Fall Factors: Do They Apply to Rope Rescue and Rope Access?

Presented by:

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FALL FACTORS: DO THEY APPLY TO ROPE RESCUE AND ROPE ACCESS?

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The purpose of this presentation is twofold. One was to offer data showing that fall factors do not apply to static ropes and the other was to gather data for our teams and classes on the forces that might occur from a fall when using our ropes for fall protection. We would also like to encourage others to perform similar tests in the hope of persuading those of you who are members of standards making committees or have input with rope access organizations to consider the following statements: 1) *fall factors do not apply to static rope, 2) fall factors are not an indicator of the severity of a fall when applied to static ropes.*

Before we continue we need to define the term fall factor.

This first definition is from the book **Mountaineering the Freedom of the Hills,** the 1982 edition. *"Fall factor, the ratio of the length of the fall (excluding rope stretch) to the total length of rope between climber and belayer. Thus if the climber places a piece of protection 60 feet out and takes a fall 20 feet beyond it, he will fall 40 feet, with 80 feet of rope out, for a fall factor of 40/80, or ½. The fall factor, rather than the length of the fall, is the major determinant of the force on the climber's body and on the placement that holds the fall: the higher the fall factor, the greater the force."*

This definition of fall factor referrers to dynamic ropes now known as high stretch ropes but today we hope we can look at fall factors from a different perspective, not as climbers using dynamic ropes but as rescuers or rope access personnel using static ropes.

There are two points from that quotation we need to address. Number 1, "the fall factor, rather than the length of the fall, is the major determinant of the force on the climber's body". In our presentation we will show that this is not true with static rope. Number 2 "the higher the fall factor, the greater the force". We will also show how this does not hold true as we apply it to static ropes used for rescue or rope access. We want to make this point very clear that we are not disputing any part of these statements as they apply to dynamic rope or are used in the context of this book. Our presentation is on static ropes and their relationship to fall factors

The International Working At Height Handbook 2001 edition defines fall factor as "Method of working out the proportional seriousness of a fall. It is the relationship between the length of the fall and the amount of rope available to distribute the impact force of the fall." This definition does not differentiate between dynamic or static rope and it implies that the higher the fall factor the greater the severity of the fall.

The US Bureau of Land Reclamation has this definition of fall factor in their Guidelines for Rope Access Work. "The fall factor can be a useful way to describe the proportional seriousness of a fall. The fall factor is defined as the maximum distance a worker can fall divided by the length of rope (or lanyard connection) between the falling worker and the anchor." Notice that they added lanyard connection to the definition.

We first presented our findings on fall factors at the International Technical Rescue Symposium held in Tucson, Arizona in 2000. That presentation indicated that fall factors do not apply to static ropes. Our presentation was followed up in 2001 by Chuck Weber, PMI's quality control engineer and ISO coordinator with his presentation titled FALL FACTORS & LIFE SAFETY ROPES A CLOSER LOOK. In it he stated, "It was confirmed from this line of testing that the static and low stretch ropes exhibit a trend of increasing impact forces generated as the length of drop and rope are increased for any given fall factor." Mr. Weber also prepared a presentation for ITRS 2002 that was presented by Dr. Stephen Attaway titled ANALYSIS OF IMPACT FORCE EQUATIONS. That presentation was followed by Dr. Attaway's own presentation PREDICTING ROPE IMPACT FORCES USING A NON-LINEAR FORCE DEFLECTION. Since then there has not been much presented about fall factors and unfortunately it appears that not enough has been done to convince users of kernmantle rope that fall factors do not apply to static ropes.

As evidence of this please consider the following:

1) In the 2007 edition of SPRAT's Safe Practices for Rope Access Work, section 10.7.3 it states "Where a fall in excess of a factor .25 fall might occur, dynamic rope should normally be used in place of static or low stretch rope" end of quote. So SPRAT is implying that a .25 fall factor is okay and anything else is unsafe on static or low stretch rope.

2) Ropeworks, a highly regarded and well respected rope access training company makes this statement in their manual "Where a fall in excess of a factor .25 fall might occur, dynamic rope should normally be used in place of static or low stretch rope." Again, this implies static rope is not acceptable for any fall factor greater than 0.25.

3) In Annex A Explanatory Material of the NFPA 1983 standard they state "When fall factors of greater than 0.25 are anticipated, such as are possible in lead climbing, dynamic ropes specifically designed for climbing should be considered." Further on it states "A fall factor of 0.25 is the <u>maximum</u> considered for NFPA 1983." In the next paragraph they state "Recent testing indicates that the formula for calculating fall factors may not translate perfectly from dynamic ropes to the more static design ropes used for fire service operations." If we compare this statement to the definition in the 1983 standard, we find that it just adds to the confusion about fall factors. This is the NFPA definition of fall factor. "A measure of fall severity calculated by dividing the distance fallen by the length of rope used to arrest the fall." Our contention is that fall factors <u>are not</u> a measure of fall severity when using static ropes as we use them in rope access or rope rescue.

