NYLON HIGHWAY 7

...especially for the vertical caver

Nylon Highway 7

July 1977
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Inside

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cover

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Details:

DEADLINE for NYLON HIGHWAY #8 is September 16, 1977. 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 are welcome.

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Resolution:

...reaching for rationality

The following policy regarding artificial climbing aids in caves was approved by the Virginia Region. Perhaps it will serve as an impetus and guide for the rest of the NSS. This policy is not intended to "legislate morality" upon cavers in the Region. However, it IS meant to establish a rationale of use of bolts, cables, etc., in caves, for it is felt by many cavers that if current trends continue unabated, serious aesthetic and safety problems may develop without anyone ever knowing why. Simply consider it in the same category as policies on safety, conservation, landowner relations, etc.

"The Virginia Region of the NSS supports the proposition that the installation of artificial anchors (e.g. bolts) and similar aids (e.g. permanently affixed ladders, ropes, etc) in caves should be kept to an absolute minimum; and that such anchors and aids should be installed only after deliberate consideration has been given to the short and long term effects, and safety and conservation consequences of such installation. Furthermore, when such devices are installed, the following guidelines should be followed:

1. The installation of artificial anchors chould be considered only when no other safe rigging point is available;
2. After an artificial anchor has been used, the bolt hanger should be removed and the threads protected;
3. When an artificial anchor is installed, a tag or similar device, bearing (i) the name of the person placing the anchor, (ii) the installation date, (iii) the purpose of the anchor, (iv) other pertinent data (such as address or telephone to contact), should be attached to the anchor;
4. Strength and conservation considerations clearly show that Phillips "red-head" type self-drilling concrete anchors should be used if the placement of a permanent artificial anchor is deemed necessary.
5. In cases where such devices as ladders, cables and the like are placed in the cave for an extended period of time, (a) thorough inspection of these devices should be performed on a regular basis and prior to use on successive trips, (b) a tag or device, bearing information as suggested for anchors in item (3) above, should be firmly attached to the device; the installers should maintain or remove but never abandon such equipment.
6. Installation of standing lines, ladders, cables, etc. presents safety, conservation and aesthetic problems. Their installation should be minimized and performed only for such purposes as the facilitation of rescue operations, safe negotiation of extremely difficult vertical pitches, instances where cave projects will require numerous visits within a designated period of time and other reasonable and prudent purposes;
7. The use of cables should be discouraged except in special circumstances, since rope alternatives are generally safer;
8. In no instance should the use of such devices be considered for convenicnce's sake, but rather as an aid to negotiating a particular cave section safely, after all other reasonable alternatives have been exhausted."

*Thanks to the region newsletter, VAR/FYI,
and Janet Queisser, Editor and VAR Chairman.

A New Look at the

Whaletail Descender

*Neil Montgomery

Ten years ago an American, Gerald Wood, invented a rappel device from a single bar of aluminium. It worked by winding the rope over a number of knobs shaped rather like whale's tails, and because of this, it was called the Whaletail Descender (Fig. 1). The rope was held in by fins on the knobs and friction was varied by changing the number of knobs used. Wood tested the Whaletail to 1500 pounds pull over one knob, used it in a number of pits, and then published an article in the NSS NEWS (Wood 1967) which generated some interest in America. They gained minor popularity, though they could not compete with the well established rappel rack.

Unfortunately, over the next few years, several disturbing incidents were reported in which the rope jumped out of the device on the brink of a pit. One such incident is related by John Baz-dresch (1974) in which a caver had the rope come entirely out of the Whaletail at the edge of Fantastic Pit. Such near accidents served to increase the apprehension people felt on using a device in which the rope was merely fed into open slots. By the early 1970's in America the whaletail had gone the way of many other experimental devices -- it was blacklisted and scarcely seen.

When in 1971 rappel-prusik caving emerged in Australia, cavers looked to the literature for ideas and American journals were particularly useful. Rappel racks and Whaletails interested us a lot, and I picked on the Whaletail as the first device to try. Soon after, the first Australian Whaletail was milled out in a machine shop and the days of cross-carabiners were clearly over. The new device was noted for its ease of control and the way in which the long aluminium frame dissipated heat. In fact, we were so delighted with the Whaletail that it was several years before anyone experimented with racks at all. When they did appear, they could not oust the Whaletail as the popular device. Cavers found the Waletail easier to use in Australian vertical caves, which are typically multi-pitch caves with very few drops over 300 feet.

Right from the start, Australians found it disconcerting to use a Whaletail with open slots; and on the very first models a safety gate was installed over the top knob. It was thought that if the rope jumped out of the device, the one remaining knob would give sufficient control to descend safely. On the two or three occasions, in six years, when a caver has jerked the rope out, this has proved to be the case. Other improvements were made in the American model. The Whaletails were milled to give a neat finish and a carabiner hole was drilled at both ends. This extra hole prolongs the life of the device since the top knob wears far faster than the others and when it is worn out, the device is turned around, i.e. the other carabiner hole is used and the gate is shifted. Wear is then taken on the only slightly worn knobs. Even when all the knobs are worn out (which takes about 3 years of average cave use), it was found that they could be rebuilt with epoxy aluminium, a very durable substance containing about 20% epoxy and 80% aluminium powder. Sufficient strength is left in the body to make the rebuilt models perfectly safe.

Obtaining a Whaletail

There are two ways of getting a Whaletail -- either to make one or by a cast model from Caving Equipment in Australia.

Cast Whaletails. These are available at $A20 plus P & P from Caving Equipment, 10 Binda St., Merrylands, N.S.W. 2160. They are of the same dimensions as that in Figure 2, except that the gate is thicker and is of cast aluminium, like the body. A number of tests were done on the cast Whaletails, and Andrew Pavey has supplied the following details.

1. An end to end pull between the carabiner holes caused an average breakage of the Whaletail body at about 8000 pounds.
2. A steel cable threaded in as the rope is placed in actual use broke at about 5000 pounds, causing slight deformation of the Whailtail.
3. A sideways pull on the gate with a metal rod caused defirmation of the guard tips on the knobs and bending of the gate at about 2000 pounds.
4. A Whaletail clamped and bashed with a sledge hammer deformed plastically, but did not fracture.

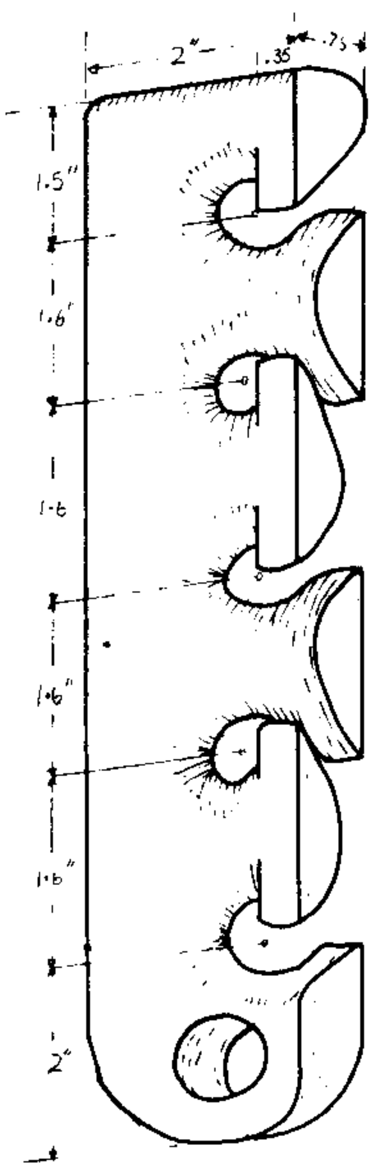


Figure 1

G. Wood's origional design from NSS NEWS, 25(12).

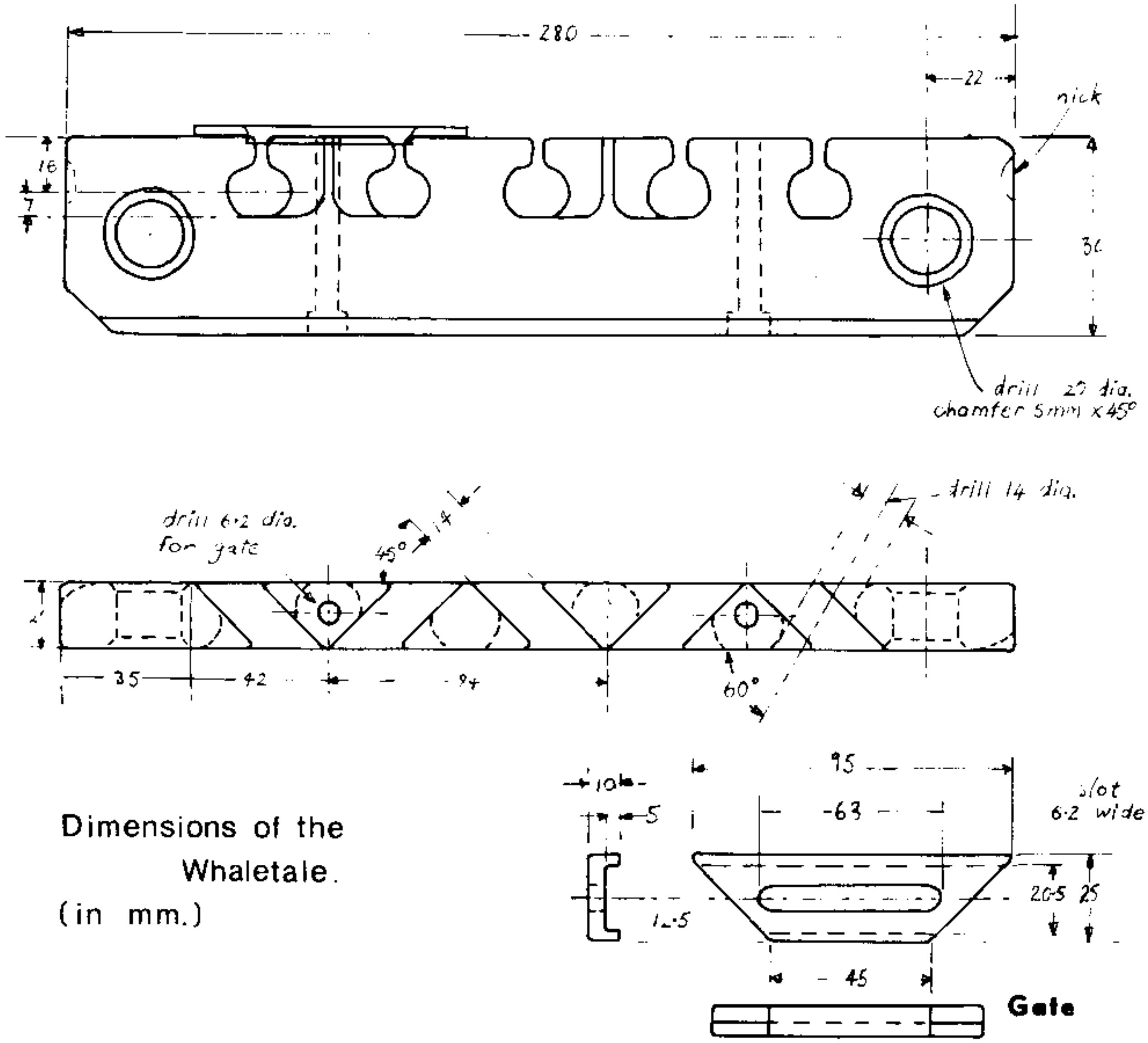
The tests indicate strengths which are easily adequate, though there is still a slight risk of fracture with cast products. The manufacturers x-ray a random sample from each batch to reduce this risk.

