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REPORT TO THE CORONER

1998 Sydney to Hobart Yacht Race

Yachting Harnesses and Lines

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1. INTRODUCTION

In June 1999 Senior Constable David Upston from the NSW Water Police Branch of the NSW Police Service contacted WorkCover NSW seeking assistance in relation to certain aspects of the Coronial Investigation into the 1998 Sydney to Hobart Yacht Race.

One of these aspects was the failure of a line, also known as a “lanyard”, when Glyn Charles, the helmsman from *Sword of Orion*, was lost overboard and never recovered. The Police held the failed line, which had been recovered before the vessel sank, and the yachting harnesses and lines used by the *Sword of Orion* crewmembers that were rescued.

As I have had extensive experience in the use of harnesses and lanyards in the industrial fall-arrest and industrial rope access industries and am Chairman of the Australian/New Zealand Standards Committee which develops the Australian Standards for these products, I was given the task of assisting in this matter.

The scope of this assistance was to act as a consultant and as such to participate in discussions between the Police, the RTA Crashlab staff and others in regard to preparation of an appropriate test program, to witness relevant tests and to provide a general report for the Coroner. RTA Crashlab is the test laboratory that was contracted to perform the drop and tensile tests and to prepare the test reports.

Copies of the test reports from RTA Crashlab, Report No’s SR2000/002, SR99/004, SR99/006 and SR99/007, were received in February 2000 and are to be read in conjunction with this report.

2. INITIAL DISCUSSIONS AND INSPECTION

I was shown the harnesses and lines by David Upston, including the failed line and a line that had been drop tested by RTA Crashlab to the test specification in the current Australian Standard AS 2227:1992 *Yachting harness and lines – Conventional lines*. The manner of failure of both lines was virtually identical in that the stitching failed completely at one end and partially at the other end, with almost no damage to the webbing.

I was advised that the manufacturer, Tuff Marine, has not manufactured these items for a number of years. Also, as one of the harnesses from the *Sword of Orion* carried the “Standards Mark” now administered by QAS, Geoff Clark from QAS was checking their records to see when Tuff Marine were last certified to use the mark on that product. The early indications were that the last certification occurred in February 1986.

From the initial inspection, the used harnesses and lines appeared to have been in excellent condition, with no visible signs of physical damage or degradation. The lack of damage to the webbing on both the failed lanyards was of concern. Structural stitch joints in webbing usually cause considerable damage to the webbing when tested to failure. The lack of webbing damage in this case raises the possibility that the stitched joint was significantly weaker than the webbing, because of the joint design, thread selection or degradation of the stitching.

3. PROPOSED TEST SCHEDULE

In general, the Standards for products such as webbing and the stitched joints, which are subject to wear and degradation with age, incorporate factors of safety in their specifications to allow for some reasonable degradation to occur during use. This results in a product with a reasonable life expectancy and makes discard criteria more obvious during a visual inspection.

It is therefore inappropriate to test a used product, such as these used lines, to the Standard test for new product and expect it to pass. An alternative test program needed to be developed to determine whether the used harnesses and lines were in a useable condition.

Australian Standard *AS2227 - Yachtsmen's Safety Harnesses and Lines* was first published in 1978 and has been revised 3 times, 1983, 1986 and 1992. In all 4 versions the webbing strength requirement has been a minimum 22 kN webbing, whilst the requirement for hooks and other "non-deteriorating" components has been 12 kN. Thus, on the basis of a system being only as strong as its weakest link, it would be reasonable to expect an in- service used harness or line to withstand a load of at least 12 kN.

It is also noted that no edition of *AS2227* includes any requirement or recommendation on the maximum service life, or shelf life of the harnesses and lines.

Based on the above principle and following discussions with the various people involved I prepared a document *Proposal for Static Line (lanyard) Testing* dated 5 July 1999, which included headings of:

a. Background
b. Summary of the Australian Standard Tests and Relevant Requirements for the Safety Line
c. Inspection and Comments
d. Proposed Testing
e. Other suggested Actions.

A copy of the proposal is included as Appendix 1.

