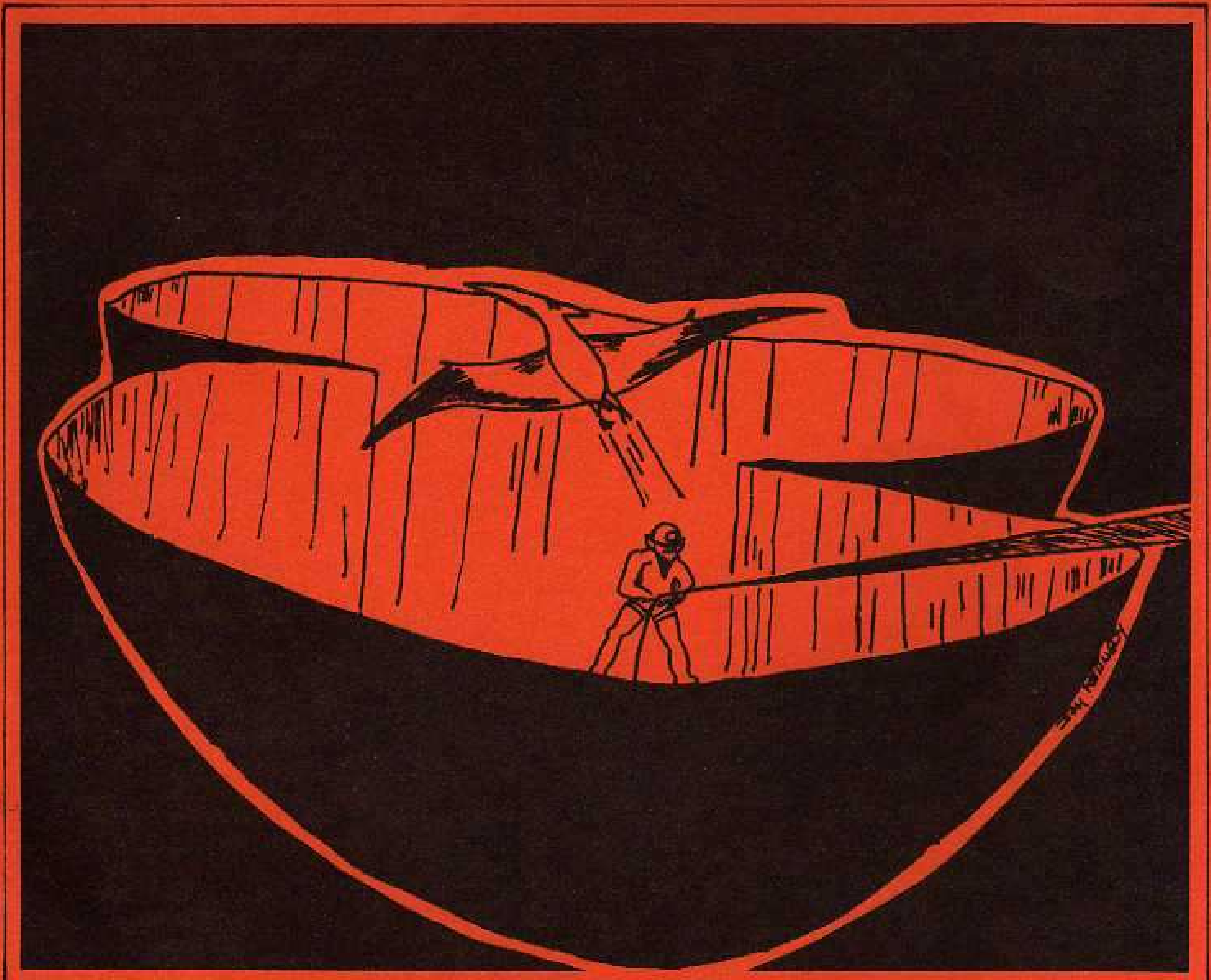
NYLON HIGHWAY 12

...especially for the vertical caver



Nylon Highway 12

NSS
Vertical
Section
June, 1980

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Officers

Kyle Isenhart - Chairman
Kirk MacGregor - Sec.-Treas.
Bill Cuddington
Allen Padgett
Richard Schreiber
Cheryl Jones - Editor

Cover

Cover art by Jay Kennedy, VPI Student Grotto, Blacksburg, VA.

DEADLINE FOR NYLON HIGHWAY #13 is a couple weeks before publication. Articles need to be typed double spaced, if at all possible, and illustrations, graphs, etc. inked, ready for final copy. One need not be a Vertical Section member to contribute. Letters to the Editor, cartoons and cover art welcome.

NYLON HIGHWAY is published by the NSS Vertical Section, and available to nonmembers for $3 per year. Grottos may receive issues for the cost of postage; $1 deposit required. Receipt of copies of articles appearing in the organization's publication concerning vertical techniques, equipment, etc., which may be considered for reprinting in the NH will be considered an exchange for one issue of the NH. Overseas subscriptions are $4 ($6 airmail) a year. Frequency of publication is based on the availability of material.

OPINIONS EXPRESSED herein are credited to the author and do not necessarily agree with those of the Vertical Section or its Executive Committee. Unsigned material may be attributed to the Editor. Reprinted material must give credit to the author and source to prevent an unhealthy curse from descending upon your evil publication. Correspondence should be addressed to the Editor.

Reverberations

From The Editor

Well, you're looking at the only issue of the HIGHWAY for 1979-80. Until recently, I had serious doubts as to whether this issue would even appear. Everyone wants the N.H., but very few ever do anything to insure its publication.

The HIGHWAY is supposed to be a major contribution to caving by the Vertical Section; but what have section members (especially most Executive Committee members) done to see that articles and art are contributed? I've never had an article on, or even results of, the annual vertical contests submitted for publication, nor an article condensing the vertical session papers so that those not attending convention may benefit from the information. Both of these have been requested from Executive Committee members on several occasions. The article by our current Chairman had to be requested several times since convention. Even the minutes were only received in May. (For what they're worth! The minutes as published are the ONLY records we have of actions taken by the Vertical Section, by-laws passed, constitutional changes, etc. The 1979 minutes don't even spell out the specific motions or constitutional changes on which votes were taken. As far as the future is concerned, most of the meeting was a waste of members' time.)

The only way I can see the N.H. surviving is if the V.S. members begin contributing or drumming up articles, and if they begin to use their vote to elect responsible and enthusiastic people to the Executive Committee. What we have now is simply a popularity contest. Section members aren't even allowed to question or speak out for or against nominees.

Yes, I'm fed up! And as of convention, 1980, I am resigning as Editor. I'm tired of beating my head against the proverbial wall to obtain articles, make positive changes within the section, and obtain support from Executive Committee members and officers. (Thanks, Kirk, for your continued support.)

