Safety and Techniques

Shock-absorbent Rigging

By William Storage

In a recent Safety & Techniques article ("Ropes, Loads, and Energy," December 1990 *NSS News*), John Ganter and I examined the way dynamic loads experienced by cavers and their equipment are dependent on properties of the rope absorbing the energy of a belayed fall or rebelay/secondary anchor failure. We showed how caving rope produces much higher loads than climbing rope for a given dynamic event. We suggested that the goal of technique development and equipment design ought to be reducing dynamic loads, not increasing equipment strength. This article takes a look at some ways of pursuing that goal.

The Problem—Dynamic Loads

Consider the case of anchor or rebelay failure. With multiple anchors and shared loading, failure is not likely. The risk increases, however, when we add an additional anchor, such as a bolt, out over the lip of a pit, to position the rope for a free hang, as in Figure 1. Many American cavers shy away from the concept of rebelays, while embracing the rope-positioning anchor. Yet the two are identical from the perspective of the forces that may occur in the event of failure. Since failure of these secondary anchors usually does not result in falling to the bottom of a pit, cavers tend to regard them as less important than the primary anchors at the pitch head. Consequently, the load is often on a single bolt rather than shared between two points, so secondary anchors are more likely to fail. Furthermore, a large amount of slack may be created if a rebelay fails, as shown in Figure 1. If a caver is hanging just below the secondary anchor (as opposed to farther down the rope), the small energy capacity of the short length of rope produces high loads. In a recent incident of this type at Rowten Pot, Nigel Robertson (1990) broke his back. The fall factor, 0.3, was in a range considered acceptable by cavers for dynamically loading a caving rope. Unfortunately, Nigel witnessed that fall-factor 0.3 with caving rope can still produce very high loads, as we mentioned in "Ropes, Loads, and Energy." If shock absorbent rigging were available, Nigel might have welcomed it.

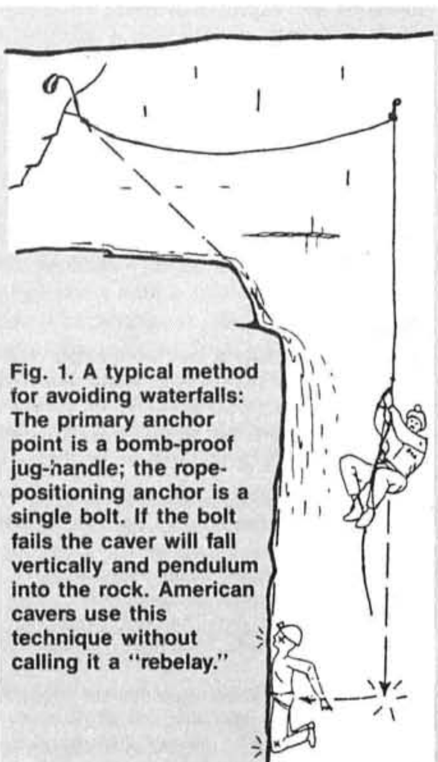

Fig. 1. A typical method for avoiding waterfalls: The primary anchor point is a bomb-proof jug-handle; the rope-positioning anchor is a single bolt. If the bolt fails the caver will fall vertically and pendulum into the rock. American cavers use this technique without calling it a "rebelay."

The First Step—Anchor Integrity

Our effort to reduce the occurrence of accidents like the one at Rowten Pot would be most productive by concentrating on preventing falls (dynamic events) from rebelay or secondary anchor failure in the first place, thus precluding the need for shock-absorbent rigging. This can be achieved by proper use of redundancy and by good bolting technique. This is the intent of our work on artificial anchors ("Artificial Anchors for the Present and Future," *NSS News*, May, 1990—update to follow this year) and non-permanent/natural anchors (work in progress).

The Second Step—Reducing Fall Factor

We must still consider failure of existing single-point rope-positioning anchors in caves, however. The dangers of the rope-positioning anchor can be reduced by realizing that it is in fact a rebelay and treating it like one, i.e. concentrate on reducing the fall-factor (Figure 2). The chapter on "Rigging Basics" in *Vertical* by Alan Warild (1988) discusses such techniques in detail.

