United States
Department of
Agriculture

Forest
Service

Engineering Staff

Washington, D.C.

Engineering Field Notes

Engineering Technical Information System

Volume 17
May-June
1985

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Equipment Development for a New Era

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Automated Special Project Specifications

GPS Satellite Control for Photogrammetric Cadastral Surveys

Techniques To Bring New Life to Timber Bridges

Engineering Field Notes

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FOREST SERVICE—USDA
Engineering Staff—Washington Office
Attn: D.J. Carroll, Editor
M.J. Baggett, Editorial Assistant
P.O. Box 2417—Washington, D.C. 20013

Telephone: Area Code 703—235-8198

Awards for the 1984 *Field Notes* Articles

We recently completed our review of your ratings for the top three 1984 Engineering Field Notes articles. It was a close race to the finish. As a matter of fact, after we calculated the total number of points for each article, we had two ties. So this year, we have four award-winning articles:

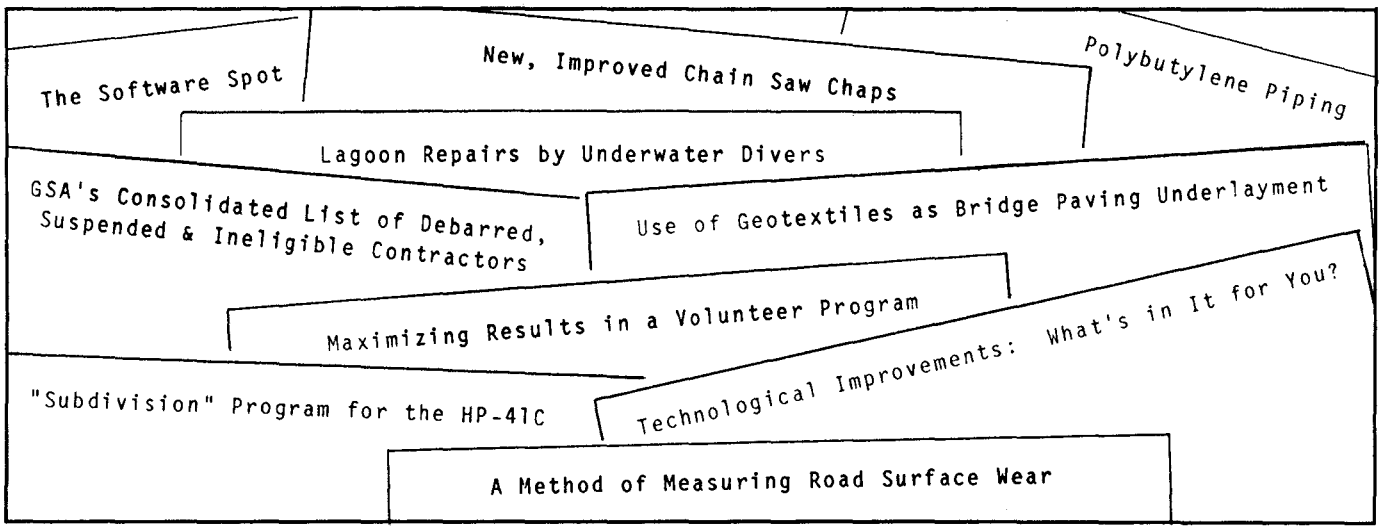
TITLE	AUTHOR
The HP-41CV Electronic Notebook System	Randy J. Lunsford, R-6 Civil Engineer Deschutes National Forest
Lining Deteriorated Culvert Pipes on the Jones Valley Road	Robert McCrea, R-5 District Engineer Shasta-Trinity National Forests
A New Field Notes Feature: The Software Spot	Constance A. Connolly, WO Technical Information Specialist
Big Lightning Creek Flood Repairs	Mervin Eriksson, R-1 Structural Engineer; and Lou Leibbrand, R-1 Supervisory Civil Engineer Idaho Panhandle National Forest

Our congratulations to the winners! The checks will be mailed as soon as the papers are processed.

We also would like to extend our thanks to all of the authors who took the time to write and submit articles, despite personnel reductions and the resulting heavier workloads. We appreciate the co-operation of all the readers who submitted rating sheets, thereby demonstrating that the authors' efforts are of value to their peers.

Why not begin preparing your article now for Field Notes--let other Forest Service employees know that you found a better way of handling a problem, how you accomplished a difficult task, or why a particular experience was interesting and valuable to you. By sharing your ideas and accomplishments, you may be helping to improve the Service-wide effectiveness and efficiency of a certain task, and who knows, you could become one of the 1985 Field Notes Articles Award winners!

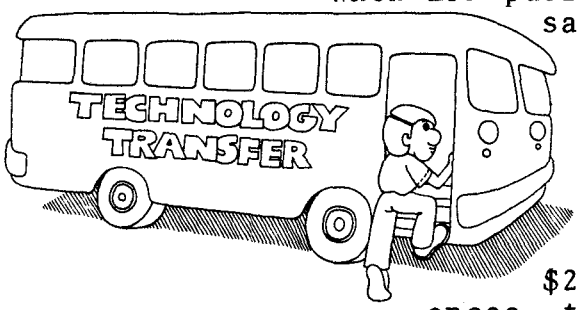
EFN Call for Papers



The above titles of just some of the articles published during 1984 should give you an idea of the breadth of experiences that EFN relates. But there is always room for YOUR story. In fact:

EFN WANTS YOU!

Yes, EFN needs you now more than ever. Your experiences won't be just read; they'll be USED by others--people facing similar problems and challenges in their Forest Service work.



When EFN publishes your article, you can have the satisfaction of knowing that you are helping the Forest Service to "transfer technology" and--perhaps--to save time and money.

In fact, one Forest Service Unit recently wrote us to say that a 1984 EFN author had helped them to save $282,600. By sharing his ideas and experiences, the author had shown the Unit a new way of performing a task that would have cost $288,000. The task ended up costing less than $6,000.

Your ideas and experiences can help, too. They may not help save $282,600, but they could help others avoid the burden of trying to find out what YOU already know! Let us hear from you.

Equipment Development for a New Era

Lee I. Northcutt
Director, Equipment Development Center
Missoula, Montana

It's not news that we're in an era of smaller budgets and fewer employees or that our resource management responsibilities are growing while the dollars are shrinking. It's a predicament most Federal agencies face.

Historically, when this Nation has needed more output at lower cost from fewer people, it has resorted to technology. The Equipment Development Program in the Forest Service was established expressly to link technology with problem solving. So the Equipment Development Centers at Missoula, Montana, and San Dimas, California, are uniquely qualified to help solve pressing resource problems. A few examples of their capability to tackle problems and help provide solutions are fire-resistant clothing and fire shelters (see figure 1); precision nursery seeders and seed dewingers; better hand tool designs; improved rock rakes; more durable reflective signs; and small cable yarding machines. These products and many more have boosted efficiency, increased production, and allowed the Forest Service to do some jobs it could not do before.

TECHNOLOGY & PROBLEM SOLVING

With technology, we are bridging the gap between resource management needs and manpower in many areas. One of our projects concerns the use of electronic equipment to process and store satellite signals for locating ground positions. We are using computer-controlled counters to count insect egg masses on branch samples to determine insect populations (see figure 2). We are working with lasers to guide tree nursery equipment and with hand-held lasers for faster, more accurate timber cruising. And we are managing the latest detection and surveillance equipment for Forest Service law enforcement needs.

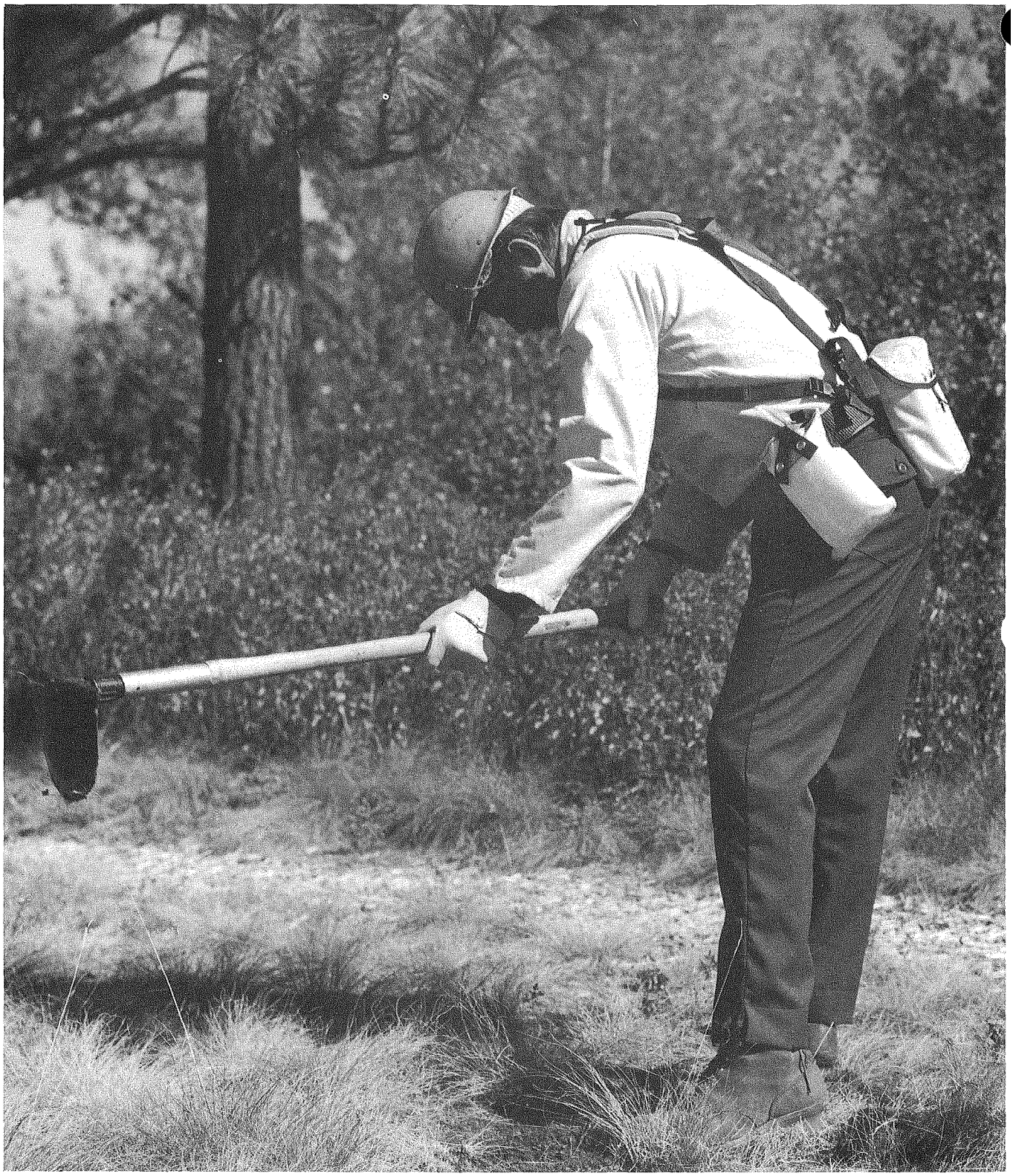


Figure 1.--Modern firefighter wearing flame-resistant clothing, as well as gloves and field pack components, and using new combination tool--all products of Equipment Development.

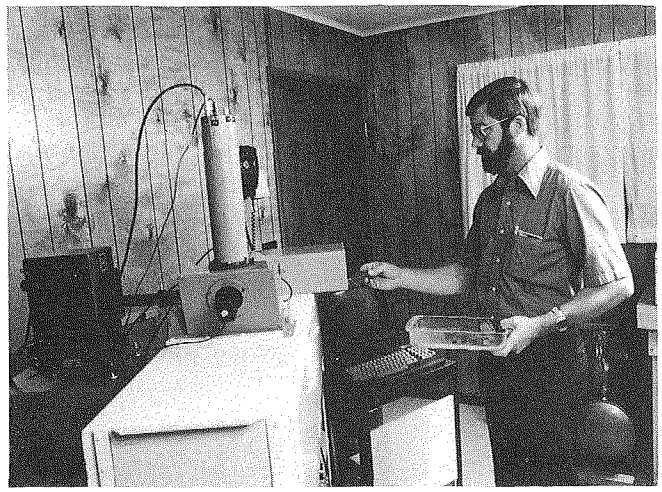


Figure 2.--Prototype egg mass counter electronically counts spruce budworm egg masses, eliminating less accurate, time-consuming manual methods of determining insect population trends and damage levels.

Because of the complicated problems we are being given, more of our work is being done with outside experts located nationwide. Continuum Dynamics of Princeton, New Jersey, is helping us with aerial spray behavior modeling. The forest engineering department at Oregon State University in Corvallis provided the principal investigator for our project on predicting soil compaction on forested land. Researchers at the Texas Agricultural Experiment Station, Vernon, Texas, are working for us on a disk-chain implement for removing brush and preparing rangeland for seeding. Medical expertise in our poison oak/ivy project is being provided by the department of dermatology, University of California, San Francisco.

The trend to use outside expertise reflects not only that problems are more complicated but also that today's communication and transportation systems provide easy access to experts across the country. Competitive bidding, too, in which the successful bidder may be thousands of miles from an Equipment Development Center, has reinforced this trend. The Centers can no longer rely solely on experts located nearby.

Our applications of technology or use of outside experts is not restricted to equipment projects. Our familiarity with Forest Service field operations and our skill in managing development projects enable us to define the problems, investigate solutions, and get the best talent available on our project teams. The products of such projects can be such things as manuals or guides, instructional films, or video tape programs.

INDUSTRY ADOPTING EQUIPMENT DEVELOPMENT PRODUCTS

One benefit of using the latest technology and more outside experts has been that private industry is adopting the products of our successful projects and marketing them.

For example, the York Rake Company manufactures Equipment Development's truck-mounted rock rake for road maintenance (see figure 3). Also, chain saw chaps designed by Equipment Development are sold by commercial suppliers throughout the country. The Diamond Scale Company has become the new source for our trail traffic counter, and the J.E. Love Company sells the Norwegian-designed Oyjord precision seeder as a direct result of our evaluation work.

Many other items are being manufactured nationwide to our plans and specifications. Examples include the MEDC tree seed dewinger, Bitterroot miniyarder (see figure 4), tree orchard seed-harvesting system (see figure 5), Birch Quik-Tach planting site scalper, FS-12 personnel parachute, and, of course, the fire shelter, fire-resistant shirts and trousers, and forest workers gloves. All these items are used by other Federal and State agencies and by private industry.

Paralleling our successes in private industry marketing, the results of other project work often are becoming the standard among Federal and State agencies and private organizations as well. Examples include the following:

(1) Measuring employee fitness and work capacity testing.

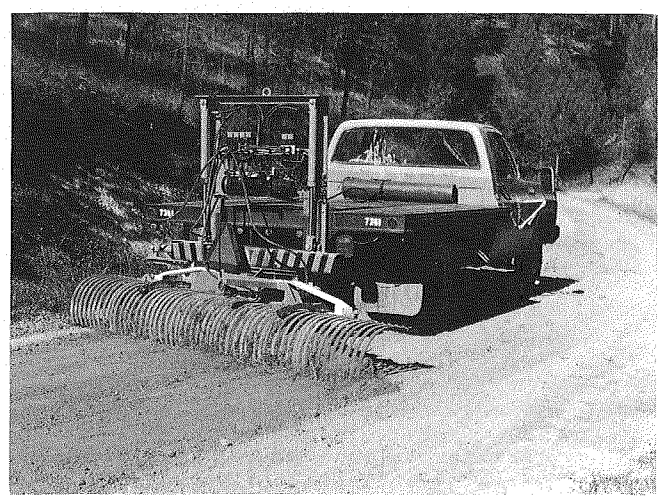


Figure 3.--Hydraulic rock rake designed by Equipment Development is now being built and sold by York Rake Co.

Figure 4.--Bitterroot Miniyarder makes yarding small materials and residues economically feasible.

Figure 5.--Seed retrieval netting system is saving thousands of dollars in Region 8 orchards annually.

(2) Techniques for hand-planting tree seedlings.

(3) Cone collecting and handling.

(4) Smokejumper paracargo procedures.

(5) Maintenance and placement guides for traffic-control devices.

(6) Heat-stress prevention.

(7) Characterizing aerial-spray aircraft.

(8) Predicting soil compaction.

(9) Installing and maintaining road traffic counting equipment.

(10) Evaluating aircraft for smokejumper use.

(11) Weather guide to aerial pesticide application.

(12) Trail maintenance guidelines.

(13) Reflective sign materials testing.

COST/BENEFITS to the FOREST SERVICE

Increasing implementation of our successes results in an improving cost/benefit ratio. A December 1983 Engineering Field Notes article, "The Role of Equipment Development in the Forest Service," cited cost/benefit ratios as high as 1:50 and 1:81 for some projects. Overall, the cost/benefit of Equipment Development was estimated conservatively at 1:5. One good example is in orchard tree seed collection. Region 8 estimates that the seed retrieval netting system jointly developed by Equipment Development and Region 8 Engineering initially saves about $25,000 annually. When considering all Equipment Development projects collectively, at least $20 million in taxpayer money is saved for every $4 million invested.

