UIAA Dynamic Rope drop testing results with loads greater than 80 kg

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The presentation and paper is based on original testing and a magazine article entitled *Heavy climbers beware!* Written by PMI's Quality Manager Chuck Weber. While the original work was looking for information about impact forces on heavy climbers, the data has proven of interest to rescue applications as well.

Whether you're new to rope rescue or a seasoned veteran, you've hopefully been predisposed to and are familiar with those "UIAA Test Results" provided with dynamic climbing rope. If not, this article should help you gain a better understanding of them.

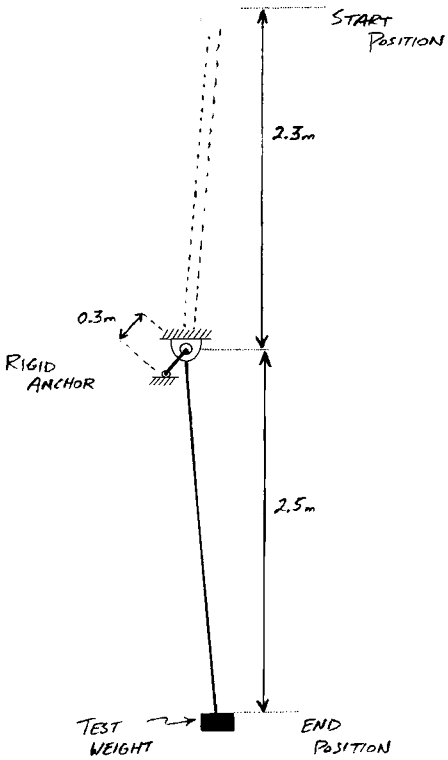
The UIAA dynamic rope tests for IMPACT FORCE, # FALLS HELD, and ELONGATION are all based on a standard test weight of 176 pounds (80kg). Let's not go into all these tests right now, but just take a closer look at that test weight. For those of us over that weight, you might have found yourself asking a question something like, "Since I'm ____ pounds over that test weight, how do those **impact force** and **number of falls** relate to me?" Chances are that you never really found an answer to your question, let go of the thought, and safely went on about your climbing adventures without incident.

The truth of the matter is that today's climbing ropes and gear bless us with very safe performance as we engage in our potentially dangerous past time. Today's climbing ropes rarely ever fail, but when they do they're cut versus pulled to failure from excessive loads. Most of your other climbing equipment will fail or pull out of the rock from high loads before your rope will ever break. However, we must never forget the ropes and our gear are NOT indestructible and high impact forces are our enemy! Here's some background why.

What are 80 kg and 12 kN all about?

80 kg (176 pounds) is this nice round magical number the UIAA selected to represent an "average climber weight" for the falling body in the required drop test. In the standard drop test the weight is connected to a rigid anchor by about a 5-meter length of rope. The "belay end" of the rope is anchored a short distance below a smooth edged hole in a steel plate (simulating a "fat carabiner"). Then the "climber's end" of the rope is threaded through this hole (top anchor) and tied to the test weight. Before the

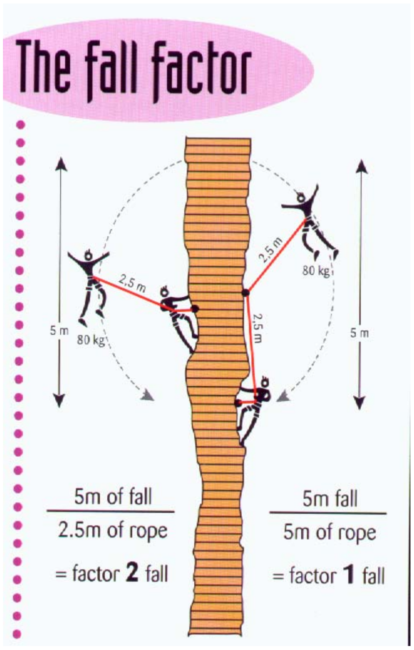
drop test the length of the rope is adjusted so that the weight hangs exactly 2.5 meters below this top anchor. (see figure 1)



To perform the drop test the weight is raised 2.3 meters above this top anchor and released for a 4.8-meter fall. Using the details of the drop test configuration this fall factor (length of fall divided by length of rope out) measures in at a hefty 1.71. As many of you already know, the maximum fall factor you could achieve in a lead-climbing fall is 2.0. To do this you'd have to fall directly onto and past your belay (see figure 2).