Good luck to the next Editor. Perhaps these comments will do their job to grate a few nerves with some positive results. But then, perhaps nothing will be altered after all. Indifference is a disease difficult to cure.

Cheryl

$ $ $ $

Money for testing grants is still available to individuals or groups wishing to do research on various pieces of equipment used in vertical caving. For further information, see NH #10 or write to Kirk MacGregor, 78 King High Ave, Downsview, Ontario, Canada M3H 3B1.

Mitchell Rig Modifications

*Gary Moss

The addition discussed in this article, though not new, is worth repeating because its simplicity and resulting improvement of the safety of this popular rig.

The modification involves the addition of a sling from the top Jumar to the seat harness. This sling should be of such a length that it will pull tight when the climber makes the largest step he is likely to make with his top Jumar. This addition allows the climber to be continuously attached by his seat harness to the standing line. This continuous attachment has several advantages:

1) Easy to rest in seat. All the climber has to do is take a large step with his top Jumar and sit down.
2) If the climber is hit by a falling rock, he will slump onto his seat harness rather than slumping into a heap on his heels.
3) If the climber's box system fails, he will fall into his seat harness and will not invert and place large loads on his ankles. It should be noted that without the box system, this rig converts into the old plummer climbing rig. As a result, the climbing box is no longer a critical component.
4) The sling going through the climbing box gets a lot of wear when climbing. If this sling breaks, as has happened before, the climber is left with only one point of contact. But if the climber is thumbing his bottom Jumar cam open, as many do for the first 30 feet, the climber will now fall. This very type of fall occurred at the Texas vertical contest.
   If a sling from the seat to the top Jumar, not the bottom Jumar, were attached, this type of fall could be prevented.

This small addition greatly improves the safety of this very popular rig. Let me also add that the Mitchell or any two point rig, an extra point of attachment (a Prusik, Jumar, Gibbs, etc.) is critical to the safety of these systems.

* * *

Long Ones Washed Easy!

*Kathy Williams

Feed all of your 600' rope into one standard-size ice chest and fill it with water. Place the rope washer on the rope spraying toward the rope-filled ice chest. Pull an arm's length of rope back and forth through the rope washer about three times (depending on the filth factor of the rope) and then feed it into another standard-sized ice chest. The rope never touches a dirty surface. Once you have pulled the entire rope through, set up a ladder in a shady corner of your garage and bring over the ice chest filled with clean rope. Place a wad of rope on the lowest step and on each successive step upwards. The rope will be dry in about three days, and will not be tangled.

Floating Knee Rig Improvements

*Gary Moss

In most standard shoulder Gibbs climbing rigs, the floating knee cam has almost become standard. Generally the shock cord that springs the knee cam loose and up the rope is run in some manner to the shoulder cam assembly. There is one main drawback to attaching the shock cord to the shoulder cam assembly. WHen the climber slips out of his shoulder cam to go up a slope or over a lip, the shock cord looses its tension, and will not automatically slide the Gibbs up the rope as intended. This means that the climber muxt pull the shock cord tight, thus using one of his arms at a time when he would probably rather use both to get over the problem area.

For several years, I have put the shock cord over the shoulder opposite the shoulder cam and attached the shock cord to the waist strap area of my seat harness. By doing this, my knee cam is now independent of what I do with my shoulder cam assembly. As an extra benefit, I find that my shoulder cam assembly a little more manageable without the spring loading of the shock cord.

The second change is one I stole from Kyle Isenhart some years ago* and is by far the more important of the two modifications. This addition consists of running a sling through the eye of the floating cam and clipping the other end into the seat carabiner. This sling should just pull tight when the climber stands up. This extra sling has three very good benefits.

1) This addition helps a great deal when going over breakovers. It is a simple manner to reach down to the seat harness and grab the sling and pull the floating cam over a lip. If left alone, the seat will automatically pull the cam up.
2) The sling allows a good measure of safety if the elastic cord were to fail. Rather than the knee cam falling to the foot cam, the cam stays in place. Then by pulling the extra sling, the climber can make the knee cam function properly; a nice extra if the climber is in a tight spot or a waterfall, and does not want to stop for repairs.
3) The best advantage is the extra protection it gives by having an extra seat attachment. If the shoulder cam system were to fail, this sling to the knee cam would keep the climber from inverting.

Using both of these small modification to my floating knee cam, I have improved both the safety and function of my shoulder Gibbs rig.

* This method was originaly demonstrated by Charlie Gibbs at the 1971 NSS Convention.

Splicing Kernmantle Rope

*D. W. Tomer

This discussion of splicing is part two of my previous article on a machine for climbing practice. The four loops I have spliced by the method to be described have held up under many hours of use. The splices are approximately the same diameter as the original rope, but they are always stiffer and not so wear resistant as the original rope. The splicing requires carefull work and is an all day job. Try it first on one of the smaller diameter climbing ropes having a soft pliable feel. Until you are experienced, stay away from husky PMI ropes; they are so round, so firm, so fully packed.

The method consists of unbraiding the sheath to expose equal lengths of core at each end of the rope. The cores are overlapped and strands from opposite ends are tied together one pair at a time. The knots make little lumps, but by offsetting them from each other, the bulk does not accumulate in one spot. The sheath strands are tied the same way and then the spliced section is finished by wrapping it with cord.

SPLICING AID

Make a splicing frame on a 1X4X16 inch board (see Figure One). Draw a line one inch from the front edge and drill a row of holes (5/64 inch or 2 mm) along it, spaced one fourch inch on centers. Make as many holes as there are strands in the core or sheath. About four inches in from the ends of the board, and in line with the holes, drive in staples of the kind electricians use to fasten cable to building frames. Leave about a sixteenth of an inch space under them so you can slip the band of a small hose clamp under. Near each corner of the board at the back edge, put in a screw eye. Link together a chain of rubber bands, run it along the back of the board, through the eyes and tie a clothes pin to each end. Push a round tooth pick into each of the drilled holes.

PREPARING THE ROPE

Dip the rope ends two inches deep into hot melted paraffin for ten seconds. This controls fraying. Cut the cauterized tips off the ends and unbraid the sheath strands until two inches of core is exposed. Put a rubber band around the core tip and re-dip it in the paraffin getting plenty on so all the strands are solidly stuck together. Also re-dip each of the sheath strands separately, getting enough on to make a one inch rigid tip. Continue unbraiding the sheath strands until you have a good solid eight inches of core exposed. This task will try your perseverance, so fortify your patience with soothing background music. Hanging the rope up by the core tip will speed this job. When both ends are ready, lay the rope out full length on the ground to make sure there are no knots and to get the twists out. If you accidentally splice up a loop with a knot in it, that is grounds for suicide.

