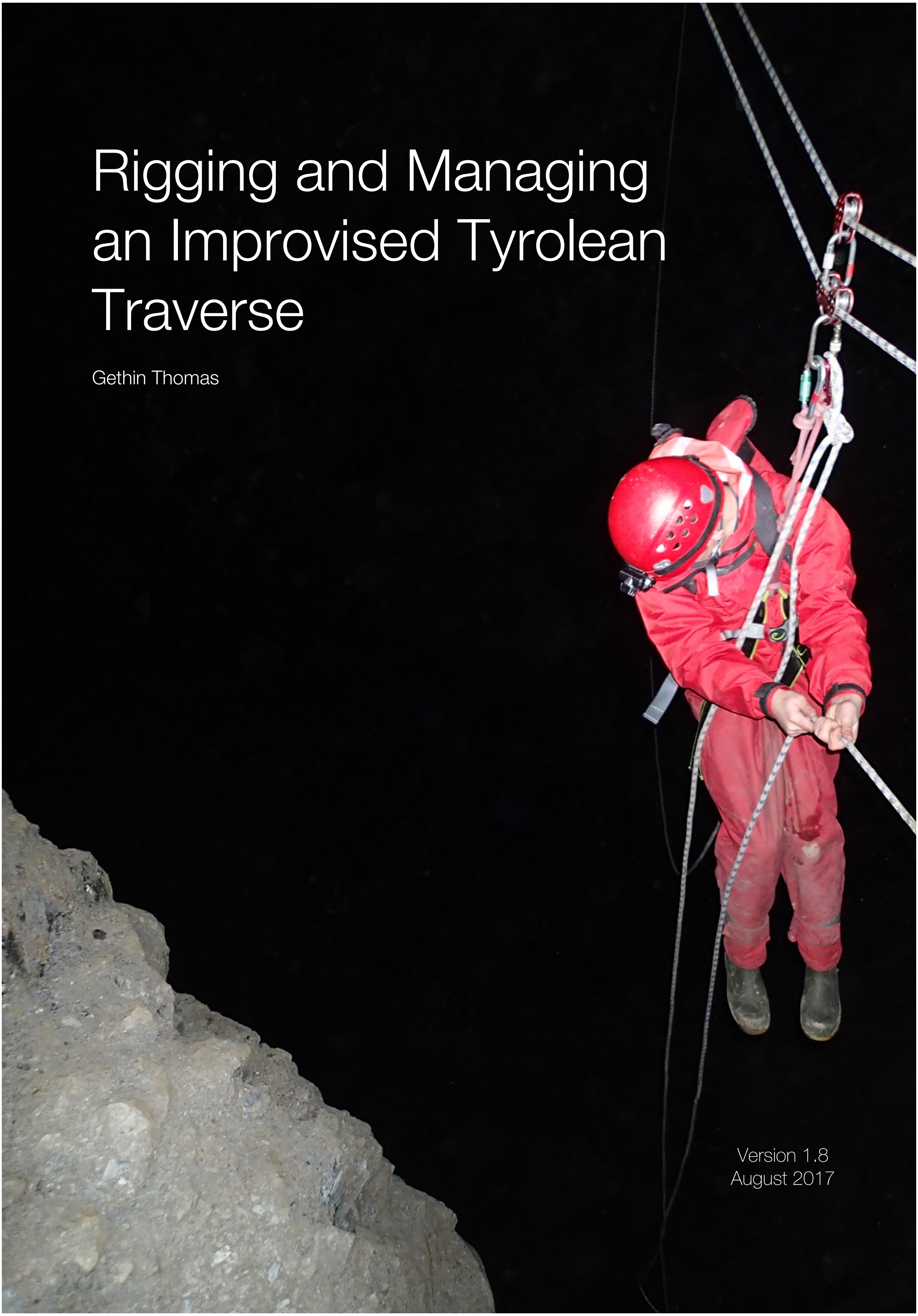
Rigging and Managing an Improvised Tyrolean Traverse

Gethin Thomas



Version 1.8
August 2017

Disclaimer

The author assumes no responsibility for the application of the techniques or principles outlined within this document. Use of these techniques are at the user's risk, and form only part of the training necessary to perform and manage the techniques outlined.

This document has made use of various openly available on-line resources and credited them accordingly. Several illustrations have been created using some of these resources and may not reflect manufacturers recommendations.

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1. Introduction

The following document has been drawn up based on research, experimentation and experience of rigging and managing Tyrolean traverses as an adventure activity, such as mine exploration, coasteering and gorge walking **with a single person load and a small (around 12 people) activity group**.

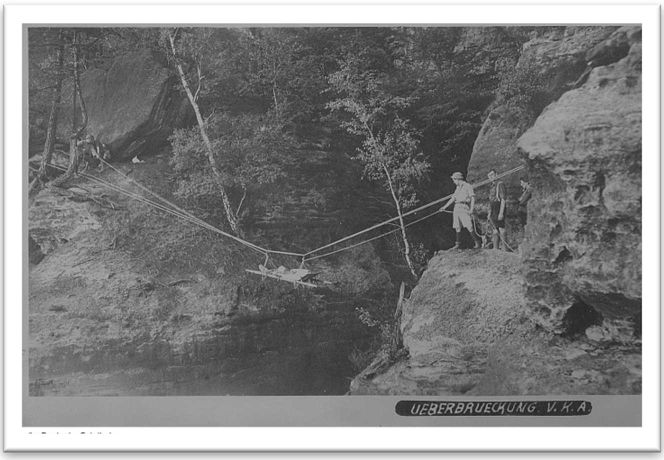

Figure 1. Deutsche Fotothek

It has been written up to the support 2 illustrations (figures 2 & 3, appendix three and four, or can be downloaded at www.train4underground.co.uk/tyrolean) highlighting a method for setting up and managing a Tyrolean traverse. This document should also prove useful to experienced practitioners to help consider methods of rigging and managing a safe Tyrolean traverse.

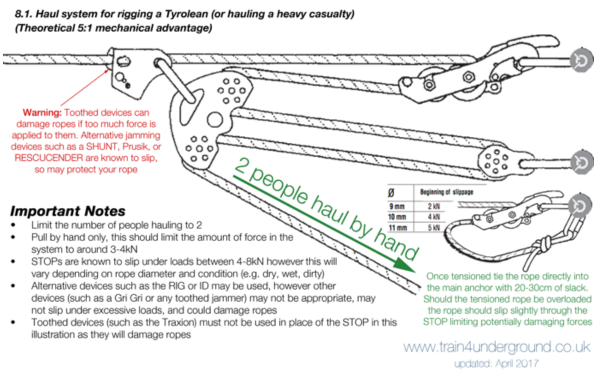

Figure 2., Rigging Guide. Gethin Thomas

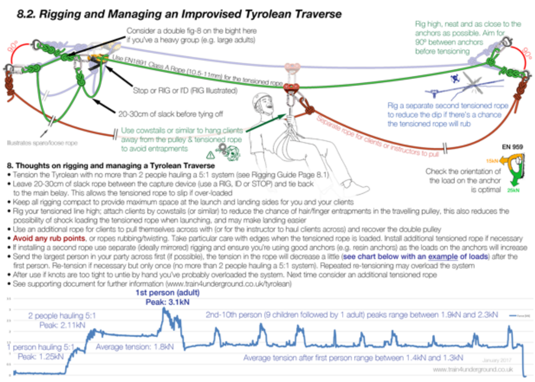

Figure 3. Rigging Guide. Gethin Thomas

2. Loads, forces and some frame of references

Throughout this document there will be several references to forces, the unit used throughout this document to derive force is the Kilo Newton (kN); a measurement of mass (in the context of this document a person) in motion subject to a force. As a rough frame of reference 1kN equated to 1 (large/static) person.

Much is made of the increased forces our equipment and anchors are likely to be exposed to when rigging and running a Tyrolean. Our equipment will be exposed to higher than normal loads principally in 2 stages; when tensioning the Tyrolean and when a load (person) is hanging mid-way across the traverse rope, this later load is amplified due to the physics of the situation.

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The theoretical forces on anchors/gear can be calculated using some trigonometry (figure 4) when a load is mid-span. However, measuring the angle in practice can be a challenge, besides, if a Tyrolean is over tensioned then ideally, we need to find that out before we hang someone in the middle of it!

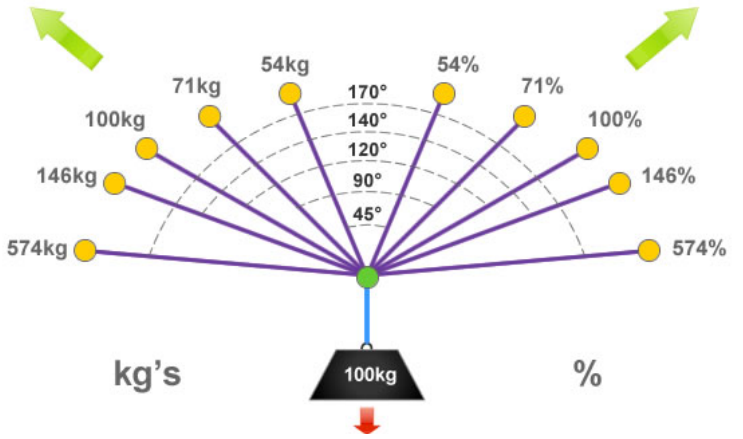

Figure 4. www.ropebook.com

We need to be mindful of how the load at either end of the Tyrolean changes as the load reaches the mid-point. Note how if a load is placed midway across the Tyrolean, and the angle at that mid-point measured to be 90º, then each anchor supports approximately 71% of the load. At 100º this goes up to 77.8% of the load (10º change of the mid-point sag yields an additional 6.8% load). At 150º there's approximately 193.2% of the load on each anchor, however take that up to 155º and the load increases to 231%, a 37.8% increase in load from just a 5º change in angle!

If a Tyrolean is tensioned so tight that when a load is hanging at the mid-point and the angle is around 160º (so very little sag) only a small increase in that angle (for example if slightly more tension is put into the system) and the increase of the load on the anchors will be dramatic (figure 5).

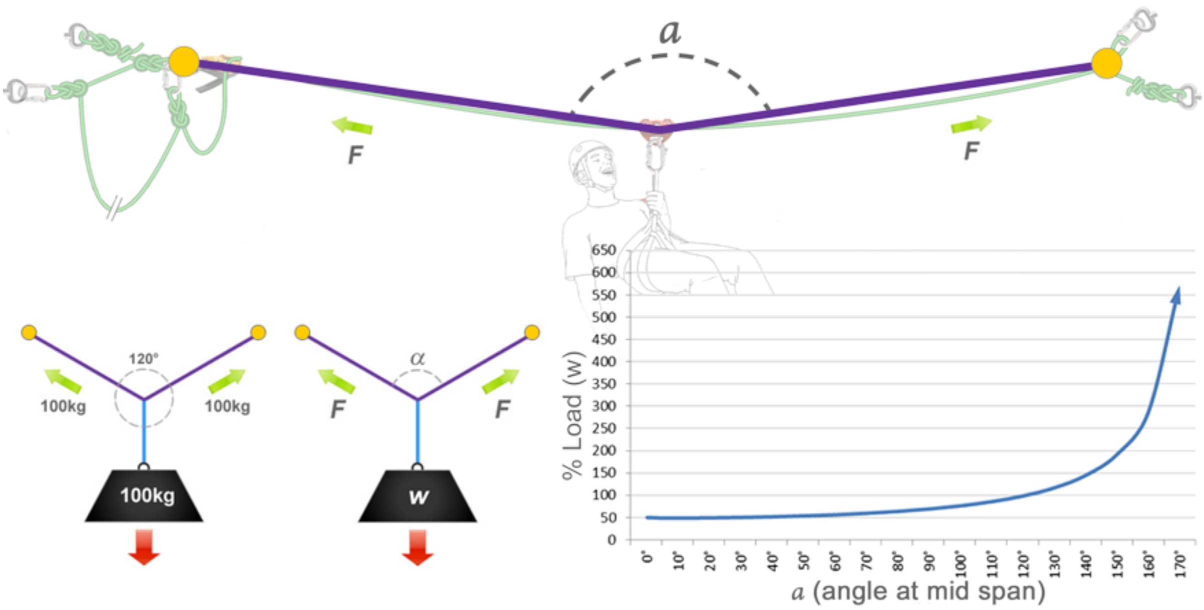

Figure 5. Elements taken from www.ropebook.com, Petzl and VRigger

The challenge in rigging a Tyrolean is finding the right compromise between reducing the sag of a Tyrolean to ensure we clear hazards, limit rub points on edges, and make the traverse manageable for clients without compromising the components and anchors used to construct it.

3. How strong is our gear?

3.1 Rope

We'll want to tension the traverse rope as much as possible to help clients progress across a Tyrolean without losing too much height and then having to regain it, as well as reduce the possibility of tensioned ropes rubbing against edges. It therefore makes sense to use a low stretch rope. Most testing and experience I'm drawing from for this document comes from using EN 1891 Type A low stretch kernmantle (semi-static) rope. The minimum requirements for this standard is (among other things) that the rope has a minimum breaking strength of 22kN for a slow static pull (tested with no knots), 15kN with a figure of eight knot and stretches less than 5% (all tested a load of 100kg in a pre-determined routine). The rope I've predominantly used, and the rope which to date most of my testing has been conducted with, is the DMM Work Safe Low Stretch (10.5mm) rope which has a minimum breaking strength of 32kN, reduced to 18kN with a figure of eight knot, the rope is credited with a 3% elongation.

Rope strength is reduced when wet and/or knotted, CMC Rescue Inc[1] saturated ropes in water for 3hrs and found they had on average an 18% reduction in strength for example (in later tests they found urine decreases the ropes strength by 14%, just saying!)

I'm aware of various other types of rope, such as 16mm sailing rope[2] with very high strengths in the range of 65kN, and very low stretch, however given their lack of versatility I've not considered them practical, and so have not looked to test them in use. This may be something for others to investigate in the future.

Knots are the main point of weakness in ropes, as highlighted by Bob Mehew during ongoing drop tests for the British Caving Association (BCA); "*A repeated observation of the four hundred or so samples that I have broken over the years is that only around ten ropes have broken elsewhere than the knot*"[3]. Different tests have been conducted on the reduction of rope strength with a variety of knots, a quick Google search will provide a range of results and some interesting YouTube viewing, but from some of the more reputable sources; Lyon[4] quotes 68-84% of the ropes original strength is retained with a figure of eight, 55-74% with a bowline and 61-72% with an alpine butterfly. Dr D. Merchant[5] quotes a ropes integrity at 65-75% of its original strength when a figure of eight is tied, 60-75% for a bowline (Yosemite), and 60-70% for an Alpine butterfly. Whereas Richard Delaney[6] quotes an average of 50% with used ropes, a figure also highlighted in the Lyon paper[5].

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[1] "How Much Does It Really Matter". J. McKently & B. Parker, ITRS 2001
[2] https://www.marlowropes.com/product/marlowbraid
[3] "Do sheath defects weaken a rope". Bob Mehew, Descent Aug/Sept 2012
[4] "Industrial rope access – Investigation into personal protective equipment". Lyon Equipment 2001
[5] "Life on the Line". Dr Dave Merchant. 2007
[6] Derating for knots. Richard Delaney, RopeLab. 2015

In addition, it's also worth highlighting that various knots have been shown to absorb varying degrees of force on initial impact, most notably in a French study on cowstails[7]. This is presumably a result of the rope slipping within the knot, absorbing the impact slightly.

Taking all of this into account, theoretically we could say that a new wet rope which conforms to the EN standard (-18% reduction in strength) with a figure of eight knot (-50%) could break as low as 9kN (22kN x 82% x 50%). However, during the Lyon research (where wet ropes were tested) no semi-static rope with a knot failed below 16kN (see chart 1).

