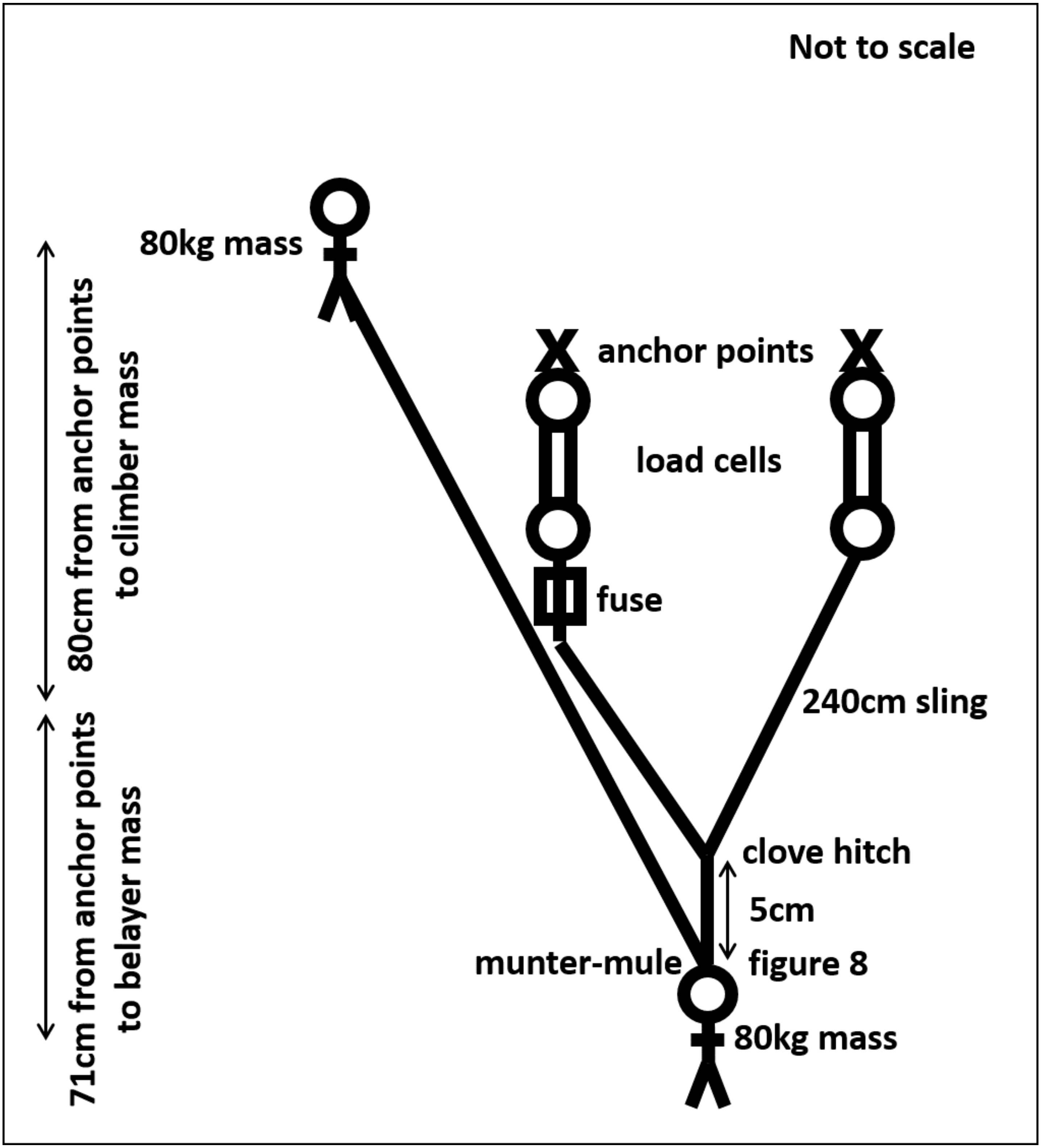
