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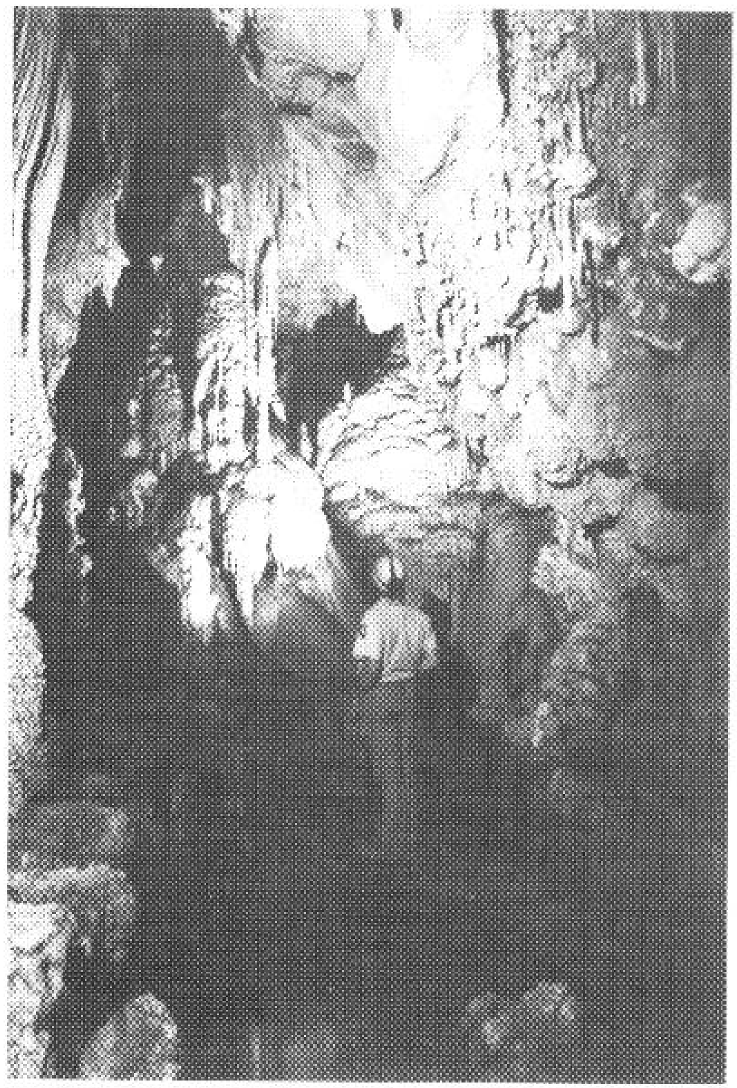
The Spelunker's Delight: Cave Surveying Made Easy



The Spelunker's Delight: Cave Surveying Made Easy

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INTRODUCTION

The purpose of this report is to document results of a laser system survey of Cottonwood Cave, one of over 110 known caves on the Guadalupe Ranger District of the Lincoln National Forest. Illustrated are laser system capabilities and the potential for automated manipulation of resulting data into resource cataloging, monitoring tools, and improvement design to aid in cave management. Cave resources exist the world over; the location for this trial of the laser system was chosen based on accessibility and the willingness of District personnel to try new technologies. Discussion of caves is made against the backdrop of the Guadalupe Ranger District, as it has been instrumental in developing Forest Service cave management programs.

No permanent benchmarks were established during the survey; it was intended for test purposes only and not to officially map the cave or provide the basis for design of improvements. The effort was made mainly to test the underground performance of the laser instrument, to aid in developing cave surveying methodologies, and to experiment with the automated reduction and manipulation of resulting data.

The test and subsequent manipulation of data met expectations. The laser system is useful for mapping, and data can provide the basis for design of improvements as well as assist in monitoring cave resources and developing trending information. Futuristic applications include computer-aided virtual reality trips into caves.

This report provides background information on caves in the Guadalupe Mountains, cave surveys, specifics on the Cottonwood cave survey, and recommendations for planning and performing cave surveys. An appendix contains a discussion of difficulties to be expected when surveying caves, details of a survey routine developed for caves in which the instrument compass fails to function properly, and information concerning manipulation of cave survey data.

BACKGROUND

Caves exist under federal, state, and private lands across the country and on every continent. The Lincoln National Forest has remarkable and important cave resources; indeed, visitors and scientists come from the world over to explore, study, and enjoy these caverns in the exposed Permian-age reef. The nonrenewable resources are extremely fragile; rising spelunking popularity and scientific interest has increased the potential for damage. The Federal Cave Resources Protection Act mandates Federal agencies to secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people. This involves management designed to preserve the delicate balance between natural undisturbed ecosystems, recreation, research, and use of surface areas above caves.

Description of Caves on the Guadalupe Ranger District

Caves on the District contain undisturbed significant world class formations, depositions, and speleothems of rare form, size, and beauty. Most caves are relatively dry; however, humidity in deeper caves is normally 99 percent, allowing many actively growing speleothems. Known caves contain pools, but none have running streams.

