United States
Department of
Agriculture

Forest Service

Engineering Staff

Washington, DC

Engineering Field Notes

Volume 27
May–August
1995

Engineering Technical Information System

Forest Service Conversion to Metric Measurement

Gerald T. Coghlan
Acting Director of Engineering
Washington Office

Issue: Recent questions about the USDA Forest Service conversion to metric measurement. Should metrication be further delayed to reduce costs and "to do less with less?"

From an overall Forest Service metric conversion perspective, Engineering is on the team, and Property & Procurement manages the Forest Service Metric Implementation Plan. Yes, there is a Forest Service Metric Implementation Plan, approved by the Leadership Team, that tiers to the USDA plan that implements the President's Executive Order (EO) 12770. No one from the President down to the Chief has withdrawn or mitigated direction to implement these orders. The EO and USDA plan say, "use, to the extent economically feasible by Sept. 30, 1992, or by such other date or dates established by the Department or Agency. . .the metric system of measurements in. . .procurements, grants, and other business-related activities." The Forest Service plan schedules activities with a target completion date of 1997. With a 5-year extension of the EO 1992 target date, it seems clear the Forest Service did not intend to lead implementation, but rather to follow and build upon implementation by other agencies. The Forest Service plan, with its 5-year delay, has been approved. Whether or not a modification to the plan for an even longer delay might be approved is problematic. Certainly, well-documented and justified exceptions will probably be tacitly, if not formally, accepted. Failure to implement without justification and approval would be disobeying a lawful order.

From a Forest Service infrastructure investment perspective, we have specific actions in the plan for implementing metrication. These build upon foundations of others, such as Federal Highway Administration (FHWA), American Association of State Highway Officials (AASHTO), and States' metrication of highway construction. Forest Service infrastructure metrication is also keyed to normal schedules for updating, such as specifications, training materials, and publications. A survey of other Federal Government metrication shows that the FHWA is surveying and designing fiscal year 1997 (FY97) transportation projects in hard metric. Similarly, State FY97 transportation projects are being prepared in hard metrics. The Government Services Administration has already completed new and renovation projects in hard metric; it is now their standard practice. The USDA Office of Operations currently prepares plans in hard metric, such as the renovation of the South Building and new developments for the Natural Resources Conservation Service at Beltsville, MD. Most other agencies are also moving toward full implementation. Clearly, the Forest Service is not leading Federal infrastructure investment metrication. The question might better be asked, will we be ready soon enough to function in a changing marketplace? How will we implement emergency relief for federally owned projects with FHWA expecting metric designs and specifications? How will we use AASHTO metric materials specifications and State metric asphalt pavement and bridge construction specifications?

It is my perspective that we have a very good plan to metricate Forest Service infrastructure investments closely on the foundation of others such that we minimize the cost and impact of development without suffering unduly from lack of preparation. It is my expectation that we will move purposefully forward with implementing the portions of the Forest Service plan involving metrication of infrastructure investments.

Energy-Efficient Lighting System Installed in USDA Jamie L. Whitten Federal Building

Ed Murtagh
USDA Office of Operations
Facilities Engineering Management

Introduction

The Energy Policy Act of 1992 and Executive Order (EO) 12902 have mandated that Federal agencies must achieve a 30-percent reduction in energy usage in Federal facilities by the year 2005, based on a 1985 baseline. This extends the previous goal of a 20-percent reduction by the year 2000, which is still in effect. As part of the effort, the U.S. Department of Agriculture (USDA) Office of Operations designed and awarded a construction contract to replace the office lighting in the Jamie L. Whitten Federal Building (former Administration Building) at the USDA Headquarters Complex in Washington, DC. The Jamie L. Whitten Federal Building, a 381,000 gross square foot office building, was built in phases between 1908 and 1930. The energy-efficient lighting technologies available today can dramatically reduce energy consumption and cost while delivering comparable lighting. This project was part of our effort to make the Jamie L. Whitten Federal Building a "showcase facility."

Under the contract, the existing lighting was replaced with energy-efficient T-8 fluorescent light fixtures with electronic ballasts. We provided each office with occupancy sensors that automatically turn off lighting fixtures in unoccupied offices. The project was designed to maintain a minimum average 50-foot-candle level, as required by the Federal Property Management Regulations. T-8 fluorescent light fixtures with electronic ballast are one of the most energy-efficient replacements for existing T-12 fluorescent light fixtures.

Lighting System Design

The lighting systems in the Jamie L. Whitten Federal Building are typically 20 years old. In many cases, the existing office lighting layouts resulted in excessive foot-candle levels. In a majority of offices, we replaced four 40-watt T-12 fluorescence lamps and standard ballast with three 32-watt T-8 lamps and electronic ballast. This reduced energy consumption by approximately 97 watts for each four-lamp fixture. When possible, lighting layouts were changed to reduce the number of light fixtures in an office while maintaining a minimum 50-foot-candle level in the offices. We installed volumetric motion occupancy sensors that use the Doppler Principle to sense movement. The occupancy sensors also have adjustable time delays and adjustable sensitivity. The exit signs were replaced with light-emitting diode lamps.

A life-cycle cost analysis was performed on this project. We assumed that the existing 20-year-old system was near the end of its useful life. The life-cycle analysis, therefore, compared this option to using the existing system for an additional 5 years and then replacing the system. The analysis found that it was cost-effective to replace the system now rather than later. The payback was approximately 1 year. Though the cost of the occupancy sensor was included in the analysis, no energy savings associated with the sensors were included in the analysis.

In addition to energy savings, we also considered comfort factors. The building's central air-conditioning systems were designed and constructed more than 30 years ago. Over this time, the use of electronic equipment increased dramatically in the offices. The designers of the original air-handler systems did not consider these loads when the cooling systems were selected. This has caused offices to overheat during the cooling season. The lighting replacement project is expected to reduce the cooling load requirements of the offices by more than 50 tons.

The project was life-cycle cost-effective partially because of the rebate program offered by the Potomac Electric Power Company (PEPCO). PEPCO typically offered a rebate of $25 per fixture and $65 per occupancy sensor. We expect to receive a total of $110,000 in rebates.

Construction Phase

The project was awarded in fiscal year 1994 for $540,000. Over a 15-month construction period, the contractors replaced over 3,500 light fixtures. Because the work was in an occupied building, they completed it after hours. Our inspectors photographed each area and the contractor covered the furniture before work was started. We found that an electrician was able to replace 10 fixtures per 8-hour shift.

Because most of the fixtures were installed before 1978, most of the ballasts were assumed to contain polychlorinated biphenyls (PCB's). All of the PCB-related work was specified to comply with the general safety and health provisions in 29 CFR 1910, 29 CFR 1926, and 40 CFR.

Lessons Learned

One problem we found quickly was that the lighting levels from the new fixtures were significantly higher than the design of 50 candles. Several individuals complained that the lighting levels were too high. Typically we addressed this problem by removing one of the three T-8 lamps. After several years of operations, the lighting efficiency will drop, and the third tube can be reinstalled.

Another problem we found was with the occupancy sensor settings. In approximately 10 percent of the offices, occupants complained about the sensors shutting off when the space was occupied or not shutting off when the space was unoccupied. We found that the sensor setting was affected by furniture, fans, plants, and curtains in the space. If there was a problem, an electrical engineer familiar with the system corrected the problem.

Overall, the new lighting system works very well, and we are expecting to save at least 800,000 kilowatts per hour per year on the lighting replacements alone.

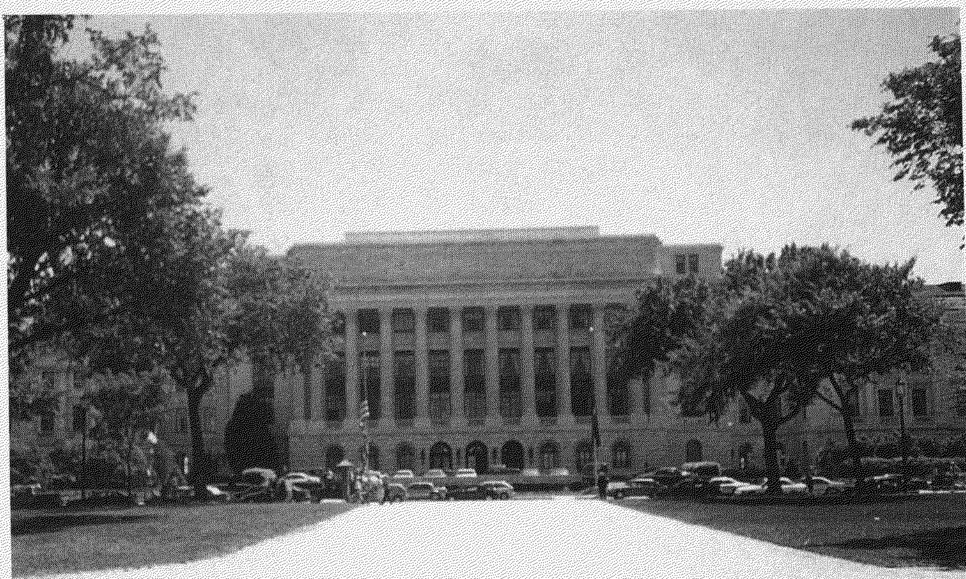


Figure 1—A new energy-efficient lighting system was installed in the USDA Jamie L. Whitten Federal Building in Washington, DC.

The Technology and Development Program: A Blueprint for Success

Keith Simila
Operations Program Leader
Missoula Technology and Development Center

Abstract

This article was originally written as part of a report for Forest Service Research. The Technology and Development (T&D) Program is seen as an example of successful implementation of development activities that are tied directly to customer oversight and satisfaction. Through the reinvention effort, Research is examining ways to broaden its mission to include more "development" and create a Research and Development unit. The article reviews the history and current role of the T&D Program as administered by Washington Office Engineering.

Background

The Forest Service Technology and Development (T&D) Program began shortly after World War II. The program was originally established in Arcadia, California, and Missoula, Montana, in 1945. The initial thrust of this work was developing equipment for wildland firefighting. The center at Arcadia resulted from the consolidation of all Forest Service fire equipment problemsolving efforts into a "laboratory sufficient to serve the fire control requirements of the Western Regions." The southern California site was selected because of the proximity of significant fire activity, the availability of technological and industrial expertise, and the availability of facilities. At approximately the same time, a group at the Aerial Fire Depot in Missoula began working on equipment for smokejumping and air cargo-dropping efforts. In 1953, this unit became the Aerial Equipment Development Center.

In the late 1940's, a conference of Forest Service Range Management administrators and researchers recognized that a major effort was needed to test, adapt, or develop suitable equipment for range seeding and other improvements. Thus, the range program became the second involved customer (sponsor) of the program. Eventually the development work became known as the Equipment Development Program.

The Equipment Development Program continued through the 1950's and early 1960's. In 1961, the decision was made to broaden it to include all program areas in need of equipment development. In the mid-1960's, the Arcadia group had a new facility built in San Dimas, California. The

Missoula group consolidated its operations and relocated to Fort Missoula. A new facility was (and is) planned for the Missoula group, but it has been delayed due to budget constraints.

Until 1981, both centers were attached to the regional offices in San Francisco and Missoula, while the Director of Engineering in the Washington Office (WO) provided the program oversight and technical direction. In 1981, the decision was made to administer both centers as detached units of the WO Engineering Staff. This was done to overcome the perception that the centers provided regional support when in reality they provided national support.

Dissatisfaction with the kinds of projects assigned to the centers, as well as timeliness of outputs, led to significant changes in the program including downsizing of the work force. In an effort to be more responsive to customers supporting the program, a decision was made, in 1986, to reorganize each center into a matrix structure. Program leaders were appointed who would be in constant, direct contact with each sponsor and field personnel seeking technological solutions to present-day problems. The reorganization (reinvention) proved to be a significant factor in continuing a viable program, as it enabled each program to provide continued oversight and feedback on how well customer needs were being met.

Since 1986, the number of sponsors and funding for the program have increased, and the kinds of activities have become more complex and diversified. In 1987, the name of the program was changed to the T&D Program. The new name more accurately reflected the activities the sponsors were requesting. Emphasis on developing new equipment was shifting to a broader problemsolving and operational support role. As resource management became more complex, the kinds of problems needing solutions were not always equipment-oriented. The flexibility in being able to broaden the role of T&D by increasing skills and support for program areas unrelated to equipment development was key to the survival and future success of the T&D Program. Over time, new sponsors were added and others reduced support or withdrew. Sponsor support comes from the National Forest System, State and Private Forestry, Administration, and International Forestry Deputy Areas. The T&D effort encompasses projects in forest transportation and facilities engineering, timber, reforestation, nurseries, fire and aviation, recreation, forest health (insects and disease), occupational safety and health, forest residues, law enforcement, range, and uniforms. The projects are national in scope and enable land managers to perform forest work more efficiently, at less cost, and with minimum hazard. The T&D Program provides long-term continuity in development, and retains a valuable technology base and recognized national expertise. T&D was born out of solving customer problems, and has expanded from its emphasis on fire-related equipment to incorporate all Forest Service programs where customers need problems solved. As Forest Service technology needs change in order to meet new demands, the program will continue to be dynamic in seeking better ways to provide the appropriate technology, equipment, and technology transfer.

Role

The historic role of the T&D Program was to develop equipment to be used in specific field applications (figures 1 and 2). The types of equipment included such items as fire tools, fire equipment, and road maintenance equipment. The T&D Program continues to dedicate a significant effort to equipment development and upgrades of previously developed equipment.

The role of the T&D Program has expanded from a single focus on equipment development to problemsolving units that assist the introduction of new technology on a broader scale, as well as provide operational support to national sponsors. This changed role is now also focused on projects that are more "soft goods," such as training manuals, publications, reports, technical tips, videos, and other technology transfer activities (figure 3). Training activities are directed toward "train-the-trainer" roles and not as a national training resource.

As changes such as downsizing the regions and the WO have occurred, expertise related to specific technical areas has shifted. The T&D centers are now viewed as Centers of Excellence where expertise that once resided in other locations can be utilized. Expertise in protective fire equipment (figure 4), fire injury investigations, explosives (figure 5), health and safety, global positioning systems (figure 6), accessibility, and others have enabled the centers to provide expertise not found anywhere else in the agency.

As new sponsors arrive and existing sponsors change, the role of T&D will continue to change. Each sponsor has unique interests and needs. Primary skills have expanded from the historical fields of mechanical, civil, and electrical engineering to specialized skills in meteorology and personnel such as various equipment specialists, foresters, landscape architects, recreation specialists, and logging engineers. Sponsors who are willing to commit to long-term project work often request special expertise to be recruited or developed.

The mission of the T&D Program is the systematic application of scientific knowledge to create new or substantially improved equipment, systems, materials, processes, techniques, and procedures that will perform a useful function or that will be suitable to meet the objectives of advanced forest management and utilization.

The project-oriented nature of the T&D Program focuses the development effort on specific problems that have technological solutions. Most projects last 3 to 5 years. Often the solutions are unknown during project initiation. As possible solutions are pursued, the feasibility, scope, and amount of development effort are examined to determine the practicality and cost-effectiveness of the solution. Once the solution

Figure 1.—Yarder developed for smallwood harvesting.

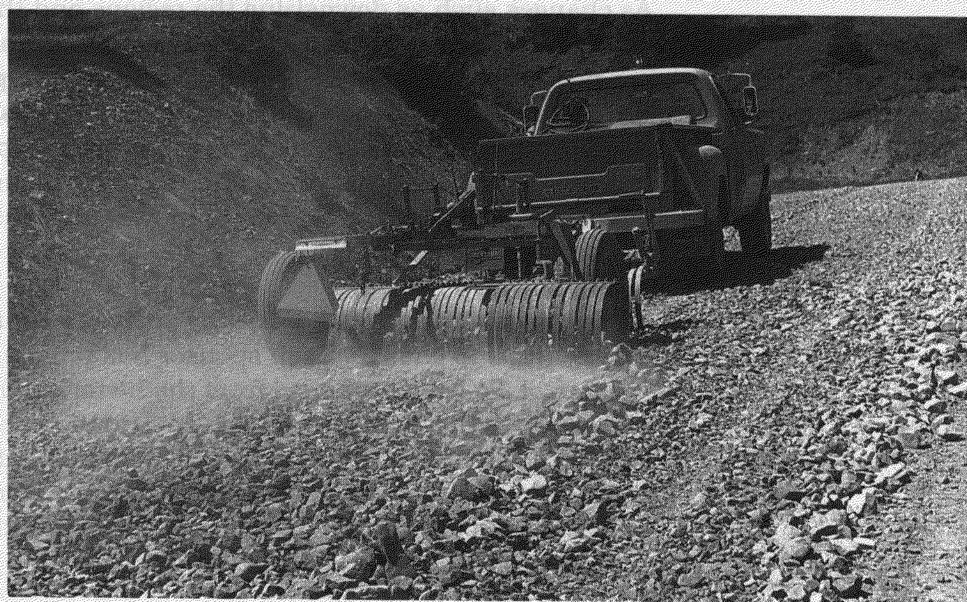


Figure 2.—Rock rake developed to improve road surface after grading.

becomes apparent, the effort focuses on developing prototypes, field testing, and documentation. The short-range nature of the projects and the focus on development often deters many research scientists away from T&D as conducted by the T&D Program. Projects assigned to the centers have a specifically defined desired outcome, a specific time frame for project accomplishment, and specific funding constraints. Many researchers also shy away from T&D work due to interest in pursuing the academic disciplines of research and the peer review process for recognition and promotion.