The Third Step—Shock Absorbers

In rare cases of complex rigging problems it still may be that shock absorbing devices are desired. This is particularly true for rescues, where the static load (e.g. rescuer, victim, and gear) is higher, and the dynamic load from failure of a rebelay or rope-positioning anchor may be high enough that an ascender cuts the rope (Fuller, 1978; Dill, 1990). Several approaches have been used.

Rigging Pitches with Climbing Rope

Rigging caves with climbing rope instead of caving rope would reduce dynamic loads, but the springiness (low spring rate) of such rope would cause two problems. First, ascending cavers dislike wasting energy fighting the bounce. Second, the bounce increases the risk of the rope sawing over sharp edges.

Shock Absorber Knots

In Europe it is common for cavers to employ knots and hitches as shock absorbers for potential rebelay failures. An overhand knot with a short loop is often used since a portion of the loop will feed through the knot when a sudden load is

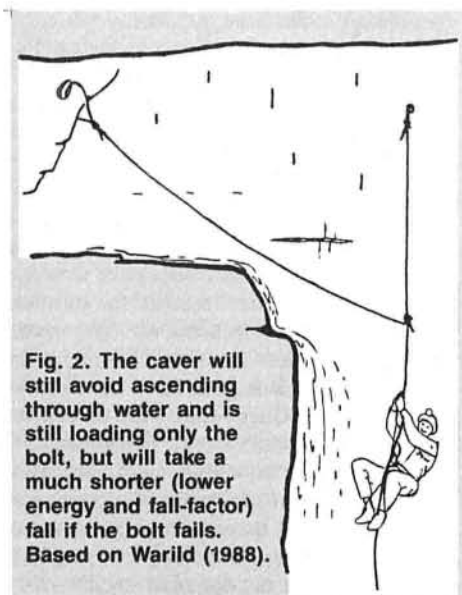

Fig. 2. The caver will still avoid ascending through water and is still loading only the bolt, but will take a much shorter (lower energy and fall-factor) fall if the bolt fails. Based on Warild (1988).

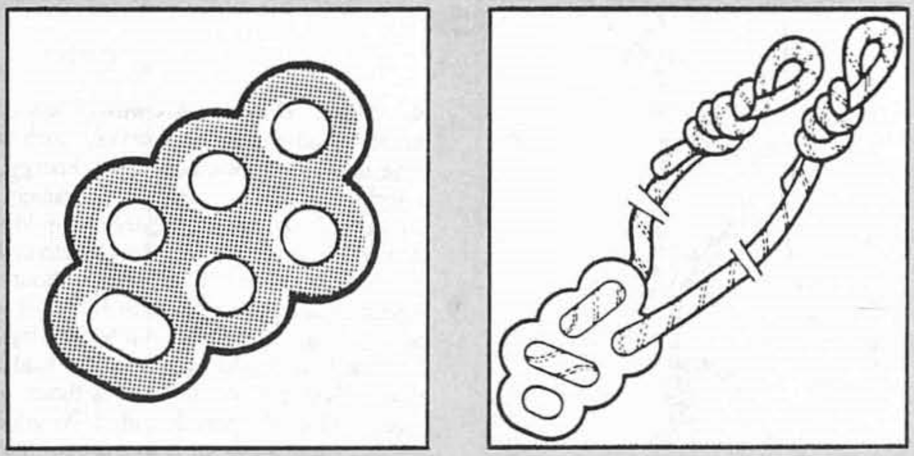

Fig. 3. A brakeplate-type shock absorber. From an advertisement by Edelrid.

applied. Meredith and Martinez (1986) instruct to use the knot in a section of rope which will only be loaded in a fall. This is sensible since while it absorbs energy, the knot also reduces rope strength. Reports from cavers indicate that the shock absorber knots are often used without this redundancy, however.

Alan Warild (1989) and others have noted that the energy absorbing capability of knots in caving situations is highly predictable. I support this observation on the grounds that knot energy absorption is a direct function of the frictional properties of the rope, which vary tremendously with water, mud, and aging. Warild has also noted that the strength reduction caused by the knots is a serious concern if they are used to reduce loads in small diameter (e.g., 8 mm) rope, which is sometimes used to rig caves (described in Warild's chapter on Advanced Rigging).

In surface rescue rigging and in lab tests, load releasing hitches, Prusik knots, and similar knots have been shown to be effective shock absorbers (Larson, 1989). Test data indicates that these are far more effective than the simple overhand-knot-with-loop arrangements used in caving. While the problem with variability of friction is still a concern with this technique, these techniques could be valuable in self-rescue situations in caves.

