EMBC Rope Rescue NIF Equipment Testing

Summary Report
2016

Contract No. CS 4912

File No. 1070-20

By:

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Introduction:

The National SAR Secretariat has provided a New Initiatives Fund to Emergency Management BC (EMBC) for a project to update the decades old rope rescue program for British Columbia SAR groups. Kirk Mauthner of Basecamp Innovations Ltd has been contracted by EMBC to conduct the following:

- Conduct research and gather information on specific rope rescue equipment and technical systems upon which EMBC does not currently have data.
- Conduct testing of specific rope systems upon which EMBC does not have data
- Draw conclusions about the information gathering and testing, and
- Make recommendations about existing and potentially new EMBC rope rescue systems

EMBC required BIL to conduct the following Systems Testing:

- Capability and Competence of Two Tensioned Rope Systems (TTRS), specifically those whereby each rope is considered Dual Capability – i.e. each rope system within a two rope rescue system concurrently capable and competent as a mainline as well as a belay, for either lowering or raising rescue loads.
- Sharp Edge Testing of TTRS and Dedicated Main, Dedicated Belay (DMDB)
- Peak Force and Elongation comparison between TTRS and DMDB
- Comparative evaluation of rope grabs
- Test and provide information on Force Limiting principles for rope rescue
- Test and compare the effect of Falling Objects (e.g. Rock Fall) between TTRS and DMDB
- Test the capability and competence of Tailing Ropes of TTRS to mitigate Human Factor considerations
- Conduct tests of various stretcher rail tie-offs
- Conduct strength tests of the adjustable BC Cave Rescue Bridle
- Test the performance of the Flat Overhand Bend for securing W3P2 type anchors

Additionally, EMBC required BIL to gather information and research on:

- CMC Rescue MPD performance use data
- Performance of single and tandem Prusiks as a belay in TTRS
- Master Attachment Point principles for stretcher and pick-off based rescues
- Provide information on the 2000 EMBC (PEP) Mountain Rescue Task Force research
- Provide information on recommended cord/rope properties for rope rescue
- Performance data on Petzl ASAP
- Compile information on testing of loss of strength over time of rope, cordage & webbing

Incorporated in the year 2000, Basecamp Innovations Ltd (BIL) provides training and consulting in technical rope rescue throughout North America and Overseas. In addition, BIL conducts research and testing services and also designs technical equipment for rope rescue and mountaineering. For disclosure, it is known by EMBC that Kirk Mauthner is the designer of the CMC Rescue MPD, which is one of the products required to be tested. BIL has an on-site purpose built drop testing tower, slow pull machine, high-end calibrated instrumentation for measuring force and distance over time as well as a CNC prototyping facility.

It is understood that the Province exclusively owns all property rights of this report which are not intellectual property rights or Incorporated Material. BIL irrevocably waives in the Province's favour any moral rights which BIL (or its employees) may have in the Produced Material, and confirms the vesting in the Province of the copyright in the Produced Material, other than any Incorporated Material.

It is expected that EMBC will seek competent instruction and training for any changes considered as a result of the findings in this report and BIL cannot be held liable for EMBC failing to do so.

Overall Summary, Conclusions and Recommendations:

Discussion:

Details of each Test Series are provided in their own respective section, as described in the Table of Contents. The following discussion takes into account all the information and test data gathered, and from this – together with Basecamp Innovations Ltd expertise as a rope rescue training provider - conclusions and recommendations are made.

The intent of the testing and research component of the EMBC Rope Rescue Project was to help arrive at recommendations of what rope rescue systems and equipment BC SAR Teams should use. As with any recommendations, good risk management must be based on the best available data, and as such, an informative review of it is required. The resultant data from the testing may have validated some ideas, invalidated others, but it must be emphasized that in many regards, the data has limited depth and breadth. For example, the testing was done predominantly on one rope type, one cordage type, and a select types and quantity of hardware, and the data collected here cannot be simply extrapolated to infer how other products might perform; as always, there are limitations to what the data can provide answers for.

One of the principal questions of this testing was to determine whether a change to Two Tensioned Rope Systems (TTRS) is warranted, or whether Dedicated Mainline, Dedicated Belay (DMDB) systems should prevail. This would be a significant and fundamental change to current practices as it challenges the very premises of why current techniques and systems are currently being used. As such, the following key factors were identified as key research and testing required to make this determination:

- A comparative analysis of sharp edge effects to tensioned and un-tensioned ropes
- A comparative analysis of falling material/objects onto tensioned and un-tensioned ropes
- The human factor considerations of Descent-Control-Device (DCD) operators having to defeat Auto-Locks during lowers with TTRS

- Quantifying the differences in Maximum Arrest Force (MAF) and Stopping Distance between TTRS and DMDB systems, as well as the differences in performance between Low Stretch and Static ropes.
- Assessing the effectiveness of the belay capability and competence of TTRS systems.

Another fundamental question which significantly affects the decision of which techniques and equipment should be used by BC SAR is the determination of how strong rope rescue systems need to be. The current paradigm for system strength relies on applying a 10:1 Static Systems Safety Factor (SSSF), whereas other rigging and design disciplines use alternative approaches, such as applying reliable Force Limiting systems and techniques, which in turn may allow for more relevant and accurate assessments of required system strengths. The theory and principles of Force Limiting Systems (FLS) are already well documented in engineering and design textbooks, but what was missing for the application to rope rescue was evidence of what the appropriate minimum and maximum force limiting values should be, and from that, system strength recommendations can be made.

Details and discussions of the Force Limiting testing are covered in Series 5. In summary however, the minimum force limiting value was found to be 6 kN, with a maximum of 12 kN. With a 6-12 kN force limiting bandwidth, rope rescue systems can be deemed strong enough if they have *at least* 20 kN of strength in their rigging. Only the relative worst case event of a 1 m drop on 3 m of rope with a 200 kg mass can technically create a potential 12 kN peak force, and with that event in mind, it is highly unrealistic that it would be possible for rescuers to rig a redirect in the system with so little rope in service whereby resultant vector forces would be of concern. As such, a 20 kN + breaking strength requirement even applies to redirects since it is highly likely that when a redirect is rigged in a system, that potential peak forces will be far lower than 12 kN.

Other data included the breaking strength values for the BC Cave Rescue stretcher bridle configuration (see Series 9), an assessment of different stretcher rail tie-offs (see Series 8), a comparative analysis between Prusiks and mechanical rope grabs when used in pulley systems (see Series 4), as well as an assessment of alternative tie-offs for securing multi-wrap anchors (see Series 10). Additional research was gathered on the CMC Rescue MPD, an examination of Master Attachment Point requirements, rope and webbing retirement criteria and locating and reviewing previous testing information from the year 2000 Mountain Rescue Task Force.

<u>TTRS or DMDB Systems:</u>

A variety of both TTRS and DMDB configurations are currently in use worldwide, but in North America, DMDB systems tend to be the norm, although there is a strong movement internationally towards using TTRS. In 2005, at the International Commission for Alpine Rescue Conference (ICAR) in Cortina, Italy, Kirk Mauthner – representing Parks Canada in the Terrestrial Rescue Commission - presented a paper demonstrating the benefits of a specific type of Two Tensioned Rope Systems, specifically Dual Capability (aka Mirrored Systems) based on BIL research. Many teams internationally now use some form of Dual Capability TTRS. However, before making any changes to systems, it is important to make a detailed examination of the *premises* of *why* a current system is in use. A detailed examination of the premises allows testing to either validate or invalidate them, and therefore changes can be made based on the best evidence. Through literature searches, conversations with long-time SAR practitioners and having consulted in matters relating to technical rope rescue since 1993, the primary reasons why DMDB systems became predominant for EMBC (PEP), as well as throughout North America, can be narrowed down to the following premises:

1. There's a belief that since an un-tensioned rope is less likely to get damaged from being subjected to a sharp edge than a tensioned rope, that from a risk management perspective, it is better to have the belay un-tensioned, and all the load held by the mainline. That way, much of the risk of damage/failure is directed towards the mainline and less exposure to the back-up rope.
2. There's a belief that potential damage/failure from falling objects (e.g. rock fall) is more likely to occur to tensioned ropes than un-tensioned ropes and therefore this is considered an argument in favour of un-tensioned belay lines.
3. There's a belief that there may be greater control of lowering a rescue load over an edge by dedicating one rope system to that task.
4. Previous testing of certain TTRS demonstrated ineffective fall arrest, or belaying of the load if one of the rope systems in a TTRS failed.
5. There is a human factor consideration that must be managed with TTRS when lowering; specifically, to lower loads, each respective DCD on a TTRS requires the operator to defeat the auto-lock to initiate and maintain a lower. It is questioned whether or not respective DCD operators would have sufficient reaction time to allow rope locking to occur, if the adjacent rope system failed for any reason.

<u>Sharp Edges (see Series Two Testing Results):</u>

In 2014, *Basecamp Innovations Ltd* conducted a series of sharp edge drop tests, directly comparing DMDB systems to TTRS. No evidence was found to support the premise of point 1 above; in fact, the data suggested that TTRS outperform DMDB system under those test conditions. This data was presented at the 2014 International Technical Rescue Symposium (ITRS) in Golden, CO. This was a major finding that directly challenged a key premise of advocating DMDB systems. Subsequently, the findings of two other independent testing initiatives by M. Forbes, Spokane WA, and R. McCullar, Mississippi, corroborated the *Basecamp Innovations Ltd* data and these were presented at the 2015 ITRS. The EMBC testing again found results consistent with previous testing efforts. Collectively, the sharp edge testing compared DMDB systems to TTRS under three dominant forms of sharp edge exposure, and in all cases, TTRS prevailed over DMDB. The three forms of sharp edge exposure testing included: 1) drop tests over a sharp edge (both directly over as well as allowing side-ways sliding of the ropes), 2) offset mass tests simulating a rescue load that is not in plumb, resulting in a sideways slide of the ropes across an edge, as well as 3) offset ropes with the mass in plumb, simulating a rescue load that had been off-plumb, but was corrected back to plumb, but the ropes had remained off plumb and then suddenly released, resulting in a sudden sideways slide of the ropes even though the mass was in the plumb line. In all configurations tested, TTRS prevailed over DMDB systems, thereby invalidating the premise of point 1 above.

Falling Object/Rock-fall (see Series 6 Testing Results):

Three types of falling object tests were conducted on both DMDB and TTRS. The first type involved actual crushed rock falling onto the respective systems, the second type involved a blunt force/strike of an object onto ropes lying on a sharp edge, and the third type of tests involved a sharp edge strike of a falling mass onto ropes lying on a flat surface. In none of the tests did the DMDB systems outperform TTRS; they essentially performed similarly, and if anything, slightly more damage occurred to DMDB systems then TTRS. These tests suggest that there is no proof to support the premise of point two above. In other words, the risk of damage/failure from falling objects does not obviously favour one system over another, and it certainly does not provide evidence in favour of DMDB systems – that premise is unfounded.

Controlling the Load:

No direct comparative analysis testing was conducted to determine which system – TTRS or DMDB – was easier or more difficult to achieve good control of the load. However, it is known and demonstrated, that good control of the load can be achieved with either system, and that many SAR teams worldwide dominantly use TTRS with success in this regard (e.g. Bergwacht Bayern - Germany; Tyrol - Austria; Tatras -Poland; SAC Switzerland, as well as many teams in North America such as Kananaskis Country Public Safety – Alberta; Parks Canada Public Safety; Sartechs – DND Canada; Olympic Mountain Rescue – Washington; Portland Mountain Rescue – Oregon, Zion National Park – Utah, among others). As with all systems, there are nuances that must be learned to effectuate smooth operations, and these must be incorporated into the training. It is also known that difficult edge transitions are best accomplished using techniques utilizing elevated ropes (i.e. high-directionals, whether natural or man-made), or lacking the option for elevated ropes, techniques involving vertically oriented stretchers, and lastly, 'vectoring' of the ropes by edge people. This applies regardless of whether TTRS or DMDB systems are used. After a review of the current BC SAR manual, it was felt that the greatest gains to attaining good control of the load are in the *process* of training, and equally important – if not more so - a revision to current EMBC Command & Control processes (to be discussed further). As such, good control of the load – particularly with edge transitions - can be accomplished with either TTRS or DMDB techniques, and load control cannot therefore be used as an argument in favour of DMDB systems.

However, once the load is below the edge, then a distinct difference in load control exists between the two approaches, favouring TTRS. With DMDB systems, any sudden jolt or inconsistent feed rate of the mainline will translate directly as a similar effect to the load, and with increased rope in service, bouncing of the load may be exacerbated. Whereas with TTRS, since roughly equal tension is placed on each rope, then a jolt or inconsistent feed from one rope system, tends to be dampened by the other rope system, and consequently the effect to the rescue load is significantly reduced. This holds true for both lowering as well as raising loads.

It has also been noted that a key load control advantage of TTRS is that since the DCD focal points are adjacent to each other, then the respective DCD operators can mirror and model proper technique to each other more quickly and effectively, and therefore any gaps or lags in skill and technique are more easily rectified than with DMDB techniques.

<u>Rescue Belaying (see Series 1 & 3 Testing Results):</u>

The entire process of controlling the line and stopping, or arresting the fall is called belaying. Fall arrest should occur in as short a distance as possible - without exceeding the upper limits of force – to minimize the risk of the rescue load striking an obstruction. There is an overarching mindset – predominantly in North America – that belaying involves using an un-tensioned rope to back up the load, and a review of rope rescue literature, and certain standards (e.g. NFPA) reflect this mindset.

Belaying, however, can be accomplished with either tensioned or un-tensioned ropes. The premise of "Dual Capability" systems, or "Mirrored Systems", is based on the concept that *each* rope system in a Two Tensioned Rope System serves simultaneously as a mainline as well as a back-up, should anything fail in the other rope system. Not all TTRS have this premise. The aim of the EMBC testing was to evaluate what the rescue belaying capability and competence is of various configurations of TTRS, *particularly with tools and equipment already familiar to SAR teams in BC*. By the very nature of how they are rigged, it can be argued that each rope system within a TTRS typically has more rope in service than the belay line in a conventional DMDB, and therefore the relative severity of a fall – or fall factor – will be less than that of a DMDB, and consequently, the demands of a TTRS belay would be less.

However, it is conceivable that the worst-case event as described by the British Columbia Council of Technical Rescue (BCCTR) in the eighties (i.e. 1 m drop of a 200 kg mass onto 3 m of rope; simulating a failed mainline just as the rescuer was negotiating the lip of an edge, close to the belay), can just as likely occur with TTRS as with DMDB systems. Additionally, a large volume of rope rescue belay testing has occurred over the past few decades since the original BCCTR Belay Competence Drop Test Method (BCDTM) was devised, and it is therefore advantageous from a comparative analysis standpoint to hold TTRS belay requirements to the same severe standard as those for DMDB systems, even though less demanding belay requirements are likely.

The Series 1 Rescue Belay tests *revealed a key concern with Prusiks* which have potentially serious implications to how they are being used for certain types of TTRS belaying, and to a certain extent, also to dedicated belay techniques. In general, it was found that when non-auto-locking DCD's (e.g. Micro Rack Brakes; Scarabs; Belay Plates and Italian Hitches) were positioned *behind* the Prusiks, that the tensioned rope entering the Prusiks, significantly and adversely affected their ability to effectuate fall arrest *under fall factor 1/3 conditions*, but less so with reduced fall factors. Significantly more glazing of Prusiks, increased stopping distances with corresponding decreased Maximum Arrest Forces (MAF) and in some cases outright failures occurred with these DCD & Prusik configurations, whereas similar prior tests with *only Prusiks and no inclusion of DCD's were generally successful and reliable*. Prusiks appear to be less capable and reliable at gripping a tensioned rope than an un-tensioned rope. Only a reduction in fall factor from 1/3 to 1/5 showed promise of acceptable fall arrest performance. Interestingly, John Dill of Yosemite SAR warned that this might be an issue, in an article he wrote in 1990 for Response Magazine, entitled, "Are You Really on Belay?"

Not only does this NIF testing data demonstrate that a DCD positioned behind Prusiks generally does not meet the criteria for successful rescue belaying for TTRS at the FF 1/3 drop heights, it also has potential adverse implications for current practices using DMDB techniques. It is not that uncommon for rescue teams using DMDB techniques to *add* a DCD *behind* a Tandem Prusik Belay configuration once the rescue load is below the edge and the attendant has good control of the load. Adding some tension to the belay in this manner prevents inadvertent over-feeding of the belay line (as sometimes occurs with un-tensioned belay lines since the rope weight can affect the true feel of the load), it also removes some of the rope stretch should something happen to the mainline, and it also helps reduce potential rope induced rock fall. The practice of adding a DCD behind the Prusiks is actively being taught in North America; however, the timing of 'when' the DCD is applied to the belay line results in very low fall factor events and therefore the severity of the adverse effects as observed during FF 1/3 events may not initially be noticed.

The Series 1 Testing then examined TTRS rescue belaying with the placement of the DCD in *front* of the Prusiks, instead of behind. The testing revealed that fall arrest performance is <u>substantially more reliable in this configuration</u>. Tests showed that at FF 1/3 drop heights, the Prusiks behind the DCD were only subjected to approximately 2 kN MAF, which is significantly lower than the MAF demands placed on them when positioned in front of the DCD. Not only did the Micro Rack, Scarab, Belay Plates (BD Guide ATC and Petzl Reverso 4) and the Double Italian Hitch all demonstrate capability and competence at the fall factor 1/3 drop heights, they all exhibited sufficient capacity at the very severe fall factor ½ (i.e. 1.5 m drop on 3 m of rope with 200 kg mass), implying that a sufficient margin of safety exists above and beyond the minimum 1 m drop test criteria.

Additionally, it was found that only a single 8 mm Prusik is warranted – and preferred - for this configuration; even a single 8 mm Prusik behind the DCD provided sufficient capacity by catching 1.5 m drops on 3 m of rope. It was also noticed that more often than not, that post drop – even with the FF ½ tests – the Prusik could be broken free and minded by hand without having to untie the release hitch. The testing demonstrated that TTRS belaying is possible using equipment that is currently familiar to BC SAR teams. However, with the very severe FF ½ drop, it was noted that the Micro Rack frame was slightly bent during the drop; this is because both the running end rope as well as the standing part of the rope impart a moment to the frame between the 1st and 2nd bar. For FF 1/3 drops, the BMS Micro Rack remained functional. The Conterra Scarab Rescue Tool did not exhibit any of the issues which brake racks are prone to. It is also paramount that the single 8 mm Prusik must be rigged in a manner whereby sufficient room exists between the Prusik and DCD such that the DCD cannot inadvertently mind the Prusik. A standard 60 cm pre-sewn sling was sufficiently long to provide this separation, assuming the Prusik was tied as a compact (i.e. as short as possible) releasable Prusik (e.g. Guide's Prusik) or even as a Valdotain Tresse Prusik (VT Prusik, with Technora sheath and sewn terminations), which is releasable under load.

One well known concern about placing a Prusik behind the DCD, is the manner in which the Prusik must be minded to allow feeding of rope into the DCD. As with Prusik belaying with DMDB systems, rescuers must be vigilant to use a technique whereby the Prusik can 'self-actuate' in the event of a fall, in other words, the Prusik must be managed in a fashion whereby it would get ripped out of the operator's hand to allow fall arrest to commence. Otherwise, it is possible for the operator to inadvertently allow excess rope run through the DCD. More discussion of this covered in Series 7 tests.

From a practical perspective, with the Prusik behind the DCD, it can be slightly more time consuming to convert from a lower to a raise, or again from a raise to a lower. Certain configurations are quite straight forward, whereas others require additional steps. It must also be recognized that configuring rescue systems with slings, Prusiks and DCD's, is often regarded as 'improvisational' in nature, usually as an attempt to work with basic – and often more lightweight - equipment and materials. It is also emphasized within professional groups – such as the Association of Canadian Mountain Guides – that improvising rescues with 'simple' equipment, requires a *very high skill* set to understand and maintain the skill set of all the subtleties and nuances of performance. For perspective, a fully accredited professional ACMG Mountain Guide is examined no less than five times in their rope rescue skills.