Figure 3.—Examples of publications of the Forest Service Technology and Development Center.

Management and Process

The T&D Program is funded as a national program. Sponsors determine the funding and level of effort needed to accomplish T&D. Funds are currently programmed as part of the WO budget, and processed through the WO Program Development and Budget group. Moneys are allocated prior to the distribution of funds to the regions. Sponsors appoint steering committees to identify projects, assign priorities, provide oversight, and recommend funding levels. The steering committees are generally comprised of field, regional, and national representatives, including various line and staff officers. The sponsor sends out requests for proposals to each region. The committees evaluate proposals for T&D work, rank them for priority, and screen them for appropriate applicability. The T&D program leader initiates action on each project by assigning it to specific experts for accomplishment. Each sponsor has a unique approach and not all use steering committees, but most follow this format.

Figure 4.—Portable fire shelter developed to protect firefighters in an emergency.

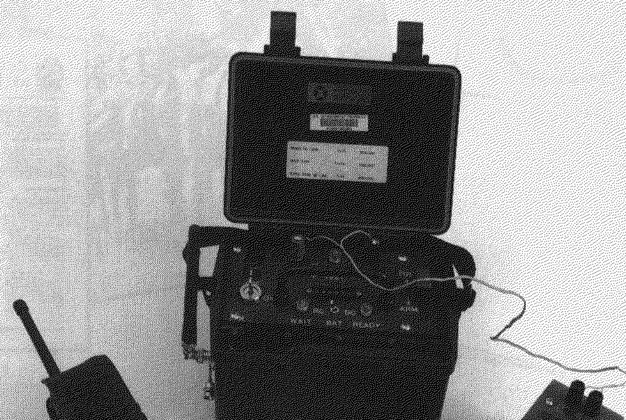


Figure 5.—Remote detonation device used to detonate explosives by radio.

Figure 6.—Global positioning system (GPS) receiver for measuring location using GPS coordinates.

Summary

The T&D Program is a success because of these primary factors:

1. The focus is on customer support and satisfaction. Sponsors come with specific problems, and T&D specialists are able to create solutions within the limits of available or newly developed technology. Projects are focused and short-term in nature.

2. The "reinvented" organization enables program leaders to have direct contact with sponsors. This gives continuous feedback to the T&D Program to ensure sponsor needs are met.

3. The steering committee concept enables interregional participation in project development by any Forest Service employee or group that has a specific interest or need in their field of expertise. It also ensures that the projects assigned are those of highest concern and importance to field personnel across all regions, with appropriate input from national program leaders.

4. The T&D center personnel are recognized within their professions and the agency for their technical expertise. Engineers, scientists, and other specialists at the T&D centers are national

experts and are called on routinely to consult and assist on special projects or teams. Where local expertise is unavailable, experts are contacted via contract or through cooperative agreement with other agencies or universities. Other national experts remain as associate staff. These include university professors, research scientists, and retirees of the T&D centers.

5. A strong emphasis is placed on technology transfer so that those who use the technology are informed and, sometimes, trained. Various media are used to convey new technology and developments including publications, videos, train-the-trainer sessions, briefings, and consultations. Publications and photography efforts are nationally recognized as products of the highly trained professionals on staff or contracted at the centers.

The T&D Program has a history of providing excellent service and expertise not always available in other parts of the Forest Service. Continued refocus on the desires of sponsors and needs of field personnel drive the centers to develop timely, practical solutions to assigned problems. Sponsors have come to rely on the expertise available to support the field units and continue strong support for T&D efforts. During times of reduced budgets and other limitations, most sponsors have recognized the value technology contributes to providing solutions at less cost than historical approaches. The T&D Program has a future because its focus and people make applying technology to problems both practical and cost-effective.

Improving Culvert Entrances to Increase Flow Capacity

Carol Grimaldi
Structural Engineer
R-5 Regional Office

History

Most of the small and medium-sized culverts on USDA Forest Service roads were designed for a 25-year storm event. In 1993, *Riparian Area Standards and Guidelines* were developed in an effort to protect the Pacific Coast salmon resources and riparian areas in the Pacific Northwest. These new riparian guidelines and the President's Forest Plan mandated that culverts should now be capable of handling a 100-year storm event.

Objective

The objective of this study is to document procedures that enhance culvert flow characteristics by modifying the inlets of culverts. The cost-effectiveness of these modifications is also a significant consideration.

Background Information

There are two conditions that limit the flow capacity of culverts:

1. **Inlet control** occurs when the flow capacity is controlled at the entrance. The depth of the headwater and the entrance geometry are the controlling parameters.

2. **Outlet control,** the culvert hydraulic performance, is determined by the governing inlet control plus the controlling water surface elevation at the outlet and the slope, length, and roughness of the culvert barrel.

The majority of culverts found on Forest Service roads flow under inlet control. Figures 1 and 2 illustrate inlet and outlet control conditions.

Inlet Treatments

The five different types of inlet treatments considered in this report (figures 3 and 4) are listed here with their definitions.

1. **Projecting inlet:** The culvert extends beyond the roadway embankment.

2. **Mitered inlet**: The culvert barrel is cut to conform with the slope of the embankment.

3. **Headwall and wingwalls:** Cast-in-place concrete structures that are constructed on the ends of the culvert barrel, and **End sections**: Performed metal or precast concrete structures that are installed on the ends of the culvert barrel.

4. **Beveled-ring inlet**: A large concrete chamfer constructed around the circumference of a concrete or corrugated metal culvert.

5. **Side-tapered inlet:** A formed section of pipe with sides tapering outward at the entrance. (The culvert height remains the same; the width is increased at the entrance.)

Each of these inlet types has a different numerical entrance loss coefficient. A list of these numerical values can be found in figure 5.

Design Criteria

Economic and risk analysis, as stated in the *Transportation Structures Handbook* (FSH 7709.56b), should be considered when selecting an inlet improvement. When inlets are improved, velocities through the culvert will increase. Since fish movement during major storms is not a consideration, it is not necessary to check culvert flow velocities during peak discharges.

Hydraulic Design Criteria

Most culverts have been sized to permit open channel flow for a 10- to 25-year storm event. The first step is to determine the design flow for a 100-year event, then to check the capacity of the culvert flowing full, based on open channel flow equations to see if it can handle the discharge for a 100-year flood. If it does, then no improvements are needed. Otherwise, one must determine whether inlet or outlet conditions control at the site. If outlet conditions control, then improvements to the culvert's inlet will not increase the capacity. When inlet conditions control, then a more effective inlet may sufficiently increase the culvert's capacity to handle the increased design flow between the original designed flow and a 100-year flow.

Performance Rating Curves

Performance curves are plots of headwater depth in feet versus flow rate in cubic feet per second for a given culvert size, inlet edge configuration, barrel shape, material, tailwater depth, length, and slope. Performance curves can be used to evaluate various inlet improvements for a particular culvert. The charts used to generate the performance curves can be found in both the *Hydraulic Design of Highway Culverts Manual*, HDS No. 5, and in the *Handbook of Steel Drainage and Highway Construction Products*. Copies of these charts, illustrating a 36-inch corrugated metal pipe (CMP), are included in figures 6 through 17.

2. **Mitered inlet**: The culvert barrel is cut to conform with the slope of the embankment.

3. **Headwall and wingwalls:** Cast-in-place concrete structures that are constructed on the ends of the culvert barrel, and **End sections**: Performed metal or precast concrete structures that are installed on the ends of the culvert barrel.

4. **Beveled-ring inlet**: A large concrete chamfer constructed around the circumference of a concrete or corrugated metal culvert.

5. **Side-tapered inlet:** A formed section of pipe with sides tapering outward at the entrance. (The culvert height remains the same; the width is increased at the entrance.)

Each of these inlet types has a different numerical entrance loss coefficient. A list of these numerical values can be found in figure 5.

Design Criteria

Economic and risk analysis, as stated in the *Transportation Structures Handbook* (FSH 7709.56b), should be considered when selecting an inlet improvement. When inlets are improved, velocities through the culvert will increase. Since fish movement during major storms is not a consideration, it is not necessary to check culvert flow velocities during peak discharges.

Hydraulic Design Criteria

Most culverts have been sized to permit open channel flow for a 10- to 25-year storm event. The first step is to determine the design flow for a 100-year event, then to check the capacity of the culvert flowing full, based on open channel flow equations to see if it can handle the discharge for a 100-year flood. If it does, then no improvements are needed. Otherwise, one must determine whether inlet or outlet conditions control at the site. If outlet conditions control, then improvements to the culvert's inlet will not increase the capacity. When inlet conditions control, then a more effective inlet may sufficiently increase the culvert's capacity to handle the increased design flow between the original designed flow and a 100-year flow.

Performance Rating Curves

Performance curves are plots of headwater depth in feet versus flow rate in cubic feet per second for a given culvert size, inlet edge configuration, barrel shape, material, tailwater depth, length, and slope. Performance curves can be used to evaluate various inlet improvements for a particular culvert. The charts used to generate the performance curves can be found in both the *Hydraulic Design of Highway Culverts Manual*, HDS No. 5, and in the *Handbook of Steel Drainage and Highway Construction Products*. Copies of these charts, illustrating a 36-inch corrugated metal pipe (CMP), are included in figures 6 through 17.

Defining Headwater and Tailwater

Headwater depth is measured from the invert of the culvert to the water surface on the upstream face of the culvert. Tailwater is defined as the depth of water downstream of the culvert measured above the invert of the outlet. Tailwater can be determined from three methods: backwater calculations from a downstream control, normal depth approximation, or field observations.

Six performance curves have been generated for several common culvert sizes. One of the curves is based on outlet control. The other five curves are based on inlet control for each of the inlet treatments previously listed. These six curves are plotted on one graph for each culvert size. It is important to note that a culvert's maximum capacity is limited by the outlet control performance curve.

A range of flows for each culvert size is determined using figures 6 and 8. The lowest value in the range is selected for a flow with the headwater depth just under the crown of the culvert. The upper value of flow is selected at a headwater depth just below the maximum available head, and checked using figure 8. Figure 8 is a plot of critical depth for a particular discharge. The maximum flow through a culvert occurs when the critical depth coincides with the top of the culvert. At least one value in between this maximum and minimum flow value is plotted.

Generating Performance Curves for Outlet Control

The performance curve for outlet control required several assumptions be made. These assumptions were generalized to create a condition where outlet control would not govern and may need to be adjusted for actual site conditions. The assumptions made are as follows. The existing culvert is a corrugated metal circular pipe, 50 feet in length, on a 5-percent gradient with the inlet projecting from the embankment. The maximum available head is 5 feet. The tailwater was determined by normal depth approximation.

Normal depth approximation is the average of the critical depth and the height of the culvert. Figure 8 is used to determine the critical depth for each value of discharge.

The values of headwater depth for the performance curve based for outlet control are determined by using figure 9. Three entrance loss coefficients are shown in this figure. They are:

- $K = 0.9$: The culvert projects from fill (no headwall).
- $K = 0.5$: The culvert has either a headwall or a headwall with square-edge wingwalls, or an end-section that conforms to the fill slope.
- $K = 0.25$: The culvert has a beveled entrance to a lesser degree than the beveled-ring inlet improvement.

Head on figure 9 is defined as the height difference between the headwater and tailwater depths. The head is determined by connecting a straight line from the size of culvert to the point on the curve for a particular length and entrance loss coefficient. A line is constructed between the selected range of discharge to the point where the first line intersected the turning line. This line is continued to obtain the value for the head. Headwater depth is determined by adding the head and the tailwater depth together, then subtracting the difference in elevation due to the slope of the pipe.

Generating Inlet Control Performance Curves

The values of headwater depth for inlet controlled culverts are determined from figure 6 by connecting a straight line from the size of the culvert and the selected range of flow values. The headwater depth on the chart is listed as a function of the diameter of the culvert. The headwater depth is calculated by multiplying the value by the diameter of the culvert. From this figure, the headwater depth for the three inlet treatments, projecting, mitered, and headwalls/end-sections, can be obtained.

Two Additional Refinements for Inlet Improvements

Beveled-Ring Inlet Improvement

Beveled edges improve the entrance flow conditions and reduce the contraction inside the culvert immediately downstream of the culvert face. The values of headwater depth for beveled inlets are determined from figure 7, using the same procedure as described above for figure 6. Entrance type A represents a 45-degree bevel, and entrance type B represents a 33.7-degree bevel.

Side-Tapered Inlet Improvement

Side-taper increases the end area at the entrance of the culvert, thus increasing the flow capacity. There are two control sections associated with side-tapered inlets. One is at the face of the taper and the other is at the throat of the culvert. This is the point where the taper connects to the barrel of the culvert. When the control occurs at the throat, the capacity of the culvert is maximized. Figure 10 is used to determine the headwater depth at the throat. The headwater depth for the performance curves is at the face of the culvert entrance. Therefore, the difference in elevation due to the slope of the length of the tapered inlet that transitions from the width at the face to the existing culvert must be subtracted. The necessary width of the side taper at the face is determined from figure 11. Plot the headwater depth at the face and the culvert size to select the width in terms of the flow. Multiply this value with the discharge that corresponds with the headwater depth to obtain the width of the side taper at the face.

Example

The following example illustrates how to use the performance curves generated for the various culvert sizes. Refer to figure 12 for the performance curve used for this example. The inlet of an existing 36-inch corrugated metal culvert projects from a road embankment. The useable headwater depth at the site is 4 feet. The discharge for a 100-year flood is 51 cubic feet per second. Determine what type of inlet improvement can handle this flow.

Plot the intersection of headwater equals 4 feet and flow equals 51 cubic feet per second on the graph. This intersection plots on the performance curve for a headwall or an end-section. Thus, an inlet improvement equal to or superior to a headwall or an end-section is necessary to increase the capacity of the existing culvert to handle the 100-year design flood.

Using this same graph and changing the example so that the available headwater depth is 4.4 feet and the 100-year flood discharge is now 70 cubic feet per second, determine what type of inlet improvement can handle this flow.

Notice that at this headwater depth of 4.4 feet, the maximum flow is limited to 64 cubic feet per second because the culvert's capacity is outlet-controlled. This is the maximum flow that the culvert can handle, even with the addition of the side-tapered inlet improvement.

Conclusion

The performance curves are to scale and can be used for each culvert size. The outlet control curve, as mentioned previously, needs to be generated for a specific site. As shown in the preceding example, performance curves for 18-, 24-, 36-, 48-, and 60-inch CMP can be used to determine whether or not an inlet improvement on an existing culvert will increase the capacity sufficiently to pass a desired flow. These performance curves are shown in figures 13 through 17.

Summary

The majority of culverts on Forest Service roads do not flow full because the entrance to the culvert limits the amount of flow that enters the culvert. By improving the entrance configuration, more water can flow through the culvert.

By evaluating a series of refinements to the inlet characteristics, it is possible to increase the capacity of a culvert until it reaches a flow limited by the culvert's outlet control.

Improvements to culvert inlets can be a cost-effective way to upgrade existing culverts so they are capable of handling increased flow requirements. This report is a guideline to help select the most effective inlet improvement. This selection is done by using performance curves. Performance curves for five inlet types are graphed together for comparison. The graphs of these performance curves for culvert sizes ranging from 18 to 60 inches are included at the end of this report.

References

*1. *Hydraulic Design of Highway Culverts*, Federal Highway Administration (FHWA) (HDS No. 5), 1985.