Rooms vary in size; some exceed 100 meters in diameter. Some have ceiling heights of 60 meters, and some contain vertical pits over 100 meters deep. Surveys reveal some caves contain several kilometers of passages.

The development of many caves is joint-controlled. Joints or fractures dictate water migration, solutional activities, and the unique geologic process in which hydrogen sulfide gases mix with ground water to dissolve huge chambers in limestone.

Cave Resources of the Guadalupe Ranger District

Caves exhibit prehistoric and historic use, fossils, bat hibernacula and nurseries, solutional formations, sediments, and other examples of hydrologic, geologic, and biologic processes. Unique, non-renewable geological formations and paleontological and biological resources, including a variety of rare and endangered plants and animals, exist in the caves.

Wildlife and vegetation are found near entrances while interiors also support bats, snakes, insects, and microorganisms. Isolated pools within unexplored passages likely contain invertebrate and microorganism populations undisturbed for thousands of years. Pristine cave ecosystems provide unique opportunities for scientific research. It is necessary to prevent disturbance or destruction from contaminants brought in by explorers or resulting from surface activities.

Faunal remains thousands of years old are found in several caves; some being quite rare. One cave contains two complete skeletons of an extinct Pleistocene Jaguar, (only a few specimens are known) another perhaps the most complete Pleistocene Short-Faced Bear skeleton ever found. Many caves contain clay deposits rich with pollen and charcoal. Stratified deposits, dating back 30,000 years, present an unparalleled record of past ecosystems. These deposits offer a unique opportunity for paleoecology study and enable reconstruction of plant and animal communities that lived in and around the caves long ago.

Recreational Opportunities in Caves

Recreation constitutes the majority of cave use. Many spelunkers hike ridges on the District in the attempt to find new caves. Some caves offer physical challenges not available anywhere else. The scenery around many caves is unsurpassed in the state, and caves on the Forest are among the most beautiful in the world.

Cave Management

In 1972 the District began the first Forest Service cave management program. It became clear that cave management prescriptions were necessary if delicate cave resources are to be preserved and protected from vandalism and unintentional damage caused by caving. Priorities included cave inventory and establishment of classifications for contents and hazards.

CAVE SURVEYS

Surveys are a necessary part of a cave management program. Mapping and inventory are required for documenting physical attributes, while realizing the extent of caves, their size and shape, and the composition and location of their various resources forms the basis for management. Surveys provide information useful to visitors, including length and grade of trails and the locations of points of interest along the way.

Viewing cave survey plots can provide the flavor of spelunking to cave enthusiasts unable to physically enter caves. To active cavers, they are a useful aid in determining which cave best deserves devotion of limited time and energy.

Methods used in the past for cave surveying include the standard traverse and cross section routine using cloth tapes, hand clinometers, and hand or staff compasses. This is probably the simplest routine used to document features along a strip or corridor.

Higher precision instruments, such as engineering levels, transits, theodolites and electronic distance measuring (EDM) devices, are used for higher order work. Distances to breaks and points of interest on walls and ceilings must be estimated when using conventional instruments, as these locations are inaccessible to head chainpersons or prism rodpersons. For example, the maximum ceiling to floor dimension in the main chamber of Cottonwood Cave was previously estimated at 27 meters (90 feet). The laser instrument measured the much greater distance of 53 meters (173 feet).

Past survey systems required head chainpersons or prism rodpersons to hike across the cave floor to walls, formations, or points of interest. The laser system functions with much less foot traffic, greatly reducing disturbances and irreversible impacts.

Cost information for past surveys is unavailable. Extrapolation of information from road projects indicates possible savings of 59 to 75 percent when using the laser system for cave surveys. (See references 1 and 2.) Laser system functionality and economics make possible the completion of more individual cave surveys—with more extensive information gathered—within the same time and budget allowed for standard methods.