Drop tests with the CMC Rescue MPD and the Petzl I'D both demonstrated capable and competent fall arrest performance with this combination of host rope (i.e. New England (Teufelberger) KMIII, with the MPD exhibiting preferably shorter stopping distances than the I'D. Both devices also exhibited competence at the FF ½ drop height. However, these drop tests allowed auto-locking actuation without interference of a DCD operator. Once auto-locking was deliberately 'disabled', and fall arrest was assessed with the addition of rope tailing, the results were different, and these are discussed the Series 7 tests.

To summarize the Series 1 testing, rescue belaying of TTRS is demonstrably capable and competent when suitable techniques are being used; therefore, rescue belaying is not an impediment to TTRS. Just as there are numerous rescue belaying techniques not suitable for DMDB systems, the same can be said for TTRS. It was found that commonly used equipment by BC SAR teams can be configured as a competent and capable TTRS rescue belay with a single Prusik as an auto-lock, positioned behind the Descent Control Device, but this must be done with appropriate Prusik minding technique. Additionally, this testing provides a basis for which additional testing and inquiry to TTRS rescue belaying can be conducted.

While the Series 1 tests focused on the relative worst-case FF 1/3 rescue belay capability and competence, the Series 3 tests focused on a comparative analysis of fall arrest performance between

TTRS and DMDB systems once the load is below the edge, in other words, FF 0. Expectedly, DMDB rescue belay techniques result in substantially higher MAF and stopping distance values. DMDB systems essentially exhibit twice as high of MAF values and almost a four-fold increase in stopping distances. The increased risk the rescue load due to increased stopping distances should be obvious, but the *unobvious* benefit of much lower MAF values with TTRS under these conditions is that the ropes are less prone to cutting on a sharp edge during fall arrest; inherently this has higher levels of safety associated with this technique. Prior testing by Basecamp Innovations Ltd (ITRS 2014) shows that complete catastrophic parting of an 11 mm kernmantle rope is possible if presented to a sharp edge when the rope tension exceeds approximately 4 kN, and this force is regularly exceeded with DMDB systems. This may be the reason why TTRS appear to perform better under sharp edge, drop and slide tests than DMDB systems.

Quantitatively, the test results in Series 3 showed that on average, a 360 kg mass, representing 3 rescuers and a patient in the stretcher, on a 45° slope, with 30 m of rope in service, would stop in approximately 1.6 m. This suggests that with 60 m of rope in service – which is not that uncommon for slope rescues – that the stopping distance would be approximately 3.2 m; compare this with the approximate 0.8 m stopping distance that a properly managed TTRS would have, it is clear that a DMDB presents a considerably higher risk to the rescuers and patient of striking an obstruction during fall arrest. The testing series clearly shows that rescue belaying using TTRS has distinct advantages over DMDB systems with un-tensioned belay lines.

A common practice among many rope rescue teams is to convert the un-tensioned belay line into a TTRS once the rescue load is below the lip of the edge and the attendant has good control of the load. This practice addresses both the MAF and excessive stopping distances mentioned above. This practice entails operating the belay as an un-tensioned rope until the load is below the lip of the edge, and then the conversion is made. The premise of keeping the belay line un-tensioned was largely based on the *now refuted* argument that it was thought to be better risk management than TTRS for sharp edges, which it isn't. Upon review of all of the points made so far, it appears that there are many arguments in favour of TTRS over DMDB systems, and that therefore a change is warranted. However, there is still the human factor consideration of the DCD operator inadvertently allowing excess rope to travel through the device until auto-locking is 'allowed' to occur.

<u>Human Factor Considerations of Defeating Auto-Locks (see Series 7 Tests):</u>

At the 2014 International Commission for Alpine Rescue (ICAR) conference in Killarney Ireland, the theme of the Terrestrial Rescue Committee was Human Factors as they relate to mountain rescue techniques. I gave a presentation focused on human factors as they relate to TTRS, with specific reference to the fact that because DCD auto-locks must be defeated to effectuate lowering, that a risk exists that excess rope may inadvertently be let out by the operator during fall arrest, and that this must be guarded against, ideally engineered out, in order to have a reliable rescue belay using TTRS. Some cursory testing conducted in 2014 by Basecamp Innovations Ltd indicated that rope tailing may be an effective way to mitigate this risk. At the 2015 ITRS conference, Mike Gibbs presented testing results confirmed that this risk, left unguarded, could result in excess rope running through the TTRS belay. Gibbs' testing did not incorporate any form of rope tailing or risk mitigation, and as such concluded that the reliability of fall arrest using DMDB systems results in potentially shorter stopping distances than with unguarded TTRS.

However, testing on DMDB systems by Basecamp Innovations Ltd in 1995 (and also by Jim Kovach of Ohio), revealed that the same human factor issues can also occur with DMDB systems, particularly with Prusik based belays. Despite good training, it is *common* to see rescuers 'allowing' the rope to be pulled through the Prusiks by the descent of the load. This is an identified problem with both DMDB as well as TTRS Prusik based systems. Additionally, numerous testers over the decades have aptly pointed out that with the Tandem Prusik Belay, that the 'proper' technique required to allow 'self-actuation' of Prusiks, results in extra slack being introduced to the belay system, and that typical drop testing does not factor this extra distance in, and therefore stopping distances from most Tandem Prusik testing is significantly understated, especially at the FF 1/3 drop heights.

To address the human factor issue, the Series 7 tests examined the effectiveness of having a separate person 'tail' the ropes of a TTRS. Also tested was the inclusion of a separate auto-lock into the system, namely the Petzl ASAP, investigated both in front (load side) and behind (anchor side) of the DCD. In all rope-tailing tests, the auto-locks were fully defeated, thereby relying solely on the rope tailing function to effectuate fall arrest.

An evaluation of rope tailing effectiveness required information on what the two-handed human gripping ability on two ropes is. Quick-look tests, along with extrapolations of the 1993 study on *Gripping Ability on Rope in Motion*, conducted by Kirk and Katie Mauthner - indicated that the *minimum* two-handed gripping ability, whereby it could be confidently stated that 'all' rescuers would be able to do, was found to be somewhere between 0.1 and 0.2 kN, with an average two-handed gripping ability being approximately 0.5 kN. Various TTRS rescue belay configurations were then tested with the auto-locks fully defeated, and only a mechanical hand, set at specific gripping ability tensions was used to tail the 'intact' rope in an attempt to stop the falling load. In reality, it would be highly likely that the DCD operator would also be applying their grip to the running end to aid in arresting the fall.

In all configurations tested except two, rope tailing at 0.2 kN was effective and reliable at stopping the load within approximately 1 m or less. Even when the mechanical hand was set to only 0.1 kN resistance, essentially all configurations were able to stop the load, with a few exceptions. The BMS Microrack, when rigged with 4 bars of friction plus the running end rigged over only 1 Hyperbar, resulted in unacceptable stopping distances, but this could be rectified by using both Hyperbars of the rack for friction. When the secondary friction post was not being used with the MPD, rope tailing was essentially ineffective, and the same was true for the Petzl I'D, even though it was already rigged with additional friction. With both devices in those configurations, rope tailing only became effective once 0.4 kN or more rope tailing tension was applied. However, rope tailing was highly effective for the MPD – even at the lowest mechanical hand setting - when the rope was rigged through the secondary friction post.

Only once the fall factor was reduced to zero (i.e. top rope belaying) was the I'D effective with rope tailing at 0.2 kN, but not at a lower resistance.

For every successful rope tailing configuration, it was also assessed in Series 1a whether or not the required level of operating friction for effective rope tailing was even practical for TTRS. Only the Conterra Scarab with the rope rigged with all 4 horns for friction exhibited too much friction to practically lower the load using TTRS techniques. Even the MPD, rigged with the rope around the secondary friction post was still smooth and easy to control, although sometimes it required rope to be fed into the device. For any rope tailing technique to be effective, the person doing the rope tailing must maintain a two-handed grip on the rope and be positioned in a strong stance, and must also be located where applying tension to the rope tails (running ends) will 'add' friction to the device. From practical experience, the location where this person stands is dependent on the type of device being used. That said, it is also very easy to redirect both rope tails (through a pulley or carabiner) to a location that is convenient for the person tailing the ropes, yet maintain the high friction orientation of the rope in the DCD.

Regarding good control of the load, an added benefit of rope tailing is that since both ropes are fed simultaneously to each respective DCD operator, by default each operator will have similar tension on their respective ropes because it will not be possible for one operator to feed rope faster than the other operator – that error is very quickly rectified by the person tailing the ropes, and this, among other things, helps provide for smooth transitions of the rescue load over an edge.

Another not so obvious benefit which was observed during a particular TTRS belay test series (Zion National Park, 2014), was that when the respective DCD focal points were rigged essentially side-by-side, equidistant from the edge, that any problem or failure of one rope system was immediately noticed by the operator of the other rope system, and their reaction time was substantially better than when the tests were conducted in a manner where the operator could not see any of what was going on with the other rope system. This suggests that as an ingoing strategy to rigging, that side-by-side rigging of focal points allows for significantly improved detection and correction of errors, especially human factors.

It is not common practice in rope rescue to incorporate the use of an industrial fall arrest rope grab in the belay. However, a particular product – the Petzl ASAP – uses technology analogous to that of how seat belts in vehicles work; that is, they are inertia based, and therefore do not require human intervention. When the Petzl ASAP was rigged in front of the DCD (load side), not only were stopping distances in excess of 1 m, but the MAF was also sufficiently high that rope sheath failure was imminent, and therefore this practice cannot be recommended (note: the manufacturer also does not recommend using the product in this manner). However, when the ASAP was positioned behind (anchor side) of the DCD, peak forces to the ASAP were low enough to not deploy the shock absorber (indicating that shock absorbers would be unnecessary in this configuration) and stopping distances were less than 1 m. The ASAP appeared to be effective in overcoming the human factor issue in this configuration. Practically, however, in discussions with users versed with the ASAP, it was pointed out that this practice would still require someone to feed the respective ropes towards the ASAP since coils of rope can inadvertently 'trip' the device into auto-locking and prevent movement. Rope cannot be simply pulled out of the pile or rope bag, through the ASAP towards the DCD without some rope manipulation. There is also the question of how a 'tripped' ASAP would be released to allow the operation to continue. Normally, with the ASAP in an industrial fall protection or rope access setting, the operator simply reverses direction of the ASAP, whereas in rope rescue, this is not always easily possible or recommended, depending on the circumstances. As such, additional work would be required to 'fine-tune' any potential methods and this was beyond the scope of this testing. It is known however, that the PGHM in Chamonix France, is using the Petzl ASAP on the back-up rope of a DMDB system using the Petzl I'D, for certain very specific crevasse rescue applications, but not for a broader use in mountain rescue.

Executive Summary of Recommended Changes to Current EMBC Systems:

The following is a quick reference summary of recommended changes to the current BC SAR program. To fully understand the following recommendations, it is imperative that the details per test series are carefully read and understood. The following is not a comprehensive list of required changes for EMBC as it is not a review and critique of the reference manuals used by BC SAR teams. Instead, the list stems from lessons learned from the EMBC testing, from prior testing, and research of other literature and consultation with other rope rescue professionals. These include my opinions as a provider of rope rescue training and consulting through Basecamp Innovations Ltd., and also based on a reflection of what other professional agencies are doing worldwide.

- Use TTRS over DMDB systems: they offer a higher level of safety when exposed to sharp edges, provide reduced risk to the rescuers due to lower MAF forces and shorter stopping distances, are less prone to cause rope induced 'rock-fall' and *are not more prone* to damage/failure from rock-fall, offer smoother descents and ascents of the rescue load due to the damping effect of the second tensioned rope. Additional benefits include quick transfers of tension between systems to solve a number of potential issues/tasks such as correcting the fall line position of the ropes (one rope can be un-tensioned, moved to the correct position, re-tensioned, and the same thing can be repeated to the next rope), or the re-alignment of edge protection by un-tensioning and re-tensioning respective ropes, passing knots, and even removing/adding ropes through high-directionals. Lifting loads using TTRS is a more efficient use of resources since the second rope also contributes to lifting of the load, and consequently each rope may require a lower mechanical advantage than with DMDB systems. There are other potential benefits such as better retention of training since each rope system does not require its own and specific operational techniques and nuances; instead, each rope system is similarly operated, therefore once a rescuer is trained for that function, these skills apply to either rope system. Detection and correction of both method/technique (i.e. rigging) and human factor errors is improved with the default side-by-side rigging and operation of TTRS devices.
- Ensure to apply effective rope tailing techniques to suitable TTRS techniques. Just as with DMDB systems, it is imperative that proper techniques are being taught and applied. While the

MPD is a purpose-built, specialized rescue tool, used internationally for the purpose of TTRS, there are also TTRS options to accomplish effective rope tailing with Prusiks and certain DCD tools already familiar to BC SAR teams. It must also be emphasized that given the relative 'newness' of having Prusiks behind the DCD in TTRS, there are likely nuances which have yet to be discovered and therefore it would be wise to proceed slowly and with caution using these techniques in controlled settings first, until firm protocols can be established. When the auto-lock was defeated, the I'D did was not a reliable rescue belay with TTRS at the FF 1/3 standard, even with rope tailing; only the addition of a Petzl ASAP provided reliability to this device – but again, there is very limited data and experience with this option.

- Use TTRS techniques which have demonstrated rescue belay capability and competence. Do not assume similar techniques, not tested in this test series, will work.
- Use Static over Low Stretch ropes; there is a big difference.
- Use reliable, purpose-built Force Limiting equipment (6-12 kN) and rig system strengths to 20+ kN. This can then be applied to vertical environments, slope rescue with multiple attendants, guiding lines and highlines. Eliminate constraints imposed by incorrect application of 10:1 SSSF.
- Allow the use of the Petzl Rescucender as a mechanical rope grab in pulley systems; triple-wrapped 8 mm Prusiks are also still suitable. The Gibbs ascender was found to be unsuitable.
- Whenever possible, utilize pulley systems made out of the mainline as a preferred risk management strategy.
- Allow W3P2 and W2P2 anchors to be finished and secured with a flat-overhand bend, with sufficiently long tails (i.e. hand-width+), properly dressed.
- Change the BC SAR Command and Communication systems to improve the management of human factors and situational awareness: (e.g. for descents, begin with a role call, then an edge transition briefing, then do dry runs until it is done correctly, then go operational. For ascents/raising, conduct an edge transition briefing immediately prior to executing the edge transition).
- Follow manufacturer's recommendation of 10-year lifespan for ropes, whether used in service or not.
- BCCR adjustable bridle is sufficiently strong for rope rescue applications.
- All of the stretcher rail tie-offs tested were substantially strong.
- When using high directionals, *equally* elevate both ropes of a TTRS; do not stagger the respective heights of the ropes. Once the rescue load is below the lip of the edge, then if required, the ropes can be lowered closer to ground height to mitigate high directional collapse risks.
- If no high directional opportunities exist, and an edge transition with a loaded stretcher is required, if patient medical conditions allow, default to vertically oriented stretchers. Once below the edge, only if required, stretchers can be re-positioned to a horizontal orientation.
- Use redundant anchor systems; note: there is a subtle difference between redundant and independent. Multiple anchor points can be collected together to create two focal points, yet are interconnected as opposed to independent, and still pass the critical point test. If anchor

point legs are long, incorporate cross-linking practices for safety to rescuers who may be clipped into the anchor systems.

Internationally, the change to preferring Dual Capability Two Tensioned Rope Systems over DMDB techniques did not occur suddenly. Since the 2005 Mirrored Systems presentation at ICAR in Cortina, Italy, many teams worldwide have contributed to the improvements made to TTRS. There was, and still is among some teams, various stages of transition from DMDB systems, where some teams are using 'hybrids' of both within the same operation, whereas others are fully using TTRS because of the already known benefits. That said, this EMBC NIF testing has contributed significantly to answering a number of unknowns, by way of acquiring and analyzing data, and the rope rescue community in general will benefit from these efforts.

For interoperability in Canada, to varying degrees, a number of professional teams have already converted their rope rescue systems to TTRS with Dual Capability using MPD's, specifically Parks Canada Public Safety, Kananaskis Country Public Safety, the Department of National Defense SARtechs, along with numerous fire departments, both voluntary and paid.

It is also worth noting that Dual Capability TTRS are a regular topic of discussion at conferences and symposiums such as ICAR and ITRS (International Technical Rescue Symposium), and is also the subject matter for a number of inquiries by researches/agencies looking to see what advancements have been made to rope rescue (see Advancing Vertical Rescue in Australia, by Scott Young, 2014).

In the early eighties, major advancements to rope rescue were made by PEP (now EMBC) through the ad hoc BCCTR initiatives, which significantly influenced most, if not all teams across North America. It also influenced and help guide certain standard setting organizations, such as NFPA, and ASTM whose target audience is predominantly the fire service and industrial teams. SAR teams in BC have a different 'mission profile' than those to which NFPA type standards are suitable. Therefore, initiatives such as this EMBC-NIF Rope Rescue Testing, along with the efforts of those who share their findings at venues such as ITRS and ICAR are the key drivers to continual improvement internationally in the efficiency and safety of rope rescue, and it is those efforts that also help standard setting bodies. Without doubt, the EMBC – NIF Rope Rescue Testing initiative of 2016 will positively contribute, once again, to the greater rope rescue community.

I would like to express my sincerest appreciate to Ian Cunnings and Andrew Morrison of *Emergency Management BC* as well as the *National SAR Secretariat* for the opportunity for *Basecamp Innovations Ltd* to conduct the research and testing on behalf of the EMBC-NIF Rope Rescue Testing initiative. In the background, a groundswell of sentiments and gratitude are being expressed by many within the BC SAR community for this leading edge, forward thinking rope rescue testing initiative. Many thanks also to Ross Cloutier, Phil Whitfield and Tom Volkers of the *NIF Rope Rescue Project Management Team* for their continued support and assistance with the project.

Lastly, I would like to express my heartfelt gratitude to the testing team who made it all happen on such short notice; they are: Gordon Irwin, Brad Kilgour, Marc Ledwidge, Steve Talsma, Earl Fröm, Tammy Stehr, Brodie Smith, Carl Trescher, Olivia Sofer, Michael Caswell, Chad Rigby and Kirsten Knechtel.

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List of Acronyms and Definitions on Log Sheets and Series Summaries:

mm millimetre

m metre

kg kilogram

kN kiloNewton

MNT Measurement Not Taken

FAS Fall Arrest System

TPB Tandem Prusik Belay

RRH Radium Release Hitch

DCD Descent Control Device

NA Not Applicable

SI Single Italian (aka Münter) hitch

DI Double Italian (aka Münter) hitch

RCSP Releasable Cordalette Single Prusik (aka Guide's Prusik); 5+m length of cord, triple wrap Prusik onto host rope, optional overhand on doubled strands, secured to pear shaped carabiner with a double-stranded single Italian hitch, secured with a half-hitch on a bight and then an overhand on a bight.

Stopping Distance total fall arrest distance, including rope stretch, knots tightening, belay unit extension, pre-rebound. Excludes fall distance.

Glazing surface deposit of molten nylon on host rope or melting of host rope sheath fibres.
Light – only surficial deposit onto host rope
Moderate – molten nylon imbedded into depths of sheath picks
Severe – hardened areas of sheath; fibres smeared/fused together

SP Short Prusik

LP Long Prusik

BAL Belay Assembly Length (e.g. length of release hitch + carabiner + Prusik)

BAE Belay Assembly Extension; difference between BAL lengths from post to pre-drop.

FLS Force Limiting System

BCCTR British Columbia Council of Technical Rescue

BCDTM Belay Competence Drop Test Method

BIL Basecamp Innovations Ltd

EMBC Emergency Management BC

TTRS Two Tensioned Rope System

DMDB Dedicated Mainline, Dedicated Belay

MAF Maximum Arrest Force

BASECAMP INNOVATIONS LTD.