Machining a Whaletail. Details for machining are shown in Figure 2. Machining is safer than casting because of the greater reliability of stock aluminium, though it is more time consuming (about 4 hours per Whaletail) and requires sophisticated equipment. It helps to machine batches of about 6-10, since once the machines are set up, blanks can be quickly run through and some operations can be done on all the blanks together.

Aluminium comes in scores of different grades and it is essential that a suitable grade is chosen. Alloy 6061 Temper T6 is probably the best. Very hard alloys must be avoided since they run risks of brittle fracture. Soft alloys wear too fast. If 6061T6 is not available, an alloy should be chosen with approximately 35-38,000 PSI yield strength and 6-10% elongation. Cost per Whailtail is around $3. Under no circumstances should an unidentified piece of aluminium be used, since some grades are dangerous.

The gate is made from 316 stainless steel, and it's fitted with a commercial $\frac{1}{4}$ inch by 2 inch bolt also of 316 stainless. The bolt head is recessed into the back of the Whaletail, and the bolt is slightly bent with a hammer to insure a tight fit in the hole (it mustn't be able to rotate). Commercial wing nuts are adequate for holding the gate on, and its wise to burr the end of the bolt thread to keep the nut on.

The basic shape of the Whaletail is obtained by milling slots at 45° to the aluminium bar and then drilling holes at 60° for the rope to pass through (see Figure 2). After machining all sharp edges and any deep scratches or tool marks must be filed away and all corners in contact with the rope smoothly radiussed.



Dimensions of the Whaletale. (in mm.)

Figure II

Using the Whaletail

The safety gate is slid up and down to allow the rope to be fed into the Whaletail. The rope must sit at right angles to the slot direction (Figure 3). While in use the gate covers the first two slots and is screwed down firmly. Friction is varied by altering the position of the rope to accomodate more or less knobs. This is generally easy to do on the pitch, though some people find it difficult with a large weight of rope below. There are five friction positions and a stop position (Figure 4). In positions 1 and 4, the rope is guided under the base of the Whaletail by a shallow notch. Intermediate amounts of friction are gained by holding the controlling hand above or below the thigh, or wrapping the rope around one foot. Good control and a smooth rappel are features of the Whaletail. It is suitable for use on drops at least up to 1000 feet in length. I used one on the 946 foot drop in Sotanito de Ahuacatlan with excellent control and without heating problems.

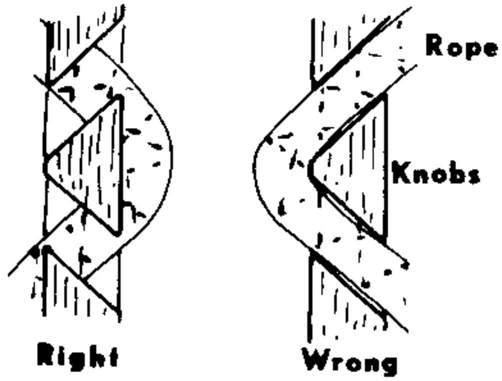


Figure III

Threading the Whaletail

(side view)

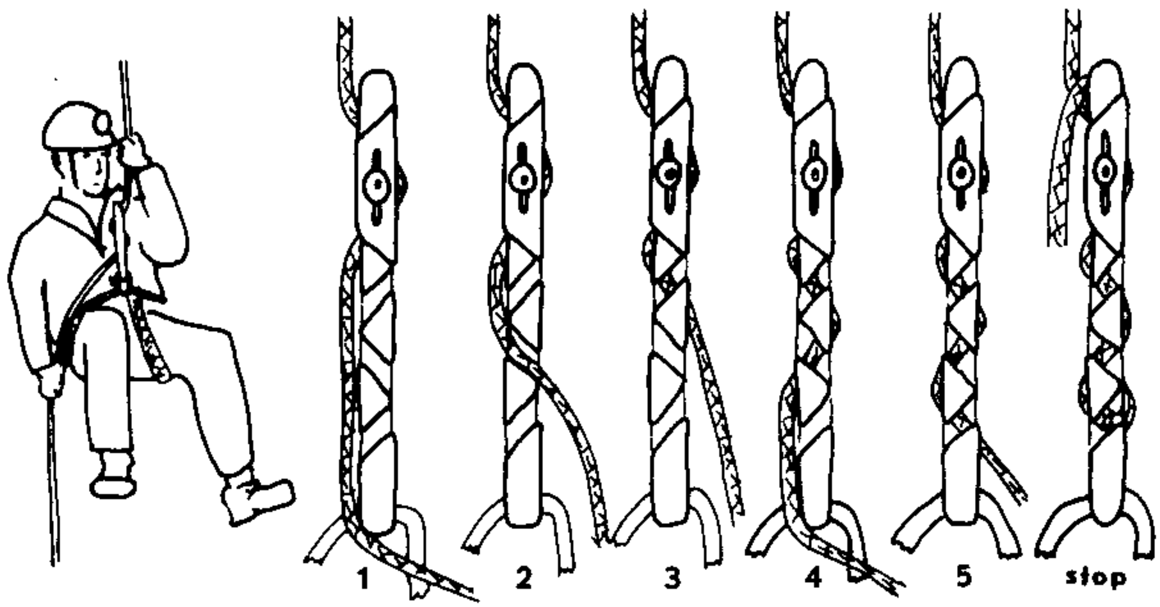


Figure IV

Using the Whaletail

Whaletail vs. the Rack

By their popularity and good safety records, both the Whaletail and the rack have proved themselves to be excellent descenders for vertical caving, but there are important differences. Although my personal use of racks is limited, I can offer the following comparison between it and the Whaletail, based on observation and on the experiences of others.

1. The rack gives finer control of friction, since it is possible to vary both the spacing and number of bars in use, and since spacing offers a continuous adjustment. Only the number of Whaletail knobs can be varied. However, it is much easier to vary the number of Whaletail knobs then it is to change the number of bars on a rack (with practice it can be done while moving). This narrows the rack's advantage on all but the longest pitches, where the Whaletail is inferior to the extra long racks and SupeRacks. This is because on a deep pit, only the top knob of the Whaletail would be in use until the caver has only about 500 feet remaining. For example, on the top 700 feet of a 1200 foot drop, only hand and foot friction could be used with the Whaletail. Using specialized versions of the rack, changes in bar spacing can give fine control all the way.

2. The Whaletail dissipates heat better than the standard rack since the whole Whaletail body heats up readily, whereas the top bars of the rack (where most heating occurs) are somewhat isolated by the rack's thin steel frame. I'm not sure how the SupeRack compares.

3. The rack gives an emergency stop by jamming up the bars. With the Whaletail, one would have to rely on a bottom belay, a trailing ascender brake, or on wrapping a leg around the rope.

4. It is much quicker to thread and unthread the Whaletail. This makes a considerable difference on multiple short pitches.

5. The Whaletail is much stronger than the standard rack, and is in the same league as the SupeRack, having strength far in excess of requirements. The standard rack can be bent by sliding it over a sharp pit edge while beginning a rappel, while the Whaletail will scarcely flex.

6. The rope is held more securely in the rack than the Whaletail, despite the Whaletail's safety gate.

7. Using either device, a negligent caver could thread the rope in the wrong way around (see Figure 3). In the case of the Whaletail, the safety gate holds the rope in, and a safe descent is still possible. The rack is likely to pop completely open on the pit edge, a perilous situation which has happened twice in Australia.

8. Most commercial racks are 3 - 5cm longer than the Whaletail.

9. The Whaletail is more easily carried than the rack when moving between pitches. Both devices tend to get in the way, but the bars on the rack can flap loosely and jam in awkard places.

10. The Whaletail has been know to bunch sheaths on several occasions on loose sheathed ropes such as some yachting ropes. Most common brands of caving rope have a relatively tight sheath however, and the problem doesn't arise.