The testing proposed included:

i. tensile testing of the stitch joints at each end of a used line,
ii. tensile testing of an unstitched length of the webbing from a used line,
iii. testing to determine the yarn in the used webbing and stitch thread; and, if appropriate,
iv. the manufacture and testing of “replica” lines in drop and tensile tests for comparison with the used results.

The pass criteria for the tests on the used lines was 12 kN .

This proposal was emailed to David Upston and RTA Crashlab for consideration and with some minor modifications was adopted as the test schedule.

I witnessed the testing performed by RTA Crashlab to this proposal on 19 July and 1 December 1999.

4. MANUFACTURE OF “REPLICA” LINES

After testing of the used lines was completed, I was asked to obtain a manufacturer prepared to manufacture “replica” lines for testing. David Upston from the Water Police supplied the hooks for the ends of these “replica” lines. A Company, SALA International Pty Ltd, agreed to manufacture “replica” lines to a specification, which I prepared and provided to them. The specification *Stitch Pattern for Sample Lanyards* is given in Appendix 2.

The thread grade was determined on the day of manufacture by a comparison between the available aramid (nylon) threads and the threads on one of the used lines. The thread appeared identical to a Metric 40, for both the main stitch box (red thread) and the bar tacks (yellow thread). The comment in the test proposal that the yellow thread appeared thicker than the red appears to have been an optical illusion.

On the day the samples were manufactured, the 16 mm bar tack machine was out of order and awaiting repair. The 25 mm bar tack machine was used. This produces a longer bar tack, but the number of stitches is the same so I accepted the change. With the number of stitches remaining the same there should be no significant change in the strength of the joint.

These “replica” samples were then tested by RTA Crashlab and are covered by their Report No’s SR2000/002 and SR99/007. I was given a copy of these reports, together with the earlier reports SR99/004 and SR99/006, in February 2000.

5. SUMMARY OF TEST RESULTS

Report No	Specimen Used/Replica	Test Drop/Tensile	Condition Wet/Dry	Peak Load (kN)	Result and Failure Location
SR99/004	Used line & harness	Drop	Wet	6.7	Fail. Stitch failure on line, harness ok but not fully loaded due to line failure.
SR99/006	Used line	Tensile	Dry	6.0	Fail. Stitch failure.
"	"	"	"	6.4	Fail. Stitch failure.
"	Used webbing	Tensile	Dry	16.6	Fail as new 22 kN webbing. Considered a PASS for used webbing as exceeded 12 kN required for hooks.
SR99/007	Replica line	Tensile	Dry	9.85	Fail. Stitch failure.
"	"	"	"	9.6	Fail. Stitch failure.
"	"	"	Wet	9.0	Fail. Stitch failure.
"	"	"	"	8.9	Fail. Stitch failure.
SR2000/ 002	Replica line	Drop	Dry	9.7	Fail. Stitch failure.
"	"	"	Wet	10.5	Fail. Stitch failure.
"	"	"	"	9.0	Fail. Hook failed. Stitching remained ok.
"	"	"	"	10.8	Fail. Both stitching and hook failed.

6. ADDITIONAL INFORMATION

During the progress of the testing the investigation continued and one of the items located by QAS was a test report from Technisearch Limited dated 16.5.84 concerning a drop test conducted in accordance with AS2227-1983 on a harness with a 1.8 m webbing line. This test report result stated:

> The stitching broke for a total of 80 mm length of webbing at the line attachment, but the remainder held.

This indicates that the product on that occasion only just passed the test and that even a minor change to the manufacturing process or materials, or due to in-service degradation would be significant and could result in the product failing the test.

7. COMMENTS

a) The lines recovered from the *Sword of Orion* crew were approx 1.5 m in length rather than the 1.8 m length sample tested by Technisearch Limited. This reduction in length results in a higher fall factor during the drop test, which produces a correspondingly higher peak load. The fall factor is the free fall distance divided by the line length and thus can range from zero for a suspended load, no fall, to 2 for a line pulled up tight prior to the load falling. In other words, the line has some energy absorbing properties, and the longer the line for a given fall distance the more energy will be absorbed, thus reducing the peak load. This is further explained in Appendix 3, an extract from the *1996 Petzl Catalogue* which explains the application of this principle in rock climbing. Petzl International is a major manufacturer of caving and climbing equipment.