EMBC Rope Rescue NIF - Equipment Testing 2016

Series 1 - Two Tensioned Rope Systems (TTRS):

Test Objectives:

One of the primary objectives of the EMBC Rope Rescue Testing NIF initiative is to determine where improvements to the safety of rope rescue systems and techniques could be made. Of particular interest is a comparison between Dedicated Mainline, Dedicated Belay (DMDB) and TTRS techniques. The purpose of this series of tests are to assess the 'capability and competence' of various TTRS techniques for their ability to perform as *Dual Capability* systems. The fundamental principle of Dual Capability systems (also known as Mirrored Systems) is that each rope system within a TTRS must be simultaneously capable of performing the function of a mainline (for lifting or lowering) as well as a back-up (belay) should one rope system fail. As such, the testing and methodology required to assess various TTRS required both Descent Control tests, Auto-Lock tests as well as Back-up/Belay tests.

Importance and Background Information:

Since TTRS techniques are fundamentally different than DMDB techniques, it is paramount to recognize that what is known – or even assumed to be known - about the performance of respective DMDB techniques does not necessarily transfer over to TTRS, even if the equipment being used is identical. As such, the testing and methodology must also fundamentally reflect how TTRS might be used and therefore modifications to the testing methodology of DMDB was required for these tests.

TTRS techniques have been in use for decades but the distinction and requirement of Dual Capability has only been around for just over a decade, and it is the added demand of a mainline to concurrently perform as a belay, should the other rope system fail that must be examined and assessed for capability and competence. It is important to note that in the 1980's the *British Columbia Council of Technical Rescue* – and then later in the early 1990's, Arnör Larson (founder of *Rigging for Rescue*) together with Seattle Mountain Rescue, did examine various TTRS, but none of the systems examined then incorporated some form of 'competent' back-up and as a result, further examination of TTRS techniques ceased. Jon Olson and Denis Fenstermaker of Seattle Mountain Rescue presented their findings at the 1992 North American Technical Rescue Symposium. A number of industrial/fire rescue training agencies, such as Roco Rescue of Baton Rouge, LA and also many mountain rescue teams across the United Kingdom, including the Royal Air Force Mountain Rescue Service also used TTRS. But after tests revealed inadequate back-ups to these techniques, many teams abandoned the idea of TTRS whereas others added a third rope to serve as a belay since neither of the two mainlines were deemed competent as a belay. However, the addition of a third rope added different complications.

The concept that *each rope system in a TTRS* must also *auto-lock* is also a relatively new and welcome risk management feature. Historically, especially with DMDB systems, only the belay was deemed necessary to have an auto-lock function. With TTRS, since each rope serves as both a mainline as well as a belay function, it therefore requires that each rope system be able to auto-lock if the ropes were inadvertently let go (sometimes referred to as the "whistle test"). While lowering with a TTRS, each respective Decent Control Device (DCD) operator must be able to vary the friction from essentially a single person load – or less – to controlling the descent of the full rescue load, which may be a multiple person load. The auto-lock must therefore be able to suddenly take on the full rescue load.

An important distinction of TTRS is that they tend to have more initial rope in service prior to having a rescue load transition over an edge than DMDB techniques since each rope system would be rigged farther back from the edge, essentially side by side, equidistant from the edge, and with sufficient room to build a pulley system should the load require to be raised. Conversely, DMDB techniques have generally encouraged the belay system to be rigged closer to the edge to minimize rope elongation so that a falling load could be caught within a shorter stopping distance; this practice however, places a higher fall arrest demand on the belay system as there is less rope in service to absorb the energy of a fall. It is this understanding that led the *British Columbia Council of Technical Rescue* (BCCTR) in 1982 to devise the now well accepted *Belay Competence Drop Test Method* (BCDTM). In fact, the wording of the current ASTM F2436 – 14 *Standard Test Method for Measuring the Performance of Synthetic Rope Rescue Belay Systems Using a Drop Test* essentially mirrors the original 1982 BCCTR BCDTM document, and upon close examination, it is clear that it this test method is intended purely for DMDB systems.

With more initial rope in service, it is conceivable then that certain TTRS would result in successful belay competence outcomes but may be marginal or possibly fail when less rope in service is used. It is important to note that both the ASTM F2436 – 14 as well as the original BCDTM assume that the relative worst case event in rope rescue in terms of demand on a belay system is an edge transition with a full rescue load gone wrong. This worst-case event has been represented in testing as a minimum 1 m drop of a 200 kg mass – representing two people plus gear – onto 3 m of rope in service. The basic success criteria of a competent belay in the BCDTM are to stop the falling load within 1m of additional travel (including rope stretch, knots tightening, belay slippage and any belay assembly extension) and with no more than 15 kN maximum arrest force (MAF). Note that 15 kN may no longer be an acceptable MAF; instead, a 12 kN MAF is more consistent with *current* fall arrest standards/regulations as many international standards only allow 6 kN MAF for one person in a harness, and 12 kN is equal to the sum of two person's maximum fall arrest force, and therefore more suitable for rope rescue. Additionally, the BCDTM required the belay system to remain functional, although it is understood that the system should be retired once the operation is over. The BCDTM also required a minimum residual rope strength - post-drop - of no less than 80% of manufacturer's minimum rated rope breaking strength. The intent of at least an 80% residual rope strength was to demonstrate that the belay system did not reduce the strength of the rope below knotted breaking strength during fall arrest.

Since very few actual rope rescue calls have only 3 m of rope in service while transitioning over the edge with a full rescue-sized load, and since TTRS often are rigged further back from the edge resulting in more rope in service, and also because many rope rescues occur on slopes and not vertical environments, the testing included reduced fall factor belay tests. The objective of those tests was to acquire data to determine whether or not certain TTRS techniques may be suitable for less demanding terrain conditions, rather than only collect data for very demanding high angle environments with very little rope in service.

Despite TTRS typically requiring less demanding belay conditions than DMDB systems due to having more rope in service, for this study, the *baseline* success criteria defining a competent belay within a TTRS will still be considered to be a successful catch of a 1 m drop of a 200 kg mass onto 3 m of rope (fall factor 1/3). Also important in defining a competent rescue belay is that there must be some assurance that some margin of safety exists above and beyond the 1 m drop height. An additional margin of safety can be ascertained by conducting drop tests at a higher fall factor which directly translate into a belay system being capable - or not - of absorbing and dissipating a greater quantity of energy than the relative worst case rescue falls. For higher fall factors, the performance criteria of stop distance and peak force may not apply, but simply knowing whether or not a particular belays system can or cannot withstand a more demanding 'hit' does; as such, only pass/fail success criteria for higher fall factors are sufficient. For this test series, all successful FF 1/3 candidates of TTRS were also subjected to a demanding fall factor ½ (1.5 m drop onto 3 m of rope). The intent of the fall factor ½ test (i.e. 1.5 m drop on 3.0 m rope) was to determine whether or not an additional safety margin which does not result in system failure, exists.

In many regards, establishing which TTRS techniques have substantiated merit, using current conventional rope rescue equipment is 'new ground'. It must be emphasized that there are many potential combinations and permutations of DCD's and belay techniques which could be considered for potential use in TTRS, but little to no data exists on which techniques may or may not work, or how they should or should not be rigged. For example, it was not known if a Double Italian Hitch should be tested with a single Prusik back-up or Tandem Prusik back-up, and equally unknown was whether the Prusik(s) should be rigged in front of the hitch or behind. As such, a number of tests were exploratory in nature and throughout the process of testing, lessons learned from one series of tests allowed for successive examination, elimination or acceptance, and modification of techniques for the next series of tests.

For this study, the TTRS techniques examined included the following:

- Single Italian Hitch with Prusik(s) Back-up
- Double Italian Hitch with Prusik(s) Back-up
- Scarab Rescue Tool with Prusik(s) Back-up
- Micro Rappel Rack with Prusik(s) Back-up
- Belay (Guide) Plates (e.g. Reverso 4; BD Guide ATC) with Prusik(s) Back-up
- CMC Rescue 11mm MPD (Multi-Purpose-Device)
- Petzl I'D (S)

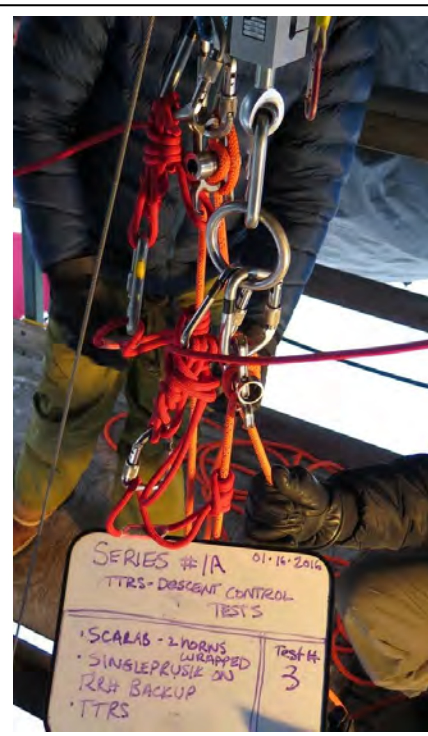
It was also the objective of these tests to try and establish guidelines and performance criteria for TTRS so that in the future, as new ideas, techniques and products come available, there would be a template for comparative testing and therefore a means for either acceptance or rejection based on comparative data. It is impossible to conduct such testing without having to refer to specific products on the market; it is not the intent to promote any particular product, but rather to provide a basis for comparison of existing products and techniques. It is understood that new products will invariably be introduced and it is incumbent on the user to conduct a comparative analysis as to whether or not a new product under consideration is suitable for TTRS.

Before any TTRS techniques were tested, a total of five FF 1/3 drop tests on just the rope alone, with bowline knots at each end were conducted to establish a baseline understanding of the performance and behaviour of just the rope. Since every make and model of rope will perform differently, it was felt that this data was important to obtain for future comparison. It would be erroneous to assume that any results with one rope type will perfectly transfer to identical behaviour with another rope type. Regardless of whether TTRS or DMDB techniques are being tested, testing results must only be treated as indicators of system behaviour and the true variation of system behaviour will be broader than those observed in these tests. As such, techniques with marginal performance must be treated with added caution and margins of safety.

Test Method and Materials:

- All ropes were new, Teufelberger (New England) 11mm KMIII ropes, manufactured in the 4th quarter of 2015; polyester sheath/nylon core; 32 carrier sheath; elongation @ 2.6 kN = 5.1%.
- All Prusiks were new 8mm nylon CMC sewn Prusiks or new 8mm CMC Prusik cord.
- Force and distance measurements were conducted using the following recently calibrated devices:
    - Rock Exotica Enforcer Load Cell
    - Chatillon DPPH-200 Force Gauge
    - Imc Data Acquisition System (model CS-7008-N with an offset uncertainty of +/- 0.01%) sampling at 5000 Hz for drop tests and 1000 Hz for slow pull tests. Load cells were Transducer Techniques HSW-10K and HSW-5K Load Cells with 0.03%FS accuracy; load cells were balanced for temperature prior to all tests. Linear displacement measurements were sampled at 5000 Hz using a Rayelco Linear Motor Transducer Model P-300A.
- Test Masses conform to ASTM F2266 (Specifications for Masses used in Testing Rescue Systems Components).
- Except where stated and/or required for testing TTRS, belay competence drop tests conformed to ASTM F2436 – 14 *Standard Test Method for Measuring the Performance of Synthetic Rope Rescue Belay Systems Using a Drop Test*.
- Unless otherwise stated, slow pull tests were conducted using *Basecamp Innovations Ltd* 135kN hydraulic slow pull machine at a rate of 100cm/min.
- Drop tests were conducted on *Basecamp Innovations Ltd* rigid steel drop tower, purpose built for rope rescue testing.

Series 1a Descent Control and Auto-Lock Tests:



Set-up photo for Series 1a Tests

For each TTRS under consideration, two rope systems were rigged side by side from a rigid I-beam anchor. A free-hanging 200 kg mass was lowered a distance and then stopped and tied-off and subjectively assessed for level of descent control difficulty. The load was then lowered again and the ropes were let go to test the auto-lock function. Subjective level of lowering difficulty assessments was then compared to actual tail tension measurements of various Descent Control Devices (DCD's) while lowering a 100 kg mass (half of a 200 kg mass).

With TTRS, each respective DCD operator would be required to essentially manage half the tension of the rescue load. As such, the level of friction for each respective DCD would likely be less than having to lower the entire rescue load. Therefore, it was important to first establish what the most likely default friction configuration would be for each given DCD to smoothly lower 'half' the load, and then for that configuration the respective tail tension was measured using a hand-held force gauge for a distance of 1m. These configurations where then used as the initial 'template' for rope tailing drop testing in Series 7. Some DCD's allow for the addition or removal of friction points. These devices were tested in multiple positions. All ropes were New England KMIII 11 mm. Descent control devices tested included: Single Italian Hitch; Double Italian Hitch; Petzl Reverso 4; Petzl ID; CMC MPD; Conterra Scarab Rescue Tool; and the BMS Micro Rack.

Series 2b TTRS Belay Competency Tests:

For all TTRS drop tests, a mechanical hand (as per ASTM F2436 – 14) set to 50N of tension was applied to the running end (in-feed) rope to simulate an operator gripping the rope during descent control. Note: 50 N tail tension was shown to be the minimum gripping ability on rope in motion of a rescuer based on the 1993 study on *Gripping Ability on Rope in Motion* by Kirk and Katie Mauthner. Adding a mechanical hand to the tests is a departure from typical BCCTR belay competence tests as it was felt that its inclusion more accurately reflects how TTRS are operated.

Each TTRS technique under consideration began with a FF 1/3 baseline test. If successful, 4 more tests at that drop height were conducted (with new materials) and if all 5 drops were successful, then an additional 'margin' test at FF ½ was conducted. If the FF1/3 test was *unsuccessful*, then the drop height was reduced to FF1/5. If the drop was successful at FF1/5, then 4 more tests at that drop height were conducted. If during any of the 'set of 5' tests for a given drop height failed, then either the drop height was reduced to the next lowest fall factor test, or it was eliminated from further testing. For successful drop sets, a slow pull test of the rope was conducted for residual strength. In certain circumstances where the 'belay' was located behind the DCD, a system strength test using the slow pull machine was conducted to determine what – if any – effect having the DCD between the belay component and the applied load would have. All data and measurements were recorded on respective log sheets.

Results and Discussion:

Series 1a:

The following table shows the required tail tension to feed a given DCD for a given friction configuration. Subjective feel for lowering was then related to a "difficulty" scale, based on tests of human gripping ability on rope in motion.

	Date: 2016 - 01 - 20		**Temp: 1°C**
	Testers: ST, EF		**RH: 94%**
Test	**Device**	**Force (N)**	**Comments**
1	SI	107.0	Easy to moderate
2	DI	~	Easy; need to feed rope into DI
3	I'D Redirected	71.0	Easy
4	MPD 2 Horns	~	Easy; need to sometimes feed rope into MPD
5	Scarab 2 Horns	27.0	Easy; but not smooth; becomes choppy
6	Scarab 4 Horns	~	Easy; but too much friction; ineffective lower
7	Micro 4 Bars	71.0	Easy; very smooth
8	Micro 2 Hyper	9.0	Easy; very smooth
9	Micro 1 Hyper	44.0	Easy; very smooth
10	Scarab 3 Horns	27.0	Easy; very smooth
11	MPD 1 Horns	200.0	Difficult; smooth
12	Reverso-Redir.	18.0	Easy; very smooth

Difficulty Scale:	
Very easy	< 50 N
Easy	51 - 100 N
Moderate	102 - 150 N
Difficult	152 - 200 N
Very Difficult	> 201 N

Series 1b:

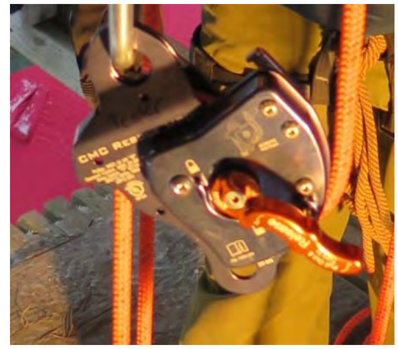
Baseline Tests (bowline to bowline, no belay or DCD):

The average Maximum Arrest Force (MAF) of a 1 m drop on 3 m of rope using a 200 kg mass was 12.3 kN with an average stopping distance of about 65 cm. What this essentially means is that for this particular brand and model of rope, the stretch and energy absorptive capacity of the rope alone, without any 'help' from a belay or DCD is very close to keeping the MAF below our intended ceiling of 12 kN. Results will vary slightly between rope types, but it is important to note that the New England KMIII 11 mm rope is classified as a "Static" rope, and not "Low Stretch", and Static ropes are recommended for rope rescue. It is tempting to assume that a lower stretch rope might help with rescue belays but this will come at a serious cost of increased stopping distance, and therefore increased risk to the rescuer of striking an obstruction during fall arrest. There exists a strong argument in favour of stopping the load as fast as possible by utilizing ropes that elongate less and belay/DCD devices favouring a higher MAF. Both of these factors improve (i.e. shorten) stopping distance. Stopping distance may not appear to be an issue with only 3 m of rope in service, but it becomes very apparent once more rope is in service, say 30 or even 100 m or more. This adverse effect of higher elongation ropes is covered in more detail in the Series 3 tests. The baseline tests show that even ropes classified as Static provide a relatively gentle catch to the rescue load, even at fall factor 1/3. Any slippage by a rescue belay will only further reduce the MAF.

Purpose-Built Mechanical Devices (I'D and MPD):

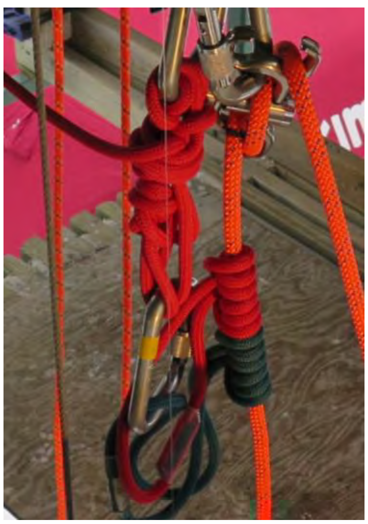
The average MAF for the I'D (S) was 7.8 kN with an average stopping distance of 81.3 cm whereas the MPD was able to stop the load more quickly with an average stopping distance of 66.7 cm and a MAF of 9.7 kN. Both devices had essentially no damaging effects to the host rope and residual rope strength was consistently higher than the manufacturers rated breaking strength, indicating little to no strength reduction to the rope during fall arrest. Even under fall factor ½ drop testing conditions, both devices were able to catch the falling load, remain functional, and retain high strength of the host rope. Under these test criteria, both the I'D (S) and the MPD appear to be capable and competent as belay devices. Each manufacturer of the respective devices has additional operational information available regarding proper use and care for both belaying and lowering which were not part of these test series, but should nonetheless be heeded. However, both devices were 'allowed' to auto-lock during drop tests; series 7 tests provide some insight to belay performance when the auto-locks are actively being defeated during fall arrest.

Petzl I'D



CMC Rescue MPD

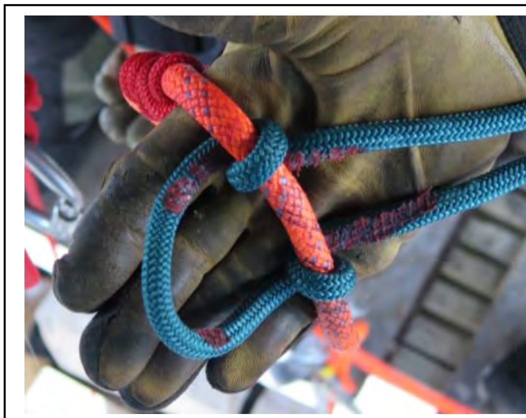
Descent Control Devices (DCD's) with Hitches as Auto-Locks:



Scarab with Tandem Prusiks in front

A key lesson reinforced from these tests is that it is false to assume that what was previously 'known' with regard to Prusik performance with DMDB systems will simply transfer and reapply to TTRS; it does not. With a DCD rigged behind the Prusik(s), one might assume that the added friction from the DCD would remove some of the fall arrest demand off the Prusiks and place it onto the DCD, and therefore make the Prusiks and/or DCD/Prusik combination even more capable of catching higher drops. In fact, the opposite occurs.