The Government and the taxpayer save money as a result of the use of the new rock rake to maintain roads, whether the truck is driven by a Forest Service employee or by a private contractor; and seedlings cost less thanks to our dewinger and seedbed thinning tool, regardless of whether those seedlings come from private or Forest Service nurseries. What we are talking about are substantial savings realized because a Forest Service group specializes in applying technology to Forest Service problems.

Paradoxically, the more successful we are in "selling" our solutions to private industry and Federal and State agencies, the less obvious becomes our role in the original effort.

When Forest Service employees order Corona Company tree-thinning clippers, a York rock rake, or Diamond Scale trail-traffic counters, there is nothing to tell them Equipment Development made these items available. Or when they order supplies for the fire cache from the General Services Administration (GSA) fire equipment catalog, they do not know that the Equipment Development Centers write and revise the specifications for more than half the fire-related items listed in that catalog, as well as helping GSA maintain quality control on those products. And when NBC-TV's "Today Show" recently covered field testing of our poison oak/ivy skin patch test kit on the Los Padres National Forest, our responsibility for the project and kit design was not mentioned.

So it is no surprise that line officers may know little about what Equipment Development does or can do for them. But the tools and equipment are available because a small, versatile staff of specialists at the two Centers concentrate attention on problems specific to managing National Forest resources.

THE FUTURE

To remain responsive to Forest Service needs, we are enlisting the help of more and more experts, both in and out of Government. Committees of field users and national specialists in the Washington Office are selecting and guiding the project work more than ever before. Much of our work is in areas that Forest Service Research has explored and has told us offer development opportunities for cost-effective products.

The Equipment Development Program helps ensure that solutions are cost effective. To do this, the Forest Service must maintain its own technical experts at the two Centers to define problems, prepare and evaluate proposals to solve them, and monitor contractor performance to guarantee that the Forest Service is getting its money's worth.

In an era of more complicated problems and more sophisticated technical solutions, relying solely on private enterprise may not be the most cost-effective way to obtain the tools and equipment that resource managers need today. Such an approach would not save work-year equivalents or money. In fact, it would increase and spread the labor and cost back to every Forest and Ranger District workbench. After all, the driving force behind creating a Service-wide Equipment Development Program was to make available a technically trained staff of professionals to solve Forest Service field problems to increase efficiency and avoid duplication. The factors that made this a good idea when the Equipment Development Program was formally established years ago are even more crucial today.

U.S. automakers and other American industries have reduced their costs and increased their efficiency by emphasizing and applying modern technology. The Forest Service--through the Equipment Development Program--is doing the same. The result: cost-effective problem solving.

The Forest Service needs experts who know and understand the resource problems it faces as well as the rapidly changing technologies available to solve them. Today, we are in the midst of a knowledge explosion that holds great promise for resource management. Equipment Development has the experience to use this knowledge to help ensure the best possible management of our National Forest lands in the years ahead.

Device To Measure Road Dustiness Now Under Development

Deborah Taylor
Highway Engineer
Washington Office Engineering Staff
& Prof. L. H. Irwin
Director
Cornell University Local Roads Program

Dust emissions from vehicles on unpaved roads can cause serious air pollution, impair visibility and safety for motorists, and pose a hazard to health via dust-borne diseases. Under certain conditions of weather and use, unpaved roads require an appreciable expenditure of maintenance dollars for the control of dust. A combination of high maintenance costs, increased public awareness of pollution problems, increased user costs, and loss of surface fines has stirred renewed interest in dust control and the quality of unpaved roads.

Currently, the USDA Forest Service maintains 342,000 miles of roads, approximately 95 percent of which are unpaved. At present, Forest Service dust control methods include reduction of vehicle speed, application of water, and use of dust palliatives. The main goal of dust control is to stabilize the surface material. Dust palliatives such as water, salts, and oils help control dust, thus reducing the rate of aggregate loss. Determining the type, quantity, and time of application of a dust control method is currently left up to "human judgment" or qualitative analysis.

Current studies on ways to reduce current dust control costs are focusing on more efficient and uniform use of dust control methods. This requires the development of a quantitative method to measure the dustiness of a road, the accomplishment of which would be useful not only to the Forest Service but to county and State highway departments as well. One source summarizes the dust problem well: "For every vehicle traveling one mile of unpaved roadway once a day, every day for a year, one ton of dust is

deposited along a 1,000-foot corridor centered on the road." With more than 2.2 million miles of aggregate- and earth-surfaced roads extending across the United States, highway agencies, the traveling public, and roadside residents have a significant dust problem.

PROJECT DESCRIPTION

The Cornell University Local Roads Program is now developing instrumentation (a Road Dust Monitor) capable of monitoring levels of road dustiness with a truck-mounted mechanism as part of a study being sponsored by the Forest Service. It is expected that the results of these efforts will produce a method of measurement that can be used in various regions of the United States and will become the basis for dust application.

As a result of field testing and interviews with Forest Service personnel conducted in the summer of 1984, we have been able to correlate visual observations with the readings from the Road Dust Monitor. Consequently, we have been able to define a range of dustiness in terms of opacity.

ACHIEVEMENTS

The present prototype Road Dust Monitor, as shown in figure 1, consists of an ordinary 8-inch by 12-inch galvanized sheet metal heating duct formed in an L-shape, an infrared transducer mounted in the duct, and an instrument package with an indicating meter. The duct and transducer are positioned behind the left rear tire of an ordinary fleet-size Forest Service pickup truck, as shown in figure 2. The transducer (by Banner Corporation) contains a light source and a photoelectric sensor. The light beam shines onto a reflector positioned on the opposite side of the duct, and this reflected light is detected by the sensor. As the rear tire kicks up dust from the aggregate road surface, the dust passes through the duct, scattering the light beam and reducing the amount of light reflected back to the sensor. The level of reflected light is measured by the sensor and converted to a voltage that is displayed on the indicating meter. Modulated infrared light is used as the source to eliminate any sensitivity to ambient sunlight.

The system sees two sources of opacity. One is the dust that collects on the optical elements (lens and reflector). The second is the dust in the air, seen when the vehicle is moving. By initializing the

system with the vehicle standing still, the readings displayed by the instrument in the moving vehicle will result solely from dust in the air. A modified preliminary design will be field tested early in April 1985 to investigate and eliminate some instrumentation alternatives.

UPCOMING ACTIVITIES

As a result of the spring 1985 testing, further modifications will be made in the instrumentation package, and several prototype devices will be built that will be placed in various National Forests around the United States during the summer of 1985. One of the primary objectives will be to obtain a larger data base on the tolerable level of road dustiness, which will, in turn, provide the information needed to refine the Road Dust Monitor and to define a multiregional "Dust Index."

Deborah Taylor will be responsible for delivering, installing, and relocating, after a 2-week period, the prototype equipment, and she will conduct a detailed evaluation of the instrumentation with Forest Service personnel at each test site. Specific test locations will be chosen in consultation with Forest Service personnel.

CONCLUDING REMARKS

This project concentrates on the development of instrumentation that will quantitatively define acceptable and unacceptable levels of dustiness. Ultimately, it will act as a tool for the development of maintenance standards to encourage better management of dust control (quantitative versus the present qualitative management). It should become possible then to compare the effectiveness of different types of dust palliatives in a given locality, and thereby refine dust control practices. It is expected that this information, along with local input, will lead to a better prediction of budget needs for dust palliatives and will improve overall road safety and aggregate performance.

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Langdon, B. B. "An Evaluation of Dust Abatement Materials Used in Region 6." Master Thesis, Oregon State University. December 1979.

USDA Forest Service. Publication FS-20, "What the Forest Service Does." May 1983.

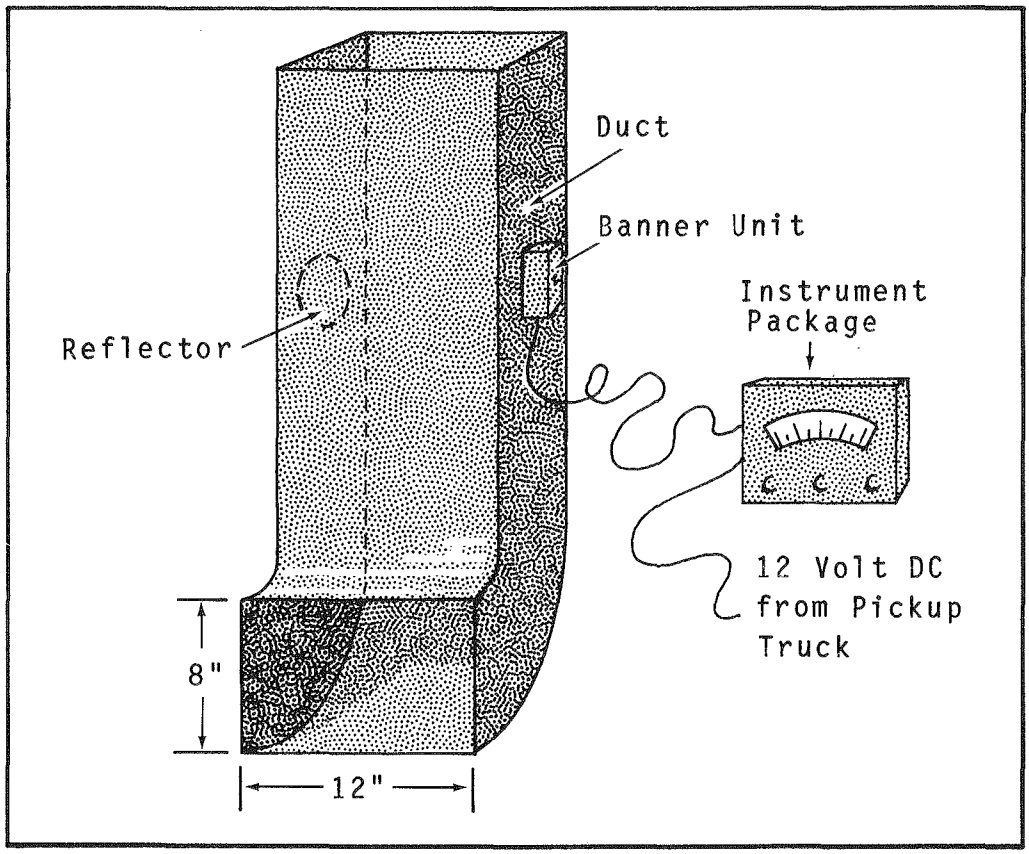

Figure 1.--Description of apparatus.

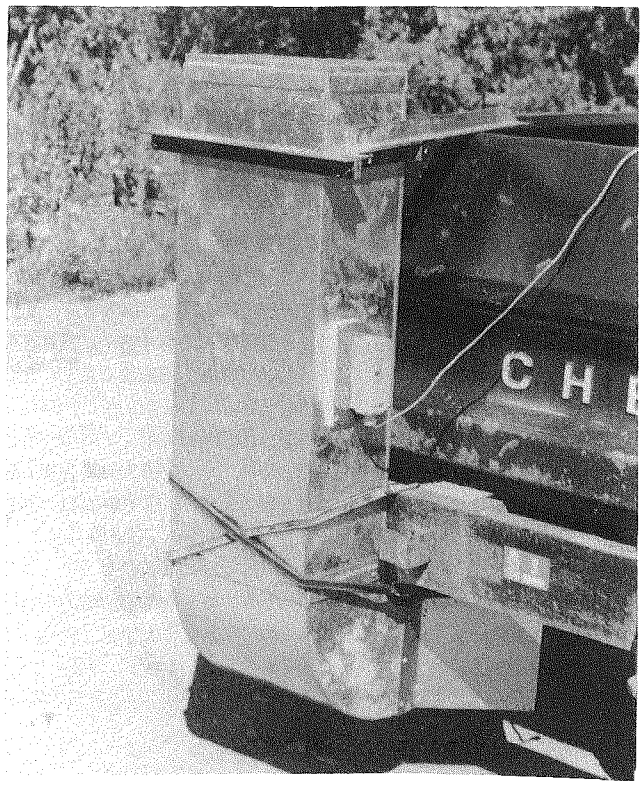

Figure 2.--Duct positioned behind left rear tire of pickup truck.

The Bausch & Lomb Resource Measurement System (RMS) as an Aid in Area Measurements

Jerry D. Greer
Project Leader
Nationwide Forestry Applications Program

A COOPERATIVE STUDY

During the summer of 1984, the USDA Forest Service and the States of New York, Vermont, and New Hampshire conducted a cooperative study to evaluate the current status of spruce and fir stands. The study was conducted to collect benchmark data so that the trends in vigor (either decline or increase) could be assessed in the future.

The project entailed the acquisition of color infrared photography over 55 different 8,000-acre sample blocks. Each sample block was stratified, and the areas of certain stands were calculated. A total of 2,860 photo plot samples were established, and mortality and vigor were determined.

The rapid completion of the interpretation phase was critical because field crews would be waiting for the results. William Ciesla, Methods Application Group (Forest Pest Management) Leader, anticipated the occurrence of literally hundreds of polygons as the vegetative types and mortality were stratified.

Each polygon would be measured for area. For each sample block, there could be as many as 16 different classes of stratified vegetation. The potential for large numbers of polygons reflecting up to 16 classes indicated that the area-measurement step could be extremely complicated and time consuming. The potential for errors in area totals and in counting and tracking the number of polygons was increased.

Because of these potential problems, Ciesla arranged with the Bausch and Lomb Corporation for the loan of a complete Resource Measurement System (RMS) unit to the Forest Service. The purpose of this agreement was to give the Nationwide Forestry Applications Program staff a chance to evaluate the RMS while carrying out the area measurement phase of a critical project. The RMS unit was seen as a system that

The Resource Measurement System as set up for the Spruce Decline project. The arrangement of components is standard and follows the recommendation of Bausch and Lomb.

could speed up the area measurement phase, improve accuracy, provide instant statistical summaries, and provide automatic recording of data.[1]

THE BAUSCH & LOMB RMS UNIT

The RMS is based on a standard Apple IIe computer. Peripherals are two Rana Elite disk drives, a NEC PC-8023A-C printer, a monochrome Zenith monitor, and a Houston Instruments HIPAD digitizing pad. The software is on a nonstandard, 40-track, $5\frac{1}{4}$-inch floppy disk.

Certain parameters in the program may be changed when an image-measurement project is started.

Sound

Normally a "dit" or "click" sound is produced as a polygon is traced. This sound assures the operator that the cursor button actuation and subsequent cursor movements are being recognized by the RMS unit. The sound is very similar to that produced by a Geiger counter and is not at all offensive. It may, however, be switched off at the operator's discretion. We recommend that it be left on.

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[1]The RMS is reviewed for the information of Forest Service employees, and neither approval nor disapproval of this product should be assumed from this article. Neither the Forest Service nor the author endorses this system over others.

Decimal Places

Select one to five decimal places to be used in the measurements. In the Spruce Decline project, we set this parameter to one place.

Motion Sensitivity

This parameter sets the least distance to be used in the measurement computation. The range is 0.1 millimeter to 25 millimeters. Smaller numbers yield more precise measurements on curved figures, but it takes more time to complete computations. With smaller numbers, erratic hand motions (that is, quivering or shaking) will introduce more errors.

You are limited to a total of 1,000 data points per measured feature. Do not exceed this number by setting this parameter too low. The table shows the motion limits and the calculated maximum lengths of

Data readout from file: PLAINVIEW SW VT 308

No.	CLASS (KEYB)	AREA
Min	2.10000	8.71395
Max	3.20000	91.41869
1	3.20000	31.93973
2	3.20000	82.77753
3	3.10000	62.45212
4	2.10000	27.20094
5	3.20000	11.33813
6	3.10000	46.29455
7	2.10000	20.77645
8	3.10000	49.07217
9	2.10000	25.08205
10	2.10000	30.66440
11	3.10000	40.87207
12	2.10000	10.75577
13	2.10000	91.41869
14	3.20000	29.09646
15	2.10000	8.71395
16	2.10000	28.55692
17	3.10000	14.63387
18	2.10000	49.86221
19	2.10000	28.60616
20	2.10000	13.38280
21	2.10000	23.78530

Data Readout from measurement file of polygons in the Spruce Decline project. Column 1 is simply a line number assigned to the data as measurements were made. Column 2 is the class designation of the polygon measured. In the Spruce Decline project, polygons were designated as 1.3, 2.1, 3.2, 3.3, and so forth. The four trailing zeros are routinely added by the program. Column 3 is the calculated area of the polygon. Five decimal places are displayed even if the precision parameter is set to one place.

Motion sensitivity limits and measurement maximums.

Motion Sensitivity Setting (mm)	Maximum Length of Perimeter That Can Be Measured		For Comparison, Equivalent Circle Diameter (cm)
	(mm)	(cm)	
0.1	100	10	3.18
0.5	500	50	15.9
1.0	1,000	100	31.8
3.0	3,000	300	95.5
4.0	4,000	400	127.3
5.0	5,000	500	159.1
10.0	10,000	1,000	318.3
15.0	15,000	1,500	477.5
20.0	20,000	2,000	636.6
25.0	25,000	2,500	795.8

NOTE:

(1) Only a range of sample motion sensitivity settings is shown. Operators may set any value between 0.1 and 25.0 in this parameter.