To go along with this 80 kg test mass, the UIAA also adopted an old US Military specification (1) of 2700 lbf (pounds force), aka 12 kN. This number is what our government once accepted as the maximum allowable force that a paratrooper could withstand when his parachute deployed and jerked his free falling body to a much slower rate of descent. So, simply translate all that to a climber taking a severe fall and you get the picture. Luckily, all of today's climbing ropes are well below that safety limit when tested with 176 pounds,

So, what happens when Joe Rescue weighs more than 176 pounds and takes a hard fall? Could Joe be subjecting himself and his gear to unsafe loads? How hard of a fall does Joe have to take before he comes close to unsafe loads? Serious questions indeed, but they're not addressed by the UIAA testing requirements.



Over the years both PMI employees and customers had been asking these basic types of questions. Since nobody seemed to have a concrete answer, we said we'd find out.

Modify the test

To try and answer those questions we had to make some changes to the standard UIAA drop test. All the data from the 39 individual drop tests conducted for this project are provided in the table and graph found at the end of this article.

The first part was to simply increase the weight. Speaking in "good-old American" units for a bit, we started with the "standard" 176 pounds and went on to test 200, 225, 250, 276, and 301 pounds. Each weight was dropped in the standard 1.71 fall factor setup and the impact forces were measured. To no one's surprise, as we increased the weight the forces increased.

The second part of the testing was to reduce the length of the drop for each of the heavier weights until the impact force was comparable to the "standard" UIAA single rope drop test using 176 pounds.

Sound confusing? Consider this example:
In the "standard" test 176 pounds was dropped a distance of 4.8 meters and gave an impact force = 1866 lbf. When we increased that weight to 225 pounds and dropped it the same distance, the impact force increased to 2261 lbf (or 21%).

Then we did more drop tests in which we continuously **reduced** the fall factor by 0.1 for each consecutive drop until we measured an impact force close to the "standard" test. With our 225 pound test weight, this occurred when we reached the 1.21 fall factor setup, measuring 1854 lbf. Each drop test for this study was performed using a brand new section of rope.

Another way to say this is that we had to reduce the length of the drop by 1.4 meters (or 29%) to make the impact forces comparable.

The results

Unlike concrete, steel bolts, or springs, there are no exact equations that can absolutely and accurately predict a climbing rope's performance (in terms of impact forces) during a fall. Numerous variables beyond the scope of this article would come into play. However, the 39 drop tests we performed using various combinations of test weights and fall factors have provided much useful information.

1) Fall Factor is key

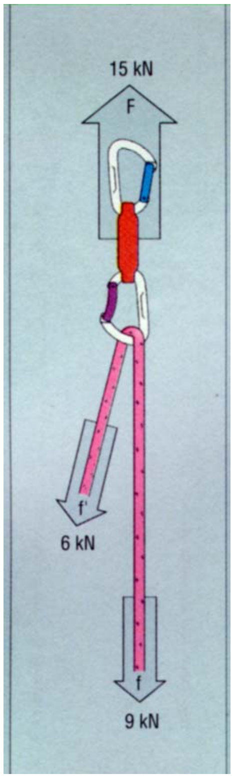
If you haven't acquired a good understanding of fall factor you need to! Perhaps this article and testing results can help provide you with a better understanding.

The graph demonstrates one simple rule – for all the weights tested, as you increase the fall factor, you **reduce** your safety because you're generating **higher** impact forces.

