READ THIS FIRST !

8/3/84.

Dear Roo –

Herewith a 'letter' that degenerated into a 'technical note'. But I'll try to tie it in to your last letter –

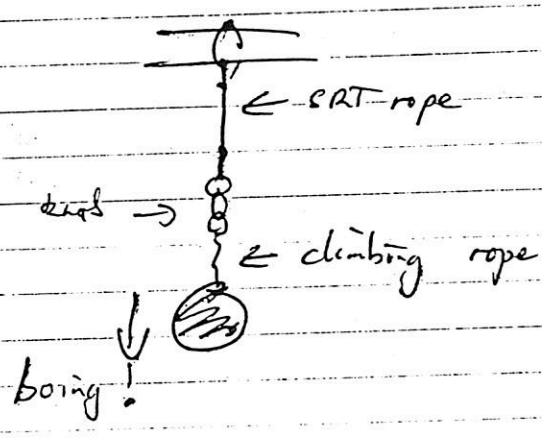
1) You say 'in dynamic FF1 [ts] tests, the rope will break when it reaches its static strength'. Not so. Calculation (avg!) see (P4) show the strain rates in FF tests are enormous – and these will greatly affect the failure stress. It could be that we are in a 'fast fracture', rather than 'tensile failure' mode.

2) Safety margins*. I feel that the 'softening' effects of belays and fleshy bodies will be the controlling factor here, and that a FF1 test with rigid attachments may be asking for a 'safety factor' of several 100x!, compared to the stresses, and the strain rates, applied to a rope when you really fall on it underground. I need more details of the Whernside tester! I shall write to Dave Elliot.

3) Rope Deterioration. This is worrying; there is no doubt that our old Marlow is a bit sick. It has been retired pending investigations.

I shall look further into this - meanwhile I'm off to cut up some PMI for use this w/e in Yorkshire (I'm not going though, shit alors).

All the best - meanwhile, use of dynamic constants is recommended - try it in a FF test, see how it changes things.



If you've any more info, esp. about testing methods, I'd much like to hear it. I shall look into 'materials science of ropes' - about which I bet there is f— all known.

Yours —

Steve

2/3/84

Dear Roc,

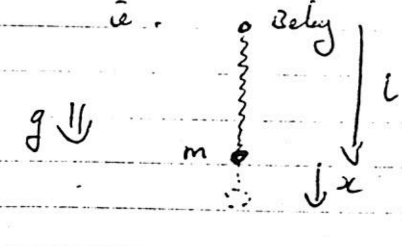
Thanks for your last letter, on ropes and all that. Apologies for the late reply; I immediately got to work on some theory of falls (see below), then stopped at a crucial point and "owing to pressure of other work" didn't get restarted. Also you probably can't read my writing.

I initially wrote a letter detailing the VASTLY COMPLEX maths of falling bodies attached to springy ropes. I shall leave that out - it's simply Simple Harmonic Motion anyhow. The

*** RESULTS *** are as follows.

1) Assumptions. (I'll come back to these later).
   a) Body is rigidly attached to rope. Rope is rigidly attached to rock or whatever.
   b) i) Rope length (unstretched) - l
      ii) Mass on end - m
      iii) Stretch with mass m - s (as fraction of l)
      iv) $x = 0$ when rope is length l, x positive downwards,

ie.



$x = sl$ when m is hanging on rope.

2) We then get:

$$x = A\sin(\omega t + \alpha) + B$$

$$v = \frac{dx}{dt} = \omega A\cos(\omega t + \alpha)$$

$$a = \frac{d^2x}{dt^2} = -\omega^2 A\sin(\omega t + \alpha)$$

$$= -\omega^2(x + B)$$

Where $A = l(2s\eta + s^2)^{\frac{1}{2}}$, ~~[struck out]~~ $B = sl$

where η = Fall Factor ~~m~~, $0 \leq \eta \leq 2$

MORE! ⟹

This gives :

Max stretch of rope $= A+B$
$= L\left[s + \sqrt{2\eta s + s^2}\right]$

Hence max **force** on rope $= mg\left[1 + \sqrt{2\eta/s + 1}\right]$

Thus the overload on the rope, compared to the "just dangling" situation is:

OVERLOAD	ROPE STRETCH (s) 1%	2%	5%	10%	50%	100%
FALL FACTOR (η) 2	21.0	15.2	10	7.4	4	3.2
1	15.1	11.0	7.4	5.6	3.2	2.7
0.5	11.0	7.4	5.6	4.3	2.7	2.4
0.2	7.4	5.6	4	3.2	2.3	2.1
0.1	5.6	4.3	3.2	2.1	2.2	2.1
0	2	2	2	2	2	2

These are also numerically equal to the max. acceleration, in 'g's, that the falling body will experience.