11. The devices are of similar weight. The Whaletail weighs about 600 grams.

12. Commercial racks are about 30% cheaper than the cast Whaletail. Racks are easier to manufacture than the machined Whaletail.

13. It is easier and more satisfactory to replace bars on the rack than rebuild the Whaletail with epoxy aluminium.

The net result of these comparisons is that the Whaletail is a better device for multipitch caving and the rack a better device for the pit caver. In the multipitch cave where long drops (over 400 feet) are rare, the rack's edge in control is outweighed by the Whaletail's size, ease of carriage and rapid on-off times. Cavers don't worry much about fine control on pits less than 150 feet, and this is especially so in big caves where fast efficient movement is important. However, for the pit caver, who finds the joy of the rappel of prime importance, and who seeks out big pits, the rack is superior. In fact, the Whaletail's popularity in Australia is partly explained by the scarcity of big pits and the general preference people have for technical multipitch caves over pits. Perhaps other cavers of the same preference might like to reconsider the Whaletail.

References

Baz-Dresch, J., 1974, "Whaletail Versus Rappel Rack", DESCENT 30, 1974: 33-5.
Wood, G., 1967, "The Whaletail Descender", NSS NEWS, (25) 12: 215-216.

*** ! Needed ! ***

COVER DRAWINGS

& CARTOONS TO MAKE US LAFF

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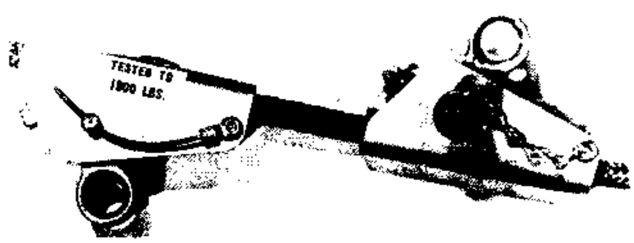

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Ribbon Eye Splice

*Don Davison Jr

Materials recommended: Nylon three-strand right-hand lay rope (Goldline, etc.), knife, scissors, marlinspike, needlenose pliers, matches, metal film can, small paintbrush, ½" strapping tape, strong nylon cord, gloves, beeswax, two felt-tipped markers of different colors, small stove.

Prepare the rope as shown in Figure 1. Tape the rope tightly with strapping tape eight inches from the end. Tie a very tight rolling hitch, backed up with a square knot, over the tape using nylon cord. Melt the ends of the cord back into the knot. Cut the very end off the rope to free the three rope strands. Unlay the strands back to the tape and, using nylon cord, tie a constrictor hitch tightly around each strand a half inch from its end. Melt the ends of the cord back to the hitch. Melt the end of each rope strand, being careful not to involve the constrictor hitch, and, using gloves, draw the melted nylon into a blunt point. Mark the ends of two strands well, each with a different color, leaving the third strand unmarked. When splicing, always work the strands in the same color sequence.

Form an eye of the appropriate size and gently work a marlinspike under a main rope strand at the point where the taped portion of the rope contacts the standing part. When a sufficient space is formaed, remove the marlinspike and insert the needlenose pliers so they point towards the taped portion of the rope. (Never twist the lay open to produce a space under a main rope strand; this will most often produce irreversible distortion, especially in hard-lay ropes such as mountain-lay Goldline.) Spread the pliers' jaws and place the end of one of the unlaid strands deep within the jaws. Note the color of the strand and draw it beneath the main rope strand, removing all twist from the unlaid strand. Pull the strand tight by tensioning each yarn individually.

Remove all twist from the unlaid strand as you tuck it under a main rope strand, but do not remove the twist from the individual yarns. Removing the twist, from the strand only, will result in a splice with less distortion and greater strength than is possible if each strand remains twisted. Removing the twist is especially important with hard-lay rope since splice distortion is greatest in this type of nylon cordage. The untwisted splice, developed by Du Pont, is called a ribbon splice because the tucked strands lie flat and flow as a tucked ribbon might. The earmarks of excellence in a splice are (a) parallel rope yarns in each tuck of the splice, and (b) smoothness of the ribbon resulting from pulling each rope yarn "in" uniformily.

Moving clockwise, looking from the loop towards the standing part of the rope, take the next strand and tuck it under the main rope strand to the right of the previous tuck. This tuck should be made a little further down the standing part of the rope than the previous one, as shown in Figure 2. The third tuck is made by turning the loop over and tucking the third unlaid strand under the main rope strand which does not have a strand under it, as is shown in figure 3. Tension all strands equally by pulling each large yarn individually. There will be either eight or nine large yarns per strand, each itself composed of four or three smaller yarns respectively. Start again with the first strand, crossing over the next main rope strand and tucking under the following one. Repeat with the other strands in the same fashion. After the second set of tucks, and after each succeeding set, loop the eye of the splice over a nail or your big toe and tension the yarns with the splice in this "natural" fashion.

Care must be taken that the filaments of previously tucked strands are not snagged or cut by the pliers or marlinspike. After each strand is tucked, twist the rope as if tightening the lay; this will help reduce distortion. After three tucks are formed with each strand, place the splice on a smooth board and pound it with a hammer on all sides; then pull each yarn tight again. Repeat the pounding after each succeeding set of tucks to help smooth and "form up" the splice.

An eye splice in nylon rope should have four full tucks per strand. If the rope has eight yarns per strand, add a fifth tuck with each strand using 3/4th of the strand (six yarns), after cutting the two outer yarns free from the strand at the constrictor hitch only. Also add a sixth tuck with each strand using half of the strand (four yarns) and a seventh tuck using a quarter strand (two yarns). This will form a smooth tapered eye splice. If nine yarns are in each strand, make a fifth and sixth tuck with 2/3 (six yarns) and 1/3 (three yarns) respectively.

Remove the rolling hitch and strapping tape stopping. Pull each yarn tight, working first with the bunch of yarns furthest from the eye, next with the bunch of yarns second furthest from the eye, etc. When all the bunches have been given attention, "form up" with the hammer and retighten the yarns working the bunches in the order opposite from the previous tightening sequence, but do not pound the splice. Next, starting with the most eyeward bunch of yarns projecting from the splice, tighten each yarn, cut the bunch with a scissors about an eighth inch from the splice, and melt the yarns together and back until just off the surface of the splice. Be careful not to melt any of the nearby nylon filaments or to cause the melted yarn to stick to the filaments of adjacent strands. After the nylon bead cools, move to the bunch of yarns next nearest the eye and repeat the proceedure. Continue until all of the yarn bunches have been trimmed and melted.

Soft nylon filaments are exposed individually in the ribbons of the splice; therefore the splice must be protected from abrasion if it is expected to maintain its strength during use underground. Melt beeswax in a metal film can. When the wax is warm enough so that it will not instantaneously solidify on the splice but rather flow into it, paint the beeswax onto the splice with a small paintbrush. Fill in all the depressions and voids in the splice and then, while the wax is still warm and soft, whip the splice tightly with strong nylon cord. The whipping should extend at least half an inch up each arm of the splice. Coat the whipping with hot beeswax and allow to cool.

Some of the information and text above was taken from : HOW TO TIE KNOTS YOU CAN DEPEND ON by the Du Pont company, Textile Fibers Department, Wilmington, Delaware, 19898, pages 12 and 13.

A good source of information on splicing and knotting is: THE ASHLEY BOOK OF KNOTS By Clifford W. Ashley; 620 pages, Doubleday & Co., Inc., Garden City, New York, 1944.

BOG Reacts to VS Motion:

Richard Schreiber (by proxy) presented the following motion at the March 1977, Board of Governors meeting, as was proposed and passed at the Morgantown, 1976, Vertical Section meeting. (See NYLON HIGHWAY #6.)

> All articles pertaining to vertical techniques or equipment to be published in the NSS NEWS or BULLETIN should first be reviewed by the Board of the Vertical Section of the NSS for accuracy. This includes not only total articles on new or old vertical equipment or techniques, but also sections within larger articles that deal with or recommend certain vertical equipment or techniques.

The motion failed for a lack of a second.