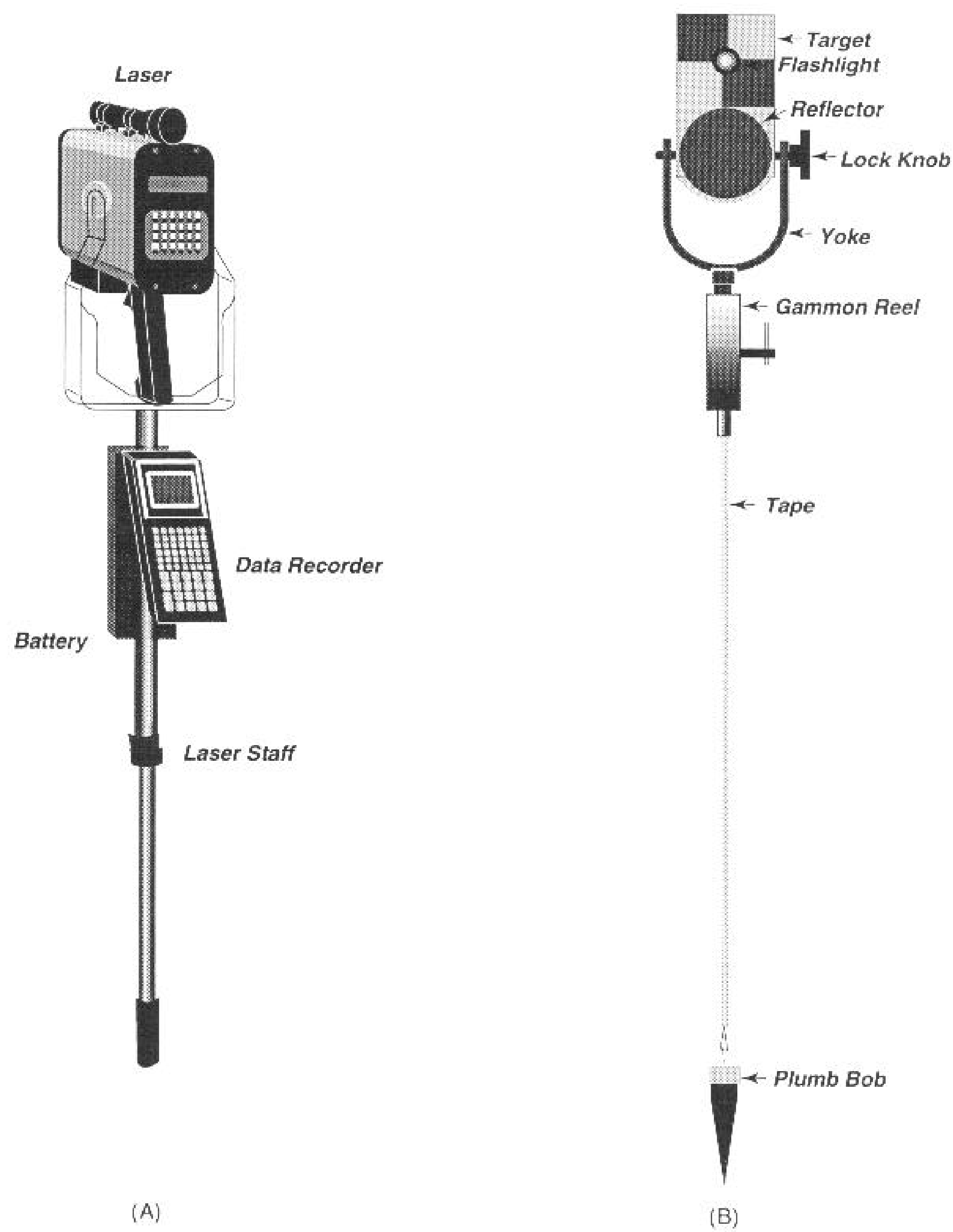
The Cottonwood Cave Survey

The instrument—the Laser Technology, Inc., (LTI) Criterion 400 Survey Laser—functioned well underground, making and downloading three dimensional measurements to the LASERSOFT survey management platform. The accuracy and precision of the laser exceeds that of hand instruments (reference 1), providing data suitable for most applications. (See figure 1 for the field hardware setup.) Prior to the effort, uncertainty existed as to the performance of the instrument compass in supplying azimuth measurements below ground.

LASERSOFT converts survey data into stacks of 3-D coordinates importable to CAD software, allowing plan, profile, cross section, and perspective views to be constructed and contoured as shown in figure 2 (see center spread, pages 4 and 5). At the time of survey, no metric version of LASERSOFT existed; therefore, figure 2 plots are in feet rather than meters. LASERSOFT was created by LTI software engineers to manage laser surveys, and runs on certain hand-held MS-DOS compatible data recorders and the PC. The Corvallis Microtechnology, Inc., (CMT) PC5-L recorder was used for this survey.

The survey was performed by Tony Beke, facilities engineer on the Lincoln; Pete Brady, maintenance worker; and Warren Sutton and Jeff Moll. The survey was supervised by Mike Harrison, a cave technician on the District, and sponsored by the recreation program at the San Dimas Technology and Development Center, San Dimas, California.

