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Dual Capability Two Tensioned Rope Systems (DC TTRS[1])

Technical Rope Rescue Systems Overhaul – the new (2016) British Columbia SAR Model

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Emergency Management British Columbia (EMBC) – the government agency responsible for public safety and BC SAR – was awarded a National SAR Secretariat National Initiatives Fund (NIF-2016) to conduct an evidence-based, comprehensive overhaul of the rope rescue standards, systems & techniques and training models which the 80+ SAR teams in BC follow. This NIF-2016 Rope Rescue Project benefits not only BC SAR teams, but also related Canadian agencies such as Department of National Defence (e.g. SARtechs and other forces using technical rope work), Parks Canada and Provincial Parks visitor safety specialists, as well as rope rescue training providers. Basecamp Innovations Ltd was contracted to conduct the rope rescue research and testing portion of this project. Other contractors and subject matter experts were also used for the development of the training and delivery models. After over 30 days of continuous testing, by a team of 13 people, a comprehensive 350-page summary report with recommendations was written and used by BC SAR and EMBC to decide which key rope rescue systems and technique changes will be adopted.

This presentation highlights only some of the key systems and technique changes adopted by EMBC and BC SAR. The list of changes is greater than the scope of this presentation, which is focused on the following key changes:

- DC TTRS in favour over DMDB techniques
- Controlled, Force Limiting Techniques instead of 10:1 Static Systems Safety Factors
- Greater emphasis on managing Human Factors (e.g. Command & Communication Protocols and rope tailing)

Background and History:

In 1982-86, the Provincial Emergency Program (now EMBC), used an ad hoc advisory group called the *British Columbia Council of Technical Rescue* (BCCTR) to create standards, techniques and make recommendations to the province on BC SAR rope rescue practices. The pioneering work by the BCCTR

[1] There are many forms of 'Two' Tensioned Rope Systems, and BC SAR/EMBC is specifically choosing to use Dual Capability systems (defined further, later). In the '80's, the BCCTR created a document defining different types of Two Tensioned Rope Systems, whereby 'Twin' systems have two ropes into the same DCD, 'Dual' systems have separate DCD's and ropes attach to different ends of the stretcher, and 'Double' referred to systems which have one DCD's, with ropes attached to opposite ends of the stretcher, but with no reference to a Back-up function in either rope. Therefore 'Dual Capability' is essence, a new category in that there is also a Back-up function with each of the two ropes, each having its own DCD, and both ropes join at a master attachment point.

led to concepts such as the Belay Competence Drop Test Method (of which the current ASTM 2436-14 Standard is modeled after), and the Kootenay Highline System; they also set the bar for many two-rope system rope rescue techniques, particularly Dedicated Main Dedicated Belay (DMDB) techniques. The Tandem Prusik Belay is just but one example. It is fair to say that the BCCTR work influenced not only SAR teams and rope rescue providers in BC, but across North America. Until 2016, the EMBC rope rescue manuals were predominantly based on work conducted by the BCCTR.

In the 30+ years since, a considerable amount of additional rope rescue research and testing has been conducted which has led to a number of advancements in equipment and techniques, most notably, the work which as been focused on Two Tensioned Rope Systems (TTRS), of which there are many forms. At the 2014 ITRS, Kirk Mauthner presented research which clearly demonstrates that TTRS yield better margins over DMDB techniques when subjected to sharp edges; these findings directly contradict one of the primary arguments posited for using an un-tensioned belay rope for sharp, abrupt edge transitions (note: a dedicated main, un-tensioned belay (DMUB) is a form of DMDB technique).

It was clear that the EMBC rope rescue program was in need of an upgrade. As such, in 2016, with the support of a federal NIF grant, EMBC once again embarked on an evidence-based approach to overhaul and modernize their rope rescue practices, techniques and training delivery model. Among many aspects, a particular focus was placed on a comparative analysis between DMDB and DC TTRS techniques, along with a greater emphasis on managing Human Factors. Additionally, in recognition of the shortcomings to using a 10:1 Static Systems Safety Factor Approach, a considerable amount of effort was placed on adopting Force Limiting principles to the rope rescue model.