2. *California Culvert Practice*, State of California, Department of Public Works, 1944.

*3. *Guidelines for Hydraulic Design of Culverts*, American Association of State Highway Officials (AASHTO), 1975.

4. "Culvert entrance refinements improve capacity at lower cost," *Rural and Urban Roads*, March 1973.

*5. *Handbook of Steel Drainage and Highway Construction Products*, American Iron and Steel Institute, latest edition.

*Note: These references are listed as mandatory references in the *Transportation Structures Handbook*.

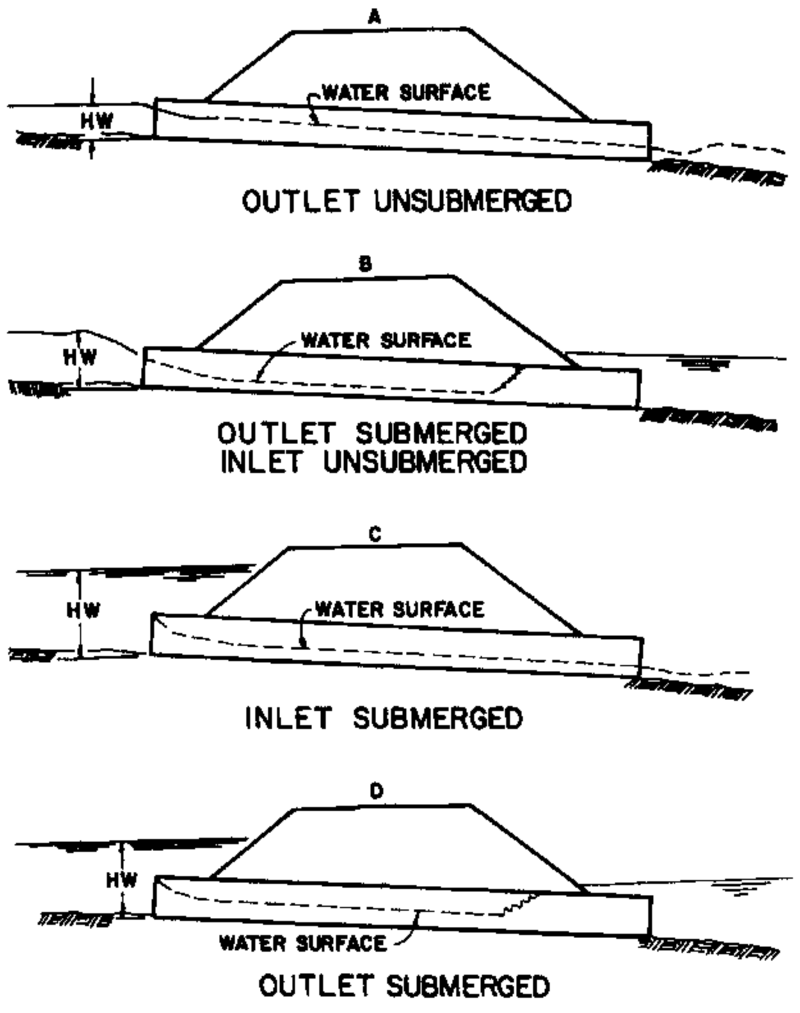


Figure 1.—Types of inlet control

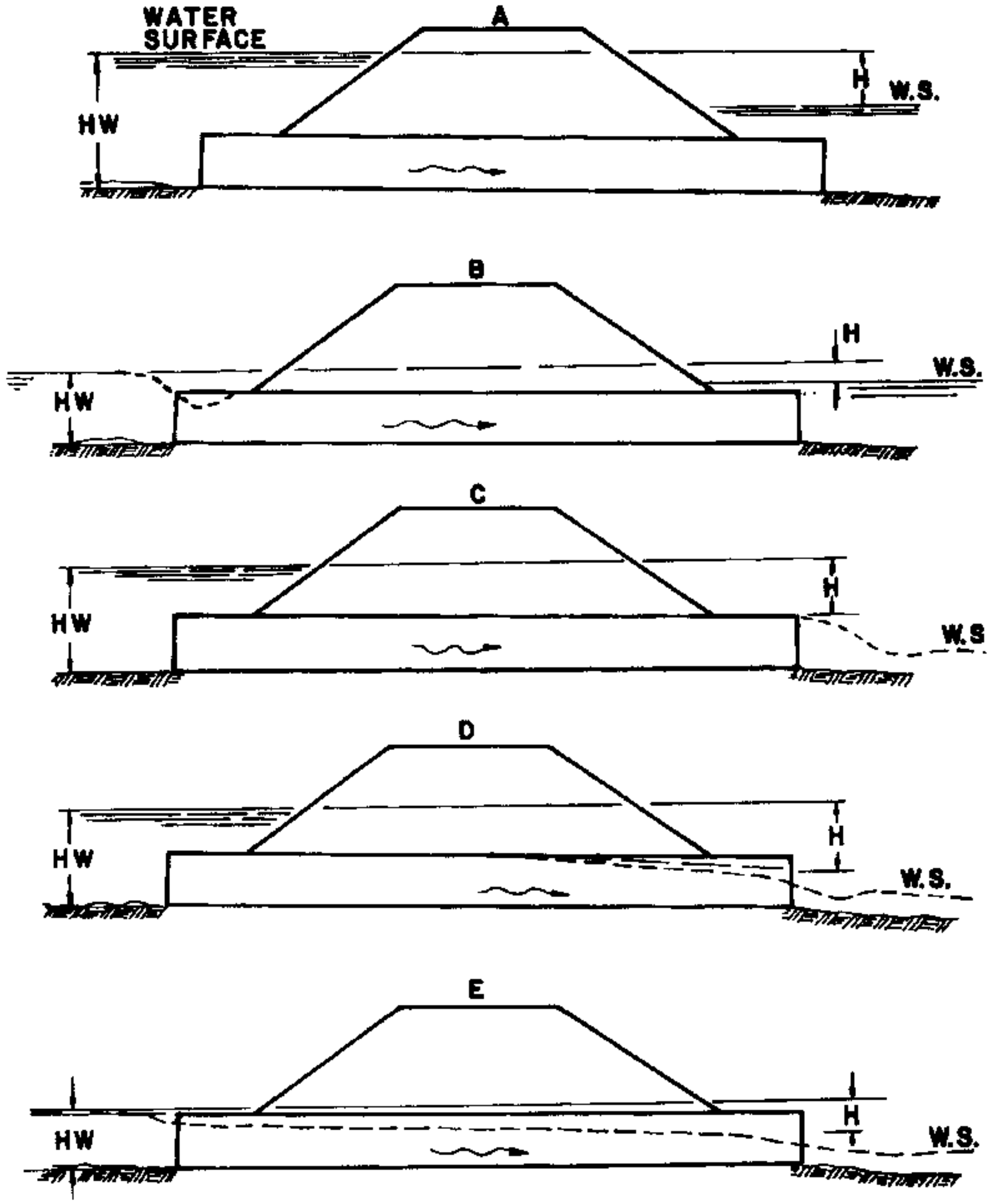


Figure 2.—Types of outlet control

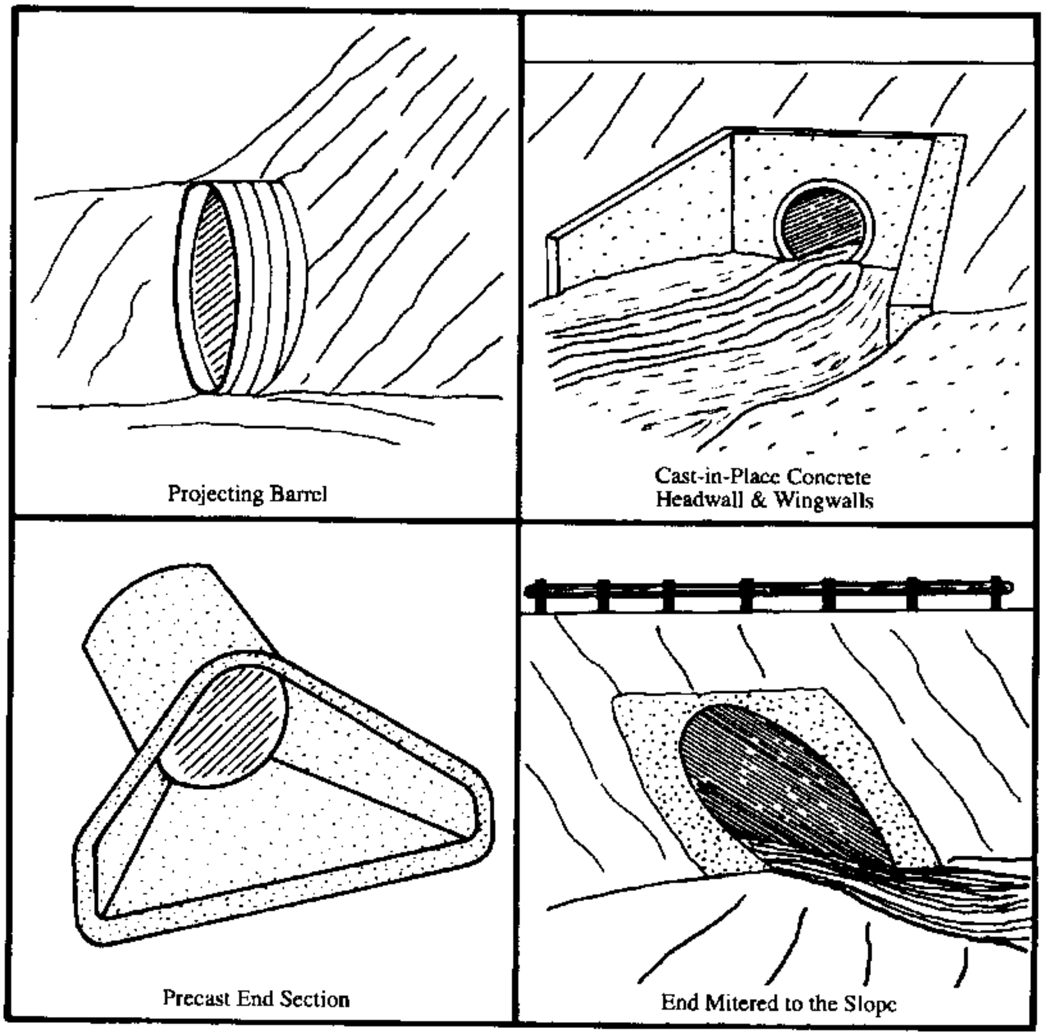
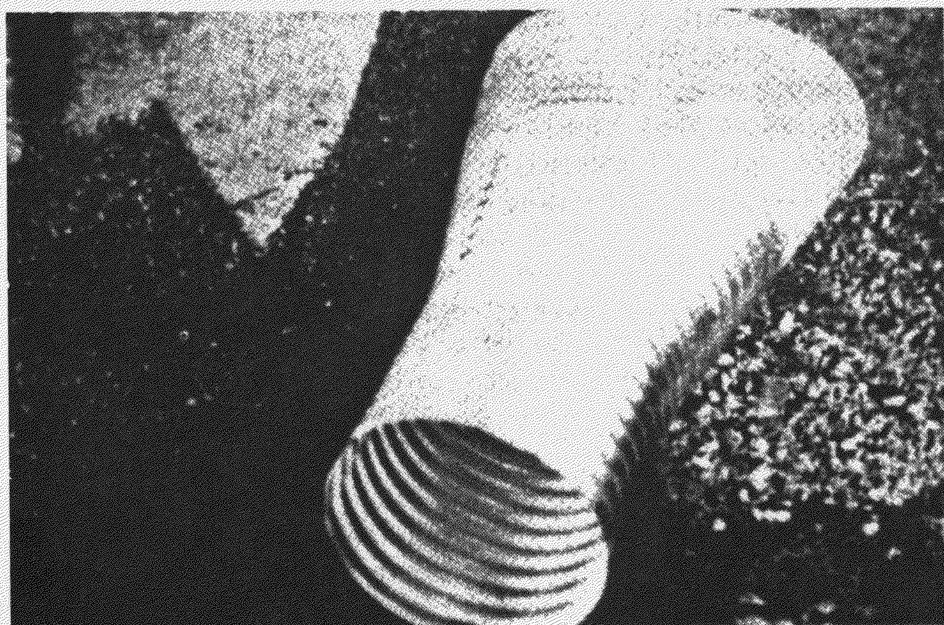


Figure 3.—Standard inlet types

Beveled Inlet with Headwall



Side-Tapered Inlet for Corrugated Metal Pipe Culvert

Figure 4.—Additional inlet types

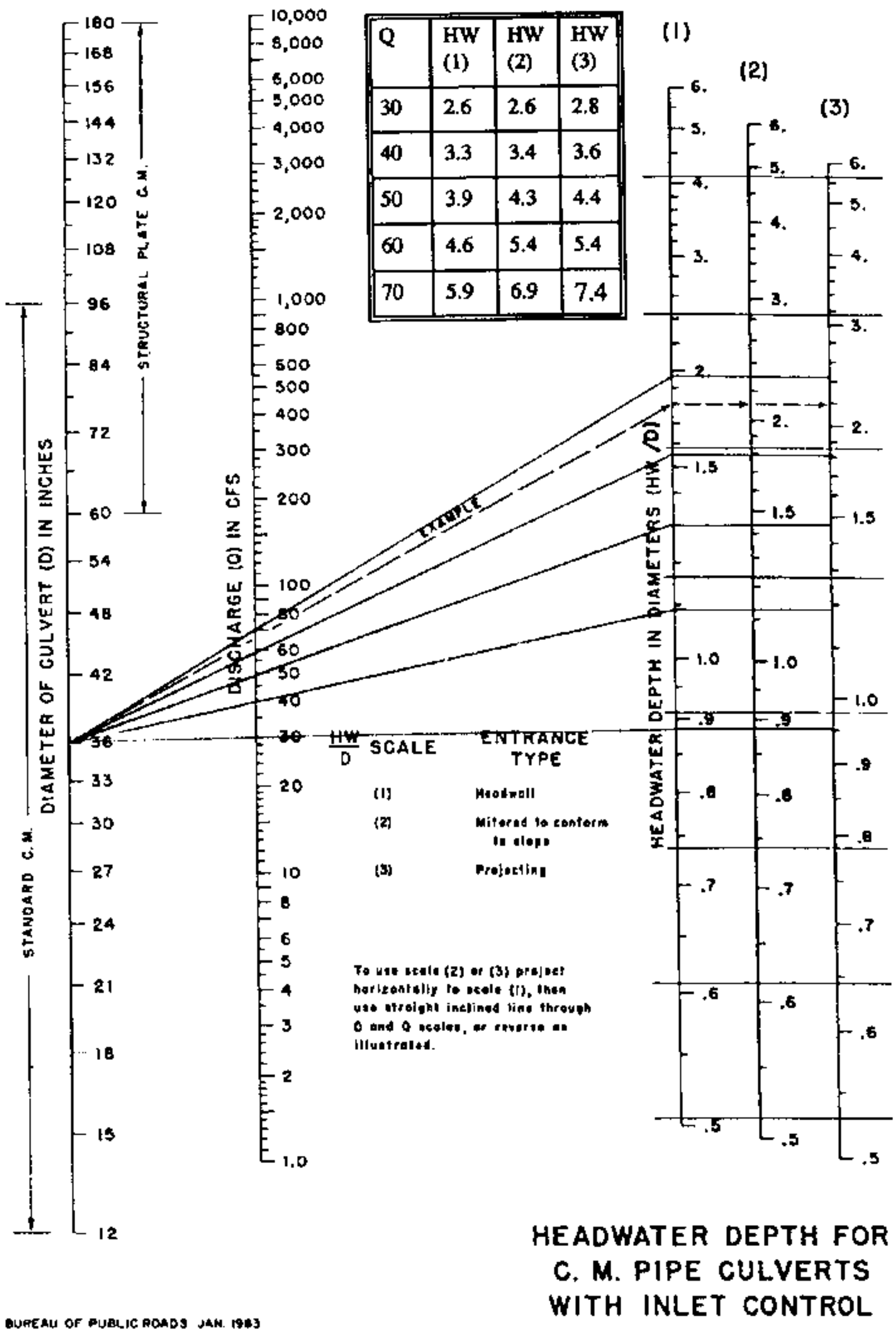
Pipe or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-section conforming to fill slope	0.5
Beveled edges, 33.7- or 45-degree bevels	0.2
Side or slope-tapered inlet	0.2