Regardless of whichever DCD was used, and regardless of whether single or Tandem Prusiks were used, Prusik performance dropped dramatically when placed in front of the DCD. Not only did Prusik gripping ability (i.e. MAF) decline, but stopping distances increased, Prusik melting and glazing increased, and in some cases outright failure occurred. Only with very high friction DCD's was there promise of a competent and capable system (e.g. see tests involving Double Italian Hitch, or Scarab with at least 3 Horns of friction with tandem Prusiks). In other cases, there was the initial appearance of a successful catch, but once tension was removed from the DCD, the rope subsequently continued to slip through the Prusik, even though the system was now essentially in a static state.



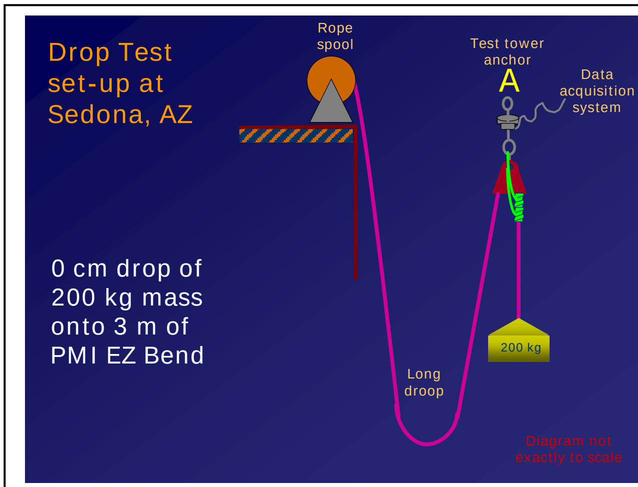
Prusik with nylon film

From the beginning, the observations and results were alarming to the testers since different outcomes were being anticipated. To ensure that the observations were not related to the choice of rope or Prusiks, some 'validation' tests were conducted on 'known' systems. Consequently, concerns with choice of rope and cordage were ruled out with successful 1 m drops on

3m of rope with 200 kg mass onto a ‘classic’ Tandem Prusik Belay with a Radium Release Hitch; results were normal and as expected. Additional drop tests were conducted with the load cells connected to both the DCD and separately to the Prusiks. One might assume that even with some tension applied by the DCD that the Prusiks would do the bulk of the fall arrest work, but this is not true. Tests confirmed considerably less gripping ability of Prusiks once tension was applied to the host rope behind the Prusiks.

The tests show that once the host rope is tensioned behind the Prusiks, fall arrest performance drops substantially. Only very high friction DCD’s resulted in successful FF 1/3 catches, specifically the Double Italian (aka Münter) Hitch and the Conterra Scarab – but only with 3 or more horns of friction – showed promise, although stopping distances exceeded the desired 1 m or less stopping distance success criteria.

As an aside – but arguably germane to the above finding – was that over 25 years ago in 1990, John Dill of Yosemite Search and Rescue wrote an article for *Response Magazine* entitled, “Are You Really on Belay”. In many regards, that article is as valid today as it was in 1990. Dill carefully attempted to summarize lessons learned from drop testing on rescue belays that first took place at the initial BCCTR Penticton 1982-1986 drop tests, then the subsequent drop test series that occurred on Forrest Equipment’s drop tower in Boulder, CO in 1987 with Dill, Hal Murray and Arnör Larson (likely the first rope rescue testing of its kind with force over time instrumentation), as well as the testing that occurred in 1989 in Sedona, AZ when Reed Thorne joined the group of testers.



In the Sedona tests there was one particular and peculiar fall factor zero test in which the Tandem Prusiks failed to catch the falling load (note: there were also 3 other tests of significance where the Prusiks failed to catch the load). But this was an anomaly to the norm of results; nonetheless it occurred, and it caused considerable consternation amongst the testers as to the cause. Speculation ranged from blaming the inclusion of the Prusik Minding Pulley ‘straightening’ the rope prior to entering the Prusiks – causing a camp of rescuers to conclude and demand the omission of having a PMP in the belay system while lowering - to the Prusiks having become loose prior to the drop (new Prusiks tend to open up more easily than used Prusiks), and even the test method came into question.

In that particular test – amongst many - the rope spool for testing was located on top of a building roof adjacent the radio tower that was being used as a drop tower, and the rope came off the spool then down to near ground, under the tower lattice and up to the redirect PMP before entering the Prusiks being tested. It was posited that possibly the ‘back-tension’ of all the rope in service hanging below the opposite side of the pulley than the Prusiks may have influenced the test(s) and caused the failure. In the end, due to time and material constraints, the testers could neither prove nor disprove any one possible cause, and as a result, John Dill very appropriately surmised in his article summary that, *“…tandem Prusiks <u>appear</u> to be less reliable at initially grabbing a straight rope than a bent one. They* *may delay before grabbing or a complete failure to grab may occur*." While Larson and Thorne felt that the effect of back-tension from the test set-up would not occur in the field since they believed that correctly rigged and tended Prusiks will have rope entering the Prusiks with little tension on them, and when jerked, the rope may "*develop waves and kinks that trigger the Prusiks like a bent rope does*." Dill went on to say that, "*In all four cases [of failure to grip] enough rope hung down from the spool side of the pulley that its weight may have prevented those kinks. This explanation is not confirmed, but it implies that if the rope enters the Prusiks straight, even the friction of rope laying in the brush or rocks, or the tension applied by a belayer hauling rope through the pulley must be carefully controlled or eliminated.*"

What is commendable and should be remembered about Dill's summary is that he distinctly made a point of emphasizing that Prusik belay failures were 'observed', and it warranted suspicion of the technique since the true cause of the failures could not conclusively be identified. While other modes of Prusik failure do exist (e.g. too loose; improperly dressed; material too stiff, among others) and have been examined over the years in more detail with other testing, the January 2016 EMBC NIF test series clearly demonstrate that a tensioned rope behind Prusiks dramatically and adversely affects fall arrest performance. Dill's summary over 25 years ago intimated this but they could neither prove nor disprove their suppositions. One of the possible reasons why this wasn't subsequently isolated as a key potential failure mode was that their testing, and essentially all subsequent Prusik belay testing centered around DMDB scenarios and conditions. In other words, testing was essentially focussed on un-tensioned belay lines and therefore the adverse effects of a tensioned rope on Prusik belay performance would likely have gone unnoticed.

Yet in practice, once the rescue load is well past the edge and in the fall line, it can become problematic to keep feeding an un-tensioned belay line as the rope mass alone can cause the belayer to unwittingly over-feed belay line, at a rate faster than what the mainline is being fed out at. To solve this, it was – and is – common practice to add a DCD ***behind*** the Prusiks to not only prevent over-feeding the belay line, but also to remove some of the rope stretch. This practice, in essence, converts the DMDB system into a type of two-tensioned rope system, with the false assumption that Prusik belay performance will remain the same. Clearly this is not true.

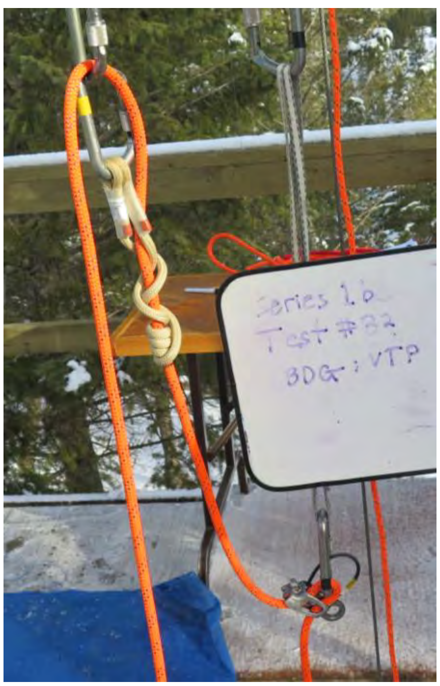
Once it became apparent that having a DCD positioned behind the Prusiks adversely affected their ability to effect fall arrest, testing then focussed on positioning the *DCD in front of the Prusiks* (i.e. Prusiks behind DCD). The technique of positioning the auto-lock behind a DCD is/has been a relatively common practice amongst teams that use the Traverse 540 Rescue belay in that once additional friction was desired to make it easier to feed out belay line and also to remove some of the rope stretch, a DCD, such as a climber belay device such as a Petzl Reverso or a Black Diamond ATC Guide, would be attached to the rope

DCD positioned in front of 540 Rescue Belay device

approximately 60-120 cm in front of the 540 Rescue Belay. There are also certain European mountain rescue teams (e.g. in Germany, Poland and Austria) that place an auto-lock behind the DCD; teams that use Dyneema TTRS tend to do this, but for different reasons). It is also a relatively common mountain guiding practice to back up non-standard lowers of clients with a Prusik clipped from the guide's belay/rappel loop to the rope – in other words, *behind* the DCD.

For this series of testing, not only did stopping distances and MAF values substantially improve with the Prusik positioned behind the DCD, it became evident that even using a single 8mm triple-wrapped Prusik was more than adequate to catch a FF 1/3 fall of a 200 kg mass. Even FF ½ falls were easily caught with this configuration. It was also noticed, that in most cases it was relatively easy to break the Prusik free after catching the load, without having to release the release hitch. DCD's tested in this configuration included the Double Italian Hitch, Microrack, Conterra Scarab, and climber belay devices (Petzl Reverso 4 and BD ATC Guide).

The cleanest and simplest setups included any of the aforementioned DCD's, together with either the VT Prusik (Valdotain Tresse Prusik) or the 'guides Prusik' (a triple-wrap Prusik constructed using the center of a 5 m length of cord, made releasable by anchoring it with an Italian hitch with doubled cord, secured with a half-hitch on a bight finished with an overhand on a bight. Note: the latter technique of tying a releasable Prusik is commonly utilized by professional mountain guides. Configuring the Prusik behind the DCD, generally resulted in a MAF to the Prusik of about 2 kN or less (instead of 7-12 kN when positioned in front of the DCD). For this reason, a single 8 mm Prusik is considered more than adequate for the task. Post drop, residual rope strengths exceeded the success criteria of having at least 80% residual strength, and the systems remained functional. As with the purpose-built mechanical devices, the configuration of an 8 mm Prusik behind the DCD meets the criteria of a capable and competent belay for TTRS under these test conditions, but does not yet address the need to assess defeated auto-lock performance, which is discussed further in Series 7 tests.



VT Prusik behind Reverso 3

From a practical operational standpoint, there was enough clearance for the Prusik to effectuate fall arrest - and be released post drop - when the DCD was extended forward of the anchor using a sewn 60 cm sling; a 120 cm sling was more than adequate. The DCD did not interfere with the Prusik with this spacing. Feeding rope into the DCD with this spacing was also easy to accomplish, and these setups all utilized commonly carried, non-specialized materials.

In an attempt to obtain more of an overall systems analysis – rather than just focus on belay performance - some additional quick-look series of tests which weren't originally called for but considered pertinent, were conducted to get an indication of how strong each respective DCD is when rigged with the Prusik behind the DCD. In general, there were no surprises when compared to previous work conducted by Basecamp Innovations Ltd. Most DCD's had the rope fail at about 20 kN where the standing part of the rope entered the DCD, with the exception of the climber belay devices (Reverso 4 and the BD ATC Guide) which place a sharper bend on the rope, and therefore rope failure occurred at a lower value. System strength for these devices were about 15 kN, which is also consistent with the strength rating marked on the Petzl I'D (S). The key difference between the ID and systems with a Prusik back-up behind the DCD is that like the MPD, the I'D tends to 'force limit', rather than come to system failure, and this is a desirable/preferential trait. This is discussed further in the Series 5 tests.

Slow-Pull System Test of Petzl Reverso 4 with Releasable Prusik anchored behind

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EMBC Rope Rescue NIF - Equipment Testing 2016

Series 2 - Sharp Edge Sliding Tests:

Test Objectives:

The objectives of these tests were to compare a TTRS (Two-Tensioned Rope System) to a DMDB (Dedicated Mainline, Dedicated Belay) when subjected to a sudden slide of the ropes across a sharp edge with no free-fall over an edge involved. Two types of rope slide tests were conducted: one type had the mass offset from the fall-line, simulating the rescue load swinging back into plumb; the second set of tests had the mass positioned plumb with the anchors and the ropes were offset at the edge simulating a sudden sweep of the ropes back into plumb. Additionally, a comparative assessment of the performance of different types of edge protection to prevent rope cutting was conducted.

Importance and Background:

Historically – at least in North America – with two rope systems, one of the primary reasons for having an *un-tensioned belay* stemmed from the logic that an un-tensioned rope is less likely to be damaged from sliding across a sharp edge than a tensioned rope, and therefore it was assumed that while damage may occur to the dedicated mainline but the belay would more likely be spared from damage. Consequently, this was then considered a better risk management strategy for sharp edges than TTRS techniques. However, in 2014 *Basecamp Innovations Ltd* conducted a series of sharp edge drop tests that demonstrated that no evidence could be found to support the premise that DMDB techniques provided higher levels of safety than TTRS. In fact, contrary to conventional thinking, the evidence clearly showed that TTRS survived better than DMDB systems when subjected to sharp edge drop tests (which included both straight over the edge drops as well as drops that resulted in the ropes sliding across a sharp edge). These results were presented at the 2014 ITRS (International Technical Rescue Symposium) in Golden, Colorado, USA. Compelled by these findings, in 2015, parallel – although independent – similar sharp edge tests were repeated by Mike Forbes of Spokane WA, USA and Russell McCullar of the Mississippi State Fire Academy. Their findings were essentially consistent with the 2014 Basecamp Innovations Ltd findings, and were separately presented at the 2015 ITRS.

Test Method and Materials:

A: Offset Mass Tests:

For 'relative' consistency between tests, a ground and hand filed angle iron steel edge was used as the sharp edge. The test mass was 200 kg and all ropes were new 11 mm New England (Teufelberger) KMIII. Some experimentation was required to create a condition severe enough to result in significant rope damage and severing of

Offset Mass Sharp Edge Test, Ropes Held by Rope Grabs

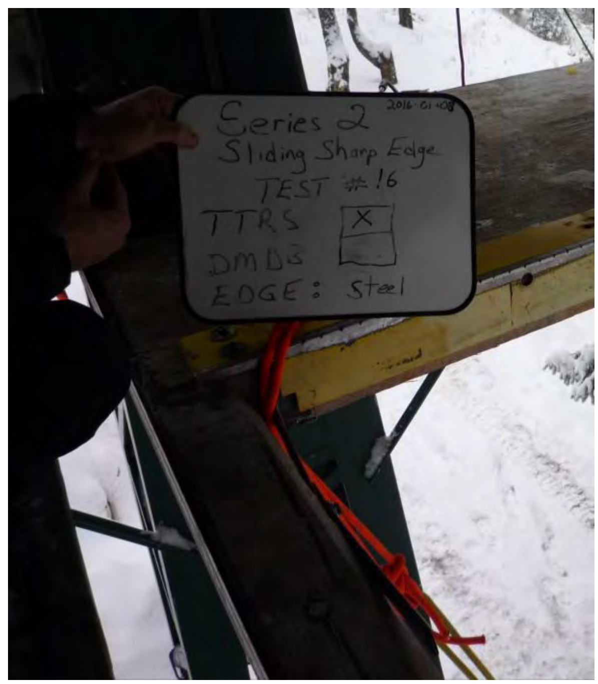
ropes, but not so severe that all ropes would fail. The intent was to 'fine tune' the test method such that any differences *between* TTRS and DMDB techniques would be revealed. It was not at all the objective to compare how sharp an edge would need to be to cause failure; it just needed to be *relatively consistent between tests in order to compare different rope techniques under similar conditions*.

Each rope was held by a Petzl Rescucender, connected to a carabiner connected to a single fixed eyebolt anchor with a separation of 10 cm between anchors. Troll Rocker rope grabs secured the ropes to the mass. A quick release hook was used to release the mass from its offset position and the ropes were allowed to slide across the sharp edge as the mass swung 'back to plumb'. Observations on rope damage/failure were written on log sheets and each test was video recorded. No force or distance measurements were taken.

B: Offset Ropes, Mass in Fall-Line Tests:

As with the Offset Mass Tests, the same ground and hand filed angle iron steel edge was used as a sharp edge, with the addition of equidistant serrations filed along the edge. The test mass was 200 kg and all ropes were new 11 mm New England (Teufelberger) KMIII. The ropes were deflected sideways and a steel quick release 'gate' was used to suddenly and consistently release them. The mass was positioned in the fall line (plumb to the anchors) by a carabiner redirect. Each rope was held by a Petzl Rescucender, connected to a carabiner connected to a single fixed eyebolt anchor with a separation of 10 cm between anchors. Troll Rocker rope grabs secured the ropes to the mass.

With the release of the offset ropes, the mass was allowed to fall with gravity resulting in the ropes quickly sliding across the level sharp edge. Observations on rope damage/failure were written on log sheets and each test was video recorded. No force or distance measurements were taken.



Offset Ropes, Mass In Plumb, Sharp Edge Tests

C: Comparison Between Different Types of Edge Protection:

Using the same test setup, edge and mass as *B: Offset Ropes, Mass in Fall-Line Tests*, different types of edge protection were placed under a single, new section of NEW England KMIII 11 mm rope. Three different edge protection were tested: multiple layers of CMC Rescue Canvas, CMC Edge Guards and CMC Ultra Pro Edge Protectors. The intent was to get some indication of how much edge protection would be required to ultimately protect the ropes from damage and also to compare the relative effectiveness of different types of edge protection for the same sharp edge. It is understood that different magnitudes of sharp edges would require different levels of protection.

Edge Protection Materials:

- CMC Edge Pad: made from 24-oz #4 canvas
- CMC Edge Guards: made with #4 duck canvas and a layer of vinyl coated polyester. The Edge Guards close with a two-inch strip of hook-and-loop.
- CMC Rescue Ultra-Pro™ Edge Protectors: made from proprietary polyethylene material.

Observations on rope damage/failure were written on log sheets and each test was video recorded. No force or distance measurements were taken.

Results and Discussion:

A: Offset Mass Tests:

The sharpened steel edge was tested positioned level and perpendicular to the plumb line as well as non-level and not perpendicular to the plumb line. In both configurations, damage to the ropes with TTRS was at best minor chafing, at worst some sheath picks were cut and the core exposed, whereas with DMDB tests, at best the mainline sheath and some core was cut, with minor chafing to the belay, at worst both main and belay lines were completely severed. In all direct comparisons, TTRS performed better than DMDB systems when subjected to respective sharp edge tests.