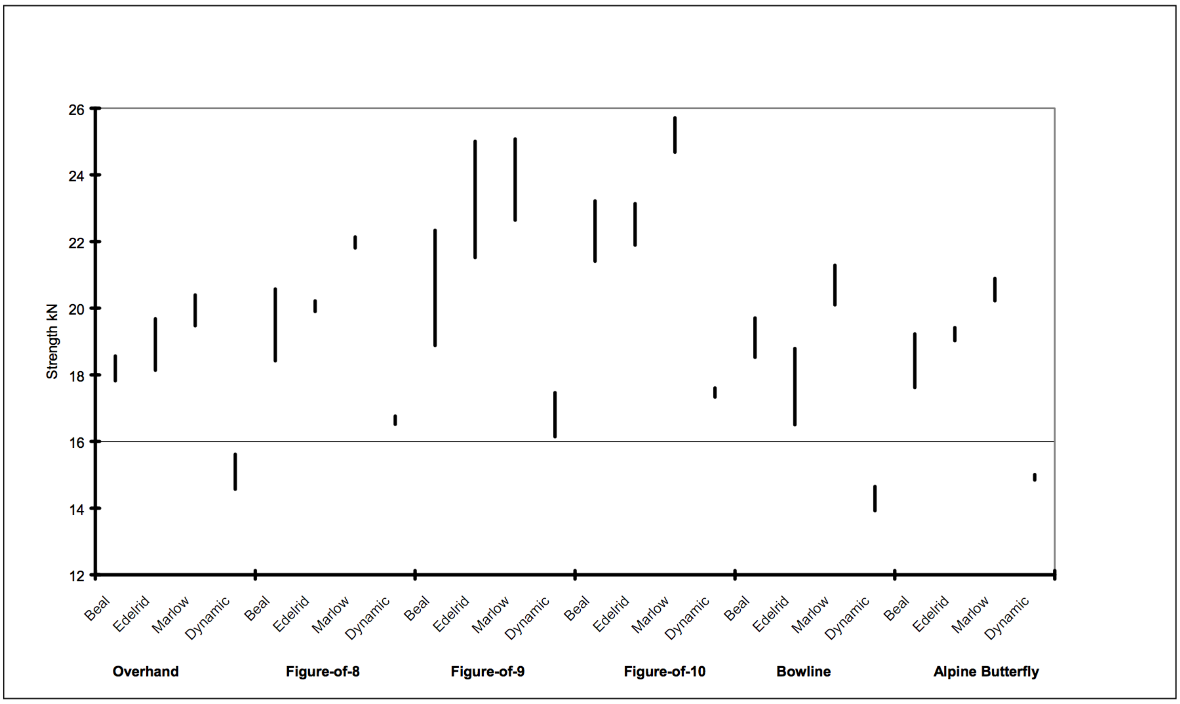

Figure 13
Knot strength (absolute)

Chart 1. Lyon

Research by Pit Schubert[8], and more recently Bob Mehew *et al*[9] and Walter Siebert[10] illustrates how a ropes performance reduce with use (less so by age). Sieberts research highlights how repeated use in top-roping can reduce the ropes strength. In a top-roping scenario Siebert evidenced that after around 800 cycles of top-roping (using a normal kernmantle rope with an 80kg mass repeatedly cycled over a karabiner) a rope's strength is reduced by around half its initial strength. The performance of these ropes plateaued until around 6,000 cycles after which the ropes performance started to dip.

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[7] "Series of tests on Cow's Tails used for progression on semi-static ropes". SFETH & EFS (translated by D, Weare). 2006
[8] http://theuiaa.org/documents/safety/About_Ageing_of_Climbing_Ropes.pdf
[9] http://british-caving.org.uk/wiki3/lib/exe/fetch.php?media=rope_testing:bca_long_term_rope_tests.pdf
[10] http://www.siebert.at/de/publikationen/from4

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Mehew *et al's* work has illustrated how a used rope, in one case used as little as 89 times showed a reduction in tolerance to drop tests (as per the BCAs Rope Testing criteria) from surviving 6 drop tests (new) to only surviving 2 (used). Of all of Mehew *at al's* rope testing the lowest failure force recoded during dynamic drop tests on used ropes EN 1891 Type A ropes with a knot was 6kN.

Together with Mehew's, Schubert and Siebert's work there is a wealth of evidence illustrating how ropes exposed to wear and tear can reduce their performance. **Ensuring ropes are well maintained and checked prior to use, as well as retiring ropes that have had a significant amount of use, is clearly a key consideration before use.**

Defining the amount of use a rope could safely be used for prior to retirement remains unanswered, however it would seem reasonable to assume that the retirement rate of a rope used frequently for Tyrolean's may well need to be retired earlier than a rope used in other applications.

3.2 Karabiners (EN 12275:2013)

The EN standard specifies (in part) that a karabiners minimum breaking strength must equal or exceed 20kN with the gate closed and 7kN with the gate open. Most aluminum krabs exceed that with most the krabs we used (DMM Shadow) rated to 24kN closed, 9kN open. Steel krabs go further with up to 45kN (closed gate) on some DMM models.

3.3 Slings (EN 566:2006)

The EN standard specifies (in part) a tensile strength of at least 22kN (figure 6). DMM 26mm nylon slings are rated to 30kN, and their 8mm dyneema 22kN.

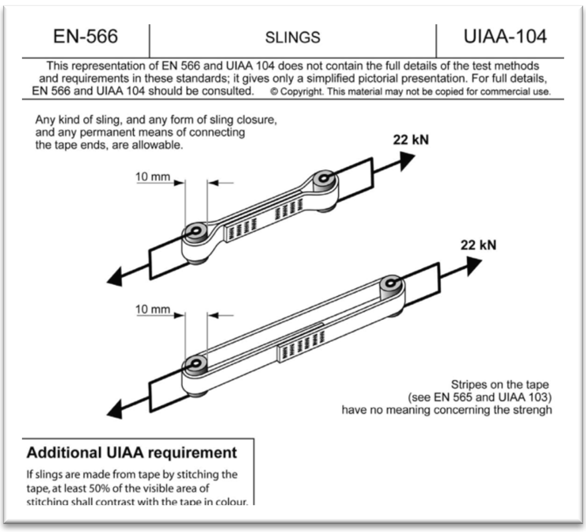

Figure 6. UIAA

Much has been made of the breaking strength of slings in dynamic situations[11] illustrating just how strong slings are (and how inappropriate it is to use them as cowstails), however also how the strength of a sling is reduced when knotted; for example one of the dyneema slings in the DMM drop tests failed as low as 10.2kN when knotted (with an overhand knot and a 100kg mass dropped with a fall factor of 1) compared to 22kN+ when subjected to the same drop tests but unknotted.

[11] http://dmmclimbing.com/knowledge/slings-at-anchors/

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Siebert[10] is highly wary of slings in his work on the discard criteria of textile components of Personal Protective Equipment (PPE) when using slings which have been exposed to the outdoors for a long period, or show signs of wear, supported by a body of work conducted by Black Diamond[12] highlighting the reduced performance in slings due to wear/abrasion and UV damage. **As with ropes clearly, we need to ensure slings are well maintained, inspected, and retired after significant use.**

3.4 Anchors (EN 959: 2007)

The EN standard specifies (in part) an axial pull (pulled straight out along the axis of the shaft) minimum strength of 15kN, and radial pull (being at right angles to the shaft of the anchor) minimum strength of 25kN (figure 7).

The Petzl Collinox glue in anchor is rated to 25kN in all directions, with the bigger Battinox rated at 50kN. However, the traditional 8mm "spit" anchors do not conform to this standard, being rated to around 15kN in radial[13], and not to be pulled in axial (with most plate hangers).

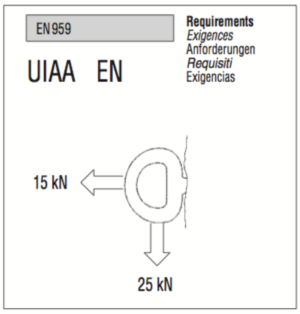

Figure 7 Petzl

Other anchors such as the Bolt Product anchor and IC anchor adopted by the BCA have been tested in axil to more than 30kN. Testing in slate[14] showed the majority (60 of the 76 anchors tested, representing a range of Collinox, 12mm Goujon, BP and IC anchors) held more than 30kN when pulled directly out, the weakest being a little over 11kN (and that anchor placed in noticeably soft/poor band of slate).

3.5 Other Anchors

As an alternative to "bolts" users may wish, or need, to build a belay with wired nuts or cams. These devices have a far lower strength, commonly ranging from 7kN to 12kN for wires, 14kN for Hex's, and 9kN to 14kN for cams[15]. Great care should be taken when building belays from these devices as when a load is placed onto the Tyrolean, during initial tensioning or use, the orientation of the belay is likely to change. Any movement of the gear placement could displace and compromise them. There's also a chance the rock surrounding the placement may fail at lower loads than those stated on the device themselves, particularly in regions of brittle or quarried rock. Threads, large spikes/boulders or trees (a common rule of thumb is any trees wider than your helmet are ok provided they are well rooted[16]) may be more appropriate if available.

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[12] https://blackdiamondequipment.com/en/qc-lab-gear-doesnt-last-forever--slings--quickdraws/qc-lab-gear-doesnt-last-forever--slings--quickdraws.html
[13] https://www.petzl.com/sfc/servlet.shepherd/version/download/068w0000001O2ssAAC
[14] http://www.train4underground.co.uk/bolts-in-slate-testing-project/
[15] Sample of strength ratings taken from DMMs website, www.dmmclimbing.com/products/nuts
[16] http://slacklineinternational.org/tree-protection/

3.6 Rope Capture Devices

In constructing a Tyrolean we are likely to use some sort of rope capture device to assist in holding and tensioning the rope; by that I mean a device that can be moved along a rope and hold a load on that rope

There are four main types of rope capture device. The devices I'm going to outline here are some belay/descending devices (e.g. the Petzl Stop), ascenders (jammers), back up devices (devices designed to accompany a rope access technician on a backup rope, and catch them should their main/working rope fail), and the Prusik knot.

Some of these devices are designed for recreational (caving/mountaineering) use and others with rope access in mind. The standards required for rope access (including planned rescues) are normally more rigorous than those applied to recreational equipment, however many devices will conform to multiple standards.

The following few pages' outline some of the more commonly used devices, and provide the more pertinent parts of the EN standard they must comply with.

3.6.1 Descenders/Belay Device (with assisted locking)

The following devices have illustrations within the manufactures documentation supporting their use in rigging a Tyrolean traverse. There may be other devices suitable but I've only focused on these three.

The Petzl STOP conforms to the EN 341 Class A standard, which in part subjects the device to a static strength test of 10 times the maximum rated load, or at least 12kN to assess its overall breaking strength. The maximum rated load of the STOP is stated as 150kg, however up to 200kg in exceptional situations.

It's worth highlighting that during some of the drop tests Lyon conducted[3] the rope snagged between the side plate and bobbin of the STOP damaging the rope. Holan & Beason[17] had similar results with dynamic loading of a STOP using just the lower capstan. This is one of the reasons I suspect, that although Petzl advocate the use of the STOP to rig a Tyrolean Lyon's preferred device is the RIG or I'D. The technical illustration provided with the TANDEM[18] pulley suggest the STOP can be used in a 5:1 mechanical advantage (MA) system to rig a traverse.

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[17] Rope Access Equipment Testing: The back-up Safety System. Jan Holan and Beason. August 2002
[18] https://www.petzl.com/GB/en/Sport/Pulleys/TANDEM#.V91eZTu8tS0

Historically Petzl illustrated slip values for this device (figure 8), however for some reason stopped doing so, probably due to the variation of slip rates in different types of ropes and factors such as how wet, dirty etc. the rope is. One of the many advantages of the STOP is peoples' familiarity with the device (particularly cavers), and people are more likely to have one, so don't need to be investing in new kit to rig a Tyrolean.

Static request (abseiling)
Sollicitation statique (rappel)
Statische Belastung (Abseilen)
Sollecitazione statica (discesa)
Solicitación estática (rápel)

Ø	**Beginning of slippage** *Début de glissement* Anfang des Durchrutschens *Inizio scorrimento* Inicio de deslizamiento
9 mm	2 kN
10 mm	4 kN
11 mm	5 kN

Figure 8. Historic information provided with Petzl STOP

Both the Petzl RIG and I'D conform to 2 EN standards; EN 341 Class A (as does the STOP) and also EN 12841 Type C. The later relates to rope access workers incorporating a "hands-free" locking function. Within the current (at the time of writing) technical information provided with the I'D and RIG on Petzl's website[19] there are instructions on using the I'D or RIG as a rope capture device for a roped Tyrolean tensioned by up to 2 people with a 3:1 MA.

An alternative rope capture device could be the GRIGRI (EN 15151-1 type 6). This is tested to a static strength of 8kN by installing the device on a rope jammed against a stopper knot and applying the appropriate force at a pre-determined rate. Petzl advocate the use of a GRIGRI as a capture device for rigging a Tyrolean, however only if a very small mechanical advantage is used (2 people hauling directly through the device only). Personal and a raft of others' anecdotal, experiences have shown the device is very difficult to release if loaded following a large load (Petzl illustrate the use of a 3:1 haul to release a jammed GIGRI). For this reason, it's my feeling that this device is less appropriate than some of the others discussed here for the rigging a Tyrolean traverse.

Also, worthy of consideration is the hypothesis that a capture device with a large radius, such as the RIG of I'D can maintain a higher strength in the rope as no knot is used, at least at one side of the traverse.

3.6.2 Ascenders and Back up devices

Essentially ascenders/back up devices (figure 9) can be split into 2 types; with or without teeth. Toothed ascenders such as a Petzl CROLL, BASIC and TIBLOC conform to EN 567 (mountaineering ascenders), and/or EN12841 Type B (work positioning device). Non-toothed back up devices such as a SHUNT, GIBBS Ascender to the ISC Mini Ropegrabs (often conforming to EN 12841 Type A; fall arresting back up devices) are more likely to allow a rope to slip when excessively loaded, however these slip rates vary between device and rope types/conditions. The EN standard for these devices stipulate (among other things) that they must hold a rope at 4kN for 3 minutes without damaging the device or rope.

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[19] https://www.petzl.com/GB/en/Professional/Tensioning-a-rope-for-a-Tyrolean?ProductName=I-D-S&Familly=Descenders#.V91XYju8tS0

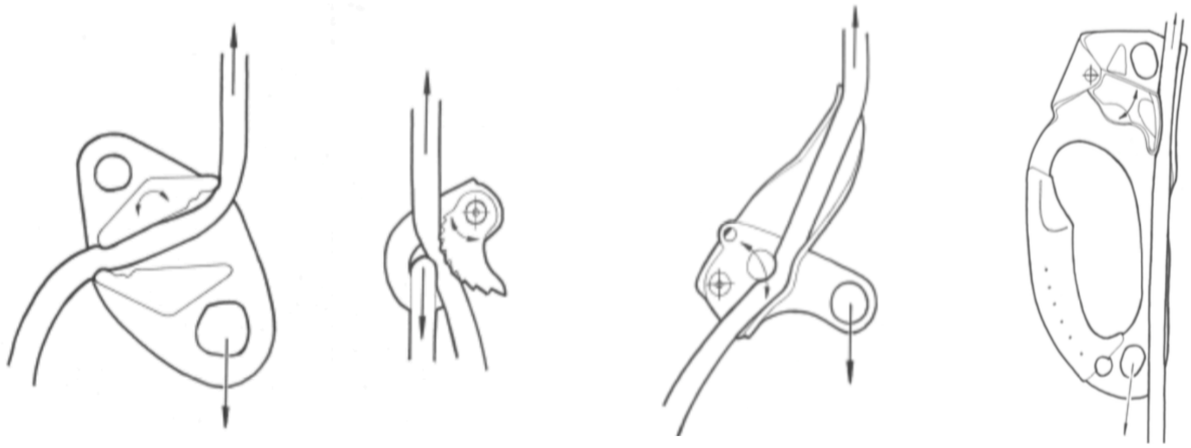

Figure 9. Illustrations taken from Lyons document on Industrial rope access

If using a toothed jammer as part of a pulley (mechanical advantage) system to tension a Tyrolean, great care should be taken to ensure the device is not exposed to excessive forces as this could damage the rope. This is one of the key considerations in rigging a Tyrolean, and likely to have been a contributing factor in some of the failures of Tyroleans over the years. **Toothed jammers should never be used as the terminal grab device in a tensioned rope.**

3.6.3 Prusiks

3 wrap 6mm-8mm accessory cord (EN 564) built prusiks are the preferred rope grab mechanism within the Mountain Rescue community, in part as they have shown to slip (between 7-14kN depending on rope types/conditions), normally without damage to the rope. 6mm cord has a breaking strength 8kN.