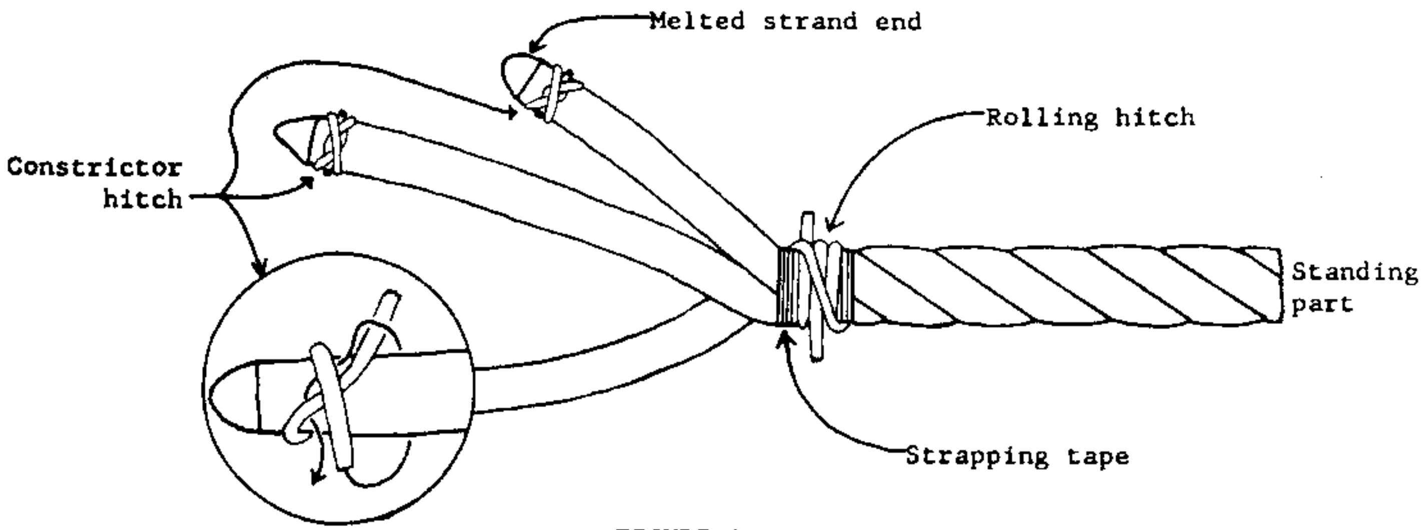


FIGURE 1

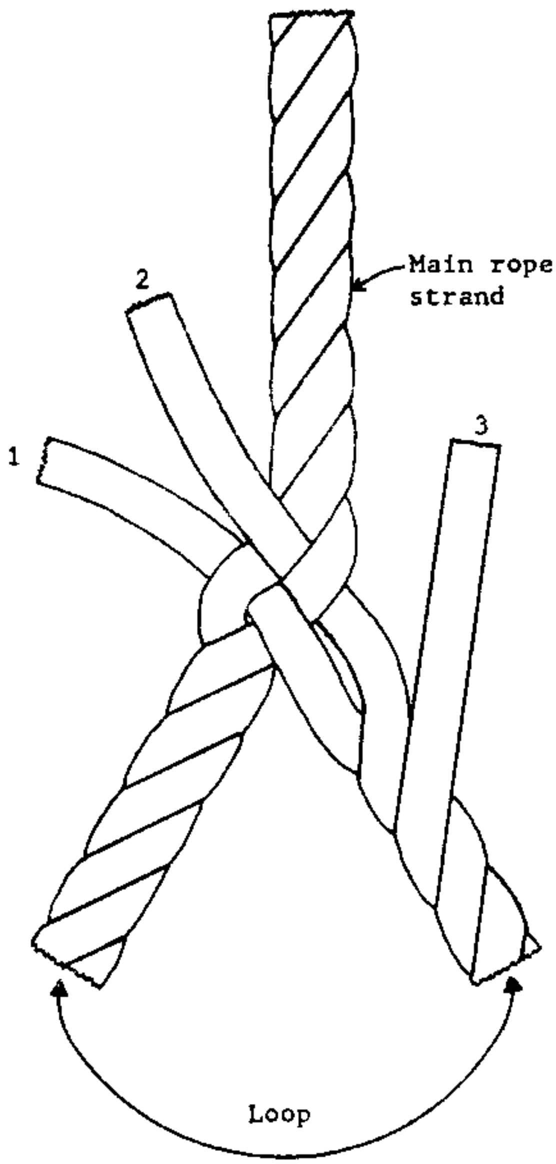


FIGURE 2

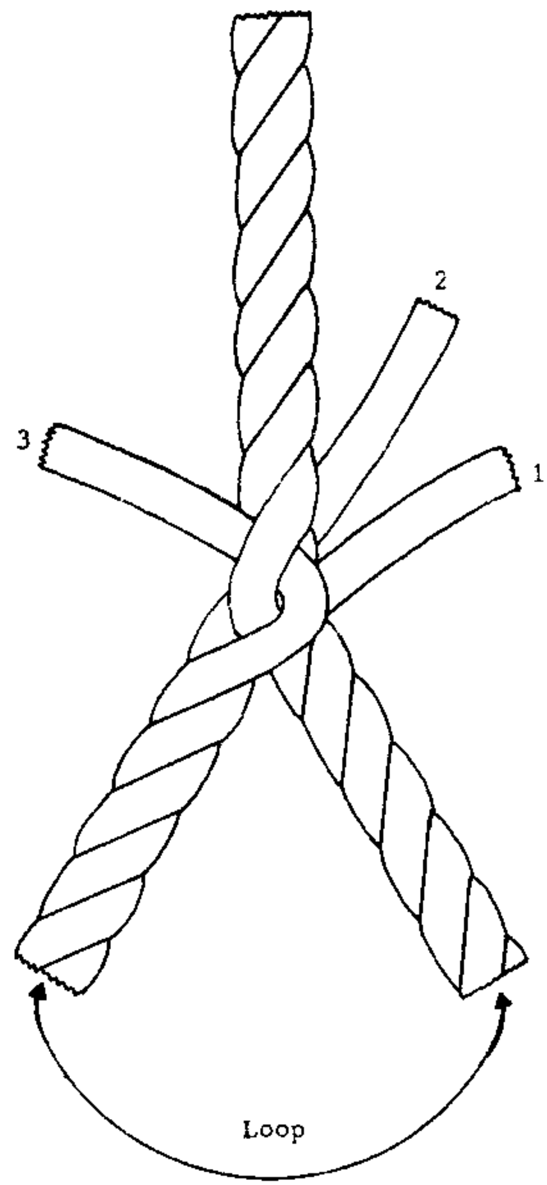


FIGURE 3

Sewn Seat Slings

...more tests and results

*Robert Thrun

I have submitted my sewing article to the NYLON HIGHWAY because the origional received little circulation and the ideas in it are still current. The articles by John Cole, which inspired my article, have been reprinted in the 1968 Speleo Digest.

John Cole recently made some tests and comments on sewn slings as part of the "On Belay" series that has been appearing in the HUNTSVILLE GROTTO NEWSLETTER. The May 1968 issue gives some test results and recommendations for sewing and tells how to make sewn seat slings. These two aritcles should be of interest to anyone who sews his slings together or is thinking of doing so. The only comment on Cole's rests I have read was in GEORGIA UNDERGROUND, May-June, 1968. The writer said that the tests show how unsafe wewn slings are -- because Cole's samples broke at from 50 to 500 pounds. Apparently he overlooked the number of stitches cole had in his samples: from 5 to 20. The test samples had far fewer stitches than would be used for vertical work.

Cole's tests helped to fill an information void. When I made my first sewn slings, I put in much more stitching than looked necessary, having only the general appearance of seat belts and assorted harnesses as my guide. I still use more stitching than appears necessary, to forestall weakening by abrasion, but having some test results gives me peace of mind. Cole's tests should be further explained and clarified. Many of the corrections I have to make concern minor semantic points that should be straightened out before things get too confused.

Why Sew?

Webbing is used for seat slings and chest harnesses because it is strong and wide, depending of course, on the particular size of webbing used. The strength is necessary for safety. Wide webbing is used in preference to narrow rope for reasons of comfort. Once the decision to use webbing has been made, a choice must be made between sewing and tying knots.

Knots can be made and undone quickly and without any special equipment. This permits the sling to be used for purposes other than rappeling and prusiking. Some cavers, consistent with the ideal of multiple utility, carry a piece of webbing with them even throughout a horizontal cave. Others find it worthwhile to develop their slings for the special purposes of rappelling and prusiking. It is for the specialists that this article is written.

In the matter of strength, sewing can be better or worse than knots, depending mainly on the quality of the sewing. Knots can be counted upon to always develop a large fraction of the strength of the material in which they are tied. Sewing can vary widely in strength from almost nothing to the full strength of the webbing.

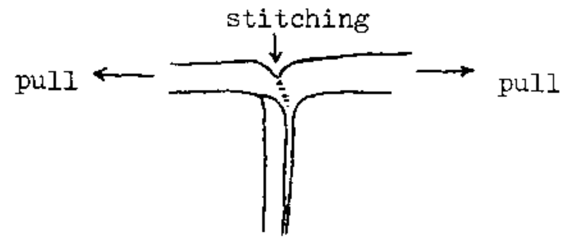
Sewn joints are much neater than knots. Knots are often uncomfortable lumps and have loose ends dangling about. A major reason for using sewn joints is in the flexibility in design that is possible. A complicated sling can be made with crossings at precise locations and angles. Pices of webbing can be doubled for strength or overlapped for comfort. D-rings and buckles are make to be sewn into place.

Materials

Cole does not consider what he calls "1 inch x 1/8 inch tubing " to have an adequate margin of safety. He probably means that comonly available 1 inch x 3/32 inch tubular nylon webbing. (Nylon tubing is something that could be used to carry liquids.) This kind of webbing is the most used seat sling material in this area, and is normally used withour doubling. It is usually claimed to have a test strength of 3000 pounds. I am a bit apprehensive about this statement because other kinds of webbing vary by 25 percent among different lots.

The size D nylon thread that Cole used is rated at $7\frac{1}{2}$ pounds. I was amazed that he would use such a small thread since I use 28 pound test thread for similar sewing. I obtained a sample of Cole's thread and tested it the way I test mine. I take several turns around a metal rod and the hook of a spring scale, and secure the ends of the test sample with three half-hitches. The thread might not develop its full strength this way, but a multiple capstan apparatus would take too much time to set up. Cole's thread broke at $6\frac{1}{2}$ pounds. A different test procedure might give a higher strength. While Cole's thread was described as untwisted, it is actually a single bundle of nylon filaments with a slight twist. Most thread consists of three such yarns twisted about themselves. For sewing purposes, the number of yarns in a thread has little effect. Cole uses single yarn, size D thread because it is readily available in his area, and it will work in his wife's sewing machine.