TYING THE STRANDS

Put the rope ends through the hose clamps on the frame. Tighten the clamps with the cores overlapping completely and the ends of the still braided parts of the sheath near the first toothpicks. (Refer to Figure One.) Select one strand from each core end, bread them loose from the mass of paraffin and tie them together with a square knot around one of the toothpicks. (See Figure Two) Clip a clothes pin to each of the loose end strands so the tension of the rubber will keep the knot tight. Pull

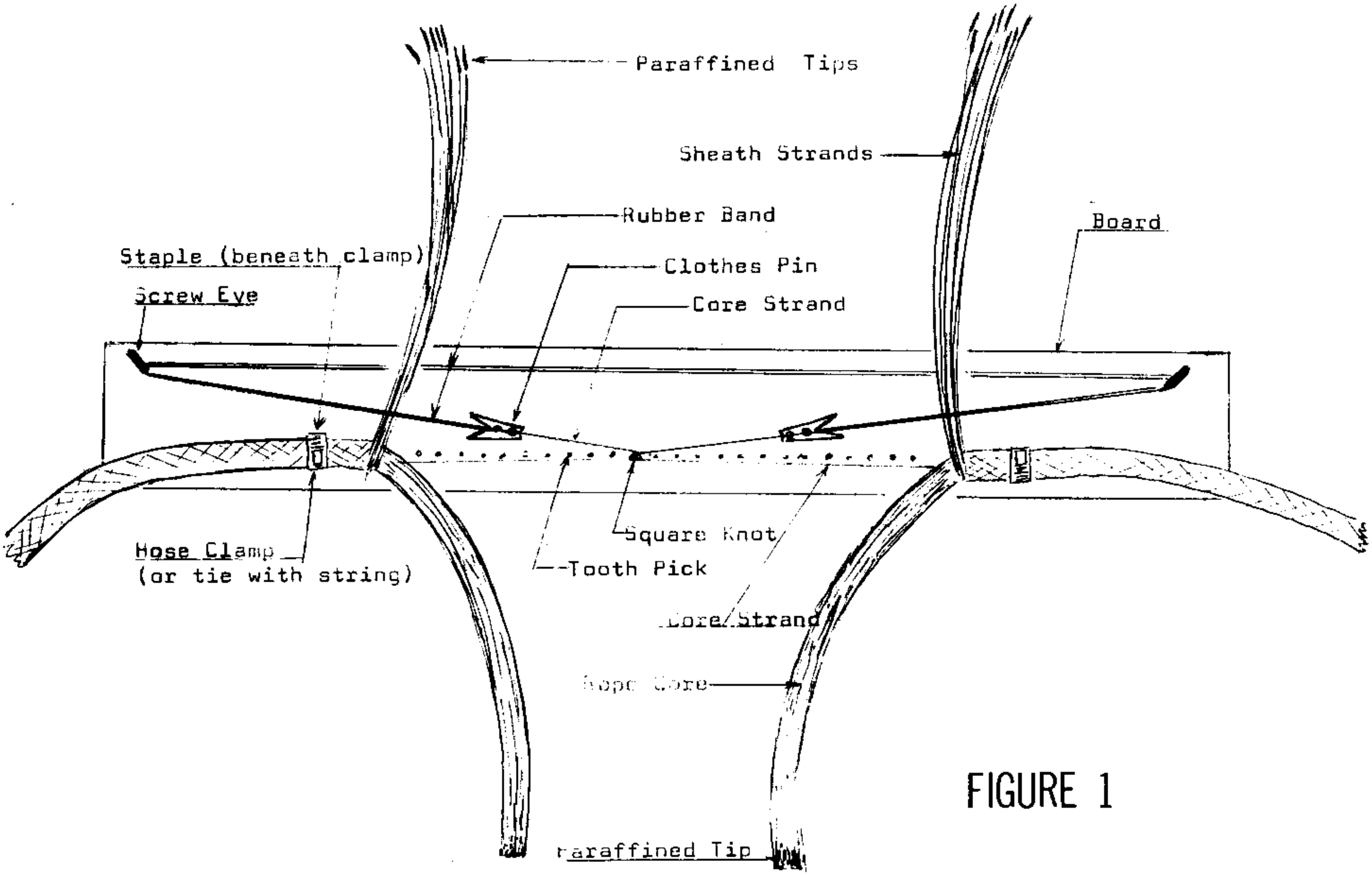

Paraffined Tips
Sheath Strands
Rubber Band
Board
Staple (beneath clamp)
Clothes Pin
Screw Eye
Core Strand
Hose Clamp
(or tie with string)
Square Knot
Tooth Pick
Core Strand
Rope Core
Paraffined Tip

FIGURE 1

out the toothpick and set it aside. Get good finger grips on the strands at the sides of the knot and pull hard to set the knot as small as possible. With the rubber band still pulling, apply super glue (cyanoacrylic) to the free end strands where they come out of the knot. This takes the "un" out of the unreliable square knot. Super glue sets up fast only in thin layers, so leave the tension on the tied knot while you select and tie a second pair of strands around another toothpick. Back to the first knot, clip its free strands off close, and move the clothes pins to the second knot. Continue until all core strands are tied. Try to keep them all the same length. Splicing the sheath is a repetition of the core strand tying proceedure. Put the toothpicks back in their holes and begin again. Unless you can unbreak and egg, don't try to rebraid the sheath strands. They take up less volume running parallel to the rope and this is helpful in keeping the splice diameter under control.

WRAPPING THE SPLICE

Having finished the tying, you will be underwhelmed by the neat professional appearance of the splice so far. It is a bulky, mixed-up, mess that will snag Jumar teeth and bits of windblown trash. So you wrap it tightly with strong cord to compress and protect it just like the old-time sailors did their rigging splices. For the wrapping, I have never used anything but carpet warp, which is a strand of untwisted fibers obtainable from carpet mills in the form of tag-end discards. Carpet warp is ideal since the fibers tend to spread out, giving a flat, smooth surface. Test the finished splice by trying to slide a Jumar over it. Tension on the rope will cause the splice to slim down a little. If there are oversize spots, try compressing them with a tighter wrap. I there are only one or two spots that are over bulky, you can surgically remove the offending knots with only a small sacrifice in rope strength. Finally, saturate the splice with Weldwood spray glue and install it ready to climb. If you fail to get a splice a Jumar will pass, all is not lost. It just means you will get good practice every fifty feet unsnapping your Jumars and putting them back on the rope above the splice.