Figure 10. Prusik cord melted onto a rope. Photo by Gethin Thomas

However, the prusik knot can damaged ropes (figure 10) as the heat build-up melts both ropes bonding them and causing them to rip apart. Using twin prusiks so loads are shared can reduce the chance of this. Prusiks certainly have their use, but have shown to slip at varied and lower rates on wet and dirty[20] ropes so may not work well underground or in wet/dirty conditions.

[20] Mud changes the performance of three rope grabs, Mortimer and Angel. 2015 http://itrsonline.org/wordpress/wp-content/uploads/2015/11/Mortimer-Mud-2015.pdf

3.7 Pulleys

Pulleys must conform to the EN 12278 standard which stipulate, in part, that they must hold a static load of 15kN, and continue to rotate with a load of 2kN. Efficiencies vary depending on type, with the better pulleys claiming 95% efficiency (so only 5% of your effort is lost).

3.8 Summary of Gear minimum strength

Rope	**6-9 kN**	Krabs	20kN	Slings	10.4kN	STOP	12kN	RIG/ID	12kN
Anchor	15kN	GriGri	8kN	Jammer	4kN	Prusik	8kN	Pulley	15kN

From all these items of gear it's the Jammer (particularly toothed jammers) that needs watching when in use, and it may be prudent to limit exposing ropes (with knots in them) to loads less than 6-9kN.

4. Minimum Breaking Strength, Working Load Limit, Safe Working Load, and the Static System Safety Factor

Within the manufactures documentation and/or on any technical equipment (such as a karabiner) there is normally a value rating for that component noted, normally in kN.

Some manufactures quote a components Minimum Breaking Strength (MBS). This is a statistically derived value calculated by testing a batch of components. By statistically analyzing the breaking strength data, an estimate can be made on the likely minimum strength of the component.

The Working Load Limit (WLL) is the mass or force that a component of technical equipment can hold, raise or lower without fear of that component failing. This was referred to as the Safe Working Load (SWL), but changed as it was felt the word "Safe" could lead to legal issues! This value is always lower than the MBS by a large ratio to provide a factor of safety. This factor is often around a value of 4 or 5.

Several manufacturers will quote their equipment's Working Load Limit, for example DMM note several devices with both their Minimum Breaking Strength and its WLL. Rigging Hubs for example are given a MBS of 45/80kN and a WLL of 10kN/16kN (a 4.5:1 ratio). Where a WLL is not documented on an item of technical equipment Richard Delaney[21] suggests a generous safety factor of 4 would be sensible, that being that if a component has a WLL of 40kN, then it should not be used in situations where that component may be exposed to a load in excess of 10kN.

In addition to the Working Load Limit there's also the Static System Safety Factor (SSSF), which is in common use by both rope access and rope rescue personnel. The idea of the SSSF was probably first introduced in the early 80s by Canadian based rope rescuers when looking at a ratio between the Minimum Breaking Strength value of

[21] Auto locking belay devices: when will the rope slip? RopeLab, 2014

components within a rope rescue system (such as a belay), and trying to come up with a value for the worst-case scenario loading onto that system, such as a through dynamic loading. A ratio of 1:10 is commonly used; this being that the static (i.e. not during a haul) load on any system should be 10 times less than the load rating for the weakest component in that system i.e. a karabiner expecting to be holding a 1kN load must be rated to at least 10kN.

In 2014 Kirk Mauthner presented a paper[22] challenging the 10:1 static safety factor, specifically it's blind adoption into all rope systems when force limiting systems (such as a device that slips when significant loads are placed on it) may be in play. He suggested a more pragmatic approach may be appropriate in some systems (provided the force limiting system didn't kick in at forces below the expected maximum load on a system) suggesting many rope technicians are over engineering their systems by following the 10:1 rule.

5. Slip rates

Some equipment, such as some non-toothed jammers and belay devices are prone to slip under excessive loads. Some manufacturers published these slip rates, although many have now stopped, given these rates fluctuate significantly depending on rope type, diameter and condition (wet, dry, dirty etc.) Here's a list of slip rates from historic and current manufacturer's instructions and observations in testing based in 10.5-11mm semi-static ropes. At the time of writing, the only device I've found to publish their slip rate are the RIG & I'D.

Device	Manufacturer noted slip rate (11mm rope)	Observed slip rates
Shunt	2.5kN	2.5-3.2kN
Rescueascender	>4kN	5.1-8.4kN
I'D/RIG	5.5-7.8kN	5.5-10.7kN
STOP	5kN	0.9-4kN
GriGri*	5kN	4-6.3kN

*GriGris become impossible to release if significantly loaded

Slip rates can clearly be useful as force limiters in systems, however as Richard Delaney points out in his article on auto locking belay devices[13], there is a significant range in slip rates depending on rope type, and so these cannot be relied on alone.

6. What sort of loads should we consider appropriate for a Tyrolean?

Before we start looking at the loads on Tyroleans it's worth having a look at the sort of loads we regularly apply in different situations, such as climbing, SRT and SRT rescues, to see what loads we could consider to be acceptable to expose our ropes and equipment to.

[22] Moving Beyond 10:1 Static System Safety Factor, Kirk Mauthner. ITRS 2014

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To build up some frame of reference let's consider the loads in either a rock climbing (figure 11) or caving ladder climb, with a top rope system. With this system, we have a belayer on the floor with a rope running up through a krab at the top of the climb and down to the climber. Should the climber fall, or needs to be lowered down, then the belayer needs to weigh the same as the climber (or be anchored to the floor), otherwise the belayer will fly up to meet the climber! This means the krab at the top of the pitch will be holding at least twice the load of the climber. If the climber exerts 1kN of force into the system then the krab at the top of the pitch would be exposed to 2kN. A larger climber or a dynamic load (such as a fall) would likely load the top krab with more than 2kN in this example. It is common practice (particularly among Outdoor Education Centers) to use a semi-static rope to rig the belay points at the head of a pitch with a figure of eight knot and one or two krabs for the belay rope. These pitch head knots and krabs are likely to be exposed to 2kN+ regularly during a climbing session.

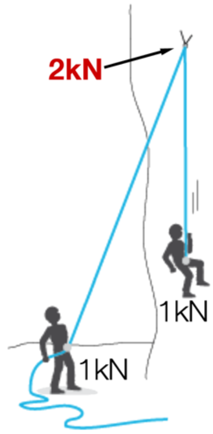


Figure 11. Elements from Petzl

In 1994-96 the French Speleology Federation wrote a report[23] (in French) highlighting some of the forces measured in a variety of rescues and anchor failures. One of the tests looked at counterbalance rescues (like a top-roping system) noting loads from 1.8kN up to 2.6kN.

In December 2015, we fixed a load cell to the top of a short (5m) SRT pitch and looked at the loads achieved when one person ascends a rope[24]; we observed peak loads of up to 1.9kN with a "jerky" ascent. We also looked at the forces achieved in rescues[25] (2 people on a rope) seeing similar peak forces around 1.9kN. Lyon did similar tests in 2001[4] noting up to 0.9kN when abseiling, 1kN in ascending (up to 1.6kN when ascending quickly).

Another consideration is how the performance of a rope may differ with regards to its tolerance to abrasion when under different tension. We all know that a rope is easier to cut when under tension, and some observations on how easy it is to cut a rope when under tension[26] supports the consensuses that **tensioned ropes should not be exposed to any sharp edges**.

Within the rope rescue community there is a current hypothesis that ropes tensioned more than 4kN have very little resistance to abrasion, catastrophically failing when exposed to even small abrasions. Although there is little tangible evidence to support this (at the time of writing), it is worthy of consideration.

Determining a load which we could consider comfortable exposing our ropes to is going to be very subjective. However, we could comfortably say providers of climbing

[23] Fédération Française de Spéleologie (French Caving School)/Spéléo Secours Français (French Cave Rescue). Mechanical Tests in Cave Rescue. Edited by Jacques Gudefin, translated by D. Weare & R. Mehew
[24] http://www.train4underground.co.uk/2015/12/01/forces-in-srt/
[25] http://www.train4underground.co.uk/2016/05/10/level-2-srt-improvised-rescues-session/
[26] http://www.train4underground.co.uk/2017/01/11/cutting-ropes-tension/

session regularly expose ropes to 2kN, occasionally higher, in a top-roping climbing session, and so not unusual.

If loads greater than 4kN are expected, then good edge protection (ideally avoiding all rub points by re-directing the rope) would seem sensible. Loads in the range of 6-9kN should be avoided as this is reaching levels where a used rope has been found to fail, and where theoretically a new wet rope with a knot could fail. Clearly, we also need to be maintaining our ropes well and not using them if they are showing signs of excessive wear or damage.

7. How tight should a Tyrolean be?

Having a tight Tyrolean is going to make life a lot easier for most. If the rope is tight and high then we can suspend our clients below the tensioned rope. This reduces the chance of finger or hair entrapment in the travelling pulley, rope burn on the tensioned rope, limits the chance of shock loading the system when people inevitably launch off the starting point, and our clients shouldn't find it too challenging to pull themselves across the Tyrolean and land on the far side. Having a tight rope also reduces the chance of a traverse dipping too much and rubbing on the floor or any edges, something that should be avoided at all costs as any rub points on a tensioned rope will likely be catastrophic.

However, as we've seen from the illustration above (figures 4 and 5) on angles and loads on anchors, if the Tyrolean is too tight then we could be exposing our equipment and anchors to very high (possibly gear or anchor breaking) loads.

There's several ways we can try to limit over tensioning a Tyrolean. Several rope rescue practitioners and literature discuss a 10% sag (or dip) in the tensioned rope prior to loading. So, say for a 10m traverse, the rope should sag 1m at its mid-point. Unfortunately, this is not that easy to work out unless you can stand at the side of the traverse and get a good look at it (particularly challenging underground!), so personally I can't see much practical value in this.

Another option is to not pull the too tight in the first place. This can be achieved by minimizing the number of people or the mechanical advantage in any pulley system when first tensioning the Tyrolean. Mountain rescue teams have adopted "the rule of 12" to address this. The basis of this rule is that a load (so the rescuer and kit) is hung midway across the Tyrolean on a rope or ropes pre-tensioned by only 2 or 3 people, just by hand (so still very slack). Once at mid-span the rope is then re-tensioned with no more than 12 people, or a mechanical advantaged pulley system that does not exceed a similar level (so no more than 2 people pulling on a 6:1 mechanically advantaged pulley system, or more than 4 people pulling on a 3:1 etc.) But for this to be effective we need to know how strong we are…

8. How hard can we pull a piece of rope?

In 1993 Kirk and Katie Mauthner conducted a study on people's gripping ability on a rope in motion[27], looking at the gripping strength of 34 volunteers. They came up with a maximum gripping ability of 0.425kN with an average of 0.209kN for 2 hands (no gloves). It is this top figure of 0.425kN which Mountain Rescue teams have used to draw up the rule of 12, so calculating that using a 6:1 haul system and 2 people hauling (taking account of a loss in effort due to friction in a pulley of 20%) will leave a highline in use loaded in the region of 3.6kN. Making use of ropes rated to 40kN keeps this within the Safe Static System Factor of 10:1[28].

In June 2013, during the Mountain Rescue England & Wales Technical Symposium, tests were conducted with all attendees hauling on a 10.5mm rope fixed to a load cell. The average force observed during these tests where higher than those observed by Mauthner, with an average of 0.47kN, this from around 50 delegates from several MR and CRO teams across the UK.

During our October 2013 tests[18], between us one person peaked at 0.7kN, with an average of 0.38kN, all with no gloves. Gloved hands pulled a little harder.

We also looked and 2 and 3 people hauling. 2 people peaked at 0.92kN, averaging 0.74kN, 3 people peaked at 1.2kN, averaging at 1kN.

From this I'd say, as a **<u>rough guide</u>, an average size person can probably haul around 0.5kN for a short period** (approximately 10 seconds), and two people around 1kN with ungloved hands on a rope. There's always going to be someone bigger and stronger, so this is something that should be taken into consideration, however these figures can serve as a guide. Haulers should also be disciplined; initiate a haul gently (not shock load the system with a big tug!) and not wrap ropes around their bodies etc. but just pull with hands.

9. Clutch Systems

Another mechanism to try and ensure our equipment is not overloaded is to use equipment that allow tensioned ropes to slip at certain loads. Several devices such as the STOP, ID, RIG, Prusik, SHUNT etc. have shown to slip and not damage ropes.

These could either be used during the tensioning phase of the rigging by using a grab device that slips as part of the mechanically advantaged hauls system.

Alternatively, (or in addition) a clutch device could be used as the capture device on the tensioned rope, and left rigged in such a way that some rope could slide through the device if the tensioned rope is overloaded. As the tensioned rope slips through the device, even marginally, it will increase the sag of the Tyrolean and so reduce the

[27] Gripping Ability on Rope in Motion. Kirk & Katie Mauthner, 1993

[28] Thanks to Chris Onions or Rescue 3 and Ogwen Valley Mountain Rescue Team for the explanation on this!

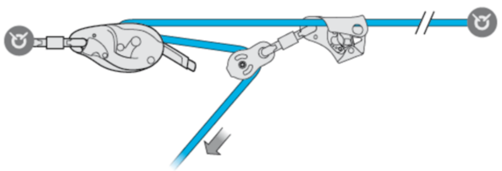
forces in the overall system. Once the load on the Tyrolean has reduced the clutch device should re-engage. Having said that if the Tyrolean is severely overloaded and the clutch device worn (for example a well-used STOP descender) there's always the chance the tensioned rope will continue to slide though the device, so some sort of backup should also be considered!

Devices have shown to slip at varied rates[13] and are depending on rope types and condition, so these devices cannot be relied on completely to safeguard a Tyrolean. **It would seem sensible to combine both a limited mechanically advantaged system and a clutch device to reduce exposing our equipment and anchors to damaging loads.**

10. Mechanical Advantages

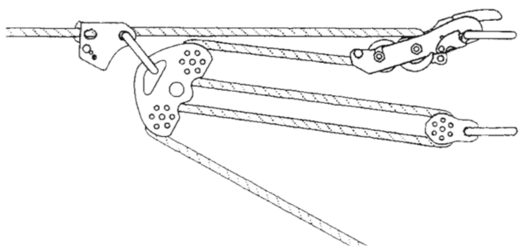
Getting 12 people to pull on a rope is only practical if there's significant safe space to work in. The reality of most Tyrolean's (particularly those rigged underground) is we'll be rigging things from a small safe working area. A solution may be to employ a mechanical advantage (pulley system) to tension a rope with the fewer people.

Here are 2 of the systems illustrated by manufactures (figures 12 and 13) as being suitable for use in rigging a Tyrolean. The RIG/I'D is a theoretical 3:1 MA, with the TANDEM and STOP a 5:1 MA. However, effort is lost at each pulley due to friction, reducing the mechanical advantage. There's also a lot of effort lost in the friction of the belay device (up to 80%), however the advantage of using a device which is designed to lower loads steadily coupled with their estimated slip rates makes up for the friction battle.