Points from this :

1) If you fall onto any unslack, but untensioned rope ($\eta = 0$) then you apply a force = double your weight when you bounce !

2) The less the stretch of the rope, the worse the consequences of a high η fall. Ie, one could over-load Marlow ($s \approx 2\%$) by a factor of up to 15 - but climbing rope ($s = 15\%$?) by about 6 (6g also

Steve Roberts' Rope Overload Tables

stretch	1%	2%	5%	10%	50%	100%
Fall factor						
2	21.0	15.2	10.0	7.4	4.0	3.2
1	15.1	11.0	7.4	5.6	3.2	2.7
0.5	11.0	7.4	5.6	4.3	2.7	2.4
0.2	7.4	5.6	4.0	3.2	2.3	2.1
0.1	5.6	4.3	3.2	2.1	2.2	2.1
0	2	2	2	2	2	2

This is a table of $(2xFF/stretch + 1)^{\frac{1}{2}}$ and is also equal to the maximum acceleration (in 'g') that the falling body will experience on stopping.

seem to be a good max. acceleration to expect the falling person to take!)

3) These ~~th~~ results are independent of the length of the rope.

– NOW –

All this is very ~~theo~~theoretical and ideal. What about:

1) Friction in the rope. This will tend to:
   a) Slow down the fall, reducing the overload.
   b) Heat up the rope – possibly lowering it's strength.

2) Elasticity of belays, etc. These will tend to reduce the Fall Factor. I <u>suspect</u> that for stiff ropes, and short falls, the elasticity of a 'soft' belay will dominate the situation – and the rope, however stiff, will not suffer. It is this that I am in the process of modelling. (Sometime).

3) Strength of rope --- This is an area in which I shall tread with caution. Strength of ropes depends on <u>strain rate</u>, temperature and environment. Ie, it's not just a question of how high the max. overload on the rope is – the ~~a~~ strength here will not ~~to~~ be simply the statically tested ~~t~~tensile strength, but will depend on the strain rate. Still sticking to the 'Rigid Belay' model, we get strain rate maxima as follows –

$$\left[\varepsilon = \sqrt{g/l}\left[\frac{1}{s} + \sqrt{2\eta + s} \right] \right]$$

2% stretch –

		Rope length (m)				
		1	5	10	50	100
EB η	2	164	116	53	28	16
	1	162	73	51	23	16
	0	158	71	50	22	16

15% stretch

η	2	27.5		8.7		2.7
	0.5	24.4		7.7		2.4
	0	22		7.0		2.2

Strain rates in rope lengths s^{-1}

These are enormous! Vast! Normal tensile testing strain rates are of the order $10^{-4} - 10^{-7}\ s^{-1}$. What relation the static strength of rope have to a fall now becomes less clear – the strain rates have put us into an explosive loading regime. EXCEPT

1) Flexible Belays again. These will considerably reduce the strain rate, esp. for stiff ropes, and short falls.

2) Rope friction. This will reduce strain rate too.

I shall program the old BEEB to simulate falls, putting in belays, friction et al, and see what comes out.

– Also, someone in Engineering, Cambridge, is doing rope testing as a Final Year Project. This needs a good going into!

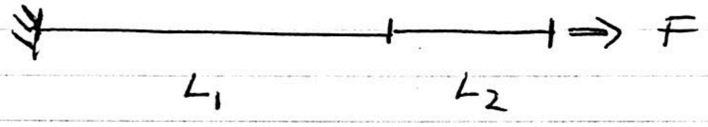
S. Cw [signature]

13/3/84

Ropes: Supplement #1.

Effects of Elastic Belays and Other Bits.

Suppose we have two bits of stretchy stuff attached in series:



The tensile force F acts on them both.

Let x_1 and x_2 be the extensions of the lengths L_1 and L_2. Hence;

$$x_1 = \lambda_1 L_1 F$$
$$x_2 = \lambda_2 L_2 F.$$

Let x be the total extension $(= x_1 + x_2)$
" L . . . . . . length $(= L_1 + L_2)$

then $x = [\lambda_1 L_1 + \lambda_2 L_2] F$

$$x = \left(\frac{\lambda_1 L_1 + \lambda_2 L_2}{L_1 + L_2}\right) [L_1 + L_2] F$$

ie. $X = \lambda L F$

where $\lambda = \dfrac{L_1\lambda_1 + L_2\lambda_2}{L_1 + L_2}$. , $L = L_1 + L_2$, $x = x_1 + x_2$.