TESTS

How strong is the splice? I refuse to sacrifice such a hard-to-come-by result by destructive testing. One test that completely satisfies me is hanging a fifty pound weight on a single rope strand patched with a glued square knot. They never show the slightest sign of strain. Most caving ropes have forty strands counting sheath and core. 40 X 50 lbs. = 2000 lbs.

ALTERNATE METHODS

Now that you have learned the hard way to do it, think about this easier, but untested way. The idea is glueing the strands instead of tying. With this method, there is little, if any, increase in bulk, so all the joints could be made in one spot, obviating the necessity of stripping back so much sheath to stagger the placement of the knots. First, flatten and spread the tips of the strands to be joined. Overlap them a quarter inch with two drops of super glue between. Immediately squeeze this joint with a pair of pliers. (Cellophane tape over the jaws first, if you expect to be able to get the pliers off the joint.) Hold the pressure a bit, then let it sit over night. The two such joints I have tested easily passed the fifty pound test. Only time will tell if a splice made this way will stand up under long useage.

Go to extremes, and where do you get? Possibly to the graveyard if you are not cautious. Here is a third idea to be cautious with: Wrap the cauterized ends of a new rope with masking tape, leaving an eightth of an inch sticking out. Gently heat the ends with a heat lamp until you get a melted mass of nylon an eighth inch deep. Let it harden and fine grind the hard ends till they are flat, smooth and at right angles to the length of the rope. Rig up a clamp that will hold these ends joined tightly together like a continuous rope. Separate the ends a crack and squeeze in a generous supply of super glue. Re-clamp tightly over night. Have every member

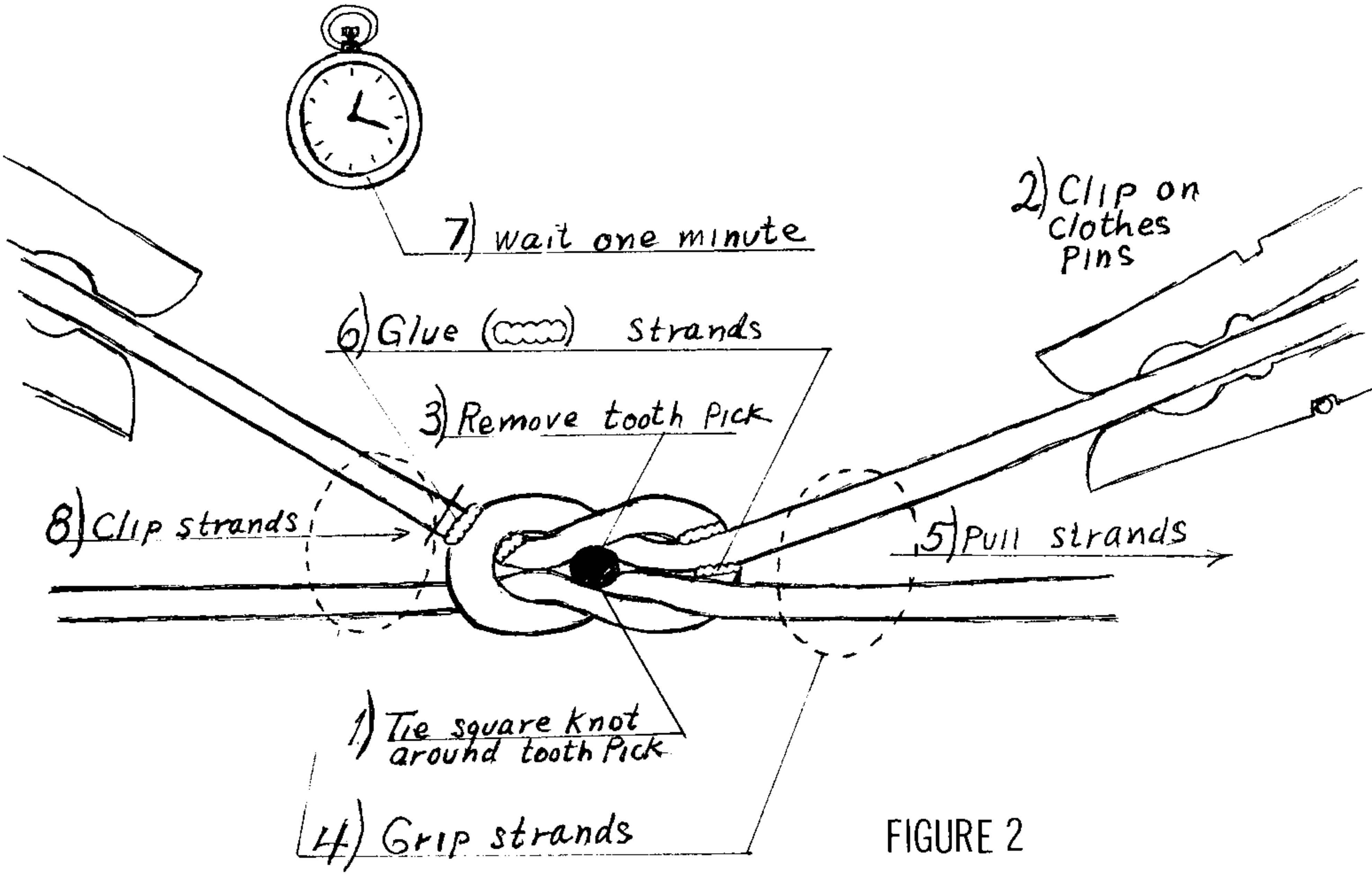

7) wait one minute
2) Clip on clothes Pins
6) Glue (ᴖᴖᴖᴖ) strands
3) Remove tooth Pick
8) Clip strands
5) Pull strands
1) Tie square knot around tooth Pick
4) Grip strands

FIGURE 2

of your grotto guess at the breaking strength of the "splice". This experiment suggests two others: (1) When the two ends are melted under the heat lamp, would they weld together if quickly joined and held until cool? (2) Is there a glue especially made for nylon that is as strong as nylon? Either of these two questions could lead to a practical five-minute rope splicing method.