Fall factors used to be about a climber and their rope. Climbers used dynamic rope and tied themselves in with a knot and were belayed with a technique or device that allowed the rope to slip which helped to dissipate the impact force of a fall.

Rescuers and rope access personnel use static ropes and secure them to an anchor with a knot, then connect themselves to the rope with a rope grab or lanyard and rope grab.

So when a climber took a fall, their fall factor was determined by the amount of rope in service and their impact force was determined by the tightening of their knot, the elongation of their rope and the slippage within their belay technique or device. If fall factors are applied to a rescuer or rope access worker we need to consider the amount of rope in service and any extensions to their systems such as lanyards or prusik loops.

By using static instead of dynamic rope, and by placing our rope grabs and lanyards at the load end of the rope we have changed the dynamics, and the original intention of fall factors.

Here are a few questions we used to help us determine if fall factors apply to the static ropes we use for rescue or rope access.

1) Is fall factor severity determined by the mass? …..Let's compare a fall factor 1 with 300 lbs and a fall factor 1 with 200 lbs.

2) Are higher fall factors always more severe than lower fall factors?

3) Is the fall factor, rather than the length of the fall, the major determinant of the forces on the rescuer or rope access worker?

4) Will drops of the same fall factor create the same force when increasing the length of the drop with all other factors being equal?

5) Is a factor 1 fall always a severe fall?

6) Do fall factors only apply to ropes of the same diameter? …. If not, then how can a fall factor be a measure of fall severity?

7) Is there a difference in forces created with the same fall factor using different diameter ropes?

8) Do fall factors only apply to new rope? If not what is a used rope? Does one fall on a new rope now make it a used rope?

9) Do fall factors only apply to single strands of rope? If not what is the fall severity on a doubled rope? If we loop our rope over an object and put on a rope grab, does that change the definition of dividing the distance fallen by the amount of rope in service?

10) Are fall factors appropriate when using a rope grab?

11) Are fall factors appropriate when using a lanyard as part of a system?

Summary

It is our analysis that the answers we got from the questions we asked prove that fall factors are not appropriate for use with static ropes. We can't pick and choose which ropes we can apply fall factors to or which fall factors apply to a particular rope. If fall factors don't apply to all static ropes that we use, if fall factors are not a measure of fall severity, if fall factors don't apply to our use of lanyards or rope grabs, then fall factors should not be part of our standards.

We believe fall factors should be eliminated from NFPA and Sprat standards. It seems to us it would be more appropriate if the standards addressed the maximum force a rope access worker, rescuer or victim should ever be subjected to. All falls can be serious but by keeping the impact force manageable we can attempt to limit injuries to our rescuers and rope access personnel. As our presentation demonstrates, impact forces are not related to fall factors when using static ropes.

So what is a manageable impact force? The British Columbia Council of Technical Rescue has the following minimum standard: "200 kg mass tied to 3 metres of rope the belay system must be able to withstand a 1 metre drop of the load and stop it in less than 1 metre of additional travel and with less than 15 kilonewtons of force". This is the original belay competency drop test standard quoted from a presentation given by Arnor Larson back on August 2, 1990.

The instructions for the 540 Rescue Belay state "designed to limit the "relative worst-case fall" of a rescue sized load (i.e. 200-280 kg) to no more than 15 kN peak force and with no more than 1 m stopping distance". Further on the directions state "Note: due to the distribution of forces between the components that comprise a rescue-sized load, the patient and the attendant are subjected to much less (e.g., less than half for two people of equal mass) of the peak force applied to the rope and belay device."

So as a rough estimate the BCCTR has said that a victim might be subjected to approximately 7 kN or 1,574 lbf. This figure is less than the maximum 8 kN or 1,800 lbf that OSHA allows an industrial worker in a full body harness to experience and one kilonewton greater than European standards permit. This could be a reasonable starting point for standards making committees to consider since in some instances we may be dealing with an already injured person.

And following that same train of thought, should any fall factor that creates less than 1,800 lbf be acceptable for a rescuer or rope access technician? OSHA doesn't care about the fall factor; they're concerned about the forces created. What should we and those that are writing our standards be concerned about, the fall factor or the impact forces?

