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Bridge Design Ethics

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Foreword

"Bridge Design Ethics" was presented at the recent Western Bridge Engineers Seminar in Coeur d'Alene, Idaho. Mr. Keeley raises a very pertinent issue—his concerns about conflicts between the need to get the job done and the desire to do the job more thoroughly in bridge design work carried out by the Federal Highway Administration (FHWA) could easily apply to other areas of engineering effort in other agencies, including the Forest Service. I have seen examples of similar conflicts and have talked with Engineers within our agency who have observed, or have been directly involved in, these conflicts.

The issue deserves our consideration, and Mr. Keeley presents it very well. As he states in his summary, the first step in solving the problem—a problem we share—is to recognize that it is real.

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—Ron Schmidt
Regional Structural Engineer
Region 10

James Keeley has worked at Western Bridge Design in Denver for 15 years—6 as a designer and the last 9 as a supervisor. In addition to supervising about half of their staff, he also designs and checks the designs of others, checks shop and falsework drawings, and assists the Construction Division in solving bridge problems.

Western Bridge Design is one of two bridge design offices in FHWA. With a permanent staff of 15, Western Bridge has been producing bridge designs since 1925 and has accumulated about 2,500 of them. Western Bridge designs cover 19 states west of the Mississippi, all with different standard traffic rails, prestressed girders, and other design elements. In addition, Western Bridge does the bridge designs for two of its contracting offices: one in Denver and the other in Vancouver, Washington.

Mr. Keeley is concerned about priority being placed on the speed, rather than the quality, of designs, which he feels creates an ethical dilemma for the designer. To avoid a singular view, comments from designers and managers from public and private offices all over the country, as well as people from the American Society of Civil Engineers (ASCE), the National Society of Professional Engineers (NSPE), the American Consulting Engineers Council (ACEC), and the Associated General Contractors of America (AGC) are included.

Introduction

Failures make engineers struggle with the most serious ethical questions.

In January 1986, the space shuttle Challenger exploded, killing all seven astronauts as the Nation watched. The impact of this failure was felt worldwide. An investigation revealed that the rocket booster joint failed, triggering the explosion. The engineers that designed this joint advised against launching the shuttle if the temperature of the joint was below 53 degrees—yet the joint temperature was believed to be 28 degrees when the shuttle was launched. The space program epitomized American engineering ingenuity and excellence; this failure caused a loss of confidence in thousands of dedicated scientists, engineers, and technicians.

Regrettably, the highway bridge business also has had its share of failures. In April 1982, 13 workers were killed when a bridge ramp structure collapsed in East Chicago, Indiana. In 1984 in Denver, one worker was killed and four others injured when eight girders fell just after the last one was erected.

Structural failures are not restricted to one engineering discipline or one state, nor are they restricted to public engineering works or those engineered in the private sector. Were designers to blame for these disasters? Their managers? Also, perhaps most importantly, what ethical dilemmas were involved in these disasters?

In the case of the Challenger, the Presidential commission investigating the disaster reported enormous management failings and technical flaws. Structural failures of public structures (similar to the ones in Indiana and Colorado) were extensively studied by a subcommittee of the U.S. House of Representatives, and their findings were published in March 1984. They did not find the fault to be restricted to designers, managers, or one engineering discipline or another. Rather, they found that a predominant cause was a lack of communication among the people that purchase, design, build, and use public structures. Their investigation also showed another critical factor: The quality of the designs for these projects was adversely affected by the pressures of time and efforts to reduce costs.

The most significant problem in bridge engineering today is the lack of priority on design time. Bridge designs often are rushed to reduce costs or meet schedules, which adversely affects design quality, professional development, and job satisfaction. In his speech commemorating the 50th anniversary of the Golden Gate Bridge, titled "A Bridge Forever," Arvid Grant reminded us that the Golden Gate Bridge served so well for 50 years because of the importance placed on its design engineering. He challenged us to do the same.

Ethics

When speed has priority over quality, a designer is caught in an ethical dilemma. Consider the following two quotes by Albert Einstein, a man regarded by many as a leading thinker not only of physics, but also of morals and ethics.

> The most important human endeavor is the striving of morality in our actions. Our inner balance and even our existence depend on it. Only morality in our actions can give beauty and dignity to life.
>
> Concern for man himself and his fate must always form the chief interest of all technical endeavors.... Never forget this in the midst of your diagrams and equations.

Ethics are those abstract ideals that constantly tug at thoughtful people to do the right thing. They are formed, tested, and re-formed, if necessary, throughout our whole lives. Ethics always involve the identification of a dilemma; that is, a choice between A and B when one would prefer to have both. They also involve the attempt to resolve the dilemma within an individual, personal value system. The "right thing" refers to standards of behavior, such as duties, rights, responsibilities, obligations, and so forth. Discussions of ethics are sometimes difficult because people have different standards or values, and quite often there just does not seem to be a "right" answer. The "right thing" for the bridge designer caught in a dilemma over speed versus quality involves conflicting duties. Ethics are very important, as Einstein wrote, because we all constantly make judgments of each other's actions, either consciously or unconsciously.

Concern for ethical conduct in our profession is apparent with ASCE's Ethics Advisory Service—perhaps the only professional society service of its kind where complaints of unethical conduct may be registered, investigated, and prosecuted. Another example of this concern is NSPE's recent video, "Gilbane Gold," which explores contemporary engineering ethics in a true-to-life setting. In addition, the book titled "Engineering Professionalism and Ethics" contains many real-life stories of engineers struggling with ethical problems. For example, one is titled "I Gave Up Ethics—To Eat." Another, "The Story Behind the Recent National Scandal Involving Engineers," describes the illegal payoffs made by two engineers to former Vice President Spiro T. Agnew and the resulting corruption.

Some people believe that if it is legal, it is moral; however, our laws establish only a minimal level of moral or ethical conduct. An article in the December 1985 issue of ASCE's *Civil Engineering* by Endy and Vesilind describes certain stages of moral development seen as young children grow into young adults. An engineer, Richard McCuen, found that an engineer's professional ethics develop in similar stages. There are three stages, and each stage has two levels. The first stage is called preprofessional; level 1 concerns self-gain without regard for others. Level 2 is self-gain using the values of others. This could relate to our ethical status when we were in school, for example. The second stage is called professional; is subdivided into level 3 (foremost loyalty to the firm) and level 4 (foremost loyalty to the profession). The third—and highest—stage is called the principled professional, with level 5 being loyalty and service to society, and level 6 emphasizing adherence to universal rules of justice and fairness and caring for mankind as well as nature. At what level do we find ourselves operating when we emphasize design speed over design quality?

Our professional ethical standards appear almost verbatim in many of our society's codes; they also appear as rules of professional conduct in our State registration rules. In addition, as Federal Government employees, we also are bound by the principles of ethical conduct spelled out in President Bush's Executive Order 12674, "Government-wide Ethics Act of 1989," signed April 12, 1989. These standards and codes all have common themes: they connect professionals to the society they are supposed to serve, and they prevent us from insulating ourselves with a self-serving elitist status—as George Bernard Shaw once said, "Every profession is a conspiracy against the laity."

Three of the ethical standards outlined in the *Civil Engineering* article pertain to the dilemma created when a designer does not have sufficient time, the most fundamental one being "service of the public interest with integrity and honor" (level 5). The second ethical principle deals with increasing the competence of the engineering profession (level 4); the third concerns honest service to the engineer's manager (level 3). The engineer has to work for the manager, who must emphasize production to meet schedules and budgets. The engineer is ethically bound to serve his or her manager, but also is bound to the first two ethics. This forms a dilemma for the engineer—especially when priority for design speed supersedes priority for design quality. In addition, continual emphasis on design production does not allow time for professional development or increased competence. This is unfortunate, as setting aside time for professional development is critical for the long-term competency of our engineers. Emphasis on production is minimizing our design quality standards and creating new engineers more concerned with speed than quality.

Quality is closely tied to ethics; in fact, it is a measure of the ethics involved in bridge making. A measure of ethics is involved when deciding which level of quality one can achieve within a production atmosphere. For example, an average level of quality would provide adequate strength, serviceability, and constructability. A higher level also would include design concepts and details to reduce life-cycle maintenance costs, such as those recommended by George Shanafelt in NCHRP Report No. 123. Because these steps would require additional time, an ethical dilemma would be created—is it better to strive for a higher quality design, or achieve quicker production?

Quality of a bridge design is difficult to define and measure because, like ethics, it involves some very abstract concepts. For example, bridge design quality should measure concepts such as completeness, thoroughness, application of innovation and creativity, and application of the best engineering practices and knowledge available. A study by ASCE has shown that the design phase of a project has the highest impact on both initial and life-cycle cost(s); decisions made in the initial stages of design establish a program that is difficult or costly to change once detailed design or construction begins. ASCE's study shows the fallacy in considering only the initial cost when establishing project requirements and also illustrates the extremely low cost of design in terms of total project life costs. (ASCE Vol. I, "Quality in the Constructed Project," fig. 2-1, p. 19.)

The Bridge Designer's Dilemma—Do You Want It Right or Right Now?