I started using heavy thread because it seemed to be the appropriate thing to use. Light material must be sewn with light thread. It seems proper to use heavy thread for heavy material. This general rule is followed in the manufacture of all kinds of sewn articles. The question came up, "Why not use a lot of fine stitching to sew webbing?" At first I was at a loss for reasons, but I have since found some for the common practice in sewing. Thread must be large enough to be pulled through thick material without breaking. This was more of a problem with cotton thread. The greater strength and lower friction of nylon makes this a problem only in extreme cases. Amateur sewers do not consider the problem of thread fusing although professionals are acutely aware of this problem. When nylon thread is pulled through thick material and around another thread under tension, enough frictional heat is developed to melt the surface of the thread. On heavy-duty machines, the thread is run through a silicon oil bath to lubricate it. The use of heavy thread further reduces the problem of fusing by increasing the strength to surface area ratio. In some sling designs, it is necessary to have two peices of webbing cross each other. At such a joint, there is always the danger of the pieces of webbing being pulled apart by a peeling action where a few stitches or a row of stitches at a time are broken. Heavy thread is better here.



Peeling action will separate a seam.

There is not too much of a problem in obtaining webbing. Dealers in climbing equipment and surplus stores sell a variety of webbing. Be careful about surplus webbing, though -- it can lose half its strength sitting in storage for several years. Getting nylon thread (Dacron is also suitable) is a bit trickier. I got my thread from an upholstery wholesaler. Cole got his from a shoe repair shop. Hand sewing awls and very heavy waxed nylon thread are available from Sears and camping dealers. Some sporting goods stores sell nylon thread intended for lashing guides to fishing rods.[1] Dressmakers, at least in this area, never use nylon thread, so fabric stores don't stock it. It is tempting to use fishing line because it is readily available in a variety of sizes. It could be used in a sewing awl, but it is unsuitable for machine sewing. When backstitching or crossing a row of stitches, the needle sometimes pierces the thread. A twisted thread will simply spread apart, but a braided fishing line will break. Most sewing machines are designed to use what is called left twist thread. Almost all thread intended for machine sewing is of this type, but odd ball types are occasionally encountered. A fairly wide range of sizes is suitable for sewing webbing, although I prefer heavy thread. The main problem encountered in the use of heavy thread is binding in the neadle's eye. If you get a large enough needle, you will have little difficulty. I use a number 24 needle with my heaviest thread.

Test Results

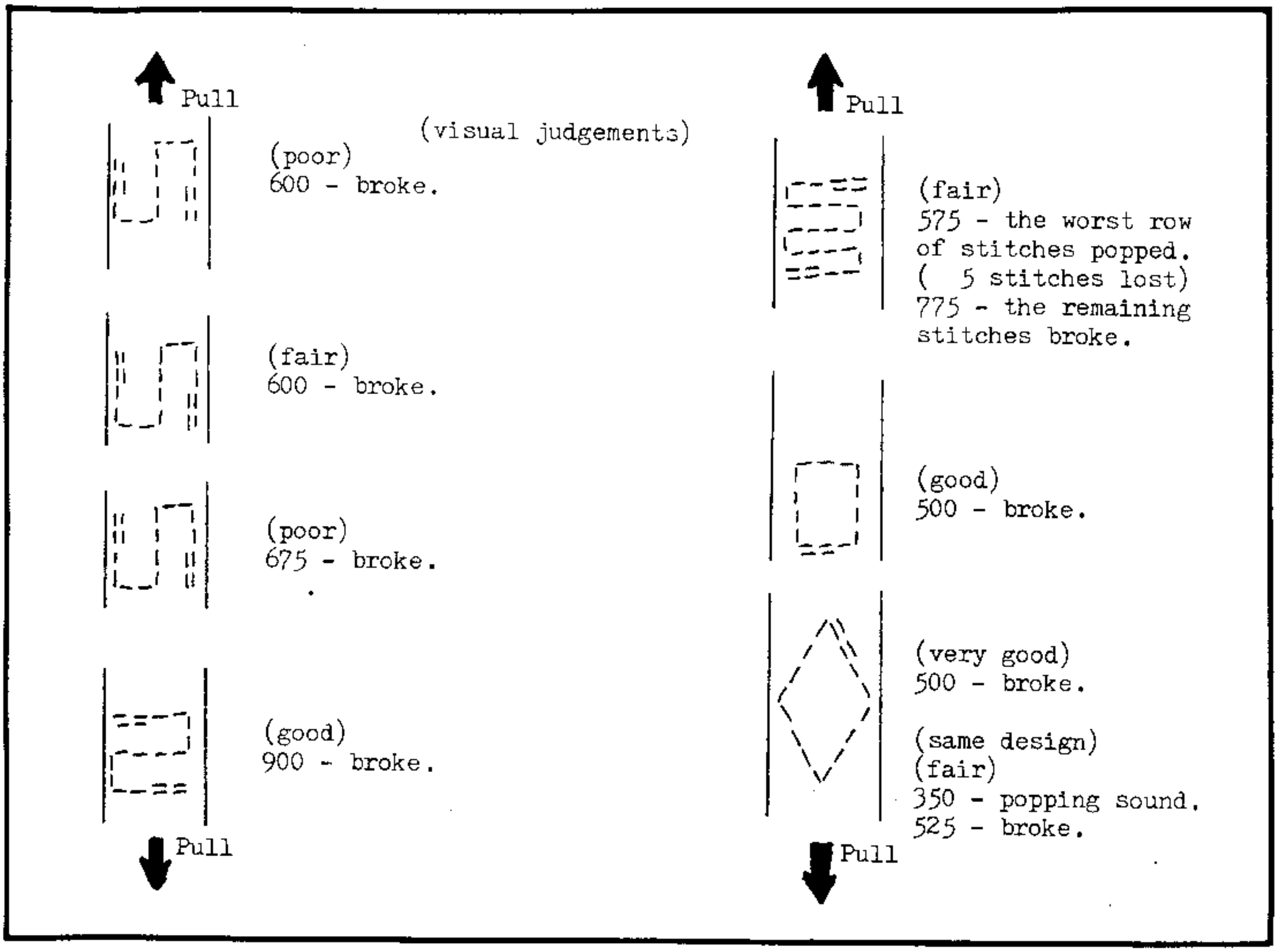
Cole's:

Cole's first article raised some questions. These were answered by Sandy Cole in a letter to me. The first question, about thread size, has already been discussed. I also asked about the way she connected her rows of stitches and how she finished off the ends of her rows of stitching. She said that "the way 15 stitches looked was ===== ". The loose ends are tied in a square knot. Her 15 stitches were actually 17 stitches, and would be the equivalent of either 17 or 19 stitches in strength, depending on where she tied her square knots. The strength of sewing should be proportional to the number of times the needle penetrates the material. This number differes by one from the number of stitches. For convenience in discussion, the number of stitches is usually referred to. Since Cole tested sewn eyes, his measurements should be divided by two to get the strength of the stitching.

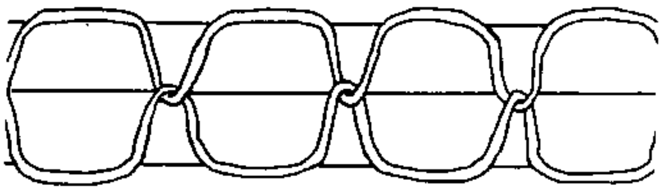
Mine:

I sewed short pieces of 3/4 inch x 3/32 inch tubular nylon webbing together with 28 pound test thread. I used the 3/4 inch webbing because of limitations of my test apparatus. It is identical in everything but width to the more commonly used 1 inch webbing. I had difficulty in obtaining good stitching in the short rows I had to work with and in keeping the two pieces of webbing lined up. I sometimes tack the two pieces together with very light thread and then go over with heavy thread. I didn't do it for the test samples because it might comfuse the results. I made a judgement of the quality of the sewing of each sample before I pulled it apart. I tried to sew six stitches per inch, but could not always maintain this spacing. There sere no sewn eyes or loops in my specimens and the results give the strength of the sewn joint directly (no need to devide by two). All numbers are pull in pounds.

At each place that the needle peirced the webbing a doubled thread goes through each side. The maximum possible strength of each stitch is twice the strength of th the thread. A cord tied into a knot does not develop its full tensile strength because of the sharp bends in the knot. Similarly, we would expect the sharp bends made in the thread by a lockstitch to weaken the thread. Other factors, such as fusing, abrasion, and thread geometry, will



prevent the stitching from developing its theoretical maximum strength.



A lockstitch greatly enlarged.

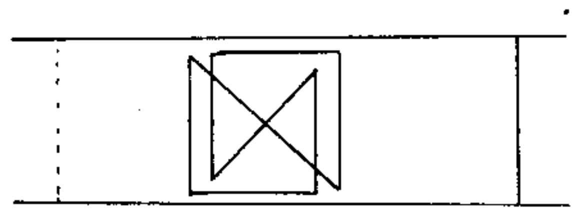
The strength of the stitching in my test samples ranges from .5 to .9 of this maximum. If you count stitches properly a and allow for the fact that Cole was testing eyes, his data falls in the same range. A comparison of our results indicates that stitching with small thread can be as effective as stitching with heavy thread. True -- but I still like sewing with heavy thread. The way to estimate the strength of sewing is not by inches of stitching, as Cole does. Very few people will use the same thread and stitch length. A better way is to multiply the number of stitches by the estimated strength per stitch. The length of stitching can be used to get the number of stitches. A conservative estimate is that each stitch will hold the tensile strength of a single thread. You might not get this much strength per stitch if your sewing machine abrades or fuses thread or your hand sewing is irregular. A further allowance should be made for abrasion of the thread when the sewn article is used.

I inspected the pieces of webbing after I had pulled the stitching apart. There was no evidence that the webbing had been damaged in the least by having been sewn.

Cole's tests seem to indicate that longitudinal stitching is slightly stronger. My best samples were transverse stitch A parachute rigger I talked to claims that the exact pattern is not too important, although excessive sewing in either a transverse or longitudinal direction should be avoided.