ITRS 2009

FORCES CREATED WITH DIFFERENT FALL FACTORS
ON PMI 12.5, 11 and 10 mm EZ-BEND ROPES

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	12.5 bow-bow	12.5 & 8m	12.5 bow-bow	12.5 & 8m	11 bow-bow	11 & 8m	11 bow-bow	11 & 8m	11 & Shunt	10 bow-bow	10 & 8m	10 & 8m	10 & 8m	10 & 8 m	2-10 & 8m
fall factor	300 lbs	300 lbs	200 lbs	200 lbs	300 lbs	300 lbs	200 lbs	200 lbs	300 lbs	300 lbs	300 lbs	300 lbs	225 lbs	200 lbs	300 lbs
0.25	new	new	pretested	pretested	new	new	pretested	pretested		new	new	used	new	used lanyd	new
1 on 4	1750	1286 3/4"			1363	1299 1 1/2"			696 13 3/4"	1767	1081 n/a		1000 4 3/4"	846 1/2"	1367 1 1/4"
2 on 8	2073	1598 1 1/2"			1880	1565 1 5/8"			699 26 1/4"	1995	1485 4"		1105 12 1/8"		1699 1 1/4"
3 on 12	2122	1750 2"			2132	1585 4"				2196	1458 17 1/4"		1218 6 1/8"		1830 1 5/8"
4 on 16	2306	**C1805 1 3/4"			2095						1581 6 3/8"		1259 4 1/2"		2046 1 1/8"
0.33															
1 on 3	1914	1380 1"			1975	1132 1"			762 12 1/4"		1178 3 1/2"			907 1/4"	1414 3/4"
2 on 6	C 2450				2129	1512 n/a			701 25 1/8"	2257	1463 3 1/4"				1823 1 1/4"
3 on 9	2472				2472	1581 3 3/4"			813 32 1/4"		1434 7 7/8"				2046 1 1/2"
4 on 12	2723				2586	1911 4 3/8"					1451 11 1/2"				2083 2 3/4"
5 on 15	2737				2637						1357 20 1/8"				
0.5															
1 on 2	3154				2066						1521 2 1/8"		1215 2"		
2 on 4	3272	1747 1 1/2"	1767	1360 3/4"	2627	1635 4"	1706	1282 1"		2355	1430 6 3/8"		1507 7"		1992 1 1/8
30" on 60"														1169 1/2"	
3 on 6	2818	2024 3"	1914	1470 1"	2929	1725 7 3/4"	1874	1870 4 1/2"		2730	**C2185 8 1/2"		1742 6 1/4"		2306 1 5/8"
4 on 8	3267	2243 1 3/4"			3019	grounded					1669 10 1/2"				2519 1 7/8"
5 on 10	3539	2291 4 1/4"			3220	1767 3 1/2"					1568 17 3/4"				
1															
1 on 1	2502				2068										
18" on 18"						1531 2 1/8"					1531 2 1/4"			981 1 1/8"	
2 on 2	3267	1725 1 7/8"	1794	1269 1 7/8"	3053	1585 6 1/4"	1512	1373 1"		3009	1605 4 1/4"	1225 n/a	1320 7 1/4"	985 4 1/4"	2110 1 1/4"
30" on 30"															
3 on 3	3483	2243 2 1/2"	2163	1504 1 1/8"	2509	C1945 6 3/8"	1944	1649 1/2"		2855	1750 6 1/8"	1335 n/a	C1360 4 1/8"	1350 1 1/8"	2472 1 3/4"
4 on 4	3912	2431 2 1/4"	2355	1786 1 7/8"	3933	2088 6 1/4"	2250	1894 3"		C 3215	1948 7 1/8"	1910 n/a	1468 7 1/4"	1296 6 1/4"	2744 3 1/4"
5 on 5														1404 5 1/2"	
0.33															
1 on 3															*Shunt failed 1526

bow-bow means bowline at anchor and bowline at mass   12.5 & 8m, 11 & 8m, 10 & 8m means bowline on one end and 8mm Prusik on other end

2-10 & 8m means doubled 10mm rope and 8mm Prusik

pretested means the rope was used in a previous drop test   all ropes were new PMI EZ-Bend except where it states "pretested"   Prusiks were used, three wrap PMI 8mm accessory cord

the numbers to the right of the recorded forces were Prusik or Shunt slippage   the letter "C" in front of a recorded force means Chatillon load cell

none of the Prusiks failed

the bowlines were not backed up and none of the bowlines failed   all but a couple bowlines were easy to untie

*the Shunt had caught 7 drops on 11mm rope with 300 lbs before it failed on this drop on the doubled 10mm rope