Risk Mitigation by Assessing Factors that Affect System Failure:

Rope rescue requires practitioners to manage the right risk at the right time. Different risks and consequences emerge or fade away depending on the respective location of the rescue load in relation to the intended end destination. The factors that can affect the failure of a rope rescue system can simply be grouped into one of four major factors:

1. Human Factors
2. Environmental Factors
3. Materials (Equipment) Factors
4. Method (Technique) Factors.

While *Human Factors* tend to dominate the potential cause of rope rescue system 'failures', it is inextricably the interaction of all these factors combined that either increase or decrease the active risks *and consequence* which need to be managed.

The comparative analysis of DC TTRS to DMDB techniques is in essence a comparison of *Method Factors;* the different 'methods' are examined in context to factors from other categories, such as *Environmental Factors* (e.g. rock fall, or sharp edges). The cumulative weighting by consequence of differences in margins between techniques is what was used to help determine the suitability of one rope rescue method over another.

Dual Capability Two Tensioned Rope System over Dedicated Main Dedicated Belay:

After taking into account various Human, Environmental, Material and Method Factors, EMBC and BC SAR has chosen to adopt the principles of DC TTRS over DMDB. For clarity, *Dual Capability*[2] is a specific form of Two Tensioned Rope System technique whereby each system is simultaneously *Capable and Competent* as both a main line function as well as a back-up function to the other line. A *capable and competent mainline* is further defined as being able to handle a full working load of 1-4 kN, with the idea that each rope in a DC TTRS can take on the full load at any time without requiring a friction change on the Descent Control Device (DCD); not all DCD's are capable and competent at doing this (e.g. single Italian Hitch). A *capable and competent backup* is further defined as being able to pass the BCCTR 1m drop on 3m of 11 mm rope with 200 kg mass, having no more than 12 kN maximum arrest force, with no more than 1m stopping distance, the system must remain functional and have at least 80% residual rope strength. An additional 1.5m drop on 3m rope with 200 kg 'strength margin' test with a 'remain functional' criteria has been added to the original BCCTR criteria. Again, not all DCD/Back-up devices & techniques can accomplish this.

The following are examples of DC TTRS that were able to pass the demanding Working Load and Back-Up function tests:

- CMC Rescue MPD with 11 mm rope threaded into secondary friction post
- Component based systems having a DCD (e.g. A Double Italian Hitch or 3 horns of a Conterra Scarab or 4-Bar Microrack with rope over the Hyperbar) extended 60 cm with sewn sling, with 3-wrap, 8mm kernmantle cord Prusik positioned 'behind' (anchor side) the DCD[3].

Sharp Edge Tests:

In all three types of sharp edge tests (drops over a sharp edge, pendulum of load across sharp edge, sudden rope 'sweep' across sharp edge), DC TTRS demonstrated greater safety margins over DMDB systems. From a 'sharp edge' perspective, no evidence could be found to warrant using an un-tensioned belay for transitioning over sharp abrupt edges. Additionally, when using a high directional, these findings also favour equally elevating both ropes in a TTRS. Equally elevating both ropes would result in simultaneous contact of the ropes to an edge should a high directional failure occur – this would result in higher margins of safety than un-equally elevated ropes for sharp edge failure modes.
This work also raised questions about the suitability of current forms of kernmantle construction ropes (read: opportunity for improvement) in that the respective rope tensions at which ropes failed are within what can occur within rope rescue operations.

Falling Object onto Rope Tests (e.g. Rock fall):

Three types of 'falling object' tests (1. falling crushed rock; 2. falling blunt platen striking rope laying on sharp edge; 3. falling 'anvil' (sharp edge object) striking ropes laying on flat surface) were conducted. In none of tests conducted did either a DC TTRS or a DMDB exhibit any difference in performance; in other

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[2] Dual Capability more aptly describes the functional requirements of the TTRS than what was previously described as "Mirrored Systems", which consequently had some erroneously believe that the systems need to 'look' the same, which they do not. For greater clarity the broader description, "Dual Capability, Two Tensioned Rope System" is now preferred.