Figure 5.—Entrance loss coefficients

*Note: "End section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

**From Reference 1

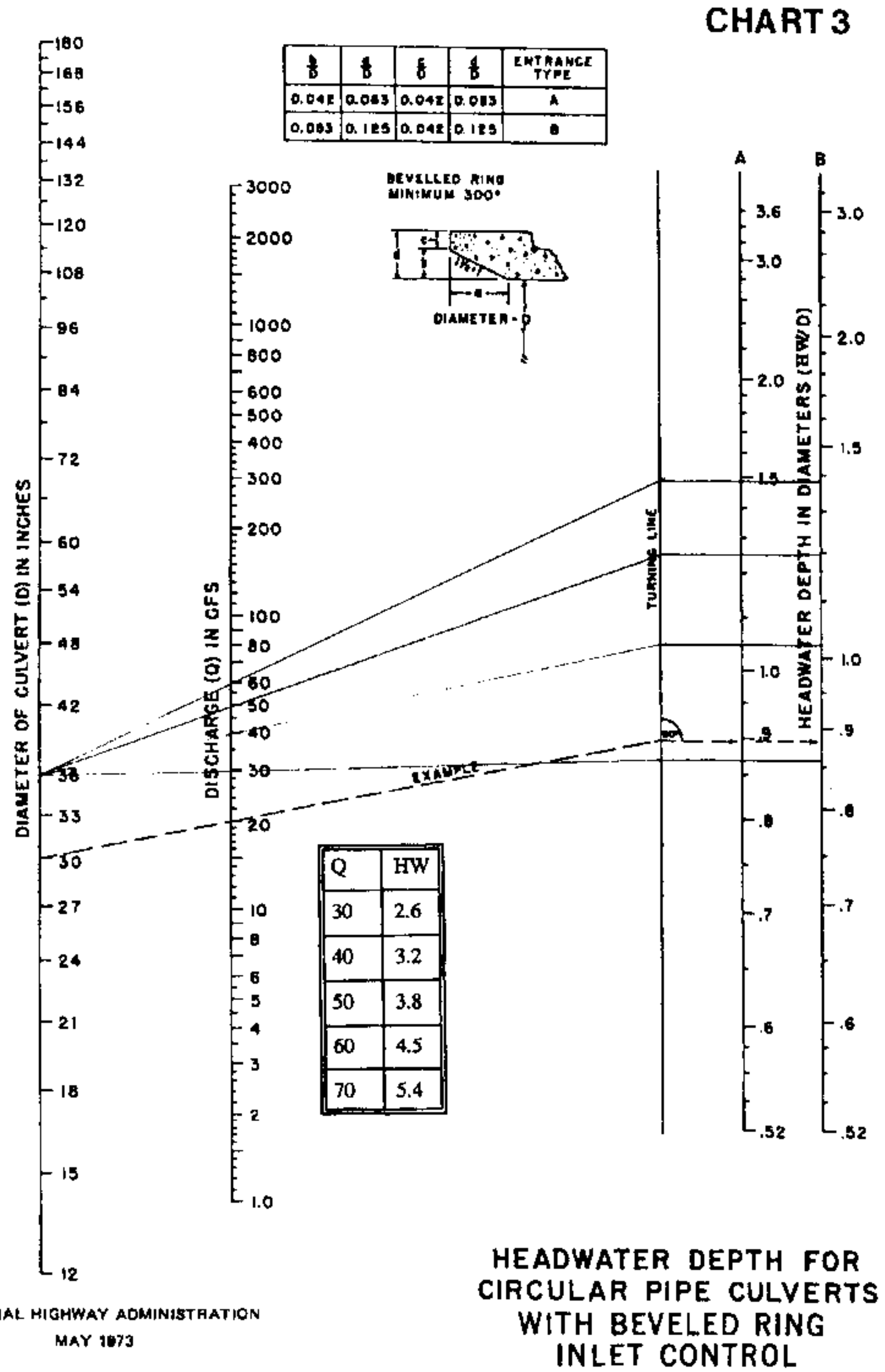
CHART 2



Q	HW (1)	HW (2)	HW (3)
30	2.6	2.6	2.8
40	3.3	3.4	3.6
50	3.9	4.3	4.4
60	4.6	5.4	5.4
70	5.9	6.9	7.4

36" CMP

Figure 6.—Headwater depth for CMP culverts with inlet control—36-inch CMP

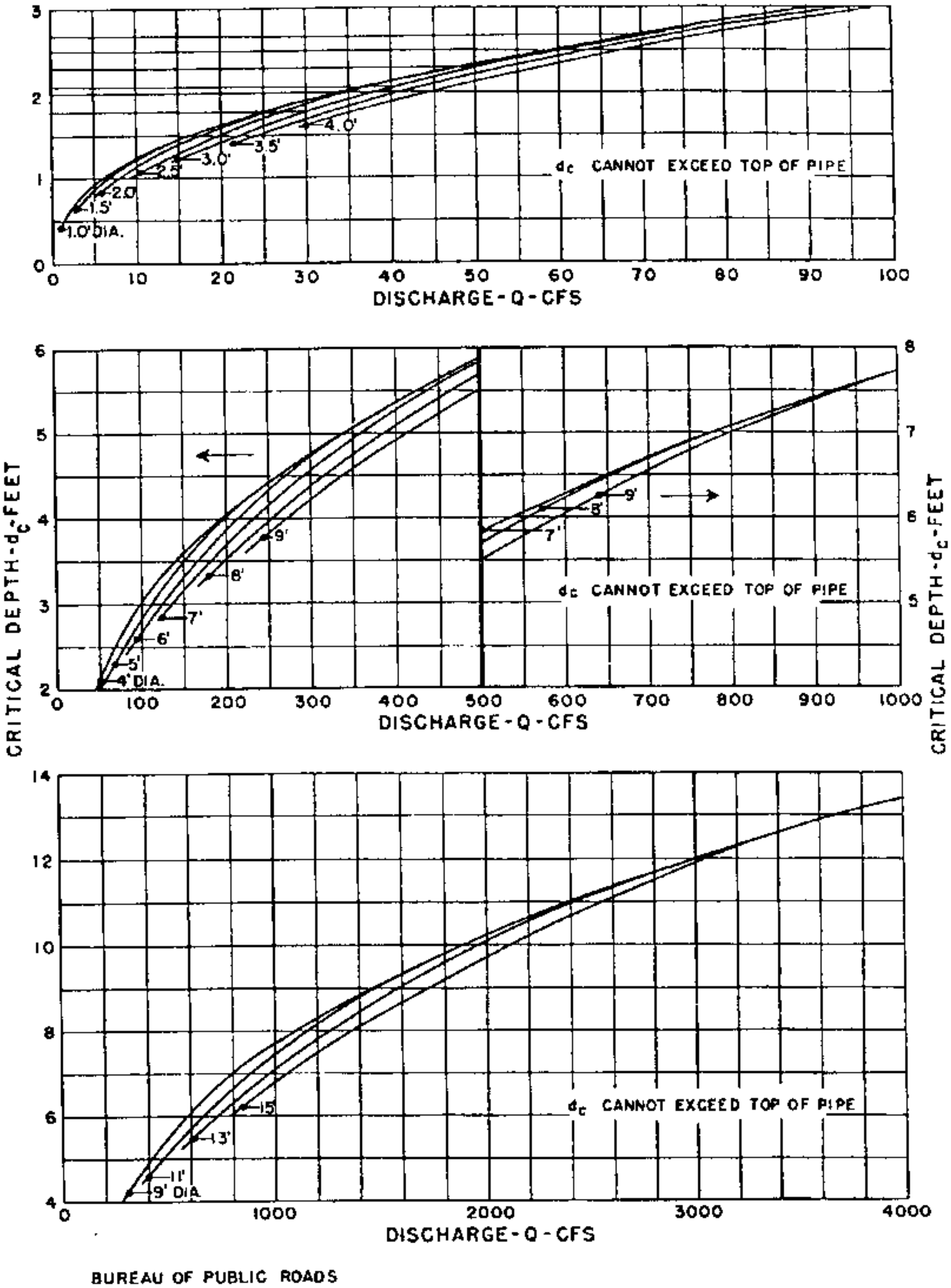


Q	HW
30	2.6
40	3.2
50	3.8
60	4.5
70	5.4

Figure 7.—Headwater depth for circular pipe culverts with beveled ring inlet control—36-inch CMP

CHART 4

Q	D_c
30	1.8
40	2.1
50	2.3
60	2.5
70	2.7



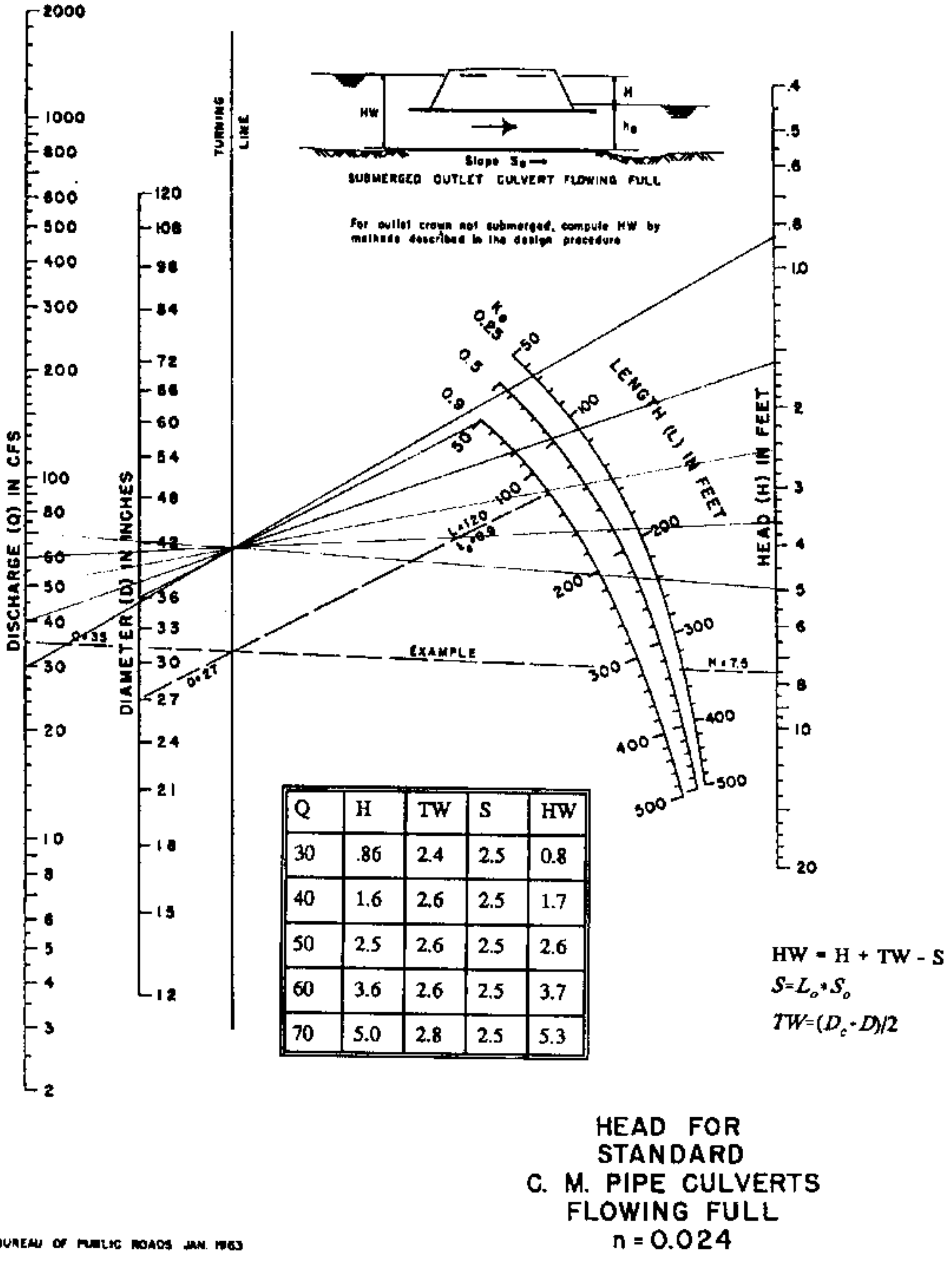
BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