The most applicable real-world rescue rigging situation with high loads and scary fall factors is most likely the litter team falling off the cliff or building edge while little rope is out from the main brake or haul. Similarly is the possible short fall onto your belayer or first piece(s) of protection during a multi-pitch climb in a lead climbing situation. Be especially wary of these short falls as they might generate higher forces than you'd expect. As much as possible, keep the fall factors low by NOT being sparse on your pro when leaving the belay to start that next pitch. In the case of belaying heavy rescue loads, make every effort to keep fall factors low. Especially with ropes that have lower elongation than UIAA dynamic climbing ropes.

2) Greater weight = greater impact force

Looking at all the tests from the same drop height (holding the fall factor constant), it is clear that as you increase the weight the impact force also increases. You can see this in the graph by picking any fall factor and going straight up, noting where each drop weight line is intersected. This relationship is also true for other fall factors that are not presented here.

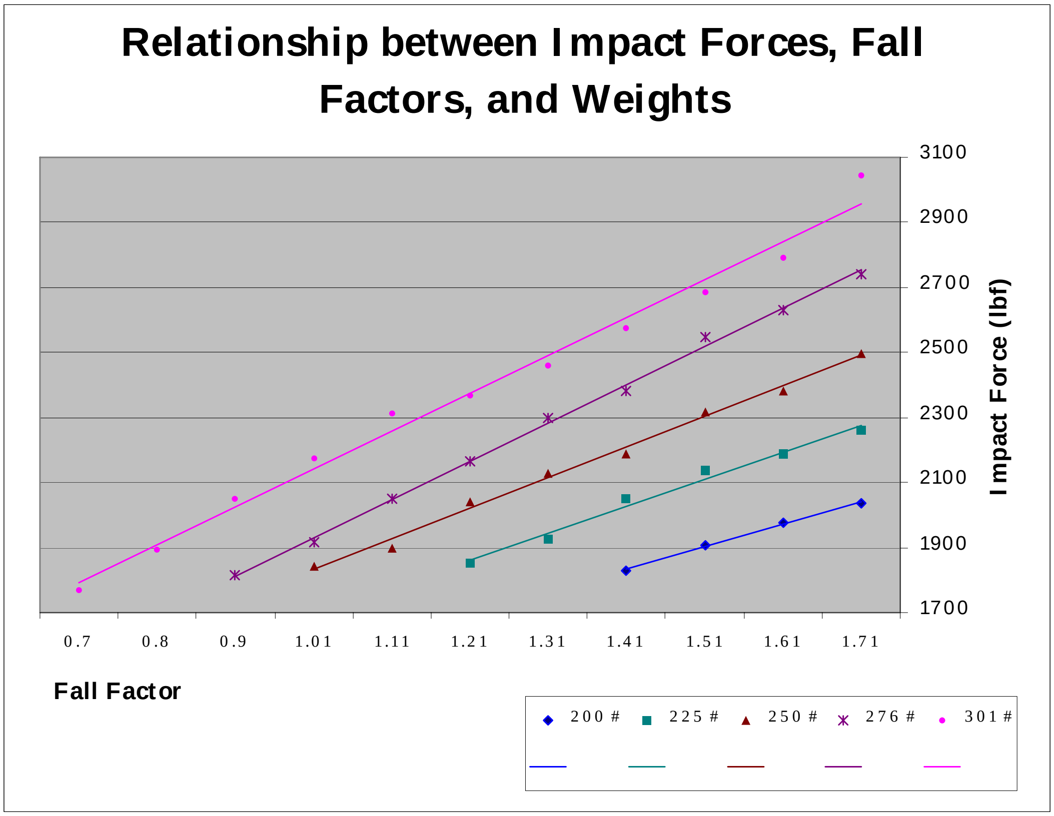


3) Dangerous loads

It is important to realize that our carabiners, bolt hangers, pieces of pro, etc. are closely related to this 12 kN upper limit for ropes. Without going into all the details, the widely accepted rule of thumb is that the top piece of gear in your system will experience **2/3 MORE** force than that felt by the falling climber (see figure 3 for example). So, one could apply this rule using any of these test result impact forces (see data table and graph) and estimate the forces on other pieces of gear in the protection system.