[3] The Drop Tests for this study, using the BCCTR criteria revealed serious and potentially dangerous shortcomings with component based TTRS when Prusiks (either single or Tandem) were placed 'in front' of the DCD. These findings also have serious negative implications to such practices when using DMDB techniques. Such systems either failed outright or had little to no margin remaining, only to fail with the 1.5 m drop test.

words, all systems and all ropes were 'damaged' similarly. Consequently, this did not become a determining factor in choosing one system over another.

Maximum Arrest Force (MAF) and Stopping Distance Tests:
In 1982, the BCCTR defined the worst-case scenario in rope rescue as an edge transition gone wrong, and the belay competence drop test method has been used as a comparative analysis tool. For 1 m drops on 3 m of rope with a 200 kg mass, all systems, regardless of whether they are DMDB or DC TTRS techniques, must pass the criteria described earlier. In practice however, it is known that certain un-tensioned belay techniques in DMDB systems will result in greater stopping distances than what would be observed through testing due to Human Factors. For example, it is not uncommon for users of the Tandem Prusik Belay to inadvertently introduce additional fall distance (and therefore stopping distance) with their technique of feeding out belay rope. DC TTRS would not have this Human Factor introduced since both ropes are under tension during edge transitions and therefore no additional inadvertent slack can be introduced. The margins are in favour of DC TTRS.

It must be noted that the worst-case scenario described above is essentially the only condition where a 'freefall' of the load can occur. This adds energy which must be dissipated, and a MAF of 12 kN or less – when divided among the components that comprise the load - falls well within tolerable limits of what humans can withstand. In all other cases, failure of one of the rope systems would essentially constitute a 'top rope' belay condition. When no freefall occurs (i.e. no additional energy is added to the system), and assuming no slippage, stopping distance is dependent on the elongation properties of the rope (i.e. a Static rope will stop the load in a shorter distance than a Low Stretch rope[4]), whereas MAF will remain essentially the same, regardless of rope elongation properties. Testing shows that a rescue load suddenly settling-in from a tensioned (and then failed) rope to an un-tensioned (now tensioned) rope can result in an MAF up to 2.5 times as much as the initial static force of tensioned rope (physics theory shows that in an 'ideal' world, this value would be double the static tension). However, MAF is substantially lower (over a third less) for TTRS when half of the load is already being supported by the 'surviving' rope.

Multiple combinations of mass and angle were tested in both DMDB and DC TTRS configurations. DMDB configurations consistently had essentially double the MAF than TTRS configurations. It was also observed that the MAF of DC TTRS was consistently below the rope tension threshold at which ropes tended to fail during the sharp edge tests. This intimates that DC TTRS have higher safety margins for 'combined' factors affecting failure.

Stopping distance, however, showed marked difference in performance favoring DC TTRS. Stopping distances were 4-12 times higher for DMDB systems than DC TTRS when using Static ropes. This difference between systems grew even greater when Low Stretch ropes were used. The increased stopping distances with DMDB systems (and with using Low Stretch ropes) directly increase the chance of the rescue load striking an obstruction during fall arrest, and therefore the safety margins favor DC TTRS.

Manual Override of Self-Braking Devices (Human Factor):
It is desirable for Two Rope systems to have a self-braking feature incorporated into each rope system. This is the fundamental principle of the 'whistle test'. With DC TTRS, the self-braking feature of each rope system must be manually overridden by an operator in order to lower the load. This is not

[4] As defined per Cordage Institute CI-1801 standard)

necessarily the case with DMDB systems. It is therefore possible from a Human Factor standpoint, that if one of the rope systems fails, that the operator of the remaining system does not execute the correct action to allow self-braking. If this Human Factor cannot be removed entirely, then it must be guarded against. The concept of tailing ropes as a back-up to an operator is commonly used in recreational climbing, particularly for backing-up novice belayers, but it is not that common in rope rescue. It was demonstrated as a viable technique at the 2015 ICAR conference, and has been used among a number of teams in North America prior to 2013.