Brake Plates and Racks

In principal, any rappel device or belay plate might be adapted to the problem of anchor failure. Several devices resembling rappel racks have been described by Serafimov (1990). Another type is an aluminum plate through which a rope is strung. When a large dynamic load is applied, an amount of slack, left hanging above the device, is pulled through it and friction in the device slowly decelerates the caver, reducing the peak dynamic force. The energy goes into heating the device, just like a rappel rack. One such device on the market is the Kisa (Ganter, 1986), available from Caving Supplies in U.K. Another, called the "Limit," is manufactured by Edelrid (Figure 3).

These devices were actually designed to be used at a lead rockclimber's harness, an environment more favorable than caves for repeatability of friction. Since they rely on friction to control dynamic loads, they are subject to the same problems as shock-absorber knots in caving applications. Like rappel racks, they really need to be adjustable to provide the desired protection. Unlike rappel racks, there is no feedback to the user; no indication of what adjustment is needed.

Yielding Devices

In industrial applications, designs relying on friction to control loads have given way to devices that yield, converting energy into permanent material deformation. A noted industrial example of this was the change from sliding grips to swage-in-tube automatic adjusters in multiple disk brakes for large vehicles. The former relies on the friction of the grips to control the load at which they slide to adjust brake pedal travel. The latter relies on the strain energy needed to deform (yield) a hollow tube. Changes in humidity and the presence of grease, dust and contaminants caused too great a variation in friction with the grips. Grips slipped at the wrong time (brakes locked on) and failed to slip on command (no brakes); both were rather serious failure modes. Since yielding is a consequence of basic material properties, the swage design is dependable; it is insensitive to environment. Similarly, mud and water in caves can cause rather large variations in the friction in brake plates and shock-absorber knots. Absorbing energy by yielding a material is not subject to the variability of friction.

The Yates Screamer

A yielding technique used in astronautics to limit loads—from the opening of braking parachutes, for example—has found its way into climbing circles. In fact one company, Yates Gear Inc., manufactures load limiters for both applications. The Yates Screamer (Figure 4) is a strap of one-inch webbing with a sewn, full-strength clip-in loop at each end. It is folded and stitched onto itself so that the tension between the loops falls on only a few threads at a time. As the applied force increases to about 500 pounds, the threads break and absorb energy. If the

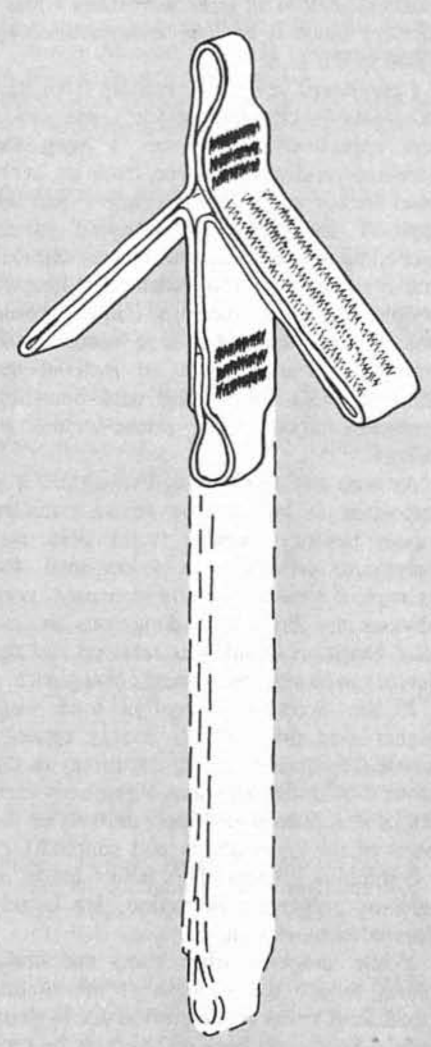

Fig. 4. The Yates Screamer, new and fully activated. The Screamer is supplied with an elastic sheath covering the central part of the unit, which keeps the wings tucked until it is activated. Earlier models, activated by ripping through a series of weak-bar tacks, were discontinued because of the potential for carabiner gate vibration.

applied load falls below 500 pounds, the remaining stitches stay intact. A fully activated (ripped open) Screamer still has strength similar to other sewn webbing loops, about 6000 pounds, and is thus adequate for rigging.