Take this test result for example. We found that a 250 pound weight in a 1.71 fall factor generated 2500 lbf at the climber's end of the rope. This is dangerously close to the rope's 2700 lbf safety limit! This impact force translates to 4166 lbf (18 kN) on the top anchor point. If this number exceeds the capacity of your top anchor pieces they might fail.

Increasing the weight a little more to 275 pounds, it would only take a 1.51 fall factor to get that same 2500 lbf impact force. Drop that 275-pound weight in a 1.71 fall factor

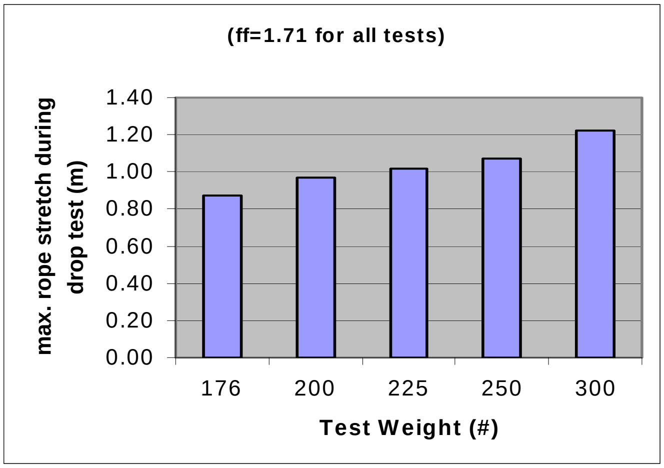


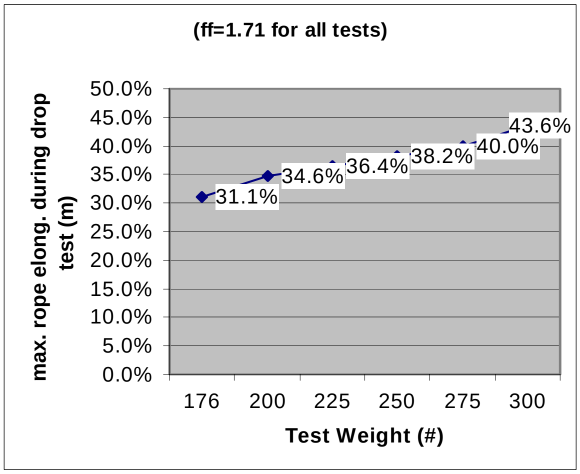
and we got 2740 lbf = unsafe! Needless to say, the 300-pound weight reached unsafe territory more quickly.

These combinations of weights and fall factors may sound unlikely to ever occur for most climbers. BUT, say you're about a 200-pound climber. How much are you really weighing with all your extra clothes, gear, pack, etc.? Whatever style of climbing you're into, aid, alpine, big-wall, ice, mixed, trad, whatever; it is always critical for you to realize the limitations of all your gear. Remember that heavier loads and higher fall factors ALWAYS add up to higher impact forces that your gear will have to absorb if you fall.

4) Stopping Distance

We also took a look at how much extra rope elongation was involved in stopping these greater loads. The graphs show that all things else being the same, one can expect about a 12% longer fall if you weigh 300 pounds as compared with your 176 pound partner.





Some important notes for all these tests are:

1) The impact forces are measured at the "falling climber's" end of the rope, NOT the anchor (or belay) end.
2) All impact forces reported here are actual measurements recorded in the PMI laboratory. These test results were not computed with any equations.
3) Each drop was onto an identical but virgin piece of PMI 10.5mm dry treated dynamic rope. As rope is normally used it will lose some of its ability to absorb energy. The impact force values presented here are in a sense actually the "best case" scenario in terms of the rope's optimal performance. Used ropes would have somewhat higher impact forces.
4) The ropes tested were PMI's 1997 production style and official UIAA test results for these ropes are: 10 falls held, 7.8 kN (1755 lbf) impact force, and an elongation of 6.8%.