Prior to conducting tests to determine the effectiveness of rope tailing for DC TTRS, some baseline testing was conducted to determine what the minimum human gripping ability is with two hands gripping two ropes (one rope in motion and one stationary) to simulate the requirements in a rope rescue DC TTRS setting. The minimum gripping ability with two hands on two ropes was found to be between 0.1 and 0.2 kN with an average gripping ability between 0.4 and 0.5 kN. Drop testing was then conducted on DC TTRS which had already passed the belay competence criteria, with the added criteria of rope tailing while the self-braking feature was manually overridden. The Petzl I'D with added friction did not pass the criteria whereas the CMC Rescue MPD (operated with the rope in the secondary friction post) as well as the component based systems did. Only techniques which passed the rope tailing criteria were adopted for use by BC SAR & EMBC.

Force Limiting Principles and System Strength Requirements (Material Factor):
A rescue system must be strong enough to neither yield nor fail from the relative worst case forces that it might be subjected to, and, under normal working conditions, the equipment must not fail from repeated use or cycling. In other words, the system must remain functional if ever subjected to the relative worst-case event. For decades, EMBC used the 10:1 Static Systems Safety Factor approach as a means to ensure sufficient rope rescue system strength. However, over the years, many shortcomings to this approach have been recognized. Instead, EMBC & BC SAR have now adopted the principles of *Force Limiting Systems* to control forces and to determine system strength requirements.

Force Limiting Systems have essentially two requirements: the first is to limit, or cap the maximum arrest force of the relative worst case event to a value which humans can tolerate, and the second requirement is to ensure that the devices interacting between the rope and anchor provide sufficiently high friction or resistance such that any sudden 'jolt', or 'settling-in' of the load onto the rope system does not result in excessive slippage, or worse (i.e. inertial runaway of the load).

As stated earlier, for any failure of a rope system in a top rope environment, the peak force from a sudden 'settling-in' to the remaining rope system can be up to 2.5 times greater than the initial static load. A substantial number of tests were conducted using various combinations of mass and angle to determine what the minimum gripping ability of rope rescue devices should be for force limiting systems. The resulting data indicated that a minimum slip force value of 6 kN is appropriate for rope rescue systems. At the high end, the maximum slip force should be 12 kN or less. In other words, the devices used for proper force limiting in DC TTRS must slip at a value of at least 6 kN, but no more than 12 kN – ideally somewhere between 8-10 kN in order to allow for some latitude for changing conditions (e.g. wet, muddy, etc.).

One strategy used by designers/engineers to determine minimum strength requirements is to multiply the highest forces which a system may be subjected to by a factor of somewhere between 1.5-2.0. The primary objective of this strategy is to ensure that the yield points of the various materials (i.e. the force at which material permanently deform) are sufficiently greater than the highest loads/forces which the system may be subjected to. However, in order to use this strategy, three key conditions must be met.

1. Loads/Forces must be known: For rope rescue, we can do this. We know our working loads (i.e. 1-4 kN) and through Force Limiting systems, we control the 'worst-case' forces to between 6-12 kN.
2. Reproducible Testing of worst case conditions: The BCCTR belay competence drop test method achieves this criterion by providing a means of comparative analysis and assessment of various devices under consideration for use in rescue, particularly DC TTRS. An acceptance/rejection criterion must exist.
3. Traceable Materials and Quality Assurance Manufacturing: The fact rope rescue products are manufactured and classified according to relevant standards (e.g. CE/EN, NFPA, ASTM, etc.) allows us to meet this criterion.

Since all three criteria above can be met, the design principle of multiplying the worst-case forces by a factor of 1.5-2.0 is available to rope rescuers. As such, EMBC & SAR BC have decided on a minimum breaking strength value of 20+ kN for all their rope rescue systems, regardless of whether the system is a simple lower/raise or pick-off in a vertical environment, a steep slope rescue, a guiding line or a highline operation. This even applies to rigging such as a redirect or a high directional. This approach, combined with Force Limiting Systems, more than adequately meets the strength demands required by the various types of systems and techniques and greatly simplifies the process for rescuers, thereby allowing a greater opportunity to focus on other risk mitigation requirements.