(2) Comparative circles can appear deceptively large. Operators must remember that lake shores, timber stands, and stratified polygons may have highly irregular, "jig-saw" margins. The limit of 1,000 data points can be reached very quickly in these situations if the parameter is set too low.

perimeters that can be measured. For estimation and comparative purposes, the approximate maximum diameters of representative circles are given for each setting.

During the Spruce Decline project, we set the parameter to 0.5 millimeter. Out of the hundreds of polygons measured, only three or four had to be "subdivided" to stay within the data limit. If the data limit is exceeded, the RMS program aborts the measurement and all data for that polygon are dumped. The operator must correct the situation either by resetting the parameter to a higher appropriate number or by splitting the large polygon into subdivisions that can be measured under the limits imposed by the data maximum.

Closure Distance

The RMS will recognize a polygon as a closed figure only if the operator returns the tracing cursor to a point near where the tracing was started. In practice, it is nearly impossible to return to the precise point of origin. This parameter permits the operator to set the minimum distance from the point of origin that the operator must reach to close the figure successfully.

The parameter may be set anywhere from 0.1 millimeter up. Accuracy will be sacrificed if the number is too large, and the figure may never close if the number is too small. Bausch and Lomb recommends a closure distance of 5.0 millimeters. We used 3.0 millimeters during the Spruce Decline project. In practice, the operator always should attempt to close the figure within a "line width" on the image. This distance is normally about 1 millimeter. The RMS will use the smaller closure distance in its computations. That is, if the operator closes the figure at 0.1 millimeter, then the 0.1-millimeter distance is used, not the larger closure distance set in the parameter. In all cases, the closure distance will be equal to or less than the number set in this parameter if the figure is closed.

There are advantages to using the RMS in projects requiring the measurement of many irregular polygons. In contrast to a planimeter (either analog or electronic), the RMS unit provides automatic continuous recording of data. With all data held in memory, statistics are easily and routinely calculated.

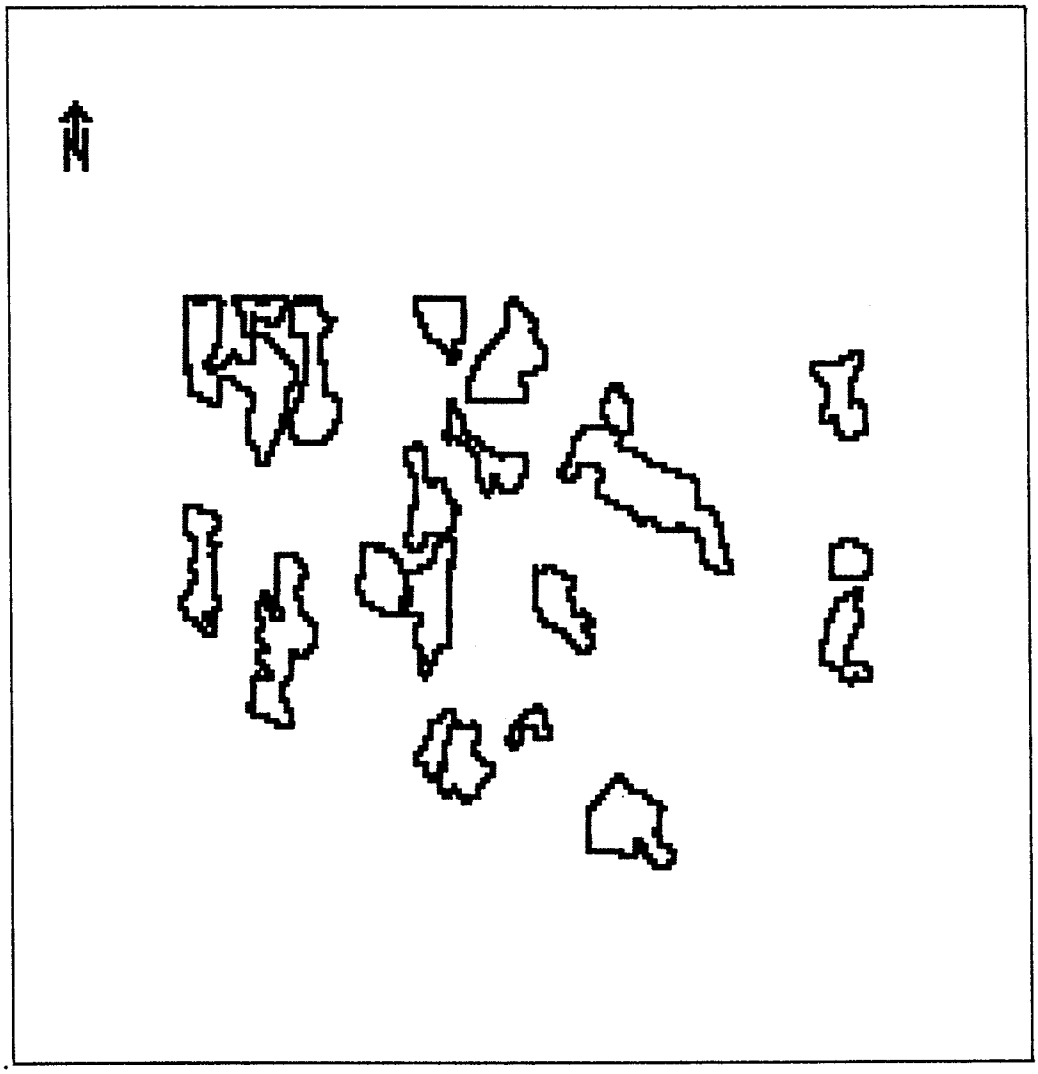
The unit appears to be very accurate. Operator inputs are required to establish the scale used in area calculations. As polygons are traced on the map or image, the outline is displayed on the monitor. This plot can be printed by the NEC printer. The computer system has very fine resolution, but the screen and printer will display the data only in a coarse way. The screen display is an aid in checking the progress of tracing polygons. The HIPAD digitizer can be used on a table, over a light table, or with a zoom transfer scope.

```
Statistics for AREA

(Total Field Area
  = 4457.20474 ACRES)
for CLASS (KEYB)  >  = 2.1
                  <  = 2.1
12 Observations
out of 21 in File

8.05 % of Total Reference Area
Sum (Obs.) = 358.805638
Mean Value = 29.9004698
Variance   = 452.19958
Std. Dev'n = 21.2649849
Sample S.D.= 22.2105523
Skew Coeff.= 1.89451214
Kurtosis   = 6.07231761
Limits: Min= 8.71395011
        Max= 91.4186857
```

Printout of statistics for an area as displayed on the monitor. These statistics are presented for each class or group of classes selected. In this case, the data about polygons labeled 2.1 (2.10000) have been requested. In the Spruce Decline project, only the number of observations and the sum of the observations (sum(obs.)) were used.

We encountered a few problems that were mostly irritations rather than impediments to the project. Once the scale is entered when a block is started, it is held only in memory. The scale is not shown on any printouts or screen displays. Because of this, initial entry errors can be carried through without detection.

The software program delivers as advertised. Some of the menus and programs seem to take an inordinate time to load in preparation for a run. There are too few opportunities to "escape" or abort a routine when an operator realizes that a mistake has occurred. Most routines must be completed before the erroneous data can be deleted or discarded. Because the tracing of the polygons produces such a large amount of data, recording the information onto disk files is slow. The program periodically will pause as data are recorded off. The operator does not have an easy opportunity to direct the computer to record off the data at more frequent intervals.



Screen print of part of the Plainview Southwest Vermont block. The polygons are displayed and printed in this coarse resolution, but the system collects finer resolution data. Each polygon represents a stratified unit of vegetation in the Spruce Decline project.

This could be a problem in locations with unpredictable power supplies because data are held in Random Access Memory and are instantly lost if a power failure occurs.

Perhaps the most troublesome problem was with the HIPAD. It worked well, but the usable area was not large enough to accommodate our 8,000-acre blocks at a scale of 1:24,000. Each block (which measured about 8 inches by 11 inches) had to be divided in half before digitizing so that each subpart would fit on the effective HIPAD area.

The manual accompanying the unit is good, but even after reading it once, the first operator took nearly 4 hours to become proficient enough with the system to produce reliable results. We eventually developed a simple step-by-step guide for photointerpreters to use. Once this introductory phase is completed, the process is exceptionally fast and easy to follow.

Some (hopefully) helpful tips.

(1) Look at feature in detail before you begin to trace its boundary--know where you are going.

(2) Prominently mark your beginning point before tracing a feature so you will know where to stop.

(3) Tape the map or image securely to the digitizer pad.

(4) Determine and stay within a safe active HIPAD area boundary (it is not active out to the edge).

(5) Write protect your program disk after parameters are in. They will not be accidentally changed, and the program will not be accidentally damaged.

(6) Watch those file names. The system permits up to 15 characters for the file name (including spaces and punctuation). This can cause problems if you depended on some subtle differentiation after character 12. The printer and screen will display all of your entry, but in memory (where it counts) you are limited to 12 characters.

(7) Keep the digitizer cursor on the surface of the HIPAD at <u>all</u> times when it is <u>active</u>. (Some parts of the RMS program <u>will</u> not run if the cursor <u>is off</u> of the pad.)

(8) <u>Do not</u>, under any circumstances, lay either a program disk or <u>data</u> disk on the HIPAD digitizer. The instrument operates with electronic systems that produce strong magnetic fields. Such fields can alter data on disks making them useless.

(9) On very intricate and complicated polygon measurement projects, place an acetate overlay on the map or image. As each polygon is finished, trace its perimeter with a colored marking pen (such as those used to write on photographs). This will help ensure that each polygon is completed.

CONCLUSION

The unit costs nearly $7,000 delivered. This will be of concern to any manager, but as in any endeavor, the price must be weighed against the potential payoff. The RMS unit could be a useful, cost-effective device in any situation where resource measurements are needed if--

(1) The projects are complex.

(2) There is a need for relatively frequent use.

(3) There is a need for complex statistical analyses.

The RMS has other features that we did not test during the Spruce Decline project. These include the ability register and count features and the ability to measure perimeter, length, breadth, and angles. We checked many of these functions after completing the Spruce Decline project and found no problems.

Automated Special Project Specifications

Lester M. Pence, Jr.
Civil Engineer
Region 8

This article describes a procedure for automating the preparation of Special Project Specifications using the Data General MV4000/MV8000. The net result of this approach is very similar to that described in the April-June 1983 issue of Engineering Field Notes using a TI 990. That article describes the preparation of a diskette containing Special Project Specifications and its distribution to the National Forests in Region 8, whereas with Data General the distribution is electronic. In both systems, the actual specifications are typed automatically by merely listing the specifications desired. All the Special Project Specifications are coded so the designer knows whether higher level administrative approvals are required.

An article in the April-June 1983 Engineering Field Notes explained Region 8's method of assembling road Special Project Specifications (SPS) using the TI 990. With the assistance of Leon Furnish, Engineering Computer Applications Group Leader, Region 8 has designed a procedure to accomplish the same task using the Data General (DG) CEO software.

On the Data General system, each individual SPS is stored in a separate document. Using the "Read" key while creating a document allows the road designer to accumulate copies of the individual SPS, which then become the SPS package for a public works or timber sale contract. This document then can be printed and included in the contract.

Below are the instructions sent to the Forests in Region 8:

(1) Create a drawer under "E" and name it "SPS".

(2) Share ownership of this drawer with others who will be accessing SPS and creating SPS contract packages.

(3) Create the following folders in this drawer:

! Getting Started

000

100

200

300

400

500

600

700

(4) When Steps 1 through 3 are completed, have your Forest Computer Specialist retrieve, via Universal File Transfer Agent (UFTA), the "79SPS" file containing the SPS from the "R8:SHARE.OUTPUT" directory. The specialist then can assist you in unloading, importing, and filing each individual SPS into its appropriate folder.

The completed drawer is organized as follows:

DRAWER	FOLDER	DOCUMENT
SPS	! Getting Started	Overview
SPS	! Getting Started	Instructions
SPS	000	List
SPS	100	Section 100 SPS
SPS	200	Section 200 SPS
SPS	300	Section 300 SPS
SPS	400	Section 400 SPS

SPS	500	Section 500 SPS
SPS	600	Section 600 SPS
SPS	700	Section 700 SPS

The instructions for constructing and printing an SPS contract package are shown in figures 1 and 2. Figure 3 shows a sample Specification and Special Project Specification List, while figure 4 shows a sample SPS contract package.

CONSTRUCTING SPS PACKAGE

1. On Main Menu, press "2" (Edit Document)

2. Press "New Line"

3. Drawer Name = "_____" Type in your established personal working drawer

4. Press "New Line"

5. Folder Name = "_____" Type in name of folder in which you wish to create this SPS package. If this folder has not been previously established, press the "Shift" and "Help" key at the same time for instructions

6. Press "New Line"

7. Document Name = "_____" Type in identifier such as "IFB 1642"

8. Press "New Line"

9. Do you wish to create this document? (Y/N) = "Y"

10. Press "New Line"

11. Type in road numbers for this project such as "ROAD NUMBERS 1602 & 1602A"

12. Press "Shift" and "Center" at the same time

13. Move cursor down 2 lines

14. Press "Read"

15. Drawer Name = "sps"

16. Press "New Line"

17. Folder Name = "____" Type in one of the following, as appropriate (100, 200, 300, 400, 500, 600, or 700)

18. Press "New Line"

19. Document Name = "_____" Type in SPS number

20. Press "New Line"

Figure 1.--Instructions for constructing an SPS contract package.

21. Execute? (Y/N) = "Y"

22. Press "New Line"

23. Move cursor 2 lines past bottom line of SPS

24. Repeat Steps 14 through 23 or

25. Press "Cancel/Exit"

26. Do you wish to exit from this document? (Y/N) = "Y"

Overy 54 lines, a page break will be established automatically. The page number and line location of the cursor are shown in the upper right corner of the screen. If you wish to change the page break to another point:

(a) Put cursor before dotted line that indicates page automatic break (cursor must be on a blank line and to the extreme left).

(b) Press "Control" and "End Page" at the same time.

(c) Repeat Steps 14 through 23.

An automatic page break will appear 54 lines after the page break just established.

DO NOT FORGET TO FILL IN BLANKS AND TABLES.

Figure 1. (cont.)--Instructions for constructing an SPS contract package.

PRINTING SPS CONTRACT PACKAGE

1. On Main Menu, Press "4" (Print Document)

2. Press "New Line"

3. Drawer Name = "_____" Type in your personal working drawer

4. Press "New Line"

5. Folder Name = "_____" Type in identifier previously established

6. Press "New Line"

7. Document = "_____" Type in identifier previously established

8. Press "New Line"

9. Print using default layout. Enter choice = "1"

10. Press "New Line"

11. Print document summary? (Y/N) = "N"

12. Press "New Line"

13. Which printer? Type in printer ID as established by your computer section

14. Press "New Line"

15. How many copies? = "1"

16. Press "New Line"

Figure 2.--Instructions for printing an SPS contract package.

SPECIFICATION AND SPECIAL PROJECT SPECIFICATION LIST

ROAD NAME	Lisa	Don	Laura
ROAD NUMBER	25	23	20
TERMINI	Here to There	MP 0 to 100	0+00 to 1+45
CONSTRUCTION			x
RECONSTRUCTION	x	x	

Note: Specifications that are referenced by other specifications are not listed below

STANDARD SPEC. OR SPS NO.	LATEST REVISION DATE				
STANDARD SPEC.	1979				
101----	-------	-----x-----	-----x-----	-----x-----	----------
102----	-------	-----x-----	-----x-----	-----x-----	----------
103----	-------	-----x-----	-----x-----	-----x-----	----------
104----	-------	-----x-----	-----x-----	-----x-----	----------
105----	-------	-----x-----	-----x-----	-----x-----	----------
106----	-------	-----x-----	-----x-----	-----x-----	----------
170----	-------	----------	----------	-----x-----	----------
201----	-------	-----x-----	----------	----------	----------
203----	-------	----------	-----x-----	-----x-----	----------
306----	-------	-----x-----	-----x-----	----------	----------
602----	-------	----------	----------	-----x-----	----------
603----	-------	-----x-----	-----x-----	-----x-----	----------
ABBREV-	--8/83-	-----x-----	-----x-----	-----x-----	----------
ERRATA-	--8/83-	-----x-----	-----x-----	-----x-----	----------
REGIONAL SPS	AS SHOWN BELOW				
104-1--	--6/82-	-----x-----	----------	----------	----------
170-1--	--6/82-	----------	----------	-----x-----	----------
201-1--	--6/82-	----------	----------	-----x-----	----------
306-1--	--8/83-	-----x-----	-----x-----	----------	----------
602-1--	--6/82-	----------	----------	-----x-----	----------
FOREST SPS	AS SHOWN BELOW				
M306-1a	-------	-----x-----	-----x-----	----------	----------
M201-1a	-------	-----x-----	----------	----------	----------

Figure 3.--Specification and Special Project Specifications List.

A SAMPLE SPS CONTRACT PACKAGE

ROAD NUMBERS 304 & 304A

201-1 (6/82)

201.02 - CLEARING AND GRUBBING

In item (a) under the first paragraph, after the word "roadway," add "or outside slope rounding areas,"

201-5 (6/82)

201.02 - CLEARING AND GRUBBING

Delete the first sentence of the last paragraph and substitute the following: "Branches on remaining trees or shrubs shall be trimmed to give a clear height of 14 feet above the roadbed."