Designers do not work alone. They are part of a team required to bring bridge projects into reality. The other team members are owners, managers, and contractors. For the most part, this article concentrates on the relationship between designer and manager, although similarities exist between the others.

Neither the designer nor the manager alone created the design dilemma of speed versus quality. Both have contributed to speed becoming more important than quality by concentrating on their own responsibilities and failing to communicate with one another.

Designers are problem-solvers rather that problem-creators and, therefore, hesitate to speak out against production pressure. They see their manager's pressure for schedules as their responsibility also. They believe that they should be able, just by working harder, to meet both speed and quality of design.

Recent time demands on designers that managers do not fully appreciate are construction support and implementing specification changes. The designer's assistance to the Construction Division at Western Bridge Design is becoming more time-consuming because of reduced project staffing levels and an overall decrease in the experience levels of our project personnel due to a large number of retirements. AASHTO specification changes are occurring more frequently and becoming more difficult to implement. These are excellent improvements in our technology, which management supports in concept; but they are difficult to implement in a production-priority design environment. The designer has an ethical responsibility to inform his or her manager about his or her time demands so that together they can work at improving the importance of design quality.

The pressures on managers to produce more designs with fewer people in less time have been steadily increasing the last 10 years. Usually, managers were first designers and, therefore, have the same attitudes toward problem-solving. However, the manager's problems are not the same—they cannot successfully apply their engineering problem-solving skills to the problems of meeting schedules by managing and supervising people. In performing their duties, managers quite often become displaced from the designer's day-to-day problems. Managers need to know the designer's problems and time demands so that realistic planning and scheduling can be done. Often, managers do not receive education or training in supervising and managing people; nor have their communication skills been effectively developed. The development of these skills should carry as much importance as engineering skills. Ethically, managers should take the lead in working out the problems that have made design speed more important than design quality.

At FHWA, Western Bridge, contracts have nearly doubled, while staff has been reduced by some 20 percent. Western Bridge was using about 11.5 people (11 full-time, one part-time) to produce $1 million worth of contracts in 1980; today, that number is 4.5 people per $1 million. This represents an amazing success story for all our team members.

In FHWA, another contributing factor to lower quality designers is the personnel appraisal system. The manager's yearly performance is measured on whether the yearly programed funds were fully committed—not on the life-cycle cost for bridges or other quantifiable quality measurements. FHWA has recognized the imbalance between yearly funding amounts and organizational capabilities and has been working on a project scheduling system for about 1 year; but because this endeavor is so large, it has not yet been implemented.

To illustrate the potential problems resulting from scheduling pressure conflicting with design quality, consider the following Western Bridge projects.

The Refugio Road Bridge crosses the Santa Inez River in Santa Barbara County, California. This bridge is on a forest access road that leads to former President Reagan's ranch. It lies about 1 mile south of the Santa Inez Fault, which is capable of producing an earthquake measuring 7 on the Richter scale. Before working on this design, Western Bridge staff were working on a Saturday on some rush jobs for the Vancouver Office. The foreman for a ranch adjacent to the bridge called. He asked how we were coming along on the design. We explained that the other work had to be finished before work could start Refugio. He explained how important it was for the new bridge to be completed as quickly as possible because during high water he had to rent a helicopter to take care of day-to-day activities on the ranch. He went on to say that he was a good friend of President Reagan and would a call from Mr. Reagan speed things up. This was design pressure. Later, when the design was nearly complete, and the allotted design time almost exhausted, it was discovered that a new seismic design code had been written (ATC-6) and that AASHTO probably would adopt it as a guide specification. The dilemma: go ahead and send it out, or incorporate the new seismic criteria? With the help of Jim Gates from CALTRANS (California Department of Transportation), Western Bridge was able to incorporate the changes required to meet the new criteria. This was a success story because the short-term urgency was quickly forgotten and the bridge will have current seismic details for the rest of its life. The design was completed in July 1982; the bridge was completed in late 1984.

The next example was not a complete success story; however, it is not an embarrassment for FHWA, but, rather, an honest example of the pressures on designers and managers alike.

The Truckee River Bridge is on a Forest Highway Route in Northern California, about 20 miles west of Reno, Nevada. The bridge crosses an environmentally sensitive river; consequently, there are many restrictions on work in the water and so forth. To meet these pressures, as well as funding obligation pressures, the project was advertised with unchecked plans. These plans were clearly marked as preliminary; that is, they were to be used for bidding purposes only. The contract stated that the plans might have some dimensional inconsistencies and that finalized plans would be furnished at the time of the contract award. It also stated that the quantities were estimates for bidding and that the final pay quantities would be based on the final adjusted plans.

Western Bridge made the design checks during advertisement and also after the contract award. As major changes at that point could have had contractual consequences, the checkers were severely compromised. The designer did an excellent job, but a number of small plan errors were inevitable. The largest problem was the discovery of a significant difference between the AASHTO 1983 Seismic Guide Specification and the current CALTRANS criteria. At this particular site, the CALTRANS criteria showed a local "hot spot" for seismic design that was not shown on the AASHTO acceleration contours. Restrainer devices and joints in the pier walls were added to help their ductility, but this could have been done better before the contract award. This project shows just some of the possible pitfalls that can be expected when the design process is not properly completed. Construction of this bridge was completed in September 1989.

Suggestions for Improvement

As the previously mentioned House subcommittee report stated, lack of understanding of each other's roles and responsibilities and the associated lack of communication are the causes of the problem over priorities in the design phase. The following four suggestions—peer review, support of ASCE's Volume II of "Quality in the Constructed Project," a joint ASCE/AASHTO bridge design standard practice manual, and improved management of bridge designers—will help improve understanding and communication.

Peer Review

Chapter 13 of ASCE's Volume I of "Quality in the Constructed Project" describes peer review as follows: "Peer review is a technique that promotes quality in design organizations and their services. It is the highest level of action to improve quality in design of constructed projects."

Both design organizations and specific projects can be peer reviewed. Organizational peer reviews focus not on any single project; rather, they consider the design organization as a whole, including its policies, procedures, and practices. Project peer reviews focus on individual projects and may either concentrate on project management or the technical recommendations put forth by the reviewer. Consider the following examples of peer review "success stories."

The Association of Soil and Foundation Engineers (ASFE) instituted a peer review program in 1978 in response to their difficulties in obtaining liability insurance because of the liability history of geotechnical firms. ASCE stated that "Within 6 years after the initiation of the ASFE Peer Review Program, the geotechnical engineering profession had achieved the lowest rate of liability claims among design disciplines." The American Consulting Engineers Council (ACEC) initiated a peer review program in 1984 for its 4,700 member firms. These reviews have received very high ratings by all those involved.

ASCE initiated its peer review program for public agencies in 1986. Sample public design organizations that have participated to date are the Allentown, Pennsylvania, Bureau of Engineering; the Savannah, Georgia, office of the U.S. Army Corps of Engineers; the Bureau of Reclamation in Denver; and the Maricopa County Highway Department in Arizona. Chapter 13 of ASCE's

Volume I provides many details of peer review, as well as descriptions of the existing ASFE and ACEC programs.

Support of ASCE's Volume II of "Quality in the Constructed Project"

Volume II of "Quality in the Constructed Project" will concentrate on defining the roles and responsibilities of the various team members involved in specific civil engineering disciplines. Volume II will extend the broader scope of Volume I, which was available for trial use and comment until December 1989. Volume I took 3 years to prepare and was the most ambitious project to be undertaken by an engineering society. Its need was established by a universal consensus from numerous national conferences concerned with dramatic design and construction failures over the last 15 years. It represents our industry's attempt to clarify the confusion as to the roles and responsibilities of the team members involved in producing construction projects. It is essential that our team members be involved in the writing of Volume II; otherwise, the courts, lawyers, and politicians will inappropriately guide our business.

A Joint ASCE/AASHTO Bridge Design Standard Practice Manual

ASCE's excellent work should be extended to our specific discipline of bridge design. We could benefit from ASCE's experience, and they have, in the past, been willing to join AASHTO in such ventures. A joint bridge design standard practice manual would provide an essential clarification of roles and responsibilities. Again, it is more appropriate that we do this instead of waiting for someone else. Such a manual could further define the high standards for bridge design that are being challenged by time restraints.

Improved Management of Bridge Designers

Managers and designers need to work toward better communication. Designers need to educate their managers with what they perceive to be their problems, rather than simply trying to accomplish miracles. They need to practice "loyal opposition": designer's must guarantee their loyalty to managers under the condition that open, honest, and unconditional communication between the designer and the manager will be permitted at any time.

Improved communication skills are just as important as engineering skills in improving management of bridge designers; the following specific suggestions might help:

(1) Allow time for professional development. This is critical for the long-term competency of our profession. Management must create time for this so that it be truly considered a priority by designers. Specifically, we need nonproduction time to allow new designers to learn on the job; time for computer development to use these tools responsibly; time for assimilating AASHTO specification changes and new guide specifications; and time for professional development (that is, time to research new technologies, and so forth).

(2) Use experienced people more effectively through predesign meetings, including checks of preliminary design concepts before a structure type is locked in, and construction feedback.