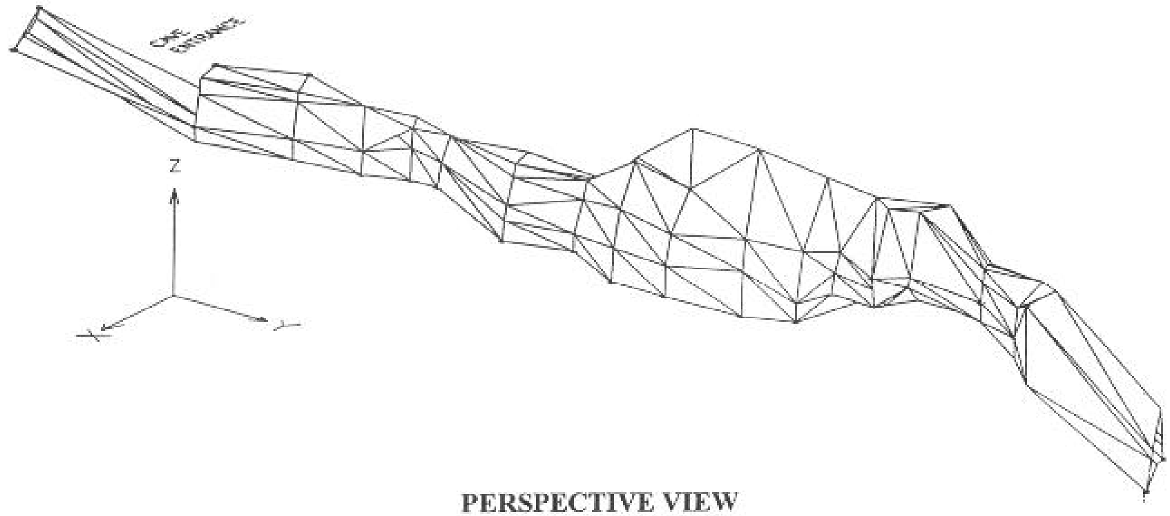
The Cottonwood Cave survey began with Foresight/Backsight (FS/BS) traverse links in an effort to determine compass performance underground. This is recommended practice for detection of local attraction problems, such as those caused by magnetic materials in the bedrock. The azimuth readings were within manufacturer tolerances, allowing a standard traverse and cross section routine. If the compass functions adequately in the cave, a "repeating radial" routine may also be used for side shots made from PI's and turning points (3). This results in the increased survey efficiency and effectiveness, as side shots may be quickly made to any point in any direction.



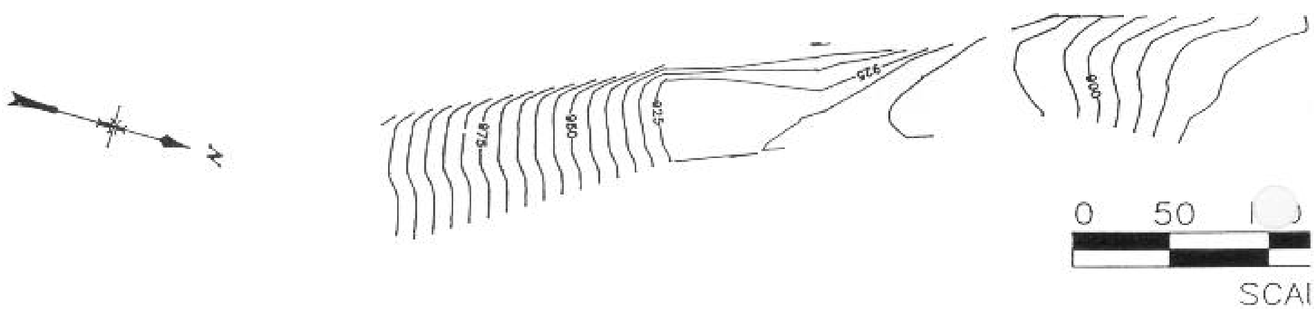
(A) Instrument, battery, and data recorder mounted on telescoping rod

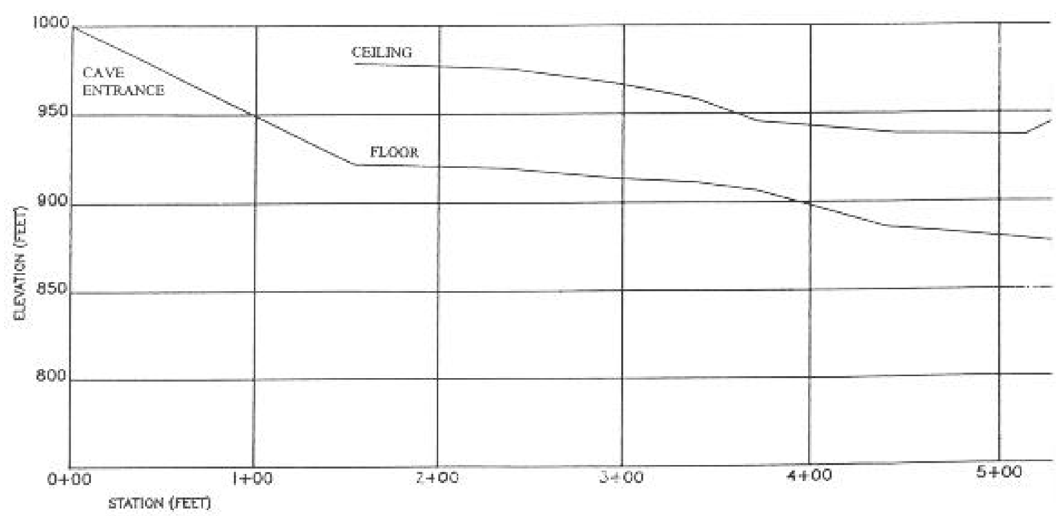
(B) Yoke-mounted reflector assembly with gammon reel, tape, and plumb-bob

Figure 1.—Laser survey system hardware.