A number of similar devices have appeared on the market over the years. John Bouchard of Wild Things was apparently the first to make them for rockclimbing; however, they do not appear in the current Wild Things catalog. A product called the Forrest Fall-Arrest was described in Mountain magazine (Durkan, 1983). We have been unable to locate Forrest Mountaineering, Ltd.; they appear to have gone out of business. DMM in U.K. advertises a load-limiter, which is actually manufactured by Yates in the U.S.

I purchased several Screamers from REI (Recreational Equipment Inc.) and ran a few experiments at home. I hung the Screamer and a short rope from an overhead anchor and rigged ascenders onto the rope. I found that by jumping in an ascending rig on a short rope, a climber could rip open a few stitches. With two people on rope, the top climber could bounce hard onto his seat harness and activate (rip out) about an inch of the stitching. This tells us that such bouncing generates about 500 pound-inches of energy.

As with any engineering evaluation, it is important to look at the device's failure modes before accepting it for field use. Premature activation, at a low load, for example if weaker stitching were used, is an obvious one. But it is not dangerous because load bearing capability is retained and the device can be replaced without consequence.

If the Screamer actuation load were higher than intended, its energy capacity would be increased, but the force on the caver would also increase. Significant variations in actuation load seem unlikely on the basis of the repeatability and simplicity of the stitching process. This failure mode, as well as premature activation, are largely precluded by design.

While shock-absorber knots and brake plates reduce the strength of the lifeline because of stress concentration due to sharp bends, Screamers have no effect on the rope they protect. Since they are loaded in series with the lifeline, it is their own strength which is crucial. Complete structural failure of a Screamer is rendered inconsequential if it is rigged in parallel with a piece of the main rope containing one foot of slack (Figure 4). Without this redundancy, a Screamer structural failure might be as dangerous as a main rope failure, depending on rigging circumstances.

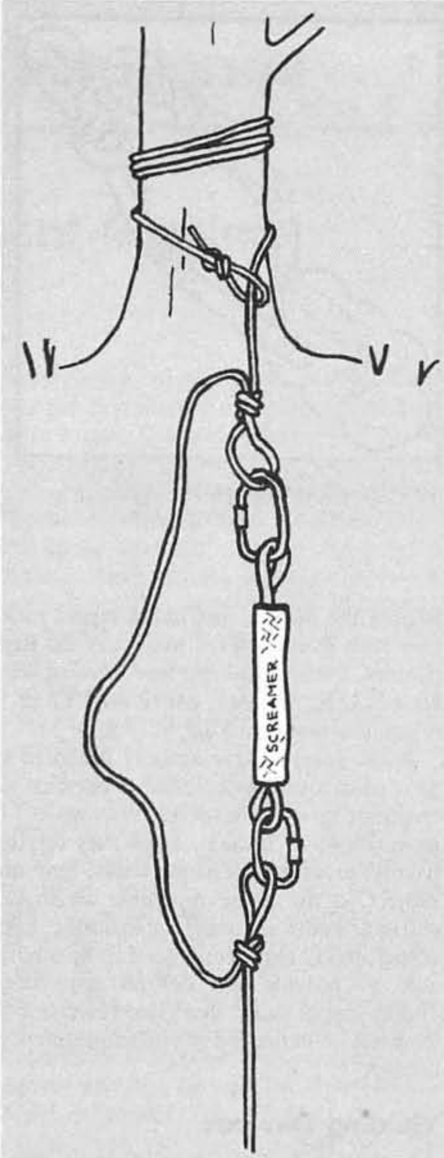

Fig. 5. This Yates Screamer will take the full climber load but is rigged in parallel with a section of the rope containing one foot of slack.

How Much Would a Screamer Help?

These failure modes—structural failure, unwanted activation, and loss of activation capability-seem to be the significant failure modes for this type of product. Considering these failure modes in light of expected uses (rigging applications) tells us that the product can be used safely; it stands little chance of hurting us on its own. But how much can it help in a fall?

To answer this question we can get a lot of volunteers to risk back injury or we can resort to an analysis of the underlying physics of the situation. The latter seems somewhat less painful.