Test 5 TTRS Post Drop

Test 6 DMDB Post Drop – Main Severed

B: Offset Ropes, Mass in Plumb Tests:

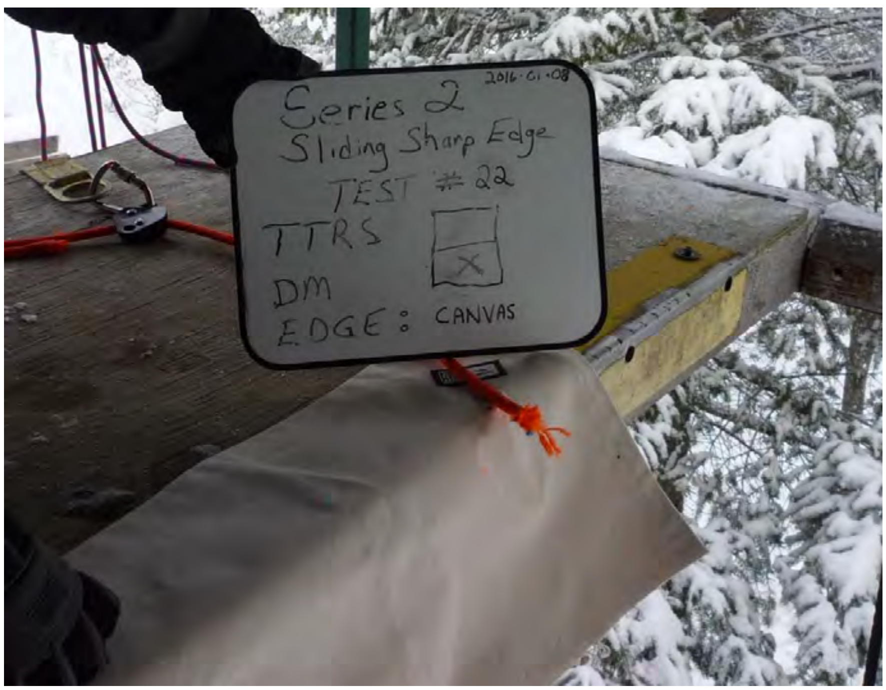
Test 17 TTRS Post Drop

Test 19 DMDB Post Drop

The intent of the serrated sharp steel edge was to create a very damaging edge for whichever system was subjected to it. With TTRS, moderate to severe sheath damage occurred to both ropes with the core exposed but not cut, whereas with the DMDB technique the dominant pattern was both the mainline and belay line being completely severed. In one test, only the mainline was completely severed and the belay had severe sheath and some core damage.

C: Edge Protection Effectiveness and Type Comparison:

With sharp, destructive edges, the testing data suggests that at least three, preferably 4 layers of canvas would be required to mitigate the risk of damage to the ropes. A single layer of canvas overlying a very sharp edge still resulted in complete severing of the rope. Therefore, a single layer of canvas cannot be recommended to protect ropes from very sharp edges, but rather be used to protect ropes from abrasion due to minor edges and terrain roughness. Even the vinyl coated canvas wrap-around edge guard did not provide enough protection to prevent severe sheath damage under these test conditions. Only the proprietary polyethylene rigid edge protector provided sufficient protection to the rope to prevent damage.



Test 22 Post Drop – Rope Severed, 1 Ply Canvas

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EMBC Rope Rescue NIF - Equipment Testing 2016

Series 3 - Force & Elongation Comparative Analysis:

Objective:

The objective of these tests were to quantify the differences in zero fall factor forces and stopping distances between TTRS and DMDB systems as well as between classification of rope types with respect to elongation, specifically Static ropes as defined by Cordage Institute standard CI-1801 Low Stretch and Static Kernmantle Life Safety Rope and Class A ropes as defined by CE/EN 1891.

Importance and Background Information:

Two important risks that must be managed in rope rescue belay systems are maximum arrest force (MAF) and stopping distance. Often, these are diametrically opposed needs as increased stopping distance can reduce MAF, but at an increased risk of the rescue load striking an obstruction during fall arrest. In the Series 1 tests, reference was made to the success criteria of a rescue belay being able to stop a falling rescue belay within 1 m stopping distance (this includes rope stretch, knots tightening up, belay slippage and any belay assembly extension, pre-rebound) and with no more than 12 kN MAF. It is important to distinguish that the real risk to the rescuer during stopping distance is the *pre-rebound* stopping distance, not the slide distance or extension at the belay or DCD. Every increase in stopping distance directly increases the risk to the rescue load to strike an obstruction during fall arrest. MAF can be properly managed by using devices which limit the peak force below a threshold value. However, zero fall factor conditions are a special case with regard to MAF. A well understood and demonstrable physics principle is that with zero fall factor scenarios, the elongation rate of the rope will make essentially no difference to MAF, regardless of whether a Dynamic, Low Stretch or Static rope are used (*presented by Kirk Mauthner at the 1989 ITRS*). It seems counterintuitive but the MAF will be essentially the same between rope types, even though stopping distances are substantially different. Increased stopping distances directly increase the risk to the rescuer striking an obstruction during fall arrest. Not only can stopping distance be influenced by the choice of reduced elongation ropes, but also by choice of technique. This series of tests provides data to quantify the peak force and elongation/extension differences between Static and Low Stretch ropes, but also between TTRS and DMDB techniques.

To provide a relatively realistic perspective of MAF and stopping distance of what might be encountered in rescue operations, tests were conducted in both a free-hanging environment using a 200 kg mass, representing two people plus gear, as well as a 45-degree slope using a 360 kg mass, representing three rescuers plus a patient and gear, as might be encountered on an over-the-side slope rescue. Additionally, to help understand the relative increase in risk to rescuers due to extension (i.e. physical displacement), two different lengths of rope in service were tested with the 45-degree angle slope, specifically 3 m and 30 m rope lengths.

Test Method and Materials:

Teufelberger (New England) 11 mm KMIII rope was used to represent a Static Rope conforming to CI 1801 and an 11 mm Marlow was used to represent a Low Stretch rope conforming to CE/EN 1891. Three tests of each rope type for both TTRS and DMDB techniques were conducted on both a 45-degree slope (using a 360 kg mass), with both 3 m and 30 m lengths of rope in service. Additionally, MAF and stopping distances comparisons between Static and Low Stretcher ropes were conducted for both DMDB and TTRS techniques.

Peak forces were recorded using Rock Exotica Enforcer Load Cells as well as the imc-DAQ system. Stopping distances for all 45-degree slope tests were measured by marking the furthest extent the test mass rolled, pre-rebound. In all free-hang tests, stopping distance was measured using the DAQ Linear Transducer. The 360 kg steel mass was comprised of 20 kg steel plates bolted to a cart housed on sturdy and efficient polyurethane dolly wheels, rolling down a rigid ramp surfaced with rigid 11 mm puck board. A descent/ascent efficiency assessment of the cart revealed an efficiency loss of approximately 2% or 0.98 efficiency (2500 lowering tension over 2550 raising tension). The angle of the ramp was measured to within +/- 0.05 degrees of 45-degrees.

For DMDB tests, the belay rope was pre-tensioned to 50N for consistency between tests; for the TTRS tests, the load will tension was equally shared between the ropes using Rock Exotica Enforcer Load Cells to confirm the respective tensions. For each test, one supporting rope was failed using a quick release and the resultant peak force and system extension was measured and recorded on log sheets.

Test 5 Set-up of cart and 30 m of rope in service

Results and Discussion:

The table below shows the difference in MAF and Stopping Distance between Static Rope and Low Stretch rope under various rope length, mass, and slope angle conditions.

Series 3 Force and Elongation Comparative Analysis		360 kg; 45° Slope 30 m Rope		360 kg; 45° Slope 3 m Rope		200 kg; Free-hang 3 m Rope	
		Avg MAF (kN)	Avg Stop Dist (cm)	Avg MAF (kN)	Avg Stop Dist (cm)	Avg MAF (kN)	Avg Stop Dist (cm)
DMDB	**Static**	5.0	155.0	5.3	50.5	4.5	53.0
	Low Stretch	5.6	279.5	5.4	54.5	5.0	46.0
TTRS	**Static**	3.3	40.5	2.7	4.0	2.7	6.5
	Low Stretch	3.3	46.5	2.8	6.0	2.7	7.5

The above data provides some key information to help quantify the advantages of using a TTRS over a DMDB technique, as well as choosing Static rope over Low Stretch rope.

MAF: This data proves that the physics principle which states that for a zero fall factor condition, peak force will be essentially the same regardless of whether a Static or Low Stretch rope is used, is true. This is especially evident when looking at the TTRS results between Static and Low Stretch; peak forces are essentially identical. Differences in Static and Low Stretch MAF for DMDB systems are more likely due to higher experimental variation when testing DMDB systems. Naturally, this could theoretically also be applied to real world conditions, meaning that there would likely be more predictable and consistent results with TTRS than with DMDB techniques under field conditions. However, what is important to understand from this data regarding MAF, is that it is erroneous to think that a higher elongation rope will provide lower peak forces under top-rope conditions. The reality is that peak forces will be essentially the same, regardless of the rope elongation rate.

The next key piece of information which the data clearly reveals is that the MAF using TTRS is substantially lower than with DMDB systems. The typical peak forces of DMDB systems are about 50% higher than what TTRS peak forces are. While a difference of just a few kN may not seem like much, it can make all the difference when ropes are inadvertently presented to a sharp edge. The sharp edge testing conducted by Basecamp Innovations Ltd in 2014 suggested that when rope tension exceeds 4 kN while presented to a specific sharp edge, it tended to sever, whereas if the rope tension could be kept below that value, complete severing of the rope was less likely to occur. There appears to be a relationship between kernmantle rope tension and the propensity to completely sever. While there may be a number of factors that affect the value at which severing occurs, it can be simply stated that less tension on a rope will result in less likelihood of severing on a sharp edge. While this may seem obvious, what is not obvious is that the 'tipping point' between severing and not severing might very well lie in the difference in tension between that of a DMDB system and a TTRS.

From a rope rescue systems behaviour perspective, in a zero fall factor environment (i.e. top-rope) it can also be said that with DMDB systems, going from an un-tensioned to suddenly a tensioned state (i.e. from an un-tensioned belay to suddenly falling onto the belay, with no free-fall) will result in a force spike – or a jolt to the system - somewhere between 2-2.5 times whatever the initial static load was (presented by Kirk Mauthner at the 1989 ITRS Conference). For TTRS, the static state to MAF ratio is closer to being only 1.3-1.5 times the initial static force. This is true for vertical as well as sloped environments. A correct understanding of how much peak force might climb to in a zero fall factor environment (which is actually the majority of time a rescue load is being subjected to) has significant implications to determining what an appropriate system strength 'actually' needs to be and also provides insight to where the ideal 'force-limiting bandwidth' needs to be for rescue work (discussed further in Series 5 Tests).

<u>Stretch:</u> The data also clearly shows that in zero fall factor environments, Low Stretch ropes, stretch considerably farther than Static ropes (except in one case in the data set, where experimental variation may have influenced the results). Longer stopping distances translate directly into increased risk of the rescuer striking an obstruction during fall arrest. Shorter stopping distances are especially noticeable with TTRS compared to DMDB techniques; the contrast in stopping distances is substantial. In some cases, the stopping distances with DMDB systems were 8-10 times greater than what occurred with TTRS. The importance of this cannot be understated. TTRS are far better at managing the risk of a rescuer striking an obstruction during fall arrest than DMDB systems do. As an example, with only 30 m of rope in service, the rescue load on the 45-degree slope using a DMDB required about 1.6 m distance to stop the load whereas with the TTRS only 0.4 m of distance was required to stop the load. Extrapolate this risk to operations with considerably more rope in service and the magnitude of risk becomes proportionally greater, even for slope rescues.

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Series 4 - Comparative Analysis Between Prusiks and Mechanical Rope Grabs when used in a Mechanical Advantage Pulley System:

Objective:

The objective of these tests was to compare the respective difference in slip force performance of Prusiks and Mechanical Rope Grabs when used in two versions of the commonly used 3:1 mechanical advantage pulley system configuration, specifically a 3:1 made out of the mainline as well as a 3:1 acting on (i.e. piggy-backed or ganged onto) the mainline.

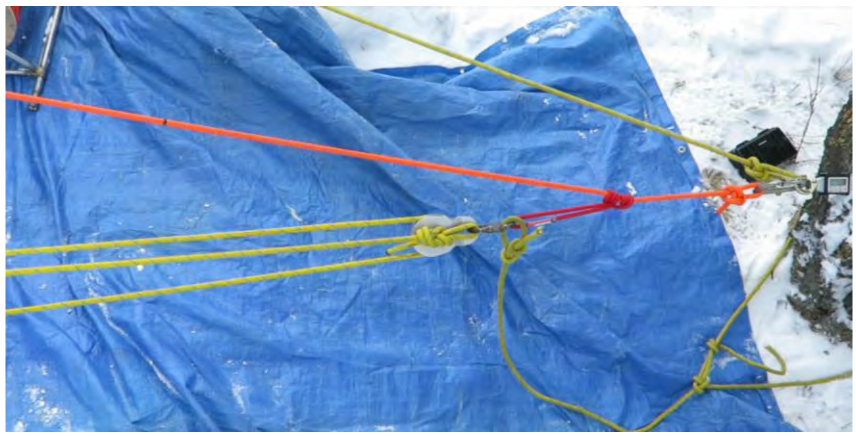
Importance and Background Information:

While hydraulic slow pull machines are commonly used to get an indication of how rope grabs perform on rope, they may not accurately represent what might really happen in an actual rope rescue setting. Hydraulic slow pull machines pull at a constant rate of speed and consequently if the rope grab suddenly slips, the rope tension will also suddenly decline until the hydraulic ram catches up and reapplies tension. This is not what happens under field conditions. Pulley systems built from synthetic fibre ropes inherently have strain energy stored in the system while hauling on the pulley system occurs. Therefore, the behaviour of the interaction between the rope and the rope grab might be different than that observed during slow pull tests with a hydraulic ram. This might be particularly true immediately after initial slippage occurs. This strain-energy effect may also be exacerbated with more rope in service as a greater quantity of rope may slip through a rope grab before forces resolve themselves. Early testing conducted by the *British Columbia Council of Technical Rescue* (BCCTR) alluded to this and consequently explored what they called “Constantly Applied Tension Tests” (CAT) in addition to conducting comparative slow pull tests using aTirfor cable winch. What the BCCTR observed back in the mid-eighties with Prusiks under CAT tests was that Prusiks tended to slip and forces resolved themselves, whereas most mechanical rope grabs (Jumar and Gibbs Ascenders) failed the rope completely with little warning, yet these same mechanical rope grabs ‘only’ failed the sheath under slow pull test conditions. The BCCTR concluded that slow pull tests may not accurately reflect what might happen in rope rescue conditions. In the BCCTR CAT test setups, they had a rope grab attached separately to a mainline, as might be done when a pulley system is ganged onto the mainline. Forces were observed on a Dillon Dynamometer. However, no tests were done as a comparison between rope grabs within a pulley system, either acting on or made out of the mainline.

The tension on the rope grab is different when the pulley system is made out of the mainline than when the pulley system is ganged onto the mainline. For example, when a 3:1 pulley system is made *out of the mainline*, the rope grab will be subjected to 2/3 of the load whereas with a 3:1 pulley system ganged *onto the mainline*, the rope grab will be subjected to 100% or 3/3 of the load. Additionally, with a pulley system made out of the mainline, the rope grab will be required to grip a *tensioned* strand of rope whereas with a pulley system ganged onto the mainline, the rope behind the rope grab will be essentially *un-tensioned*. These tests allow a comparison of slip force and behaviour between different rope grabs and two types of the same mechanical advantage pulley system.

Methods and Materials:

For these tests, a 3:1 mechanical advantage pulley system was constructed with 5 metres between the anchor and the rope grab being tested. Both a pulley system made out of the mainline as well as ganged onto the mainline were tested. All ropes to which the rope grabs were applied were new, unused New England KMIII 11 mm ropes. Triple wrapped Prusiks were new CMC Rescue 8 mm sewn Prusiks. The mechanical rope grabs in this test series include the Gibbs Ascender with a Stainless Steel shell, and a Petzl Rescucender. The Rock Exotica Enforcer Load Cell was connected directly to the rope grab being tested, and therefore rope grab tension was directly measured, which - in the case of a pulley system made out of the mainline - is not the same as the tension on the mainline. Rope was pulled through the pulley system using a gas-powered capstan winch with a fixed rate of speed of 12m/min for consistency between tests. The pull was applied either until failure occurred or once 1 m of slippage had occurred. Force graphs were recorded for all tests.



3:1 Pulley System Acting On Mainline Test Set-up with Single 8 mm Prusik

Results and Discussion:

The intent of the test method was to obtain data that was relevant and meaningful to rope rescue with respect to what might actually happen in field conditions. The test method involved actual mechanical advantage pulley systems using static rescue rope. The strain energy while pulling on the pulley system was contained essentially to the pulley system only, as the mainline extending from the rope grab in these tests was relatively short (i.e. 1 m). Field conditions will often result with more mainline in service in front of the rope grab. However, it is dominantly the length of the pulley system 'throw distance' (i.e. the distance between the fixed and traveling pulleys when fully extended) that will affect how far a rope grab might slip – or do its thing – because the quantity of strain energy will be essentially the same for the same mechanical advantage, same rope type and same number of people pulling on the pulley system.

Therefore, it is the magnitude of extension (slippage) that a rope grab might be subjected to during the first slip, that is of greatest concern. A second, or multiple of subsequent slips would require the haul team to essentially ignore the first slip, and keep going – a practice that would be counter to good risk management. As such, for interpretation of results, it is important to focus on what happens to a rope grab during the first slip. All rope grabs can be brought to failure, especially with slow pull machines, but this isn't necessarily the data that should be used for comparative analysis for the purpose of rope rescue. And in a sense, neither should peak force. Far too often in rope rescue testing, only the peak force is provided for rope grabs, and this data can be very misleading. Careful examination of each and every force-over-time graph reveals relevant and meaningful data, especially between the first and second slip points - if they exist – coupled with video in order to see the physical effects during those periods. Videos are provided for all tests conducted in this test series.

With rope grabs, regardless of whether they are mechanical or textile (i.e. hitches), there is often a difference in what happens at the first point of slip, or more accurately, the first point at which static gripping is lost, and then what happens after that point. It is a reasonable argument to state that the ideal rope grab for rope rescue would statically grip the rope without slipping until a specific threshold force is reached, upon which the rope grab would slip and forces would resolve themselves through slippage, and correspondingly there would be little to no damage to the rope system (i.e. the system remains functional). The key target slip force threshold (discussed further in Series 5) lies in a bandwidth somewhere between 6-12 kN.

First Slip (Stiction) Results:

All rope grabs tested were able to statically grip at least 6 kN, and all rope grabs except the Gibbs Ascender was able to slip and cause little to no rope damage; the Gibbs Ascender failed the rope sheath during the first slip. Note: chafing and light glazing of the host rope was considered acceptable since it is understood that a considerable amount of energy will be released out of the system, and that it would be natural for there to be chafing and/or glazing from such an event; what is important however, is that the system remains functional after the first slip. It could also be argued that if some compromising damage does occur, that it happens to the rope grab and not the host rope. The consequence of failing/damaging the host rope is far more serious than failing/damaging a rope grab. Single 8 mm Prusik Hitches tended to deposit a light to moderate amount of molten Prusik material to the host rope then appear to fuse to the host rope. Continued pulling however, resulted in subsequent slips before Prusik failure occurred.

Rope Grab Comparison - When Used in a 3:1 Pulley System

3:1 Pulley System Acting on Mainline	**Avg First Slip Force**	**Average Pk Force**	**Typical Result at First Slip**	**Typical Result after First Slip**
Single Prusik	8.5	11.6	slipped suddenly 0-40 cm	slip/stick until hitch failed
Gibbs Ascender	7.0	7.7	settled-in 15 cm; broke sheath	sheath bunching; core strands failing
Rescucender	8.0	11.8	slip about 20cm; light glaze	slip/stick, rope chafing
Tandem Prusiks	11.1	16.0	Continuous slipping & melting	slip/stick, nylon melting
3:1 Pulley System Made Out of Mainline	**Avg First Slip Force**	**Average Pk Force**	**Typical Result at First Slip**	**Typical Result after First Slip**
Single Prusik	6.3	9.1	sudden, then continuous slip	slip/stick, nylon melting
Gibbs Ascender	6.6	7.0	in 10 cm, broke sheath, some core	sheath bunching, core strands failing
Rescucender	8.2	11.1	slipped 10-20 cm, chafing	sheath failure after 2nd slip
Tandem Prusiks	8.0	13.2	sudden slip up to 30 cm	slip/stick, nylon melting

After First Slip Results:

All rope grabs required a greater force to cause a second slip to occur and only Tandem Prusiks exceeded the desired upper limit of the force limiting bandwidth of 12 kN. While it can be argued that it would be very difficult for a pulley system haul team to generate that magnitude of force, it should be recognized that forces exceeding 15 kN is high enough to yield other rope rescue components. For perspective of how hard it would be for a haul team to generate 12 kN of tension, in the mid-eighties the BCCTR developed the “multiple of 12 principle”, whereby experimentation revealed that if the combination of people of pulling multiplied by the mechanical advantage is 12 or less, then the rope tension will be about 3 kN (assuming hard hand-over-hand pulling with no ‘heave-ho’). This would then require six people pulling on a 3:1 MA to achieve 3 kN of tension on the host rope. This principle has been proven through experiments literally hundreds of times. Given this, to achieve 12 kN of tension would require a fourfold increase in pulling capability, something which is highly unlikely to occur.