So now we have the effective stretchiness for two bits of rope joined together.

Interesting cases

1) You fall onto 6 feet of SRT rope, attached to your harness. Aagh!
(L_1 --- etc = rope, L_2 --- etc = harness)
A few guesses. Even a tight harness is pretty stretchy.
say $\lambda_2 = 10\lambda_1$.
But its effective length is quite small, say 6".

This gives $\lambda \simeq 2\lambda_1$

So we feel as if we are falling on twice as stretchy a rope!

More to the point, $x_1 = x\left[1 + \frac{\lambda_2 L_2}{\lambda_1 L_1}\right]^{-1}$

$$= x\left[1 + \frac{10 \times 1/12}{1 \times 1}\right]^{-1}$$

$$\simeq x/2.$$

– Our nice SRT rope only gets stretched ½ as much.

2) ~~You~~ You are clipped into a short loop of rope by your cowstail at a changeover, and lob off. Shit alors!

Here, say $L_1 = L_2$, $\lambda_2 = 7\lambda_1$ (15% stretch cowstail, 2% stretch SRT rope)

$$\Rightarrow \lambda = 4\lambda_1$$

Boing! everything gets stretched & stressed only ¼ of what it would otherwise ...

3) You lob off the head of a pitch, ~~with~~ where SRT rope is belayed by tape. Luckily you are attached by your rack with 2 feet of SRT rope twixt you & the tape, which is 2 feet long. You are wearing your trusty harness.

Effectively, the harness is a continuation of the tape, making it, say, 6" longer. Say λ_2 (of tape) is $10 \times \lambda_1$ (of rope) (probably an under estimate).

$$\lambda = \frac{L_1\lambda_1 + L_2\lambda_2}{L_1 + L_2} = \frac{2 \cdot 1 + 2\frac{1}{2} \cdot 10}{4\frac{1}{2}}$$

$$= 6\lambda_1$$ Booioing!

Saved again!, by a factor of 6.

MORAL: Use stretchy cowstails & tape belays.

(I know this is an oversimplified model, but the results are interesting, no?)

(ish) Steve

MORE

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14/4/84.

Dear Roo:

Phil has passed on to me your 'how we tests ropes' letter ... interesting! Some points / questions:

1) Where does the rope usually break? I would guess that it would do so at the knots – but you say rope is long enough to avoid 'end effects' ..... ?

2) In which case, do ~~we~~ you use fig-8 knots or bowlines as standard?

3) If it does break at the knots, whereabouts in the knot does it break?

4) Re your point about the jammers – I think Dave Elliot, in the last Caves + Caving, said that jammers didn't break under shock loading to rope-breaking stresses – but stripped the rope! It's only under slow, static, loading that jammers unpeel at 400kg (so this 'rated strength' is in fact pretty meaningless unless you happen to weigh 63 stones)

5) Your point about 2-component ropes – I think that for the purposes of my (very simplistic) calculation, ~~then~~ the sheath can be neglected – it doesn't contribute much to the strength of the rope, or its elasticity.

I think ~~this~~ what Phil + I have to be very careful about is going overboard on the materials science of ropes – as you rightly say, what matters is whether cavers find themselves attached to thin air at inconvenient moments. With this in mind – I'm quite aware that the numbers I've produced don't necessarily mean much to a real situation in detail, but I think that they give rise to some interesting ideas + questions.

One thing that has occurred to me that could have a big effect on the properties of ropes, and what it feels like to fall on them, is the <u>damping</u> in the rope. I think one of Phil's missives has already mentioned this, as a property of the polymer fibre itself. However, what I think may be more important is the damping produced by fibres rubbing over one another during rope extension – here, the details of the rope weave will be very important. Larry 'Smoky' Caldwell (PMI man) told us all kinds of stuff (which I have almost completely forgotten) about how they tailor their ropes for different purposes principally by changing the weave of the core. This might be worth looking into.