(3) Experiment with upward appraisal, a new management technique pioneered by the Florida Power and Light Company. This system allows each employee to evaluate the performance of not only the person he or she supervises, but also his or her superior. I understand that AT&T also has implemented this system with good success.

(4) Consider using "total quality management," which emphasizes achieving customer satisfaction, giving everyone responsibility, and making continuous improvement. It also includes emphasis on effective communication, top management support and direction, and long-term commitment. The Federal Lands Highway Division, under FHWA, has implemented this new management system.

Summary

The most significant problem facing bridge designers today is not enough priority on design time. Because managers of designers have more funds to commit each year, and fewer people than 10 years ago, pressure to reduce design time is inevitable. The designer tries to serve two masters: the manager's need for design production, and his or her duty to the public to give them the high-quality design they deserve. This creates an ethical dilemma for the designer. Our professional ethics require us to "serve the public interest with integrity and honor" and to provide honest service to the engineer's manager. The pressures of time also make it difficult to adhere to our ethical principle to strive to increase our competence as professionals.

Those of you with less than 10 years remaining in your careers should think about this: Would you rather produce "X" number of designs and exceed your previous production rate or produce fewer—but higher quality—designs? Would you like to show the younger designers by example that quality is at least as important as speed?

We can effect a change for the better. The first step is to recognize that the problem is real and must be dealt with. Our complacent attitude about dealing with this problem is the reason it has increased for the past 10 years. By making an effort to improve communication in our organizations, we will gain the satisfaction that we are doing something to combat a very difficult problem. Because, after taking that first step, we may be able to return to quality engineering as a priority during design. Our job satisfaction will increase because, as Einstein told us, "Only morality in our actions can give beauty and dignity to life."

To all designers—speak up for the importance of the design phase. Be honest with your managers about your problems. To all managers—listen to your designers and come to grips with what is really important—speed or quality—because you have the power to return emphasis to quality.

The Road Maintenance Management System

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Introduction

Managers of the National Forests in North Carolina were not satisfied with the method used to identify road maintenance needs and their costs. Several seemingly unanswerable questions, such as where to best spend the Forests' limited dollars, continued to surface each year when the time arrived to disperse funds to meet maintenance needs. Road maintenance included many different aspects of the transportation system. As is the case on most, if not all, Forests, funds could not cover all needs, so managers had to make some tough spending decisions.

The most bothersome question was whether the funds were being used in a manner to get the "biggest bang" out of them while meeting obligations. With so many factors to consider, it became apparent that a better system had to be developed to address this issue.

Inventory

Without a good inventory, most efforts rely on a good memory and hunches. Following the old adage, "the wheel that squeaks the loudest gets the grease," may not be the best way to approach road maintenance.

Fortunately, Region 8 has used the Transportation Information System (TIS) for many years and, therefore, did not need to start from scratch. This system fully meets the need for a basic inventory with attributes.

Condition Survey

The maintenance management methods being used included performing condition surveys, but the information gathered was not being used very well. It was simply too much information to sort out.

A list of features was developed that, if addressed, would cover all the different facets of maintenance. Subsequently, a rating scheme based on a clear-cut guide was developed. Using these tools, along with the condition survey information, all the needs associated with each road segment on the system were numerically rated.

Computer Program

The backbone of the system is a program residing on the Data General MV 20000, located in the Supervisor's Office. The Road Maintenance Management System (RMMS) program is used to input, store, manipulate, and/or retrieve information from six data bases—Maintenance Needs, Criteria for Further Investigation, Criteria for Distributing Funds, District Input Table, Fund Distribution Input, and TIS.

Safety

Once the individual features were rated as to their condition, a method was developed to weigh the safety factor of the condition survey separately from all other factors. This was accomplished by adding a screen within the program that allows this to be done very easily.

Thus, safety factors were ensured appropriate importance, while allowing adjustments to the weights to correctly reflect this importance.

Data Input

The development of input screens required the Forests to analyze its need for information to ensure the gathering of pertinent data. By tying the program to TIS, a separate, yet identical inventory data base did not have to be developed. An added benefit was the advantage of having all the TIS data available when creating reports.

Additional information was added to TIS using these input screens. Input fields were created for conditions rating, sale usage, available purchaser coop funds, and the like. In addition, fields were included to input specific costs to meet identified needs.

Variable Input

To provide consistency, a method had to be developed so that all road segments were treated equally. Given their use, need, importance to the system, and various other factors, each segment had to stand on its own merits, yet be treated fairly. Using routines within the program, an employee may determine, for example, the number of times roads should be bladed and ditches should be pulled, based on variables set by the program manager, the various condition information, and other input.

A report was developed to display all road segments where conditions for the various factors exceeded threshold levels. By studying this report, funds can be assigned to specific needs other than blading and ditch pulling. Even though blading and ditch pulling are by far the Forests' largest expenditure, such needs as signing, mowing, brushing, and many others must be addressed each year.

These threshold values also are variables that can be adjusted to fine tune this report.

District Information

Overhead and accomplishment costs vary by District. All ditch pulling and blading on the Forests are accomplished by contract, and the unit costs do not vary during the year. All costs associated with activities using force account crews must be included except overhead, which is calculated separately.

Available Funds

One of the best features of this program permits the manager to input the available road maintenance funds, allowing the program to distribute these funds to meet the needs by priority until all the funds are expended. Coop funds from purchasers and commercial users are utilized to the extent that they are available.

The figure entered as available road maintenance funds is available after covering costs at the Zones and/or Supervisor's Office for management, contract administration, and any other projects not included in the program.

Funds Distribution

Depending on the management style on the Forest, decisions have to be made as to how the funds are to be distributed (that is, whether the funds will be sent to the Districts along with their annual budgets, held for contracting at the Zone or Supervisor's Office level, or divided between the two).

Using the Funds Distribution Input screen allows the system manager to enter these variables. Each of the 17 different fund categories can be tailored to meet the needs of the Forests.

Reports

The Forests developed 24 standard reports that list input data and display the results of the various aspects of the program. Using this information and the variables available, the manager can tailor the results so they reflect the needs.

The persons on the Zones and Districts and in the Supervisor's Office who are responsible for accomplishing road maintenance can use these reports as their work plans and make adjustments as needed throughout the year.

Application on the Ground

In every management system, the best test comes when it is tried in the real world. How does it fit the ground situation? After using it for 2 years, making the necessary modifications, and adjusting the parameters, RMMS has proven itself to be a very useful tool to Forest managers.

Each year, feedback from the field units must be evaluated and adjustments made to meet the ever-changing world of maintenance management. If the reports do not reflect the true needs, something must be updated or corrected in the data or in the variables within the program.

Conclusion

Road maintenance management may be accomplished in many ways. Perhaps one of the best ways to do this is to use computer inventories and data manipulation, along with on-the-ground surveys and feedback. RMMS successfully uses these aspects and has proven to be a valuable management tool.

The author has prepared a user's guide for those interested in trying the program on other Forests. He will be happy to send you the computer program via the Data General and the user's guide by mail. Send requests to M.Martin:RO8AF11A.

Tire-Retaining Structures

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Introduction

During the past several years, various low tire-retaining structures have been built on the Plumas National Forest in Region 5. These include walls only a few tires high, gravity structures up to 5 feet high, and a "designed" tire-faced geotextile reinforced wall 10 feet high. Figures 1a, b, and c show typical drawings used in constructing each of these wall types, which have been used to add road width in steep slope areas, to provide shoulder support on paved roads, and to fix washouts or slide areas on roads in storm damage repair projects.

For small structures, and particularly for force account work, tire walls offer a quick, easy, and inexpensive repair solution for many projects. Advantages of tire walls include the following: low cost (used tires are typically free and plentiful), their recycling role, facilitation of small construction projects (tires are similar to lightweight building blocks that can be easily handled and assembled into many configurations), and their durability and damage-resistant qualities. Disadvantages include: size limitations (because they are best suited for low, small structures), questionable esthetic value (they are visually unappealing, but they are often appropriate below a road in areas not readily visible to travelers), and their vulnerability to fire.

Low Roadway Shoulder Structures (Figure 1a)

For years, tires have been used as low-height-retaining structures in a variety of settings as support for roadway shoulders, oversteep banks, and so forth (figure 2). Typically these structures are a single row of tires stacked, vertically or with some batter, three to six tires (2 to 4 feet) high. The tires are usually not connected in any manner, although rebar or posts may stake them to the ground. The tires are backfilled with native material or shot rock, which is often seeded and mulched.

This structure usually requires no special design, provided it is only about 3 feet high and has some batter. It should be made of tires backfilled inside the hole and tamped to achieve proper compaction. The tires should be placed on a "foundation" bench dug into firm, preferably indigenous material. This bench should be at least 1 foot wide in front of the bottom tires.