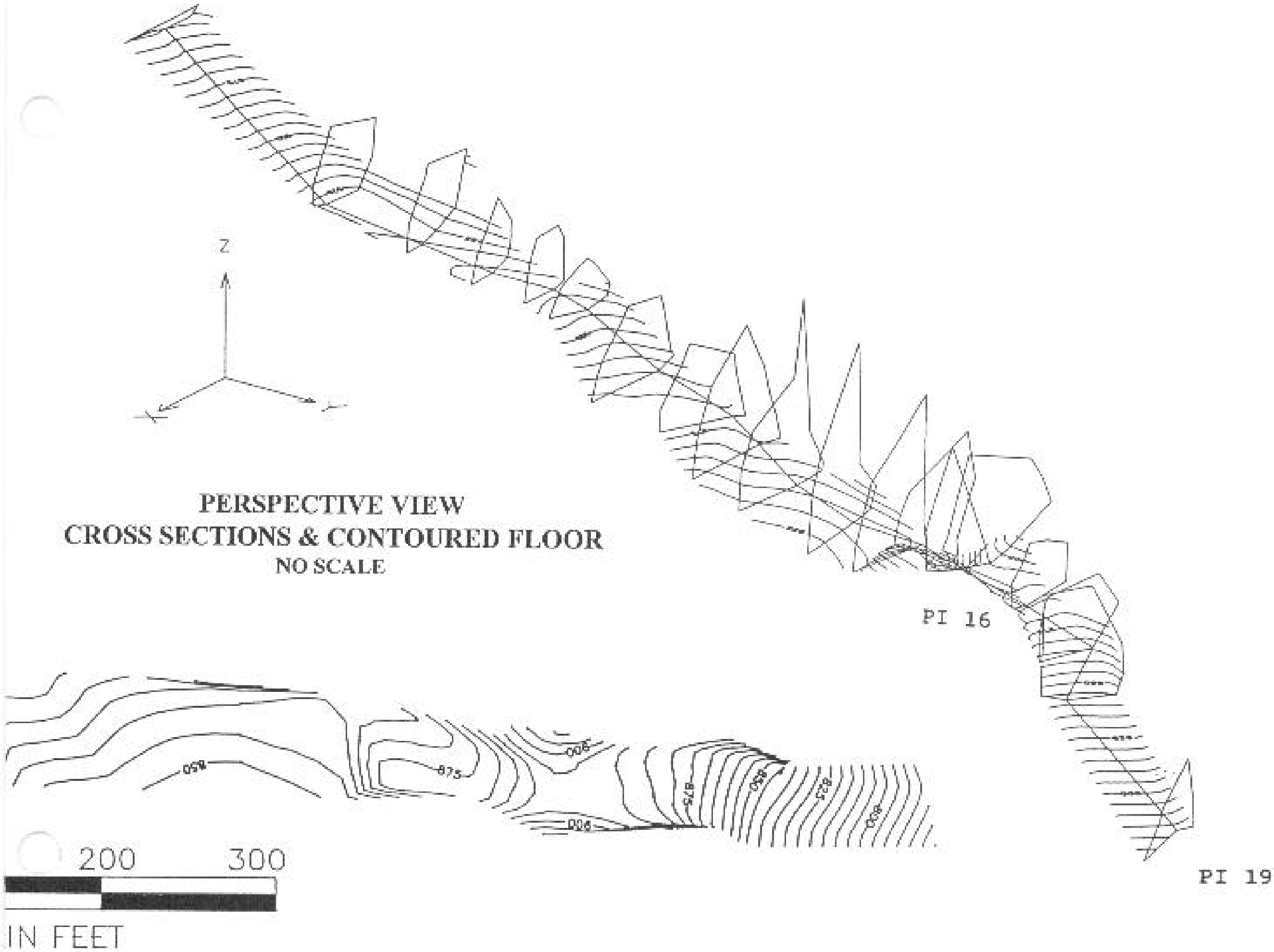
PERSPECTIVE VIEW
TRIANGULATED IRREGULAR NETWORK
NO SCALE



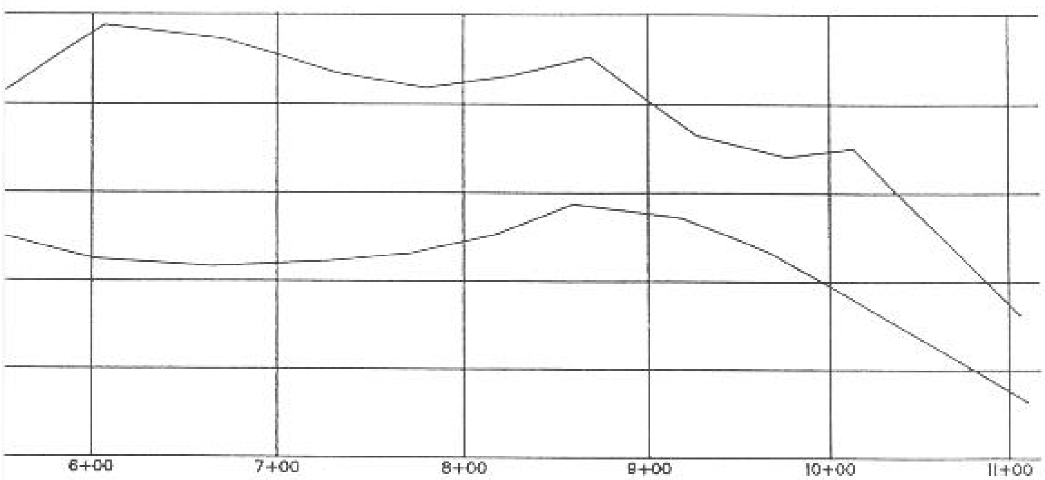


PLAN AND
CONTOURED FLOOR PLAN

Figure 2



PERSPECTIVE VIEW
CROSS SECTIONS & CONTOURED FLOOR
NO SCALE



OFILE VIEWS
EILING AND FLOOR PROFILES

s ey plots.

Compass malfunction due to magnetic anomalies would dictate execution of a "triangulating traverse" routine, with cross sectioning, as described in the appendix.

The survey consists of a 342 meter (1120 foot) traverse having 19 Points of Intersection (PI's), and shows a 70 meter (230 foot) drop in elevation. Each traverse "link" is composed of a foresight from one PI to the next, and a backsight from that PI back to the previous Points of Intersection.

This traversing routine allows averaging of FS/BS data, increasing accuracy and highlighting discrepancies, as BS data should be the same—within instrument sensor tolerances, operator error, and accounting for directional differences—as the FS data. Table 1 provides the data for traverse link 3-4:

The occurrence of discrepancies between distance and inclination readings on a link, barring instrument operator error (such as not properly plumbing the instrument or reflector rod, and sensor tolerances) are unlikely. Azimuth readings, however, are subject to localized attraction and should be carefully monitored as to differences between FS and BS on a link. Note the opposing sign on the vertical inclination, as the FS is looking downhill (and thus has a negative sign) and the BS is looking uphill. The difference in azimuth is approximately 180 degrees.

The plan, or plot of horizontal change on the traverse, shows change in direction versus horizontal distance between PI's. The profile, or plot of vertical change on the traverse, shows slope versus horizontal distance between PI's. Each PI is cross sectioned along the bisect angle in the traverse. The cross section is simply a slice illustrating cave dimensions on the angle bisector, and is made up of "side shots" from the PI (or a turning point) to points of interest on the cave floor, walls, ceiling, or formations. (See figure 2 for plots of the survey.)

Table 1.—Traverse 3-4 data.

	FS - PI 3 to PI 4	BS - PI 4 to PI 3
azimuth (degrees)	333.7	153.5
vertical inclination (degrees)	-5.7	5.8
slope distance (meters, feet)	17.34, 56.9	17.47, 57.3

The bisect direction can be determined by LASERSOFT or approximated using the road surveyor's method know as "throwing a wammie."