Stiction (Static-Dynamic-Static) Friction:

The behavior of a rope grab to grip the rope, then slip, re-grip, then slip again is due to a physical requirement of having to overcome static friction, or stiction, and since ‘dynamic friction’ is usually lower than static friction, rope will tend to run through the rope grab until forces resolve themselves to the point where dynamic friction is once again sufficient to regain static friction. It is therefore of interest to examine where this dynamic to static friction point is, as this value affects how much rope might slip through the rope grab during the dynamic friction phase. The general trend shows that the ‘re-grip’ force was about half of the initial slip force, which usually resulted in a typical range of 15-30 cm of rope slipping through the respective rope grabs.

Under certain conditions, only the Petzl Rescucender resulted in ‘re-grip’ forces as low as 1 kN (see tests 19 & 21). This means that temporarily the Rescucender essentially lost all of its grip, and consequently this would place a greater demand on the device to successfully ‘re-grip’ the rope. When the pulley system is made out of the mainline, a slipping rope grab must then re-grip a tensioned rope, and it was under these conditions where sheath failure with the Rescucender occurred – but only after subsequent slips, not the first slip. In order to achieve a subsequent slip with a Rescucender, a tension of at least 11-12 kN would be required. It’s debatable if this is possible under normal conditions. It can also be said that Prusik failures occurred after subsequent slips, which also required tensions similar to the Rescucender to achieve. The difference, however, is that of relative risk. The Rescucender damaged the mainline, whereas with Prusiks the host rope remained intact.

With pulley systems acting on the mainline (i.e. piggy-backed or ganged onto the mainline), the observed rope grab slippage might translate directly to fall distance to the rescue load, whereas only minor settling in would occur to a pulley system made out of the mainline, since slippage would be of the rope grab on the already tensioned mainline.

It was also observed that *all* rope grabs slipped at a lower force when gripping a tensioned rope than an un-tensioned rope. This was true for the initial slip force, maximum force as well as ‘re-grip’ force. The implication of this was noticed most dramatically in the Series 1 Tests, where Prusiks were considerably less effective at gripping a tensioned rope than an un-tensioned rope; in fact, this consideration was important enough to warrant alternative techniques for rescue belaying. For haul systems however, this reduction in gripping ability on tensioned ropes is still within the desired force limiting bandwidth for rope rescue systems.

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EMBC Rope Rescue NIF - Equipment Testing 2016

Series 5 - Force Limiting Systems Tests:

Objective:

The objective of these tests were to provide data to help establish the upper and lower limits of what the ideal force-limiting bandwidth should be for rope rescue systems.

Importance and Background Information:

Before considering the use of Force-Limiting Systems, it is important to understand what has come before, and for what reasons. In the eighties, the *Provincial Emergency Program* (now EMBC) adopted a 10:1 Static Systems Safety Factor (SSSF) approach as an attempt to provide rescuers with a simple tool to ensure they have sufficient strength in their rigging. In practice, a 10:1 SSSF would require a 20 kN system breaking strength if a 2 kN load (e.g. 2 people plus gear) statically hangs on the rope, assuming no redirects or changes in direction. Therefore, there are 18 kN of excess strength – or margin of safety - in the rigging. From an engineering design perspective, it is important to understand that the intent of having a 20 kN breaking strength is not for the 2 kN static load that is being applied to the rigging, but rather it is to provide a sufficiently high enough margin above and beyond the highest potential relative worst-case peak force event such that the equipment does not yield or fail. In rope rescue, this relative worst case event is being represented as a 1m drop of a 200 kg mass onto 3m of rope, and it can produce approximately 10-12 kN of peak force. It is this latter force for which a 20 kN breaking strength provides sufficient assurance.

In that same decade, the *British Columbia Council of Technical Rescue* (BCCTR) then developed the *Belay Competence Drop Test Method* (BCDTM) which allowed for no more than 1 m stopping distance and no more than 15 kN maximum arrest force (MAF). In other words, the belay force was 'limited' to no more than 15 kN. What the 10:1 SSSF essentially provided then, was approximately a 5 kN excess strength margin above the 15 kN limit. Typical rope rescue belay systems resulted in a maximum arrest force (MAF) of about 10-12 kN. Another way to view this is that the breaking strength of the rigging is approximately 1.5-2 times stronger than the worst case MAF so that these forces do not yield or fail the equipment; in a way, this is the roundabout end goal of using a 10:1 SSSF approach. But there are limitations to this approach and it can – and has - lead to misguided thinking and techniques.

It is important to emphasize that the BCCTR began the process of using 10:1 SSSF to address the rigging strength needs of the *relative worst case event*, in other words, an edge transition gone wrong, with little rope in service, with a full rescue-sized load, hence the 1 m drop of 200 kg on 3 m of rope. For this very specific singular event, the application of a 10:1 SSSF approach seems reasonable, because the net result of using it provides a system strength about 1.5-2 times stronger than the worst-case potential force.

However, the concept of the 10:1 SSSF has since been more broadly applied to many other aspects of rope rescue, such as over-the-side slope rescue, Highlines, Guiding Lines, and Pick-offs, among others.

Unfortunately, using a 10:1 SSSF approach to these scenarios will mislead rescuers into thinking that stronger rigging will be required, especially if the initial static loads are higher than a static 2 kN load, as might occur with Highlines or certain slope rescues. For example, with a 45-degree angle, and with 3 rescuers and a patient in the stretcher (total mass 360 kg), the resultant rope tension might now be approximately 2.5 kN instead of the aforementioned 2 kN. Strict adherence to 10:1 SSSF would then require a minimum system breaking strength of 25 kN, which is now beyond the knotted capability of typical 11 mm static kernmantle ropes.

As a solution, some rescuers might then think that 12.5mm ropes with a knotted breaking strength of about 28 kN would be required for this task. The irony of this - and also proof of how 10:1 can misguide rescuers - is that the worst-case maximum force event of a slope rescue is far lower than the peak force of a 1m drop on 3m of rope with 200 kg mass. Yet strict adherence to following 10:1 SSSF would have rescuers build the system even stronger for a slope rescue than what is required for a more severe event such as for an edge transition gone wrong. In other words, even a 20 kN system strength is already substantially strong for a slope rescue because the peak force under those conditions will be much less than that of a 1 m drop of a 200 kg mass on 3 m of rope, even though the initial static force might be 2.5 kN, and not 2 kN.

Force Limiting System for Fall Protection

The peak force test results of *Series 3* (i.e. MAF values for rescue loads on steep slopes) help demonstrate why using 10:1 SSSF can misguide rescuers, and also why a better tool is needed to help rescuers more accurately understand what the rope rescue system strength requirements need to be. Instead of using Static Systems Safety Factors, a paradigm shift to Force Limiting Systems can be used.

The basic principle of Force Limiting Systems is to have a built-in mechanism in the rigging whereby if the forces get too high, that the ropes can slip until forces can resolve themselves again, rather than relying purely on the strength of the rigging to compensate for the high forces. Force Limiting must occur at a high enough force such that unnecessary slippage does not occur, such as during operational loads. Conversely, Force Limiting Systems must have an upper limit to force limiting. Because humans are involved in rope rescue, it is the upper limit of human tolerance to sudden arrest forces that dictate this upper limit of Force Limiting Systems. As such, there must be a minimum as well as a maximum force within Force Limiting Systems. Theoretically, the MAF of a fall must occur within this bandwidth.

With rope rescue, regardless of whether the operation is in the vertical realm, a slope rescue, or even highlines and guiding lines, the upper force limit will not change because this value is dependent on the upper limit of human tolerance to arresting forces. By default, then, since the upper limit of force can be the same value for all rope rescue configurations, then so too can rope rescue system strength. It can be shown that if the MAF of rope rescue systems is kept below 12 kN (essentially 6 kN per person with a 2-person load), then the minimum system strength of the rigging should be about 1.5-2 times stronger, or about 20 kN, even for systems with rope redirects. This approach to determining system strength arrives at the same strength value as using the 10:1 SSSF approach (for the worst case), but it also helps prevents the misguided notion that system strength must change with changing static loads. Rather than using a SSSF approach, it is worth recognizing that many modern engineering techniques focus on determining and/or reliably controlling the relative worst case force within a specific operational bandwidth; this approach makes it far easier to determine system strength requirements. Examples of force-limited systems relevant to rope rescue include very common industrial fall protection systems whereby the fall arrest system is specifically force limited to no more than 6 kN on a human body, yet there is a *minimum* deployment force for these systems to work. In other words, the system should not deploy if a worker is merely statically hanging on the system; it must be shocked first before deploying. Therefore, an 'operational bandwidth' does exist for Industrial Fall Protection systems.

Another example of force-limiting systems which have an 'operational bandwidth' are pressure relief valves on hydraulic systems which serve to prevent over-pressuring of hydraulic components in a highly controlled way, yet a minimum amount of pressure is required to actuate various hydraulic components. If the hydraulic system is over-pressured, then fluid simply flows through the pressure relief valve and dumps fluid back into the reservoir, but if the system is under-pressured then the mechanical components do not operate.

The concept of an ideal operating 'bandwidth' can also be applied to rope rescue systems, particularly to back-up systems, but also mainlines and haul systems (extrapolate this thinking further in that highlines and guiding lines are also essentially haul systems). *Not only must there be a reliable, controlled maximum allowable force (MAF), which can be defensibly argued to be 12 kN, but there must also be a minimum slip force capability to prevent runaway loads under moderate forces. The minimum slip force value must be high enough to stop a slipping load within a short stopping distance in order to mitigate the risk of the rescue load striking an obstruction*. Data from this test series as well as Series 3 are helpful in determining the lower slip force value.

Again, the objective of these tests are to provide data to help establish what an ideal force-limiting bandwidth is for rope rescue systems. The MAF is more dictated by human tolerance to a sudden arresting force, along with its respective regulations, whereas the minimum slip force requirement is based more on appropriately managing the risk of 'allowable' or 'acceptable' fall arrest stopping distances, and preventing 'inertial runaway' loads (i.e. a fall that cannot be stopped as there is insufficient gripping ability or resistance provided by the back-up or belay system).

It is important that rope rescue systems have sufficient minimum slip force capabilities to prevent inertial runaway. To determine what this minimum slip force value should be, tests were conducted with different size masses at different slope angles, representing the maximum static tension a rope rescue system would normally be brought to. A variable friction mechanical device, set at incrementally decreasing slip force values was used to hold the load. The loads were suddenly released (zero fall factor), and force and respective slip distance were measured. The key data is the force at which inertial runaway commenced, and this was determined for each mass and slope angle combination.

Test Method and Materials:

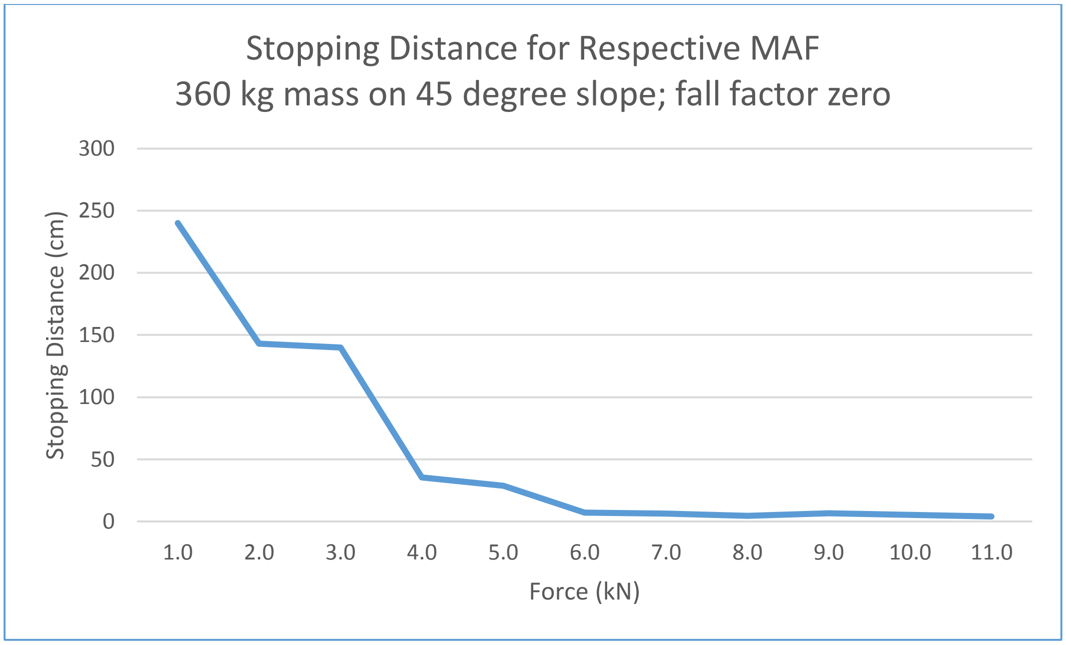
- The following slope angle and test mass combinations were examined.
    - 200 kg mass in a vertical free-hang; represents 1 rescuer + patient in a vertical environment; typical operating environment is vertical to 70 degrees for 1 person to easily manage a stretcher.
    - 280 kg mass on a 70-degree slope; represents 2 rescuers + patient, maximum slope angle; two rescuers can manage a patient in a stretcher within 45-70 degree angle.
    - 360 kg mass on a 45-degree slope; represents 3 rescuers + patient, maximum slope angle; 3 rescuers can manage a patient in a stretcher within 20-45 degree slope angle.
    - 360 kg mass in a vertical free-hang; represents an accidental lower of slope rescue team over a vertical section of terrain. A 'jolt' or sudden transfer of tension onto the rope system should not result in an inertial runaway.
- All ropes were new, 11 mm Teufelberger (New England) KMIII.
- The variable friction DCD was a Troll ProAllp Tech descender
- Forces measured with a Rock Exotica Enforcer Load Cell
- Slide distance was measured from the exit point of the DCD.
- The ramp for the 45 and 70-degree slope angle tests were a rigid ramp surfaced with 11 mm puck board (the same ramp as what was used in the Series 3 tests).

Results and Discussion:

Force Limiting Systems Test with a 70° Angle Ramp

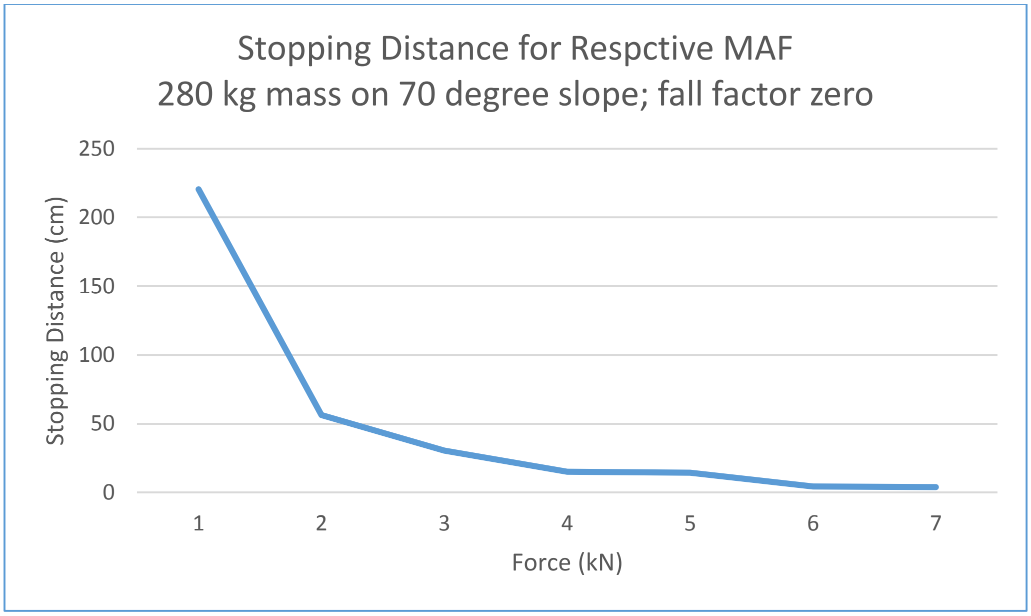
The first set of tests utilized a 360 kg mass on a wheeled cart, held by a rope on a 45 ° slope. The supporting rope was failed and the respective force and corresponding stopping distance was recorded. As arresting force was decreased, stopping distance naturally increased, until such a point that the arresting force was insufficient to stop the load.

The following graph illustrates the results. Although the graph represents actual data points from testing, similar results can be determined using relatively basic Newtonian formulas. Basic physics spring constant theory teaches us that a sudden transfer of tension of a mass onto an un-tensioned (or un-loaded) spring – with no free-fall involved – will result in a doubling of the resting, or static force. Since a rope behaves somewhat like a spring, in theory a 2 kN static load will impart an MAF of 4 kN if suddenly released and allowed to settle into an un-tensioned rope with no slack in it. However, due to knots tightening up and also due to the non-linear elongation behavior (i.e. modulus) of static ropes, the MAF will be closer to 5 kN (for confirmation of this, see Series 3 Results and Discussion Summary Table). It is fair to say that with rope rescue systems using Static ropes, that the peak force of suddenly ‘settling-in’ to an un-tensioned rope will multiply the static force about 2.5 times. In other words, if a rope rescue system is suddenly ‘jolted’, but no free-fall occurs, expect the rope tension to spike 2-2.5 times the static force.



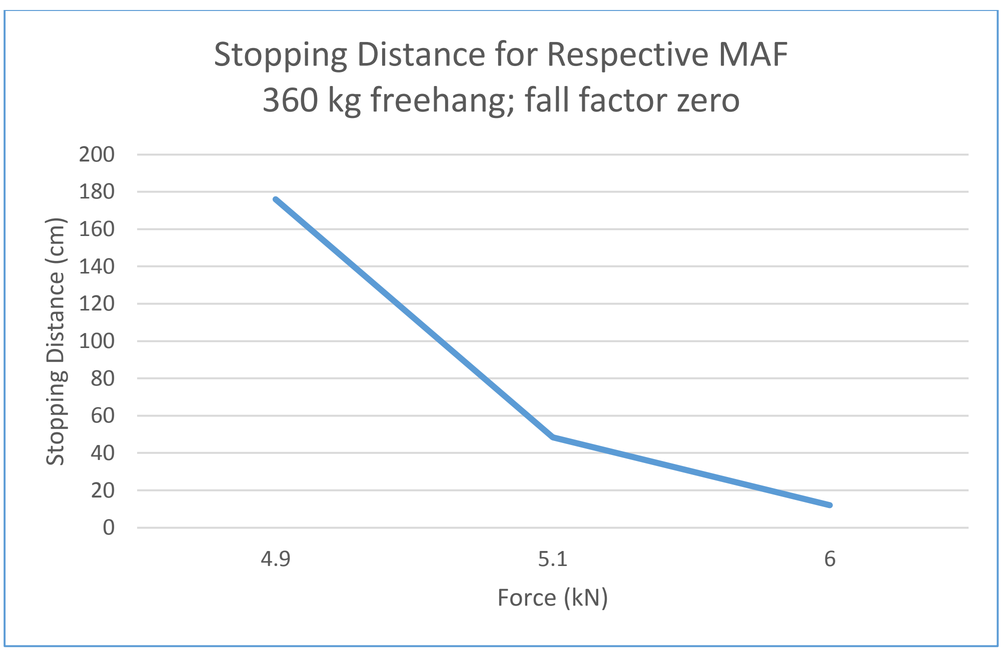
As mentioned before, the 360 kg mass represents 3 rescuers with equipment and a patient in the stretcher; the 45° slope represents the most likely maximum slope angle that might be used with 3 rescuers. At this slope angle, the static rope tension would be about 2.5 kN, and rope tensions higher than this may cause practical issues with smooth lowering/raising of loads, and also makes the ropes more prone to cutting. For reasons of risk management, any steeper, and it would be preferable to use fewer rescuers to reduce the tension on every fiber supporting the load; for angles between 45 and 70°, two rescuers are more common. As such, since 45 ° is the steepest that a 360 kg mass would be brought to, it then represents a relative worst-case event should anything happen to one of the ropes. If one rope suddenly fails, and the objective of the back-up is stop the load as fast as possible – there will be rope stretch – then the test data below clearly shows that 6 kN or more of minimum force is required to prevent device slippage. Mathematical equations confirm this.