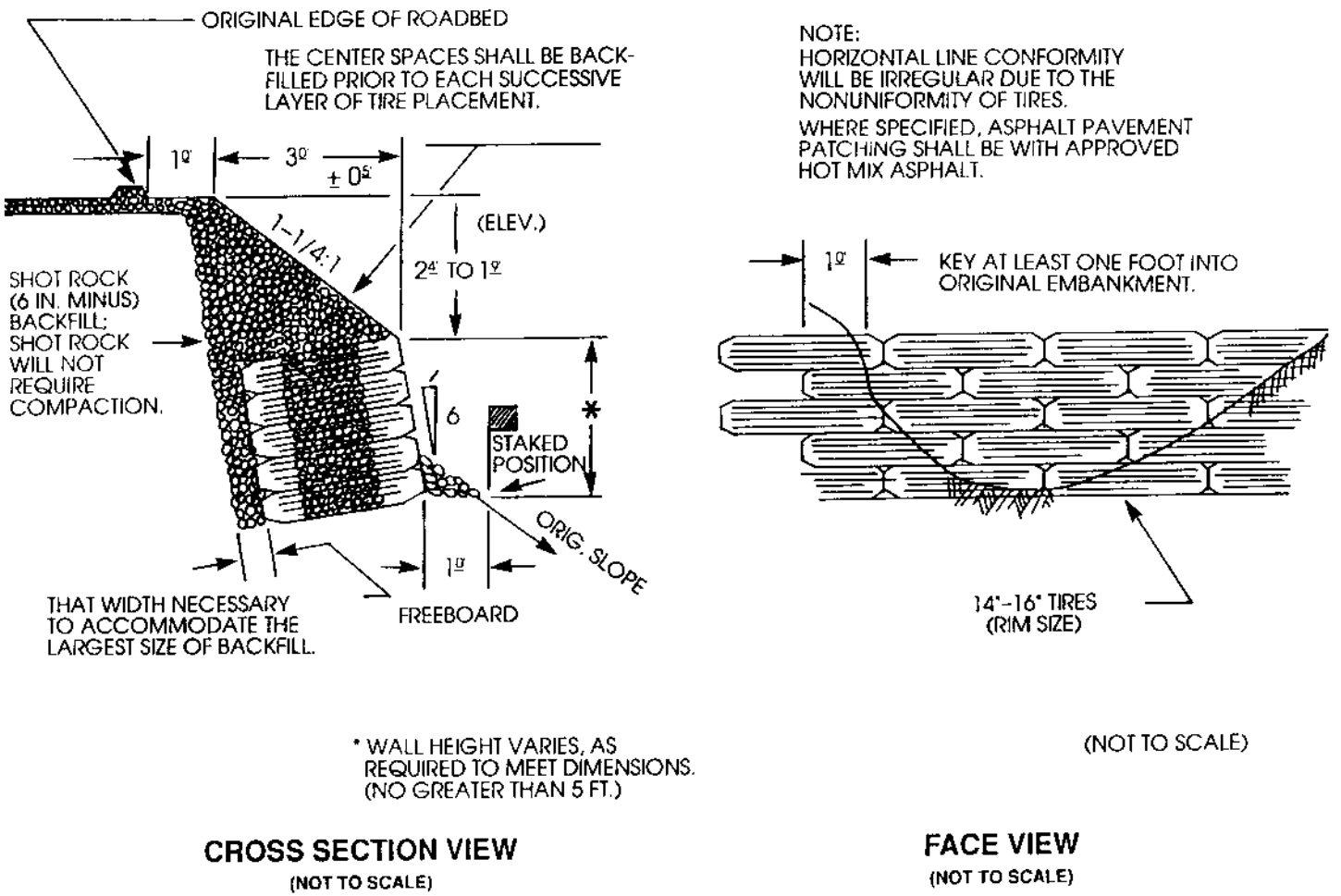

Figure 1a.—Typical used tire retaining wall (wall shoulder construction).

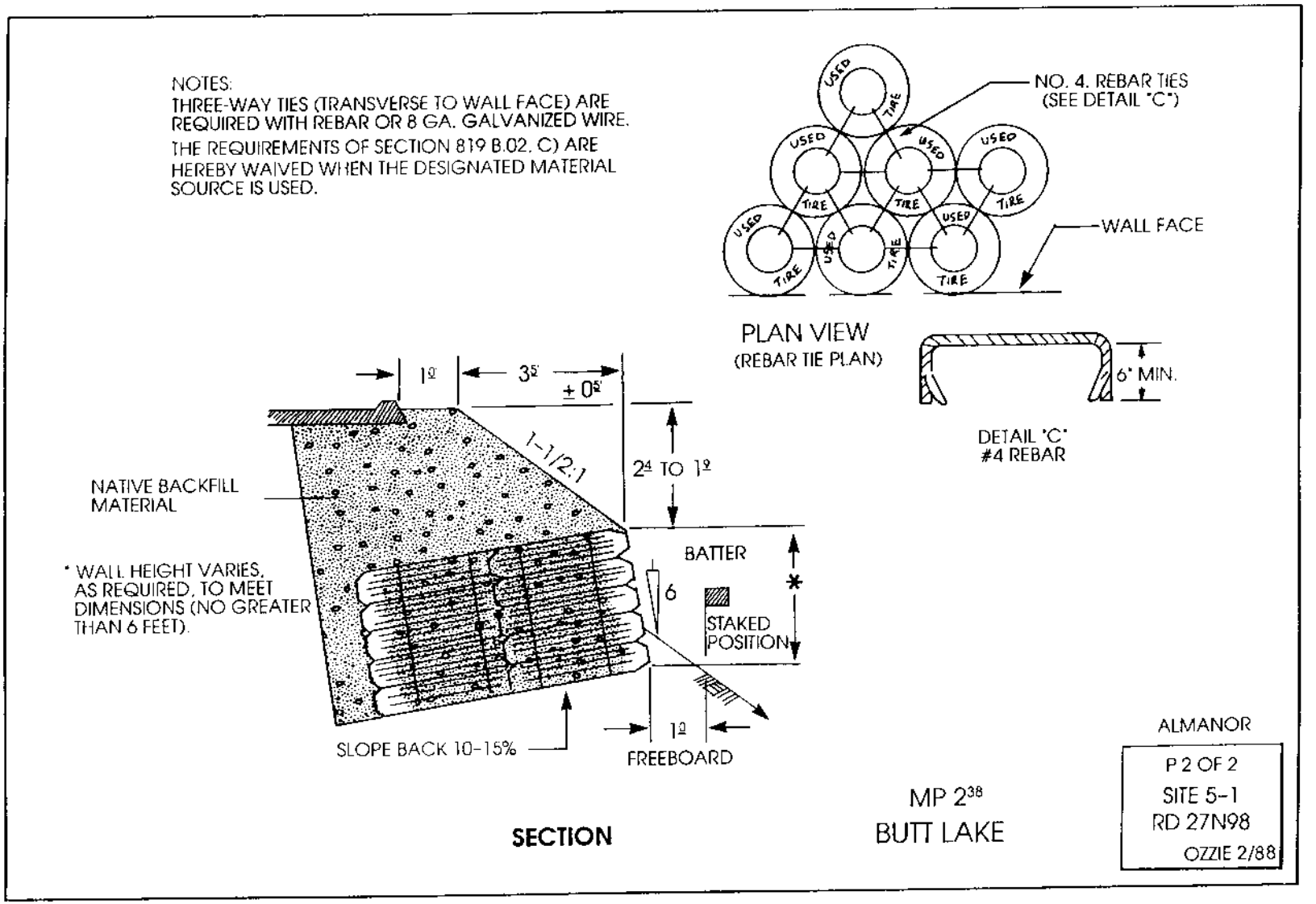

Figure 1b.—Typical used tire retaining wall (construction detail).