One might expect that a 'bouncy' rope, with a 'loose' core would tend to have more damping than a 'hard' rope, with a nearly straight core. This would mean that a fall onto a supposedly stretchy rope might stop you a bit more abruptly than expected! However, the real importance of this is perhaps related to Bill Hawkswell's finding that after one fall, a rope's properties change dramatically in the direction of reduced flexibility and increased stiffness. This is probably due to the fibres in the core sliding over one another and 'locking'. If so, a rope that survives one or two FFI tests may not be the same rope anymore .... Maybe test ropes should be 'flexed' and 'unlocked' between tests ... I wonder what difference this would make to how many they survive?

See ya –

copy to PMS.

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Dr. Phil Sargent,
Microcircuit Eng. Group,
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-2 APR 1984

Dear Phil,

Thanks very much for the bumpf on the rope dynamics. I8ve found it very difficult to fully understand, but I can at least follow the arguements involved. When the implications of all this are clearer to me I shall send further comments. One part I'm not happy with is the strain rate. If the core of the rope and the sheath are separate, then doesn't this complicate matters further than Steve's equations would imply?

One other point - at the weekend we were discussing the actual breaking forces of the ropes. You pointed out that Marlow, although still only a FF1 fall, still broke at much higher forces than other SRT ropes. This is undoubtly true, but what matters to the caver is whether the rope breaks or not. At present, there is a trade-off between static nature and shock absorbtion in ropes, and I personnally would sacrifice some of the excellent prussiking characteristics of marlow, for a bouncier but safer one. At least then when I fall off some pitch top and my rope doesn't snap, I don't get a broken pelvis either.

Anyway I really wrote to give full details of the rig that we've been using. Inclosed is a schematic diagram of the tree, and below are the methods.

1) Attach sample to the grounded 80Kg weight.
2) Haul up the weigth and attach other end of sample to the chain.
3) Lower off the weight to tighten ~~other~~ up the knots. A couple of bounces insure that they are firm.
4) Raise up weight to the desired fall factor.
5) Release weight.

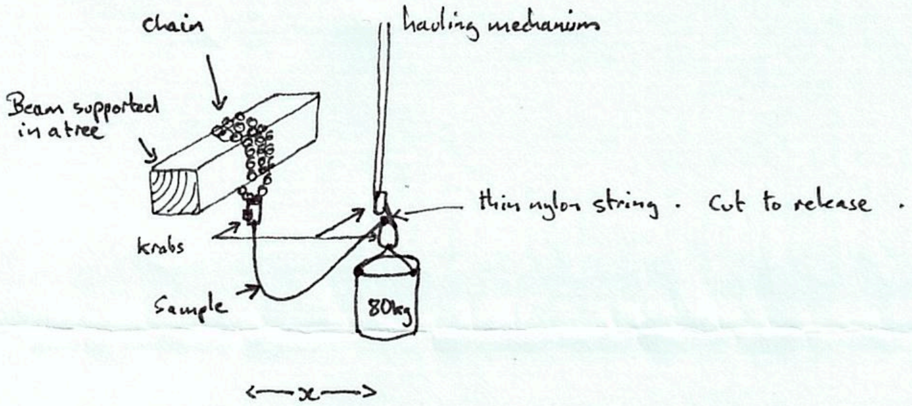
several points.

1) Allways test using the same knot at each end of the sample, unless testing relative knot strenghts.
2) Weight is attached by a thin nylon string which is cut to release the weight.
3) Sample length should be long enough to avoid 'end effects' (> 1m) and short enough to prevent the weight hitting the ground.
4) A rope is deemed safe if ~~xxxxxxxxxxxxxx~~ a sample taken from one end can survive two successive FF1s.
5) The forces that actually break the ropes, even ropes like Edlreid never mind Marlow, are probably ~~xxxxxx~~ far greater than the force at which petzl jammers break anyway.

One a complete different note, you mentioned, or hinted at a slight shortage of personnel for this summers CUCC expedition to Austria. I should liked to be considered for a place if that is at all possible. I beleive I could contribute a lot to work, having been to the Picos three times including Xitu in '81 with OUCC and York in '83 which I led. My reasons for being interested I admit are slightly parasitic, I've never been to Austria, and I have had the 'pleasure' of caving with CUCC before: Dissappointment Pot two summers ago. Gail should remember it 'cos she was completly knackered before,during an afterwards.

Thanks again for your letter and I'll be in touch,

Rog.



1) FF1 when knots are level.

2) Horizontal displacement "x" = 0.5m (Lessens FF)

3) Usual sample length ≃ 1.25m

4) Chain and crabs are steel. (Less dilution of FF).