Heave-Ho!

On the 19th of October 2013, Dena Procter, Bob Mehew and myself spent a few hours pulling some rope attached to a load cell! The aim of the session was to look at what sort of loads are achieved by people pulling on a rope, followed by the loads on anchors in rigging a Tyrolean traverse and finally the loads on a Tyrolean in use.

Our tests were conducted outside, on moist gravelly ground using 12m of Beal Pro-Static 10.5mm EN 1891 Type A rope. In the Tyrolean rigging two large trees were used as anchors, one very significant and another around 30cm in diameter. One load cell was used to measure both the peak force achieved during the tensioning and the stable load on the anchor after rigging and having removed the hauling rig.

This information is not conclusive, but may serve to provide a frame of reference of the loadings on anchors and equipment during hauls.

Results

Test 1

Two handed, un-gloved pull on the rope. Each person pulled 5 times holding for at least 5 seconds, recording the peak force of the pull and the average load of a steady pull. All measurements in kN

	Dena		Gethin		Bob	
	Peak	Average	Peak	Average	Peak	Average
Pull 1	0.48	0.21	0.53	0.4	0.48	0.38
Pull 2	0.48	0.29	0.7	0.49	0.4	0.32
Pull 3	0.49	0.49	0.74	0.46	0.42	0.34
Pull 4	0.49	0.29	0.67	0.46	0.42	0.3
Pull 5	0.44	0.27	0.65	0.44	0.42	0.34
Average	0.48	0.31	0.66	0.45	0.43	0.34

Highest Peak: 0.74kN. Average (mean) un-gloved between all of us: **0.37kN**

Test 2

Two handed gloved pull on the rope. Each person pulled 5 times holding for at least 5 seconds, recording the peak force of the pull and the average load of a steady pull. All measurements in kN

	Dena		Gethin		Bob	
	Peak	Average	Peak	Average	Peak	Average
Pull 1	0.4	0.36	0.84	0.52	0.49	0.4
Pull 2	0.38	0.35	0.84	0.54	0.57	0.51
Pull 3	0.39	0.31	0.67	0.46	0.42	0.31
Pull 4	0.42	0.37	0.67	0.48	0.45	0.37
Pull 5	0.38	0.34	0.66	0.49	0.48	0.4

Average	0.39	0.35	0.74	0.5	0.48	0.4

Highest Peak: 0.84kN. Average (mean) gloved between all of us: **0.41kN**

Test 3

Two handed gloved pull on the rope. Each person pulled 5 times holding for at least 5 seconds, recording the peak force of the pull and the average load of a steady pull. All measurements in kN

	Dena & Gethin		Dena, Gethin & Bob	
	Peak	Average	Peak	Average
Pull 1	0.83	0.75	1.23	1
Pull 2	0.91	0.73	1.28	1.1
Pull 3	0.95	0.75	2.04	1
Pull 4	0.92	0.75	1.26	1
Pull 5	0.92	0.74	2.3	1
Average	0.906	**0.744**	1.2	**1.02**

Test 4

Pulling a rope through a Petzl Stop (threaded through the lower pulley only) as tight as possible with no mechanical advantage. The first figure is the peak force during the pull, and the second the load on the anchor once pulled as tight as possible.

	Peak	After
Dena	0.4	0.2
Gethin	0.6	0.35
Bob	0.8	0.25

Tests 5, 6 & 7

3 to 1 theoretical mechanical advantage using a small pulley (Petzl Oscillante) and Stop (lower pulley only). Test 7 5:1 theoretical mechanical advantage with using a Petzl Tandem and Oscillante, just one pull test. The fist figure is the peak, the highest force achieved during the pull, the second the average of a 5 second sustained pull.