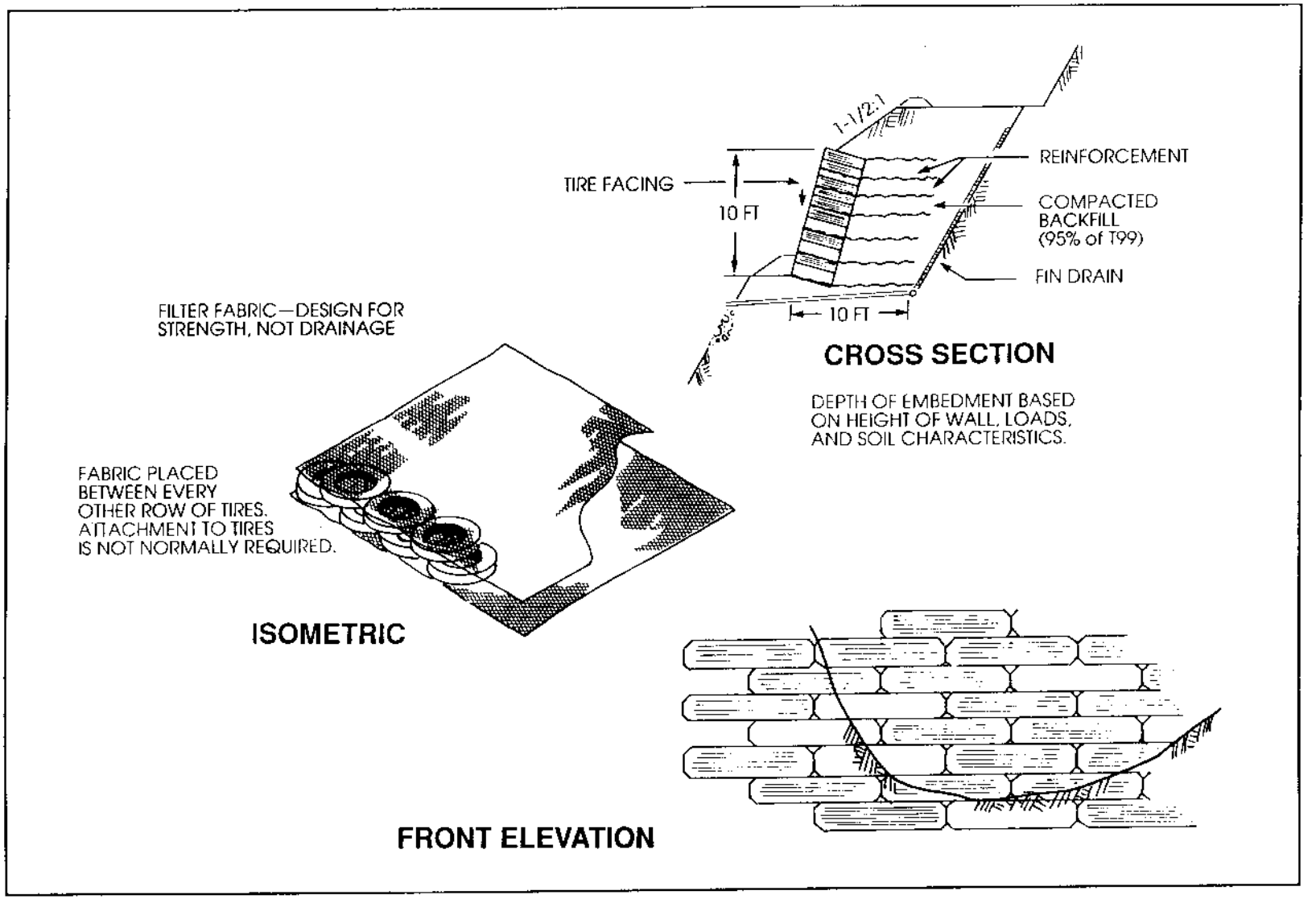

Figure 1c.—Used tire/geographic retaining wall.

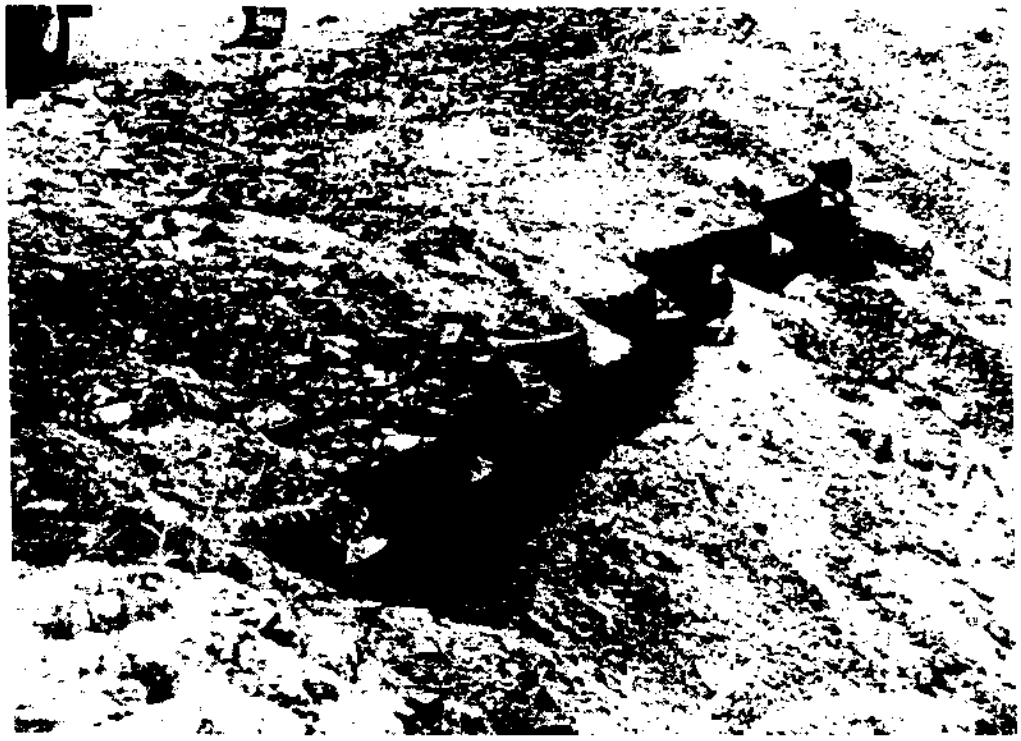

Figure 2.—Low roadway shoulder retaining structure.

Tire Gravity Retaining Structures (Figure 1b)

Tire gravity retaining structures are low tire walls designed and built to stay in place as a result of their weight and resistance to sliding. Low roadway shoulder structures are included in this category, but this definition applies particularly to tire walls up to 6 feet high that are designed for stability or have a somewhat standardized arrangement with a good performance history.

The individual tires are often clipped together (figure 3); metal posts may be driven through the stacks of tires, and they may be placed in multiple rows (that is, two to three rows of tires deep into the slope). Also, they may be stacked, placed with a slight batter (such as a 1H:6V slope), and backfilled with shot rock. Because the tires are tied together, they act as a unit to resist lateral forces and support an embankment. Thus, they perform as a gravity structure. The California Department of Transportation (CALTRANS) has experimented with tire walls and recently has published a brochure on the subject titled "Use of Discarded Tires in Highway Maintenance" (TRANSLAB brochure number TL/REC/1/88).

Whole tires are used in construction, but only the middle hole of each tire is backfilled. The void in the tires between the sidewalls typically does not fill up, so the average unit weight of the structure is about half that of one made entirely of soil, or about 60 to 70 pounds per cubic foot. Thus, as a gravity structure, it needs a slightly wider base than a conventional gravity

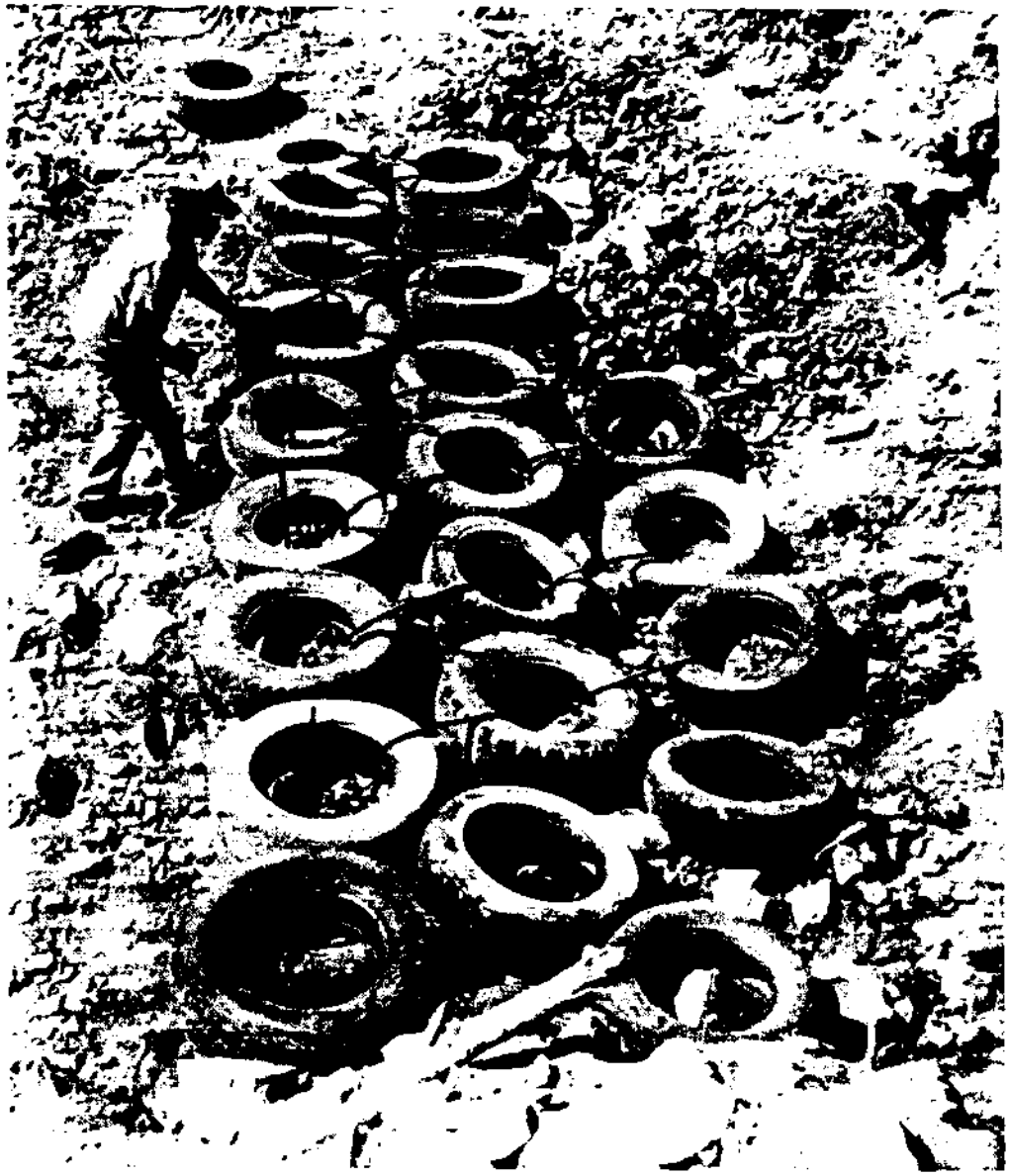

Figure 3.—Construction of a gravity tire wall showing rebar tying rows of tires together.

wall. For a wall up to 5 feet high of nonplastic, granular soil with normal traffic loading, the base width should be at least 0.7 times the wall height (at least two rows of tires deep).