36" CMP

Figure 8.—Critical depth, circular pipe—36-inch CMP

CHART 6



Q	H	TW	S	HW
30	.86	2.4	2.5	0.8
40	1.6	2.6	2.5	1.7
50	2.5	2.6	2.5	2.6
60	3.6	2.6	2.5	3.7
70	5.0	2.8	2.5	5.3

HW = H + TW - S

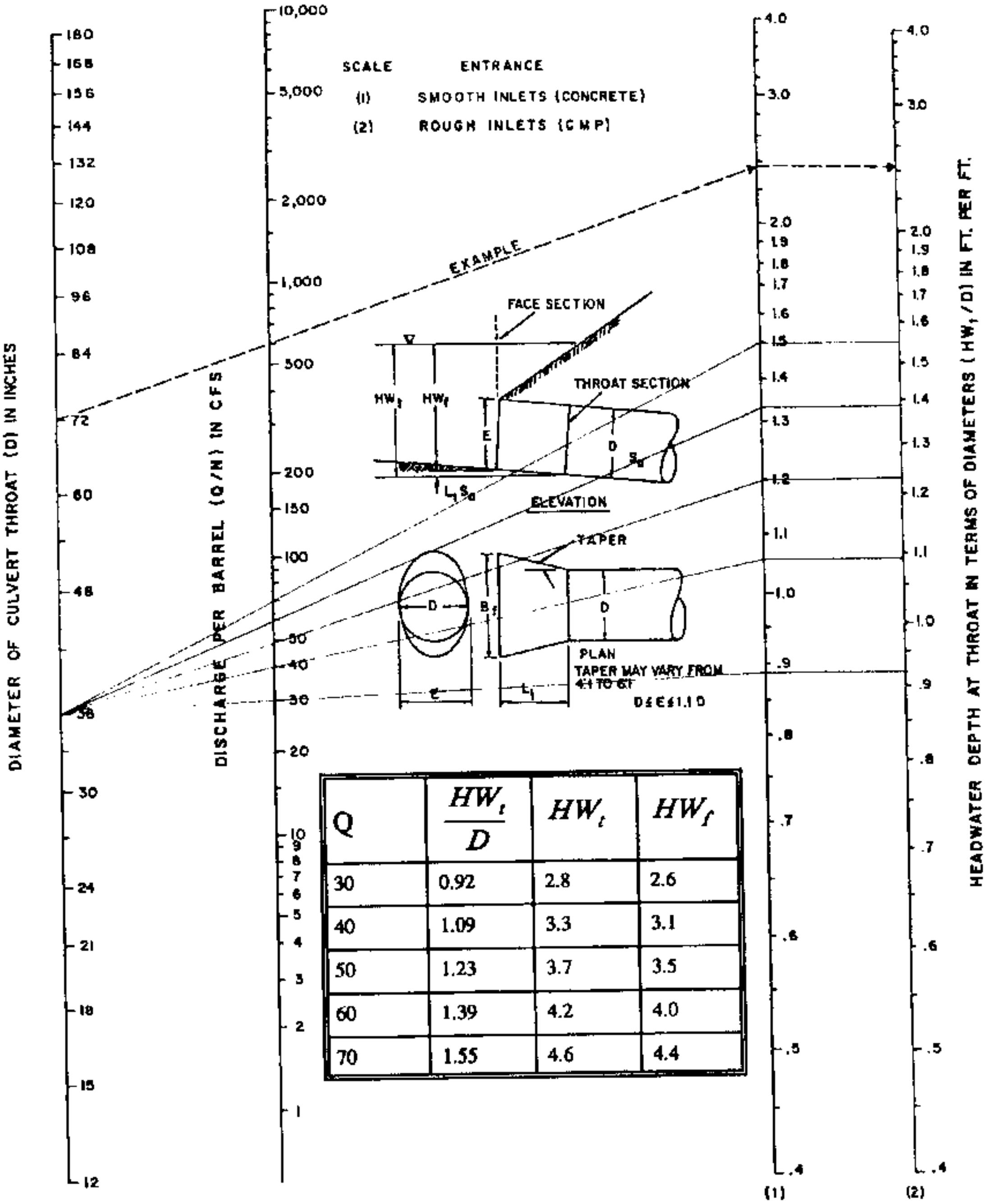
$S = L_o * S_o$

$TW = (D_c - D)/2$

36" CMP

Figure 9.—Head for standard CMP culverts flowing full: n = 0.024—36-inch CMP

CHART 55

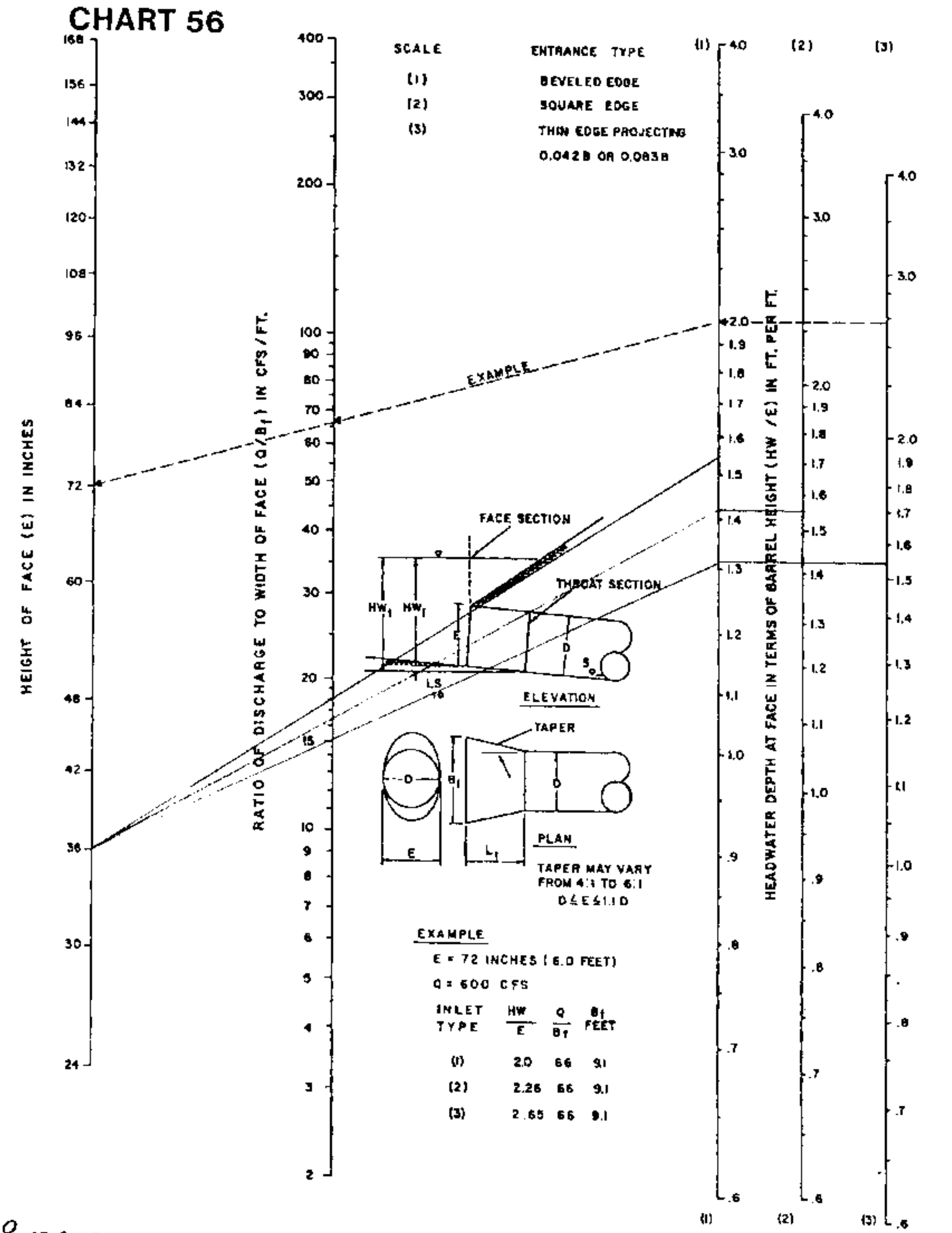


Q	$\frac{HW_t}{D}$	HW_t	HW_f
30	0.92	2.8	2.6
40	1.09	3.3	3.1
50	1.23	3.7	3.5
60	1.39	4.2	4.0
70	1.55	4.6	4.4

THROAT CONTROL
FOR SIDE-TAPERED INLETS TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

36" CMP

Figure 10.—Throat control for side-tapered inlets to pipe culvert (circular section only)—36-inch CMP



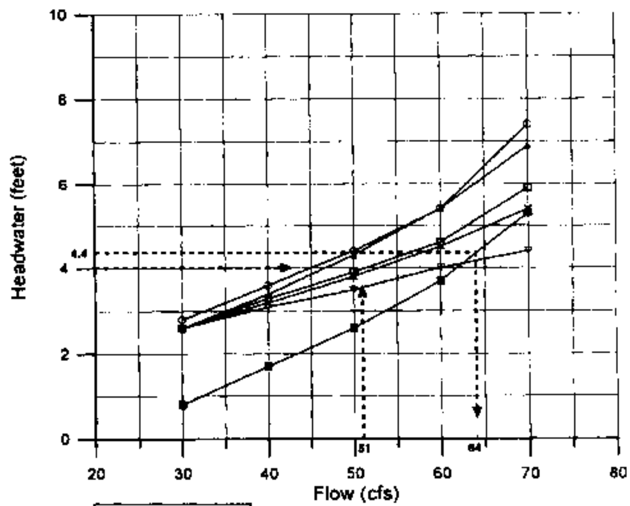
$\frac{Q}{B_f}$=18 for Q = 70 cfs

$B_f \geq 3.9' \geq 47''$

36" CMP

Figure 11.—Face control for side-tapered inlets to pipe culverts (non-rectangular sections only)—36-inch CMP

Performance Curves
36" CMP



Example:

There is an existing 36-inch CMP at 5 percent slope. Available headwater depth = 4 foot. Determine the type of inlet improvement needed to handle the Q_{100} = 51 cfs.

Determine the capacity of the culvert having an available headwater depth of 4.4 feet.

Figure 12.—Performance curves—36-inch CMP

Performance Curves
18" CMP

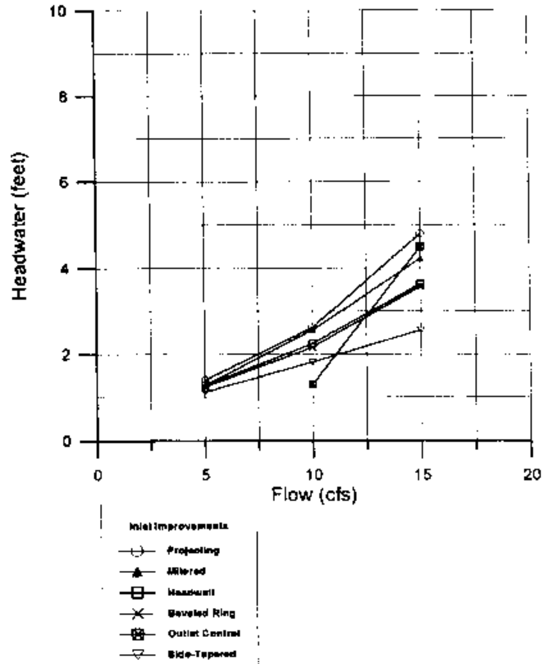


Figure 13.—Performance curves—18-inch CMP

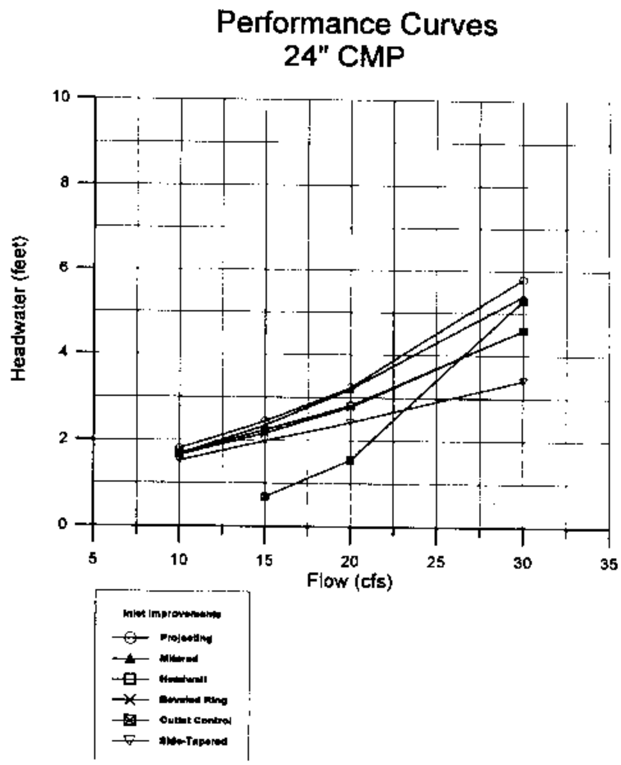


Figure 14.—Performance curves—24-inch CMP

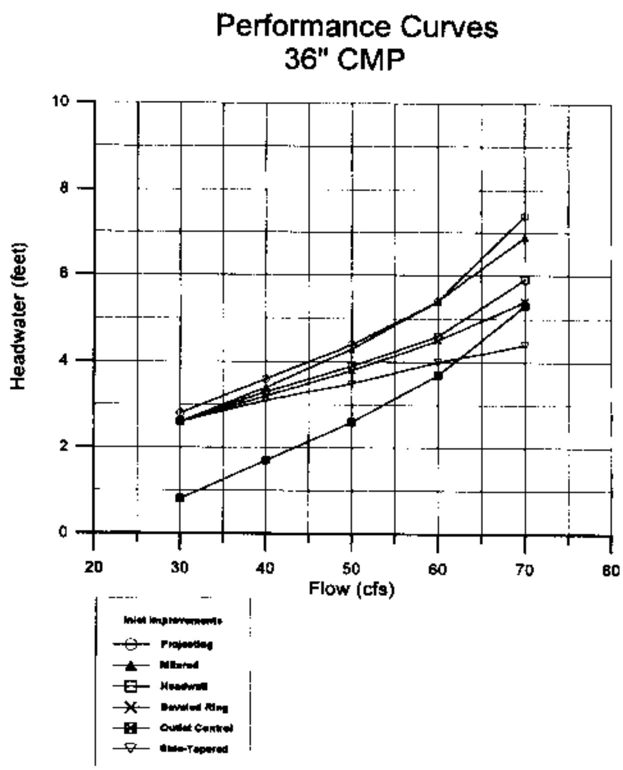


Figure 15.—Performance curves—36-inch CMP

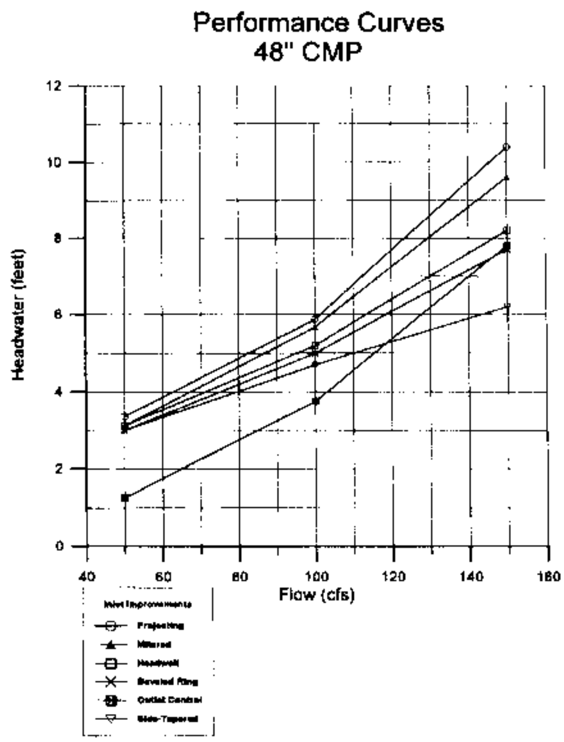


Figure 16.—Performance curves—48-inch CMP

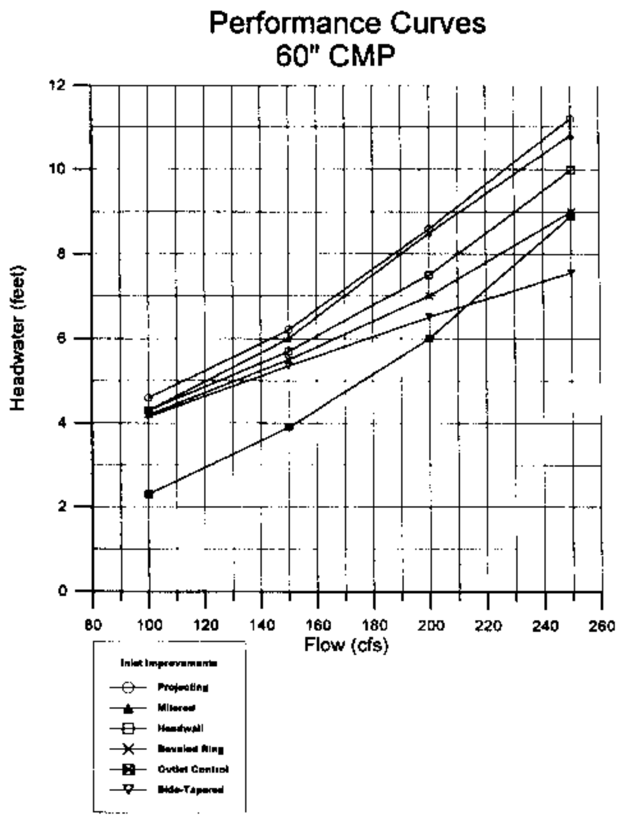


Figure 17.—Performance curves—60-inch CMP

Stabilization With Standard and Nonstandard Stabilizers: Road Operations and Maintenance Workshop (Colorado Springs, May 1995)

Pete Bolander
Regional Pavement Engineer
Region 6, RO

Forward

This article compiles the presentation handouts I gave to the attendees at the Rocky Mountain Regions Road Operation and Maintenance Workshop in May 1995 for my presentation on road stabilization. Though the handouts are neither complete nor in narrative format, hopefully this information will give an overview of the various products and methods for the stabilization of unpaved roads or even trail surfaces. Figures 1 through 6 were not a part of the presentation, but were added to this article to provide the reader with an idea of various stabilization construction practices.

Questions concerning this article or requests for Data General (DG) copies of it can be directed to Peter Bolander at 503-326-3249 or via the DG at R06C.

Objective

This report gives an overview of various traditional and nontraditional stabilization products for native and unpaved road surfaces. The overview includes information on matching the stabilization method to the material type, helpful hints for construction and maintenance, and potential environmental concerns about various stabilization products.

Introduction

Stabilization has the advantages of:

- reducing dust,
- improving material strength,
- reducing aggregate or pavement thickness,
- conserving aggregate materials,
- reducing costs, and
- providing temporary or permanent wearing surfaces.

Definitions

- Stabilization—Any treatment that makes the material more stable (increased strength, increased stiffness, decreased permeability, decreased swelling, decreased frost susceptibility, increased material durability, and decreased sensitivity to moisture). Treatments typically include the addition of a stabilizing agent followed by compaction.

- Stabilizing agents—Includes either cementing agents, modifiers, or waterproofing agents.

- Cementing agents—Includes Portland cement, lime, asphalt cement, lime-fly ash, lignin, and possibly synthetic polymer emulsions and tree resin emulsions. These agents bind/glue the material particles together temporarily or permanently.

- Modifiers—Improve the engineering characteristics of the material by methods other than physically "cementing" the particles together. These methods and materials include compaction, mechanically blending, Portland cement, lime, asphalt cement, chlorides, polypropylene fibers, enzymes, and some other chemical products.

Matching the Stabilization Product/Method to the Material Type

When selecting a stabilization treatment, consider:

- What is the desired condition (objective) and does the treatment help achieve that condition for the required service life? (Warning: some products have a longer life than others, and some may not function as a wearing surface.)

- What are the risks (probability and consequences) of failure associated with the treatment?

- Are there contractors available to construct the treatment?

- Is the treatment cost-effective and is the funding available to complete the treatment?

- Is the treatment suitable for the expected construction and long-term climatic conditions? (Warning: some products fare well in wet or freeze/thaw conditions and some don't.)