3:1	Peak	After
Dena	0.7	0.25
Gethin	1.5	1.25
Bob	0.74	0.7
Dena & Gethin	1.5	1.43
Dena, Gethin & Bob	1.84	1.87
5: 1 with Dena, Gethin & Bob	2.85	2.5

Test 10, 11, 12 & 13

Comparable tests with the Petzl Rig. The full data was unfortunately lost, however we do have the observed peak loads and the load on the anchors after the pulls.
Test 10 & 11

Pulling by hand only through a Petzl Rig

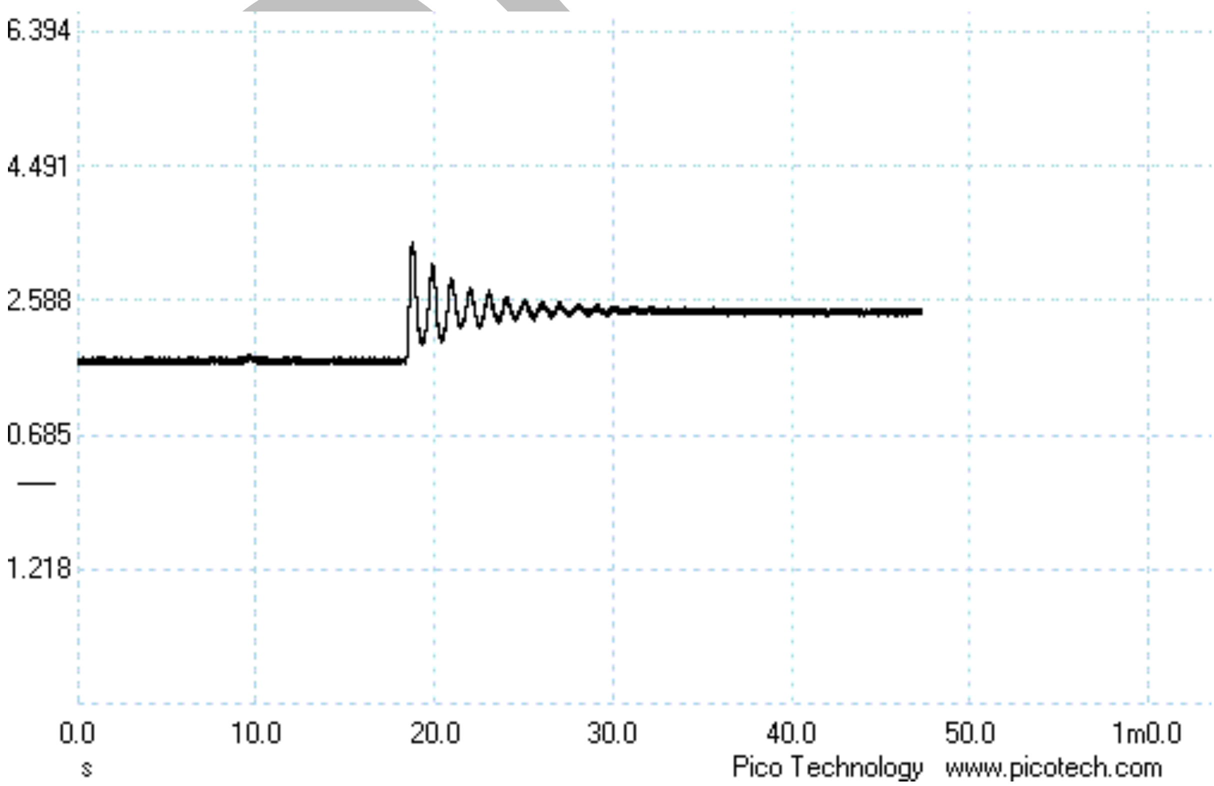
Hands only	Peak	After
Dena	Data missing	
Gethin		
Bob		
Dena & Gethin	0.8	0.3
Dena, Gethin & Bob	1.46	0.46

Test 12 & 13

	Peak	After
3:1, Dena, Gethin & Bob	1.9	1.88
5:1, Dena, Gethin & Bob	2.9	2.59

Tests on Tyroleans in use

We then conducted 2 tests looking at how the anchors fair when the tyrolean is in use. The span of the tyrolean was around 10m. For the first test we conducted a fall factor 1 drop test with an 85kg mass about 1m along the span of the tyrolean to simulate a person launching on take off. The result was an elegant trace illustrated here



Prior to the drop the rope was tensioned by 2 of us to 1.718kN. The peak impact was 3.423kN with the load stabilising at 2.455kN.

Following this test we moved the 85kg mass along the rope to look at the loadings, which resulted as follows

Distance	1.10m	3m	5m	7m
Load	2.455kN	2.721kN	2.839kN	2.662kN

A few days later I had the chance to revisit some of the rigging options for a tyrolean with the results on the next page.