To throw a wammie, you stand over the PI facing your best guess as to direction, extend one arm towards the back PI and the other towards the front PI. Close your eyes and bring palms together in a clap; your hands will be pointing in the approximate direction. With practice, the direction may be determined within ±3 degrees of actual.

Some difficulties to be expected during cave surveying are found in the appendix.

CONCLUSIONS

The laser survey system is available to aid in cave management. The laser instrument functions properly in limestone formations devoid of bedrock containing magnetic anomalies, while a "triangulating traverse" has been developed for sites that do contain local attraction problems. The system provides accurate and effective measurements of "hard to reach" cave walls and floors, with potentially less disturbance to fragile underground resources.

Based on information from laser system use on road projects, cost savings of 59 to 75 percent are possible.

RECOMMENDATIONS FOR PERFORMING CAVE SURVEYS

A. Ensure the cave management plan includes establishment of survey parameters including what the survey is expected to accomplish. Survey standards, precision, location of points to be surveyed, and survey methodology will be dictated by this information. Some examples are as follows:

1. Measure, map, and plot physical features, such as size, length, slopes, depths, heights, sections, formations, and resources.
2. Provide the basis for design of improvements, such as gates, trails, handrails, and other facilities.
3. Provide the basis for monitoring and trending of cave resources.

An example of this in Cottonwood Cave involves the slope between PI 16 and PI 19, as shown in figure 2. Cave specialists estimate each visitor moves 0.03 m^3 (1 ft^3) of soil down the slope. Contour maps generated from subsequent surveys may be overlaid and earthwork quantities calculated to monitor this situation and plan its alleviation.

B. Prior to conducting the survey, the points to besurveyed must be located and the formations and features to be documented or cataloged should be reviewed by the crew.

C. The survey crew must be fully trained on laser system use, capabilities, and limitations.

D. The survey crew must be familiar with the cave and the information in A and B above.

E. Perform a test of the compass, such as FS/BS traverse links, to determine available or required survey methodology. Remember, the compass is extremely sensitive not only to naturally occurring magnetic attraction, but ferric metal and equipment including flashlights, watches, and data recorder.