This is the recommended evaluation procedure:

1. Define the situation.

2. Classify surface material and depth (gradation, hydrometer analysis, and Atterberg limits).

3. Choose feasible stabilization methods. (If needed, get help to "fine tune" the application percentages.)

4. Estimate the amount of additive.

5. Evaluate the costs to implement various alternative (life-cycle costs).

6. Select the most economical and practical alternative.

7. Perform moisture density, strength, or other necessary tests to validate the estimate of additive.

8. Select the amount of additive for construction, and check construction costs.

9. If personnel have limited experience with additives, perform a field test (1/4 mile ideal); strongly recommend constructing a control (do nothing/just compact) section.

Traditional Products and Methods

See tables at the end of this article. Table 1 provides a generic guide in matching soil type to the most common stabilization methods. Table 2 lists suppliers of various stabilization additives in the Northwest. Tables 3 through 10 are additional guides one can use to match soil type to the correct stabilization method.

Nontraditional Products and Methods

See Table 7. It is common that chemical stabilizers (electrolytes and enzymes) require a minimum plasticity index (PI) of 17 or a minimum of 5 percent smaller than 0.002 millimeters. It is also common that tree resin and synthetic polymer emulsions can be used with a range of materials.

Specific Products and Methods

Compaction

Compaction increases the strength and decreases the moisture sensitivity of the material. This results in decreased surface deformations on native-surfaced roads and/or decreased aggregate requirements due to more particle-to-particle contact.

- Construction hints: Ensure the correct equipment is being used for the type of material being compacted and that the in-place moisture is suitable for compaction (optimum moisture content by American Association of State Highway Officials (AASHTO) T-99).
  - Sheepsfoot: Fine-grained soils.
  - Tamping foot: All materials except clean sands and clean gravels.

- Vibratory: Gravels (heavyweight and low-frequency), sandy material (lightweight and high-frequency), clayey material (heavyweight and low-frequency).

- Maintenance hints: After a native surface or aggregate surface is bladed, compaction at the optimum moisture will improve the road's performance.

- Other:
  - Environmental: No environmental concerns.
  - Relative costs: Low in that compaction is required for all stabilization methods and all that is needed is the proper compaction equipment and possibly additional moisture.

- References:
  - Hyster: *Compaction Handbook*, sixth edition, 1986.
  - Ingersoll-Rand: *Compaction Data Handbook*, 1984.
  - *Roads and Street* articles, June, July, and August 1970:
    "Compaction: The Art Advances But Misconceptions Linger"
    "Simplified Field Testing for Earth Compaction Control"
    "Equipment Selection for Soil Compaction"
  - "Factors That Influence Field Compaction of Soils," Highway Research Board, Bulletin 272, 1960.
  - "The Compaction of Soil and Rock Materials for Highway Purposes," Federal Highway Administration (FHWA), Report No. FHWA-RD-73-8, August 1966.

Blending

Blending includes adding filler or fine material (minus No. 200) to produce a well-graded material with or without PI. This modifies the material and results in increased strength and density.

- Designing application amount: Filler: use blending charts or equations; fines: typical to add 1 to 2 percent by dry weight of clay binder.

- Construction hints: The material should be blended dry to moist. If the material is blade-mixed, one needs at least 10 passes of the blade to get complete mixing.

- Maintenance hints: One can blade the surface. Some surfaces that were blended using clay binder may need to be ripped first with rippers or with carbide teeth mounted beneath the blade; recommend blading when the surface is moist.

- Other
  - Environmental: None.
  - Relative costs: Fine material (stabilite, central Oregon bentonite) costs between $80 to $100 per ton, and adds about another $1 to $2 per ton to the aggregate costs.

Asphalt

Asphalt binds material particles together and darkens the treated material.

- Designing application amount: See Asphalt Institute MS-19 reference. Asphalt is typically 3 to 6 percent by weight. It is different than a hot or cold mix asphalt cement in that there are more voids in the mix.

- Construction hints: See Asphalt Institute MS-19 reference.

- Maintenance hints: Typically surfaced with a bituminous surface treatment (BST) or hot/cold mix asphalt concrete to prevent moisture infiltration to the underlying layers.

- Other:
  - Environmental: Not researched.
  - Relative costs: $125 to $200 per ton.
  - Lime/asphalt and cement/asphalt: Commonly used on reconstruction projects of a cracked or deteriorated asphalt wearing surface where the surface and the underlying base course are mixed to create a new base course. It is typically 1/2 to 1 percent lime or cement, to anywhere between 4 to 7 percent asphalt emulsion (CSS-1 or CMS2-2s).

- References:
  - *A Basic Asphalt Emulsion Manual*, manual series no. 19 (MS-19), Asphalt Institute, second edition.

Portland Cement

Portland cement is like lime, but it has pozzolanic materials in the cement and it hardens relatively rapidly. It binds the material particles together. It is sometimes called cement-treated base (CTB) if aggregate is treated, or soil-cement if soil is treated. Note that this process is not like concrete in that all the voids are not filled with cement. Portland cement lightens the treated material.

- Designing application amount: See Portland Cement Association references. It is typically 5 to 10 percent by weight. The surface will not get shrinkage cracks if the unconfined strengths are keep less than 700 psi.

- Construction hints: It is typical to use type I or type II cement. Portland cement requires good compaction shortly after mixing, adequate but not excessive water, and proper curing. Water should be available to hydrate the cement, but remember that excess water weakens the final cement bond. Typically, one adds 1/4 percent extra water per each percent of cement added to the mix. One can use phenolphalein to determine the uniformity and depth of mixing. The surface must be kept moist during its cure (7 days minimum), either by periodic waterings or by sealing the surface, typically with a fog seal.

- Maintenance hints: Typically a BST or hot/cold mix asphalt concrete surface-placed. If it is not surfaced, do not try blading since the bond action will be destroyed (maybe your blade as well!). It is best to patch with similar material, using vertical pothole faces.

- Other:
  - Environmental: None known.
  - Relative costs: About $90 to $120 per ton.
  - Roller-compacted concrete (RCC): very similar to concrete in that the voids are all filled with cement (about 14 percent) with just a fog seal applied to seal the surface. This provides a decent running surface for low-speed traffic. Shrinkage cracks will develop every 40 to 60 feet.

- References: None known
  - Portland Cement Association handbooks/publications:
    - *Soil-Cement Laboratory Handbook.*
    - *Soil-Cement Construction Handbook.*
    - *Soil-Cement Inspectors Handbook.*
    - *Cement-Treated Aggregate Base.*

Lime

Lime is primarily used to treat fine-grained soils. Quicklime (CaO), dolomitic quicklime ($CaO + MgO$), hydrated high-calcium lime ($CA(OH)_2$), and monohydrated dolomitic lime ($Ca(OH)_2 + MgO$) are used. The lime combines with pozzolanic materials in the soil and water to flocculate and agglomerate (clump together) and modify the soil. With time, cementation slowly takes place if silica and alumina are present in the material. The quality of the lime is a function of the lime's purity and fineness.

- Designing application amount: This is a function of the desired strength, typically 2 to 6 percent. More is not necessarily better. See chapter 3 of *Lime Stabilization—Reactions, Properties, Design, and Construction* for some design aids.

- Construction hints: Quicklime can burn on moist skin, so be careful! You may need to "mellow" for a day or two when adding lime to a clay soil. To develop the cementing action, the lime needs warm temperatures to cure (7 days minimum, 28 days preferred). Due to its slow cure, the material can be worked for a period of time after placement. Higher strengths will develop if the soil is compacted. One can use phenolphalein to determine the uniformity and depth of mixing. Keep the material moist during the curing process.

- Maintenance hints: There are none, since a surface coat is typically applied. If a wearing surface is not used, periodic blading will remove surface deformations without harming the lime-soil interaction.

- Other:
  - Environmental: Lime and water create an alkaline environment in the soil matrix. This is not considered a concern, but can become one if bulk lime is accidentally dumped in water.
  - Relative costs: About $50 to $80 per ton.

- References:
  - *Lime Stabilization—Reactions, Properties, Design, and Construction*, State of the Art Report 5, Transportation Research Board (TRB), Washington, DC, 1987.
  - *Lime Stabilization Construction Manual*, National Lime Association, Bulletin 326, 1969.

Lime/Fly Ash

Fly ash is typically added with hydrated lime if natural pozzolan is not present in the soil. The quality of fly ash is a function of its fineness. It is also used as a filler when added to fine-grained material. Fly ash is the residue that results from the combustion of coal and is transported from the boilers by flue gases. It is not cementitious, but in finely divided form and in the presence of moisture it chemically reacts with the hydrated lime to form compounds that possess cementitious properties.

- Designing application amount: It is typical to have 2.5 to 4 percent lime and 10 to 15 percent fly ash, with the typical lime to fly ash ratio between 1:3 to 1:4. See the references for various different design methods.

- Construction hints: Fly ash requires good mixing, compaction shortly after mixing, adequate but not excessive water, and proper curing. You will need some extra water available for hydration of the lime and fly ash (1 to 3 percent). You can use phenolphalein to determine the uniformity and depth of mixing.

- Maintenance hints: None, since a surface coat is typically applied. If not applied, the surface will have a tendency to get slippery when wet.

- Other:
  - Environmental: Fly ash must be covered or kept moist to minimize dust.
  - Relative costs: $50 to $80 per ton.
  - Class "C" fly ash has some compounds similar to cement and works well with nonplastic materials.
  - Kiln dust is a byproduct of the cement manufacturing process.

- References:
  - *Lime-Fly ash-Stabilized Bases and Subbases*, NCHRP Report #37, TRB, Washington, DC, 1976.
  - "Non-Standard Stabilizers," FHWA Final Report, FHWA-FLP-92-011, July 1992.

Chlorides

You can use either calcium or magnesium chloride to modify the soil. Calcium chloride is commonly used for base stabilization. Chlorides typically improve compaction (act as a wetting agent) and help retain moisture (lower the vapor pressure, thus giving up water slower). It is recommended with 10 percent or more passing the No. 200 sieve and that the fines have some clay-like properties. Chlorides come in liquid, flake, or pellet form, and darken the treated material.

- Designing application amount: It is typical to use between 6 to 10 pounds of solids per ton of aggregate if CaCl flakes (typically 77 percent pure) are used (equates to 1.6 to 2.6 gallons per ton of aggregate if 38 percent solids are CaCl, assuming 10 pounds per gallon for CaCl; that's about 1/2 gallon per square yard if treating a 4-inch depth). When a liquid chloride is used, some folks apply a .2-gallon-per-square-yard "seal" application after compaction.

- Construction hints: This may have to be applied in a series of passes to prevent runoff. It is best to apply chlorides when the material is damp. It is recommended to compact close to optimum moisture to gain the maximum benefit from the stabilization product. Chlorides will dry out leather boots and gloves.

- Maintenance hints: Chlorides can be bladed dry, but it is best if they are bladed when some moisture is present. Chlorides will slowly leach with time.

- Other:
  - Environmental: May impact vegetation for 5 to 10 feet on either side of the roadway. Acceptable LC50 test results.
  - Relative costs: Liquid (FOB) is typically $0.50 to $1.25 per gallon; flakes (FOB) are typically $0.50 to $1.30 per pound, both a function of the purchased amount and the supplier.

Lignins

Lignins are a byproduct of the wood-pulping process. It physically binds material particles together and darkens the treated material.

- Designing application amount: Typically mixed one part lignin to one part water and applied in three applications. The total diluted application rate is close to 2 gallons per square yard when treating 4 to 6 inches of material.

- Construction hints: On existing roads, the material is bermed to the side and .6 gallons per square yard (diluted) are applied; the berm material is incorporated onto the road and 1 gallon per square yard is applied, the material is then blade-mixed and compacted. Four-tenths of a gallon per square yard is applied as a top dressing.

- Maintenance hints: It is common that a hard crust forms, so blade when the road surface is moist. Lignin is water soluble.

- Other:
  - Environmental: Acceptable LC50 test results.
  - Relative costs: FOB undiluted is $0.30 to $0.80 per gallon, a function of the amount purchased and the supplier.

Electrolytes and Enzymes

- Designing application amount: most need some clay particles (less than 2 microns) to work in the material. See the recommendation in "Nonstandard Stabilizers" as well as considering some trials in the laboratory. No real change in the color of the treated material.

- Construction hints: See "Non-Standard Stabilizers." If wet weather and traffic occur at the same time, the electrolytes should have a wearing surface applied.

- Maintenance hints: Typically the stabilized surface can be reworked.

- Other:
  - Environmental: The concentrates may pose some concern; once they are diluted with water they are considered okay.
  - Relative costs: Low since there is such a high dilution ratio with water.

- References:
  - "Non-Standard Stabilizers," FHWA Final Report, FHWA-FLP-92-011, July 1992.

Tree Resin Emulsions

Tree resin emulsions are organic resinous tree pitch that binds the material particles together once it has cured, and typically darkens the treated material.

- Designing application amount: Typically 1 to 3 percent residual is used to modify the material, and 4 to 7 percent is used to satisfactorily bind the material. Suppliers recommend about 1/3 gallon per square yard of diluted mix. It is typical to dilute one part concentrate to four parts water. Note that each manufacturer has a different percentage of solids in their concentrate, that the source of the tree resin may make a difference, and that some manufacturers may add other ingredients to the concentrate.

- Construction hints: Tree resin emulsions can be applied in concentrated or diluted form. They might have a tendency to plug spray nozzle or pumps. They need to be compacted at the correct moisture content, but should not be compacted until there is a reduction in the water content, occurring either naturally or by mechanical aeration.

- Maintenance hints: Once bladed, the bond is permanently broken; some "sweetening" with additional material may rejuvenate the material.

- Other:
  - Environmental: Not researched.
  - Relative costs: $1 to $4 per gallon (FOB), a function of the amount purchased and the supplier.

Latex Acrylic Polymer Emulsions

Latex acrylic polymer emulsions are synthetic polymer emulsions that bind the material particles together once they cure. Some products are more water soluble than others, which will effect their long-term durability. They do not change the color of the treated material.

- Designing application amount: The amount of "solids" remaining after curing determines the strength of the bond. It is typical to apply the diluted product 1/4 to 1 gallon per square yard and typical to dilute part of the concentrate to anywhere from 9 to 25 parts water. Each manufacturer has a different dilution ratio recommendation and percent solids of their concentrate.

- Construction hints: Construction equipment needs to be cleaned very soon after application so that the emulsion does not cure on the equipment or in the hoses and pumps. The emulsion needs to be compacted at the correct moisture content, but should not be compacted until there is a reduction in the water content that occurs either naturally or by mechanical aeration.

- Maintenance hints: Once bladed, the bond is permanently broken and cannot be rejuvenated.

- Other
  - Environmental: Not researched.
  - Relative costs: Concentrate (FOB) costs about $3 to $9 per gallon, a function of the amount purchased and the supplier.

Nonorganic Fibers

Nonorganic fibers are 1- to 1.5-inch long discrete fibrillated polypropylene strands that are mixed or blended into the material. During the mixing, the fibers are opened and mechanically help to reinforce the material. They come in dark green or black, and have been used to stabilize grass playing fields and in soil-cement-treated materials.

- Designing application amount: They are typically .1 to .5 percent by weight.

- Construction hints: Nonorganic fibers need to be vigorously mixed to get the strands opened, therefore we recommend using a pulvamixer or a rotory mixer.

- Maintenance hints: None.

- Other:
  - Environmental: None.
  - Relative costs: Not researched.

Other

Some potential options include:
- Metal mats.
- Wood chips or chunkwood.
- Geowebs.
- Geotextiles.
- Stabilizers.
- Sealing/waterproofing the surface.

References

Gusey, "Trail Hardening," *Engineering Field Notes*, volume 23, May–June 1991.

Monlux, "Barrier-Free Accessible Trail Surface Materials—Northern Region Materials Engineering Investigation," *Engineering Field Notes*, volume 26, September–October 1993.

Monlux, "Dust Abatement Product Comparisons in the Northern Region," *Engineering Field Notes*, volume 26, May–June 1993.

Northwest Technology Transfer Center, "Operating Tips—Road Dust Suppressants," Winter 1986.

Scholen, "Coordinated Technology Implementation Program (CTIP) Study No. F-5; Nonstandard Stabilization," *Engineering Field Notes*, volume 26, May–June 1993.

Scholen, "Non-Standard Stabilizers," FHWA Report No. FHWA FLD-92-011, July 1992.

Scholen, "Surfacing Trails with Non-Standard Stabilizers," *Engineering Field Notes*, volume 26, November–December 1993.