*for 2 of the 7 drops the Shunt was attached to a Sterling Marathon 24 inch lanyard and caught a ff 1 (825 lbf) and ff 2 drop (810 lbf) of 300 lbs, before this series of testing

**no reading on Load Cell Central Force Meter

FORCES CREATED WITH DIFFERENT FALL FACTORS
ON PMI 12.5 mm EZ-BEND STATIC ROPE

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	bowline-bowline	bowline-8mm Prusik	bowline-bowline	bowline-8mm Prusik	
	300 lbs	300 lbs	200 lbs	200 lbs	
fall factor	new	new	pretested	pretested	
0.25					
1 on 4	L-1750 C-1700	L-1286 C-0000 ps 3/4"			L=Load Cell Central Force Meter
2 on 8	L-2073 C-2010	L-1598 C-1245 ps 1 1/2"			C=Chatillon indicator
3 on 12	L-2122 C-2075	L-1750 C-1415 ps 2"			ps=Prusik slippage
4 on 16	L-2306 C-2275	L-0000 C-1805 ps 1 3/4"			
0.33					
1 on 3	L-1914 C-1870	L-1380 C-1035 ps 1"			petested means the rope was new but had been used in a
2 on 6	C-2450 L-2382				previous test
3 on 9	L-2472 C-2420				
4 on 12	L-2723 C-2675				bowline-bowline means the rope was tied to the mass
5 on 15	L-2737 C-2705				and the other end was tied at the anchor
0.5					
1 on 2	L-3154 C-3105				bowline-8mm Prusik means the rope was tied at one end
2 on 4	L-3272 C-3230	L-1747 C-1400 ps 1 1/2"	L-1767 C-1520	L-1360 C-1095 ps 3/4"	and the other end was secured with a Prusik
30" on 60"					
3 on 6	L-2818 C-2765	L-2024 C-2000 ps 3"	L-1914 C-1670	L-1470 C-1230 ps 1"	none of the bowlines were backed up and none of the
4 on 8	L-3267 C-3215	L-2243 C-2185 ps 1 3/4"			bowlines failed
5 on 10	L-3539 C-3485	L-2291 C-2235 ps 4 1/4"			
1					the used Prusiks were triple wrapped PMI 8mm accessory
1 on 1	L-2502 C-2440				cord tied with a double overhand bend
18" on 18"					none of the Prusiks failed
2 on 2	L-3267 C-3220	L-1725 C-1680 ps 1 7/8"	L-1794 C-1745	L-1269 C-1215 ps 1 7/8"	
30" on 30"					
3 on 3	L-3483 C-3440	L-2243 C-2200 ps 2 1/2"	L-2163 C-1910	L-1504 C-1250 ps 1 1/8"	
4 on 4	L-3912 C-3885	L-2431 C-2215 ps 2 1/4"	L-2355 C-2095	L-1786 C-1545 ps 1 7/8"	

FORCES CREATED WITH DIFFERENT FALL FACTORS
ON PMI EZ-BEND 11mm STATIC ROPE

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	bowline-bowline	bowline-8mm Prusik	bowline-bowline	bowline-8mm Prusik	bowline-Shunt	
fall factor	300 lbs new	300 lbs new	200 lbs pretested	200 lbs pretested	300 lbs new	
0.25						
1 on 4	L-1363 C-1300	L-1299 C-1250 ps 1 1/2"			L-696 s=13 3/4"	L=Load Cell Central
2 on 8	L-1880 C-1535	L-1565 C-1520 ps 1 5/8"			L-699 s=26 1/4"	Force Meter
3 on 12	L-2132 C-2075	L-1585 C-1535 ps 4"				
4 on 16	L-2095 C-2040					C=Chatillon indicator
0.33						
1 on 3	L-1975 C-1925	L-1132 C- 865 ps 1"			L-762 s=12 1/4"	ps=Prusik Slippage
2 on 6	L-2129 C-2075	L-1512 C-1175			L-701 s=25 1/8"	
3 on 9	L-2472 C-2420	L-1581 C-1240 ps 3 3/4"			L-813 s=32 1/4"	pretested means used
4 on 12	L-2586 C2535	L-1911 C-1865 ps 4 3/8"				in a previous test
5 on 15	L-2637 C-2590					
0.5						bowline-bowline means
1 on 2	L-2066 C-2025					knot used each end
2 on 4	L-2627 C-2570	L-1635 C-1625 ps 4"	L-1706 C-1450	L-1282 C-1030 ps 1"		
30" on 60"						bowline-8m Prusik
3 on 6	L-2929 C-2885	L-1725 C-1720 ps 7 3/4"	L-1874 C-1620	L-1870 C-1645 ps 4 1/2"		means knot one end &
4 on 8	L-3019 C-2970	hit ground				Prusik other end
5 on 10	L-3220 C-3170	L-1767 C-1425 ps 3 1/2"				
1						bowlines not backed up
1 on 1	L-2068 C-2010					no bowlines failed
18" on 18"		L-1531 C-1525 ps 2 1/8"				
2 on 2	L-3053 C-3000	L-1585 C-1280 ps 6 1/4"	L-1512 C-1475	L-1373 C-1110 ps 1"		Prusiks were used, three
30" on 30"						wrap PMI 8mm accessory
3 on 3	L-2509 C-2775	C-1945 L-1592 ps 6 3/8"	L-1944 C-1700	L-1649 C-1395 ps 1/2"		cord tied with a double
4 on 4	L-3933 C-3880	L-2088 C-2080 ps 6 1/4"	L-2250 C-2180	L-1894 C-1650 ps 3"		overhand bend
5 on 5						
						none of the Prusiks
						failed