304-1 (6/82)

304.01 - DESCRIPTION

Add the following statement:

> "This work shall also consist of mixing two or more aggregates on the roadbed or mixing one or more aggregates with the existing subgrade material."

552-1 (3/83)

552.02(c) - CONCRETE COMPRESSIVE STRENGTH

Delete paragraph 2 and all of paragraph 3 except item (3) and add the following requirements:

> "For each strength test, a total of 4 test specimens shall be made. Two of the test specimens shall be used for the 7-day strength test. The remaining test specimens shall be used for the 28-day strength test. The 28-day strength test shall be the average of the strengths of the 2 specimens, except that if any specimen shows definite evidence, other than low strength, of improper sampling, molding, handling, curing, or testing, it shall be discarded, and the strength of the remaining cylinder shall be considered the test result."

Figure 4.--Sample SPS contract package.

"All costs associated with collecting specimens and subsequent testing shall be the responsibility of the Forest Service. Concrete for specimens shall be furnished by the Contractor at no cost to the Forest Service."

"The average of the 28-day strength tests for each structural element shall be sufficient to ensure that the minimum compressive strength requirements are met."

552.04 - CEMENT REQUIREMENTS

In the first sentence after the word "Type," add the words "I or."

552.08(b) - HOT WEATHER

Delete the remainder of the first sentence after the phrase "exceed 90 Degrees Fahrenheit."

552.11(q) - PIERS AND ABUTMENT

In the second paragraph, after "Type II," add "or I."

552.13(b) - METHODS

(2)b. Plastic Sheets - add:

"Color of plastic sheets shall be white or transparent."

552.16 - BASIS OF PAYMENT

At the end of the first paragraph, add the following requirement:

"The average 7-day strength shall equal or exceed those values for minimum 7-day compressive strength shown in Section 552.02(c) prior to allowing more than 75% of the price of the concrete for a structural element. The 28-day strength tests shall be completed and accepted prior to allowing more than 90% of the price of the concrete for a structural element."

Figure 4. (cont.)--Sample SPS contract package.

619-2 (6/82)

619.06 - SACKED SOIL CEMENT RIPRAP

Delete the first paragraph and substitute the following:

"Sacked soil cement riprap may be composed of any combination of gravel, sand, silt, and clay with the following limitations: Top soil shall not be used; at least 55 percent of the mixed soil shall pass the No. 4 sieve, with not more than 15 percent passing the No. 200 sieve; and the maximum size gravel shall pass the 1-½-inch sieve. Excluding gravel, the soil shall be pulverized so that no lumps exceed ½ inch in diameter. The cement and soil shall be thoroughly and uniformly mixed before placing in sacks. Sacks shall be at least 10-ounce burlap or equivalent. The minimum weight of the filled sack shall be 50 pounds."

Figure 4. (cont.)--Sample SPS contract package.

GPS Satellite Control for Photogrammetric Cadastral Surveys

Vic Hedman
Land Surveyor
Region 9

INTRODUCTION

The tools of measurement made available to the cadastral surveyor over the last few decades now have an added dimension of geodetic positioning using global satellites. Measurements to first and second order standards of geodetic positioning by a technique known as radio interferometry offer a method for filling the voids within and between the arcs of National Geodetic Survey (NGS) horizontal control. The densification of the geodetic network is essential to fully use its advantages and accuracies for large area horizontal control projects.

At the present stage of development, use of radio interferometry for geodetic positioning has its limitations. The Navstar Global Positioning System (GPS) is planned to be fully operational by the end of this decade when a total of 18 satellites are in orbit. The four operational satellites now in orbit have a limited viewing period of less than 4 hours per day. Viewing, as a timing measurement of high frequency radio waves, is affected by any obstructions on line between the satellites and the geodetic receivers placed over ground stations. Combining geodetic positioning with the most accessible locations to control analytical photogrammetric aerotriangulation were the conditions required for a test township project on the Superior National Forest in St. Louis County, Minnesota.

PROJECT AREA

The project area is township 57 north, range 13 west, fourth principal meridian, in St. Louis County, Minnesota. It is 50 miles north of Duluth, Minnesota, on the Aurora Ranger District. Townships on the Superior National Forest include many swamps and lakes and generally have an elevation differential of less than 200 feet. The timber cover is principally spruce, birch, and aspen, with crown heights of 50 to 60 feet. At the turn of this

century, the timber was pine, but logging and repeated fires have taken their toll.

The ownership pattern in this township requires the location and monumentation of 300 corner positions and the location and marking of 92 miles of National Forest Boundary (see figure 1).

GPS SATELLITE CONTROL

Geodetic positioning to not less than second order (1:50,000) accuracies is attained by GPS satellite measurements. Positional accuracies to less than 10 centimeters were specified and attained for this project. Spacing of the control was established near the project perimeter and within the project area essential for bridging of aerial photography and photogrammetric measurements by aerotriangulation. (See figure 2.)

With GPS control location generally limited to where four-wheel-drive vehicles or helicopters can carry the GPS geodetic receivers, accessibility to these locations influences the selection of project areas at this time. The six GPS stations and the two NGS stations for this project were all accessible and found to be the minimum number of control stations needed to control target areas of township size for photogrammetric measurements.

The method for GPS measurements is similar to a closed traverse using one NGS station as a master station and a second NGS station as a check station. These stations can be many miles outside the project area because the operation is by simultaneous measurements at the master station and for one or two GPS stations within the project area. The field operations were made over a 4-day period using three geodetic receivers as follows:

June 14 - Occupied Stations GPS-6, GPS-4, GPS-3.
June 15 - Occupied Station, GPS-3, GPS-1, and NGS-Banks (eccentric).[1]

---

[1]Station Banks is a National Geodetic Survey Station just to the north of a paved county road. The tree clearance that would have been required to receive satellite signals was not acceptable. A targeted eccentric position was set in a clearing about 800 feet to the southwest, and its geodetic position was determined by field traverse measurements.

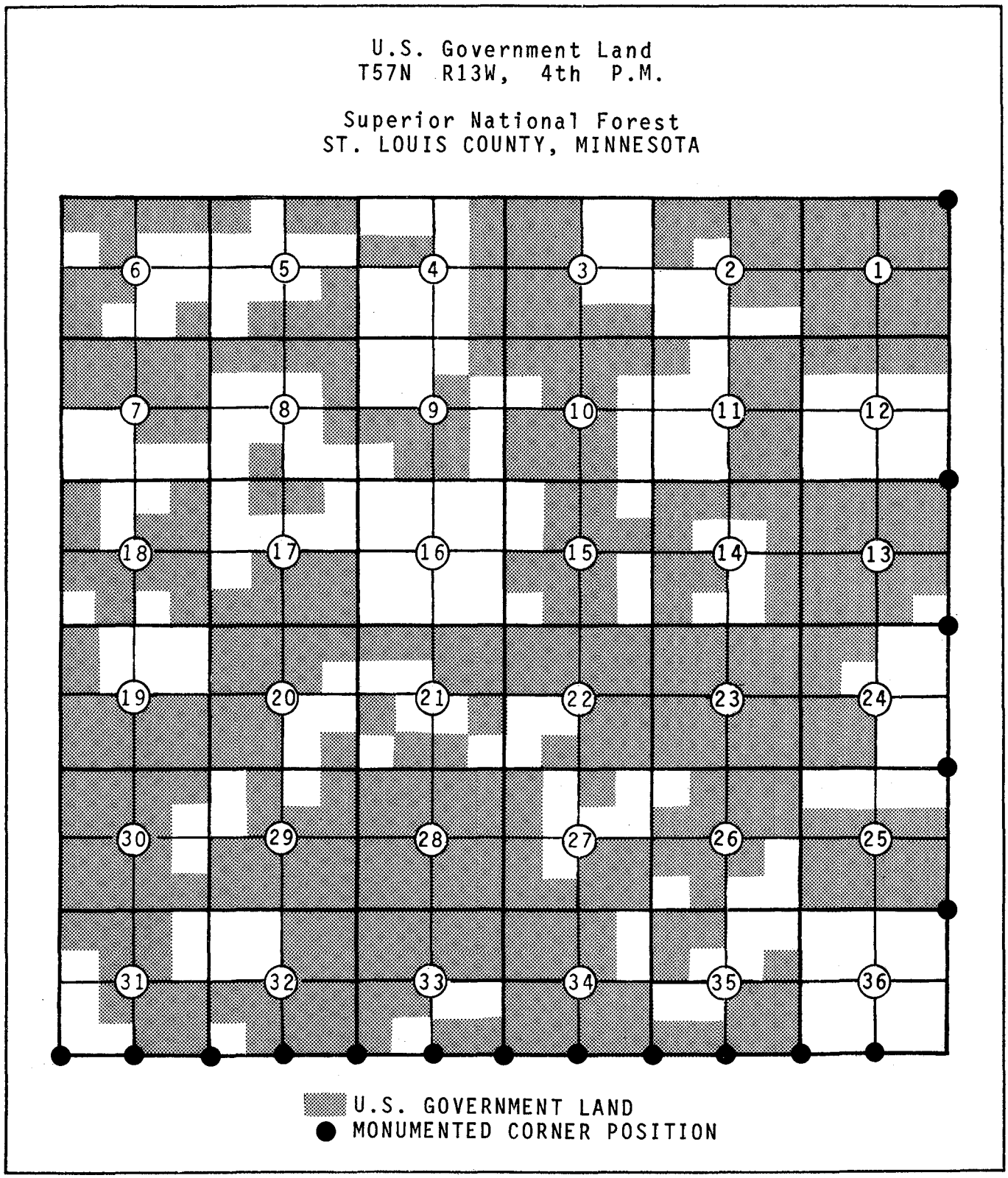


Figure 1.--U.S. Government land corner positions, Superior National Forest.

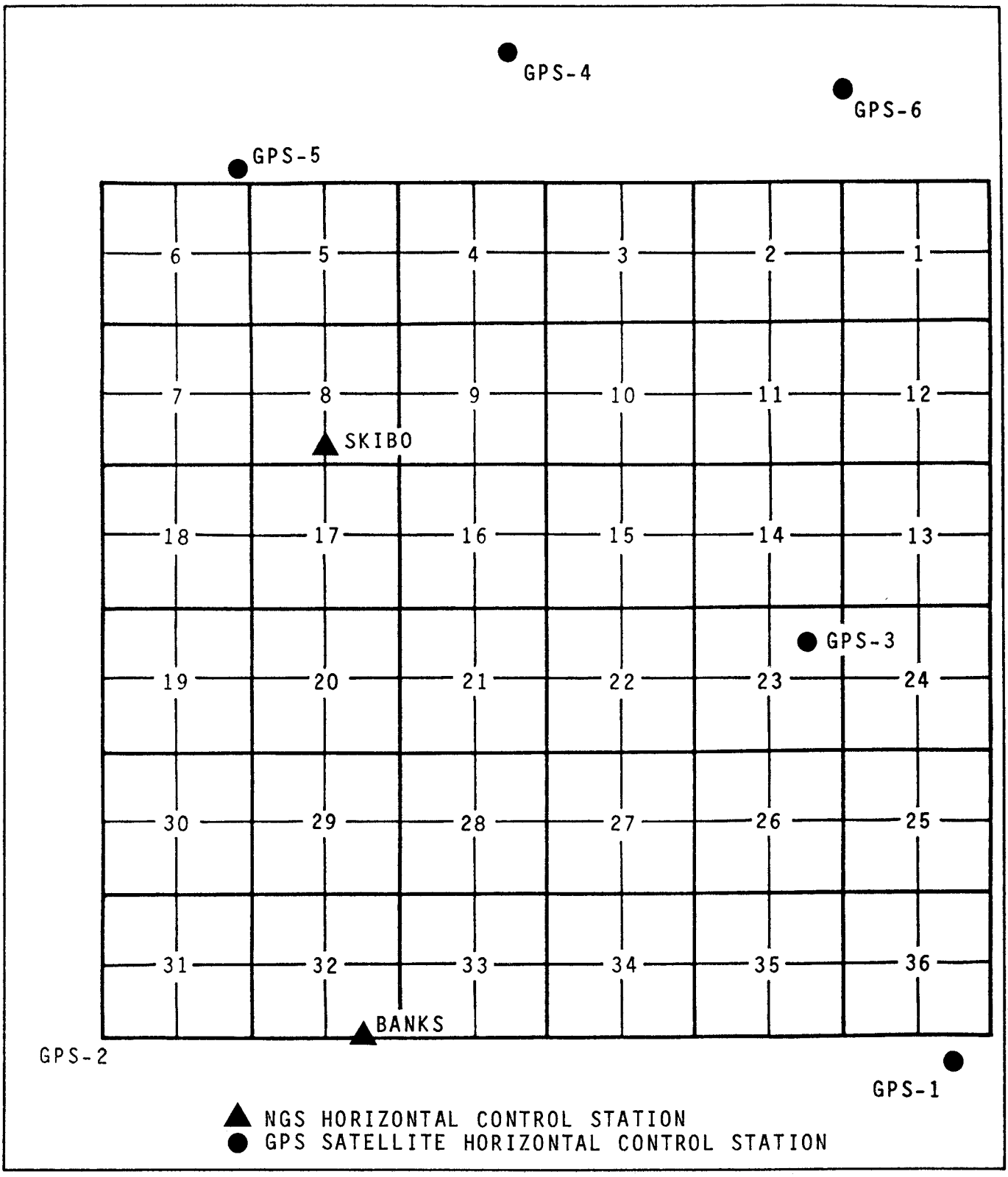


Figure 2.--GPS control stations for project area, T57N R13W, 4th P.M., Superior National Forest, St. Louis County, Minnesota.

June 16 - Occupied Banks (eccentric), GPS-2, NGS-Skibo.
June 17 - Occupied Skibo, GPS-5, GPS-4.

The sequence of measurements was a clockwise movement around the perimeter of the township with an overlap of one station for each set of measurements.

RADIO INTERFEROMETRY

In a 1983 report prepared by the Federal Geodetic Control Committee (FGCC), interferometric surveying is identified as a system using radio signals from satellites of the GPS to determine three-dimensional relative positions of survey stations to first order (1:100,000) accuracies. The Macrometer is the first instrument to combine very long baseline interferometry with the new GPS.

The system was tested by the FGCC in January 1983 for baselines varying from 8 to 42 kilometers. Results showed positional accuracies of under 10 centimeters. The FGCC and the contractor of this project are the first known sources for GPS satellite surveying at this time.

Four satellites were operational for this project. Their orbital planes are about 63 degrees inclined to the equator and at about 20,000 kilometers above the Earth's surface. The satellites are in two orbital planes. (See figure 3.)

Each satellite is equipped with radio transmitters broadcasting wavelengths of 19 and 23 centimeters. Each satellite has a precise atomic clock measuring in microseconds (millionth of a second). The geodetic coordinates are established by measuring the phase delay of the radio wavelengths at each of the ground geodetic receivers. The adjustments are made relative to the NGS master station, which was Skibo for this project. (See figure 4.)