RIG/ID. 3:1 Thoretical Mechanical Advantage

Figure 12. Petzl



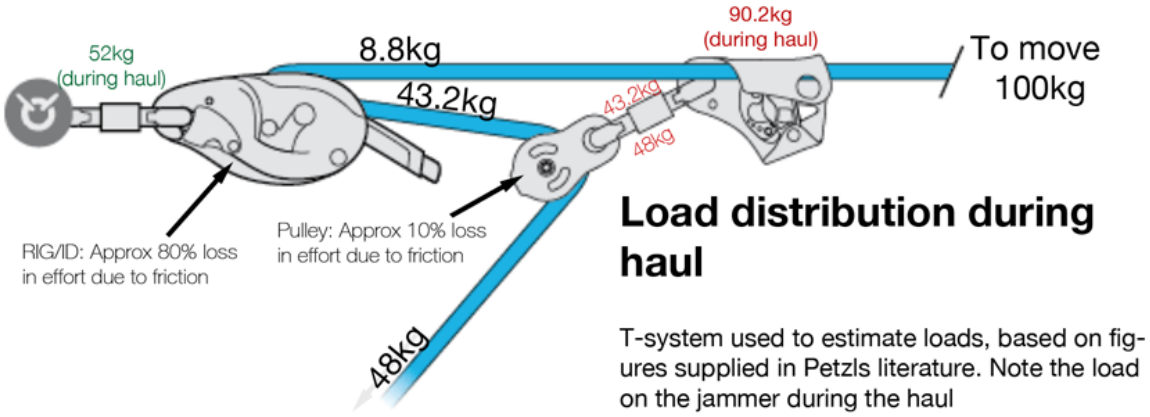
STOP and Tandem Pulley. Thoretical 5:1 Mechanical Advantage

Figure 13. Petzl

The best pulleys available (at the time or writing) quote a 95% efficiency. Calculating the friction around the descender/belay device is a little more challenging, as once the rope starts moving through the device the friction coefficient changes from a static to sliding value. In calculating the MA with a descender/belay device it's probably easier to ignore the rope running through it, so the 3:1 illustrated above becomes a 2:1 and the 5:1 a 4:1. This theory is somewhat supported when we look at the figures supplied by Petzl for the use of a RIG/ID and STOP in a haul[29] and also illustrated here (figures 14 and

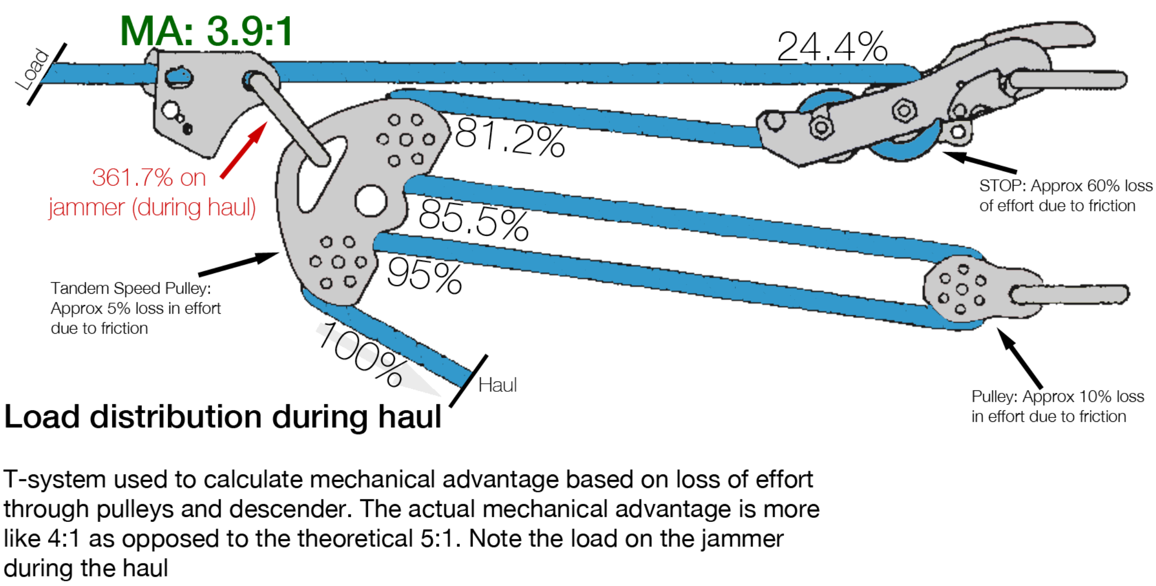
[29] https://www.petzl.com/US/en/Professional/I-D-efficiency-at-the-head-of-the-system-?ProductName=I-D-S#.WDWMWHecbgE

15).



Theoretical 3:1 Haul with a ID, closer to 2:1

Figure 14. Taken from Petzl illustration



Theoretical 5:1 haul with a Petzl STOP, closer to 4:1

Figure 15. Taken from Petzl illustration

One key consideration with each of these systems is to calculate the theoretical load on the jammer during the hauling process. Jammers may start to damage ropes if exposed to greater loads than 4kN. With the 3:1 system we could expect in the region of 195% of the effort put into the haul on the jammer, and on the 5:1 in the region of 363% of the effort.

Providing less than 1kN of effort is put into either of these systems then the jammer shouldn't be over-burdened. Alternatively, a non-toothed jamming device or a prusik would reduce the chance of damaging the rope, however neither are completely fail-safe.

Rigging and Managing an Improvised Tyrolean Traverse

My suggestion, based on the variety of information on how hard people pull on a rope, would be to **limit any hauling on no more than 2 people with un-gloved hands if using the 5:1 system, or 4 people if hauling on the 3:1 system**. Hauling should be initiated gently, and pulled by hand (not wrapped around the body) from a standing position (so not using body weight to haul). It may be prudent for larger/stronger practitioners to consider using a non-toothed jammer when tensioning a Tyrolean.

11. Finishing off the Rigging

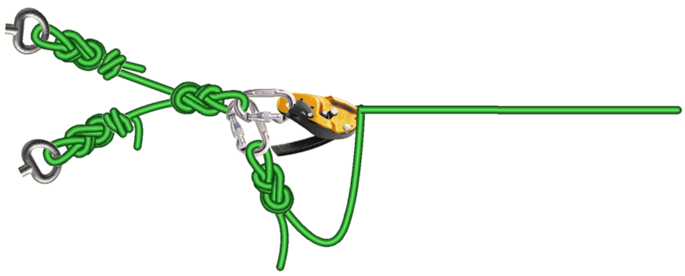


Figure 16. VRigger

Once the tensioning is completed then a short length of slack rope should be left coming from the belay device, and secured to the main anchor (figure 16). Should the rope to slip through the belay device the dip at the mid-point of the traverse will increase, reducing the overall force within the system. It may not take much rope slippage (a few cm at may suffice) to reduce the forces involved and so allow the belay device to grab the rope again. If there was a catastrophic failure of the belay device, or should the device slip uncontrollably, then the rope is backed up (providing it wasn't damaged when the belay device failed), however not with so much slack that a client travelling across the Tyrolean may hit the deck.

12. Pitch head redirection

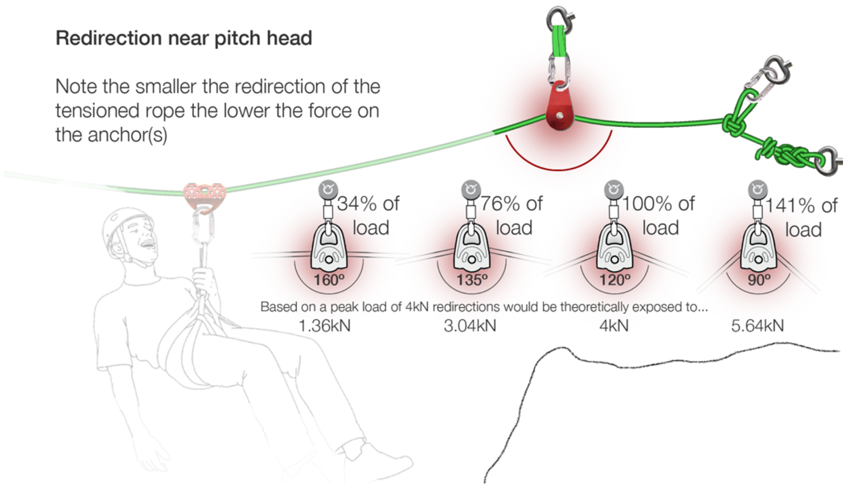


Figure 17. Elements from Petzl and VRigger

It may be necessary/advantageous to redirect the tensioned rope near the take-off or landing point to reduce the chance of the tensioned rope rubbing on the floor. The load on the anchor supporting the redirection will vary depending on how extreme the redirection[30] is. The greater the redirection, the better your anchor is going to need to be. Very small redirections may only require 1 anchor, whereas significant changes in the direction of the tensioned rope may require multiple equalized anchors (figure 17). It's worth using a broad pulley on the redirection if possible as it'll be kinder to the rope and allow some movement, however some pulleys

[30] https://www.ropebook.com/information/angular-vector-forces/

have very low working load limits so it's worth checking the specs of the pulley you choose for this job.

13. Anchors and belay building

Selecting sound anchors and bringing them all together to create a "bomb proof" belay is one of the key skills required for building a safe Tyrolean. Loads of 4.5kN[31] have been observed on a single tensioned rope (when a large adult launched themselves onto a pre-used Tyrolean, dynamically loading the tensioned rope). Observations by RopeLab[14] has shown that in some situations clutch devices have held over 10kN before slipping.

When bringing multiple anchors together we need to be mindful of the angle between each anchor. If we aim to rig at 90^0, with the load midway between 2 anchors, then theoretically each anchor takes approximately 70% of the load.

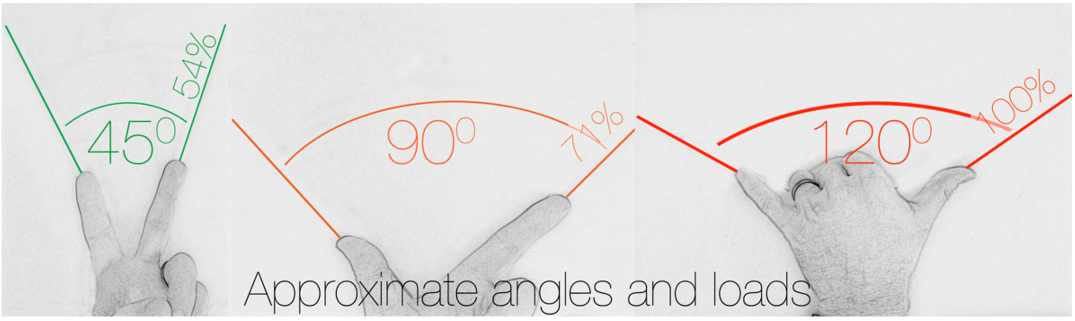


Figure 18. Gethin Thomas

Working with 90º provides a good compromise between load sharing and maximizing the working space at a pitch head/stance, the lower the angle between each anchor, the more space rigging will take up, reducing the working area available to manage clients on and off the Tyrolean.

Also, worthy of consideration is that the load is only equally split between two anchors if the load is placed directly between them. If a load is off to one side, then a greater proportion of that load with be placed on the anchor its nearest to. This is also the case if one leg of a belay is longer than the other (the greater proportion of the load placed on the shorter leg), or if one leg of a belay is built from 2 strands of rope, and another from one (the two strands taking the greater load)[32] as there is more stretch in the single or shorter rope, off-setting the load slightly when under tension. The illustration below (figure 19) highlights which anchor would be exposed to the greater load if rigged in this way, and is something we should be mindful of when rigging, favoring better anchors if possible.

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[31] https://www.dropbox.com/s/58c580yn681pql7/Tyroleans%20data.xlsx?dl=0

[32] "Tying it all Together". M. Gibbs. Rigging for Rescue. 2012

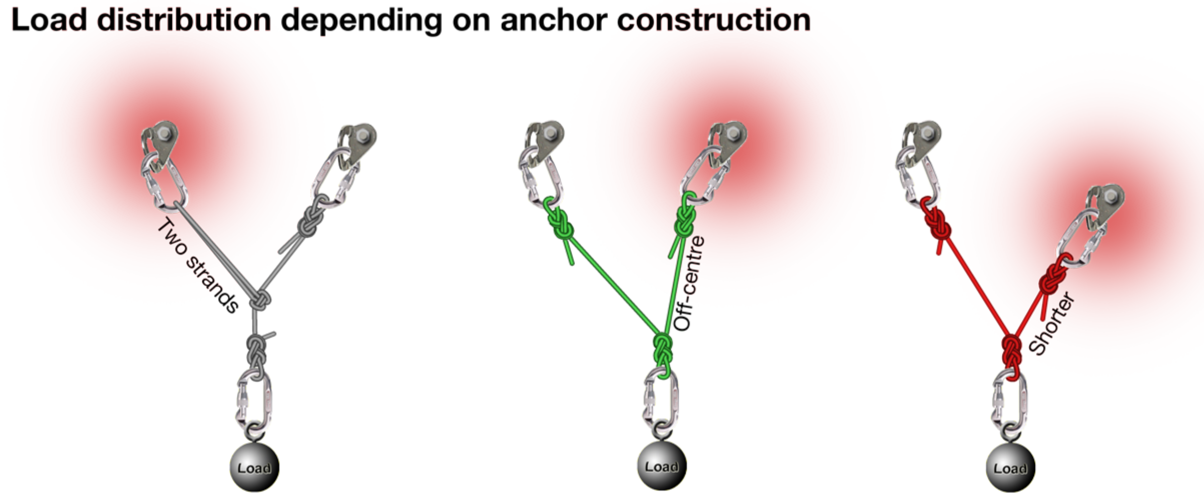

Figure 19. VRigger

We should also be mindful of the anchor placement/orientation when bringing multiple anchors together to form a belay (figure 20).

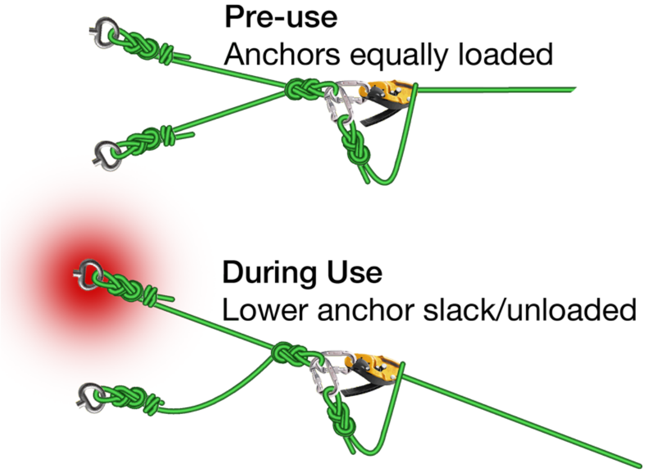

Figure 20. VRigger

For example, if one anchor is above another, as the load travels across the Tyrolean, the orientation of the belay will change (figure 20), shifting the load away from one (or more) of the anchors used to build the belay.

If we bring 2 EN959 anchors together being pulled out in their weakest orientation (should hold 15kN), and brought together with 90º between each anchor (so 71% of the load on each anchor) we'll have constructed a belay capable of holding over 21kN. If these anchors were loaded in their strongest orientation, then that capability goes up to over 35kN. Each anchor, even at its weakest orientation, should hold more than the maximum slip rate noted by RopeLab of a clutch device, so the merits of choosing EN959 anchors is clear. If constructing belays from traditional rock climbing protection these belays must be very robust, taking into consideration of not only the components used, but also the rock.

To bring the anchors together we could use a sling (nylon slings are probably better based on the DMM drop tests[9]) and an overhand knot, this has the advantage of being simple and takes up little space.

Arguably better would be to use the ends of the rope we plan to use for the tensioned Tyrolean and use it's ends to construct the belays. In this way, we are always changing the section of rope most vulnerable to failure (those within the knots, and around the anchors/krabs used in rigging).

Ropes should never be pre-tied and repeatedly used without the knots being undone after each use, as this would increase the wear on one section of the rope, exposing it to possible failure. Something, in part, highlighted by the BMC in their investigation of a failed postman's walk[33], and highlighted by Sieberts study on top ropes.

14. Managing clients across

Given you're likely to be working around an area with a big drop it's likely you'll need some method to look after your clients as they get on and off the Tyrolean. A simple traverse line protected by cowstails is the obvious solution unless you can rig your Tyrolean well away from the drop and manage your clients on and off clear of any fall hazards.