CALTRANS recommends using uniform size tires, but Forest experience indicates that tire size is not critical, provided widely varying sizes are not placed side by side. CALTRANS also recommends stacking tires vertically, which can be easily anchored with a metal post through them. Forests usually stagger the tires one-half-tire diameter on each successive lift. This makes it difficult to anchor the tires with a metal post, but it creates a more continuous facing. Both methods have worked successfully. Clips made from

0.5-inch rebar are used to hold adjacent tires together. This wall type costs from $10 to $15 per square foot.

Tire-Faced Geotextile Reinforced Wall (Figure 1c)

A unique 10-foot-high tire wall recently was designed and constructed on the Plumas using a geotextile reinforcement combined with 250 used tires for the facing members (figure 4). Because used tires are abundant, the geotextile cost is minimal, and construction is easy, this wall type costs as little as $13 per square foot or less. The actual installation cost was $17 per square foot, (including a geocomposite fin drain), because of unusually slow production rates for compacting the backfill with a whacker and other inefficient construction methods.

The design consisted of geotextile layers on a 15-inch (38-cm) vertical spacing and two rows of tires, staggered on top of each other, placed to the front edge of the fabric (and wall face) between each fabric layer. The fabric is a slit-film woven geotextile (AMOCO 2006). Soil was compacted behind each layer of tires in 7- to 8-inch (18- to 20-cm) lifts. This procedure was repeated for each of the 16 vertical rows of tires used. A final geotextile layers was placed over the uppermost tires before the remains roadway fill was added. Local material was backfilled into the middle hole of each tire and hand compacted.

This wall type should be built with a 1H:4V face batter and tires staggered horizontally, one-half-tire diameter on each successive layer, to prevent the backfill soil from falling through the holes into the spaces between tires on the next lower layer. Additional stagger and vertical offset of the tires provide planting space in the tire holes for vegetation, which adds long-term biotechnical stabilization to the wall and improves its appearance. Randomly sized tires were used and have performed well.

Building the wall face with tires placed on the geotextile reinforcement two rows high works with minimal tire movement during compaction of the backfill (a backhoe operated within 6 inches (15 cm) of the tires, and no movement occurred). If heavier compaction equipment were being used, or a higher wall were being constructed, a layer of fabric between each row of tires might be necessary. Also, to improve sliding resistance, the tires could be attached to the fabric by threading a several-foot-long strip of fabric through each tire hole and burying it in the backfill.

Lateral movement of the "unattached" tires and long-term settlement of the tire face are concerns with a tire wall of moderate height. After more than a year in place, the top row of tires has settled about 1 foot (0.3 m or 10 percent of the wall height), and no deformation has occurred in the supported road surface. Maximum height of this design concept may be limited by such settlement.

Tips on Tire Wall Construction

Construction of tire-retaining walls has proven to be quick, simple, and inexpensive and lends itself to normal construction labor and equipment or force account work. Appearance of finished walls has been satisfactory, as seen in

a.

b.

Figure 4.—Construction of a tire-faced geotextile reinforced wall showing (a) a lower lift of fabrice and tires and (b) the wall near completion.

figures 5 and 6. Attention to the following areas will result in a quality wall with enduring performance:

(1) The foundation is crucial. Do not skimp on the freeboard placed in front of the first row of tires—never let any tires extend over unsupported side cast material. If in doubt, get geotechnical or Engineering input.

(2) End treatment requires special attention. Excavation done by heavy equipment usually will disturb more than "neat lines" shown on drawings. Therefore, allow enough room (extend the wall) at wall ends to backfill and compact on a stable slope—usually 1.5H:1V or flatter. This means that the side end rows of tires must extend back into undisturbed ground far enough to allow backfill of the gap (on a 1.5H:1V slope) in front of the last tire.

(3) While the backfill behind the tires is easily compacted with standard equipment, the material inside the tires is compacted with greater care. Some compaction is desirable, but do not overdo it. Routine heel compaction is adequate for low walls. For higher walls, backfill material, such as shot rock or gravel, is desirable.

(4) The wall face will settle with most native soils, causing the front of the tires to tip slightly downward compared to the back of the tires. Therefore, place the tires with a 10- to 15-percent backward tilt to allow for this effect.

(5) Battering prevents backfill leakage. Soil can leak out of the small triangles formed by overlapping tires in a vertical wall face. To prevent this, walls should be constructed with a batter of at least 1H:4-6V. An alternate solution can be to set a 6-inch rock in the triangle of each tire as it is put in place.

(6) Drainage is required for most walls. Fin drains are ideal for higher walls. Shot rock backfill is adequate for low walls.

(7) Matching tire sizes are not significant. In snow country, it is desirable to have at least 50-percent "mud and snow" tires.

Lastly, tire-retaining walls are but one alternative amid a number of wall types available to the designer, including welded-wire walls, timber-faced walls, reinforced earth walls, cribwalls, gabions, reinforced fills, and so forth. Tire walls are relatively inexpensive but should be used only after considering other alternatives and all site factors.

For more information on the subject, contact Ozzie Cummins at (916) 283-0555 (DG: RO5F11D56A) or Gordon Keller at (916) 283-2050 (DG: RO5F11A).

Figure 5.—Completed tire-faced geotextile reinforced wall 1 year after construction.

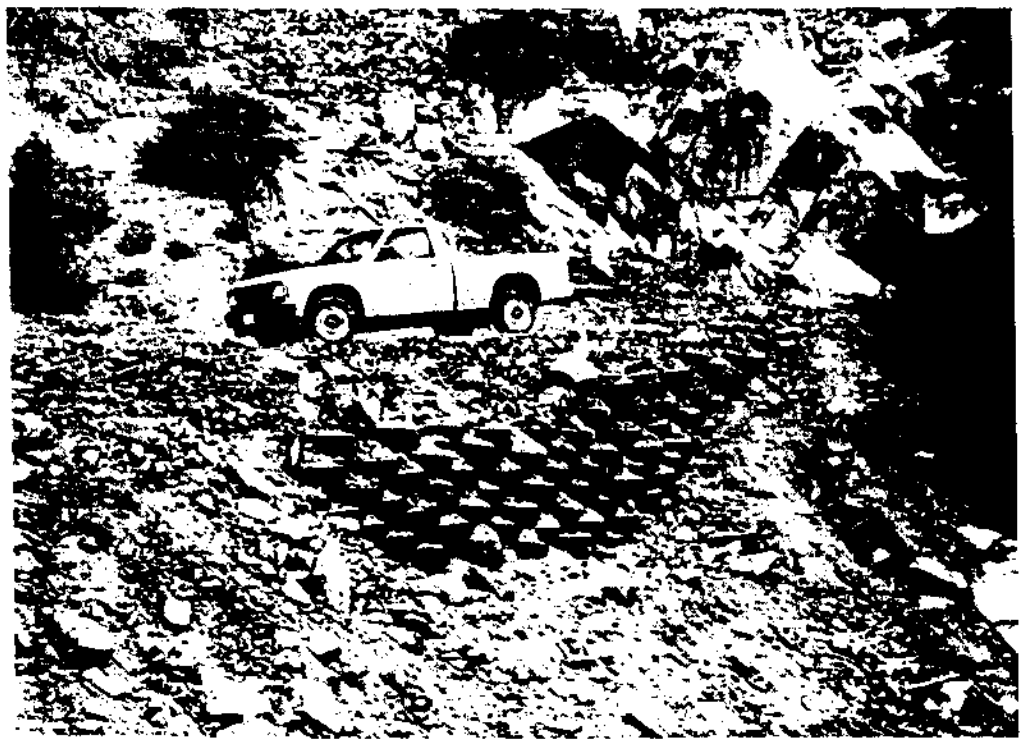

Figure 6.—Completed tire gravity retaining wall.

Treatment of Acid Mine Drainage by Wetland Construction

Michael Tripp, P.E.
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Introduction

Acid mine drainage from abandoned coal mines has long been recognized as a serious threat to water quality, with subsequent deleterious effects on fisheries, wildlife, plant growth, and soil productivity. Despite improved knowledge of pyrite oxidation and advancements in engineering, the basic technology of acid mine drainage treatment has changed little over the past 30 years. Neutralization by addition of a base, oxidation by aeration, and precipitation in settling basins are still the accepted treatments. These standard approaches are expensive, however, and require long-term commitments for maintenance.