F. When performing simple mapping surveys, using the standard traverse and cross section routine, consider making cross sections perpendicular to the length of the cave rather than on the bisect angle in the traverse line. This will typically minimize cross sectional measurements and area, and give a better representation of cave dimensions.

G. A safety plan specific to survey crew activities must be prepared. The crew must receive training on special safety gear for caves. Safety meetings designed to increase awareness of safe practices in caves are highly recommended.

Additional information on the LASERSOFT survey platform and the laser survey instrument may be found in the January-April 1994 issue of Engineering Field Notes (Reference 3).

REFERENCES

1) Jeffry E. Moll, "Low Volume Roads Survey Laser," *Project Report*, Technology and Development Program, SDTDC, USDA Forest Service, May 1992.

2) Gordon W. Griswold, "Field Application and Review of Hand-Held Laser Instrument Grand Mesa, Uncompahgre, and Gunnison National Forests, Gunnison Engineering Zone," *Engineering Field Notes*, May-August 1994.

3) Jeffry E. Moll, "The Lasersoft Revolution," *Engineering Field Notes*, January-April 1994.

DIFFICULTIES OF CAVE SURVEYING

Several difficulties were encountered during the Cottonwood cave survey, some of which are specific to surveying in low-light or no-light environments. Use of "reflector assemblies," with flashlight targets, reflectors, and bull's-eye plumb bubbles, is helpful as the flashlight is necessary for sighting the laser instrument.

A. In the course of rod plumbing, the rod person's headlamp sometimes was confused for the target light by the laser operator. (See figure 1.) This results in null laser readings, as the instrument must be aimed at the reflector for measurements to be made (with the filter installed on the instrument). The rod person can alleviate the problem by shielding the headlamp and any lights other than the target from the view of the laser operator.

B. The laser instrument successfully makes azimuth measurements only when instrument inclination is in the vertical window of ± 15 degrees. Several traverse links were steeper than 15 degrees; the instrument makes slope distance and inclination measurements, but not the azimuth.

The azimuth measurement is made by scrolling to the azimuth screen on the instrument, holding the instrument within the 15 degree window, sighting the target with the EDM sight, re-triggering the instrument, and scrolling back to the horizontal vector screen. The problem arises when attempting to use the EDM sight in the dark.

The operator on this survey shined a pen light into the sight, illuminating it, but this introduced sufficient local attraction to cause compass errors of up to 12 degrees. A scope light may be the solution to this problem. The sighting triangle is visible in the low-light environment; with practice, properly using the EDM sight in the dark may become easier.

C. Vertical inclination readings are made only in the vertical window of ± 60 degrees. When cross sectioning walls and the ceiling of the cave—which involves removing the filter from the instrument and not using the reflector assembly—inclinations are often outside this window. One solution is attaching a vertical inclination scale, in degrees, to the side of the instrument. Vertical inclination readings may be manually estimated from the scale and keyed into the VI slot of the LASERSOFT data entry screen. A sheet of plastic, with scale gradations in indelible ink, would make a suitable scale.

For cross sections made along the angle bisect, the direction may be estimated by throwing a wammie and illuminated with a flashlight. This azimuth is manually keyed into the appropriate slot of each data entry screen as are the inclination readings.

THE TRIANGULATING TRAVERSE SURVEY ROUTINE

Should local attraction adversely affect laser instrument azimuth readings, a triangulating traverse routine may be used to complete the survey without relying on horizontal angle measurements, except possibly a reference azimuth. Basically, PI's for more than one traverse—the number depending on the width of the project corridor and site conditions—are located, with sufficient side shots made to form triangles linking all PI's. If traverse #1 has "n" PI's, traverse #2 has " n-1," then traverse #3 again has "n" Pi's, and so forth. Each traverse is surveyed in the standard fashion, with FS and/or BS between PI's, depending on the required accuracy. An example of how traverse #1 might appear in plan view is as follows:

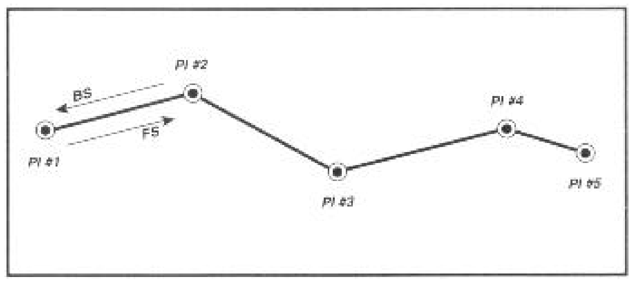


Figure 3.—Traverse #1.

Traverse #2 PI's are laid out as follows, with enough distance between traverses to give depth to the resulting triangles (approximately one-half the distance between PI's):

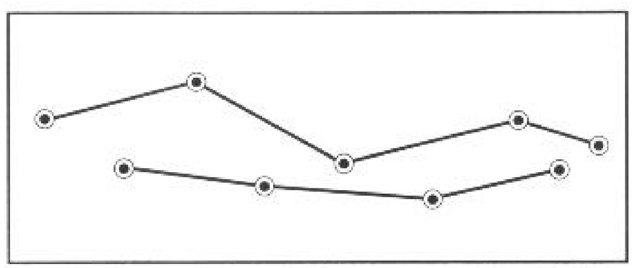


Figure 4.—Traverse #1 and traverse #2.