Your clients may need to pull themselves across a horizontal Tyrolean. Securing the travelling pulley to the mid-point of a second slack rope secured at both ends of the traverse (the orange rope in the accompanying "8. Managing an Improvised Tyrolean Traverse" illustration) will provide clients something to pull, and keep clients from trying to pull the tensioned rope (which may result in finger entrapments or friction burns).

This second line could also be used to pull your clients across should they struggle. Being able to set up a simple haul system at one side may be necessary to land a larger client that's struggling. This shouldn't be too much of a problem as you're likely to have a redundant pulley and jammer from the haul used to tension the traverse in the first place.

Rigging the tensioned rope high and tight, clients will need to be attached to the travelling pulley, which may prove tricky (especially for short clients!) There are various solutions such as taking advantage of what's around you; i.e. are there any large rocks people can stand on, or can they stand on your knee to clip onto the pulley? It's also important to remember your clients are also going to have to get off at the far side! This can be tricky if you're working alone and can only manage to assist clients on one side of the traverse.

[33] https://www.thebmc.co.uk/media/files/Gear/TCM11_01_Low%20stretch.pdf

Rigging and Managing an Improvised Tyrolean Traverse

One possible solution is to create an adjustable cowstail on the travelling pulley. This could be another descender on either a fixed line to the traveling pulley or to the pulley direct (figure 21). This enables you to attach your clients to the Tyrolean away from the edge, tension them up (to reduce shock loading the tensioned rope) and enable them to lower themselves down at the landing spot if needed. Although care should be taken if encouraging clients to lower themselves to ensure they cannot fall any distance and hurt themselves.

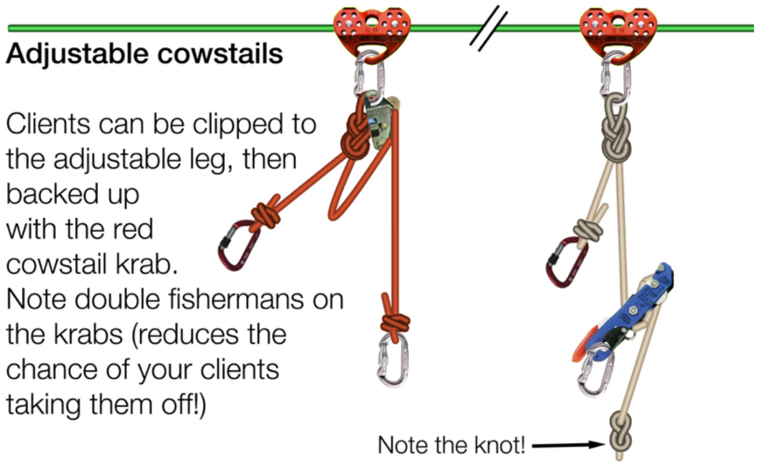

Figure 21. VRigger

On a descending Tyrolean (zip line) the end of the break rope could be used for the adjustable cowstail (although it's worth changing the figure of eight knot to an alpine butterfly on the travelling pulley).

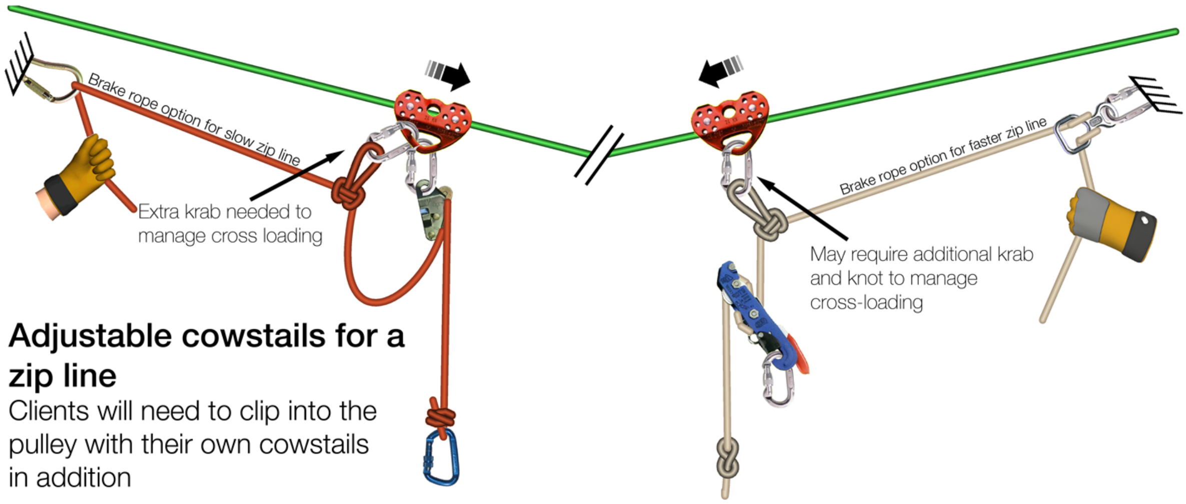

Figure 22. VRigger

A descending Tyrolean may need a brake line to slow your clients down[34]. The brake needs to be managed at the top of the Tyrolean either with a friction device that can manage a swift moving rope running through it such as a large figure of eight descender or an Italian hitch through a large steel krab (figure 22). It may be that a simple loop in a large steel krab will provide enough friction to manage your clients; however, all this needs great care, if your clients go to fast you may not be able to stop them! With all these systems, a gloved hand (a thick pair or cheap gardening gloves are great for this) will be needed.

[34] https://www.youtube.com/watch?v=0y59IJAVUqA

15. Rescues & rescue considerations

Most rescues should be easily managed if a second rope is used on the travelling pulley, giving instructors the option of pulling stuck client across. Having to travel across the Tyrolean to assist an injured client should be a last resort; as doing so will put some very high loads on the Tyrolean. If you've rigged your Tyrolean with just 1 tensioned rope, I'd rule out putting a 2-person load on the system.

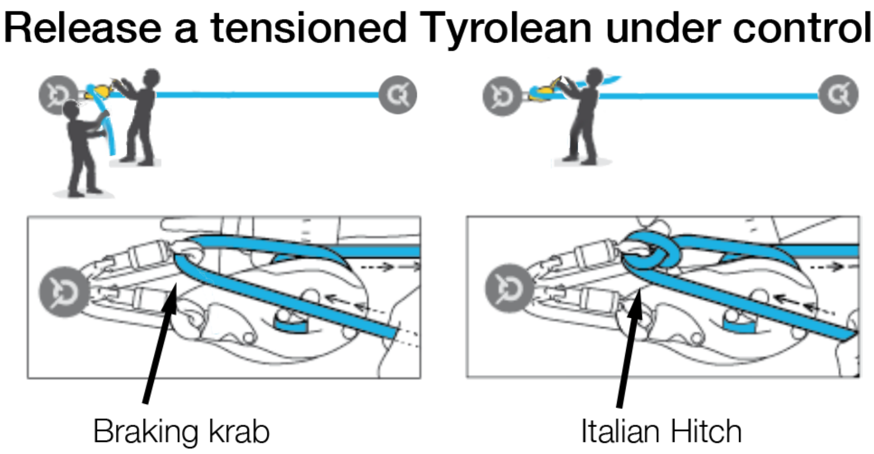

Figure 23. Elements from Petzl

Another option may be to release the tensioned Tyrolean and lower the client to the ground. This can only be accomplished if there's a suitable place to lower the client to (it's not going to work if you're Tyrolean goes over water!) and if you've enough spare rope. To manage this, you're going to need a braking krab, and may need to install an Italian hitch onto the braking krab to keep the lower under control (figure 23).

There are several publications advocating having a releasable Tyrolean on both sides of the traverse. Personally, in an adventure setting, I see little value and some concerns in this. Installing a releasable Tyrolean on both sides requires someone competent operating on both sides (imaging the repercussions of someone releasing the far side by accident!) Also, installing a releasable system on both sides is going to eat up valuable operating space, as additional knots and krabs are required; potentially pushing clients closer to the edge of the traverse.

Belaying from either side of the Tyrolean is also another frequently considered safety measure. Much of this thinking comes from the Kootenay High Line System[35], a system developed in the mid 80s by British Columbian rope rescue teams. The idea of this is a rope is paid out on one side, and taken in on the other. If the tensioned rope fails then the belay catches the client. Unfortunately, this system only works if both belay ropes are very tight, and the drop below the tensioned rope is sufficient. In reality, this system is unlikely to catch a client before they hit the deck, as illustrated in some testing by the RopeLab team[36], and so is probably of little use to us.

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[35] http://www.paci.com.au/downloads_public/ERT/Highlines_Paper_1997.pdf
[36] https://youtu.be/kAJuLjx-2k8

16. Observed loads at anchors when running a Tyrolean

Figure 24. Gethin Thomas

In October 2013 Dena Proctor (CIC), Bob Mehew (BCA E & T), and I conducted various tests and measurements with 2 calibrated load cells[37] (figure 24) looking into the forces achieved by people hauling on a fixed rope. Further to these tests I investigated the loads on anchors during use of a Tyrolean. Testing was limited as the load cells needed to be connected to a laptop and required a power supply, however a suitable site with 2 large trees proving an approximate 12m horizontal apart was located for the testing. Several tests were conducted using both single and twin tensioned ropes with a single person load[38], as well as some testing on a 12mm cable.

The Tyrolean testing looked at the loads achieved by an 85kg mass (me!) travelling across the tensioned rope. Measurements were taken of the initial tension, when the load was first placed on the rope, mid-way across the Tyrolean and at the far point. We also looked at the loads when the mass bounced around at the mid-point of the traverse, and the tension in the un-loaded rope after use. Finally, we looked at the loads prior to, during and after a dynamic launch from the take off point of the Tyrolean. To hold the ropes in place they were tensioned by 1 person using a 9:1 (theoretical) mechanical advantage with the ropes held in place by the lower capstan of a STOP only (figure 24). New (washed and dried) Beal, Pro-static, 10.5mm semi-static (EN 1891, Type A) ropes were used on these tests, with the travelling load suspended from a Petzl Tandem (red/rope) pulley.

Here is a summary of the results (note all figures are in kN).

Single rope
3 cycles, rope re-tensioned between each cycle.

Test	Initial	Start	Mid	End	Bouncing (mid-point)	End tension	% loss in tension
1	1.33kN	1.346kN	2.13kN	1.596kN	2.841kN	0.744kN	-44%
2	1.416kN	2.197kN	2.371kN	1.883kN	3.22kN	0.976kN	-31%
4	1.905kN	2.734kN	2.854kN	2.433kN	3.94kN	1.379kN	-28%
Average	1.55kN	2.09kN	2.45kN	1.97kN	3.33kN	1.03kN	-34%
% difference from initial load		135%	158%	127%	215%	66%	-34%

[37] http://www.train4underground.co.uk/wp-content/uploads/2016/12/HeaveHo.pdf
[38] https://youtu.be/LMIzYiMKsF4

Dynamic launching (jumping onto the Tyrolean) 5 cycles, rope re-tensioned once following previous tests but not re-tensioned between each cycle

Test	Prior to loading	Peak	Post loading	% loss in tension
1	0.757kN	3.165kN	0.561kN	-26%
2	0.561kN	3.103kN	0.514kN	-8%
3	0.514kN	3.007kN	0.445kN	-13%
4	0.445kN	3.048kN	0.454kN	-2%
5	0.454kN	3.186kN	0.429kN	-6%
Average	0.55kN	3.1kN	0.48kN	-12%

Observations from the limited testing with a single rope

- A considerable amount of tension is lost after the first use; repeated use also reduces the tension on the rope (but not as dramatically as the first use)
- Bouncing and dynamic loading increases the load within the system considerably
- Repeated re-tensioning increases the loads within the system
- Highest peak load on anchors was 3.94kN

We then conducted various similar tests with twin tensioned ropes, with load cells placed on both ropes, and then to a shared anchor (belay). The travelling load was secured to the tensioned ropes with 2 stacked tandem pulleys (figure 25), with the upper pulley clipped into the lower pulley. Ropes re-tensioned between tests.

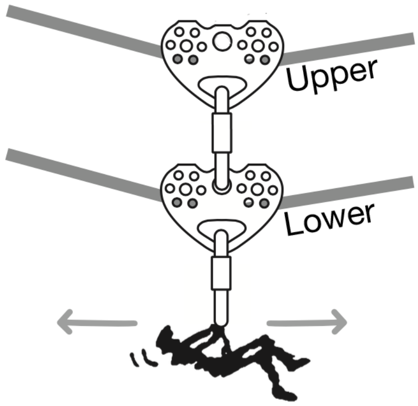


Figure 25. Petzl

Test and rope		Prior to loading	Start	Mid	End	Bouncing (mid-point)	End tension	% loss in tension
5	Upper	0.965kN	0.991kN	1.477kN	1.152kN	1.627kN	0.664kN	-31%
	Lower	1.018kN	1.182kN	1.609kN	1.345kN	2.516kN	0.731kN	-28%
	Total	1.983kN	2.173kN	3.086kN	2.497kN	4.143kN	1.395kN	
6	Upper	0.892kN	0.953kN	1.437kN	1.191kN	2.362kN	0.622kN	-30%
	Lower	1.048kN	1.153kN	1.61kN	1.393kN	2.488kN	0.75kN	-28%
	Total	1.94kN	2.106kN	3.047kN	2.584kN	4.85kN	1.372kN	
Average		1.96kN	2.14kN	3.07kN	2.54kN	4.5kN	1.38kN	-29%

Dynamic tests with twin tensioned ropes. Ropes re-tensioned once (following previous tests with twin ropes, but not re-tensioned between tests).

Test	Rope	Start	Peak	End	% tension loss
1	Upper	0.974	1.305	0.914	-6%
	Lower	0.819	3.603	0.768	-6%
	Total	1.793	4.908	1.682	-6%
2	Upper	0.914	1.298	0.938	3%
	Lower	0.768	3.278	0.759	-1%
	Total	1.682	4.576	1.697	1%
3	Upper	0.938	1.291	0.881	-6%
	Lower	0.759	3.402	0.768	1%
	Total	1.697	4.693	1.649	-3%
4	Upper	0.881	1.298	0.869	-1%
	Lower	0.768	3.451	0.762	-1%
	Total	1.649	4.749	1.631	-1%
5	Upper	0.869	1.264	0.916	5%
	Lower	0.762	3.278	0.734	-4%
	Total	1.631	4.542	1.65	1%
Average		1.6904	4.6936	1.6618	-2%

Observations of the twin ropes:

- In use, the sag of the traverse was less than that of a single rope
- The lower of the two tensioned ropes took ¾ of the load at times
- Loads on the anchors were noticeably higher than those on a single rope
- Loss of tension was slightly less throughout the tests (particularly the dynamic tests) than those observed with the single rope
- Highest peak load (on anchors, i.e. both tensioned ropes combined) was 4.9kN

Cable

In addition to the rope tests we also tested a 12m length of 12mm cable. The cable was secured at one end to the load cell then anchor. On the opposite side the first 3 tests had the cable secured to the anchor with a short length of 10.5mm semi static rope, then the last 3 tests with the cable secured to the anchor with a chain. No belay devices were used to hold the cable and no mechanical advantage used to haul the cable into position.