Summary of Fundamental Requirements of a Dual Capability Two Tensioned Rope System:
Prior to being accepted as a viable technique for consideration as a DC TTRS, a system must be tested and validated against the following criteria:

- Force Limiting between 6-12 kN for all Descent Control Devices, Back-ups and rope grabs.
- System strength must be 20+ kN (including testing of a rope loaded into a DCD)
- Rope Tailing at 0.1 kN shall be effective for devices whereby the Self-Braking feature is being manually overridden.
- Backup function must pass the Belay Competence Criteria of being able to:

    - Catch a 1 m drop of a 200 kg mass onto 3 m of 11 mm kernmantle rope
    - Have a Maximum Arrest force not exceeding 12 kN
    - Stop the load in no more than 1 m (including rope stretch, knots tightening up, belay unit extension and any slippage through the belay).
    - The system must remain functional (to complete the operation)
    - Residual rope strength 80% or greater (i.e. greater than the knotted strength of the rope).
    - Remain functional after a 1.5 m drop onto 3 m of rope (the MAF and stopping distance criteria do not apply to this test; it is a strength margin test to determine if sufficient excess capacity exists above and beyond the prescribed relative worst case event of a 1 m drop onto 3 m of rope with a 200 kg mass).

Command & Communication Protocols (Human Factor):
A number of changes were made to the EMBC Command and Communication Protocols with an emphasis on enhancing situational awareness amongst all members, especially prior to having to carry out a task. One of the more significant changes made is the inclusion of an Edge Transition Briefing by the Control, immediately following a Role Call for readiness. In the edge transition briefing, the Control describes how the edge transition will be executed, what commands will be used and in what order, as well as a physical demonstration of the desired speed. Group consensus is required. Immediately following the Edge Transition Briefing, the team conducts one or more 'Dry Runs' before 'Going Operational'.
Upon retroflection (and considering the many poorly executed edge transitions during training exercises over the years), it was determined that it is an unrealistic expectation for a team to successfully and smoothly negotiate an edge transition – especially with a loaded stretcher – based solely on prior training, likely whereby skills have waned, and also likely different conditions than what was encountered during prior training. The objective of the Edge Transition Briefing and Dry Run(s) is to raise the skills, abilities, enhance communication and the situational awareness level of all team members to the highest possible level prior to actually having to execute the respective tasks. Since incorporating Edge Transition Briefings and Dry Runs as part of the Command and Communication protocols, edge transitions have become markedly more controlled and effective.
The Edge Transition Briefing is also conducted for coming back up over edges. The rescue load is first raised to a position just below the lip of the edge where the attendant is within earshot of the Control. A plan for the edge transition is discussed, and the commands are agreed upon prior to executing the edge transition.

Overall Summary:
EMBC and BC SAR have adopted a number of significant changes to their rope rescue techniques and protocols. A substantial amount of testing and research was conducted to provide evidence-based decision making to the process of assessing the risks associated with the four factors affecting potential failure (Material, Method, Environment and Human Factors). This paper & corresponding presentation only highlights some of the dominant changes. In summary, these are:

- Use of Dual Capability Two Tensioned Rope Systems for operations instead of Dedicated Main, Dedicated Belay systems. It is important to note that there are many forms of Two Tensioned Rope Systems and *not all qualify* as being Dual Capability. They must be tested and assessed before being accepted; protocols are developed for each device/technique considered.
- Rope Tailing will be used for guarding against Human Factors whenever self-braking devices are being manually overridden.
- All systems (e.g. all angles of stretcher lowers and/or raises, pick-offs, highlines and guiding lines) must be Force Limiting (6-12 kN) and have a minimum 20 kN breaking strength (EMBC & BC SAR will no longer use the 10:1 SSSF approach).
- Edge Transitions are executed with both ropes under tension. No compelling evidence was found to substantiate and therefore warrant the use of an un-tensioned rope for this phase of an operation. Sharp edges must be well protected against.
- Rock Fall (falling objects) was found not be an influencing factor in deciding between using tensioned or un-tensioned ropes.
- When using a high directional, ropes will be equally elevated (they may be lowered if the high directional is no longer required). When no high directional is available for sharp, abrupt edge

transitions, the option of a vertically oriented stretcher shall be considered first; if warranted, the stretcher may be leveled once below the lip of the edge.

- Static ropes are preferred over Low Stretch ropes to help mitigate risks associated with stopping distance.
- Command & Communication Structure and Protocols have been modified to place a greater emphasis on managing Human Factor risks (e.g. Edge Transition Briefings along with Dry Runs, et al.).

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