b) A possible reason for the stitch joint failing with so little damage to the webbing is given in the Standard. The Standard specifies the webbing must be Class C22 or D22 to AS 1753, ie at least 22 kN breaking strength, whereas metal components need to only withstand 12 kN and the only strength requirement for the stitching is that it pass the drop test. As the drop test is unlikely to result in peak loads in excess of 12 kN there is no reason for a manufacturer to have the stitching stronger than necessary to pass the test.

c) The line and harness may be called upon to resist loads from a number of potential sources, essentially water pressure pushing the wearer, a fall should the vessel roll onto its side or impact from a moving object such as the boom. I can only provide comment on the likely forces involved in a fall.

   The force in the line as a result of a fall depends on a number of factors, essentially the falling mass, the distance fallen, the line material properties and the length of the line. For the materials normally used for industrial fall-arrest harnesses, synthetic fibre rope or webbing, a 4 m fall on a 2 m lanyard (ie a fall factor 2 test) with a 100 kg dummy generates peak loads of approx 15 kN. Similarly a 6 kN load can be generated by a 1 m fall on a 2 m lanyard (ie a fall factor of 0.5).

   As the line can be subjected to a fall factor of up to 2 in the event of the crew member being above the anchor during a roll over there is some question as to the validity of the test being less severe than the worst potential fall in use.

d) In the RTA Crashlab reports, reference is made to the load bearing stitch pattern being a “non-deteriorating” component and thus AS 2227 requires it to meet a tensile force of 12 kN. The stitching is not “non-deteriorating” as it is susceptible to degradation from ultraviolet light, internally damaged by fine salt crystals forming if dried without proper rinsing and general chafing during use.

e) In the RTA Crashlab reports on the “replica” lines reference is made to the bar tacks being longer in the “replica” lanyards and thus expected to give a greater load capacity. This is partially incorrect in that the bar tacks were longer by virtue of a larger distance between the stitches, but actually contained the same number of stitches. The resultant change in strength due to the longer bar tacks should therefore be negligible. The increased strength achieved is more likely to have been due to the materials being new rather than used.

f) The fact that the hooks failed in two of the tests on the “replica” lines is significant and of concern if these hooks are still being used on current lines, as they did not reach the required 12 kN. In relation to the used lines this adds further confusion as it could be that the longer 1.8 m line tested for compliance with AS 2227 in 1984 may have had enough stretch to keep the peak load below that at which the hooks fail. Alternatively, these hooks could be from a bad batch or a weaker hook from a different manufacturer and be of no relevance.

8. SUMMARY

a. The testing clearly proved that the used lines at the time of test were unable to withstand a force of 12 kN, whether applied as a shock load in a drop test, or a gentle pull in a tension test. Of the three tests performed the highest peak load was only 6.7 kN. The testing also showed that the stitching was the weak point in the lines.

b. The testing of the used lines and the new “replica” lines raises serious doubt as to whether the lines complied with AS 2227-1983 at the time of manufacture. The testing was however not conclusive proof that they did not comply.

c. The testing of the used harness recovered from the *Sword of Orion* is inconclusive, even though the harness remained intact after the test. As the line failed, the peak load that the harness was subjected to was significantly less than it would reach in a test where the line passed.

9. RECOMMENDATIONS

a. All Tuff Marine harnesses and lines, of the type tested, remaining in use be withdrawn from service.

b. The Australian Standard AS2227 be reviewed and the following points be considered in the review:

   i. The marking of the manufacture date and maximum life, or an expiry date, on the products.

   ii. Adding a requirement that all load bearing joints in lines, and at the line attachment point on the harness, whether stitched, glued, spliced or fused be capable of withstanding either the same load as the base material, or a specified load that includes a safety factor for reasonable in-service degradation. This should be confirmed by a test.

   iii. As the fall factor results in a higher peak load for a shorter line it may be appropriate to test the shortest line to be manufactured.

   iv. There is little point in simply calling for a stronger line, as there is a limit to the forces the body in the harness can withstand.