If the terrain is steeper than 45 °, then likely only two rescuers would tend the stretcher. As with a 3-rescuer operation, if the operational rope rescue objective is not to exceed a static rope tension of about 2.5 kN (again, for reasons of practicality and reducing the chance of rope cutting from sharp edges), then the 70 ° angle once again becomes another relative worst-case reference point. As such, another set of tests were conducted with a 280 kg mass on a wheeled cart, held by a rope on a 70 ° incline. Various levels of tension were applied to the 'belay', and the corresponding stopping distances were measured or a zero fall factor event (i.e. sudden settling-in to the back-up rope).



Once again, the data clearly shows that a minimum of 6 kN of MAF tension is required to prevent unnecessary movement (i.e. slippage) of the rescue load from a 'jolt' to the rescue system.

One last set of tests involved a 360 kg free-hanging mass, suddenly settling-in to a back-up rope to simulate an accidental lowering of a 3-rescuer plus patient load over a vertical section of terrain, as might occur during a slope rescue. Only a few tests were conducted to demonstrate this.



At an MAF of 5 kN, the data shows that approximately 40-60 cm of slippage might occur through the back-up, whereas if the minimum slip force was 6 kN, then the amount of slippage might be below 20 cm. A sudden settling-in of a 360 kg mass in a free-hang should be expected to slip some of the MAF of the back-up device is only 6 kN.

Summary of Key Points:

The data gathered from Series 3 and this test series suggest that a reasonable minimum slip force value for rope rescue is 6 kN or more. For the upper limit of force limiting, the maximum arrest force is dictated more by human tolerance to sudden arresting forces, and fall protection regulations already reflect this by allowing no more than 6 kN to a person hanging in a harness. Therefore, if two rescuers are hanging on the rope system, then assuming each rescuer is the same mass, then an MAF of 12 kN at the belay device will translate to roughly 6 kN (or less, due to the mass of rescue equipment contributing to the MAF) per person. As such, a reasonable Force Limiting bandwidth for rope rescue is 6-12 kN.

While the Force Limiting 'bandwidth' can be 6-12 kN, it is preferable to favour devices that perform in the middle of that range in order to take into account variations in conditions. Testing is generally done in controlled environments using new, clean, dry ropes. Changes in those variable will result in a drift in performance. As such, the 'ideal' force limiting range would be the 8-10 kN target, with an allowable bandwidth of 6-12 kN. If the 'working load' is kept between 1-4 kN (this factors in the rope tension while the rescue load is being moved), then any jolt to the system would likely not result in slippage, except at the extreme upper end of the working load, as described earlier. Additionally, it can be demonstrated that if the upper limit of MAF is limited to 10-12 kN, then rope rescue system strength should be 1.5-2 times stronger than that, or approximately 20+ kN in order to not yield or fail the equipment should it be subjected to the relative worst-case event, such as the proverbial 1 m drop of a 200 kg mass onto 3 m of rope, resulting in an MAF of about 10 kN, but less than 12 kN (see Series 1 drop test data for actual results).

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Series 6 - Comparative Effects of Rock-Fall Simulations Between TTRS and DMDB Systems:

Objective:

The objective of these tests were to determine if a difference in performance exists between Two-Tensioned Rope Systems (TTRS) and Dedicated Mainline, Dedicated Belay (DMDB) systems when subjected to falling objects (e.g. rock-fall) impacting both ropes at the same time.

Importance and Background Information:

Many proponents of DMDB systems argue that an un-tensioned belay is less prone to damage/failure from being struck by a falling object - such as rock-fall - than a tensioned belay, and therefore this belief is being used in support of using un-tensioned belay systems. However, counter to this belief are numerous known cases of ropes getting completely 'chopped' in two by rock-fall, even though the ropes were un-tensioned. Prior to 2014, there was also a belief that an un-tensioned belay will perform better than a tensioned rope system when subjected to sharp edges, such as a drop or slide across a sharp edge. *Basecamp Innovations Ltd.'s* testing in 2014 demonstrated that there is no evidence to support this belief and in fact that it appears that two tensioned rope systems perform better under these conditions than DMDB systems. As such, the premise, or basis of belief and therefore preference of technique to help guard against the relative damage/failure from falling objects striking ropes must also be subject to evidence based decision making.

Creating a repeatable 'Rock-fall' test is nearly impossible given the nature of uncontrollable variables that exist. At best, the test methods subjected each respective rope system to 'similar' falling object conditions. After some experimentation to refine test methods, three different types of tests were conducted on both TTRS and DMDB systems.

Test Method and Materials:

All ropes were new 11 mm Teufelberger (New England) KMIII ropes; the test mass was 200 kg.

<u>Falling Crushed/Screened Rock Tests:</u>

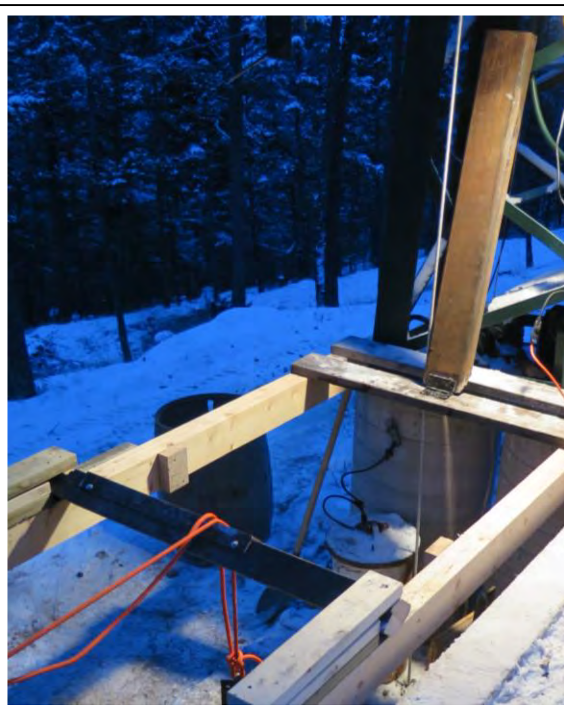
The first test method involved a 3.1 m drop of a known volume and mass (34 kg; 75 lbf) of crushed/screened <1" sewer rock free-falling down a 23.5x46 cm containment shaft, allowing direct and simultaneous impact to both TTRS and DMDB rope systems, while they were bent over a sharp, un-protected angle iron edge. The TTRS and the DMDB systems each had a 200 kg mass hanging from them,

Rockfall Test Tower

Loading Shaft with Rock

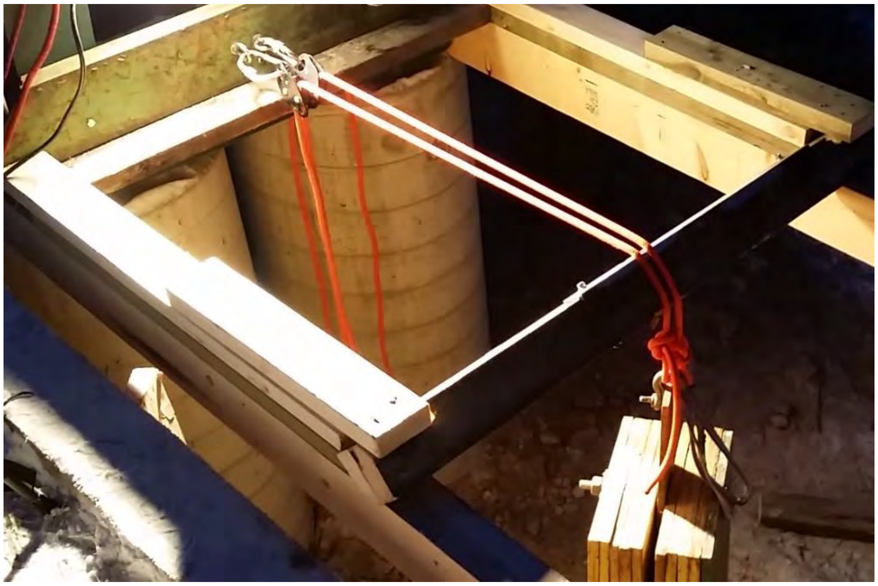
and each mass was positioned such that the falling rock did not impact them, thereby removing this variable as an influencing factor. The rock mass was suddenly released by a simple gate mechanism,
allowing a free-fall of the rock mass directly onto the respective rope systems. The objective of this test method was to subject each rope system to the same rock-fall event, and therefore allow side-by-side comparisons to be made. This was the only test method that involved actual rock material as the 'object' striking the ropes. During the rock-fall event, it could not be known exactly how each rock impacted each respective rope, other than a known volume and mass of rocks fell onto the vicinity of the ropes. These drops were repeated a number of times and comparative observations were made on each rope system.

Blunt Force (Smack) Rope Strike Tests:

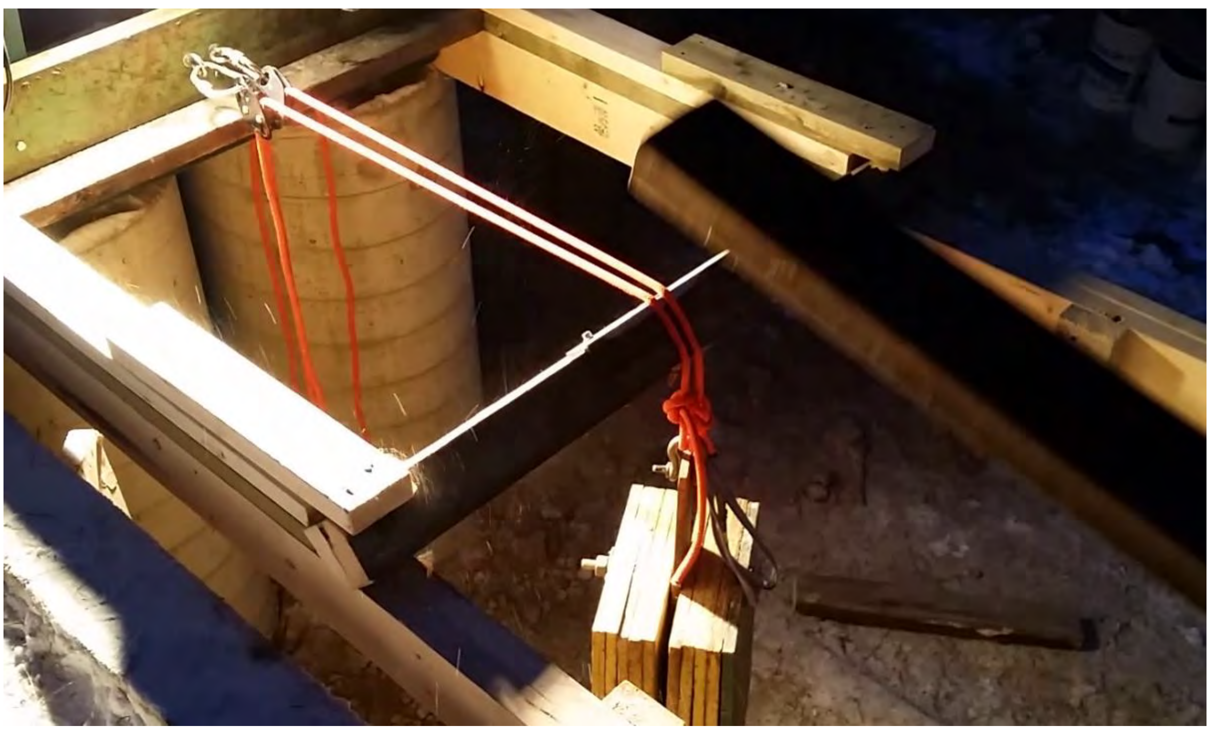


Smack Test Set-up

The second test method involved a blunt force being applied to both ropes by a falling object – in this case the flat side of a rectangular steel tube - while the ropes were bent over a sharp angle iron edge. The sharp angle iron edge was positioned vertically, or 'skyward' with the sharp edge presented perpendicular to the falling flat steel mass. A 25 kg section of rectangular steel tubing with dimensions of 8 x 15.2 x 120 cm was anchored at its base by a hinge, level with the ropes. From a vertical position, the steel tube was allowed to free-fall and pivot at its hinge to a horizontal position with the distal end of the 15.2 cm wide section of steel tube striking the ropes. This test was dubbed the "Smack Test". This test method is different than the third test method in that the rope fibres being struck were bent over a sharp edge, and that the falling object struck the ropes with its flat surface. The TTRS and the DMDB systems were independently tested and a comparison of results between tests was conducted. A 200 kg mass hung from the respective TTRS and DMDB rope systems.



Smack Test Set-up



Smack Test Pre-Impact

Falling Anvil (Sharp Edge) Strike Tests:

The third test method involved using the same falling steel mass apparatus as test method two but rather than striking the ropes with a blunt flat surface, a sharpened angle iron edge welded to the rectangular steel tube was allowed to strike the ropes. Each respective rope system had the ropes lying

Falling Anvil Test Set-up

over a flat steel I-beam surface, then over a rounded steel edge to a 200 kg mass. This test method was dubbed the “Falling Anvil” test. The primary difference between these tests and those in the Blunt Force tests, was that it was the sharp edge that directly impacted the ropes, as opposed to a blunt/flat surface suddenly compressing the ropes against a sharp edge. The intent was to simulate the sharp edge of a falling object – e.g. rock – simultaneously striking both ropes of the respective TTRS and DMDB systems.

Falling Anvil Close-up

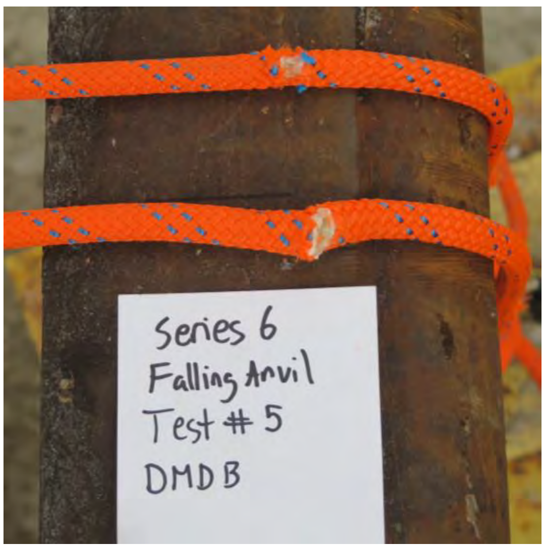
Results and Discussion:

Post Rockfall Test: DMDB on Left, TTRS on Right. No visible difference.

In none of the ‘Falling Rock’ tests were any differences in performance observed between the TTRS and DMDB systems. In all cases, the rock fall event caused light chafing to each rope, with no visible difference between either rope in each respective system, nor between systems. Prior to the tests, it was ‘assumed’ that a tensioned rope will result in more damage from a rock fall insult, but this did not appear to be the case; no visible differences were detected between an un-tensioned or a tensioned rope.

Limited tests were conducted with the Blunt Force, or ‘Smack’ tests. In the direct comparison between DMDB and TTRS, The DMDB resulted in the mainline having 2 sheath picks cut with the core exposed and no damage occurred to the belay line, whereas with the TTRS each rope had only 1 pick partially cut and no core exposed. Based on the limited tests, that TTRS received less damage than DMDB. Testing was halted using this test method as it was felt that not much more could be learnt and a more severe test method was required. As such, the test apparatus was modified to the Falling Anvil method, whereby a sharp edge strikes the respective ropes rather than a blunt flat surface.

The Falling Anvil tests is an extremely harsh test and damage to ropes was anticipated. In each of the TTRS tests, each respective rope was severed half-way, or less. In each of the DMDB tests, each respective rope was severed half-way, or more. While it is expected to have some variation between tests, it was abundantly clear that there is *no evidence* to support the belief that a DMDB system should be used over a TTRS with respect to higher resiliency to failure/damage from being struck by falling objects. DMDB and TTRS performed either very similarly, or slightly in favour of TTRS.



Falling Anvil Test 5 DMDB Post Photo

Falling Anvil Test 6 TTRS Post Photo

BASECAMP INNOVATIONS LTD.

EMBC Rope Rescue NIF - Equipment Testing 2016

Series 7 - Assessing the Effectiveness of Tailing Ropes in TTRS:

Objective:

The objective of these tests were to determine whether or not active rope tailing can be a reliable method for mitigating the human factor risk of a Descent Control Device (DCD) operator panicking and not allowing a TTRS to auto-lock and stop a falling load.

Importance and Background Information:

Inherent with TTRS is the requirement of each rope system operator to defeat the auto-lock of a DCD in order to lower rescue loads. If during lowering, one rope system fails, then the remaining system must be able to catch the load. However, a human factor risk exists in that there is a chance that the operator may inadvertently allow excessive rope to pass through the remaining rope system before the auto-lock can do its function to stop the load. To safeguard against this, it is being suggested to have a separate person whose sole job it is to actively grip and feed both ropes simultaneously to each DCD operator. If a failure occurs in any one system, and, if the DCD operator continues to let rope run through, then as a defense, the 'rope tailer' can stop movement by holding fast on the ropes. Rope tailing is a standard practice amongst professional outdoor educators (e.g. rock, alpine and mountain guides) for rock climbing whereby novice belayers are being actively backed-up by another person – or people – should the climber fall and the belayer not do their job properly. It is also a common practice to 'tail' the ropes for what is referred to as "bottom belays". With certain DCD's – not all - it is possible to slow and stop the descent of an out-of-control rappeller by pulling down on the ropes being rappelled on. The concept of applying rope tailing to rescue belays is simply an extension of this practice.

While maintaining a strong stance, the 'Rope Tailer' grabs both ropes with both hands and feeds them simultaneously to both DCD operators, and is ready to hold the ropes fast should an uncontrolled lower occur at either DCD location.

Several factors must be considered whether Tailing Ropes in TTRS would be effective. First, there is a physical limit to how much gripping ability a rescuer can apply to two ropes, one of which will be stationary and the other possibly moving (the failed rope would be stationary and the potentially running rope would be the remaining intact system). Two-handed gripping ability of two ropes must be based on a magnitude where all rescuers would be able to accomplish – in other words, this value must not be based on the average gripping ability, as that would mean half of rescuers would not be able to apply that quantity of gripping ability. The second factor is that the magnitude of tension on the tailing rope must be within what rescuers can grip.

The testing for this series was divided into two components.

1. Series 7a. Determine what rescuer's two-handed gripping ability on rope in motion is.
2. Series 7b. Determine how much tension must be applied to various DCD's to effectively stop a fall using rope tailing.