Test	Initial	Start	Mid	End	Bouncing (mid-point)
1	0.123	1.544	2.053	0.052	4.198
2	0.13	1.588	2.238	0.098	5.409
3	0.088	1.405	1.954	0.053	5.409
Average	0.114	1.512	2.082	0.068	5.005
4	0.175	2.013	2.819	0.168	6.351

5	0.182	1.791	2.565	0.156	6.698
6	0.17	1.802	2.464	0.151	6.704
Average	0.176	1.869	2.616	0.158	6.584

Dynamic tests (launching onto the traverse). Cable secured at far end by chain direct to the anchor

Test	Start	Peak	After	% loss in tension
1	0.271	4.371	0.159	-41%
2	0.159	3.824	0.143	-10%
3	0.143	2.951	0.15	5%
4	0.15	4.509	0.153	2%
5	0.153	4.17	0.156	-
Average	0.1752	3.965	0.1522	11%

Observations

- Loads dramatically increase on a cable between being unloaded and loaded
- Securing a cable directly to an anchor increases the loadings within the system
- Dynamic loads are high, close to equipment damaging levels (average 6.6kN when secured with a cable)
- Dynamic loading hurts! This is a personal observation following the days testing (note the cable testing was conducted on a different day from the rope testing so the discomfort was not the result of multiple tests that day)

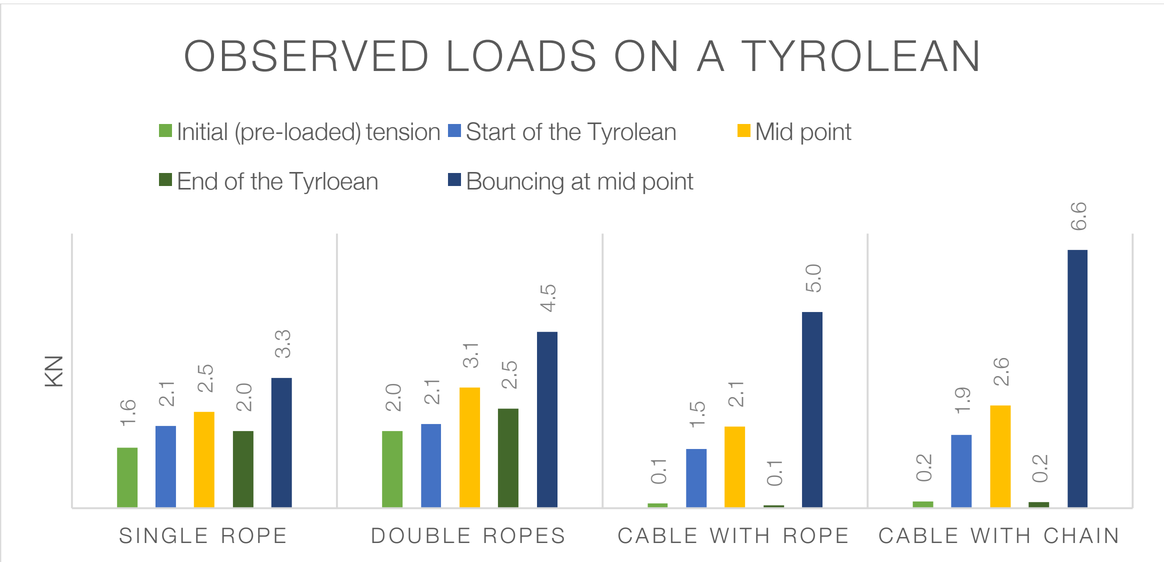


Chart 2

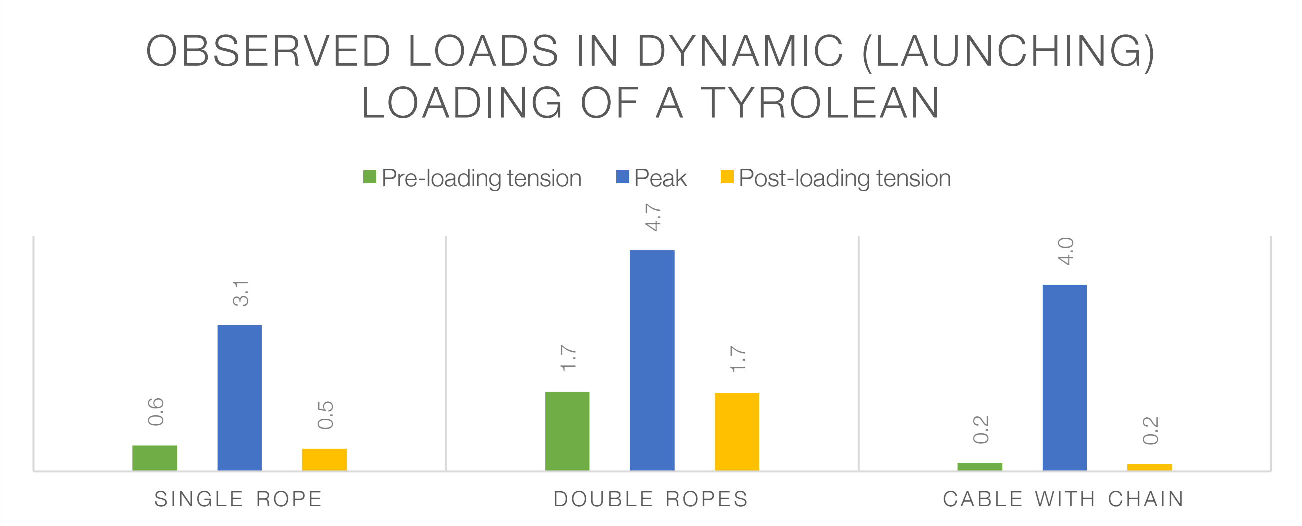


Chart 3

Following on from these tests a Rock Exotica Enforcer[39] was purchased (figure 26). This highly portable device enabled measurements of the forces involved in Tyroleans with groups at a variety of locations.

Figure 26. Rock Exotica

One of the locations, a popular underground trip, involves a short (approx. 12m) near horizontal Tyrolean. At the time of writing (January 2017) data on over 60 young people (Primary & Secondary School children) and their accompanying staff has been recorded. The Tyrolean was rigged with 2 people hauling on a 5:1 system (as illustrated on page one of this document) using a part threaded STOP (lower pulley only) as the capture device, all rigged on a single EN 1891 Type A DMM Pro Static semi-static rope. The following peak loads were recorded

	Number of samples	Peak	Average
Students	57	3.18kN	2.27kN
Adults	10	4.55kN*	3.09kN
Total	**67**	**4.55kN***	**2.39kN**

*Observed peak load was a dynamic loading onto the Tyrolean by a large adult (1.54kN) with loose cowstails and jumping onto the tensioned rope

The second test site was a downward slopping "zip-line" within a local gorge, approximately 20m long. Tensioning was as illustrated, however some rigged using a STOP, others a RIG as the capture device. Again EN 1891 Type A DMM Pro-Static semi-static rope was used. The following peak loads were recorded.

		Number of samples	Peak	Average
STOP	Students	22	2.02kN	1.58kN
	Adults	3	2.26kN	2.02kN
RIG	Students	28	2.31kN	2.46kN
	Adults	3	2.46kN	2.23kN
	Total	**56**	**2.46kN**	**1.74kN**

39 http://www.rockexotica.com/enforcer-load-cell/

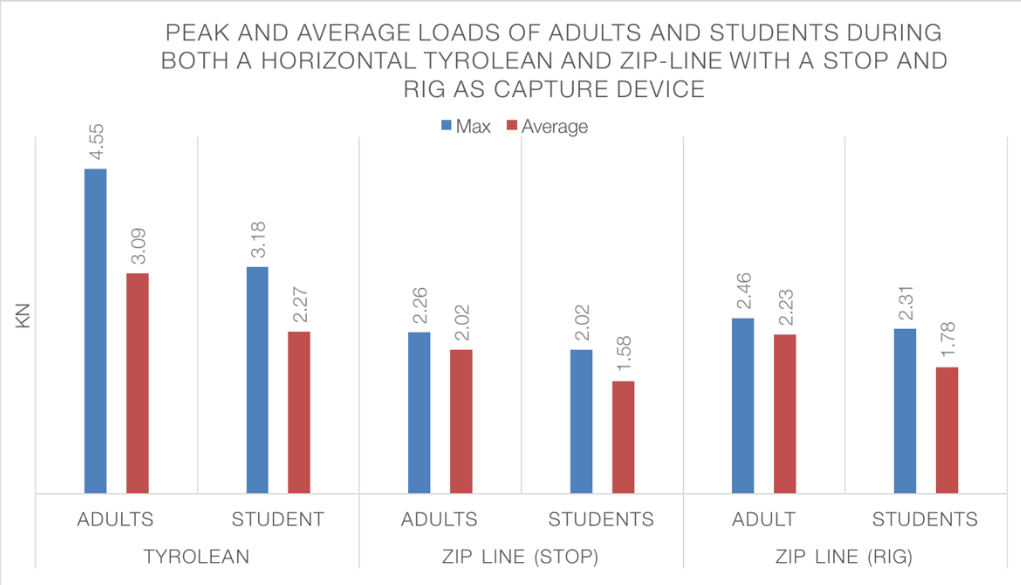


Chart 4

Another useful attribute of the Rock Exotica Enforcer is being able to take 2 samples every second and gain a picture of the loads at an anchor during a session with a group. The following are several annotated charts illustrating the loads on one side of a Tyrolean during some typical sessions (including the loads during the initial haul, and the unloaded tension in the rope before and after the session). Of all the samples taken, I've tried to include samples from each of the sites, using different capture devices, that had very similar peak loads during the hauling stage to provide some form of comparison.

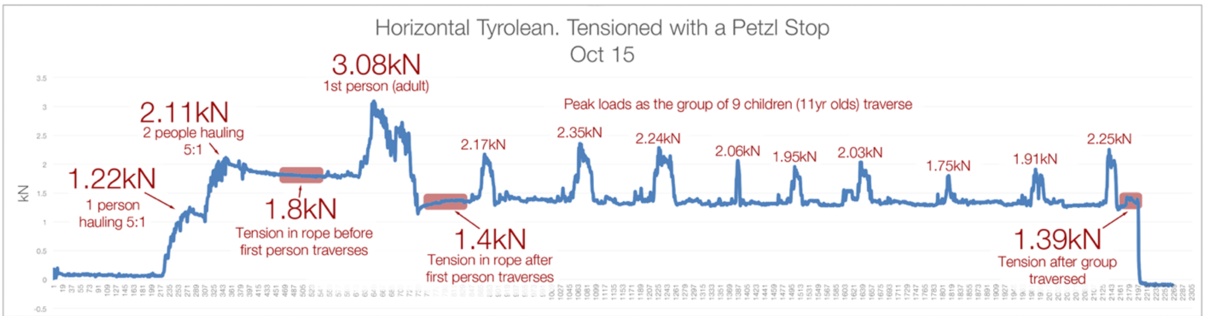


Figure 27

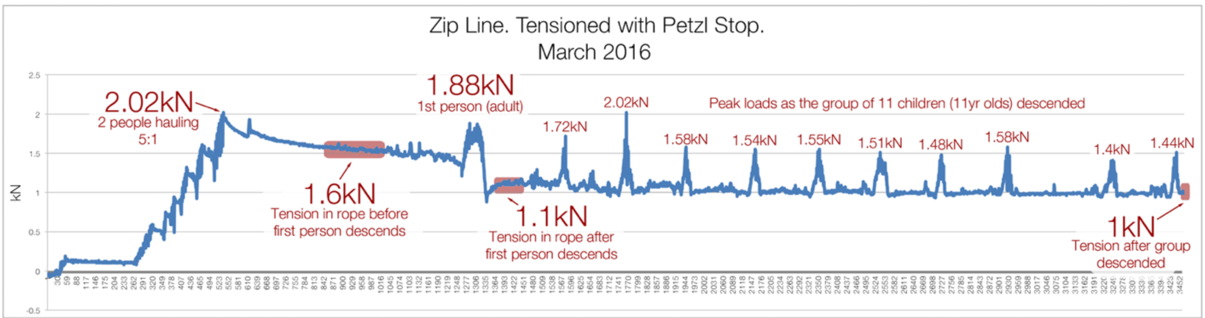


Figure 28

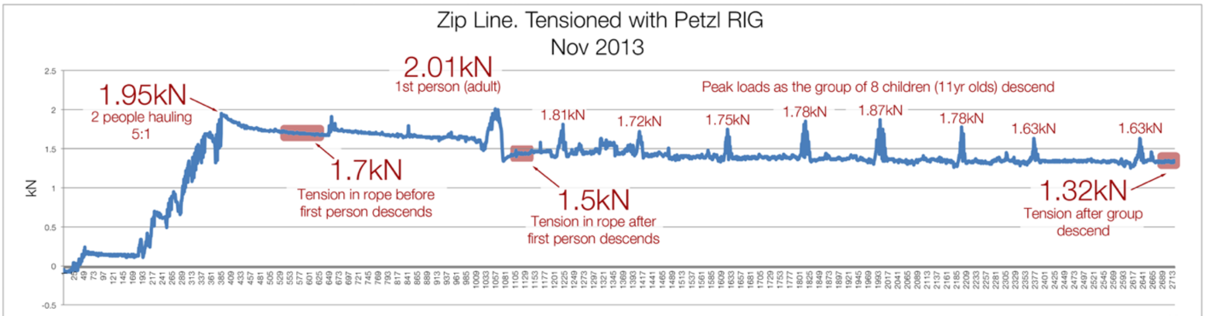


Figure 29

Observations

- The horizontal Tyrolean produced higher loads on the anchors than those under similar tension of a descending Tyrolean (or zip-line)
- Tension in the rope decreases following the initial tensioning
- Peak loads are achieved (predominantly) by the first person on the traverse, although in each case an adult (teacher) was the first to use the traverse
- Tension in the rope decreases further following the first person crossing
- Following the first person crossing the tension in the system remains relatively consistent
- The Petzl RIG appears to perform a little more consistently than the STOP

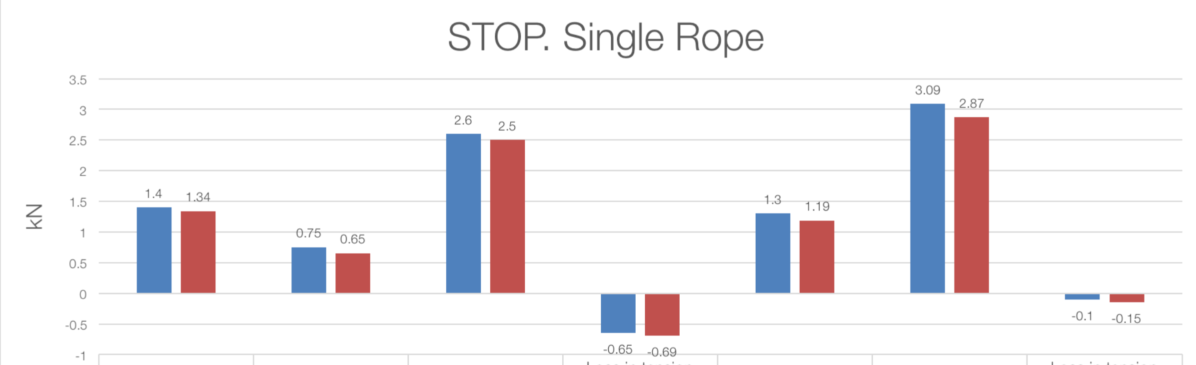
Further to these tests in December 2016 I wanted to look at how both 10mm and 11mm ropes performed, when used in both a single or twin rope configuration with both a STOP or RIG as the capture devices.

An 85kg mass was sent across the tensioned ropes 6 times, then the ropes re-tensioned and the same mass sent across another 4 times.

Of interest was how the 10mm rope achieved higher peak loads in both tensioning and use than the 11mm rope, both with the STOP and RIG, and with a single or twin rope system, this using the same mechanical advantage and personnel to create the tensioned system. We could assume that the lower diameter rope will have less friction and so higher tensions can be achieved. Smaller diameter ropes have also shown to slip in devices such as a STOP, this was evident during the testing as the 10mm rope within the STOP visibly sipped through the device during the tensioning process, yet still held a higher load than the 11mm throughout the testing.