Terrel, Epps, Barenberg, Mitchell, and Thompson, *Soil Stabilization in Pavement Structures—A Users' Manual*, volumes 1 and 2, FHWA P-80-2, 1979.

Transportation Research Board, "Compendium 12—Surface Treatment," 1980.

USDA Forest Service, Region 6, "A Guide to Liquid Spray Applications for Erosion Control, Dust Abatement, and Tackifiers," draft, January 1995.

USDA Forest Service, Region 6, *Selection and Maintenance Guide for Surface Treatments, Pavements, and Stabilized Surfaces*, EM 7700-30, July 1994. Really should be the *Design, Construction, and Maintenance Guide.*

Table 1.—Most effective stabilization methods for use with different soil types

Soil Type	Most Effective Stabilization Method
Coarse granular soils	Mechanical blending, soil-asphalt, soil-cement, lime-flyash
Fine granular soils	Mechanical blending, Portland cement stabilization, lime-flyash, soil-asphalt, chlorides
Clays of low plasticity	Compaction, Portland cement stabilization, chemical waterproofers, lime modification
Clays of high plasticity	Lime stabilization

Source: *Soil Stabilization in Pavement Structures, A Users' Manual—Volume 2, Mixture Design Considerations*, p. 11

Table 2.—Suppliers

Stabilizing Materials	Supplier(s)
Lime	Continental Lime, 604-278-4611
Clay Additives	
Central Oregon Bentonite	Prineville, OR, 503-477-3351
Stabilite	Soil Stabilization, 209-383-3296
Fuller Earth	???
Pelbon, Cote-N-Flo	American Colloid, 708-392-4600, ext. 161
Enzymes/Electrolytes	
EMC^2	Soil Stabilization, 209-383-3296
Condor SS	Earth Sciences Products Corp., 503-697-3815
Perma-Zyme	National Perma-Zyme, 800-648-0313
Con-Aid	Nilex Corporation, 303-766-2000
Latex Acrylic Polymers	
Soil Sement	Midwest Industrial Supply, 800-321-0699
Soil Master WR	Environmental Soil System Inc., 800-368-4115
Dust/Base Seal	Base Seal International, 817-526-5550
Aerospray 70A	Cytec Industries, 800-835-9844
Marloc	Reclamare Company, 206-824-2385
Soil Seal	Soil Stabilization, 209-383-3296
Tree Resin Emulsions	
Dust Control E	Lyman Dust Control, 800-952-6457 Pacific Chemical Inc., 604-828-0218
Road Oyl	Soil Stabilization, 209-383-3296
Chlorides	
MgCl	Pelletox, 800-452-0736
DustGard	Pacific Chemical Inc., 604-828-0218
DustOff	Cargill Salt Division, 360-573-6757
Lignin	
Dustac	Georgia Pacific, 206-572-8181
Other	
Synthetic Fibers (TurfGrids) & Stabilizer	Stabilizer, 800-336-2468
Synthetic Fibers (FiberGrids)	Synthetic Industries, 800-252-2167

Table 3.—Summary of various modifiers and stabilizers (from a presentation given to OSU in 1992)

Method	Typical Materials That Work Okay	Comments	Typical Application Rate (% dry wt)	$/SY (material only for 4" depth)
Asphalt	clean aggregate SE > 30, PI < 6 No. 200 < 10	proper cure weather, needs surfacing, cement or lime added	2–4%	1.60 (4% @ $200/ton)
Cement	dirty aggregate sands, silts PI < 30	1 week cure, needs surfacing, UCS: 200 to 1,000 psi	4–12%	1.20 (6% @ $100/ton)
Roller-compacted concrete (RCC)	graded aggregate	limited experience, no surfacing needed	12% +	2.40 (12% @ $100/ton)
Lime/fly ash	dirty aggregate fine-grained soils	1 to 2 week cure, UCS: 500 to 1,000 psi	2–4% lime 10–15% fly ash	—
Cement/fly ash	dirty aggregate	limited experience, class "C" fly ash, UCS: 200 to 1,000 psi	4–10% total	1.25 (8% class "C" @ $80/ton
Lime	dirty aggregate fine-graded soil PI > 12, No. 200 > 30 clay content > 10	2 week + cure, UCS: 50 to 150 psi needs surfacing	3–5%	0.50 (5% @ $60/ton)
Clay Additives -Stabilite & -COB	clean aggregate No. 200 < 8% PI < 5	rain may leach add., no surfacing needed,	2–3%	0.75 (3% @ $100/ton)
Enzymes - BioCat 300 - EMC Squared	dirty aggregate PI > 6 clay content > 5	limited experience no surfacing needed	 1 gal/240 cf 1 gal/324 cf	—
Resin Emul. - Road Oyl - Soil Sement	all aggregate	limited experience	 1–3% residual 1 gal/60 sf	 3.50 (1% @ $5/Gal)
Condor SS	fine-grained soil PI > 6, No. 200 > 20	sprayed or injected	1/4 gal for 100 gal	—
Lignon or Chlorides	dirty aggregate	rain will leach add.	1 gal/sy	1.00 ($1/Gal)
Gradation Modification - Grading T - Blending	all aggregate	 fines need to be dry	 — —	 +$.50/CY —

Note: "Clay content" material < .2 microns

Table 4.—Summary of recommended stabilization type and recommended amount of admixture

Method	Addition Weight, %	Soil Type: Coarse Granular	Fine Granular	Low Plastic Clay	High Plastic Clay	Special Advantage	Climatic Limitations	Construction Safety Precautions
Cement	3–5	A				strength increases in short time	no frozen soils, air temp 40 °F and rising, need 1 week before freeze	cement; no contact with wet skin for very long; safety glasses and protective clothing worn
	5–9		A					
	9–12			A				
	10–16				B			
Lime	–	N/A	N/A			rapid clay plasticity decrease	no frozen soils, air temp 40 °F and rising, need 4 weeks before freeze	quicklime; no contact with wet skin at all; safety glasses and protective clothing worn
	2–6			A				
	2–8				A			
Lime & fly ash	3–5% lime 10–20% fly ash	A	A			same as lime	same as lime	same as lime
	5–9% lime 10–25% fly ash			B				
	–				N/A			
Asphalt	3–6	A	A			–	hot, dry weather preferred for all asphalt stabilization	hot mix asphalt may be as high as 350 °F, some cutbacks have flash points below 100 °F
	5–9			B				
	–				N/A			

Key: A = very suitable, B = adaptable, N/A = not applicable

Sources: Combination of *Soil Stabilization in Pavement Structures, A Users' Manual—Volume 2, Mixture Design Considerations*, p. 26; and *Evaluation of Alternate Systems For Surfacing Forest Roads—Final Report*, p. 47

Table 5.—Product selection chart

Product	Traffic Volumes[7] Average Daily Traffic			Subgrade Type[2]			Surface Material Fines Content Passing No. 200 Sieve					Climate[8]			Environmental Impacts[5]
	Light <100	Medium 100-250	Heavy >250	Clay	Silt	Granular	<5%	5–10%	10-20%	20-30%	>30%	Rainy	Normal	Dry Spells	
Calcium	A	A	B	A	B	C	C	B	A	B	C[3]	C[1,3]	A	C	B
Magnesium Chloride	A	A	B	A	B	C	C	B	A	B	C[3]	C[1,3]	A	B	B
Ligno-sulfonates	A	B	C[6]	A	B	C	C	B	A	A	B[3]	B[1]	A	A	B
Petroleum Products	B	C	C[6]	B	B	B	C	B	B	C[4]	C[4]	C[3]	B	B	B

Dust Palliative Performance: A = Good, B = Fair, C = Poor

Notes:

[1] May leach out in heavy rain.

[2] Subgrade will mix with surface material and impact the quality of fines.

[3] May become slippery in wet weather.

[4] Difficult to coat all particles and prevent "dust pockets."

[5] All products listed may have an adverse environmental impact if used improperly.

[6] Hard surface crust promotes potholes and breakup under heavy traffic.

[7] Heavy traffic may require higher or more frequent application rates, especially with high truck volumes.

[8] Dry spells are periods of 20 days or more with less than 40 percent relative humidity.

Source: *Guidelines for Cost Effective Use and Application of Dust Palliatives*, by Roads & Transportation Association of Canada, p. 12; 1987.

Table 6.—Soil types and stabilization methods which appear best suited for specific applications

Purpose	Soil Type	Recommended Stabilization Methods
1. Subgrade Stabilization		
A. Improved load-carrying and stress-distributing characteristics	coarse granular	SA, SC, MB, C
	fine granular	SA, SC, MB, C
	clays of low PI	C, SC, CMS, LMS, SL
	clays of high PI	SL, LMS
B. Reduce frost susceptibility	fine granular	CMS, SA, SC, LF
	clays of low PI	CMS, SC, SL, CW, LMS
C. Waterproofing and improved runoff	clays of low PI	CMS, SA, CW, LMS, SL
D. Control of shrinkage and swell	clays of low PI	CMS, SC, CW, C, LMS, SL
	clays of high PI	SL
E. Reduce resiliency	clays of high PI	SL, LMS
	elastic silts and clays	SC, CMS
2. Base course stabilization		
A. Improvement of substandard materials	fine granular	SC, SA, LF, MB
	clays of low PI	SC, SL
B. Improved load-carrying and stress-distributing characteristics	coarse granular	SA, SC, MB, LF
	fine granular	SC, SA, LF, MB
C. Reduction of pumping	fine granular	SC, SA, LF, MB, membranes
3. Shoulders (unsurfaced)		
A. Improved load-carrying ability	all soils	See section 1A above; also MB
B. Improved durability	all soils	See section 1A above
C. Waterproofing and improved runoff	plastic soils	CMS, SL, CW, LMS
D. Control of shrinkage and swell	plastic soils	See section 1E above
4. Dust palliative	fine granular	CMS, CL, SA, oil, or bituminous surface spray
	plastic soils	CL, CMS, SL, LMS
5. Ditch lining	fine granular	PSC, CS, SA
	plastic soils	PCS, CS
6. Patching and reconstruction	granular soils	SC, SA, LF, MB

KEY

C	Compaction	CW	Chemical Waterproofers	PSC	Plastic Soil Cement
CMS	Cement Modified Soil	LF	Lime Flyash	SA	Soil Asphalt
CL	Chlorides	LMS	Lime Modified Soil	SC	Soil Cement
CS	Chemical Solidifiers	MB	Mechanical Blending	SL	Soil Lime

Source: *Soil Stabilization in Pavement Structures, A Users' Manual–Volume 2 Mixture Design Consideration*, p. 12

Table 7.—Recommended treatments for stabilization of in-place material

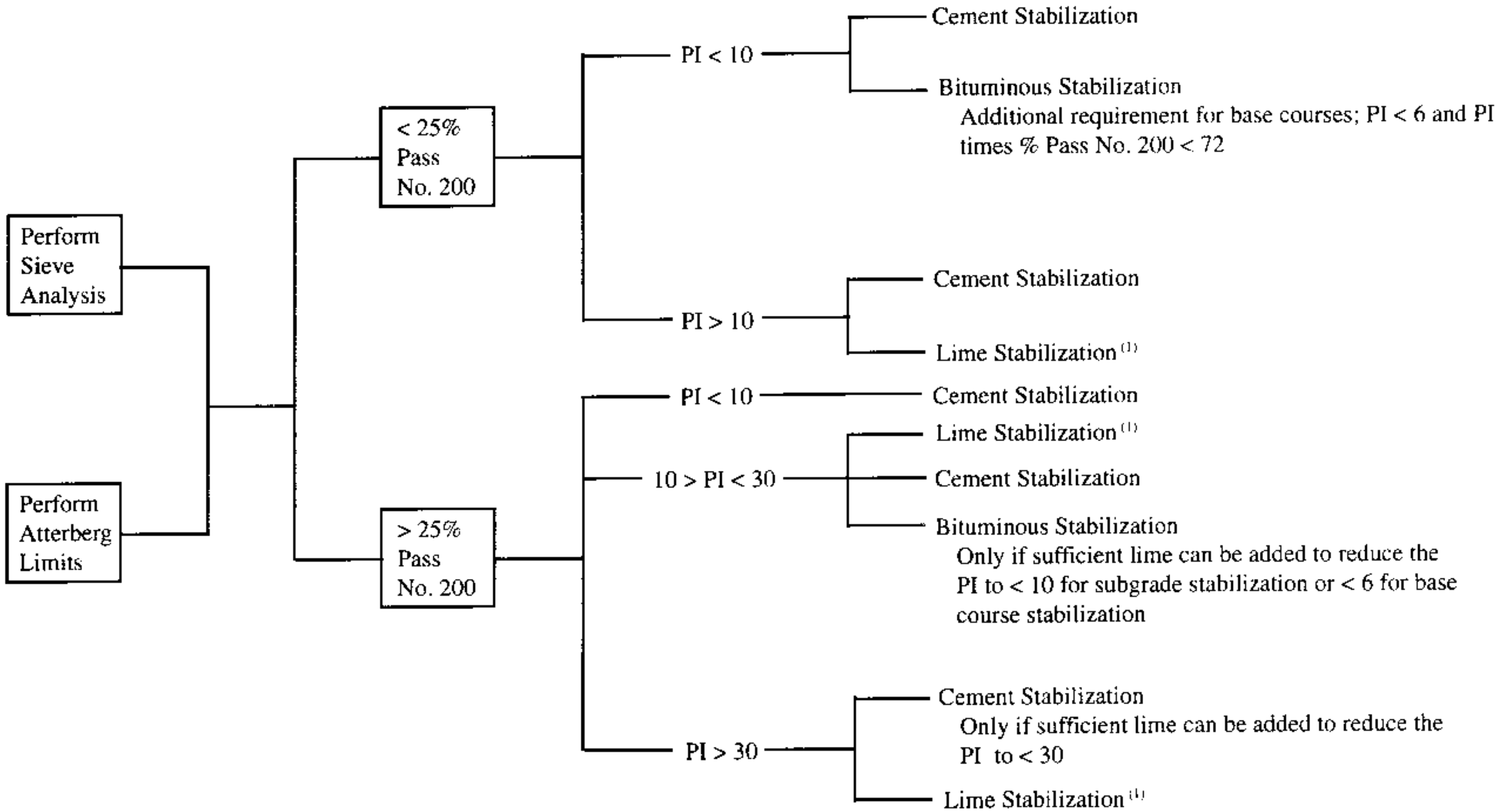
In-Place Material	Compact (N/A)	Asphalt (2–6)	Cement (4–12)	RCC (12+)	Lime (3–5)	Lime/ Fly Ash (2–4/10–15)	Cement/ Fly Ash (4–10)	Clay Additive (2–3)	Enxymes & Electrolytes	Resin & Polymer Emulsion (spray/mix)	Gradation Blending
	(Note 1)	(Note 2)	(Note 3)	(Note 4)	(Note 5)	(Note 6)	(Note 7)	(Note 8)	(Note 9)	(Note 10)	(Note 11)
Clean Aggregate		XX						XX		XX	XX
Dirty Aggregate	XX		XX	XX		XX	XX		XX	XX	
Well-Graded Aggregate	XX	Note 12	XX				XX	Note 12	Nore 12	XX	
Clean Sand		XX									XX
Dirty Sand	XX		XX	XX		XX	XX		Note 12	Note 12	
Granular Soils	XX			XX				Note 12			
Silt Soils	XX		XX				XX				
Clay Soils	XX				XX	XX			Note 12		

Important!!—For all treatments, one needs to ensure that (1) the appropriate application rates determined by laboratory analysis or by the manufacturer are applied in the field at the appropriate curing conditions; (2) complete mixing of the additive for the desired depth occurs during construction; and (3) compaction occurs at the correct moisture. A materials engineer would be able to assist in the correct treatment and application percentage for each of the above.