Stitching Pattern

I have seen several recommendations for stitching patterns appear in the caving and climbing literature. Cole, in the September, 1968, HUNTSVILLE GROTTO NEWSLETTER, mentions a "double-box, double-W stitching pattern." This is a basically sound pattern and is similar to the pattern specified by Military Specifications for parachute harness sewing. Many seat belts and leather goods use a pattern that has a box with an "X" in the middle of it.



The box-X pattern is easy to sew.

This is a fairly good pattern, but I have come to the conclusion that the main reason it is used is that it can be sewn without lifting the needle from the work or having to backstitch at the end. These considerations would become important if several hundred pieces had to be sewn each day. John Armitage (SUMMIT, Dec., 1966) made some slings by placing one end of a piece of tubular webbing inside the other. This is a very poor arrangement because it places unequal forces on the two ends. Some others have recommended sewing more and more at a joint until the needle becomes hard to push through the material. As stated, this is not a good practice. After the first few stitches are in place and the material is restrained from moving, the needle force increases. A second and more drastic increase comes when all the interstices are closed or filled. After this, to force a needle through, you must stretch or break the fibers of the webbing. It is a good idea to experiment to see when this second increase occurs (using a couple of scraps of webbing) and then use a stitching pattern that is not as tight for your slings.

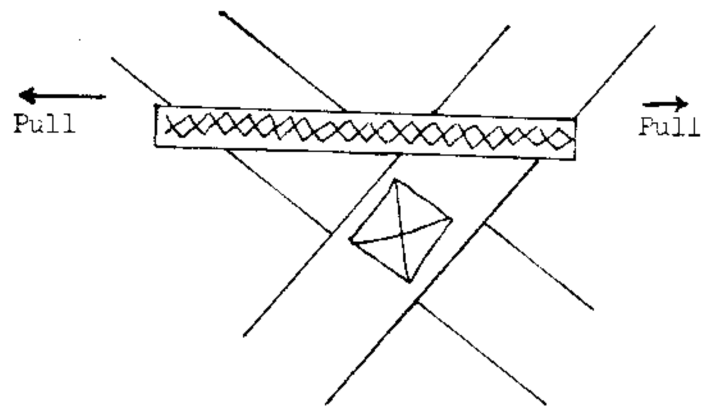
Excessive longitudinal or transverse stitching is to be avoided. Webbing is made up of very many longitudinal yarns and a few transverse yarns. Often just a single yarn that spirals up the webbing. Both longitudinal and transverse stitching can lead to overstressing of the transverse yarns very quickly. The webbing must spread apart each place the thread goes through. A row of transverse stitches will concentrate the spreading along a single transverse yarn. Longitudinal stitches will slip between the longitudinal yarns. Being recessed will protect the stitching from abrasion, but it will spread the webbing apart more than the same number of stitches in any other pattern. It is difficult to come up with a stitching pattern that has no longitudinal or transverse rows, and I do not say you should avoid them completely. However, the bulk of the stitching should be done at some other angle. The exact design used for stitching is largely a matter of taste. I prefer to have the rows of stitches cross each other frequently. If the thread is broken, the stitching can unravel only to the next crossing.

I do not use rivets in my slings. The webbing must be spread very far apart to put them in, and all the stress is concentrated on a few transverse yarns. At places where there is danger of two pieces of webbing being peeled apart, I will put another piece of webbing across both of them to reinforce the joint.

~ ~

Nylon thread of many strengths and sizes may be obtained from Paragear Equipment Co. A catalogue may be received by writing 3839 W. Oakton Street, Skokie, IL 60076. **Ed.**

Reprinted, in part, from THE POTOMAC CAVER, December, 1968. A section detailing a few seat slings was ommitted.



Lighter webbing reinforces joint.

POSTSCRIPT, 1977. The other major article on sewn slings, by Cal Magnussen, appeared in OFF BELAY and was reprinted in NYLON HIGHWAY No. 3. I think some more work should be done -- with different sizes of thread, wider webbing, different densities of stitching, and hand sewing. I would be interested in hearing from someone with acess to testing equipment which is able to handle larger specimens than what I tested.

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Ergonomics & Efficient Climbing Systems

*Dick Graham

Ergonomics, the science of human engineering, can be applied to climbing a rope to determine the minumum time to ascedl any distance, and to design an efficient climbing system.

Ergonomics, the science of human engineering, can be applied to climbing a rope to determine the minimum time to ascend any distance, and to design an efficient climbing system. Specifically, results of bicycle tests, ergometer measurements, and theoretical estimates, combined with simple mechanics, show: (1) That the limit for a 100 foot climb is being approached; (2) the Gibbs climbing system (cam at foot and knee) is very efficient; and (3) no one has yet come near the time limit for a 300 or 400 foot climb.

Basic Physics Review

Most people are no doubt already acquainted with two basic quantities in mechanics: Force and distance. Force is measured in units of pounds, and distance in feet.

Energy, or work, is that quantity exerted by a force moving a distance and is measured in foot-pounds, joules, ergs, calories, or British Thermal Units (BTU). One BTU will raise the temperature of one pound of water one degree Fahrenheit. One calorie will raise the temperature of one gram of water one degree Centigrade. Obviously then, 1 calorie equals 0.0039685 BTU. As a more concrete example, a person must exert one foot-pound of energy to raise a pound of cement one foot. The formula for energy is, then, $W=Fd$, where F is the force that must be exerted to move something a distance d.

The last important quantity is power, the rate at which energy is exerted. The formula for power over a time interval of duration t is $P=W/t$, where W is the energy. One horsepower is defined as 550 foot-pounds per second, so the formula for horsepower is $P=W/(550t)$, where W is measured in foot pounds, and t, in seconds.

Now consider a 175 pound person climbing 100 feet. The total work involved is 17,500 foot-pounds, enough energy to melt 1.4 ounces of aluminum, or break a number of bones and cause severe internal damage to a human body. If the climber is on the rope at the end of a long trip, the climb may take 8 minutes or 480 seconds. The horsepower required is

$$P = 17500/(550 \times 480)$$

$$= .066 \text{ Horsepower.}$$

If the climber is Bill Stone, he may take only 29 seconds and require

$$P = 17500/(550 \times 29)$$

$$= 1.1 \text{ Horsepower}$$

A super climber may take only 10 seconds, which requires 3.2 Horsepower.

The first climber's performance is obviously not very taxing; Bill Stone's climb is obviously difficult to repeat. The last performance appears very difficult for anyone to equal. Is it impossible? To answer this question and discuss climbing performance in general, we will have to take a closer look at ergonomics.

Horsepower Output

Most measurements of human power output produce the same qualitative results: A large amount of power can be produced for one or two seconds; the power output then falls off rapidly until about 5 minutes; the power output drops only slightly from 5 or 10 minutes to two hours. Although quantitative results of tests vary, it is certain that a person in good condition can produce 0.1 HP for many hours. Figure 1 shows the results of three ergometer tests, one estimate, and an actual short-duration measurement. This is a graph of peak power output -- that is, curve A indicates that a person can use all his energy to peoduce about 1.5 HP for 0.5 minutes, or 0.75 HP for 3 minutes, but not both consecutively. Notice the estimated curve lies considerably above curves C,D, and E; subjects measured on bicycles and with ergometers consistently produce less power than what has been calculated for athletes in competition. This difference is probably due to the lack of sufficient motivation in a laboratory, or non-competitive, environment.

Table 1 shows estimated average horsepower required to run five distances and the duration of each event. The horsepower values are estimated from reference (2) data independent of Figure 1 and show good correlation with the Figure 1 data.

Both the Figure 1 and Table I data also agree with Edholm (1): A good athlete can exert one HP for one minute, and 0.5 HP for two hours.

Applications

The time, t, required for a person of weight, W, to climb a length, d, of rope using P horsepower is given by

$$t = Wd/(550 \times P),$$

which is plotted in figures 2 and 3 for distances of 100 and 400 feet, and for a 125, 150, 175, and 200 pound person (weight includes climbing gear also). Figure 1 shows that the maximum power a person can produce for 30 seconds, the approximate time to climb 100 feet, is 1.5 HP. According to Figure 2, this corresponds to a time of from 15 to 24 seconds, depending on the weight of the climber. It appears then that the absolute limit for a 175 pound climber is 21 seconds for 100 feet.

To determine the absolute limit for climbing 400 feet, first look at Figure 1 to determine how much power a person can produce for 30 seconds, the approximate time to climb 100 feet, is 1.5 HP. According to Figure 2, this corresponds to a time of from 15 to 24 seconds, depending on the weight of the climber. It appears then that the absolute limit for a 175 pound climber is 21 seconds for 100 feet.

To determine the absolute limit for climbing 400 feet, first look at Figure 1 to determine how much power a person can produce for the duration of the climb (about .75 HP), then, from Figure 3, find the time corresponding to the power output (about 170 seconds for 175 pounds).

These limits are based upon gross considerations of total horsepower, and not ap-

DISTANCE	SPEED	HP	DURATION	ENERGY
100M	23Mph	2.0*	0.16 Min.	11,000 Ft-lb.
400	20	1.25	0.75	30,938
800	17	.7	2.5	57,750
1500	16	.6	3.5	69,300
26Mi.	13	.4	120.0	1,600,000

*This is an average. According to reference 1, a sprinter exerts from 3 to 4.5 horsepower accelerating at the start of a race.

Table I

Estimated HP required for running

plied horsepower; that is, not all of the energy produced by a person can be applied to one specific task; some of it is always "wasted".

Limiting Factors

Friction and acceleration:

After a 175 pound person has climbed 100 vertical feet, he has expended 17,500 foot pounds of energy and he now represents 17,500 foot-pounds of potential energy. But what work does a person do in running 100 horizontal feet? At the end of the race, a runner has the same potential energy he had when he started. The climber constantly pushes against an easily measurable force: Gravity. The forces against which a runner "pushes" are of a totally different origin.