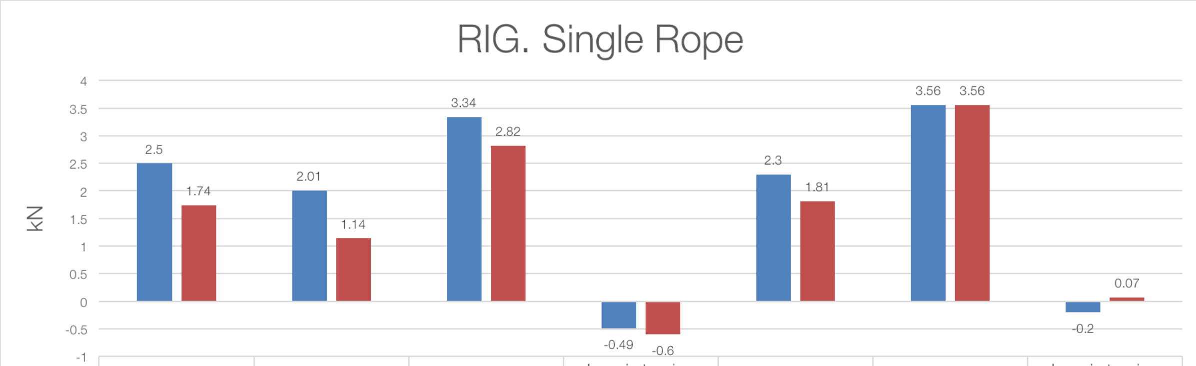
As with all previously observed samples there was a spike in the peak force during the initial tensioning, then a comparable, often higher spike in peak force as the load was placed at the mid-point. Looking at the charts of the tests the ropes rigged with a RIG as the capture device appeared to lose less tension between initial tensioning and uses than the ropes rigged with a STOP.

Following re-tensioning the drop off in tension of the rope after use was significantly less than the drop off in tension observed following the initial loading. In fact, in 3 of the 4 set-ups the 11mm rope maintained a higher tension following re-tensioning and 4 crossings, than the initial pre-use tension.



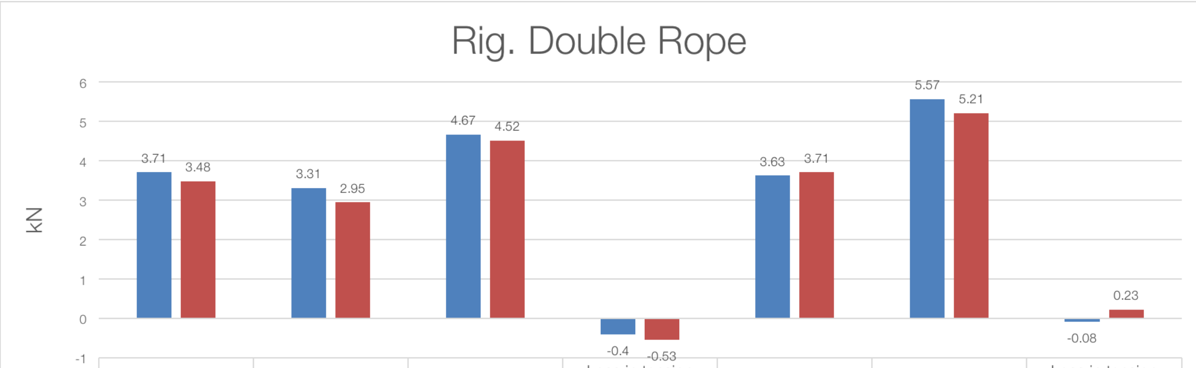
	Initial tension in the rope (start)	Tension after 4 crossings	Peak load during crossings	Loss in tension compared to start following first crossings	Tension in the rope following re-tension	Peak load during crossings	Loss in tension compared to start following last crossings
10mm	1.4	0.75	2.6	-0.65	1.3	3.09	-0.1
11mm	1.34	0.65	2.5	-0.69	1.19	2.87	-0.15

Chart 5



	Initial tension in the rope (start)	Tension after 4 crossings	Peak load during crossings	Loss in tension compared to start following first crossings	Tension in the rope following re-tension	Peak load during crossings	Loss in tension compared to start following last crossings
10mm	2.5	2.01	3.34	-0.49	2.3	3.56	-0.2
11mm	1.74	1.14	2.82	-0.6	1.81	3.56	0.07

Chart 6



	Initial tension in the rope (start)	Tension after 4 crossings	Peak load during crossings	Loss in tension compared to start following first crossings	Tension in the rope following re-tension	Peak load during crossings	Loss in tension compared to start following last crossings
10mm	3.71	3.31	4.67	-0.4	3.63	5.57	-0.08
11mm	3.48	2.95	4.52	-0.53	3.71	5.21	0.23

Chart 7

Rigging and Managing an Improvised Tyrolean Traverse

Following the initial round of testing I discovered the data from the 11mm sample on the STOP was missing. The testing was repeated with the same ropes later, however tensioned by just one person hauling on a 11:1 MA system (figure 30). I'd expected to reach similar tensions as 2 people hauling on a 5:1 system, however this was not the case. One person hauling an 11:1 system resulted in noticeably higher loads. One hypothesis for this is that as one person grips a rope, the rope kinks providing better grip. A second (third and so on) person hauling is not going to be able to do this so unlikely to be able to haul with a similar force as the first person. This was noticed in our 2013 testing[33].

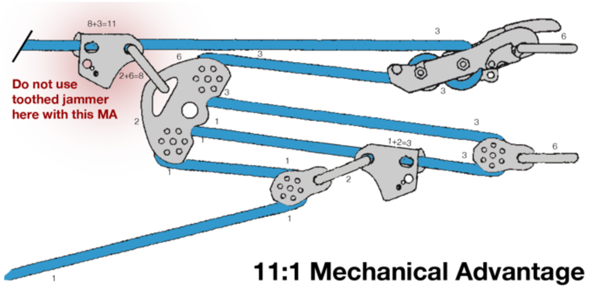
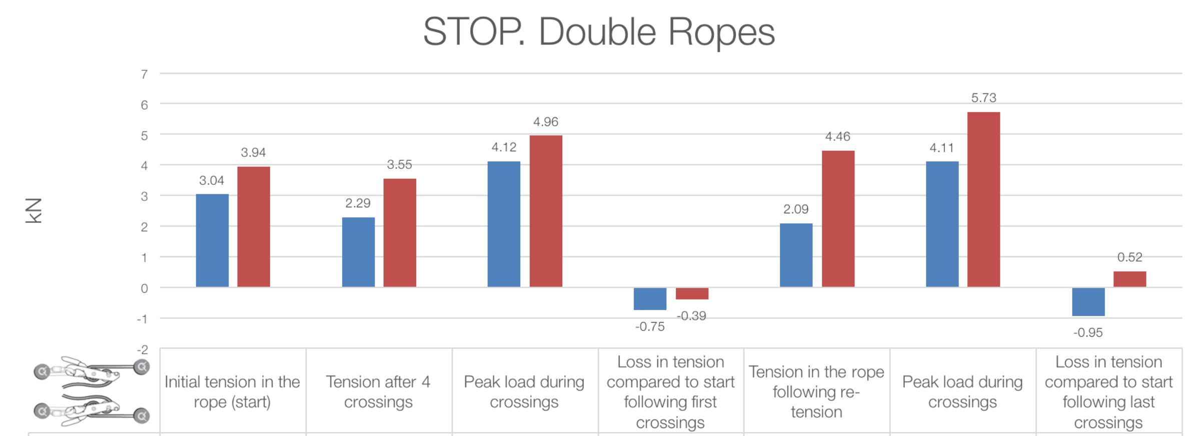


Figure 30. Elements from Petzl

This haul system could also put the initial jammer (highlighted in the illustration) under compromising loads. In this situation, a non-toothed jammer (or Prusik) was and should be used.



	Initial tension in the rope (start)	Tension after 4 crossings	Peak load during crossings	Loss in tension compared to start following first crossings	Tension in the rope following re-tension	Peak load during crossings	Loss in tension compared to start following last crossings
10mm	3.04	2.29	4.12	-0.75	2.09	4.11	-0.95
11mm (Jan 17)	3.94	3.55	4.96	-0.39	4.46	5.73	0.52

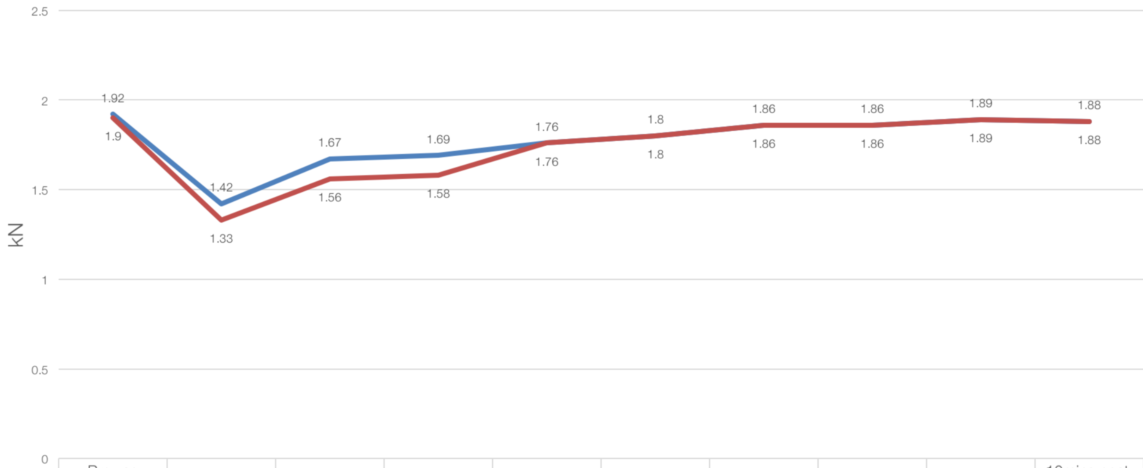
Chart 8

Another observation relates to how the tension in the Tyrolean reduces during use.

It's clear that following the initial tensioning the loads measured gradually decrease. I'd attribute this to the knots settling and rope stretching. Following the first crossing of a Tyrolean the tension in the rope is significantly reduced. Again, I'd attributed this to the knots settling further, possibly re-aligning, and rope stretching. During use the tension of the rope continues to reduce after each crossing, however not as dramatically as observed following the initial crossing, suggesting the tension may plateau after a certain number of crossings.

We were able to investigate this hypothesis as part of a body of work conducted through the University of Central Lancaster (UCLAN) in January 2017[40].

In one of the bodies of UCLANs work we tensioned a single rope to 1.9kN (with load cells situated at both sides of a 12m span). An 80kg mass was then sent across the traverse 5 times then removed from the traverse and a measure of the tension of the rope taken. The rope was then re-tensioned to 1.9kN and the load sent across another 5 times. This was repeated until 40 crossings was achieved, with a final reading taken 10 minutes after the cycles.



	Pre use tension	5 crossing	10 crsossing	15 crossings	20 crossings	25 crossings	30 crossings	35 crossings	40 crossings	10mins post test
Left	1.92	1.42	1.67	1.69	1.76	1.8	1.86	1.86	1.89	1.88
Right	1.9	1.33	1.56	1.58	1.76	1.8	1.86	1.86	1.89	1.88

Chart 9

From the chart (chart 9) it's clear that the tension in the rope dips significantly after the first crossings. After each set of crossings, the tension post use continues to dip, however as the cycles continue the range between the initial tension and the post use tension reduces, and appears to plateau after around 35-40 crossings, with the final cycles illustrating only a very slight drop in tension after use compared to its pre-use tension.

This may be an area which requires further work to satisfy ourselves that the plateaued tension within the rope is not so high as to cause component failure. There is concern that as the stretch within the rope is removed, if that's what we're seeing, the rope may eventually fail.

Until further information is available, it may be prudent to suggest if re-tensioning is needed, then it should be done only once during a normal session. It may also be prudent to limit the number of uses of a Tyrolean before dismantling and re-rigging. The

[40] "A Study of Improvised Tyrolean; Loads and Usage", L. Collins, G. Thomas, C. Onions, S. Alfree, O. Sander, & S. Rosser. Pending publication

number of crossings again warrants further research, and any figure quoted is bound to be subjective, however from the observations of the UCLAN work there is evidence to suggest the tension in the system plateaus after 30-35 crossings, however this with the rope re-tensioned after every 5 crossings. If ropes were not re-tensioned it would seem logical to assume a greater number of uses could be made of the Tyrolean before it should be re-rigged.

17. One tensioned rope or two?

Within the rope rescue/access community it is common/best practice to use 2 ropes. This community produces a wealth of information and as such it's easy to see how many practitioners will advocate the use of two ropes in a Tyrolean within the adventure community.

Using a second, equally tensioned, rope will reduce the sag in a Tyrolean[41] and should share the load on the tensioned rope. However, there is a trade-off. Loads at the anchors will increase due to the reduced sag, so consideration must be made as to how robust belays are. If two clutch devices are used then the slip rate of the system also increase from 10kN (based on the worst-case observations from RopeLab) to 20kN.

Practitioners will also need to carry twice as much kit!

My feeling is that in most adventure activity sessions a single rope, with no rub points, would be acceptable, provided they are not over tensioned, over/dynamically loaded in use, the ropes and equipment used is in good order, and any rescue can be achieved by hauling a client across the Tyrolean, or lowering them to the ground.

If there's the possibility of needing to put more than one person on the Tyrolean, if you're working with physically large clients, a large number of clients or there's any concern that the tensioned ropes may sag and rub against the floor or other static edges/objects then it may be prudent to rig with two tensioned ropes.

In my investigations, I've seen and discussed the merits of various two rope systems. Some practitioners advocate the use of a dynamic rope and a semi static rope equally tensioned, with the view that should the semi static rope fail the dynamic rope will catch the load. Others advocate having one rope tensioned more than another, again with the view that should one fail the other will catch the load.

Kirk Mauthner investigated the loadings on twin tensioned ropes during hauls and lowers[42]. From his investigations he, and many rope rescue practitioners, have now adopted a "mirrored" rope system, in that rather than having one very tight rope and a looser back up, both ropes on a haul/lower are kept at roughly the same tension. In this way if one rope was to fail there's less of a dynamic impact on the second rope (with its inevitable injuries to the rescuer and casualty).

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[41] https://www.youtube.com/watch?v=LMIzYiMKsF4&feature=youtu.be
[42] "Dual Capability Two Tensioned Rope Systems", Mauthner 2016

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Mauthner's investigation also suggests that two equally tensioned ropes are more tolerant to edges compared to one "main" tight rope and a second "belay" looser rope[43]. This is worth bearing in mind when considering the construction on multiple tensioned lines in a Tyrolean **suggesting it would be safer to rig two equally tensioned matching (in type) ropes rather than having one taught and another looser**.

Managing two tensioned ropes can be a challenge in rigging. Any twists in the ropes should be avoided, with both ropes kept separated slightly. Use of a rigging hub (figure 31) can help in these situations. However, the rigging leading to the hub, and anchors used should be substantial due to the loads they may be exposed to. In this illustration, the figure of eight knot attached to the rigging plate is likely to be the most vulnerable part of the rigging. Tying a big fat knot such as a figure of eight on the bight and using large steel karabiners may be advantageous at this point in the rigging.

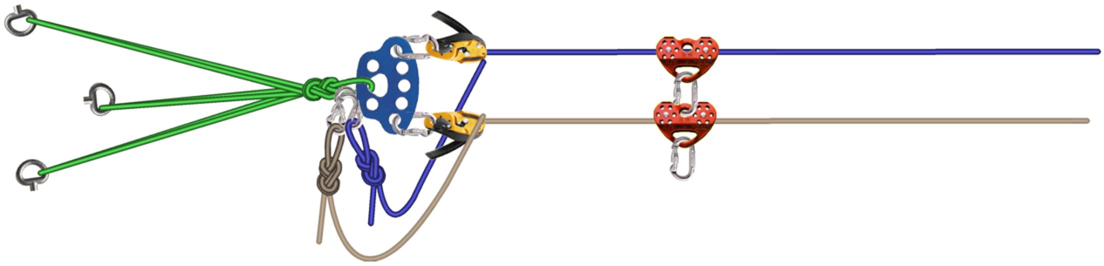

Figure 31. VRigger

Practitioners should also be mindful of how the travelling pulleys are secured to the tensioned rope. If the twin ropes are not well aligned then the side of the pulley can rub along the tensioned rope (figure 32) with potential catastrophic results[44]. Using tandem pulleys instead of single pulleys may help manage this.