Note 1—need appropriate moisture and compaction equipment; increasing compaction effort increases stabilization potential
Note 2—typically emulsions are used; to stabilize against freeze/thaw cycles, one needs to perform laboratory tests
Note 3—to stabilize against wet/dry and freeze/thaw cycles, one needs to perform laboratory tests
Note 4—RCC; to stabilize against wet/dry and freeze/thaw cycles, one needs to perform laboratory tests
Note 5—appropriate application percentages need to be determined from laboratory tests; needs time to cure (3,000-degree days)
Note 6—appropriate application percentages need to be determined from laboratory tests; needs time to cure (3,000-degree days)
Note 7—appropriate application percentages need to be determined from laboratory tests; rates in table are based upon 50 percent cement, 50 percent flyash
Note 8—typically use either Central Oregon Bentonite (COB) or Stabilite (Soil Stabilization Inc.)
Note 9—appropriate application percentages need to be determined from laboratory tests; typical products are BIO-Cat 300 or EMC Squared, both from Soil Stabilization Inc.
Note 10—appropriate application percentages need to be determined from laboratory tests; typical products are Road Oyl (an emulsified mineral pitch by Soil Stabilization Inc.) or Soil Sement, Soil Master, Dust/Base Seal (emulsified acrylic co-polymers with various additives or concentrations); can be mixed or sprayed on the surface
Note 11—need laboratory tests to determine the appropriate material and quantities
Note 12—stabilization may be possible, depends on a sieve analysis and other characteristics of the in-place material
Note: Another product available but not addressed above: polymer strands or organic fibers mixed with soil to increase strength

Source: Pete Bolander

Table 8.—Selection of stabilizers flowchart



Editor's Addition 1): Additional lime requirement; the clay (particles < 2 microns) should be greater than 10 percent

Source: *Soil Stabilization in Pavement Structures, A Users' Manual—Volume 2, Mixture Design Consideration*, p.24

Table 9.—Aid in selecting a commercial stabilization unit

USCS Soil Classification	Stabilization Agent Recommended	Restriction on LL, PL, PI of soil	Restrictions on % Pass No. 200	Remarks
SW or SP	Bituminous Portland Cement	— —	— —	—
SW-SM, SP-SM, SM-SC, or SP-SC	Bituminous Portland Cement Lime	PI not to exceed 10 PI not to exceed 30 PI not less than 12	— — —	—
SM, SC, or SM-SC	Bituminous Portland Cement Lime	PI not to exceed 10 PI not to exceed ((50-P200)/4 + 20) PI not less than 12	Not to exceed 30%	—
GM or GP	Bituminous Portland Cement	— —	— —	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
GW-GM, GP-GM, GM-GC, or GP-GC	Bituminous Portland Cement	PI not to exceed 10 PI not to exceed 30	— —	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
	Lime	PI not less than 12	—	
GM-GC, or GM-GC	Bituminous Portland Cement	PI not to exceed 10 PI not to exceed ((50-P200)/4 + 20)	Not to exceed 30%	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
	Lime	PI not less than 12		
CH, CL, MH, ML, OH, OL, or ML-CL	Portland Cement Lime	LL less than 40 and PI less than 20 —	— —	Organic and strongly acid soils falling within this area are not susceptible of stabilization by ordinary means

Definitions: LL = liquid limit, PL = plastic limit, PI = plasticity index, P200 = % passing No. 200 sieve,
USCS = Unified Soil Classification System

Source: *Soil Stabilization in Pavement Structures, A Users' Manual—Volume 2, Mixture Design Considerations*, p. 13

Table 10.—Summary of soil stabilization methods for airfield pavements

1	3	5	6	7	8	9	10	11	23	24
					Relative Effect on Soil Types					
Type of Stabilization	Stabilization Method	Primary Mechanism of Stabilization	Usual Method Evaluation	Quantity of Additive Required by Weight	Coarse Granular	Fine Granular	Fine Grained Soils: Low Plasticity	Fine Grained Soils: High Plasticity	Limitations	Unique Advantages
Modification	Compaction	increase internal friction and particle-to-particle attraction through increased density and more favorable structure	density, water content, and strength tests		B	A-WG B-PG	A	B	ultimate change in properties small compared to that achieve by some stabilizers	low cost and ease of control
	Mechanical Blending of Soils	increase internal friction through better gradation	grain size analysis, compaction and bearing tests		A	A	N/A	N/A	sufficient modification of detrimental soil may be costly	can make unsuitable soil suitable
	Calcium Chloride	deliquescence of salt; lowering of freezing point; base exchange	density and moisture tests	1/4–1%	N/A	A	B		leaches with time	low cost
	Sodium Chloride	deliquescence of salt; lowering of freezing point; base exchange; increase density	density and moisture tests	1/4–1%	N/A	A	B		leaches with time	low cost
	Cement	base exchange; alteration of clay; hydration	Atterberg limits grain size, strength tests	1–4% 2–6%	N/A	N/A	A	B	cost may not be justified by modest property improvement	construction expedient; improve unsuitable soils
	Bitumens	coats soil grains or aggregates; retards moisture	water soaption compression, volume change	1–4%	B	A	B	B N/A	cost may not be justified by modest property improvement	helps maintain "as constructed" condition
	Organic Cationic Compounds	alters clay minerals to act as hydrophoria agent	water soaption compression, volume change	Trace (Less than 1%)	N?A	N?A	A	A	difficulty in obtaining uniform mixtures with trace amounts	helps maintain "as constructed" condition
	Lime	base exchange; alteration of clay; pozzolanic action	attendees limited grain size, strength tests	1–4% 2–6%	N/A	N/A	B	A	cost may not be justified by modest property improvement	construction expedient; improve unsuitable soils

Table 10.—Summary of soil stabilization methods for airfield pavements (cont'd.)

					Relative Effect on Soil Types					
1	3	5	6	7	8	9	10	11	23	24
Type of Stabilization	Stabilization Method	Primary Mechanism of Stabilization	Usual Method Evaluation	Quantity of Additive Required by Weight	Coarse Granular	Fine Granular	Fine Gained Soils: Low Plasticity	Fine Gained Soils: High Plasticity	Limitations	Unique Advantages
Cementing Agents	Cement	hydration of cement; pozzolanic action; alteration of clay minerals	durability and strength tests	3–8% 5–9% 9–12% 10–16%	A	A	A	B	organic soils, some fat clays, sands, and gravels of highly uniform grain size and acidic pozzolanic sands do not respond to treatment	develops high strength more rapidly than lime or lime flyash products
	Lime, hydrated and quick	flocculation; pozzolanic action of lime, silica, and alumina; alteration of clay minerals	durability and strength tests	2–6% 2–8%	N/A[1]	N/A[1]	A	A	gravel and sand soils with less than 25% finer than the #200 sieve do not respond to treatment; quicklime is caustic	construction expedient; quickly lowers elasticity of clay; moderate delay between mixing and compacting not critical
	Bituminous	coats and binds soil aggregates; retards moisture absorption	viscosity and strength tests	3–6% 5–9%	A	A	B	N/A	creeps under high temperature or sustained load; cutbacks and emulsions require warm temperature for curing	waterproofing effect
	Lime flyash	pozzolanic action of lime, silica, and alumina; alteration of clay minerals	durability and strength tests	3–5% lime 10–20% flyash 5–9% lime 10–25% flyash	A	A	B	N/A	develops strength slowly; requires warm temperatures (+50 °F) for long duration to cure sufficiently	cure can be interrupted and restarted without adverse effects; construction speed not essential

<u>Notes</u>

1 Not suitable unless granular material contains excess plastic fines

2. Unclassified and still primarily in research stage or limited to only local usage by cost factor includes:
   (a) phosphoric acid
   (b) calcium acrylate
   (c) sulphite lignin
   (d) amiline furfural
   (e) resins
   (f) molasses

<u>Code For Columns 8–11</u>

A—Most suitable soil type for given stabilization method—significant property improvement

B—Moderate property improvement

N/A—Not suitable for use with given soil

WG—Well-graded soils

PG—Poorly graded soils

Source: *Soil Testing Services, Inc.* 1963. Columns 2, 4, 12–22 removed by author.

Figure 1.—Application of class "C" fly ash to the City of Portland, Oregon, Springwater Trail, September 1992.

Figure 2.—Closeup of central Oregon bentonite and aggregate on belt prior to being mixed in pugmill, Deschutes National Forest, August 1988.

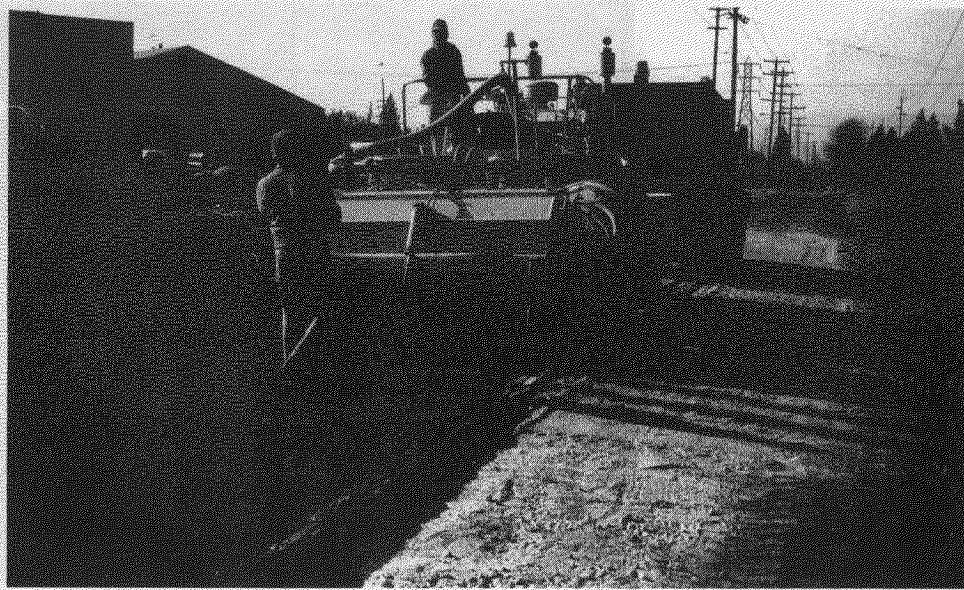


Figure 3.—Mixing of in-place aggregate and class "C" fly ash on the City of Portland, Oregon, Springwater Trail, September 1992. Note the water truck in front of the rotary mixer.

Figure 4.—Mixing and shaping in-place aggregate and Bio-Cat 300 on the Gifford Pinchot National Forest, August 1988.

Figure 5.—Compaction of a soil-cement mixture on the Wallowa-Whitman National Forest, using a pneumatic tire-roller, August 1966.

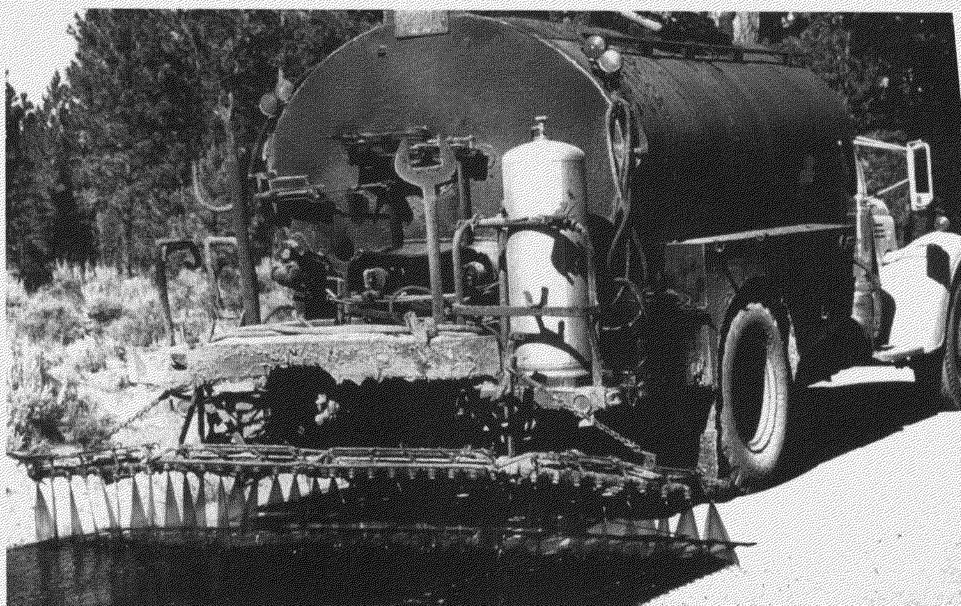


Figure 6.—Application of lignin sulfonate on a road surface treated with central Oregon bentonite, Deschutes National Forest, August 1988.

Ergonomics

> ***Editor's Note**: This article is being republished with the permission of the National Park Service. It was originally published in volume 39, number 1, of* GRIST.

Sitting can be dangerous to your health, especially if you spend hours at a keyboard. Carpal tunnel syndrome, once fairly rare, is now the cause of the second most frequently performed surgery. Related injuries include neck and lower back pain. Rick Morris, CC, DE, CCSP, gives the following tips for redesigning your environment to protect against injury—whether your desk-sitting happens at work or at home.

1. The top of your computer monitor should be at eye level directly in front of you.

2. The height of your chair should be adjusted until your feet are on the ground, your back is against the seat back, and your knees are level or slightly lower than your hips.

3. The table's height should be such that your arms are bent at a 90-degree angle and your hands rest flat on your keyboard without having to be extended or flexed.

4. The low back support must fit into the curve of your lower back. Do not have it so low as to push your buttocks forward, forcing your lumbar spine away from the supporting cushion.

5. Adjust the armrests so that with your arms bent at 90 degrees, your shoulders completely relax and drop, and your forearms rest comfortably on them.

6. Rest against your chair. Sit straight and allow yourself to tilt back whenever it feels comfortable.

7. Use a wrist cushion and avoid bending your wrists forward or backward or resting on a hard surface. Avoid wrist deviations either to the little finger or thumb side; instead, move your forearm.

8. Try to tap lightly on the keyboard. Don't take your aggressions out on the plastic; it will always win and you will go faster with a lighter touch.

9. If using a phone often, use a headset.

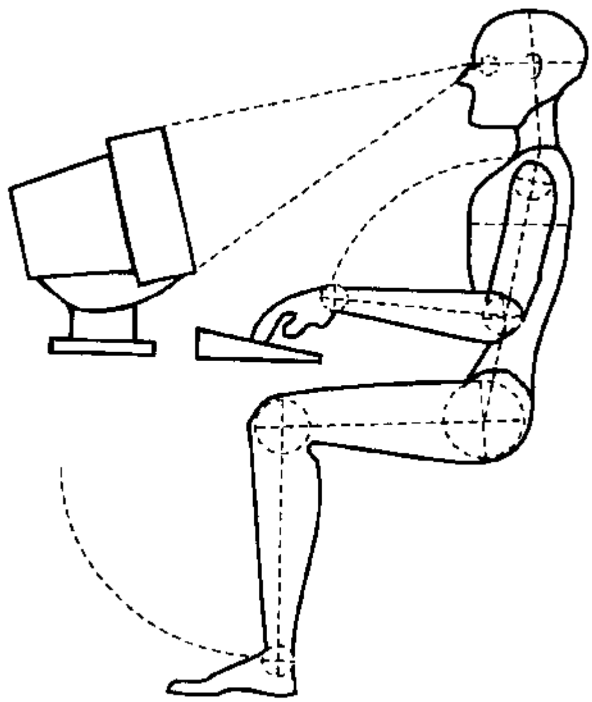
10. Take 5- to 10-minute breaks from keypunching hourly. During these breaks:

    - Do wrist and back stretches.

    - Focus your eyes on an object at least 20 feet away (you may want to do this several times each hour).

11. If there is significant reflection in your monitor, look for the source. Close the blind, lower the fluorescent lighting, and use table lamps that focus on your work and not your monitor.

12. When several monitors are used, put them as close together as possible. At the beginning of any discomfort related to your repetitive motion, seek help immediately. Injury prevention can save you a lot of pain—and money.



Engineering Field Notes

Administrative Distribution

The Series THE ENGINEERING FIELD NOTES is published periodically as a means of exchanging engineering-related ideas and information on activities, problems encountered and solutions developed, or other data that may be of value to Engineers Service-wide.

Submittals Field personnel should send material through their Regional Information Coordinator for review by the Regional Office to ensure inclusion of information that is accurate, timely, and of interest Service-wide.

Regional Information Coordinators

R-1 Clyde Weller	R-4 Ted Wood	R-9 Fred Hintsala
R-2 Lois Bachensky	R-5 Rich Farrington	R-10 Betsy Walatka
R-3 Bill Woodward	R-6 Carl Wofford	WO Bryon Foss
	R-8 Bob Bowers	

Inquiries Regional Information Coordinators should send material for publication and direct any questions, comments, or recommendations to the following address:

Forest Service—USDA
Engineering Staff— Washington Office
ATTN: Sonja Turner, Editor
201 14th Street SW
Washington, DC 20250

Telephone: (202) 205-1421