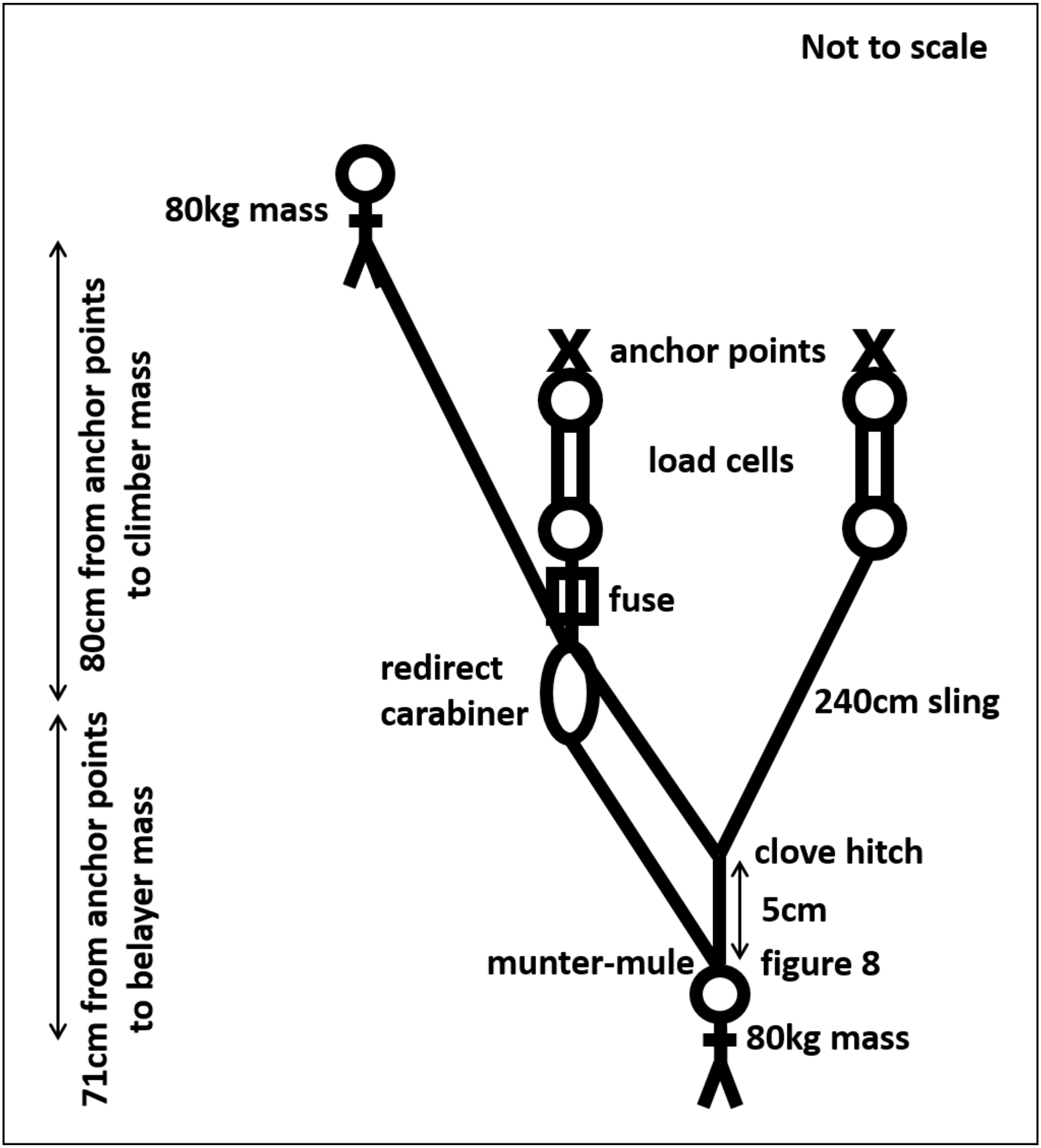