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APPENDICIES

Appendix 1

Proposal for Static Line (lanyard) Testing

1. Background

A used harness is to be tested as part of a Coronial Inquest into the 1998 Sydney to Hobart Yacht Race. A webbing safety line (lanyard) apparently failed on the Sword of Orion allowing the helmsman to be washed overboard. The testing is therefore to focus on another safety line taken from the yacht to investigate whether it was adequate for the purpose.

Australian Standard *AS2227 - Yachtsmen's Safety Harnesses and Lines* was first published in 1978 and has been revised 3 times, 1983, 1986 and 1992.

From information provided it appears that the harness and lanyard were manufactured approx 13 to 14 years ago with the intention of complying with the original 1978 Standard.

In general Standards for products such as webbing, which are subject to wear and degradation with age, incorporate factors of safety in their specifications to allow for some reasonable degradation to occur during the life of the product. This results in a product with a reasonable life and makes discard criteria more obvious.

It is therefore inappropriate to test a used product, of this type, to the Standard test and expect it to pass. An alternative test program needs to be developed to determine whether the harness and lanyard are in a serviceable condition at the commencement of testing.

2. Summary of Australian Standard Tests and Relevant Requirements for the Safety Line

1978

- Safety line no longer than 2m.
- Webbing to Class C22 or D22 to AS 1753 (i.e. $\geq$ 22 kN dry and wet breaking force) and not less than 40 mm wide.
- Thread, similar properties to the materials being sewn. May be rot treated natural fibre or may contain natural fibre.
- Load bearing components such as hooks shall withstand 12 kN without breaking or showing signs of flaws, defects or deterioration.
- Load test: Dynamic test, tested wet.

100 kg dummy 2m fall on 2 m lanyard or less. Amended in amendment 1 of August 1979 to include and alternative of a 136 to 147 kg dummy dropped 1.47m.

- Instructions include " The safety line and harness and line should frequently be inspected for signs of deterioration."

1983

Essentially identical to 1978. Main change was introduction of a children's harness and associated tests.

1986

Essentially identical to 1978, except:
- Safety line must be detachable at the wearer's end on adult harnesses.
- Allowed webbing that did not comply with AS 1753, so long as meets the dry break force test from AS 1753 for 22 kN.

1992
Essentially identical to 1986, except:
- Reference to natural thread no longer exists.

Summary: The webbing requirement has always been 22 kN webbing whilst the requirement for hooks and other "non-deteriorating" components has been 12 kN.

3. Inspection and Comments

On 30 June 1999 I inspected the remains of the safety line reported to have failed on the Sword of Orion, the safety line already tested to the current AS 2227 drop test and an undamaged specimen. Both safety lines had failed in a similar manner, total failure of the stitching and one end and partial failure at the other end with no significant damage to the webbing itself.

From visual inspection of the stitch pattern and the stitch thread on the safety lines the following comments are made:

- The harness and safety line appeared to be in excellent condition with no visual sign of significant damage or deterioration.
- There are two coloured threads used, yellow for three stitched "bars" and red for a large rectangle with diagonals.
- The red thread appears to be the same as that used elsewhere for attaching labels and to be thinner than the yellow thread.
- The lack of damage to the webbing of the failed samples is unusual. A stitched joint, other than if to attach labels or for other decorative purposes, would be expected to cause significant damage to the webbing during failure. This lack of webbing damage would suggest that either the stitching had weakened significantly or the stitch pattern was significantly weaker than the webbing.

4. Proposed Testing.

Test the safety line only.

<u>Test 1: Webbing and Stitch Joint Test.</u> (by RTA Crashlab)

Break test generally to AS 1753, conducted wet, but test with the safety line hook as one end and a webbing bollard as the other support. This includes the stitch joint in the test length, and allows the test to be repeated on the other end.
As all hooks, the structural anchor point and other "non deteriorating" items are to withstand 12 kN rather than the webbing load of 22 kN, reaching 12 kN without failure commencing would be deemed a pass.

Test 2: Webbing only Test. (by RTA Crashlab)

Break test generally to AS 1753 using the webbing from test 1. Again test wet. Purpose is to determine the strength of the webbing, and to compare with the joint strength. Again 12 kN would be considered a pass, although the webbing when new would be expected to achieve 22 kN.

As the webbing being tested in this test may have been damaged in the bollard in test 1 the result could be lower, but will give an indicative result for comparison.