The runner must produce energy to overcome not only external forces (wind resistance), but also internal forces. In fact, most energy produced by a sprinter is used to overcome friction in joints, and acceleration and deceleration of limbs. The last column of Table I lists the approximate total energy expended by a runner. Although a 100 foot (30 meter) race is not listed, it would most likely be run at 23 mph, would take 3 seconds, and require 2 HP. The total energy required would be

$$E = 550tP$$

$$= 550 \times 3 \times 2$$

$$= 3300 \text{ Foot-pounds,}$$

or about 19% of the energy required to raise 175 pounds 100 vertical feet. Now the question is: Must the climber also exert 3300 foot-pounds in addition to the 17,500? In addition to joint friction and acceleration of the limbs, a measurable amount of energy must be used to overcome rope friction.

Critical dimensions:

Another factor in the internal dissipation of energy is the rate of leg movement. Tests have shown that, for untrained bicyclists, maximum horsepower occures in the range of 65-90 rpm of the pedals; for experienced bicyclists the rate is lower. The distance between pedals on most 10-speed bicycles is 14 inches, almost the same step size one obtains with the Jumar-box method of climbing. Since there are 86 14 inch steps in 100 feet, a 30 second climb corresponds to 172 steps per minute, or 3 steps per second -- an extremely fast and inefficient pace. A 20 inch step corresponds to 120 steps per minute or 2 steps per second, a more reasonable pace, but still too fast for maximum efficiency. However, if 80 steps per minute are efficient, then for a 30 second climb, each step would have to be 2.5 feet, a ridiculously long step. Unless the climbing system used gears, the optimum step size is probably between 18 and 22 inches. The disadvantage of knots is that a climber cannot easily maintain this large a step since a knot has at least two inches of slack. Most Texas and 3 knot systems involve a large step to counteract this problem, but the gross movements involved in a long step prevent these methods from being fast.

Conclusion

Energy must be expended in climbing a rope to overcome the following (in order of importance): Gravity, external friction, and internal forces. Because these last two categories require a significant amount of energy, Figures 2 and 3 are not exact -- the times should be increased by at least 5%. Table II lists the standard climbing systems in order of efficiency and the corresponding best times each system can possibly produce for the 100 foot and 400 foot climbs, based upon Figures 1, 2, and 3, and some fudge factors for efficiency.

Two good short articles dealing with related subjects are "Future Performance in Footracing", SCIENTIFIC AMERICAN, June 1976, and "Esquire's Olympic Preview...", ESQUIRE, July 1976.

This analysis deals solely with efficiency of climbing systems for speed climbing, and is not intended to provide any information on the suitability of systems for actual cave use. Please do not reference this article in any form without written permission of the author.

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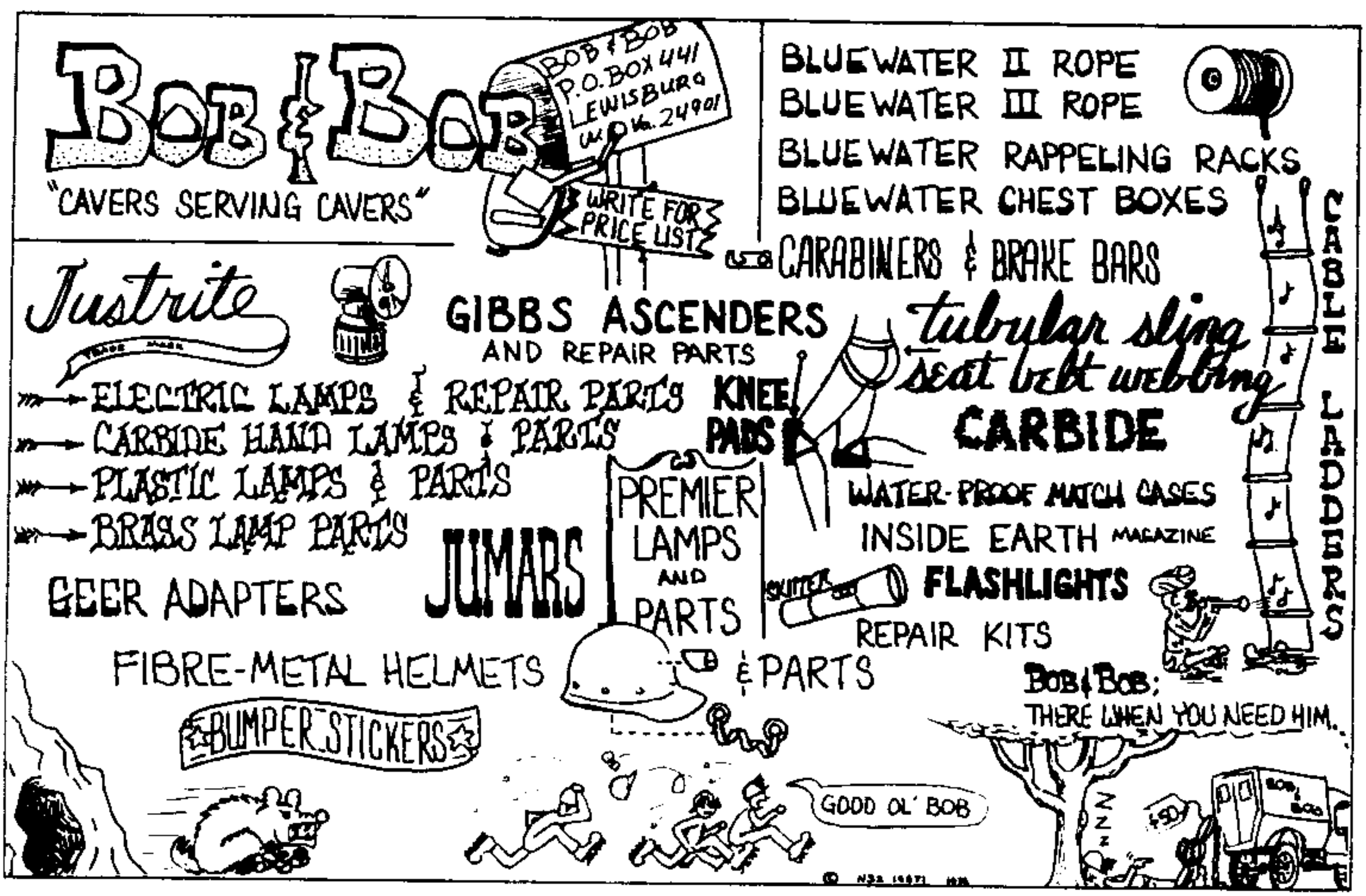
1. Whitt, F.R. and Wilson, D., BICYCLING SCIENCE, MIT Press.
2. Edholm, E.G., THE BIOLOGY OF WORK, McGraw-Hill.

SYSTEM	CURRENT RECORD/EST. BEST 100 feet	400 feet	DISADVANTAGES
Gibbs	28/24	5:54/3:10	
Jumar-box with extension handle	/32	7:50/3:40	Arm movement wastes energy.
Jumar-box	44/40	5:56/4:10	Arm movement wastes energy. Step size too small.
2-knot with box	1:07/50	/4:50	Same as above. Step size even smaller.
Inchworm	/	/5:20	Legs are moved together.
3-knot	1:25/1:05	10:01/5:20	Gross movements are inefficient for fast climbing.
2-knot Texas	2:20/1:35	14:55/9:00	Same as above

MINIMUM CLIMBING TIMES FOR STANDARD CLIMBING SYSTEMS (175 weight)