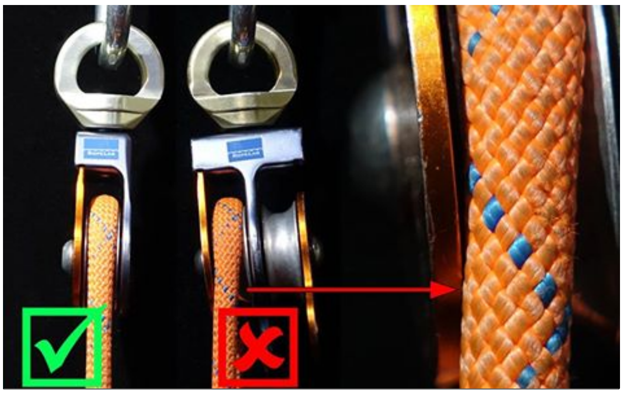

Figure 32. RopeLab

If managing a descending "zip-line" in particular, practitioners should ensure the break rope linked to the descending pulley (figure 22) doesn't twist the pulley, exposing the pulley cheek to a potential rub point. Care should also be taken to ensure the break rope does not run near the tensioned rope as the fast-moving rope rubbing against the static tensioned rope could wear through the tensioned rope.

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[43] https://www.youtube.com/watch?v=-43yf8SDs4M
[44] https://www.youtube.com/watch?v=unF2shRE2KY&list=PL_WXU4hpW9t6EfnIu8IwNZ3OFX9bJWaB6
note in this video how the tensioned rope jerks around before failing. The current thinking on this failure is due to the rope rubbing on the side plate of the pulley used

Figure 33. Petzl

Furthermore, if both pulleys are stacked (figures 26 and 32), our 2013 testing illustrated that the lower tensioned rope was exposed to up to ¾ the load whereas the upper tensioned rope just ¼ of the load.

There are various methods to which can be used to help manage these issues. Some practitioners thread a figure of eight descender through both tensioned ropes (prior to rigging and tensioning) to be used instead of a travelling pulley. This can work, however may not make for an efficient crossing. Alternatively, practitioners could make use of a Kootenay pulley (figure 33) which is wide enough for two (or more) ropes to run through it at the same time, and not rub along the side plate. However, at over £200 each (at the time of writing) and its bulky size such a device may not be as practical as some of the other options.

Some practitioners have suggested rigging both tensioned ropes side by side, so the clients can hang in-between two tensioned ropes. I've no experience of this method, however theoretically I can't see many issues with it, providing the pulley run free, and anchors are such that they lend themselves to rigging these ropes effectively. Using swivel devices between the pulleys and clients may help reduce twisting of the travelling pulleys in this system.

18. Summary and Thanks

When initiating this project, like several others I suspect, I was anxious of the loads expected to be seen during a Tyrolean. The loads/forces involved although not massive are significant, and should not be discounted, however my feelings now are that with a few simple guidelines practitioners can be managing safe and efficient Tyrolean

- Practitioners should focus on good rigging to avoid rub points and enable clients to hang free of the tensioned rope
- Limit haul teams when tensioning the ropes to 2 disciplined people
- Take care if rigging with a toothed jammer in a haul system
- Use of a clutch device (and tie it off with a short tail to allow for some slippage)
- Ensure good management of clients on and off the Tyrolean (to avoid dynamic loading)
- Ensure all equipment is in good order, ensuring ropes are fully de-rigged following sessions, and
- Hardware checked for bur marks which may cause ropes to be damaged
- Consider 2 ropes or pitch head redirections if there's any concern with rub points

Thanks to all those who have taken time to help with this project, in particular Bob Mehew, Dena Proctor, Mel Hooper, Andy McLaren, Loel Collins, Chris Onions, and Richard Terrell.

Rigging and Managing an Improvised Tyrolean Traverse

Appendix One

Note from Petzl regarding the use of a Petzl STOP in a Tyrolean

From: **Petzl - Technical question** technicalquestion@petzl.fr
Subject: RE: Fwd: Clarification on rigging Tyrolean Traverse lines (high lines) with a Petzl Stop [ref:_00D20HrHq._500w0XKZb5:ref]
Date: 11 September 2013 at 15:27
To: gethin.thomas

PT

Hello

With our experience, we dont have any restriction on the STOP descender to use it for tensioning a tyrolean other than specifyed in technical notice.

ID and STOP both have advantages and disadvantages but regarding Petzl recommendation, they both can be used respecting technical notice

Thanks for your trust, were staying at your entire disposal

All the best
Customer service

Rigging and Managing an Improvised Tyrolean Traverse

Appendix Two

Note from Lyon on the use of a Petzl STOP in a Tyrolean (specifically asked about the use of a STOP in a "half belay" mode using just the lower pulley/capstan of the STOP)

Paul Witheridge
Use of the STOP in cableways
To: Gethin Thomas, **Cc:** Scott Shaw

Inbox - gethin.thomas@ 18 September 2013 at 14:06
Details
PW

Dear Gethin

Many thanks for the e-mail regarding use of the PETZL STOP. As the UK and Ireland distributor we would like to offer a reply from our perspective.

The technique you describe of 'half threading' the PETZL STOP (threading only around the cam and not around the top bobbin, between the upper swing side plate retaining pin)has not to our knowledge ever been approved by PETZL for any operation.

The technique is one that appears to have been developed by users many years ago to allow easier movement of the rope through the STOP when hauling or short distance ascending.

There are many of these 'user developed' techniques widely discussed in books and on forums and internet sites. Descending a loaded rope by placing the rope between the cam and upper bobbin alone and then loading the attachment connector was one that did the rounds years ago. Common use or comment does not mean that they are approved or encouraged by the manufacturer.

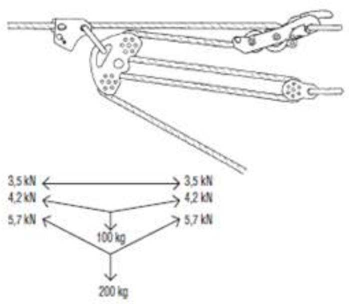
So why is 'half threading' the STOP for tensioned cableways not such a good idea (apart from it being outside the manufacturer's instructions)?

Well, all the figures quoted over the years by PETZL for the STOP's static and dynamic performance on rope are based on correct threading of the device. Using these figures as a basis for confirming a system is going to function acceptably is no good if the STOP is threaded in a different way. The 5kN load before slippage figure mentioned is only relevant when applied slowly and when threaded in this configuration. The same is true of the dynamic figures of 40cm slippage with a 3kN impact force.

The indicative figures shown in the TANDEM instructions of the forces applied to a tensioned cableway illustrate that loads of 4.2kN can be achieved with a 100Kg load on the rope. In a 'half thread' configuration there is less friction on the rope on the 'dead' side of the cam and therefore the potential that the performance of the cam on the rope, will be affected. As the difference between the theoretical 4.2kN load and the 5kN slippage load is not great (especially when you take into account different rope characteristics, wear, humidity etc.) this may be significant.

3. Installing a tyrolean traverse

A. Direct hauling system



So, if you want to continue to use the STOP for cableway tensioning in a way that has the acceptance of PETZL as the manufacturer it must be threaded as shown above.

With regard to suggestions about alternative devices. When the STOP is used in the configuration above the additional friction in the STOP can reduce the actual mechanical advantage significantly. The introduction of the PETZL I'D and RIG devices offers two alternatives that allow more efficient hauling or tensioning, with a number of added benefits for both outdoor professional and industrial users. The I'D and RIG both offer smoother take in and pay out, have a 'lock' function via the handle that eliminates the need for hard or soft locking and may be used as a belay device as well as a descender and progress capture device. They are also significantly more rope friendly should unexpected events occur and higher dynamic forces be applied. The I'D for example can absorb sudden dynamic loads in excess of 12kN without significant rope damage – a load that would see catastrophic rope failure in the STOP

PETZL are not suggesting that either of these products ***must*** be used instead of the STOP for cableways, but users in the UK are picking up on these benefits and it is no surprise that word is going around that there are alternatives to the STOP.

Ultimately, any decision on what system or device to use for tensioning cableways is down to the user.

I hope that this goes some way to answering the questions you posed.

Regards

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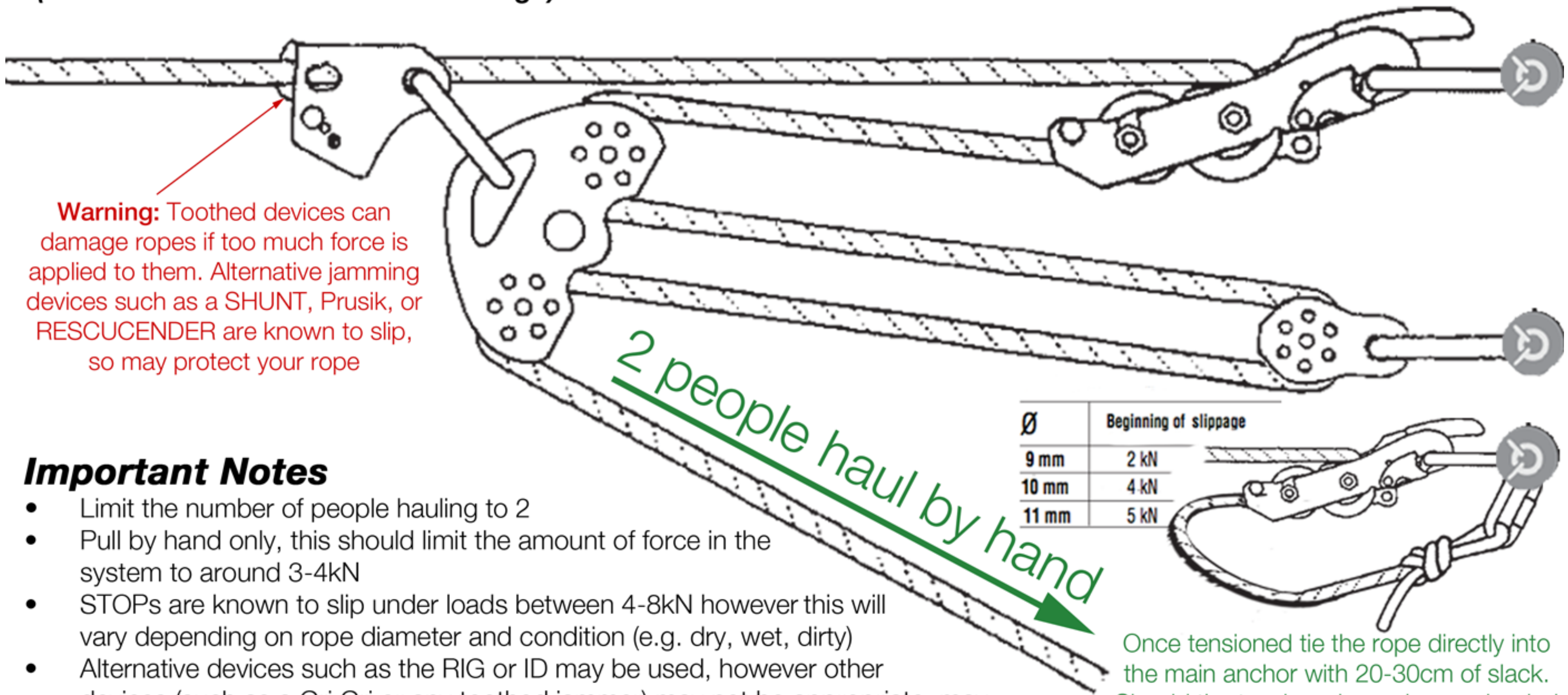
8.1. Haul system for rigging a Tyrolean (or hauling a heavy casualty)
(Theoretical 5:1 mechanical advantage)



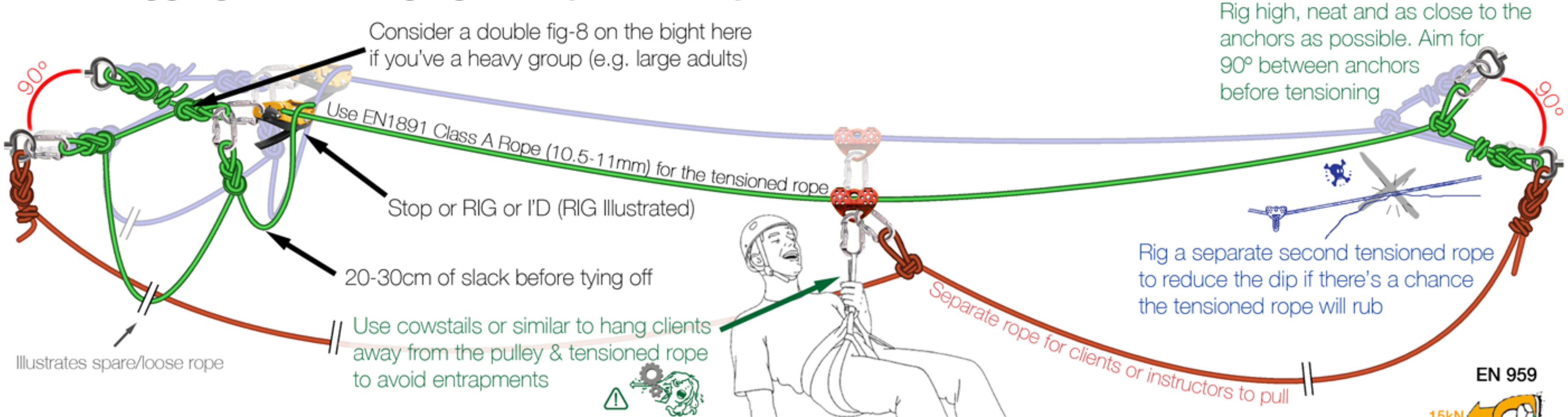
Ø	Beginning of slippage
9 mm	2 kN
10 mm	4 kN
11 mm	5 kN

Important Notes

- Limit the number of people hauling to 2
- Pull by hand only, this should limit the amount of force in the system to around 3-4kN
- STOPs are known to slip under loads between 4-8kN however this will vary depending on rope diameter and condition (e.g. dry, wet, dirty)
- Alternative devices such as the RIG or ID may be used, however other devices (such as a Gri Gri or any toothed jammer) may not be appropriate, may not slip under excessive loads, and could damage ropes
- Toothed devices (such as the Traxion) must not be used in place of the STOP in this illustration as they will damage ropes

www.train4underground.co.uk
updated: April 2017

8.2. Rigging and Managing an Improvised Tyrolean Traverse



8. Thoughts on rigging and managing a Tyrolean Traverse

- Tension the Tyrolean with no more than 2 people hauling a 5:1 system (see Rigging Guide Page 8.1)
- Leave 20-30cm of slack rope between the capture device (use a RIG, ID or STOP) and tie back to the main belay. This allows the tensioned rope to slip if over-loaded
- Keep all rigging compact to provide maximum space at the launch and landing sides for you and your clients
- Rig your tensioned line high; attach clients by cowstails (or similar) to reduce the chance of hair/finger entrapments in the travelling pulley, this also reduces the possibility of shock loading the tensioned rope when launching, and may make landing easier
- Use an additional rope for clients to pull themselves across with (or for the instructor to haul clients across) and recover the double pulley
- **Avoid any rub points**, or ropes rubbing/twisting. Take particular care with edges when the tensioned rope is loaded. Install additional tensioned rope if necessary
- If installing a second rope use separate (ideally mirrored) rigging and ensure you're using good anchors (e.g. resin anchors) as the loads on the anchors will increase
- Send the largest person in your party across first (if possible), the tension in the rope will decrease a little (**see chart below with an example of loads**) after the first person. Re-tension if necessary but only once (no more than 2 people hauling a 5:1 system). Repeated re-tensioning may overload the system
- After use if knots are too tight to untie by hand you've probably overloaded the system. Next time consider an additional tensioned rope
- See supporting document for further information (www.train4underground.co.uk/tyrolean)