An opinion I don't like to hear: "It won't work".
Three words I like to hear: "Let's try it". (cautiously)

* * *

TREASURER'S REPORT

NSS VERTICAL SECTION

AUGUST 6, 1979

INCOME:

Membership	$359.00
Subscriptions	243.00
Back Issues	169.05
Advertisements	32.00
TOTAL	$803.05

EXPENSES:

Postage		$265.52
Photocopy		1.00
NYLON HIGHWAY supplies		109.70
Advertisements		18.30
Printing		395.83
Dues reminders	$ 25.00	
NH #10	116.40	
NH #11	254.43	
TOTAL		$790.35

AMOUNT FORWARDED	$ 12.70
AMOUNT CARRIED OVER (78-79)	638.59
*TOTAL IN TREASURY	651.29

Members	125
New	47
Renew	78
Subscribers	74

Cheryl
8-6-79

Minutes: 1979

Kirk MacGregor called the meeting to order. Additional board members present were Bill Cuddington and Richard Schreiber. Kirk read a written report from Treasurer and Editor Cheryl Jones. In addition to the treasurer's report, she offered back issues of NYLON HIGHWAY for $2 each (#1, 5, 8, 9, 10, 11 avail.) She also requested articles for publication. (See attached Treasurer's report)

A question seet as to issues was distributed to those present.

A general discussion about postal nonprofit status was held.

The Section chair reported on testing grants -- none issued, none requested.

A proposed constitutional ammendment was read. A synopsis was given by MacGregor. Discussion and comments from Isenhart, Cuddington and Beach. There was a motion to ammend the ammendment to delete Editor. Vote 28 Yes, 2 No. Each section of the ammendment was voted on. Unanimous on each issue.

Vote to go back to 5 person board. Passed unanimous.

A motion concerning voting proceedures was discussed,passed 28 Yes, 2 No.

The question of being a member to stay on board passed unanimous.

There was then some confusing discussion on bylaws as to who takes what jobs. A request was made to send for Bill Mixon to sort out the mess.

A motion was made to first elect sec-treas., and second elect 4 other board members at large. Also allowing loosers to re-run. Passed 20 Yes, 2 No.

The motion was made that the board as elected shall select from 4 members at large a chairman. Passed Unanimous.

Discussion was held and motions made on the duties of the Sec-Treas. These included: correspondence, keeping membership list up to date, handling section's money, Treasurer's report, minutes of meeting, annual Internal Organization reports. Passed unanimously.

The policy of offering testing grants was extended for another year by unanimous vote.

There was discussion addressing the problem of cash flow between Editor and Sec-Treas.

After Discussion it was felt the intent of the section that the board investigate methods of savings in mail rates for NYLON HIGHWAY. Also investigation of using a savings account.

Elections were held.

Editor: by acclimation, Cheryl Jones
Sec-Tres: by acclimation, Kirk MacGregor
At large board members by ballot: Kyle Isenhart, Richard Schreiber, Bill Cuddington, Allen Padgett

The meeting was adjourned.

Submitted by Allen Padgett
acting for Foxy Ferguson

Rigging the Tyrolean Traverse

*J. A. Jones & K. Isenhart

I. Background

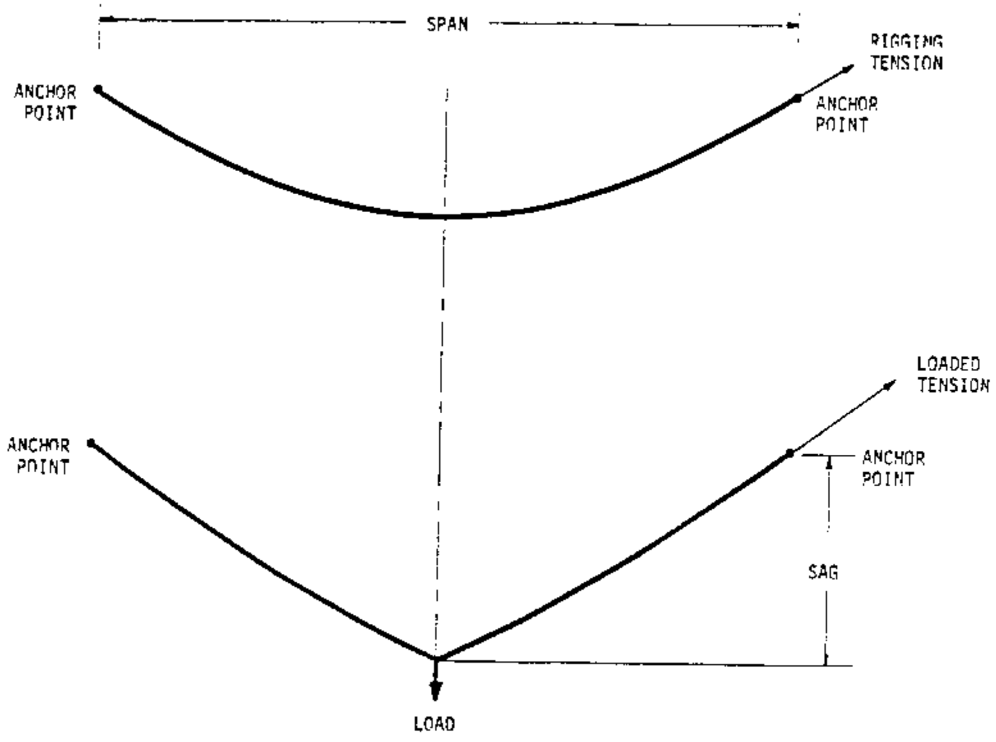
The Tyrolean traverse is a rope-rigging technique used by climbers to cross canyons or wide crevasses, particularly during search and rescue operations. Such a rigging typically involves the stretching of a rope or cable from an anchor point on one side of the abyss to a second anchor point at essentially the same elevation on the opposite side (see Figure 1, page 2). In doing this, the climber usually applies tension to the free end of the rope by means of a block-and-tackle until: 1) he feels that the sag in the unloaded rope is not excessive and will probably not become so when the load is applied; or 2) he estimates or measures a tension in the unloaded rope which he believes is sufficient. The climber then ties off the free end of the rope, attaches himself to the rope by means of a pulley, and steps off the ledge into space. If his estimations have been correct, the climber traverses the abyss horizontally, suspended in the air like a spider on its web. If not, the tension in the rope from which he hangs almost immediately skyrockets past the maximum safe working tension and the rope snaps--an event which the climber may or may not survive.

Obviously, it would be far safer for the climber if he could somehow predict the final tension in the loaded rope <u>before</u> he placed his weight on it. In response to this need, several people have devised mathematical techniques for modeling the loaded Tyrolean traverse. These models are typically based upon the laws of trigonometry and for the sake of simplicity contain the assumption that the rope is stretched <u>in a straight line</u> from each anchor point to the suspended load. Using this technique, one can estimate the tension in the loaded rope, given: 1) the weight of the load, 2) the width of the span across which the traverse is to be rigged, and 3) the vertical distance the load will sag below the anchor points.