Table II



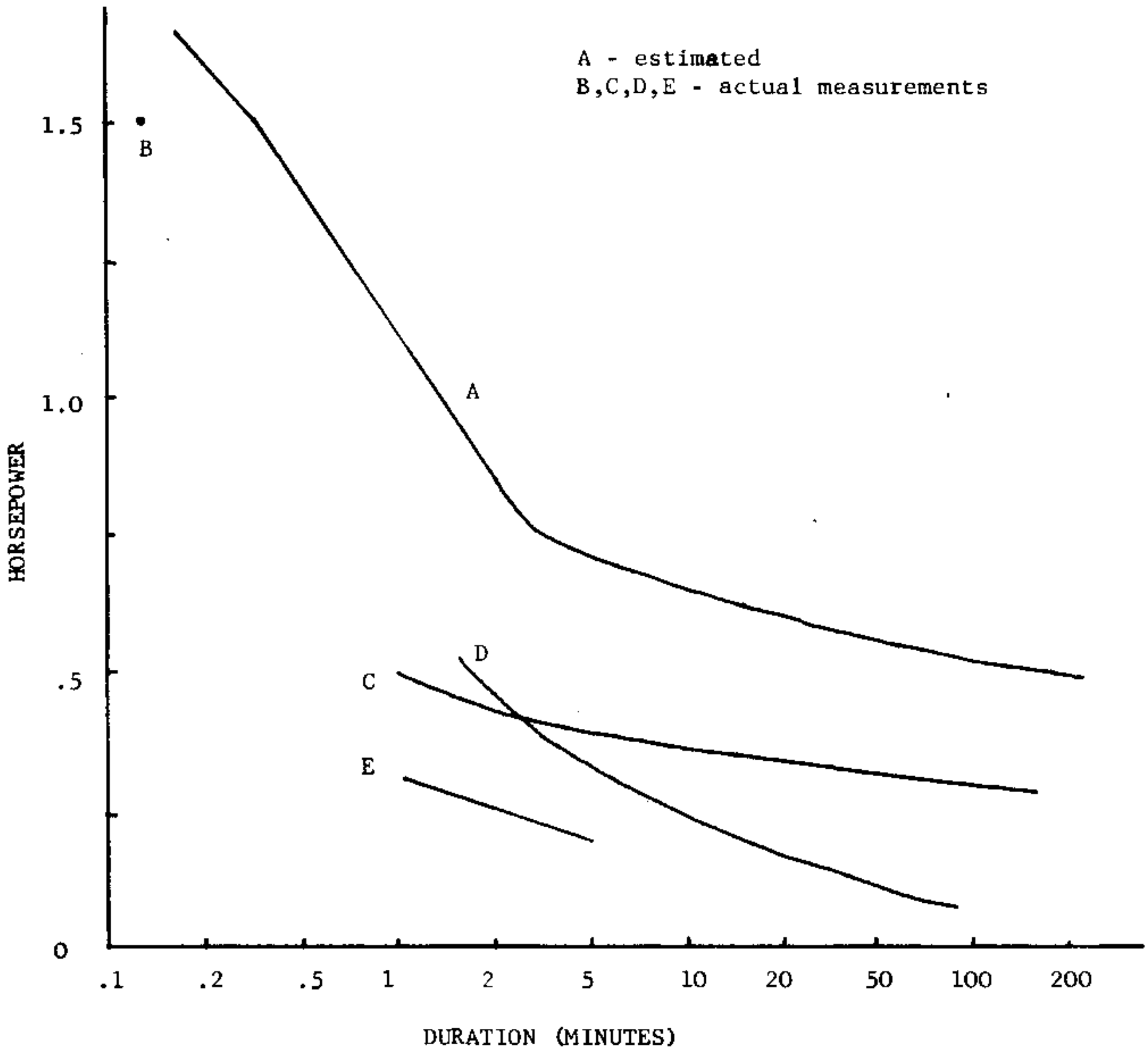


Figure 1. Peak Human Power Output for Different Durations
Copied from Bicycling Science

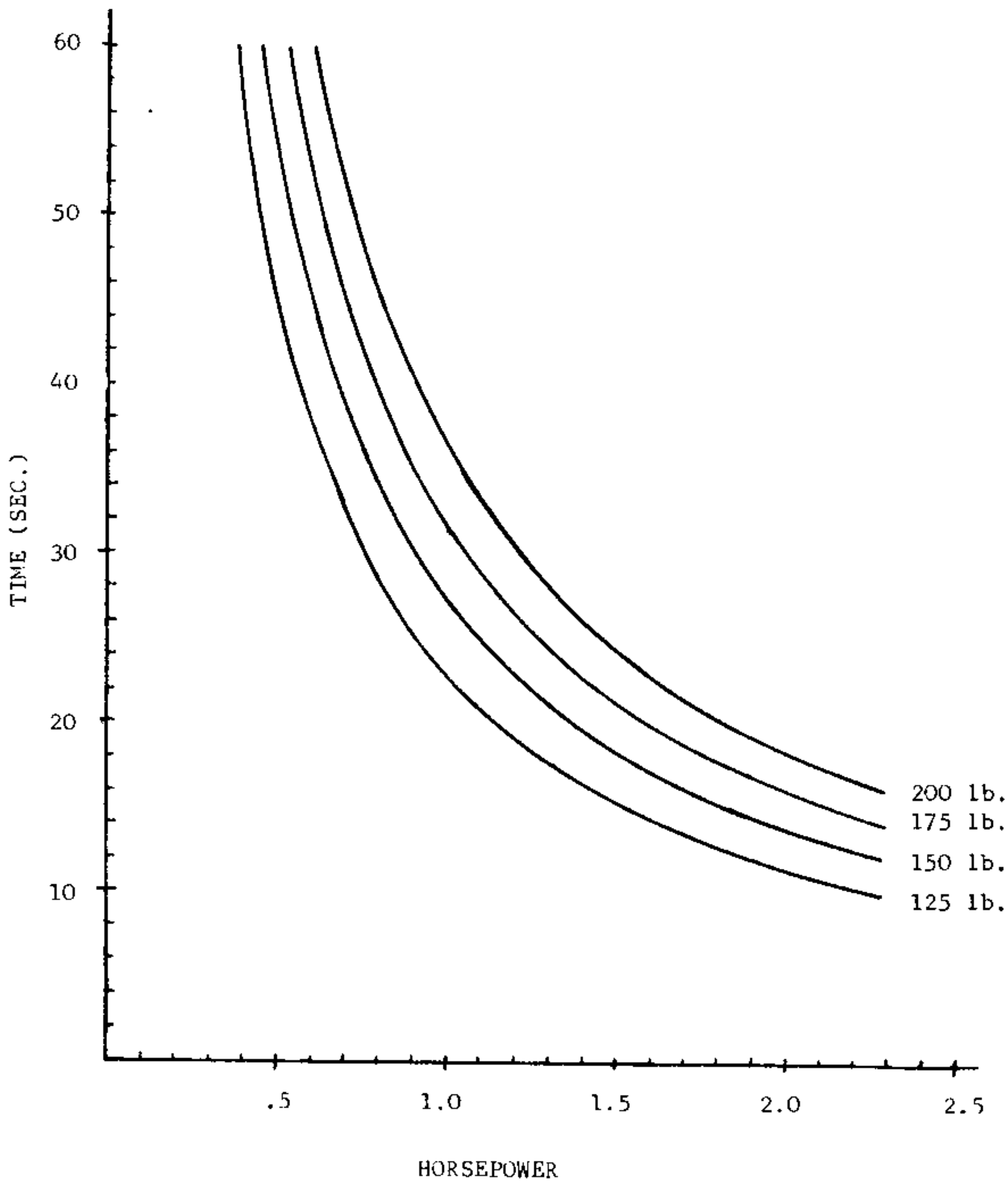


Figure 2. Time to climb 100 feet as a function of horsepower.

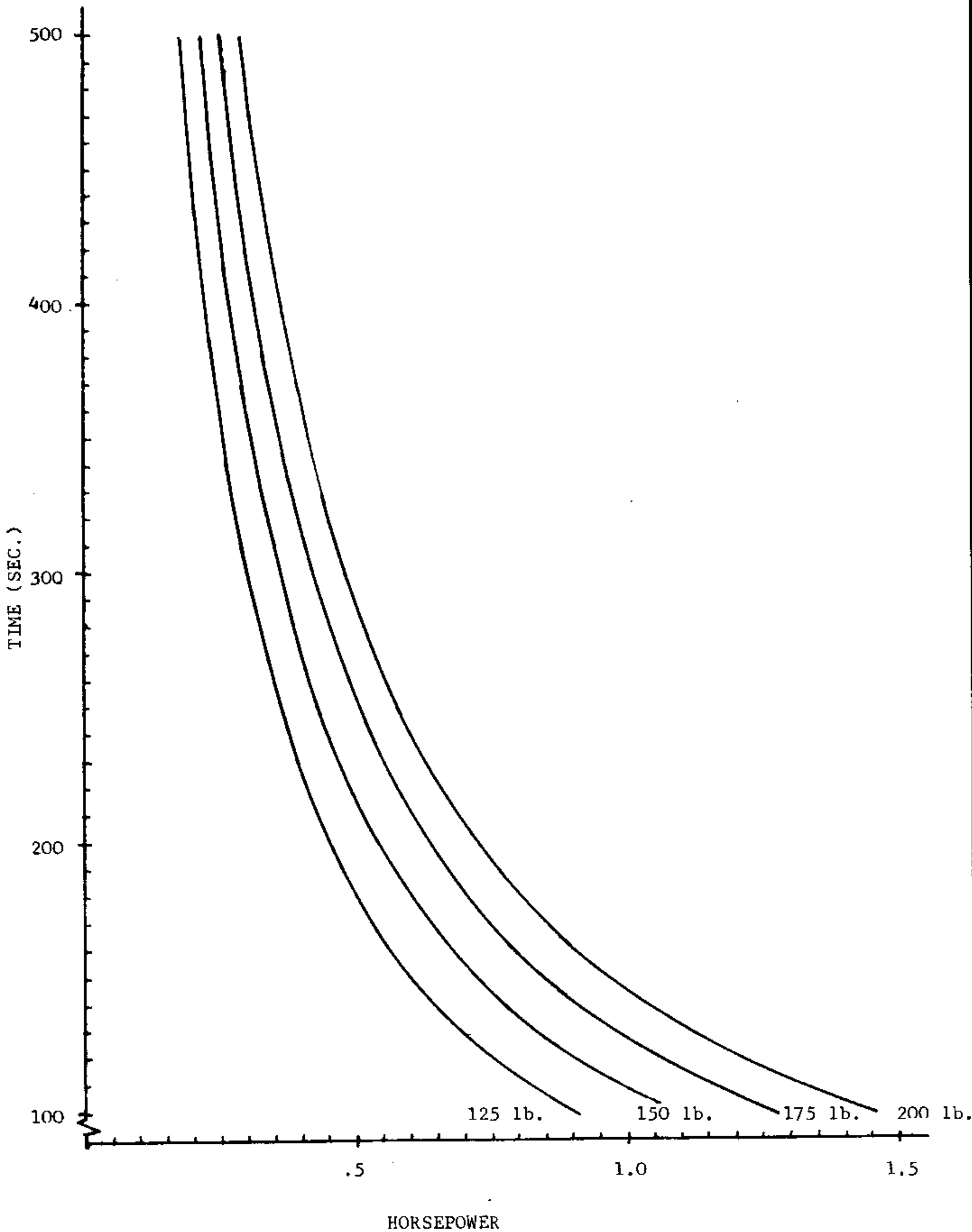


Figure 3. Time to climb 400 feet as a function of horsepower.

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