IMPORTANT

The data presented here should only be used for general comparisons and understanding of the relationship between fall factors, weights, and impact forces. Do not misinterpret the data as an absolute formula for determining impact forces. Other name brands, diameters, and types of ropes were not tested and should NOT be assumed to have the exact same numbers.

The purpose of this article is simply to share these testing results with the intent of helping climbers make safer climbing situation decisions. The results of this testing may be useful in determining whether a severe fall situation is capable of generating forces high enough to cause failure of a component in a climbing system.

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Reference:

(1) 1950's US military parachute research which led to publication of test report WCLE-53-292 as well as Pilot ejection tests by Henzel in 1967, and Webb in 1964.

Special thanks to:

Austin Newman who performed all the testing represented in this article in the PMI drop tower while he worked at PMI for two summers before completing his studies at local UTC.

Figures 2 and 3 compliments of BEAL 1999 and Petzl 1996 Catalogs, respectively.

About the authors:

Chuck Weber has been climbing for 10 years and for the last 5+ years has been employed as PMI's Quality Manager and ISO System Coordinator. He has the uncommon luxury of access to a UIAA replicate drop tower at PMI. In addition to his routine ISO Quality System and testing duties, he occasionally has the opportunity to do more interesting stuff in the drop tower. This article is one example.

Steve Hudson is President of Pigeon Mountain Industries, Inc., America's leading manufacturer of life safety ropes. Mr. Hudson is also Deputy Director of Walker County Emergency Management Agency that operates a 21-station fire and rescue department and the county's 911 center. He also is active on a ASTM standards committee and two NFPA committees, all of which are actively setting standards on technical rescue. He served on the NASAR board of Directors for over nine years and with the National Cave Rescue Commission for over seventeen years.

Drop #	Fall Factor	drop length (m)	Weight of Basket	Impact force (pounds)	Impact force (kN)
1 **"**standard"	**1.71**	**4.8**	**176**	**1866**	**8.3**
2	1.71	4.8	200	2038	9.1
3	1.61	4.5	200	1978	8.8
4	1.51	4.2	200	1908	8.5
5	1.41	3.9	200	1830	8.1
6	1.71	4.8	225	2261	10.1
7	1.61	4.5	225	2190	9.7
8	1.51	4.2	225	2136	9.5
9	1.41	3.9	225	2048	9.1
10	1.31	3.7	225	1925	8.6
11	1.21	3.4	225	1854	8.2
12	1.71	4.8	250	2499	11.1
13	1.61	4.5	250	2383	10.6
14	1.51	4.2	250	2315	10.3
15	1.41	3.9	250	2190	9.7
16	1.31	3.7	250	2128	9.5
17	1.21	3.4	250	2039	9.1
18	1.11	3.1	250	1900	8.5
19	1.01	2.8	250	1842	8.2
20	1.71	4.8	276	2740	12.2
21	1.61	4.5	276	2632	11.7
22	1.51	4.2	276	2549	11.3
23	1.41	3.9	276	2383	10.6
24	1.31	3.7	276	2297	10.2
25	1.21	3.4	276	2167	9.6
26	1.11	3.1	276	2051	9.1
27	1.01	2.8	276	1915	8.5
28	0.91	2.5	276	1816	8.1
29	1.71	4.8	301	3046	13.5
30	1.61	4.5	301	2793	12.4
31	1.51	4.2	301	2686	11.9
32	1.41	3.9	301	2575	11.5
33	1.31	3.7	301	2460	10.9
34	1.21	3.4	301	2368	10.5
35	1.11	3.1	301	2312	10.3
36	1.01	2.8	301	2175	9.7
37	0.91	2.5	301	2052	9.1
38	0.81	2.3	301	1895	8.4
39	0.71	2.0	301	1768	7.9