Knowing the actuation load of Screamers (about 500 pounds) and their extension or rip-out length (about one foot) tells us that their energy consumption is about 500 pound-feet. With this knowledge we can modify load-elongation curves, such as those used in "Ropes, Loads, and Energy," to include the characteristics of Screamers.

Figure 5 shows a comparison of load-elongation curves for a ten-foot length of 11 mm caving rope, with and without a Screamer attached. A fall with 450 lb.-ft. of energy (e.g. a 180 lb. climber taking a 2.5-foot fall) results in a dynamic load of about 1300 pounds (ouch!) without the Screamer and 500 pounds with it. An added benefit of the Screamer is that anchor loads are similarly reduced. This is, of course, the whole reason rockclimbers use them.

Conclusion

Improving anchor quality reduces the probability of a dynamic event (fall). Proper rigging reduces the fall height and energy in the event of a fall. Shock absorbers reduce the dynamic load (force) for a given fall height. Shock absorbent rigging for cavers will be a concern as long as accidents occur from anchor failures, such as the one at Rowten Pot. I think the Screamer goes a long way toward filling this need; and should be on hand when existing rigging is used for cave rescues. The greatest potential for preventing injuries from anchor failure probably lies in improving our technique for rigging and bolting. That is where the Safety and Techniques Committee will continue to direct its attention.

Acknowledgments

John Ganter and Steve Worthington helped with literature searches and provided valuable input to this article. The McDonnell Douglas Astronautics Company supplied test data on Yates Screamers. John Marquart provided results of his study of rope characteristics and editorial assistance. John Dill of the Search and Rescue Office at Yosemite National Park provided information on rescue rigging along with extensive and insightful recommendations.

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Durkan, Dave. 1983. "Gear" (column). *Mountain* #93, Sept./Oct., p. 48.

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Robertson, Nigel. 1990. "Short, Sharp Shock at Rowten Pot." *Caves and Caving* 48, Summer, pp. 31-32.

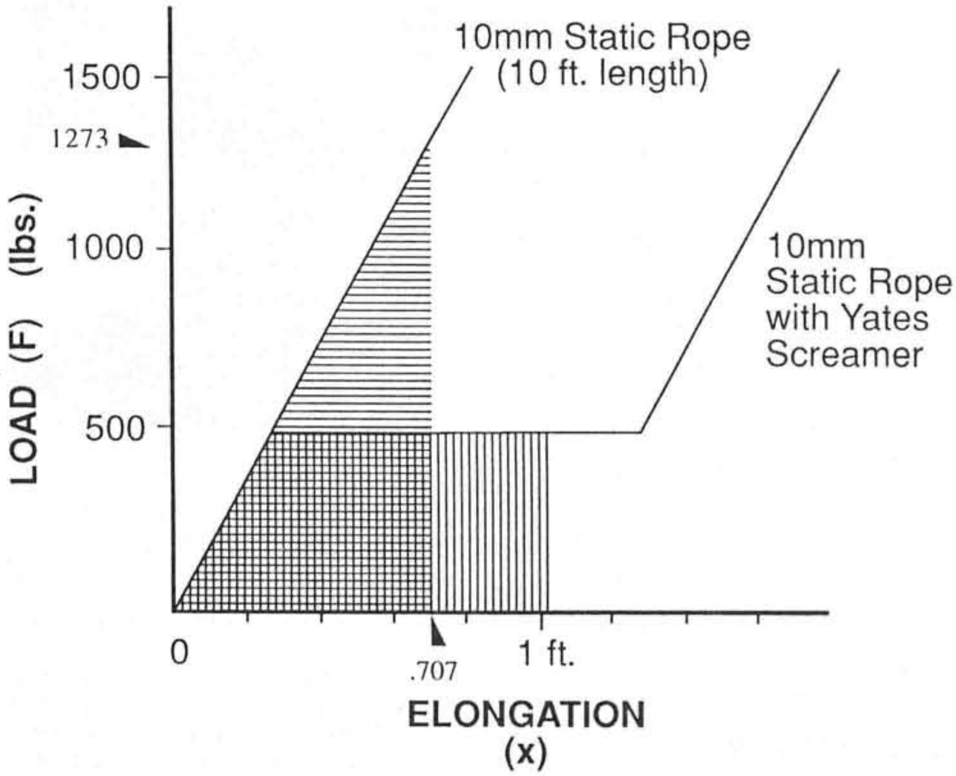

Fig. 6. Comparison of load-elongation curves for a 10-ft length of rope with and without a Screamer: The elongation of the 11--mm caving rope is nearly linear with respect to load in this region of the curves. The shaded area under each curve represents an energy of 450 lb.-ft. Resulting loads are read from the vertical axis. The spring rate of 1800 lb./ft. (10 ft. length) used here is for illustrative purposes and is a rough estimate only. Spring rates vary greatly by rope type and age. This simplistic example also neglects several lower-order effects that would change the outcome in an actual fall underground.