Test 3: Material Properties. (by others as yet unknown)

Test the webbing and the 2 different stitch threads to determine the materials and denier. Of potential significance is the thread material for the presence of natural fibre, which is usually more susceptible to rot in a damp environment, or nylon, which is more susceptible to UV.

Test 4: (if deemed of value).

If sufficient information is provided from test 3 and similar materials are currently available then a replica safety line could be manufactured, and tested to give an indication of the as new performance.

5. Other suggested Actions.

Check for available information re the testing conducted on the harness and safety line for Standards Accreditation, especially whether there is any detail on the stitch thread or stitch pattern. This would be of use in comparing to the samples in hand. Even a photograph will help if no technical specification. This may be available from QAS or the test lab that conducted the testing.

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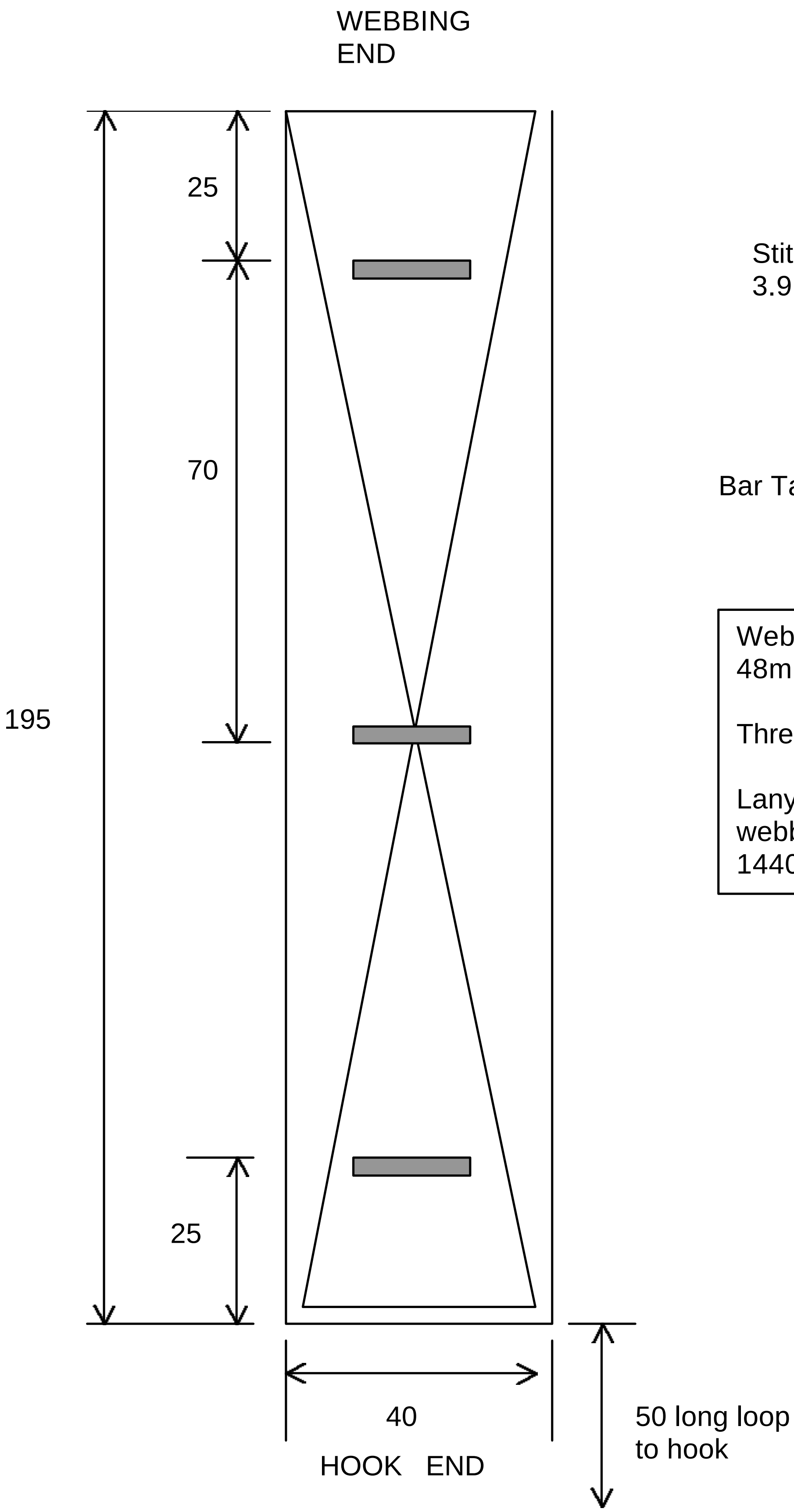
5 July 1999