There are two shortcomings inherent in a mathematical model of this type. First, the simplifying assumption that a free-hanging rope can be represented by a straight line immediately removes the model from the realm of the real world. As most people realize, flexible cables, wires, and ropes sag quite noticeably between their points of suspension due to the action of the earth's gravity. And as climbers who rig rope certainly know, the amount of sag in a suspended rope or cable depends upon the weight of the rope, its elasticity, and the tension placed upon its ends. As the weight or the elasticity of the rope increases, the sag also increases; whereas, as the tension on the ends of the rope increases, the sag decreases. Obviously, there are only two hypothetical situations in which a rope would extend horizontally in a straight line: 1) the rope is weightless, or 2) the rope is totally inelastic and the applied tension is infinitely great. Both of these conditions are physically unattainable on earth.

The second and perhaps more significant shortcoming of the type of mathematical model outlined above is that it is not really predictive at all. Even though one may know the exact weight of the load and the precise horizontal distance between the anchor points, since one cannot say beforehand how much the suspended load will sag beneath the elevation of the anchor points, one cannot obtain a meaningful estimate of the tension in the loaded rope.

Figure 1--Schematic diagram of a Tyrolean traverse, showing its configuration before and after a load is placed at its center



II. Our Approach

From the foregoing discussion, it is apparent that the climber is still in need of a predictive technique, based upon a mathematical model which reflects physical reality. Such a technique must enable the climber to rig the unloaded Tyrolean traverse with the proper rope tension, so that when he applies a known load, the final rope tension will not exceed a certain expected value. Furthermore, the technique must utilize data such as the horizontal distance between the anchor points, the weight of the rope per unit length, and the tensile properties of the rope. We feel that our technique does just this.

Our solution is based on the fact that a flexible cable of uniform weight per unit length which is supported by its ends hangs in a curve called a catenary. This curve is defined mathematically as follows:

$$y = a[\cosh(x/a) - 1]$$ [1]

where a is a constant and cosh is the hyperbolic cosine, which is defined as follows:

$$\cosh(n) \equiv 1/2\ (e^{n} + e^{-n})$$

In general, the larger the value of a, the "flatter" the catenary.

When a rope or cable is represented by a catenary, there are four parameters of interest: x, y, s, and T/w. These parameters are illustrated in the figure on page 4. In this figure, x is the horizontal coordinate of point P; y is the vertical coordinate of point P; s is the length of the rope or cable from point O to point P; T is the tension in the rope or cable at point P; and w is the weight of the rope or cable per unit length.

If any two of the four key parameters are known, the remaining two can be calculated. For example, if a climber had a perfectly inelastic rope of known length and weight, then when he rigged it, he would know precisely the values of s and w. Furthermore, when he applied a known tension T to the end of the rope, he could calculate exactly the half-span distance x, the vertical sag in the rope y, and for that matter the value of a, as follows:

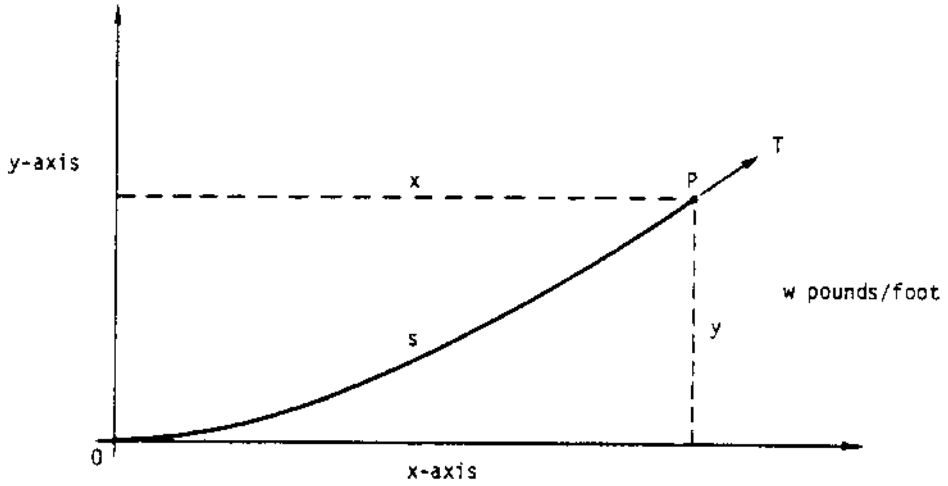
$$x = T/w\sqrt{1 - (ws/T)^2}\ \tanh^{-1}(ws/T)$$ [1]

$$y = T/w - T/w\sqrt{1 - (ws/T)^2}$$ [1]

$$a = T/w\sqrt{1 - (ws/T)^2}$$ [1]

Of course, other trigonometric information, such as the angle the rope makes with respect to the vertical or the horizontal at the anchor point, could then be derived as desired.

Figure 2--Key parameters of a catenary



Two obstacles prevent one from using the catenary equations directly to solve the problem of the Tyrolean traverse. First, no rope or cable is perfectly inelastic. Obviously, at a given tension, steel cable stretches much less than does Nylon rope; but even steel cable stretches measurably under tension. Consequently, one is faced with the following situation: the tension necessary to suspend a rope or cable depends in part upon its weight per unit length and the weight per unit length depends upon how much the rope stretches under the prevailing tension. Thus, a suspended elastic rope stretches until an equilibrium is attained between rope tension and rope elasticity. As one might imagine, finding the rope tension and rope elongation at which this balance occurs is no simple matter. In fact, a series of trial-and-error calculations must be carried out to home in on the correct answer.

Second, when the load is applied to the center of the Tyrolean traverse, the shape of the rope or cable changes drastically. The increased rope tension flattens the arc assumed by the rope between the rig point and the suspended load, making the rope appear nearly straight. Obviously, the center-loaded traverse no longer hangs in the shape of the original simple catenary, but the rope does still approximate a section of a new catenary (see Figure 1). Consequently, with a small amount of manipulation, the catenary equations can be used to model the loaded traverse. Once again, trial-and-error calculation must be employed to find the new equilibrium rope tension and rope elongation. As the reader can see, the use of a mathematical model incorporating the effects of both rope weight and rope elasticity demands a considerable amount of computation. Nevertheless, this is the price of an accurate solution to the problem of the Tyrolean traverse.

We have overcome the barriers imposed by mathematical complexity by using a digital electronic computer. We supply such data as: 1) the weight per unit length of the unstretched rope or cable with which the Tyrolean traverse is to be rigged; 2) the elongation-versus-tension data for the same rope or cable; 3) the width of the span to be crossed; and 4) the weight of the load to be placed at the center of the traverse. The computer then calculates such information as: 1) the proper rigging tension for the unloaded traverse; 2) the sag in the rope or cable before and after the load is applied; 3) the elongation of the rope or cable both before and after the load is applied; and 4) several pieces of trigonometric data related to the shape of the catenary which the rope or cable approximates. All of this output is presented as a function of the static tension experienced by the rope after the load is applied.