FORCES CREATED WITH DIFFERENT FALL FACTORS
ON PMI 10mm EZ-BEND STATIC ROPE

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	bowline-bowline	bowline-8mm Prusik	bowline-8mm Prusik	bowline-8mm Prusik	bowline-8mm Prusik	doubled 10mm-8mm Prusik
fall factor	300 lbs new	300 lbs new	300 lbs used lanyard	225 lbs new	200 lbs used lanyard	300 lbs
0.25						
1 on 4	L-1767 C-1420	L-1081 C-1030		L-1000 C- 940 ps 4 3/4"	L-846 ps 1/2"	L-1367 ps 1 1/4"
2 on 8	L-1995 C-1940	L-1485 C-1430 ps 4"		L-1105 C-1045 ps 12 1/8"		L-1699 ps 1 1/4"
3 on 12	L-2196 C-2150	L-1458 C-1410 ps 17 1/4"		L-1218 C-1160 ps 6 1/8"		L-1830 ps 1 5/8"
4 on 16		L-1581 C-1530 ps 6 3/8"		L-1259 C-1195 ps 4 1/2"		L-2046 ps 1 1/8"
0.33						
1 on 3		L-1178 C-1135 ps 3 1/2"			L-907 ps 1/4"	L-1414 ps 3/4"
2 on 6	L-2257 C-2205	L-1463 C-1405 ps 3 1/4"				L-1823 ps 1 1/4"
3 on 9		L-1434 C-1370 ps 7 7/8"				L-2046 ps 1 1/2"
4 on 12		L-1451 C-1405 ps 11 1/2"				L-2083 ps 2 3/4"
5 on 15		L-1357 C-1315 ps 20 1/8"				
0.5						
1 on 2		L-1521 C-1450 ps 2 1/8"		L-1215 C-1210 ps 2"		
2 on 4	L-2355 C-2295	L-1430 C-1385 ps 6 3/8"		L-1507 C-1495 ps 7"		L-1992 ps 1 1/8"
30" on 60"					L-1169 ps 1/2"	
3 on 6	L-2730 C-2380	L-0000 C-2185 ps 8 1/2"		L-1742 C-1535 ps 6 1/4"		L-2306 ps 1 5/8"
4 on 8		L-1669 C-1630 ps 10 1/2"				L-2519 ps 1 7/8"
5 on 10		L-1568 C-1510 ps 17 3/4"				
1						
1 on 1						
18" on 18"		L-1531 C-1485 ps 2 1/4"			L-981 ps 1 1/8"	
2 on 2	L-3009 C-2950	L-1605 C-1565 ps 4 1/4"	L-1225	L-1320 C-1265 ps 7 1/4"	L-985 ps 4 1/4"	L-2110 ps 1 1/4"
30" on 30"						
3 on 3	L-2855 C-2515	L-1750 C-1710 ps 6 1/8"	L-1335	C-1360 L-1252 ps 4 1/8"	L-1350 ps 1 1/8"	L-2472 ps 1 3/4"
4 on 4	C-3215 L-3110	L-1948 C-1915 ps 7 1/8"	L-1910	L-1468 C-1210 ps 7 1/4"	L-1296 ps 6 1/4"	L-2744 ps 3 1/4"
5 on 5					L-1404 ps 5 1/2"	
0.33						
1 on 3						Shunt failed 1526 after
						multiple drops

L=Load Cell Central Force Meter, C=Chatillon indicator, ps=prusik slippage

bowline-bowline means knot used each end, bowline-8m Prusik means knot one end and Prusik other end

Prusiks were used, 3 wrap PMI 8mm accessory cord tied with double overhand bend, bowlines not backed up