Appendix 2



Stitching at approx
3.9mm/stitch

Bar Tack, 16mm long

Webbing: 22 kN polyester,
48mm wide.

Thread: Aramid.

Lanyard length between
webbing ends: approx
1440mm

Stitch Pattern for Sample Lanyards.
(NOT TO SCALE, all dimensions are mm, nominal)
Hooks to be supplied by Police.

Some basic truths, simple math and common sense

Okay, you're climbing, your rope and harness are secure, the anchor is bombproof, and you feel pretty safe. The thought of falling doesn't upset you. Everything's cool.

Maybe. But every fall creates an enormous amount of energy. We are, after all, relatively large creatures, and gravity is a formidable force - as any belayer who has caught a screamer can attest.

What's more, the shock load from the fall is transmitted all through your security system, and is nearly doubled at the anchor or pro on top. And every element in the chain has to sustain the shock without breaking if your fall is going to cause you nothing worse than scrapes and bruises.

Fall factor explained

A lot of climbers don't really understand the fall factor concept; however, it's pretty simple, even if you hated math (this is math you can use in later life. In fact, you can use it to have a later life).

Fall Factor is simply the length of the fall divided by the length of the rope from faller to belayer. The equation looks like this:

$$\text{fall factor} = \frac{\text{length of fall}}{\text{length of rope}}$$

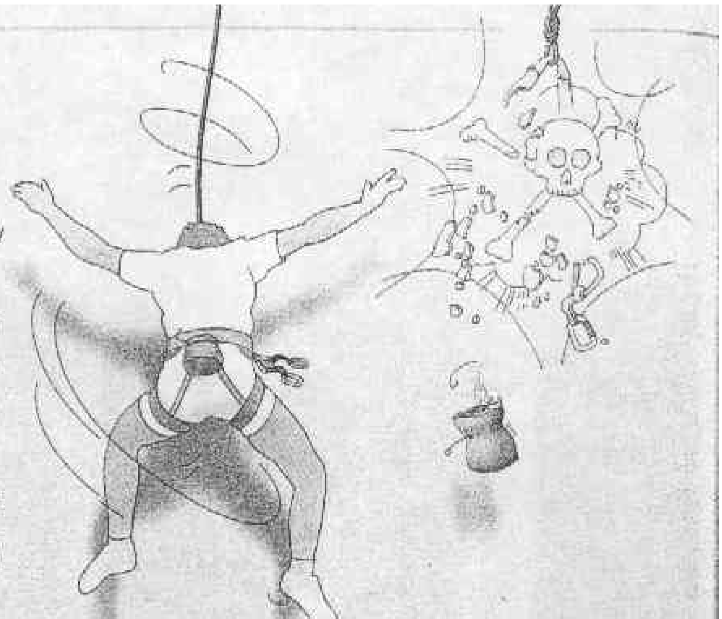
Fall Factor 2 is the maximum you should encounter in a typical climbing fall, since the height of a fall can't exceed two times the length of the rope. Normally, a Fall Factor 2 can only occur when a leader who has placed no protection falls past the belayer, or the anchor if it's a solo climb. As soon as protection is placed, the distance of the fall as a function of the rope length is lessened, and the Fall Factor drops below 2.