The Macrometer receiver is a 3-foot-square aluminum ground plate mounted on a tripod and centered over the station mark. (See figures 5 and 6.) The ground plate serves to absorb false signal noise. The actual receiver, centered in the ground plate, is made up of four small gold-plated dipoles set at right angles to a center antenna and all covered by a transparent dome to be weathertight. A microcomputer, tape recorder (to record the radio signals), and a display panel are mounted within the vehicle and are connected by a 100-foot-long

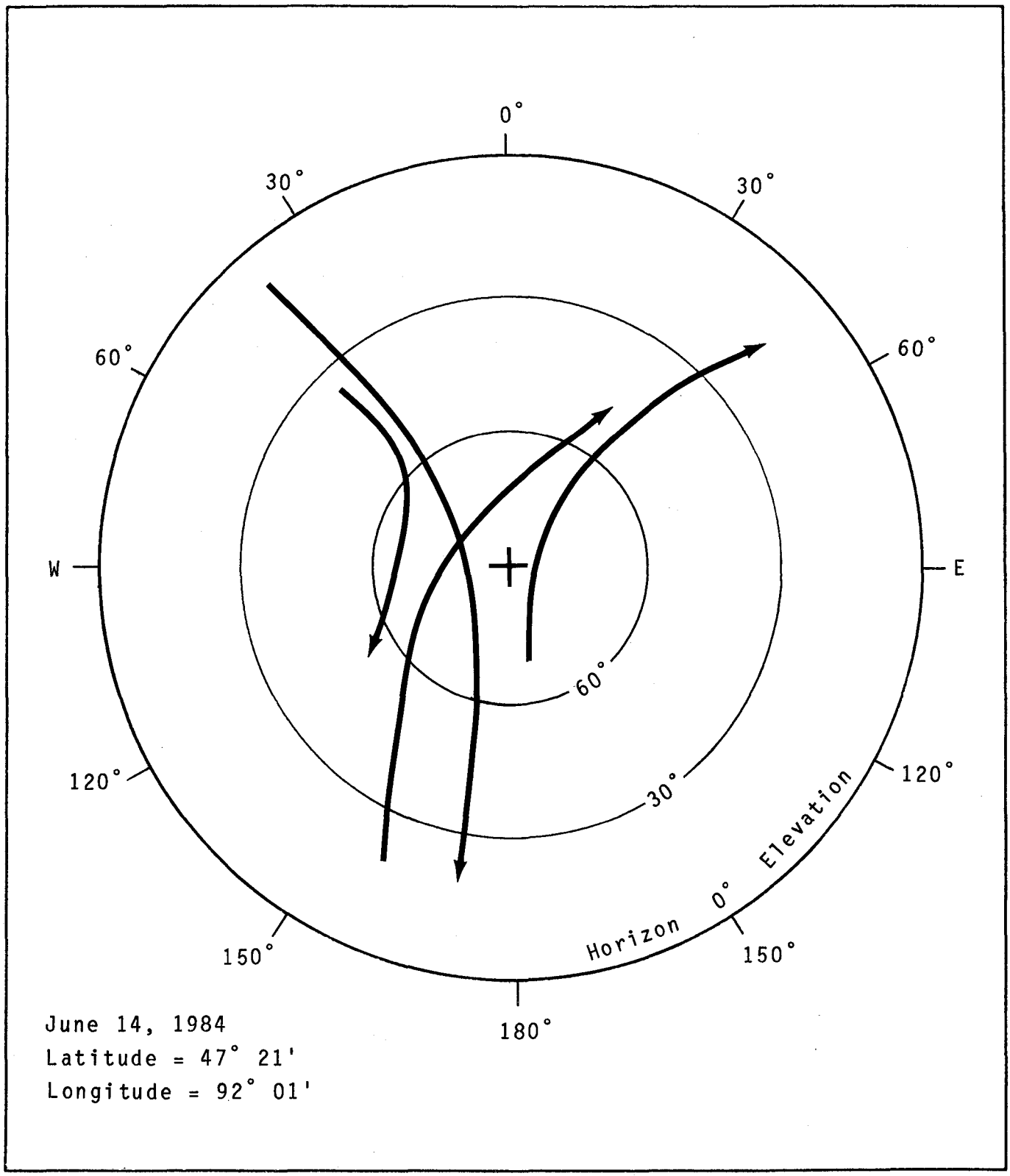


Figure 3.--Orbit of GPS satellites.

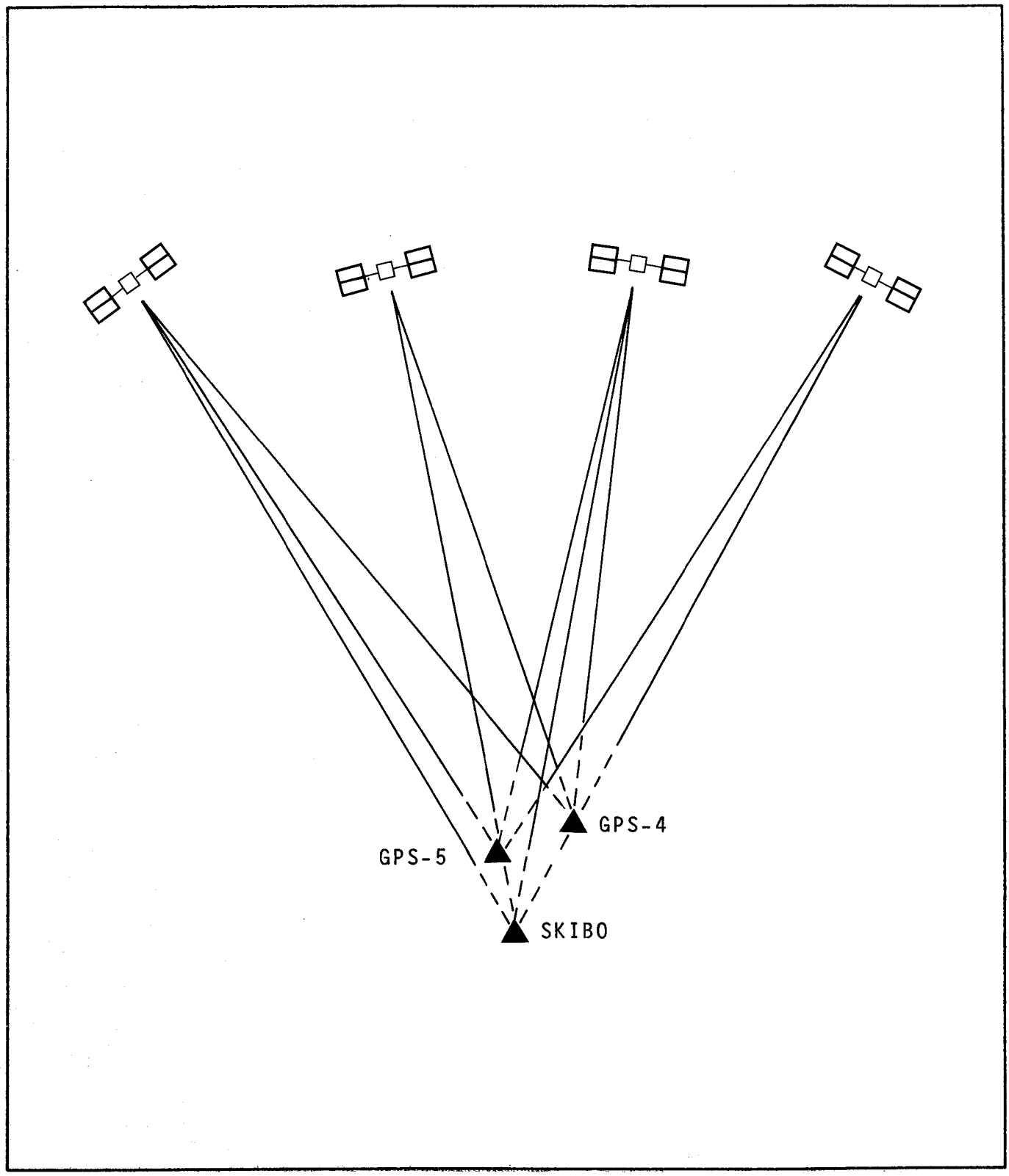


Figure 4.--Satellite radio wave transmission.

receiver cable. Power is provided by a portable generator placed outside the vehicle during operations.

Before field operations, the receiver units are time-synchronized with each other. The allowable drift between receivers during measurement is about 2 microseconds per hour over the 3 to 3½ hours of operation. Amplitude of the signals received and the active channels being received is shown on the display panel during operations.

GPS operations are on universal time referenced to zero longitude at Greenwich, England. The satellite signals were received on the project site about 7:00 p.m. local time and ended about 10:30 p.m. Signals are received 4 minutes earlier each day based on the sidereal day.

GPS STATION LOCATION

Figure 3 shows the approximate orbital planes of four active satellites for azimuth and elevation from entrance to exit and for the date and location of observation. To use the full range of signal "visibility," clearance is needed to about 20 degrees above the horizon. Site selection is

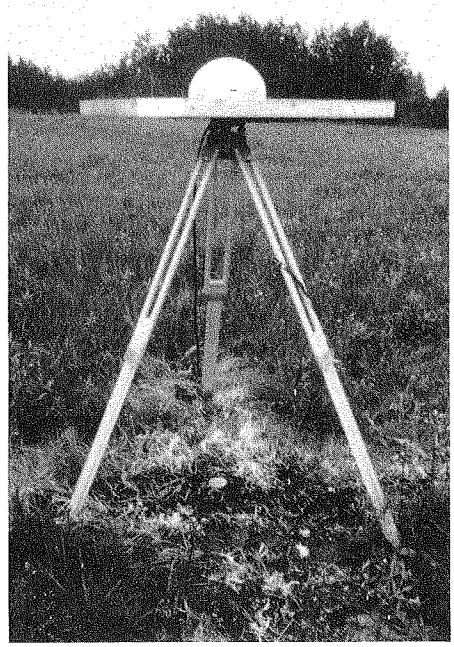


Figure 5.--The Macrometer receiver.

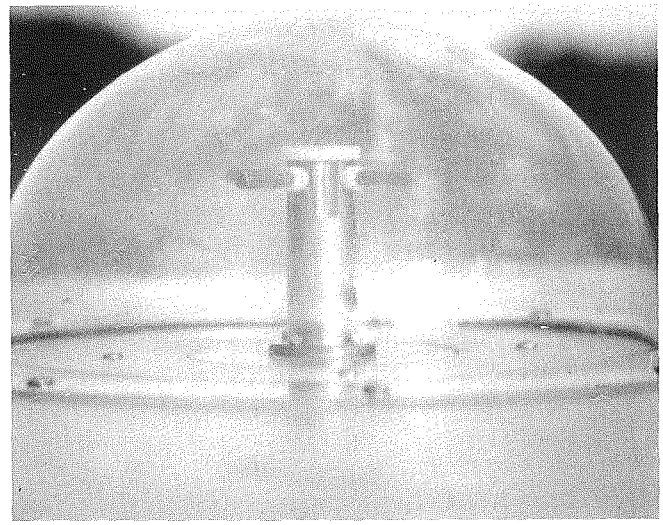


Figure 6.--Closeup of the Macrometer receiver.

directed to open areas, to areas of minimum tree clearing, or to heavy clearing of timber if there is no alternative. (See figure 7.)

GPS STATION DESCRIPTIONS

GPS-1

Open area 50 feet east of the centerline of the county road and about 100 feet west of railroad tracks. Station marked by brass capped monument stamped:

GPS-1
USFS
1984

GPS-2

Wide open area 85 feet north of the centerline of the county road and $\frac{3}{4}$ mile west of project area to take advantage of opening. Station marked by brass capped monument. (This control point is west of the six aerial photography flight strips covering the project area. An auxiliary station was established by traverse control between GPS-2 and Banks. The target is a concrete box road culvert at the southwest corner of the project. Identifiable point visible at intersection of abutment and wing wall.)

GPS-3

Open area about 100 feet west of railroad tracks. Point marked by brass capped monument.

GPS-4

Open area on west side of railroad tracks and southwest from U.S. Coast and Geodetic Survey bench mark set in the southeast corner of railroad bridge abutment. Elevation established on GPS-4 from the

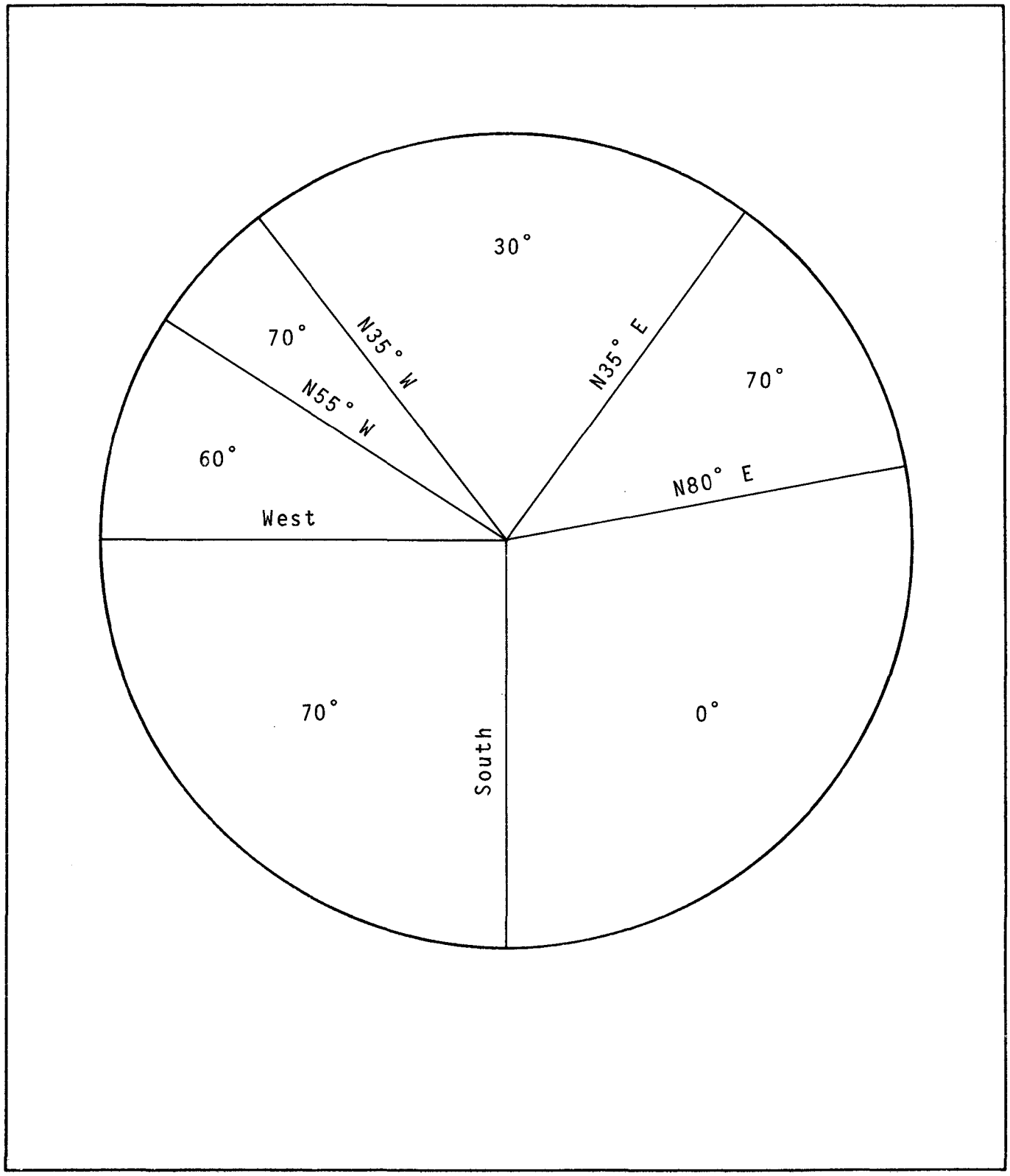


Figure 7.--Satellite visibility, northern Minnesota (clearance requirements below zenith).

bench mark as one of two vertical reference coordinates for radio interferometry. Elevation control measures the Earth's geoidal surface in relation to the ellipsoid.

GPS-5

An antenna station requiring a 120-foot-diameter clearing in a spruce-aspen-birch-timber type with crown heights of 50 to 60 feet. From station GPS-5 in the center of the clearing, the tree crown clearance is 45 degrees above the horizon. The geodetic antenna receiver was placed on top of a 30-foot tower that provided a horizon clearance of about 27 degrees and was adequate to receive satellite signals. Signals can be received through open tree crowns.

Banks Eccentric

A check station set in an opening about 200 feet south of the county road and south 70 degrees 55 minutes 33 seconds, west 796.8 feet from NGS station Banks. An NGS vertical bench mark about 50 feet north of the eccentric station was used to transfer an elevation to the eccentric station.

Skibo

This is a second order NGS horizontal control station used as the master station of reference for each of the GPS stations. Its NGS-published coordinates are latitude 47 degrees 25 minutes 55.209 seconds and longitude 92 degrees 00 minutes 54.383 seconds.

The coordinates of the GPS stations were adjusted mathematically by the contractor to station Skibo. The GPS closure on station Skibo was 88 millimeters, or 0.3 feet. (See table 1.)

PHOTOGRAMMETRY

The project area was covered with six flight strips at a scale of 1:12,000. (See figure 8.)

Color aerial photography was used to show better definition of natural feature calls as recorded in the official Government survey notes. The photographs also were used to support corner recoveries and restoration. Photograph targets were made from white-painted, exterior plywood. The targets, 4-foot-long by 8- to 12-inch-wide wings, were placed as a cross centered on the station monument.

Photocoordinate measurements of photocoordinate targets by aerotriangulation methods were made on a US-2 analytical plotter. Measurements were made in

Table 1.--X, Y, Z coordinates by global positioning system satellites.