Background

The Jones Branch watershed is located on the Stearns Ranger District of the Daniel Boone National Forest in Kentucky. Large-scale, underground coal mining in this watershed occurred during the first decade of this century. After 30 years of mining, the Forest Service acquired the tract of land on which the Jones Branch mines are located. Throughout the years, the Forest Service has monitored a number of parameters in the Jones Branch watershed, including both flow and water quality.

Acid mine drainage in this watershed is predominantly from two portals. Combined flow from these portals varies from 23 to 75 gallons per minute (gpm), with a low pH (from 2.5 to 3.5) and a high concentration of heavy metals. Total dissolved solids of 6,100 parts per million were found to exist, with iron concentrations of 1,250 parts per million the most predominant.

Design & Construction

Because natural wetlands have been shown to improve water quality, the U.S. Department of the Interior (USDI) Bureau of Mines, the Tennessee Valley Authority, and others support the "operational" aspect of this technology. However, this approach also was labeled "experimental."

Wetland areas dominated by cattails, certain algae, and other plant species offer the potential to treat small flows of acid mine water moving through them (figure 1). Algae remove the heavy metals, the water is aerated, and the metals are precipitated. Plant uptake also aids, though minimally, in the water treatment process.

Figure 1.—The Jones Branch Wetland treats acid water that has drained from abandoned mines.

The Jones Branch design is based on published Bureau of Mines guidelines, along with the knowledge and experience of others in this area of water treatment. Such important parameters as volume, flow velocity, flow depth, and retention time in the wetland were used as design controls. Monitoring and evaluation procedures were incorporated into the design for improved understanding of the processes involved.

The Jones Branch Wetland is unique in that the chemical composition of the heavy metals in the water is 20 times greater than recommended for treatment by the Bureau of Mines. Studies also indicate that for a wetland to function best, the pH should be at or above 4.0, with iron concentrations less than 50 parts per million. Also, the existing topography does not provide the recommended "space criteria" of 200 to 600 square feet of surface area per flowing gallon.

The Jones Branch Wetland provides approximately 11,000 square feet of treatment area. This allows for 480 square feet of surface area per flowing gallon at 23 gpm and 150 square feet of surface area per flowing gallon at 75 gpm. The higher flows, however, are projected to occur only as short-term responses during high runoff periods. The wetland, as designed, will be within Bureau of Mines criteria more than 80 percent of the time, with a life expectancy of 30 years.

Flow velocities are also critical to allow for maximum contact and retention time. Flow velocities from 0.01 to 0.1 feet per second are recommended to achieve maximum contact time. For the Jones Branch, the contact time is 120 minutes. Flow velocities and contact time are controlled by a series of 25 cells with dividing or baffle walls (figure 2). Earthen embankments are preferred for the dividing walls; however, the treatment area at Jones Branch would have been reduced by 20 percent because of topographical restrictions so concrete block walls were used instead. Leveling walls also were constructed in the series of cells to prevent water channelization and to allow for water dispersal. Each cell is approximately 25 feet square between walls. A water depth of 1.5 to 2.0 inches above the organic substrate is critical to allow for optimum plant growth and to prevent muskrat inhabitation.

The organic substrate consists of 18 inches of spent mushroom compost on 9 inches of crushed limestone with a minimum calcium content of 80 percent. The main function of the substrate is to provide a base for plant life. The crushed limestone also aids in the neutralization of water acidity.

Cattails were harvested from a local source with a similar water quality as that water to be treated. Precautions were taken to prevent excess drying and breakage. Cattails were transplanted within 24 hours with a 5- to 6-inch root mass. A plant spacing of 36 inches, offset 12 inches in each row reduced flow channelization.

Figure 2.—Dividing walls control flow velocities and contact time of water through the wetland.

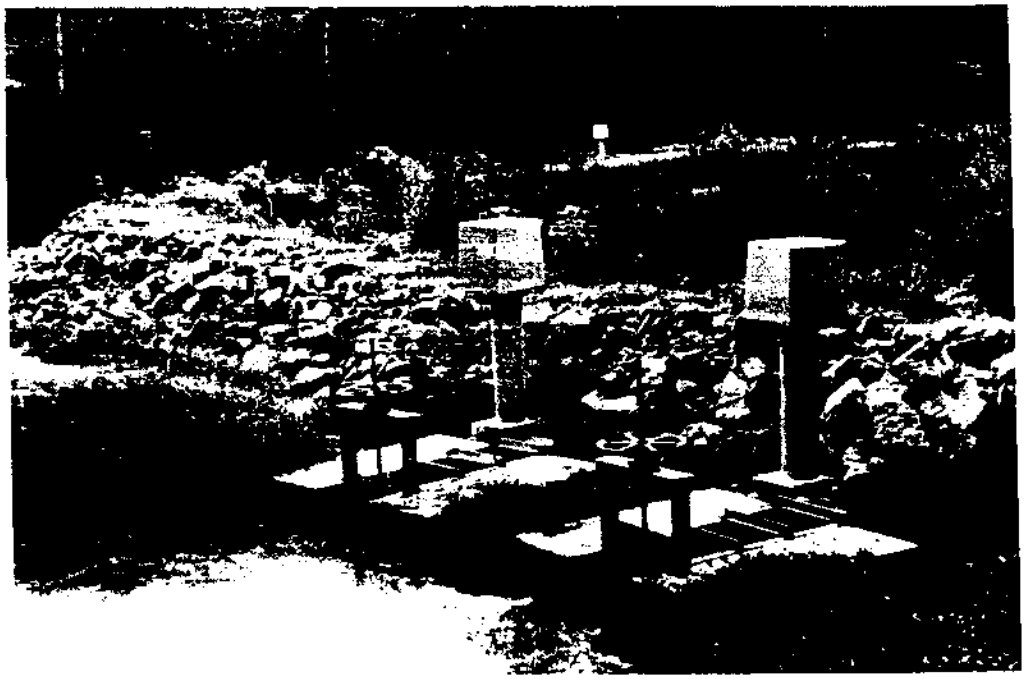

Figure 3.—Monitoring equipment checks water quality and flow.

Water quality and flow measurement is accomplished by several monitoring wells and flumes (figure 3). Monitoring of these parameters is being performed by the Northeastern Forest Experiment and Research Station in Berea, Kentucky.

The Kentucky Division of Abandoned Lands, from a fifth grant through the USDI Office of Surface and Mining, provided project funding to the Daniel Boone National Forest, and a $72,451 construction contract for $72,451 was awarded June 16, 1988. The project was completed on June 23, 1989, after being suspended from mid-November 1988 to mid-April 1989.

Water quality improved dramatically soon after completion. Iron concentrations of under 4 parts per million and pH improvement to 6.1 were observed after the sixth cell, and iron concentrations of under 1 part per million, with a pH of 7.8, were observed at the system outlet. These results are early and tentative but seem very promising.

At 23 gpm over 30 years, approximately 360 million gallons will flow through the wetland. Treatment of each gallon of mine discharge will cost $0.20 per thousand gallons, whereas conventional chemical treatment would cost $1.00 per thousand gallons.

Conclusion

This acid mine drainage treatment requires little maintenance and is an inexpensive method, compared with standard chemical methods. Great potential exists for the use of manmade wetlands in acid mine drainage treatment.

The Jones Branch Wetland has proven that not only low flows and metal concentrations can be treated, but also greater flows and heavier metal concentrations, with benefits to water quality, fisheries, wildlife, and plant growth.

NAD-27 Versus NAD-83

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Land Surveyor
Region 9

Preface

Measurement of latitude and longitude on the Earth's surface within the United States began about the middle of the nineteenth century as an operation of the U.S. Coast and Geodetic Survey. Baselines were measured from which to extend arcs of triangulation over long distances. These arcs formed a skeleton latitudinal and longitudinal coverage of the country that was adjusted to establish the North American Datum of 1927 (NAD-27). The network is centered on Meades Ranch, a triangulation station in central Kansas.

NAD-27 has been the basic horizontal control for the mapping of the United States and for related large area projects. The volume of data referenced to NAD-27 is enormous. There is now a new measurement system—the North American Datum of 1983 (NAD-83). Why is there a new datum and what is its relation to NAD-27?

NAD-83 is the result of modern measurement technology. Baseline lengths are measured electronically to greater accuracies and at closer intervals. The inconsistencies uncovered in NAD-27 required a readjustment of the entire network. This adjustment, combined with changing the NAD-27 reference ellipsoid to the World Global System ellipsoid, became NAD-83. After 50 to 60 years of using NAD-27, conversion to NAD-83 becomes a major consideration.

North American Datums

The North American Datums of horizontal control are based on geodesy. Geodesy is the branch of applied mathematics that determines the shape and area of large tracts of country, the exact positions of geographical points, and the curvature, shape, and dimensions of the Earth.

Measurements are subject to limitations in exactness. The positional changes between NAD-27 and NAD-83 have to be noted. Table 1 presents some of the differences between NAD-27 and NAD-83 across the United States, including first order National Geodetic Survey (NGS) stations that were used for Global Positioning System (GPS) relative positioning in Region 9.