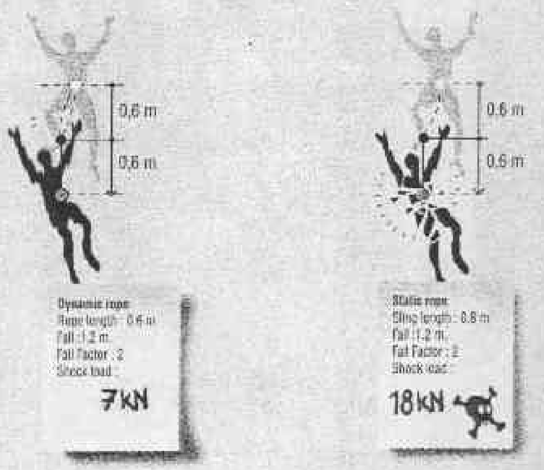
Your life depends on the stretch of the rope

Shock load is the result of three factors : the nature of the rope, the fall factor (we'll get to that in a minute), and the weight of the falling object. That is you.

Obviously, the only part of this equation that can reduce the force of any fall is the bungee-like stretch of the dynamic rope (unless, of course, you can lose weight real fast). Thus, climbing safety systems are designed around the shock-absorbing quality of dynamic rope. It cushions the fall, reduces the impact force and the chance of system failure. In fact, the dynamic rope is the one "given" in the whole system. It is designed to limit the force of one climber's weight (80 kg) in a worst-case fall (Fall Factor 2) to not more than 12 kN. The rest of the gear can be designed to work with this known maximum force.

More rope means more stretch to absorb a fall. Which explains why a Fall Factor 2 drop of four meters develops the same shock force - 9 kN - as one of 20 meters, assuming a dynamic rope is used that conforms to UIAA standards. What's happening is that the increasing length of the fall (and the greater shock force that goes with it) is compensated by the greater length of the rope available to absorb the shock load.





You don't get stretch from a static rope

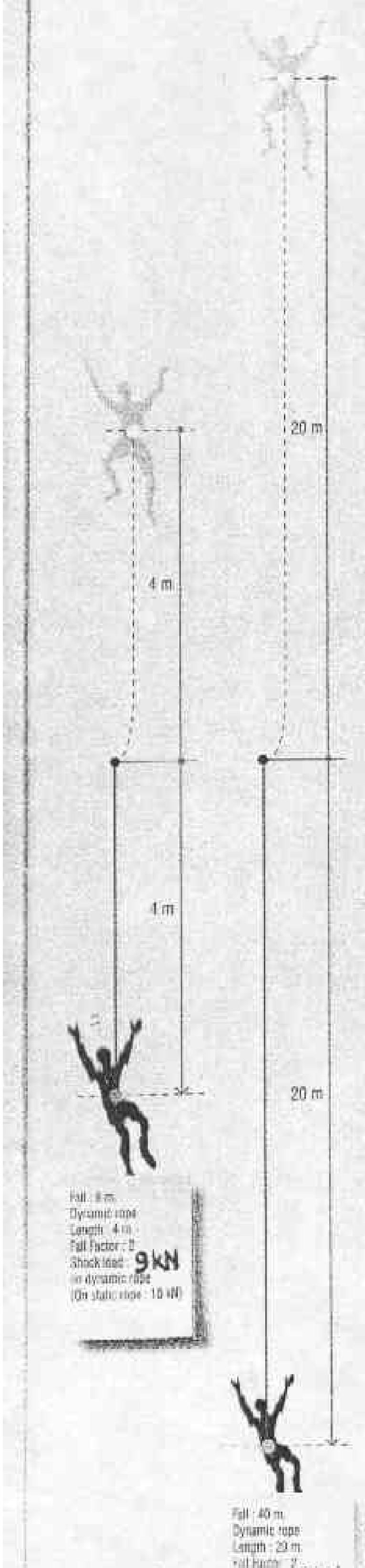
Static ropes - traditionally used mostly in caving and rescue but now also used for sport rappelling and even in climbing gyms - are designed to minimize stretch (cavers hate feeling like yo-yo's). So their ability to absorb shock is marginal, particularly along short lengths of rope. What's more, static ropes aren't as well-defined by industry codes as dynamic ropes, so they vary in elasticity according to the manufacturer and the country of origin. They're often about as non-dynamic as a cable, and transmit virtually all the shock load to the safety system and the body. And in a climbing situation, a very short fall can develop enough force to be critical.