Figure 2: Test Set 1, Quad vs. Ponytail


Not to scale
80kg mass
anchor points
load cells
fuse
240cm sling
clove hitch
5cm
figure 8
munter-mule
80kg mass
80cm from anchor points to climber mass
71cm from anchor points to belayer mass


Not to scale
80kg mass
80cm from anchor points to climber mass
anchor points
load cells
fuse
redirect carabiner
240cm sling
71cm from anchor points to belayer mass
clove hitch
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80kg mass

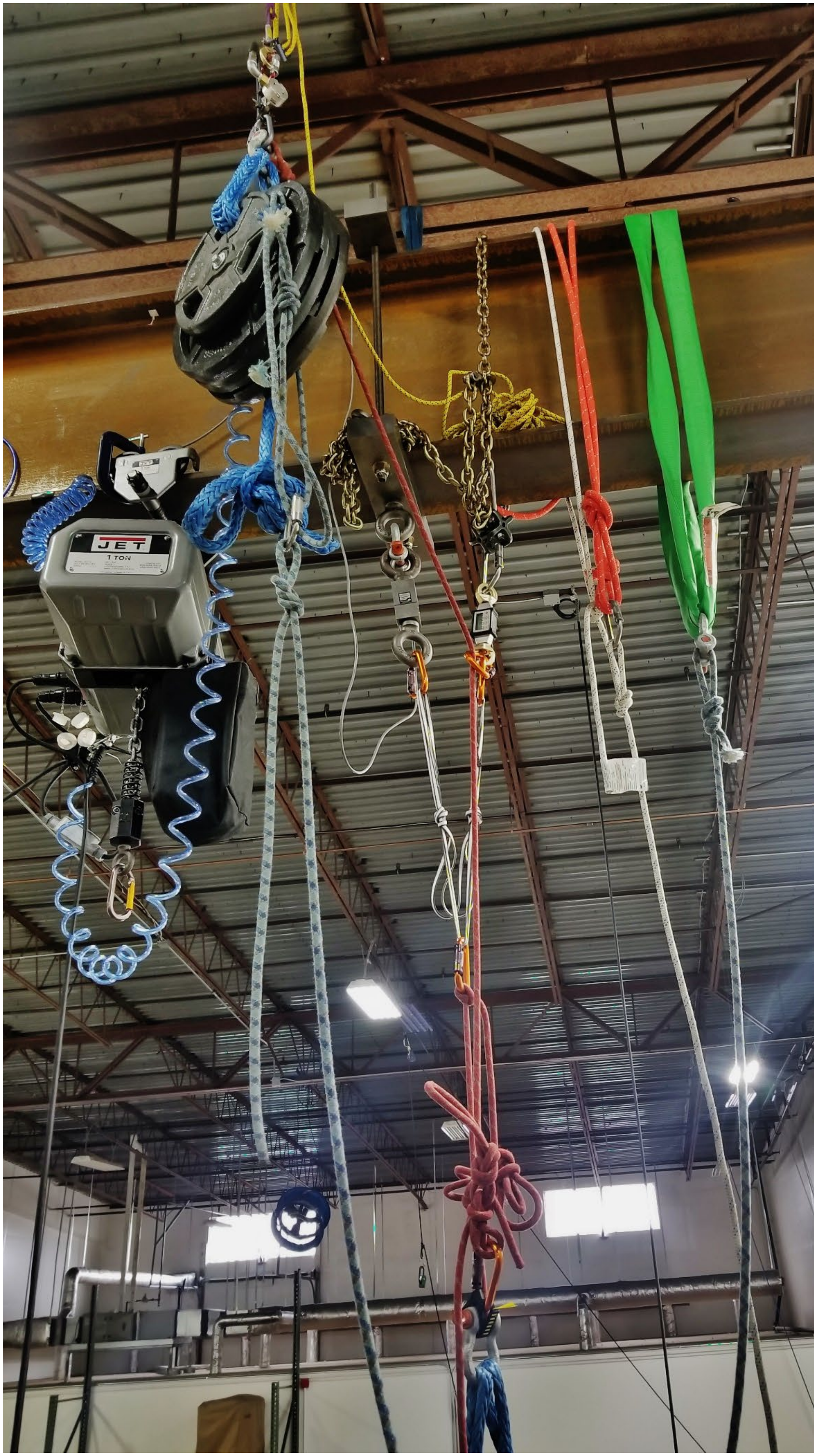

Figure 5: General rigging for test sets 1 and 3; differences vary between test sets. Test set 2 does not redirect the rope through the carabiner on the load cell with the fuse.

Figure 6: Detail of load cell with fuse and redirect carabiner.

Results

Test Set 1: Quad vs. Ponytail

The peak forces for the first set of test cases are detailed in Table 1 below. In each case, the belayer mass was completely displaced, stopping at the redirect carabiner, as a result of the force of the falling climber mass. The fuse broke during each test.

Test Set 2: Fall Factor 2

The peak forces for the second set of test cases are detailed in Table 2 below. For these shorter falls, a redirected quad was first tested for comparison between the longer and shorter fall parameters (120cm and 80cm above the anchor components, respectively). Despite the difference in fall length, the test parameters yielded comparable peak forces. During both factor 2 tests, the fuse did not break as a result of the falling climber mass. In the case of the quad, the distrubtion of load between the fuse anchor component and the other component was approximately a 40/60 split. In the case of the ponytail, the split was approximately 25/75.

Test Set 3: Variable Extension

The peak forces for the third set of test cases are detailed in Table 3 below. The quads were rigged such that the limiting knots were even, as might typically be employed in the field, such that the amount of extension is equivalent to half of the distance of material between the knots. For example, in the 10cm extension case, the knots had 20cm of sling material between them.