We have carried out calculations of the type outlined above for a fairly wide range of conditions. For example, we employed tensile and weight data representative of four types of rope which are currently in use in the field: PMI, Blue Water II, Blue Water Super III, and Goldline. We have considered spans ranging from 50 feet to 300 feet. And we have postulated loads ranging from 150 pounds to 400 pounds. We feel that these values will encompass most situations normally encountered in the field.

A portion of our data is presented on the following page. Table 1 shows the rigging tension for an initially unloaded Tyrolean traverse which will result in a 750-pound static rope tension after the load is applied. Table 2 shows the vertical sag for a center-loaded Tyrolean traverse which is under a 750-pound static rope tension. In addition to the four rope types mentioned above, Table 1 includes data for two hypothetical inelastic ropes, one weighing 5 pounds per 100 feet and a second weighing 11.6 pounds per 100 feet. These particular weights were selected to correspond approximately to the weights of normal climbing rope and 0.25-inch steel cable, respectively. Likewise, Table 2 includes data for these same two hypothetical ropes as well as for a hypothetical weightless, inelastic rope. These hypothetical cases are intended to serve as a useful comparison to the real cases.

In both Tables 1 and 2, there are two numerical values shown for each combination of span, load, and rope type. This is a consequence of the variation from sample to sample within a given type of rope. We gathered our tension-versus-elongation data by testing several samples of each type of rope. In each test, we recorded the tension necessary to produce each of a series of specified elongations. Unfortunately, we observed a fairly high sample-to-sample variation within each rope type; and rather than attempt to arrive at a meaningful average behavior for each type of rope, we used the two extremes. Consequently, the first number of each pair reflects

Table 1--Rigging tension in pounds for an initially unloaded Tyrolean traverse which will result in a 750-pound static rope tension after the load is applied

Load (pounds)	I	II	III	IV	V	VI
			50-foot span			
150	659 661	671 662	654 680	710 715	7	17
200	593 601	612 600	594 626	679 687	6	13
300	428 440	445 451	429 487	595 609	4	9
400	225 253	213 270	218 308	487 527	3	7
			100-foot span			
150	658 659	670 660	652 679	709 714	14	33
200	592 599	610 598	593 624	678 686	11	25
300	425 438	443 448	426 485	594 608	8	17
400	222 251	210 268	215 305	485 526	6	14
			200-foot span			
150	655 657	667 657	649 676	708 713	28	63
200	588 595	606 594	589 621	676 684	22	49
300	420 433	437 444	422 481	591 606	15	34
400	216 247	203 265	210 299	481 524	12	27
			300-foot span			
150	652 654	664 655	646 674	706 712	42	91
200	584 592	602 591	586 617	674 682	32	71
300	415 428	432 440	417 477	589 604	22	50
400	211 243	198 261	205 292	477 522	17	39

Table 2--Vertical sag in feet for a center-loaded Tyrolean traverse which is under a 750-pound static rope tension

50-foot span

Load (pounds)	I	II	III	IV	V	VI	VII
150	2.5 2.5	2.5 2.5	2.5 2.5	2.5 2.5	2.5	2.6	2.5
200	3.4 3.4	3.4 3.4	3.4 3.4	3.4 3.4	3.4	3.4	3.4
300	5.1 5.1	5.1 5.1	5.1 5.1	5.1 5.1	5.1	5.2	5.1
400	7.0 6.9	6.9 6.9	6.9 6.9	7.0 6.9	6.9	7.0	6.9

100-foot span

Load (pounds)	I	II	III	IV	V	VI	VII
150	5.1 5.1	5.1 5.1	5.1 5.1	5.1 5.1	5.1	5.2	5.0
200	6.8 6.8	6.8 6.8	6.8 6.8	6.8 6.8	6.8	6.9	6.7
300	10.3 10.3	10.3 10.3	10.3 10.3	10.3 10.3	10.3	10.4	10.2
400	14.0 13.9	13.9 13.9	13.9 13.9	14.0 13.9	13.9	14.1	13.8

200-foot span

Load (pounds)	I	II	III	IV	V	VI	VII
150	10.4 10.4	10.4 10.4	10.4 10.4	10.4 10.4	10.4	10.8	10.1
200	13.8 13.8	13.8 13.8	13.8 13.8	13.8 13.8	13.8	14.3	13.5
300	20.8 20.8	20.8 20.8	20.8 20.8	20.8 20.8	20.8	21.3	20.4
400	28.1 28.1	28.1 28.1	28.1 28.1	28.1 28.1	28.1	28.6	27.7

300-foot span

Load (pounds)	I	II	III	IV	V	VI	VII
150	15.9 15.9	15.9 15.9	15.9 15.9	15.9 15.8	15.8	16.9	15.1
200	21.0 21.0	21.0 21.0	21.0 21.0	21.0 21.0	21.0	22.0	20.2
300	31.5 31.5	31.5 31.5	31.5 31.5	31.5 31.5	31.5	32.6	30.6
400	42.5 42.5	42.5 42.5	42.5 42.5	42.5 42.4	42.4	43.7	41.5

I ≡ PMI (weight, 5.7 pounds per 100 feet)
II ≡ Blue Water II (weight, 5.6 pounds per 100 feet)
III ≡ Blue Water Super III (weight, 5.6 pounds per 100 feet)
IV ≡ Goldline (weight, 6.2 pounds per 100 feet)
V ≡ hypothetical totally inelastic rope (weight, 5 pounds per 100 feet)
VI ≡ hypothetical totally inelastic rope (weight, 11.6 pounds per 100 feet)
VII ≡ hypothetical totally inelastic, weightless rope

the behavior of the rope sample with the least elasticity; while the second reflects the behavior of the rope sample with the greatest elasticity. It is our hope that by presenting the data in this manner we have bracketed the actual behavior of the rope used by climbers in the field.

One can draw several general conclusions from the foregoing data. First, the elasticity of the rope is critically important when one is rigging horizontally. An elastic rope responds to increasing tension by stretching, thereby lengthening the catenary and limiting the maximum tension experienced by the rope. As an example, consider the behavior of Goldline rigged across a 50-foot span. When this rope is rigged with a tension of approximately 710 pounds and a 150-pound load is then placed at the center of the traverse, the rope tension increases to 750 pounds--an increase of only 40 pounds! Of course, if the load is increased to 400 pounds, the rigging tension must be reduced to approximately 487 pounds to prevent the loaded rope tension from exceeding 750 pounds. Thus, one observes that an elastic rope can be rigged quite tautly without producing an excessively high rope tension when it is loaded. It is this "forgiving" nature of elastic rope which has undoubtedly saved the lives of many climbers.