Pictures from the second set of testing are available here:
https://www.dropbox.com/sh/ujc6newvod9bf5u/D5YdF1EuGD

Tyrolean Rigging Loads

These are the results of pull tests on a variety of rigging methods for setting a tyrolean traverses conducted on the 24th of October, 2013. The rope was anchored to the base of a large tree using a dyneema sling and steel krab, spanning 2.8m, anchored at the other end around another large tree adding 1.7m to the span of the rope. The load cells were attached between the dyneema sling and belay/capture device to measure the load on the anchor, and between the jammer and pulley on the haul line to measure the load on the jammer (given that jammers are rated to 4kN a potential weak point). The rope used was a Beal Pro-Static EN 1891Type A, with Petzl rescue pulleys (38mm) and a Petzl Tandem (red, rope) pulley used in the rigging. I also tested a Mini Traxion, which must not be used to rig a tyrolean (as they cannot be released when loaded, and damage 11mm ropes at around 5kN) for interest. In observing the mini traxion function it didn't seem to engage at loads in excess of 1kN, hence low "after" results. All pull tests by one person using two hands with no gloves.

The "peak" figure was the highest load recorded on the anchor/jammer load cells during the rigging, with the "after" figure representing a rough average of the load on the rigged tyrolean having removed the jammer. All measurements in kN. Figures in red mark the highest figures recorded. These results are in no way conclusive, however may provide an idea of the loads on anchors and equipment during the rigging of a tyrolean.

		Gri Gri		Stop (normal)		Stop (lower pulley only)		Rig		Mini Traxion (DO NOT USE!)	
		Peak	After	Peak	After	Peak	After	Peak	After	Peak	After
Hand, no mechanical advantage	Anchor	0.300	0.035	0.265	0.025	0.307	0.035	0.424	0.060	0.604	0.253
	Jammer										
3:1	Anchor	0.999	0.431	0.798	0.390	0.861	0.369	0.974	0.414	1.234	0.756
	Jammer	1.326		1.188		1.167		1.366		0.762	
3:1 (with redirection)	Anchor	2.259	0.407	2.239	0.386	2.474	0.434	2.599	0.369	2.301	0.132
	Jammer	0.913		1.003		1.107		0.982		0.392	
5:1 with Petzl Tandem	Anchor	1.574	0.632	1.706	0.618	1.463	0.549	1.512	0.417	1.83	0.576
	Jammer	1.696		2.218		1.943		2.012		1.641	
6:1 Compound	Anchor	2.834	1.107	2.717	0.919	3.138	1.118	2.951	0.860	3.671	1.921
	Jammer	0.852		1.106		1.222		1.174		0.618	
12:1 Compound with Petzl Tandem	Anchor	2.239	1.314	4.766	1.427	4.724	1.425	4.841	1.190	2.591	1.51
	Jammer	2.019		3.700		3.577		3.659		1.587	

Cells highlighted in red indicate loads on the jammer are getting close to the 4kN working load of the jammer.

Tyrolean In Use Loads

Follow up work on the forces on anchors during use of a tyrolean. I used 2 Beal Pro Static EN 1891 Type A ropes, one that had been used on the previous tests and the other, a used older rope, feeling dry and a little grubby. The tyrolean was rigged between 2 very significant trees, spanning 12m and 3m above the floor. I used a Petzl Stop as a capture device, using the lower pulley only of the stop. All loaded tests done using a person weighing 85kg. Cell A was placed on the lower rope, and Cell B on the higher rope.

Static tests

Normal use, steady loading, hang for 5 seconds to get initial load reading, moved to mid point (6m) and held for 5 seconds, then to the far point and held for 5 seconds, then back to the mid point and repeatedly bounced. Tests 1 to 4 and 10 all on a single rope Test 5 and 9 on twin ropes. All ropes re-tightened after previous test. All measurements in kN. % based on initial un-weighted load.