Table 1: Quad vs. Ponytail, Longer Drops

	Quad (19cm Extension)		**Ponytail**	
#	**Fuse (kN)**	**Remaining Component (kN)**	**Fuse (kN)**	**Remaining Component (kN)**
1	3.4	8.4	3.6	7.9
2	3.5	8.8	3.2	7.8
3	3.3	9.1	3.4	7.7
$\bar{x}$	**3.4**	**8.8**	**3.4**	**7.8**

Table 2: Fall Factor 2, Shorter Drops

Test Case	**Fuse (kN)**	**Remaining (kN)**
Quad w/Redirect	3.6	8.8
Quad FF2	3.2	4.8
Ponytail FF2	1.9	5.6

*Note: fuses did not break during FF2 falls.

Table 3: Variable Extension, Shorter Drops

Extension Length (cm)	**Fuse (kN)**	**Remaining (kN)**
10	3.5	8.6
19	3.6	8.8
39	3.6	12.1

Discussion

Owing to limitations of materials and facility availability, these data represent a very small number of samples, in some cases only one test case. These results and attendant conclusions are not definitive. However, the data afford insight into the merits and concerns for various anchor rigging and belay options and also reflect prior research.

Test parameters were designed to be as realistic as possible. The falls in the first test set represent a conservative fall—in effect, these tests would represent a case where the lead climber's feet are near the anchor components. Many climbers would recognize this as a short distance above the anchor and may or may not choose to place protection at this point. A less conservative climber advancing beyond these distances would create even greater fall forces than those seen in this testing. The second and third test cases are even more conservative (as the distance to the lead climber mass was reduced to avoid the test mass hitting the floor), but still generate significant forces. The use of a munter with overhand slip hitch results in little rope slip in the belay system, akin to that of many ABDs, which are increasingly common in multipitch climbing owing to the additional security afforded by the assisting brake mechanism. A belay device which allows rope to slip (munter, tube device, etc.) would likely reduce total forces demonstrated in this study (Petzl America n.d. b).