STATION	LATITUDE			LONGITUDE			HEIGHT METER	EASTING FEET	NORTHING FEET	ELEV FEET
	DEG	MIN	SEC	DEG	MIN	SEC				
SKIBO	47	25	55.20900	92	0	54.38300	549.550	2,268,500.639	341,822.281	1,802.982
GPS-5 ECC	47	27	42.95577	92	1	36.80783	481.939	2,265,432.693	352,696.860	1,581.161
GPS-4	47	28	20.58551	91	59	17.83368	486.689	2,274,925.871	356,643.864	1,596.744
GPS-6	47	28	6.34303	91	56	20.06837	510.225	2,287,158.103	355,380.575	1,673.964
GPS-3	47	24	30.40498	91	56	43.19828	503.696	2,285,896.003	333,481.501	1,652.541
BANKS ECC	47	22	18.36915	92	0	39.24403	485.352	2,269,850.853	319,870.061	1,592,359
GPS-2	47	22	20.17989	92	3	35.72535	459.559	2,257,702.591	319,886.212	1,507.736
GPS-1	47	22	11.13345	91	55	32.56132	502.633	2,290,968.239	319,446.090	1,649.055

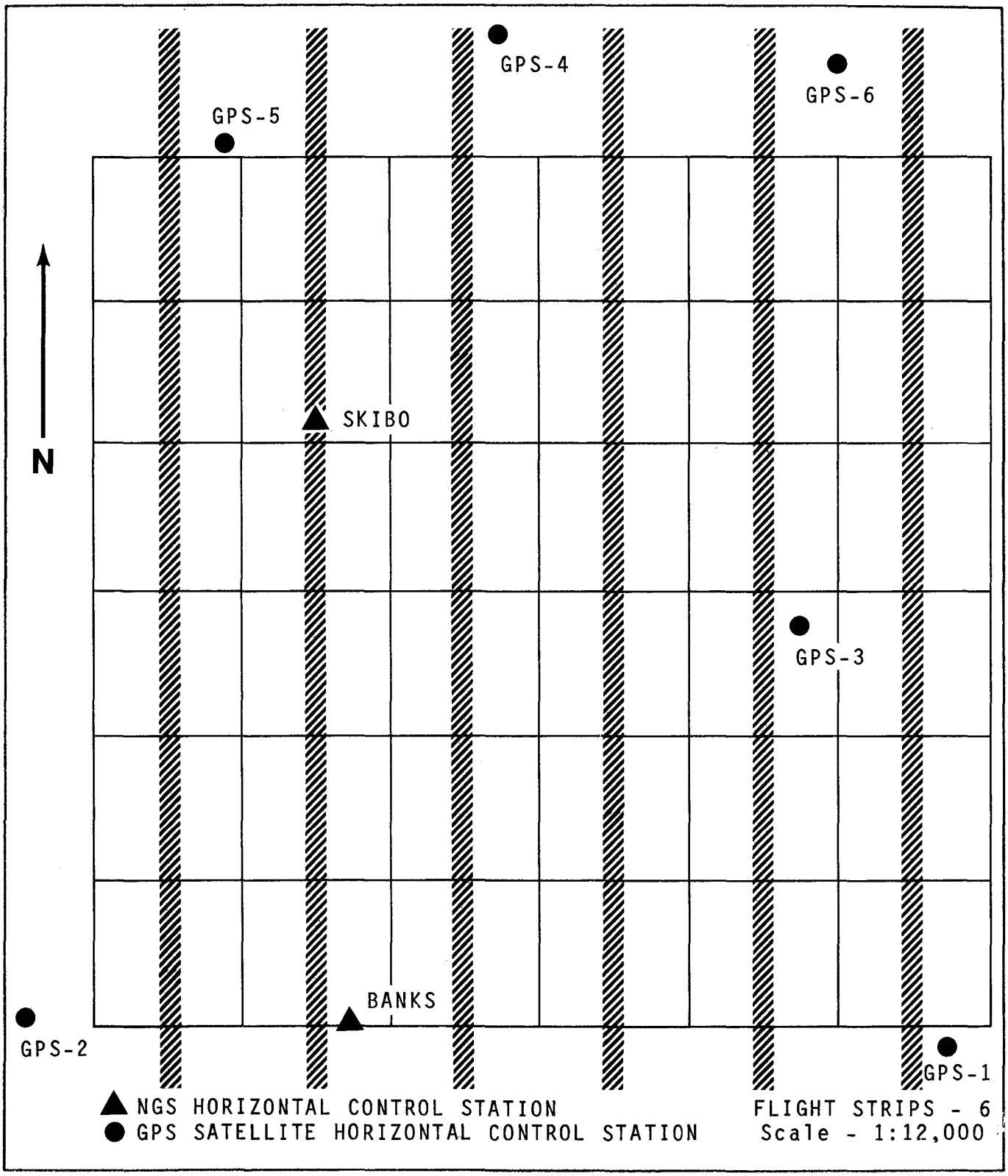


Figure 8.--Flight strips for photographing project area. Color aerial photography for T57N R13W, 4th P.M., Superior National Forest, St. Louis County, Minnesota.

microns and converted to feet. (See table 2.) Vertical control of targets was established from existing NGS level lines.

SUMMARY

Geodetic positioning to first and second order standards of accuracy by radio interferometry is a significant advancement in technology for the better use of the existing NGS horizontal control network. It places geodetic control within reasonable reach for the control surveyor. With the increasing need to place land corners on the State Plane Coordinate System as well as for other control uses, the users now have a powerful tool of accurate control.

Some limitations in this approach have been recognized. Obstructions from topography and tree cover and vehicle inaccessibility can preclude the use of interferometry in many areas. These are obstacles to be overcome by equipment development, improved portability, and an increase in the number of satellites.

Federal Geodetic Control Committee standards and specifications for densification of horizontal control by photogrammetry require a minimum of eight horizontal central points and four vertical control points spaced around the perimeter of the project. The spacing is to provide a horizontal control point for each six stereo models. Such spacing can be

Table 2.--Analytical block adjustment of photocoordinates of ground control targets.

Station	Latitude[a]	Longitude[a]
GPS-1	-0.1 feet	0.0 feet
GPS-2 Ecc.	0.0	0.0
GPS-3	-0.2	0.6
GPS-4	1.0	0.1
GPS-5	0.0	-0.1
GPS-6	0.1	0.2
Banks-Ecc.	-0.6	-0.1
Skibo	-0.4	-0.6
Root mean square	0.3	0.2

[a]Corrections applied to NGS and GPS horizontal control stations. Equal weight factors set at 0.3 feet, which is specified positional tolerance of GPS field control.

limited by accessibility of the control point for GPS survey operations and will become evident in bridging of flight strips. Table 2 reflects excellent results in holding to the four corners of the township project but shows marginal third order results within the project area where control was minimal.

CONCLUSIONS

The FGCC's acceptance of photogrammetric measurements for densification of horizontal control is a recognition of the advances made by photogrammetric technology. However, the requirements for acceptance are and must be rigid to warrant geodetic positioning within the national horizontal geodetic network.[2]

Field control for the establishment of photocoordinates should indicate accuracies of second order (1 part in 50,000) or better within the horizontal control network. The FGCC recommendation for a minimum of eight properly spaced horizontal control points near the perimeter and within the project area is essential for the bridging of project aerial photography and attaining a root mean square of adjusted coordinates that will meet minimum standards of third order photocoordinate accuracies.

Traverse is a method to establish control where needed between NGS horizontal control stations. Third order accuracies are attainable using normal conventional techniques, but the more demanding requirements and specifications to attain second order or better traverse accuracies invite cost and accuracy comparison with alternate methods. With GPS satellite control being accurate to within 10 centimeters of positioning relative to master NGS control stations, use of GPS control warrants strong consideration, especially if the end result is the establishment of photocoordinates for acceptance and densification of the national horizontal control network. When the 18 satellites are in orbit at the end of this decade as planned, it is predicted that accuracies of 5 centimeters of horizontal position can be attained within 20 minutes of observation

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[2]FGCC standards and specifications are available from the National Geodetic Survey, National Oceanic and Atmospheric Administration, Rockville, Maryland 20852.

time at any time of day or night. Such rapid and accurate results along with expected improved portability of equipment will have a major impact on the control survey methods of the future.

RECOMMENDATIONS

The equipment now being used for geodetic positioning by radio interferometry lacks portability and could be classified as laboratory equipment. Current stages of development indicate future portable suitcase containment. Conservative planning leans toward delaying purchase until the equipment has backpack portability and until there are more than the present four active satellites in place. Until planning includes establishment of a number of points within a Region or State area, contracting should be considered.

With the advent and rapid development of radio interferometry and resultant precise accuracies, the user must become familiar with geodesy and geodetic positioning. The interchangeability of geodetic latitudes and longitudes with State plane coordinates, comparison of geodetic with grid lengths and bearings, and comparison of the geoid with the ellipsoid must become part of the knowledge and skills of the user in this rapidly developing era of space age surveying.

Techniques To Bring New Life to Timber Bridges

Frank W. Muchmore
Regional Structural Engineer
Region 1

INTRODUCTION

In these times of tight budgets, high interest rates, and high material and labor costs, the Forest Service has placed renewed emphasis on reducing maintenance and construction costs. This paper will explore some of the unique aspects associated with the inspection, maintenance, and renovation of timber bridges.

The Forest Service manages one of the largest and most extensive transportation systems in the world. This vast transportation network of roads and trails with over 13,000 bridges serves the five basic land resource needs--timber production, watershed protection, forage production, wildlife habitat, and recreation--on nearly 190 million acres of forested and related watershed lands on 154 National Forests and 19 National Grasslands in 44 States and Puerto Rico.

To facilitate management and use of its resources, the Forest Service annually constructs or reconstructs approximately 9,000 miles (14,000 kilometers) of roads and 1,000 miles (1,600 kilometers) of trails and maintains an existing transportation system of about 230,000 miles (370,000 kilometers) of low-volume roads and 100,000 miles (161,000 kilometers) of trails. The overwhelming majority of these roads are single lane, unsurfaced or aggregate surfaced. As a general rule, most of these roads are designed for traffic volumes of less than 100 average daily traffic count and for speeds of 40 miles per hour (65 kilometers per hour) or less. To this road system, the Forest Service annually adds between 100 and 250 bridges. The total number of bridges is approximately 13,000, of which approximately 3,200 are trail bridges. About one-half of these bridges are constructed of wood or have a major component fabricated from wood, such as deck, stringer system, or substructure. Use of wood for new construction varies from year to year depending

on material costs, but the overall ratio remains about the same. In fiscal year 1981, 155 treated timber and native log bridges were constructed. Bridge design and inspection of major complex bridges are handled by personnel in each of the nine Regional Offices. Construction, operation, inspection (except for major, complex bridges), and maintenance are carried out by personnel on each of the National Forests.

WHY USE WOOD?

As a structural material, wood has many advantages and some disadvantages. Dr. John F. Levy of the Imperial College of Science and Technology, London, states wood's major disadvantage: "As far as a fungus is concerned, wood consists of a large number of conveniently orientated holes surrounded by food." The key to using wood as a long-lasting structural material is to make it unpalatable to decay fungi and microorganisms and to wood-boring insects and marine organisms. As shown in figure 1, preservatives basically form a protective shell that renders the wood unpalatable or toxic to these little "critters." Treatment with the proper preservative process dramatically increases the useful life of

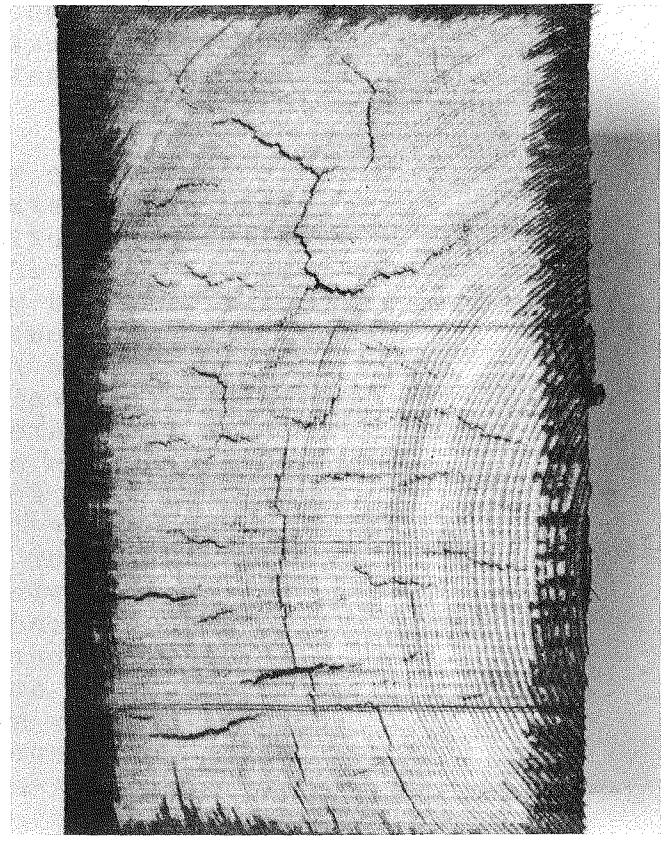

Figure 1.--Sawed cross section of pressure-treated Douglas-fir bridge stringer.

wood. For example, Barry A. Richardson states in "Wood Preserving" (The Construction Press, 1978) that in temperate climates a normal transmission pole pressure treated with creosote will have a typical life of 45 to 60 years, whereas an untreated identical pole will last only 6 to 12 years. A similarly treated railroad tie can be expected to last more than 35 years in comparison to only 8 to 10 years for untreated wood.

Richardson, in discussing the advantages of preserved wood, states:

> Preserved wood must be regarded as an entirely new structural material and must not be considered as just an improved form of wood, as it can be used in entirely different circumstances and certainly in more severe exposure situations. The most obvious advantage of preserved wood is that it can be used with impunity in situations where normal untreated species would inevitably decay, but it may be argued that, in many situations, this is a property that it enjoys together with many competitive materials. In fact, the use of wood has many advantages. It is extremely simple to fabricate structures from wood and, even in the most sophisticated production processes, the tooling costs are relatively low compared with those for competitive materials. Wood is ideal if it is necessary to erect an individual structure for a particular purpose, but it is equally suitable for small batch or mass production. When these working properties are combined with the other advantages of wood, such as its high strength to weight ratio, its excellent thermal insulation and fire resistance, its immunity to deicing chemicals, and the unique aesthetic properties of finished wood, it sometimes becomes difficult to understand why alternative materials have ever been considered! However, there is one feature of wood which is unique amongst all structural materials; it is a crop which can be farmed, whereas its competitors such as stone, brick, metal, and plastic are all derived from exhaustible mineral sources.

With all these various advantages, structural timber, which is exposed to the elements, when properly selected and preserved, can give satisfactory service for 40 years or more at costs that are competitive with other structural materials.

TIMBER BRIDGE INSPECTION

An important factor in ensuring a long, useful life for timber bridges is an effective inspection and maintenance program. Of course, the effect of proper choice of materials, preservative treatments, design details, and, to some degree, construction practices should not be overlooked. However, once a timber structure is put into service, a systematic inspection and maintenance program can significantly increase the structures useful life.

There are many other factors that contribute to timber bridge deterioration, such as traffic damage from impact or heavy loads and stream-induced damage from ice, drift, scour, and flooding. However, since these factors are common to all types of bridges, they will not be discussed here.

Even with the use of properly treated timber, it must be recognized that decay eventually will occur and is still the primary cause for timber bridge replacements. A preventive maintenance program including simple supplemental preservative treatments, coordinated with a systematic inspection program, can significantly prolong the service life of timber bridges. During the service life of the structure, the detrimental effects of decay can be minimized by alert inspectors who can locate developing decay or areas likely to decay. With this information, maintenance personnel can make the necessary repairs or supplemental in-place treatments to curb the development of decay before serious damage is done.

Inspecting Wood Bridges for Decay

Inspectors must recognize potential problem areas where decay can occur in individual bridges. They also must be able to determine the presence and define the limits of any decay present. Variations in structural designs, materials used, bridge age, and various exposure factors make this a complex assignment.

Decay Defined

Decay in wood is caused by living fungi, which are simple plants having the unique capability to break down and use wood cell-wall material as food. These fungi are propagated by germination of fungus spores, which are functionally equivalent to the seeds of higher plants. These spores, which are produced in massive numbers, are microscopic; they are distributed so widely by wind, insects, and other means that they are commonly present on most exposed surfaces.

Most spores never germinate for lack of a favorable environment. All of the following conditions must prevail to support decay fungus growth: sufficient oxygen supply; favorable temperature range, 32 °F (0 °C) to 90 °F (32 °C); adequate food supply (wood cells); and available water (that is, above fiber saturation point, approximately 30 percent moisture content for most species).

Once established, the fungus continues to grow at an accelerating rate as long as favorable conditions prevail. Depriving the fungus of any one or more of these required conditions will effectively curtail decay. Proper preservative treatment effectively provides a toxic barrier to the decay fungus' food supply, thus no decay takes place.

A common misconception is the use of the term "dry rot," which erroneously carries the connotation that dry wood will rot. Even the growth of "dry rot" fungus requires the moisture content of wood to be above the fiber saturation point. Wood maintained at moisture contents below fiber saturation can be considered safely dry from decay hazard, including from "dry rot."

Bridge Inspection Procedures

Because of the many different bridge designs, ages, and site environments, detailed recommendations for inspection procedures would be too voluminous for this paper. However, some basic considerations will be presented.

Visual Indicators of Decay. The inspection of timber bridges should be undertaken systematically, working from the lowest substructure members to the superstructure, or in reverse order. One advantage of starting below is the opportunity to observe load reactions in the decking and supporting structural members from passing before the actual inspection of the components. Telltale signs to watch for include abnormal deflections, looseness of joints or fasteners, or the presence of water forced from joint interfaces. These conditions may indicate the presence of decay.

Visual indicators of the presence of decay may include:

(1) Characteristic fungus fruiting structures. These may be mushroom-like or shelf- or hoof-shaped projections of flat, leathery material commonly found in partially enclosed areas (see figure 2).