Slings and runners are just like static rope

Used for security, without a dynamic rope, runners are just as dangerous as static rope. As the second diagram shows, a Fall Factor 2 develops enough shock load to risk failure of the runner, the harness or carabiners, not to mention a lot of failure in the climber's skeletal system.

This is worth saying again : a fall of less than four feet on a static rope or sling can create enough shock force to cause serious injury or death.

Bearing in mind that the human body can only handle, for a brief instant, a shock force of 12 kN without risking serious injury, you don't want to go around absorbing 18 kN. And, you should know that 18 kN is getting really close to, or over, the minimum limits set by the UIAA on all the gear in your safety system. Here they are, for purposes of comparison : anchors : 25 kN, carabiners : 20 kN, slings : 22 kN, harnesses: 15 kN.

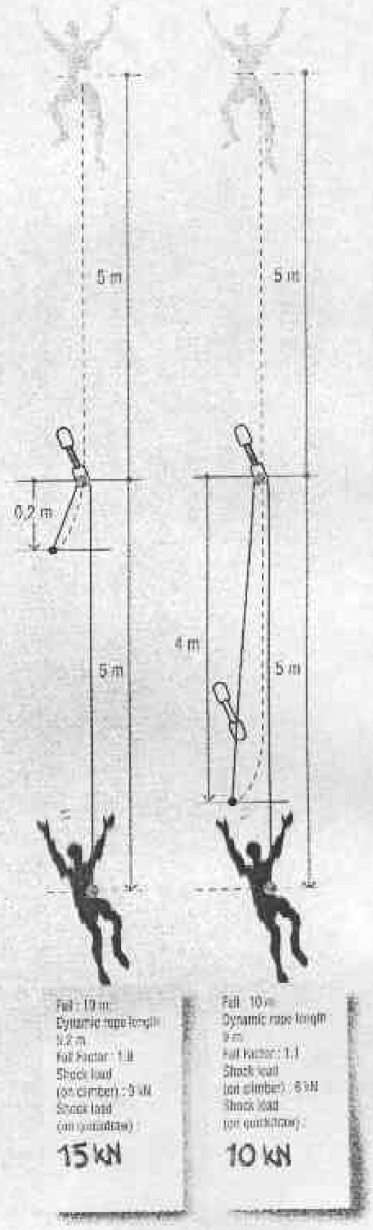


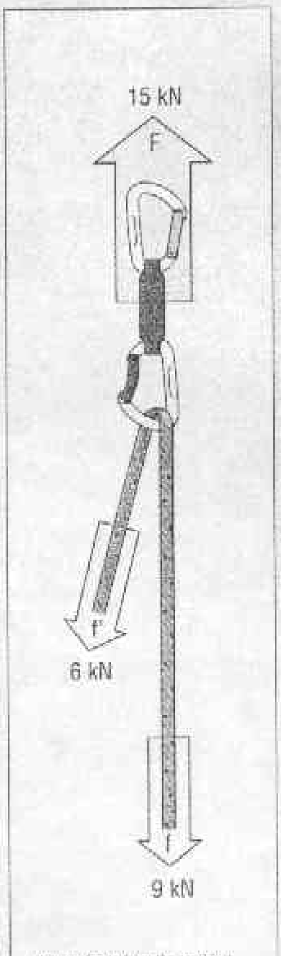
Meanwhile, up at the 'biner...

Physics isn't our friend in a fall. The same mechanical advantage we use in pulleys works against us when we're on the end of a rope. Because at the point where the rope returns, normally at the carabiner, the force of the fall is increased by approximately 66% (it would be doubled except for the friction of the rope against the metal).

So, starting with our 9 kN maximum shock force with a dynamic rope, the force on the carabiner becomes 15 kN in a Fall Factor 1,9 fall. That's a lot. You better hope it's a good anchor or placement.

Now apply that same math to a static rope. The Factor 1,9 fall, with its normal shock force of 18 kN, becomes a shock force of 30 kN (multiply 18 kN by 1.66). In this case, you couldn't even count on a stout tree. And it wouldn't matter if the anchor held, because something else would undoubtedly fail.





Return of rope from the carabiner toward the ground. On passing through the 'biner, the rope multiplies by nearly two the force applied to the anchor.

All the values given here are measured in laboratory testing with a 80 kg load and fixed rope.