		Test 1	Test 2	Test 3	Test 4	Test 5	Test 9	Test 10
Initial tensioned on anchors	Cell A	1.33	1.416	Data missing	1.905	1.018	1.048	0.838
	Cell B	Not tested				0.965	0.892	Not tested
Start with 85kg mass	Cell A	1.346 101%	2.197 155%	Data missing	2.734 144%	1.182 116%	1.153 110%	0.888 106%
	Cell B	Not tested				0.991 103%	0.953 107%	Not tested
Mid point with 85kg mass	Cell A	2.13 160%	2.371 167%	2.616	2.854 150%	1.609 158%	1.61 154%	2.061 246%
	Cell B	Not tested				1.477 153%	1.437 161%	Not tested
Far point with 85kg mass	Cell A	1.596 120%	1.883 133%	2.169	2.433 128%	1.345 132%	1.393 133%	1.79 214%
	Cell B	Not tested				1.152 119%	1.191 134%	Not tested
Mid point bouncing (peak)	Cell A	2.841 214%	3.222 228%	3.685	3.94 207%	2.516 247%	2.488 237%	3.098 370%
	Cell B	Not tested				1.627 169%	2.362 265%	Not tested
Load on anchor once mass removed	Cell A	0.744 56%	0.976 69%	1.272	1.379 72%	0.731 72%	0.750 72%	0.624 74%
	Cell B	Not tested				0.667 69%	0.622 70%	Not tested

Dynamic tests

Jumping/launching onto the tyrolean from one side. Similar to that seen by an enthusiastic client! Ropes not re-tightened between tests, so would simulate a group of 5 launching onto the tyrolean. The “Start” and “After” figures are the load on the anchors with an weighted tyrolean.

		Start	Jump 1	After	Jump 2	After	Jump 3	After	Jump 4	After	Jump 5	End
		Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average
Double Ropes	Cell A bottom rope	0.819	3.603	0.768	3.278	0.759	3.402	0.768	3.451	0.762	3.278	0.734
	Cell B top rope	0.974	1.305	0.914	1.298	0.938	1.291	0.881	1.298	0.869	1.264	0.916
	Total	1.793	4.908	1.682	4.576	1.697	4.693	1.649	4.749	1.631	4.542	1.65

Single Rope	Cell A bottom rope	Not tested										
	Cell B top rope	0.757	3.165	0.561	3.103	0.514	3.007	0.445	3.048	0.454	3.186	0.429

In the dynamic tests the reduction of the load on the anchors following the tests could, in part, be attributed to the settling of knots and the slight slippage of the rope through the stop. From observations the rope had clearly slipped about 1cm following the second or third jump.

Peak forces did not reach 4kN in any of the tests, so we could assume that a stop rigged with the lower pulley only could be slipping around that load.

Using two ropes with similar tension significantly reduces the dip of the tyrolean in use (in observations, almost by half compared to a single rope). The reduced dip increases the angle between the anchors (from the load/person travelling across the tyrolean), increasing the load on the anchors, as illustrated in the higher total load seen in the double rope table.

Tests with a cable

The following tests were conducted using a cable rather than a rope, with no “clutch” mechanism rigged. The initial 3 tests used a short length of rope to hold the cable to the anchor (chain) at the far side, the last three tests we managed to tighten the cable and attach it directly to the chain. All measurements in kN, all percentages based on the initial, un-weighted cable load on anchors (start).

	Test 1	Test 2	Test 3	Cable re-tensioned at this point, removing the short length of rope used between the anchor and cable, and clipping the cable directly into a chain	Test 5	Test 6	Test 7
Start	0.123	0.130	0.088		0.175	0.182	0.170
Loaded (85kg)	1.544	1.588	1.405		2.013	1.791	1.802
Mid Point	2.053	2.238	1.954		2.819	2.565	2.464
Bouncing at mid point peak	4.198	5.409	5.409		6.351	6.698	6.704
End	0.052	0.098	0.053		0.168	0.156	0.151

Dynamic tests with a cable

	Jump 1	Jump 2	Jump 3	Jump 4	Jump 5
Start	0.271	0.159	0.143	0.150	0.153
Peak	4.371	3.824	2.951	4.509	4.17
After	0.159	0.143	0.150	0.153	0.156

2 person load (85kg + 85kg = 170kg)

	Test 1
Start	0.156
Mid Point	4.883
Bouncing at mid point peak	-
End	0.161