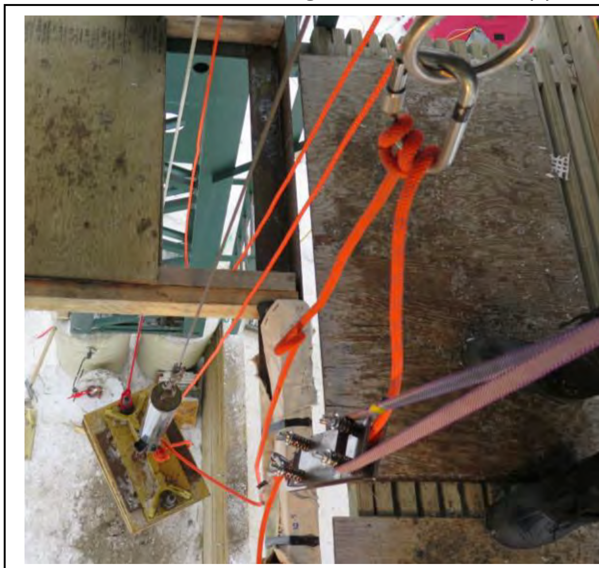
Test Method and Materials:

Series 7a – Determining Rescuer's Two Handed Gripping Ability

Rescuers were tested three times each for their ability to simultaneously grip two ropes with both gloved hands, for a total of 3 seconds each test; the footing was a level gravel surface. One of the ropes being gripped was under tension while the other was not, simulating one failed rope and one intact rope system. The intact rope was pulled at a rate of 12 m/min using a gas powered capstan winch. Forces were recorded by a Rock Exotica Enforcer Load Cell sampling in Fast Mode; force over time graphs were recorded. All ropes were New England KMIII 11 mm. A total of 8 rescuers were tested.

Series 7b – Determining The Tail-Tension Required to Stop a Falling Load

Based on the results of Series 7a and Series 1a, a series of drop tests were conducted at various fall factors and various levels of tail tension to determine whether or not the falling load could be stopped within a 'reasonable' distance using rope tailing. For each DCD system tested, no auto-lock was used. A mechanical hand at pre-set tension levels was used to simulate a person tailing the ropes. The testing procedure started with a Fall Factor 1/3 with a 200 kg mass, with the mechanical hand set at 0.4 kN, then 0.2 kN, then 0.1 kN. Fall Factors were then reduced to 1/5th, then Fall Factor zero (simulating a sudden settling-in to the remaining rope system, with no free-fall involved). If a particular DCD, fall factor and mechanical hand combination failed to stop the falling load, then no further testing was done at either higher fall factors or reduced mechanical hand tensions. Rope tailing effectiveness was considered most capable if the load could be stopped with the least



Tailing Ropes Test Set up with Mechanical Hand

required tail tension (0.1 kN) for the highest fall factor (1/3) within ideally 1 m slide distance. A table summarizing rope tailing capability per device per fall factor per required tail tension was developed.

In addition to assessing rope tailing by rescuer's gripping the ropes, testing was also conducted to determine if a Petzl ASAP fall protection device could be utilized – either in front or behind the DCD – as an alternative to rope tailing in order to mitigate the risk of an operator inadvertently allowing excessive rope run through the DCD. Two devices, the Petzl I'D and the MPD were used to determine the effectiveness of using the ASAP. In all drops, the Auto-Lock of the I'D and the MPD were defeated, allowing rope to run through the device.

Results and Discussion:

Series 7a:

The average human gripping ability of two ropes using both hands (gloved) was found to be about 0.5 kN. Since the small sample size did not produce a normal distribution, a meaningful minus 3 sigma standard deviation inference as the minimum gripping ability of the population could not yet be obtained – a greater sample size would be required. However, in the 1993 Study by Kirk and Katie Mauthner on Gripping Ability on Rope in Motion, it was determined that the minimum gripping ability by a rescuer using one gloved hand on rope in motion was about 50N, with an average of just over 200N (0.2 kN). The minimum gripping ability of 50 N represented a value which essentially 100% of the rescue population would be able to grip. The average single hand gripping ability value of just over 0.2 kN, when doubled, is roughly what was measured in this study as a two handed gripping ability on rope in motion. It can therefore be argued that a reasonable and conservative minimum two-handed gripping ability could be 0.1 kN (2 x 50N).

Two-Handed Gripping Ability on Two Ropes in Motion Tests					
		Individual Test			Average
Test Subject	**Mass**	**1**	**2**	**3**	**(N)**
1	87	0.5	0.6	0.6	0.57
2	102	0.6	0.5	0.5	0.53
3	91	0.7	0.5	0.6	0.60
4	75	0.3	0.4	0.3	0.33
5	82	0.5	0.7	0.6	0.60
6	57	0.3	0.3	0.3	0.30
7	70	0.4	0.5	0.6	0.50
8	85	0.5	0.5	0.5	0.50
				Overall Average	0.5

Series 7b:

The following table shows the respective slide distance (in cm) of various DCD's for given fall factors and given mechanical hand tensions. Unless otherwise stated, a tilde in the data indicates that rope tailing is capable at that given fall factor and tail tension. Slide distance is given for the upper limit of a particular combination; assume shorter slide distances for reduced fall factors and/or higher tail tensions.

The data suggests that rope tailing with only 0.1 kN of tail tension requirement is effective for the worst-case fall factor 1/3 event, with the auto-locks fully defeated using the CMC Rescue MPD when the rope was clipped into the secondary friction post, the Double Italian Hitch and rope redirected climber belay devices such as the Petzl Reverso (testing was also conducted on the Black Diamond Guide ATC, and DMM Pivot with similar results). The Conterra Scarab was also considered capable when at least 3 Horns for friction were utilized as well as the Microrack when more than 1 Hyperbar was utilized. Rope tailing effectiveness dramatically improved when the fall factor was less than 1/3 and also when slightly more tail tension was applied (i.e. 0.2 kN instead of 0.1 kN). Rope tailing was effective for all devices at low fall factors and tail tension just below average gripping ability. In all tests, it was assumed that absolutely no tail tension was being applied by the DCD operator, which in some regards can be viewed as unrealistic as that would mean the operator would have completely let go of the rope but is still managing to somehow defeat the DCD auto-lock.

With the exception of a couple of DCD friction configurations, if both the DCD operator and the person tailing the ropes each applied only their respective minimum gripping ability (defined as an amount that 100% of the rescue population *would* be able to accomplish), then stopping the falling load within approximately 1 m is likely, even with the worst-case fall factor 1/3. It is also important to note that most TTRS have more rope initial rope in service, and therefore fall factors lower than 1/3 - since each DCD focal point would be roughly equidistant from the edge, and such TTRS are preferentially rigged to allow for raising of the load, even if the primary objective is for descent only.

Mechanical Hand Rope Tailing Effectiveness Tests									
	0.4 kN			**0.2 kN**			**0.1 kN**		
Device	FF0	FF0.2	FF0.3	FF0	FF1/5	FF1/3	FF0	FF1/5	FF1/3
I'D	~	~	72.5	6.0	Ground	Ground	~	Ground	N/A
MPD 2H	~	~	16.5	~	~	11.0	~	~	45.5
MPD 1H	68.5	Ground	Ground	~	~	Ground	N/A	N/A	N/A
DI	~	~	23.0	~	~	44.0	~	~	48.5
Scarab 3H	~	~	9.0	~	~	98.0	~	100.0	170.5
Microrack 1H	~	~	46.0	~	~	108.0	21.0	181.5	Ground
Reverso	~	~	35.0	7.0	46.0	68.0	~	~	81.0
Slide distance (cm) shown for respective device, fall factor and mechanical hand tension									

Petzl ASAP Tests:

Both the Petzl I'D and the CMC Rescue MPD were tested with a Petzl ASAP positioned in front as well as behind the respective DCD's. In conversations with a Petzl America representative, it was pointed out that Petzl does not recommend backing up rescue-sized loads with the ASAP connected to the anchor, but they do allow the ASAP to be used with a 2-person load during descent (e.g. companion rescue) whereby the ASAP travels with the load. With greater than 1-person loads, it was recommended to use the larger Petzl shock absorber (name: Absorbica) which has a 2 m deployment length, and is intended to keep the MAF below 6 kN under normal conditions). Petzl also pointed out that their in-house testing revealed that 'generally speaking', the sheath of a kernmantle rescue rope can be torn/parted by toothed rope grabs – of which the ASAP is one - at approximately 7 kN using their brand of rope, though this value varies with other rope brands, some having lower than 7 kN values. This information is consistent with other testing of toothed rope grabs. A key criteria of a successful rescue belay is that it remains functional, post-drop, so that the hanging rescue load can still be transported back to safety. A torn/parted sheath would not qualify as being considered functional.

ASAP Behind DCD Pre-drop

For all tests, each respective DCD had the auto-lock function fully defeated, allowing rope to flow through the device as if lowering a rescue-sized load. The MAF was recorded only at the ASAP. For the drop tests with the ASAP positioned in front of the DCD, in both cases the shock absorbers deployed in excess of 1 m and forces slightly exceeded 6 kN. This MAF value is very close to the point of sheath failure, and this reinforces Petzl's concern for using the ASAP in this manner and therefore they do not recommend it in configuration. When the ASAP was positioned behind the respective DCD's, the DCD's absorbed much of the energy of the fall and therefore removed much of the fall arrest demand to the ASAP, and consequently the MAF in each case was about 2.5 kN (which is consistent with the force Prusiks were subjected to when placed behind the DCD in the Series 1 tests) and the shock absorber was not deployed. Post drop, the system appeared to be fully functional and neither the ropes nor devices were damaged.

ASAP Rope Tailing Tests:					
	DCD	**ASAP Peak Force (kN)**	**DCD Slide (cm)**	**Final Rope Length (cm)**	**Absorber Deployment (cm)**
ASAP Behind DCD	I'D	2.5	26.5	370.0	0.0
	MPD	2.4	29.0	363.5	0.0
ASAP In Front of DCD	I'D	6.5	96.5	427.5	113.0
	MPD	6.1	~	~	101.0

With the limited testing conducted, it appears that placing the ASAP behind the respective DCD's, with sufficient room for the shock absorber to deploy (e.g. 1 m), can be an effective way to mitigate the risk an inadvertent run-away load. Rigging the ASAP behind the MPD was quite straightforward as the same anchor as the MPD could be used for the ASAP, but with the MPD extended forward. However, the I'D must have the in-feed rope redirected through a carabiner for additional friction, which made rigging the ASAP 'behind' more problematic. For the tests, the ASAP was rigged onto the in-feed rope (i.e. behind the DCD), but anchored to a separate anchor in front of the I'D since the redirected rope orientation has the end of the rope facing the direction of the load. In field conditions, it is generally not practical or not possible to locate and build an anchor somewhere between the I'D and the edge to serve as the ASAP anchor. An alternative might be to extend the I'D approximately 1m from the main anchor and reposition and connect the redirect carabiner directly to the anchor, then the ASAP can be connected to that anchor and be positioned on the rope in between the redirect carabiner and the I'D.

BASECAMP INNOVATIONS LTD.

EMBC Rope Rescue NIF - Equipment Testing 2016

Series 8 - Stretcher Rail Tie-Off Tests:

Objective:

The objective of these tests was to the compare the capability, competency, functionality and efficiency of three different stretcher rail tie-offs, using either 25 mm tubular webbing or 8 mm cord. The three tie-offs tested were:

1. A clove hitch blocked with a double overhand knot (CH-DOB)
2. A clove hitch backed up with two half hitches (CH-THH)
3. A round turn backed up with two half hitches (RT-THH)

Importance and Background Information:

When commercially made patient tie-in straps are unavailable, patients can be secured into the stretcher using either 25 mm tubular webbing or 8 mm accessory cord, which are materials commonly carried by EMBC teams. Questions have come up in the past as to which tie-off technique is preferred, and while it seems that any/all of the three suggested techniques may work, no data was available to support this. In addition to knowing the relative strength of the tie-offs in question, it is also useful to know how 'secure' they are as well (i.e. do they slip under tension).

Test Set-up with Webbing

Test Method and Materials:

Three slow pull tests of each parameter were conducted using a hydraulic slow pull machine, pulling at 100 mm/min were conducted on each respective tie-off technique. Data was collected using the data acquisition system sampling at 1000 Hz, and force over time graphs were generated. All tie-offs were done around a 25 mm diameter steel bar, simulating a commonly sized stretcher rail. Materials were new 25 mm tubular nylon and new CMC Rescue 8 mm kernmantle accessory cord.

Results and Discussion:

Webbing	Avg (kN)	Range (kN)	Failure point/mode:
CH-DOB	15.2	14.1-16.1	in clove hitch
CH-THH	15.0	14.6-15.4	in clove hitch
RT-THH	14.0	12.9-14.9	in round turn
Cord			
CH-DOB	12.7	11.6-14.1	in clove hitch
CH-THH	13.8	13.3-14.3	in clove hitch
RT-THH	11.5	9.0-13.4	in round turn except one case of tail pulling through at 9.0 kN

All ties-offs tested have ample average strength to be considered as a suitable stretcher rail tie-off. Cord appeared to 'settle-in' and initially slip more than webbing but not to a point of concern, even when taking into account one case where the tail eventually slipped through with a Round-Turn and Two Half-Hitches tie-off; in this case, the force required to do this was 9.0 kN and it is difficult to conceive of a realistic circumstance where this could potentially occur when used as a patient restraint tie-off.

BASECAMP INNOVATIONS LTD.

EMBC Rope Rescue NIF - Equipment Testing 2016

Series 9 - Adjustable Rope Stretcher Bridle Tests:

Objective:

The objective of these tests was to determine the strength capability and competence of the Alberta & British Columbia Cave Rescue (ABCCR) Adjustable Rope Stretcher Bridle configuration.

Importance and Background Information:

The concept of using Prusiks doubled back onto the stretcher bridle leg to create an adjustable stretcher bridle configuration has been in use in British Columbia SAR since the mid to late seventies. Numerous variations of essentially the same concept have been used, including but not limited to Prusiks on their doubled-selves using 6 through 8 mm cord, to Prusiks connected to either cord or rope then doubled back on themselves. To narrow down the scope of such testing, the configuration tested was the one as suggested/used by ABCCR, and even then, there are variations in Prusik and Rope/cord diameter for this configuration. The version tested utilized 6mm Prusik Cord doubled back onto 9mm Accessory Cord and built as per instructions provided by Phil Whitfield, the provincial coordinator of BC Cave Rescue.

Test Method and Materials:

A rigid steel fixture that replicates the dimensions and connection points of a Cascade 200 stretcher was attached to a hydraulic slow pull machine, using a pull rate of 100 mm/min. The data acquisition system sampled at 1000 Hz and force over time graphs were generated. The adjustments of each bridle leg were first done while clipped to a Cascade 200 stretcher in a horizontal orientation, then the adjusted bridle was transferred to the test fixture; each bridle length was individually measured.

Slow Pull Test of BCCR Stretcher Bridle

Results:

A total of 3 bridles were slow pull tested. The first test resulted in the data being inadvertently truncated at 27 kN and therefore the peak force of the breaking strength was missed. The remaining two tests resulted in breaking strengths of 35.5 and 35.1 kN. Common to all tests were that the Prusiks slid about 10-15 cm and then the foot and head bridle sections independently and consistently failed at the figure of eight on a bight knots where they clipped into the bridle master attachment point shackle. The foot and head bridle sections did not fail simultaneously. The force curves reveal when each of the foot and head bridle failed, it might be fair to say that the lower of the two peak forces on the curve would more accurately reflect what each bridle leg would fail at independently. The highest peak force obtained on the force curves occurred when both the foot and head bridle were contributing to peak force.

Conclusion:

Strength is not a concern for this bridle configuration, even with 6mm cord for the Prusiks and 9mm cord for the bridle legs using new materials, even if the entire stretcher load is being supported by one half of the bridle configuration. It is unknown what the strength degradation rate is with use and wear.

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EMBC Rope Rescue NIF - Equipment Testing 2016

Series 10 - Flat Overhand Bend Tests for Anchors:

Objective:

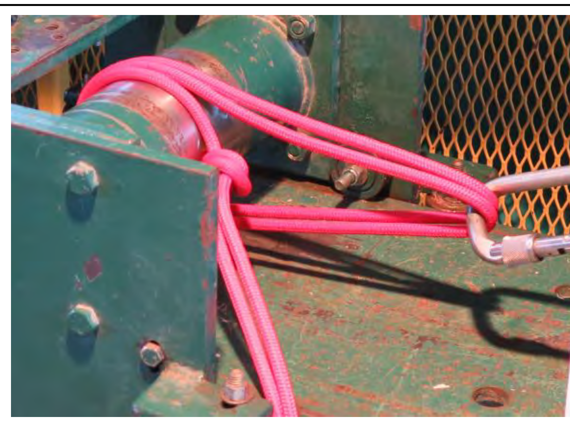
The objective of these tests was to determine the suitability and breaking strength of using a Flat Overhand Bend instead of an Overhand Follow-Through Bend (aka Ring Bend) for webbing, or a Double Overhand Bend (aka Double Fisherman's Bend) for cord - when building Wrap Three, Pull Two type anchors.

Importance and Background Information:

The current method adopted by EMBC for building a Wrap 3 Pull 2 anchor – specifically with 25 mm webbing – is to secure the webbing ends with an Overhand Follow Through Bend (Ring Bend) and position the Bend facing the direction of pull. The orientation and isolation of the Bend is to make it easier to initially inspect and also make it easier to untie afterwards as very little tension reaches the Bend in this location. A common misconception is believing that isolating the tie improves breaking strength – which it does not. However, it can be time-consuming to tie W3P2 anchors in this manner, especially if more than one of these types of anchors are required to build a rope rescue system. Given that little tension reaches the Overhand Follow Through Bend, the question has come up whether the Overhand Follow-Through Bend could be replaced by the much-faster-to-tie Flat Overhand Bend (FOB).

Under consideration for these tests were the configurations of W2P1, W2P2 and W3P2 using both 25 mm tubular webbing and 8 mm cord as materials. Of interest are both the breaking strength and relative security of the FOB as it is known to 'roll' under high loads.

Test Set-up with Webbing



Test Set-up with Cord

Test Method and Materials:

Except where otherwise noted, three slow pull tests were conducted for each parameter. All pulls were conducted using a hydraulic slow pull machine, pulling at a rate of 100 mm/min. All anchors were tied around a 100 mm diameter smooth steel bollard, and all anchors were clipped to a steel SMC carabiner. All data was recorded using the data acquisition system sampling at 1000 Hz. Force over time graphs were generated for all tests. Materials were new 25mm tubular webbing and new CMC Rescue 8 mm Accessory Cord (part # 293038). All Bends were tied by the same person for consistency between tests.

Results:

Webbing:	**Test 1 (kN)**	**Test 2 (kN)**	**Test 3 (kN)**	**Avg (kN)**	**Comments:**
W2P1	21.9	33.1	-	27.5	Failed at FOB and once at carabiner
W2P2	37.7	37.7	35.3	36.9	FOB began to roll; failed at carabiner
W3P2	37.0	36.3	30.2	34.5	Failed at carabiner; no FOB rolling
Cord:	**Test 1 (kN)**	**Test 2 (kN)**	**Test 3 (kN)**	**Avg (kN)**	**Comments:**
W2P1	23.7	22.2	-	23.0	FOB began to roll; failed at carabiner
W2P2	31.5	31.0	34.3	32.3	FOB rolled off end of cord tails
W3P2	47.1	-	-	>45.0	No FOB rolling; test stopped, high force

Conclusions and Discussion:

The W3P2 and W2P2 anchor configurations are most commonly rigged anchors within EMBC teams, using 25 mm tubular webbing; in none of the tests conducted with webbing did rolling of the Flat Overhand Bend present as a failure mode. Breaks consistently occurred where the outer wrap of webbing sheared the inner wrap of webbing where it was clipped into the carabiner. This is the same failure mode and general breaking strength as when this anchor system is tied using an Overhand Follow Through Bend. Tying this anchor system with cord is relatively uncommon but it is done. The tests with cord however, produced some rolling of the FOB, but not consistently, and when it did, they were at very high forces – and at a very high sustained force (i.e. tens of seconds) to cause failure, as opposed to a shock force, which would only last only tenths of seconds.

Based on these tests, and assuming that the ties are properly dressed (i.e. snug and twist free) there does not appear to be a concern for securing the tails of these anchor system configurations using a Flat Overhand Bend. The breaking strengths remain high and rolling does not appear to be a failure mode. Additionally, this form of anchor system is commonly applied to anchors such as trees, whereby the friction would be substantially higher than a smooth steel bollard, and therefore under these conditions, tension to the tie-off would be logarithmically less.