On the other hand, the inelasticity of cables can be a hidden hazard. As an example, consider the behavior of a hypothetical totally inelastic cable, whose weight is 5 pounds per 100 feet, rigged across the same 50-foot span. When this cable is rigged with a tension of only ∿7 pounds and a 150-pound load is then placed at the center of the traverse, the cable tension increases to 750 pounds--an increase of 743 pounds! Furthermore, if the load is increased to 400 pounds, the rigging tension must be reduced to approximately 3 pounds to prevent the loaded tension from exceeding 750 pounds. Moreover, it appears from our data that the lighter the cable per unit length, the more severe this hazard becomes. Obviously, steel cable is not totally inelastic, but its behavior must closely approximate the hypothetical case described above. And even though the ultimate strength of a steel cable far exceeds that of rope, one can see how a taut horizontally-rigged cable could be snapped by the application of a relatively small load at its center.

One can also draw two specific conclusions from the particular cases we modeled. With respect to rigging tension, the span width was not a very significant factor. It is rather surprising that for a given rope type and load, the rigging tension for the 300-foot span was essentially the same as that for the 50-foot span. With respect to the amount of sag in the rope after loading, compared to the sample-to-sample variation within a given type of rope, all rope types behaved essentially the same.

The reader may wonder why we chose 750 pounds as our maximum static loaded rope tension. It is not unusual for people involved in outdoor sports to use rope at a much higher loading than industrial safety standards would permit. Because of the extremely high quality of the special ropes used for mountaineering and caving, climbers commonly use a working load which is 15% of the maximum breaking strength of the rope. However, due to the harsh conditions under which these ropes are used in the field, extreme care must be taken to inspect them regularly and to document the history of all climbing lines. The maximum industrial working load for new Nylon rope is 11% of its maximum breaking strength. This standard is set by the National Safety Council and is recommended by OSHA. In situations where there is a chance of personal injury, this maximum working load is adjusted downward, even if the rope is new or has been inspected and found to be in excellent condition. In light of these facts, we have elected not to publish any data for main line tensions in excess of 750 pounds. We feel that this value will in most cases fall below the maximum industrial working load standard for the rope types in question. Nevertheless, we urge all readers to incorporate reasonable working loads and to exercise mature judgment and common sense when using the data presented herein.

For his own protection, the reader should also realize that our analysis reflects the behavior of rope under conditions of static loading only. We have made no allowance for the higher rope tensions which may be produced instantaneously by rapidly-applied loads. Such "shock-loading" could generate rope tensions which far exceed the safety limits of any rope.

In summary, we recommend that a climber planning to rig the Tyrolean traverse carefully consider all of the properties of the rope or cable he intends to use. It is critically important that he know the tensile properties and weight of the rope as well as its ultimate strength. With this data in hand, the climber can rig the unloaded traverse with the proper rope tension so that when he places his weight upon it, the tension in the rope will not exceed his expectations.

III. References

1. Philip Franklin, "Analytical Geometry," in Marks' Standard Handbook for Mechanical Engineers, ed. Theodore Baumeister (New York: McGraw-Hill Book Company, 1967), pp. 2-56--2-58.

We wish to express our thanks to Borg-Warner Chemicals Division of Borg-Warner Corporation for the use of the test equipment on which the tensile data for the various rope types were generated, and for the computer time required to develop and run our simulation program. We also wish to thank Blue Water Ltd. and Pigeon Mountain Industries (PMI) for sending us the rope samples we used in this project.

a word on
Expansion Bolts

*Bill Storage

You may have wondered about the strength of the expansion bolts you use for rappel anchors. A primary concern seems to be the reduction in strength due to corrosion. Over the last few years, I have done some experimentation with bolts and bolt-hangers and the results may interest vertically inclined cavers. The nature of bolt failure however, is such that other considerations must be taken into account in an evaluation of their safe use.

Several quarter-inch rawl-drive bolts with SMC hangers were left hanging in the corrosive atmosphere (due to industrial pollution) of the Cuyahoga River Gorge near Akron, Ohio. After eight years these were removed and tested. The bolts and hangers were tested together and with new parts. The loading was applied in such a manner as to duplicate the loading conditions of actual use. Not one bolt or hanger failed below 3000 pounds. This was surprising, considering the 5 to 15 percent reduction in cross-sectional area of each hanger due to corrosion.

An examination of the parts led to several interesting generalizations. Basically the hangers are somewhat more affected by rust than the bolts. Corrosion is usually worse on the visible surfaces. Bolts generally fail before hangers.

In pull-testing, bolts fail by shearing due to an overload. In most cases, however, a bolt will fail because of fatigue. A small crack will initiate at a dent, corrosion pit, or, most commonly, a material flaw. This enlarges until the useful cross-sectional area cannot support the load. Many cavers fail to note this subtlety. When a bolt (or any piece of caving equipment) fails, it is not the result of overloading, but a deficiency of the material. The bolt-hanger failure discussed by Davison in the NSS NEWS (Oct., '77) and the failure a few years ago of a bolt in Lewis Cave were of this nature.

An understanding of this type of failure necessitates a statistical consideration. How can we continue to rappel from a single bolt (as is the case in several locations in Canadian Hole) when we are assured that a certain percentage, however small, of bolts will fail because of material defects? Bolts are not manufactured with the quality control necessary for trusting lives to them.

The tensile strength of vertical gear should not be the sole basis for deciding how safe it is. Reliability is the main issue. My testing supports the ability of bolts to withstand a corrosive environment but the possibility of a manufacturing flaw always exists. Redundancy takes time, but might save your life. Bolts are cheap. Use several.

(Reprinted from the HUNTSVILLE GROTTO NEWSLETTER, June, 1979, who reprinted it from the D.C. SPELEOGRAPH, Jan., 1979.)

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OH, AND ABOUT THAT OLD ROPE.........

Cornell Mountaineering instructor Tom Andrews got a bit of a surprise recently when he put up a banner across a street here with a retired piece of Blue Water III. The rope ran the full length of the banner on top and bottom, and was tied to a good sized tree on either side of the street. Just as he finished putting it up, Tom saw a Ryder truck heading straight for the banner, the top of the truck just above the lower rope. The driver wasn't worried; no flimsy banner was going to stop him, especially at 30 mph, but soon found differently. With a groaning of trees, the truck came to an abrupt halt with the banner still in place. Tom had to cut the rope to take the banner down though -- he still hasn't been able to untie the knots!

Bill Nesheim (Reprinted from the DRIPSTONE, Spring, 1980.)