NAD-83 Effects on Mapping

A U.S. Department of Interior general information letter, titled "Implementing North American Datum 1983 for the National Mapping Program," reads in part: "The U.S. Geological Survey (USGS) is faced with the problem of converting nearly 55,000 of its primary series maps to the new NAD-83.

Table 1.—Comparison of NAD-27 with NAD-83.

Location		*Latitude*	*Longitude*	*Differences*
Capitol	-27	38-53-22.909	77-00-33.706	
(Washington, D.C.)	-83	38-53-23.311	77-00-32.623	NE - 94.8 feet
Capitol	-27	38-34-45.064	92-10-21.923	
(Missouri)	-83	38-34-45.184	92-10-22.580	NW - 53.6 feet
Space Needle	-27	47-37-14.446	122-20-52.973	
(Seattle)	-83	47-37-13.800	122-20-57.429	SW - 312.2 feet
First Order NGS Stations		*Latitude*	*Longitude*	*Differences*
Finland	-27	47-27-23.269	91-14-15.293	
(Minnesota)	-83	47-27-22.947	91-14-15.867	SW - 51.2 feet
Tauno	-27	45-57-59.015	88-39-06.313	
(Wisconsin)	-83	45-57-58.868	88-39-06.787	SW - 36.6 feet
Paulding	-27	46-24-01.677	89-13-05.806	
(Michigan)	-83	46-24-01.481	89-13-06.318	SW - 41.0 feet
Penrod	-27	37-37-08.523	91-71-05.326	
(Missouri)	-83	37-37-08.689	91-71-05.819	NW - 26.0 feet
Deer	-27	37-57-47.588	86-39-42.898	
(Indiana)	-83	37-57-47.799	86-39-42.842	NE - 21.8 feet
Bald	-27	38-26-52.876	79-55-53.552	
(West Virginia)	-83	38-26-53.298	79-55-52.777	NE - 75.0 feet

Conversion to NAD-83 will be of increased importance as use is made of the Global Positioning System (GPS) and other satellite-derived data that basically are referenced to the center or mass of the Earth." The letter also states: "A pilot project consisting of 36 7.5 minute maps covering the state of Rhode Island was initiated to develop the technical aspects of the conversion and to enable the USGS to assess the impact on the map-user community."

These maps show the mapped area positioned on NAD-83 on one side and the existing map originally produced on NAD-27 on the reverse. "This will enable users to graphically compare the resulting differences between NAD-27 and NAD-83. The differences are not constant but vary with each quadrangle."

The effects of NAD-83 on one of the pilot NAD-27 quadrangles show a difference of 0.36 arc seconds in latitude to the north and 1.75 arc seconds in longitude to the east—a difference of 138 feet on the ground. These distances will vary as do the differences between NAD-27 and NAD-83 coordinates for the areas being compared.

Comparison of NAD-27 & NAD-83

A geodetic reference network should represent reliable internal consistencies within the arcs of triangulation and a high order of relative accuracy between distant points on the Earth's surface. However, GPS measurements between first order stations on NAD-27, when compared with NAD-83 coordinates, show differences up to several feet. The differences are measured in tenths of a foot.

NAD-83 has made significant relative position changes on geodetic control stations over the entire United States. The users of either NAD-27 or NAD-83 must be aware that any intermix of datums will lead to unacceptable results. The datum used must be within that datum and so identified for all other users.

The problems created by use of two horizontal control datums, the internal consistency and accuracy of each datum, and the impact of GPS being incorporated within the NAD-83 network cast doubt on the further use of NAD-27.

Recommendations

The following are recommended for using NAD-27 and NAD-83:

(1) USGS quadrangle maps are geodetically obsolete in relation to NAD-83. Identify scaled positions from these maps as NAD-27.

(2) Confine NAD-27 coordinates within the NAD-27 network and NAD-83 coordinates within the NAD-83 network. Intermingling is not acceptable. Identification of which datum used should be mandatory.

(3) Replace NAD-83 as the national horizontal control reference datum. Accelerate the transition to the exclusive use of NAD-83 coordinates.

Sudan Reforestation & Anti-Desertification Project: A Summary

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Washington Office

The USDA Forest Service and the U.S. Department of the Interior entered into a participating agreement with the U.S. Agency for International Development (A.I.D.) to provide technical assistance and training to the Government of Sudan to support the Sudan Reforestation and Anti-Desertification (SRAAD) Project. The objective of the project was to conduct a forest inventory involving satellite image mapping (LANDSAT), image processing, and related areas, including computer data base management systems. The technology will afford the retrieval, display, and use of forest inventory data to assist in resource management and sustainable land use.

Three Forest Service employees—Gyde Lund (Washington Office Timber Management), Tony Jasumback (Missioula Technology and Development Center), and Ray Allison (Washington Office Engineering)—traveled to Sudan to provide assistance and training in support of the project. Gyde Lund provided the technical assistance and training on techniques of forest inventory, and Tony Jasumback and Ray Allison concentrated on applying Global Positioning System (GPS) technology to the project.

Inventory & Mapping

A comprehensive development project was originally designed and approved to assist Sudan in meeting its forestry mapping and inventory needs. The SRAAD Project calls for the inventory and mapping of a large area of forest lands in Central Sudan (10 to 15 degrees north latitude and from 22 ½ to 33 ½ degrees east longitude). This area was amended because of the provision of Section 513 of the Foreign Assistance Act to include only a pilot area, namely, the Kasgeil Rural Council, south of Al Ubayyid.

To present the forest resource information for the whole of Kasgeil in one map and still conform to the sheet lines of the Sudan 1:250,000 map series, the SRAAD Project will publish a nonstandard sheet covering the area of 12 to 13 degrees north latitude and 29 degrees, 50 minutes to 31 degrees, 30 minutes east longitude. A second map of a subset of the area, which shows greater detail of forest information for the Kasgeil Rural Council, will be published at a scale of 1:100,000 on an image base designed in consultation with the Sudan Survey Department.

GPS units were used to establish the controls that will evaluate the accuracy of the satellite image maps. Also, GPS units were used to locate and estab-

lish the forest inventory plots. Discussed were techniques to digitize, with GPS units, roads and trails, property lines, and the like that are not visible on the image maps and to plot these features at 1:100,000 and overlay the data onto the image maps.

Both the Sudanese surveyors and the forestry groups received training on operating GPS units. There are tremendous potential applications in Sudan for the concept of 1:100,000 image maps, resource overlays, and the data collection capabilities of GPS technology. The Sudanese proved to be extremely interested and qualified in all aspects of the project. Many suggested innovative approaches to solving various problems as they came up.

Improving Management Decisions

The conflicts and problems confronting the resource manager in Sudan are serious and life-threatening. The lack of resource information or of the processes to evaluate this information occasionally presents the manager with insurmountable problems. The fragile interface between available natural resources and population practices presents the manager with very limited management alternatives.

The state-of-the-art processes provided by the SRAAD project promise to equip Sudan resource managers with a dramatic increase in information and processes with which to improve management decisions. The geocoded 1:100,000 scale thematic mapper image maps, forest inventory techniques, and GPS data collection capability will provide an effective system for resource information management and also a pattern for implementation in other third world countries.

Errata to "Hells Canyon Boat Dock on the Snake River" Article

The last page of the "Hells Canyon Boat Dock on the Snake River" article, which appeared in the January-February issue of *Engineering Field Notes*, was inadvertantly left out. Following is the information from that page. Please cut this out and insert it into your January-February issue. Sorry for the inconvenience.

☆ U.S.G.P.O.: 1990- 717-013/04513

sheave at the top of the tower failed when the sintered material turned into powder, causing the cable to come off the sheave and slide over the angle iron frame at the top of the tower. Although the cable was severely kinked, there were no broken strands, and the Forest Service put the cable back into service. The Forest Service purchased new sheaves and machined the hub to receive roller bearings complete with inner and outer hardened races. Personnel machined the hub to receive a grease zerk for periodic lubrication. These measures seem to have solved the problem.

A second problem resulted from heavy jet boats ramming into the vinyl bumper strips around the top edge of the dock. Oak bumpers (2-inch by 4-inch) were installed at the bow end of the two inner slips, but because they last only about 2 years, something more durable than oak may be needed.

The third problem occurred 3 years after the sheave-bearing failure. The cable between the trolley and the counterweight failed where it had kinked when the sheave bearing failed. Although the cable selected to support the counterweight was sized to give a 5.9 factor of safety based on a working load of 55 percent of its tensile strength and, under normal use, should not have failed, the severe kinking caused by the cable sliding over the sharp edge of the angle iron work hardened the wires and caused premature failure. The counterweight dropped about 8 feet onto the concrete base, but no significant damage occurred. The only visible damage was two hairline cracks in the base and one small chip at the bottom edge of the counterweight.

The Design Engineer conducts an annual operational and structural inspection. The design of this dock facility was difficult and challenging but the fact that there have been only three significant maintenance problems in 4 years of service indicates that the design prescription has been fulfilled. Public response to the boat dock has been very positive.

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