Also noteworthy is the use of a rigid mass in this study. Rigid masses are relatively poor analogs for the human body in drop testing in many cases. However, provided a conservative estimate of forces is relevant (i.e. greater than realistic forces were human bodies present in place of test masses), rigid masses can be used without limitation. That is, if the test parameters are otherwise the same, rigid masses allow for comparison between systems or techniques subject to the same test parameters, despite greater than real-world forces. If realistic force estimates are needed, prior research shows that a reduction by approximately 15% yields a realistic approximation provided that the energy gained by the human body is small in comparison to other elements in the system, such as a dynamic climbing rope (Holden, May, & Farnham, 2009). Finally, a baseline test in this study to determine the force necessary to break the fuses used in the study used the same parameters as prior research by the author with the exception of rigid masses in this study as opposed to soft masses. This single sample comparison yielded a lower peak force (6.4kN) using rigid masses than that of otherwise identical parameters in prior testing ($\bar{x}$ = 8.0kN).

The results imply that should an anchor component fail, the subsequent load on the remaining anchor component will indeed be greater for sliding rigging as opposed to fixed length rigging. The limited sample here indicates an increase in peak force of approximately 1kN or approximately 13% for 19cm (7.5in) of extension. The relatively small absolute difference in peak force does not immediately discount the use of sliding systems in anchor rigging. The data also indicate a positive correlation between extension length and peak force, though more testing would be required to precisely describe the nature of this relationship. Catastrophically high loads (12.1kN) could result from extension, sufficient to cause significant harm to the climbing party or cause complete anchor failure. However, further testing is warranted to determine the extent to which the 12.1kN load measured is an outlier. Even the lower peak forces represented in the data of approximately 8kN are sufficient to break smaller pieces of protection. Therefore, extension and shock loading concerns must not be overlooked simply because a dynamic rope is present in the climbing system.

In addition to exploring anchor component failure by means of a high-factor fall with the climber's rope redirected through an anchor component, true factor 2 falls were also tested. While redirecting the leader's rope through an anchor component is a relatively common practice in the field, this introduces a "pulley effect" on the component used for this purpose, increasing the peak force and therefore potential for component failure. When anchor components are dubious, the traditional wisdom is to minimize forces on the anchor by the belayer catching a factor 2 fall directly, thus shielding the anchor from load. We replicated this in our testing with factor 2 falls directly on the belayer mass for both a sliding and fixed length rigging. The fuse did not rupture in these tests, likely owing to potential distribution of the load (as opposed to concentrating the load on a single anchor component). Unfortunately, the pragmatic implications are not clear as a direct factor 2 fall onto a live belayer could cause considerable harm. Additionally, as many belay devices require the belayer to adopt a likely untrained upward braking position in such falls, the belayer may fail to maintain an adequate brake and therefore drop the falling climber. In these cases, the climbing party might elect a fixed point belay instead. These tests also added two additional data points to the comparisons in load distribution between sliding and fixed length riggings, and were comparable to other prior study in this regard.

Recommendations

Though relatively rare, catastrophic failure of climbing anchors does occur. The vast majority of anchors are not subject to factor 2 falls. Indeed, in the case of multipitch climbing, anchors are subject to falls infrequently relative to other climbing contexts (single pitch climbing, indoor climbing) as climbers may want to stay within the limits of their movement skills on multipitch routes. Consequently, the performance of climbing anchors in factor 2 falls is not well established. Further, even experienced climbers may have relatively little experience assessing the strength of climbing protection or anchors given the relative infrequence of factor 2 falls and attendant feedback regarding an anchor's performance under such demands. Additionally, the limited data on climber assessment of protection demonstrates a wide range of presumed strength of individual placements (Manes, Bedogni, & Rogora, 2012), suggesting a significant human factor with considerable variability in evaluating protection and anchor strength, even among experts. This problem is amplified in more variable media such as ice and snow (Beverly & Attaway, 2014). In short, climbers have precious little direct real-world experience assessing climbing protection systems for worst-case, catastrophic failure and would be wise to hedge accordingly.