Subsequent traverses are laid out in similar fashion. Side shots between PI's are surveyed-in as follows:

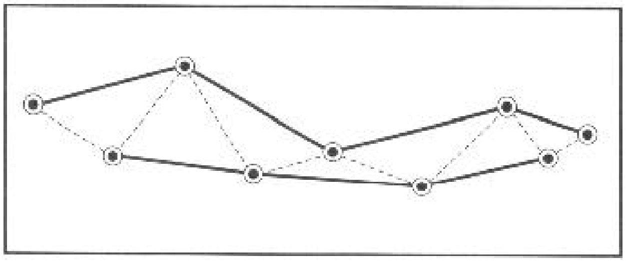


Figure 5.—Side shots forming triangles between traverse #1 and traverse #2.

The law of cosines is used to reduce horizontal distances on triangle sides to a solution of all interior angles, which, with a reference azimuth made—perhaps outside the cave—are used to calculate azimuths for all traverse links and, subsequently, 3-D coordinates for all PI's. Bisect directions are estimated for cross section side shots from select PI's by throwing a wammie.

DATA CONVERSION AND IMPORT INTO AUTOCAD

The ASCII conversion routine in the LASERSOFT software converts raw traverse and side shot data into an ASCII file containing 3-D coordinates for each point surveyed. The points are then imported into Tontocad as follows:

1. The ASCII file built from LASERSOFT is renamed from having an .ACD extension to a .DAT extension.

2. From Tontocad, a horizontal scale factor is selected from the File/Utilities menu so that text brought in will have adequate size. For this project, 50 was used. Under the Programs menu and the Survey/COGO sub menu, Import Point/Traverse File option is selected.

3. From the dialog box that appears, the appropriate file to be imported is selected. Plot points only option is selected. The format of the ASCII file LASERSOFT creates is comma delineated as follows: point number, northing, easting, elevation, comments.

   This option may be selected from the dialog box. The options "plot point numbers as text," "write comments as text," and "plot Autocad points" are also selected.

The 3-D points of the cave can be viewed from any direction by changing view point (point command).

Sorting Points

Now comes the task of determining from the scattering of points which points are associated with the floor, walls, and ceiling of the cave. Since an organized approach of gathering the survey data was used, it was not difficult to construct the cross sections at each of the traverse points. All of the points were assigned a number by the conversion routine. The point numbers are organized such that traverse point number is first, then the side shot numbers are consecutive in the order they were made. This rule applies to each cross section. The side shots were made along the bisect angle, starting at the left side from the floor working toward the ceiling, with the same procedure on the right side. The corresponding point numbers were in the same sequence. Using the following procedure, the traverse and cross sections are drawn in Autocad:

1. The traverse is drawn by connecting all of the traverse points with a 3-D poly line. The traverse points are easily identified, as they have the smallest point number along a cross section.

2. The point numbers along the cross section of each traverse point are connected by a 3-D poly line, starting at the traverse point, and follow the sequence of point numbers for left and right sides of the cross section.

Contouring the Floor

The surface modeling module from Eagle Point Software was used to assist in contouring the floor of this particular cave. Eagle Point uses the TIN (triangulated irregular network) method for modeling surfaces. The TIN is an array of lines connecting 3-D points in the form of triangles. Once the TIN is formed from a set of data points, a grid—or contours—may be constructed.

Before the floor is contoured, its separation from the ceiling is required. The overhanging data points along the walls and the ceiling of the cave would obviously confuse the software. Building a TIN from all of the data points was attempted in this case, but resulted in a fatal error in the software. It is likely contouring caves is an application not foreseen or provided for by software designers. Separating the floor from the ceiling is accomplished by selecting the floor points and placing them in a separate Autocad layer. By viewing the cave from a 3-D view point, the floor can easily be visualized and selected for a layer change. A TIN is then constructed only on the points in the floor layer. These steps are summarized below:

1. Initiate Eagle Point and open the cave drawing. Freeze all layers except the floor layer.

2. A boundary is drawn around the perimeter of the floor points with a closed 3-D poly line. The Surface Modeling menu under EDSC is selected. Under TIN, select Boundary. A dialog box pops up and asks for the surface model library. At this point, surface model for the floor is created. The boundary is then selected.

3. Under the TIN menu, Make TIN is selected. From the dialog box that appears, Make TIN and Make Contours are selected. When prompted by the software to select points, "all" is entered. When prompted concerning a boundary, "yes" and "p" for predefined are entered.

4. The program proceeds to generate contours.

The initial completion of the above procedure, including transferring survey data into Autocad, constructing cross sections, and contouring the cave floor required three hours of CAD operator time. It is estimated that the experience gained would allow the operator to cut this time in half for subsequent executions of the effort. The time required will obviously depend on the individual CAD operator's experience and abilities.

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