Calculations:

F = load or force, x = elongation or extension,
A = Energy = area under curve

k = spring rate of rope = 1800 lb. /ft.
$F = 1800x$
A (without Screamer) $= 1/2\ kx^2 = 900x^2$

Given that A = 450, then $x = \sqrt{450/900} = .707$, and
$F = (.707)(1800) = 1273$ lb.

Load with Screamer = 500 lb. for 70 lb.-ft. $\leq A \leq$ 570 lb.-ft.

Serafimov, Konstantin. 1990. "The New Falling Energy Absorber 'FRAMS'." *Nylon Highway* No. 30, January, 1990, pp. 4-6.

Warild, Alan. 1988. *Vertical.* Sydney, Australia: The Speleological Research Council Ltd. pp 64-66.

Addresses of Suppliers

Caving Supplies, 19 London Rd., Buxton, Derbyshire SK17 9PA, England

DMM International Ltd., Llanberis, Gwynedd, U.K.Edelrid, D-7972, Isny, Germany

REI, P.O. Box 88125, Seattle, WA 98138-2125

Wild Things, Box 182, N. Conway, NH 03860

Yates Gear Inc., 1600 East Cypress Ave., Suite 8, Redding, CA 96002.

Ropes, Loads and Reader Comments

By William Storage

Dr. John Marquart noted several errors that appeared in "Ropes, Loads, and Energy." First, in the table accompanying Figure 2, page 318, the energy absorption per foot of dynamic rope is misentered as 4300 lb.-ft. It should read 430 lb.-ft. John also noted that the units of Area are mislabeled throughout the table as lb.-ft/lb. which should read lb.-ft./ft. Finally, John noted inconsistencies in the values used for rope spring rates. I invited him to help in our study of rope characteristics. He arrived at the average value of 180 lb.ft./ft. used in the above article. Dr. Marquart will join us in further studies of rope characteristics.

Other readers questioned our position that for the load application speeds encountered in falls, rope strength is independent of application speed. Several readers suggested that high load application speeds result in low ultimate strength values. In general the opposite is true. Juvinall (1983) states, "...both the yield and ultimate strengths tend to increase with speed of load application." We maintain our original assertion and suggest that notions to the contrary arise from not understanding that dynamic load values are the consequence of rope stiffness. A number of studies aimed specifically at nylon rope and yarn support this. Those with sufficient interest to pursue some rather obscure references should consult the following:

Dunn, B.J. 1979. "Ropes Made from Man-Made Fibres." Section D, Publication 217. Bridon Fibres and Plastics, Newcastle Upon Tyne, England.

Figucia, Frank Jr. 1969. "The Effect of Strain Rate and Ply Geometry on the Stress-Strain Properties of Nylon Yarns." Technical Report (70-25-CE. US Army Natick Laboratories. Natick, Mass.

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Lenzburg, Arova. 1975. "How Old Is Your Rope." *Off Belay* #15, Apr. 1976. pp. 16-20.

Morton, W.E. and J.W.S. Hearle. 1962. Physical Properties of Textile Fibres. Manchester, England: The Textile Institute. p. 352.

Newman, S.B. and H.G. Wheeler. 1945. "Impact Strength of Nylon and of Sisal Ropes." *Journal of Research of the National Bureau of Standards,* Vol. 35. Washington, D.C. pp. 417-431.

Steinberg, H.L. "A Study of Personal Fall Safety Equipment." National Bureau of Standards, Report PB-269355. Washington, D.C. p. 70.

Obituary

Christopher Farley Yeager
NSS 31232 "The Kid"

On Friday, March 1, 1991, Indiana caver Chris Yeager was killed when his rappel rack became detached from his seat harness at the top of a 23-m shaft near Camp II in southern Mexico's Sistema Cuicateco. Chris was participating in the 1991 Proyecto Papalo expedition. After crossing a rebelay at the top of the pitch, Chris detached his last safety, and transferred his weight to his rack. Apparently his rack accidentally opened the "locking-D" carabiner that attached his rack to his seat harness, and he fell. The rack was found, still attached to the rope, two meters below the rebelay.