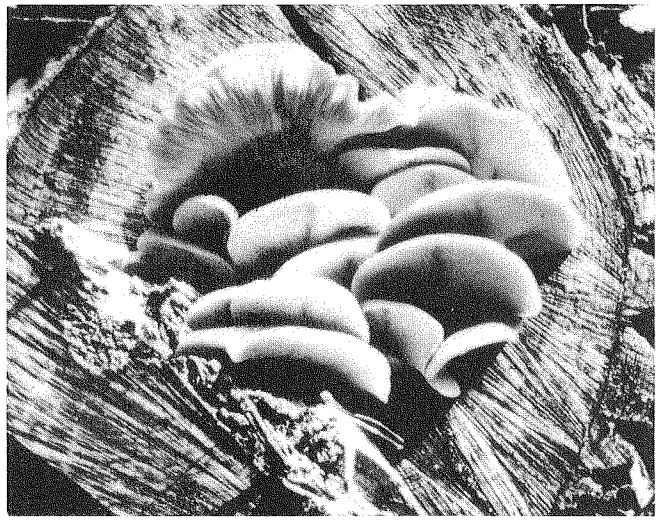

Figure 2.--Examples of decay fungus fruiting bodies in growing or fresh condition.

(2) Abnormal surface shrinkage or "sunken" faces.

(3) Insect activity. Carpenter ants or termites are attracted to decayed wood.

Visual indicators of conditions conducive to decay include:

(1) Excessive wetting, evidenced by watermarks or stains. Since a high moisture content is one of the conditions required for decay, this can be an important indicator.

(2) Rust stains on wood surfaces. This also indicates possible excessive wood wetting.

(3) Growth of vegetation on bridge members. Moss, grasses, and other plants growing in soil, accumulated on any wood member not normally in soil contact also may indicate potentially hazardous wetting.

(4) Accumulation of soil on any wood surfaces can trap water and increase decay hazard.

(5) Joint interfaces, mechanical fasteners, field fabrication, and wood adjacent to other water-trapping areas are potential sites of decay fungus growth.

(6) Water-catching seasoning checks in exposed wood faces.

Excessive moisture accumulations are probably the most common visual indicator of conditions that promote development of decay.

Detecting Decay. It is difficult to detect and determine the extent of decay, particularly when it is internal. External decay can be detected visually or by probing with a pointed tool, such as an awl, an ice pick, or a prospector's rock pick as shown in figure 3. The rock pick is also useful for sounding wood members. Sounding involves striking the wood member and listening to the sound produced. A dull or hollow sound may indicate internal decay. Internal moisture content may be measured with a probe-type moisture meter. Boring or coring are the most widely used techniques for detecting and defining the limits of internal decay. A recently developed instrument called the Shigometer is useful in the detection of early internal decay.

Figure 4 shows an electric drill being used for boring stringers. Care must be taken so that holes resulting from boring or coring do not promote entry of water or decay fungus spores into the wood. Whenever possible, holes should be oriented to let gravity aid in keeping water out of the hole and when possible should be plugged with treated plugs.

Figure 5 shows typical internal decay locations resulting from development of seasoning checks and the use of fasteners (nails, drift-pins, and so forth) penetrating the outer treated shell and establishing a path for entry of decay spores into the untreated inner portions of a structural member. Obviously, designs that minimize the use of penetrating fasteners also will minimize the introduction of internal decay hazard.

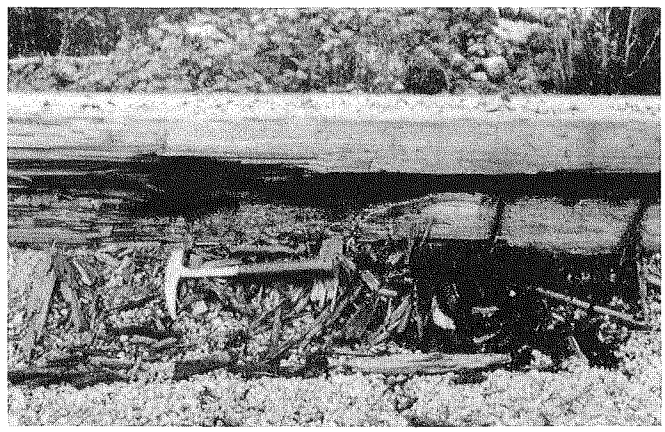

Figure 3.--Prospector's rock pick for probing and sounding timber members.

Figure 4.--Boring untreated stringer at bearing area with electric drill.

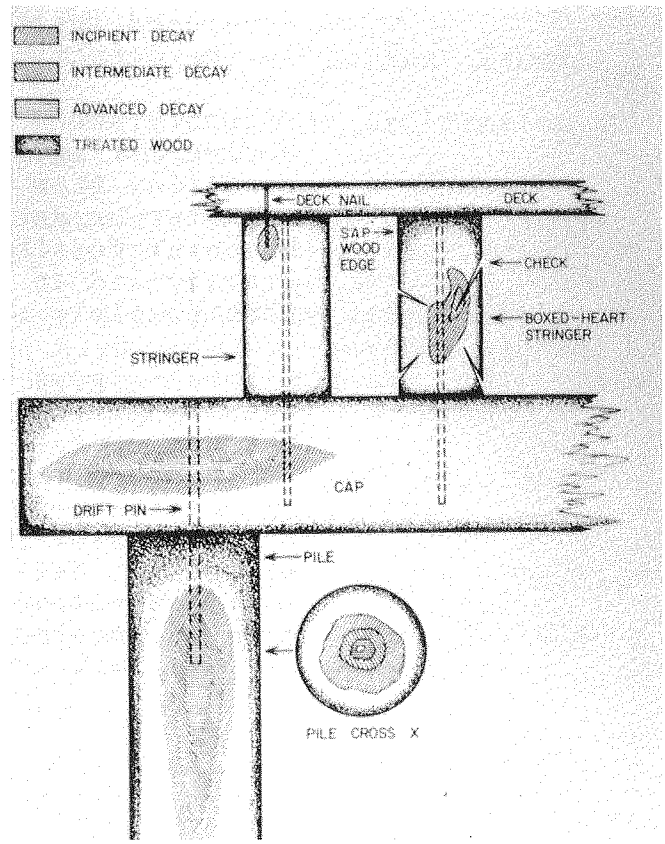

Figure 5.--Schematic diagram of portion of pile bent, stringers, and deck showing locations where decay may occur.

Strength Loss Associated with Decay

There is relatively little information in the literature on strength loss resulting from amount or severity of decay in bridge timbers. It has been shown that strength loss is roughly proportional to the loss of sound wood in the section. It is recommended that a zero strength value be assigned to any decay detected and that the sound wood be

assigned its full strength value. In other words, use the section properties and normal allowable stresses of the remaining sound wood only when calculating a member's strength. While this may result in a conservative estimate of the residual strength of the member, it is appropriate because incipient decay is difficult to detect and because the decay fungus generally will continue to grow and spread until some remedial action is taken, and such corrective action may be delayed, resulting in a further actual strength loss.

BRIDGE MAINTENANCE

Timber bridge maintenance may be divided logically into three categories. These are:

(1) Preventive maintenance. Decay has not started, but conditions conducive to decay are definitely present. It may include control of moisture and use of in-place preservative treatments.

(2) Early remedial maintenance. Decay is present, but major maintenance is not required for the bridge to continue normal service. However, the bridge is likely to become more structurally damaged and load limited if corrective measures are not applied. It may include those preventive maintenance measures given above, plus replacement of decayed minor members such as pieces of curb, guardrail, and running planks (wearing surface).

(3) Major maintenance or replacement. Decay has progressed in major load-carrying members until moderate to severe loss of structural strength makes repair or replacement mandatory or requires that load restrictions be placed on the bridge. It may consist of any measures discussed above, plus replacement of portions on all of the structural deck, stringers, or timber substructure.

Unfortunately, most timber bridge maintenance is ignored until it reaches the third category, requiring major repairs or complete replacement. Figure 6 shows examples of this.

Preventive & Early Remedial Maintenance

Control of moisture is probably the most cost-effective and practical general technique for extending the service life of new and existing timber bridges. This protective measure undoubtedly has contributed significantly to the exceptionally long service life obtained from many old covered

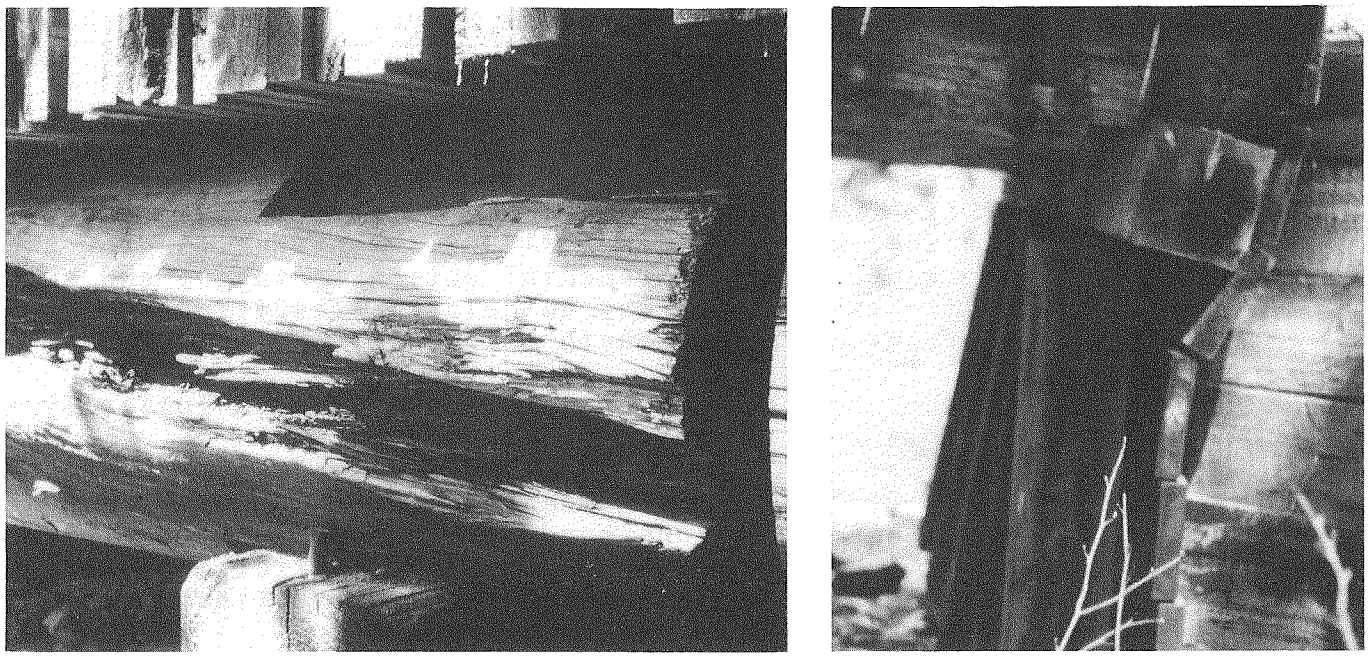

Figure 6.--Examples of deterioration that may have caused major structural damage.

wooden bridges. However, in most of the more modern timber bridge designs, preservative treatments have been relied upon to control decay, and the older principle of keeping water away from the structural members sometimes is given less emphasis.

Conversely, some attempts to control moisture have proven detrimental. Examples are the following:

(1) Using roll-roofing material as water-diverting covers or caps on stringers, pile, or post tops can be harmful. As roofing material ages, it dries out and becomes permeable to water from above. More harm than good may be done by capping piles or posts because the cap tends to trap moisture and inhibits drying.

(2) Sheet metal covers between pile or post tops and overlying stringer support caps are also of questionable value. The metal usually is installed before the cap is placed. When the drift pins are driven down through the cap into the pile or post, the metal is punctured and dimpled, creating a "funnel" for trapped water to enter the pile top and run down the drift pin past the treated top surface into the unpreserved inner wood. Again, the metal also

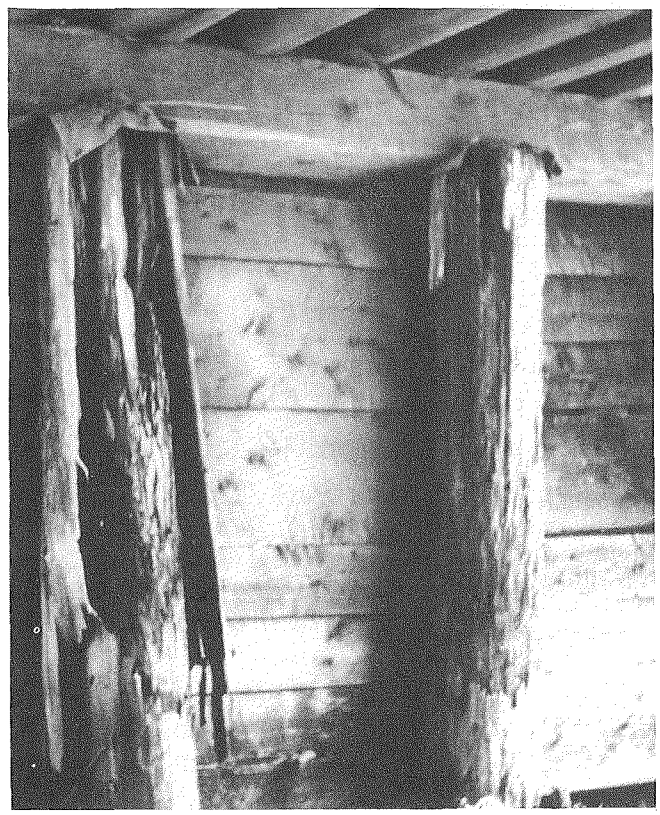

Figure 7.--Sheet metal caps between pile tops and stringer support caps may increase decay hazard.

inhibits drying, thus creating a dual high-moisture condition that is conducive to the growth of decay fungi, as shown in figure 7.

(3) Sheet metal caps on exposed pile or post tops, as shown in figure 8, also are generally regarded as contributing to early decay. Exposed metal caps seem to attract vandals who cannot resist punching holes in the metal caps with sharp objects or bullets. The net result again is the creation of "funnels" for water entrance and, at the same time, the inhibition of the drying of the pile or post top. An effective design criterion to promote good drainage is to avoid level surfaces on the tops of posts and other places.

More effective moisture-proofing uses bituminous or asphaltic mastics in lieu of sheet metal or roll roofing material as end grain coatings, joint fillers or seals, and check-filling compound. Care must be taken not to form water-entrapment areas under such coatings. Also, since petroleum compounds can dry out, lose their elasticity, and eventually crack, an effective maintenance program will include reapplication where feasible.

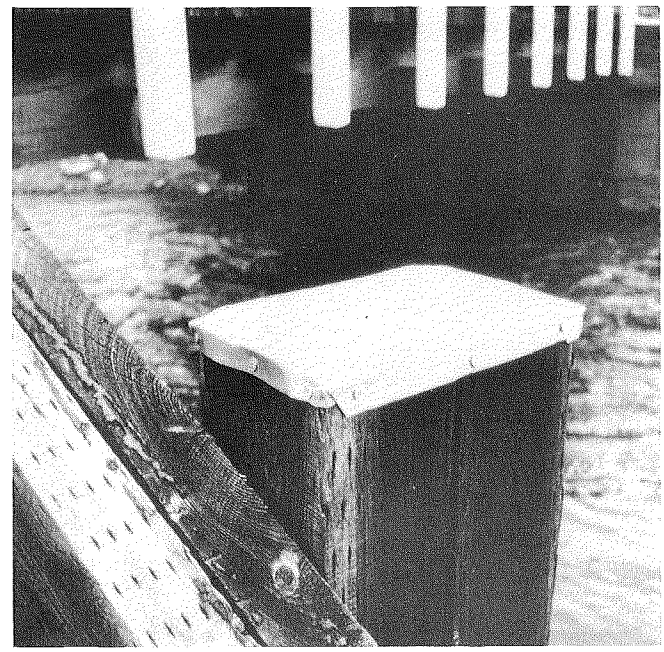

Figure 8.--Sheet metal caps on exposed pile or post caps may become punctured and funnel water into pile top.

Perhaps the most effective and practical method to control moisture on most wood bridge designs is to prevent water passage through the deck. In effect, make the bridge deck an impervious roof over the supporting stringers. If the timber deck is sufficiently rigid and stable, a well-maintained asphalt mat (usually at least 3 inches thick) can be quite effective.

If the deck is not sufficiently rigid or stable to support an asphalt mat, redecking normally will be required if such a mat is to be used. If a new deck is required, properly treated glued-laminated deck panels offer several advantages. Besides providing better support for asphalt mats, deck panels are produced at a moisture content of about 12 percent and thus will be subject to very little shrinkage during service, helping to minimize crack formation in the mat. However, experience has shown that reflective cracking of the asphalt mat usually occurs over the panel interfaces. This may not be detrimental because in original development of deck panels, "treatment" was considered the moisture barrier, not the asphalt.

In-place Treatments

Supplemental or in-place preservative treatments have been used little on timber bridges in the past. Commonly, decay has not been detected until after it has become so severe that the member needed to be replaced. However, increased emphasis on periodic inspections, with attention given to early detection

of decay and conditions conducive to decay, makes in-place treatments more practical as a means of extending the life of partially decayed members rather than replacing them.

Conventional preservatives are available for in-place treatment. These include various liquid- and grease-type preservative compounds. Generally, pentachlorophenol solutions and fluor-chrome-arsenic-phenol (FCAP) have been found to be the most effective when flooded onto the top surfaces of test units. Liquid preservatives can be applied to in-place timber surfaces most effectively by spraying or brushing/flooding.