In constructing climbing anchors, as ever, it is clear that the most important attribute is the strength and security of individual anchor components. Given the large forces involved, no rigging system can compensate for poor components. The large forces involved also imply the potential for the failure of the anchor components as loads may exceed the breaking strength of stoppers, cams, ice screws, pitons, etc. or otherwise compromise the placement or the rock itself. Loads to individual components can be reduced by incorporating the belayer into the system by allowing for factor 2 falls, but the effect on the belayer and the potential for the belayer to drop the falling climber would generally advise against this. Therefore, the traditional wisdom of avoiding high factor falls directly onto the climbing anchor is still prudent. If this seems likely, there are many options a party may consider, including fixed point belaying. Otherwise, retreat may be the best course of action.

All else being equal, comparing sliding and fixed length rigging systems yields the classic tradeoff, that of load distribution versus extension and shock load. The crux of the matter hinges on the strength of the anchor components relative to their security (i.e. the likelihood of failure, whether by poor placement, breaking the component, or breaking the rock). A sliding system can reduce the likelihood of component failure by distributing the load, though significant edge cases may still result in poor distribution. Should a dubious component fail, the resulting shock load will place a greater peak load on the remaining component(s) than if a fixed length rigging were used. In cases of severe extension, loads are sufficient to break all but the strongest anchor components (modern bolts in good repair), to say nothing of the likelihood that such forces might break the surrounding rock or ice or rip the equipment from the climbing medium. Given the potential edge cases in which distribution is ineffective and the unknown amount of extension that might keep peak forces in tolerable limits in any given anchor, it is difficult to recommend sliding rigging as a superior alternative to fixed length options.

Some climbers cite the ease of use associated with sliding rigging systems as a compelling rationale for their application. For example, the quad features two independent masterpoints (aka “pockets”) which can provide additional clipping space to aid anchor organization. The quad also isolates the movement of party members at the anchor, thereby avoiding one member pulling another off balance while shifting at an anchor. However, both of these are simply matters of convenience. Perhaps more compelling is the argument toward efficiency and attendant speed by keeping the limiting knots of the quad pre-tied, ready to deploy immediately at the next anchor stance. This saves time, which can be of value on long routes. Further, when ice climbing or in other cold conditions, anchor rigging is often facilitated by removing handwear—this is unnecessary with a quad. In order to gain this efficiency, the limiting knots of the quad need to be placed sufficiently far apart to adjust readily to variable spacing among anchor components. This is problematic as it forces a tradeoff between versatility in the rigging system and increasing the potential extension. The data above demonstrate that the distance of extension can matter significantly in the event of anchor component failure. Consequently, if a party elects a sliding rigging system, potential extension should be limited to not more than 6 inches (15cm). This reduces additional force due to extension compared to a fixed length rigging system. Limiting extension to less than 6 inches curtails the versatility of a sliding rigging and may demand frequent adjustment of limiting knots; in these cases, a ponytail anchor is more efficient. The cautious reader might also measure the distance between limiter knots when practicing rigging a quad to ensure that their estimation of 6 inches of extension is accurate.

Conclusion

When constructing a multi-component climbing anchor, two basic rigging strategies dominate: sliding and fixed length systems. The various specific rigging options for these two major systems harbor a fundamental tradeoff between extension and load distribution, respectively. In the case of anchor component failure, extension results in greater force on the remaining anchor component(s), with increasing peak force positively correlated with amount of extension. Therefore, climbers are advised to keep potential extension amounts quite small (<=6 inches) if electing a sliding rigging method, or to choose an alternate rigging.

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