The shaft Chris fell down is approximately 850 m vertical, and 4 kilometers from the main Cheve entrance. With the consent of Chris' father, expedition members buried Chris in a nearby bivouac spot on Wednesday, March 13. A body recovery was deemed too hazardous to attempt due to the distance, difficulty, and nature of the cave.

Twenty-five years old, "The Kid" had been caving for four years, mostly in Indiana and TAG. He led the push of Indiana's Two Bit Cave, which is presently Indiana's second deepest. He also worked on caving projects in Sullivan's Annex and the Wyandotte Cave Ridge area. In December, Chris completed a through-trip in Mexico's Sistema Purification and successfully bottomed Cueva del Borborllon. Prior to the expedition, he climbed Mexican volcanoes Popocatepetl (5400 m) and Orizaba (5700 m). Orizaba is Mexico's highest mountain.

Chris is survived by his father and mother, Durbin and Willa Dean Yeager, and his brother Allan. All live in Coatesville, Indiana, a small town west of Indianapolis. He leaves behind many caving friends in Indiana and TAG, who will never forget his

Chris Yeager

enthusiasm, spirit, and dedication. We miss him dearly and wish he were here.

—John W. Stembel, Friend

Forum

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Cave Diving Kudos

Kudos to John Schweyen for his excellent article on cave diving in McFails Cave (*NSS News*, March 1991).

Mr. Schweyen's ability to interject a certain humor into the intricate nature of his push through the sumps of McFails made for very enjoyable reading.—*Mark Johnston, NSS 32857, Lubbock, Texas*

Errata

William K. Jones should have been credited with the section on "Locust Creek Cave Hydrology," a sidebar to John Schweyen's article, "Locust Creek Cave—Recent Extensions," in the May 1991 *NSS News*.

GYPKAP Discoveries Clarification

In the February 1991 *NSS News*, Steve Peerman and Dave Belski did a superb job in describing the gypsum cave discoveries of the GYPKAP. I am writing to clarify two points, one concerning the occurrence of salamanders in gypsum caves and the other about the world's largest room in a gypsum cave.

Tiger salamanders have been observed in other gypsum caves in the Southwest. Neotonic Barred Tiger salamanders were found in Nescatunga Cave in western Oklahoma by John Pollack in January 1969 when members of the Central Oklahoma Grotto were showing John and me the cave. Herpetologist Jeffery Black later studied this population (Black 1969). In his 1971 monograph on Oklahoma cave life, Black mentions other probable sightings of similar salamanders in Alabaster Cave and other Oklahoma caves.

The Trash-A-Dome Pit in Burro Cave, while unusually large for a room in a gypsum cave, is not the largest such room in the world. The dimensions given in the article are 41 by 54 m with a height of 55 m. (I have converted the dimension to metric because I am opposed to using the obsolete English measuring system, especially when doing an international comparison.) The largest gypsum sinkhole is Pozo de Gavilan in northern Mexico. It is formed in Jurassic gypsum and soft-gypsum cemented alluvium that covers the gypsum. At the bottom, it is 78 by 88 m. There is a 99-m vertical drop to get into the cave. A large and deep lake exists on one side of the pit. The volume of Pozo de Gavilan is at least 5.5 times the volume of the room in Burro Cave. See Russell and Raines (1967) for a map and description of the pit.

Some cavers would argue that Pozo de Gavilan is not a gypsum cave since it is not in darkness and is not entirely formed in gypsum. For people who espouse such a definition of a cave, the world's largest room in a gypsum cave is in Himmelreichhohle in Germany. This cave has a rectangular room 170 m long, 70 m wide and averages 15 m in height. The volume of this room is about 1.5 times the volume of the room in Burro Cave. Stolberg published a map of the cave in 1926. Hensler (1968) wrote a description in English of this and other caves of the Harz region; his map is based on Stolberg's 1931 survey. Reinboth (1970) published the most detailed map of the cave.

Kempe (1978) and Breisch (1978) give a

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ACCIDENTS/INCIDENTS

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American Caving Accidents
505 Roosevelt Street
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