Experimental work has shown that internally applied (through a series of bored holes) fumigants can successfully arrest established decay fungi for 6 to 10 years. Both Vapam and Chloropicrin have been registered for use as internal decay-arresting fumigants in utility poles. Although this technique has not been used extensively for bridge timbers, it has been used successfully to arrest decay fungi in infected Douglas-fir utility poles and wharf curbs.

Major Maintenance

When decay in treated or untreated wood is allowed to progress unchecked, complete deterioration ultimately takes place. At some stage, a structural member becomes too weak to carry the loads imposed on it. An alert bridge inspector should detect the loss of strength before these conditions advance far enough to cause structural failures, such as those shown in figure 9. When timber structural members must be replaced because of deterioration from decay, such replacement should be with properly treated members. Solid sawn or glued-laminated members, such as stringers, deck panels, wheel guards, rail posts, and substructure members, should be pressure treated after fabrication to provide economical, long-lasting service.

When major replacement of structural members is required, the designer of the repairs should try to use details that will not trap moisture, soil, or other debris and thus create conditions conducive to decay. Also, field fabrication of wood members (cuts, holes, daps, and so forth) should be held to an absolute minimum, since field treatment (flooding, spraying, soaking, brushing) is not nearly as effective as in-plant pressure treating after fabrication. The control of moisture access to the structural members should be of primary concern.

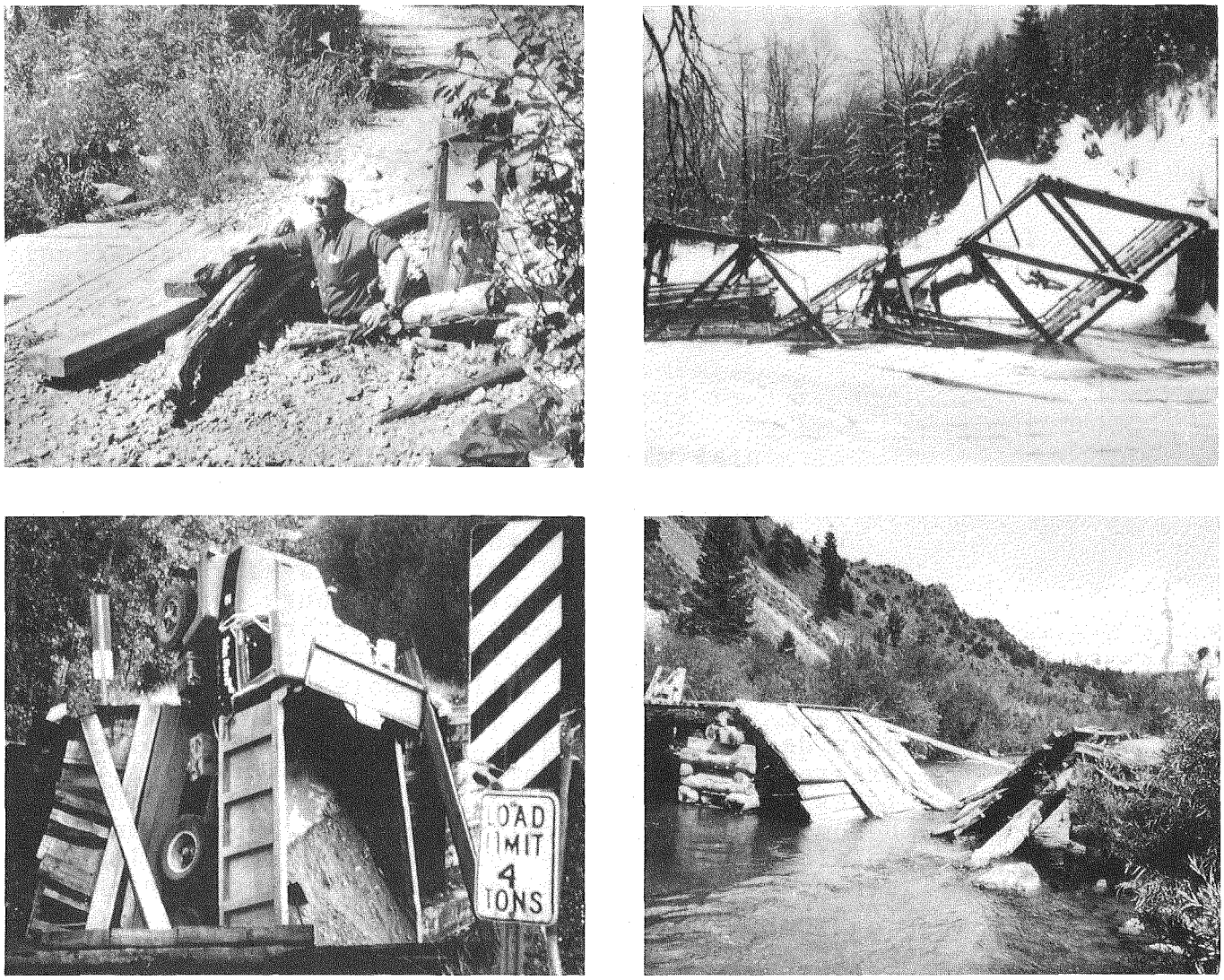

Figure 9.--Timely inspections can detect loss of strength before major structural failures occur.

BRIDGE RENOVATION & REPLACEMENT

The various components of composite structures frequently deteriorate at quite different rates. For example, a bridge with steel girders or trusses and timber floor stringers and/or decking that has not been subjected to deicing chemicals may have deteriorated timber members but still have functionally adequate steel members. When this condition exists, it may be feasible and economical just to replace the timber members. A thorough inspection and load-rating analysis should be performed. If the steel members still have adequate load-carrying capacity and the bridge geometry is still adequate, it is usually quite economical to renovate the wood portions of the structure, thus providing many more

years of service for a relatively modest cost. Examples of bridges renovated or under renovation in Region 1 follow.

Schwartz Creek Bridge over the Clark Fork River

The Schwartz Creek Bridge is a 222-foot (68-meter), 4-span, single-lane 14-foot-wide (4.3-meter-wide) bridge across the Clark Fork River at Schwartz Creek near Missoula, Montana. It was designed for AASHTO H20-S16-44 standard highway loading and built in 1953. It consists of reinforced concrete piers and abutments; twin wide-flange steel longitudinal girders; a nail-laminated, treated timber deck (2-inch by 10-inch (51-millimeter by 254-millimeter) S2E members on edge, nailed together); steel running plates; and timber post and rail bridge railing system (see figure 10).

The steel running plates were too widely spaced, and over the years traffic wear reduced the timber deck thickness, primarily on the approach spans, to the point where it was no longer adequate for legal highway loads. Decay was insignificant. The county assumed maintenance jurisdiction of the road but would not accept the bridge unless it met AASHTO highway loading criteria. Consequently, the Forest Service prepared and awarded a contract to:

(1) Replace approach span decking with glued-laminated deck panels (see figures 11 and 12).

(2) Remove existing curb and railing and replace with curb and railing designed to meet Forest Service and county requirements.

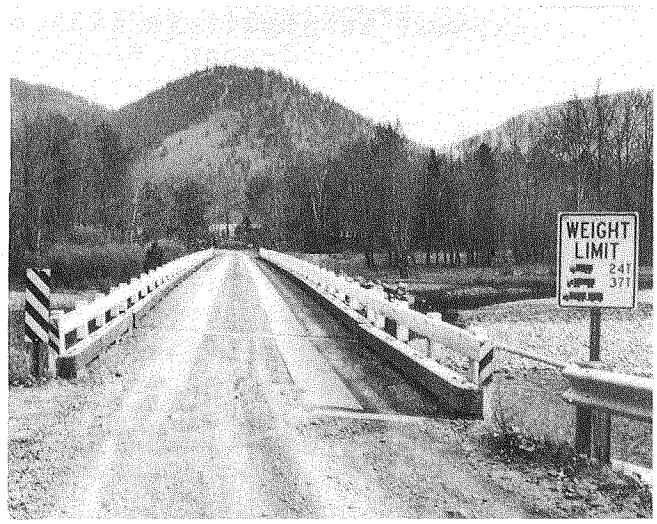

Figure 10.--Schwartz Creek Bridge across Clark Fork River near Missoula, Montana, before renovation.

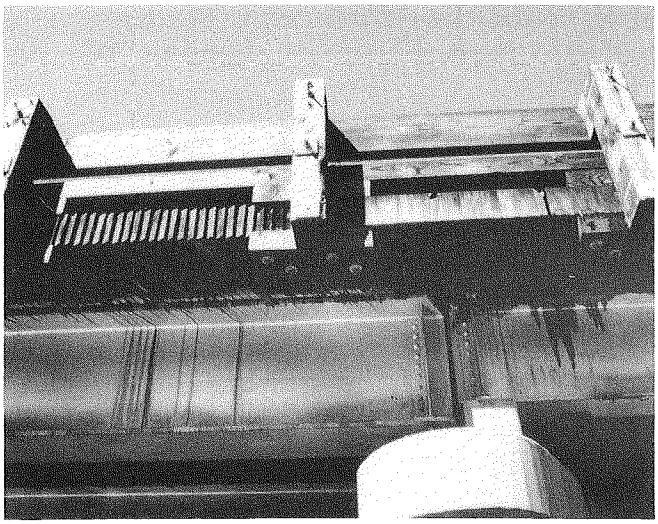

Figure 11.--Schwartz Creek Bridge: Original nail-laminated decking at left; new glue-laminated decking at right.

Figure 12.--Clips holding glue-laminated deck panels to steel stringers (note "bleeding" of pentachlorophenol and oil as result of full-cell treatment process).

(3) Remove the steel running plates and install timber running planks full width (see figure 13). Treated plywood was used to make up the $\frac{1}{2}$-inch (13 millimeter) difference in thickness between the retained main span decking and the new approach span glued-laminated panels. The work was done for approximately $50,000, or $16 per square foot ($172 per square meter), in 1981.

Simmons Creek Bridge

The Simmons Creek Bridge is on the St. Joe River road between Avery and Red Ives in northern Idaho. Built in 1935 for 15-ton truck loading, it is a 3-span, 86-foot (26-meter), single-lane (12-foot (3.7-meter) width) bridge consisting of treated timber stringer and nail-laminated deck approach spans, twin steel girders with a nail-laminated deck main span, and reinforced concrete piers and abutments. The bridge's inadequate load capacity (15 tons, or 13.6 metric tons) and width (12 feet, or 3.7 meters) dictated replacement. All wood was pressure treated, and decay was not a significant factor, even after 45 years!

A double-lane, curved concrete bridge had been designed for HS30 ($1\frac{1}{2}$ times HS20-44) loading in 1970. Changing management plans no longer required

Figure 13.--Schwartz Creek Bridge completed project.

the heavier loading, so the concrete double-lane bridge was redesigned in 1979 for AASHTO HS20-44 loading, and bids were solicited. The low bid of $190,000 ($99 per square foot, or $1,065 per square meter) exceeded the funds available, so bids were rejected. The Forest Service then decided to renovate the existing single-lane bridge to its current single-lane standards (HS20-44 loading, 14-foot (4.3-meter) width).

New timber approach-span stringers, main span steel wide-flange girders, glued-laminated panel decking, timber running planks, and bridge railing were installed in 1980. Forest Service personnel performed all work. Total cost was $46,000 for materials, equipment, and labor ($38 per square foot, or $409 per square meter). While this cost represents work done by Forest Service personnel, the cost to perform the same work under contract would have been perhaps slightly higher but probably would not have exceeded $50 per square foot, or $538 per square meter.

Markley & Durnham Bridges

These two pony truss bridges, similar in size and design, are across the Gallatin River, several miles apart, between Bozeman and West Yellowstone, Montana. They were originally built by private owners, but through a recent land exchange have become Forest Service property. One is 75 feet (23 meters) long, the other is 79 feet (24 meter) long; both are 16 feet (4.9 meters) wide with steel trusses made up with welded joints from old pin-connected trusses salvaged from another unknown site. The floor system consisted of untreated timber floor stringers supported on steel floor beams between trusses (see figure 14) and untreated timber plank decking, with treated timber abutments. Both bridges were posted for a 10-ton (9-metric-ton) weight limit. The first Forest Service inspection in 1980 revealed the presence of serious deck decay (see figure 15) and a badly cracked stringer (see figure 16) in the Markley Bridge, with less serious deterioration noted in the decking and stringers of the Durnham Bridge. The Markley Bridge weight limit was immediately reduced to 3 tons (2.7 metric tons), and a contract was prepared and awarded in 1981 to remove and dispose of all timber decking and floor stringers; to sandblast and repaint all structural steel; and to replace all timber with pressure-treated timber.

Glued-laminated floor stringers, sawn floor planking, running planks, and curbs were designed to increase the bridge's load capacity to an occasional 25-ton vehicle (see figure 17). The cost of this work was

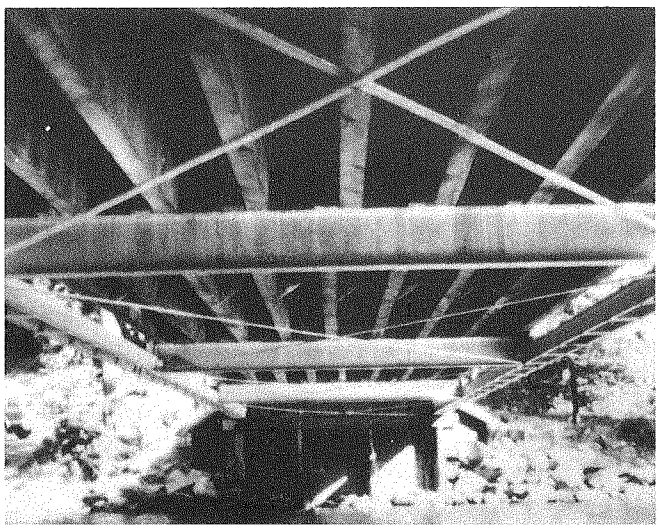

Figure 14.--Underside of Markley Bridge.

Figure 15.--Markley Bridge: Decay in untreated deck planking. Decay at left goes completely through plank.

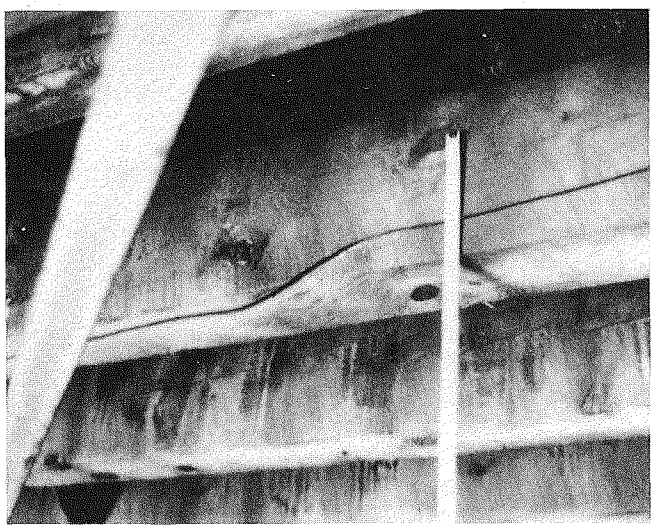

Figure 16.--Markley Bridge: Cracked floor stringer. Decay present at deck-stringer interface also.

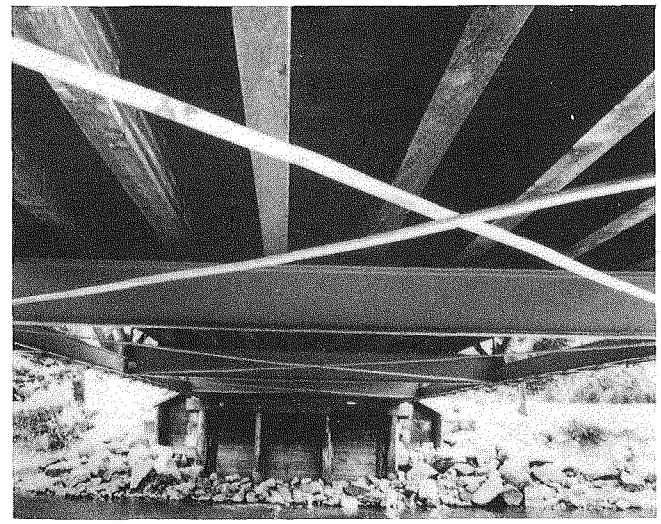

Figure 17.--Markley Bridge: Rebuilt underside. Note glued-laminated floor stringers.

$22,000, or $16 per square foot ($172 per square meter). Similar work was planned for the Durnham Bridge in 1983.

CONCLUSION

Wood, when properly treated to prevent early decay deterioration, is an economical and practical structural material for many short-span bridges. An important factor in ensuring long, useful lives for timber bridges is an effective inspection and maintenance program. Systematic scheduled inspections coupled with effective and timely preventive maintenance will ensure a lifespan competitive with other structural materials, such as steel and concrete. Proper design considerations that minimize water-trapping details and fasteners penetrating the treated surface into untreated wood are very important. As wood decays, loss of strength is roughly proportional to the loss of sound wood in the section. Knowledgeable maintenance procedures will add significantly to the useful life of treated timber bridges.

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Volume 17
May-June 1985

Engineering Field Notes