TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

SYNTHESIS 2

Stage Construction

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U.S.Agency for International Development

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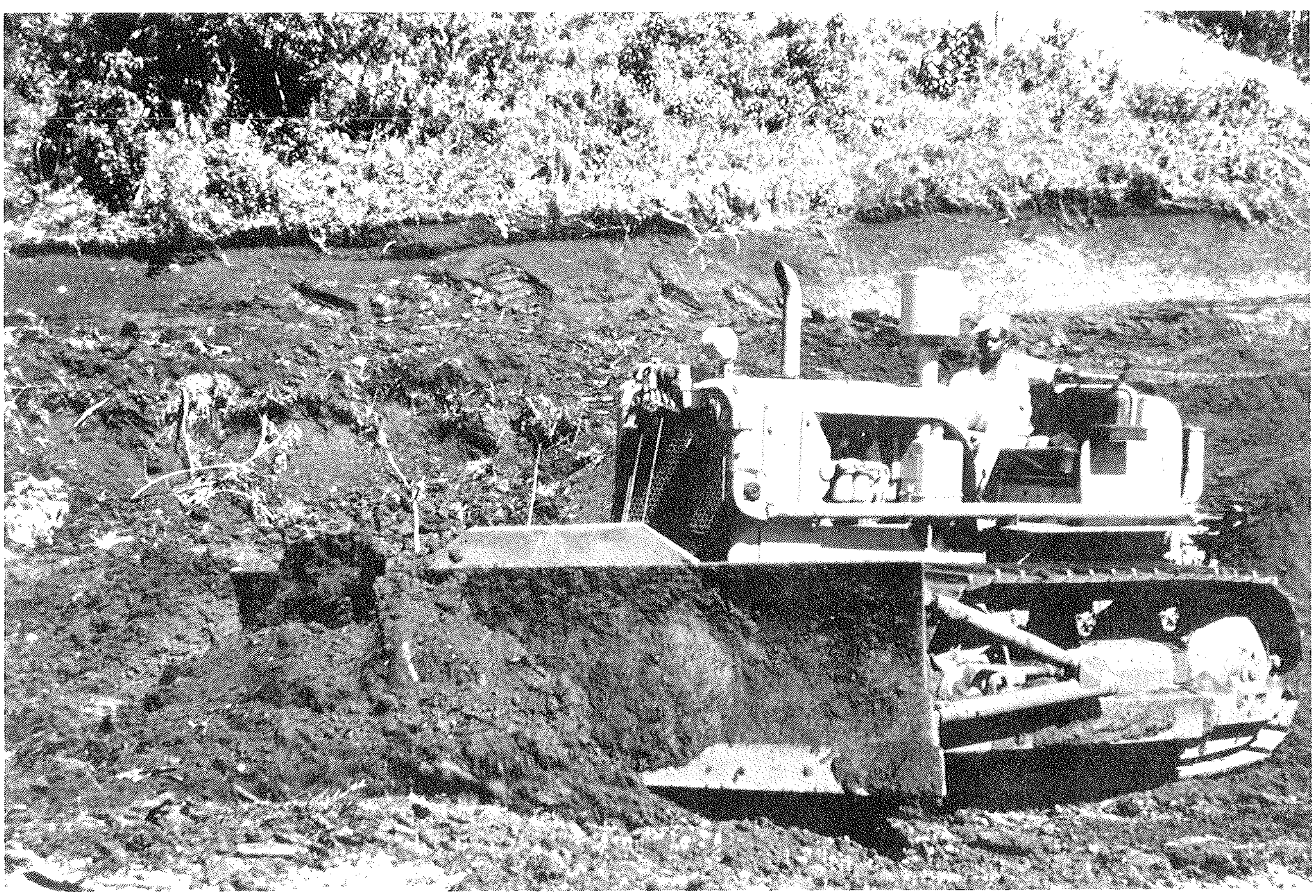
Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Cover photo: Bulldozer is used in roughgrading a roadway in southern Ethiopia.



Contents

Project Description

The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 400 vehicles a day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly enhanced with respect to economics, quality, and performance by the use of low-volume road technology that is available in many parts of the world.

In October 1977 the Transportation Research Board (TRB) began this 3-year special project under the sponsorship of the U.S. Agency for International Development (AID) to enhance rural transportation in developing countries by providing improved access to existing information on the planning, design, construction, and maintenance of low-volume roads. With advice and guidance from a project steering committee, TRB defines, produces, and transmits information products through a network of correspondents in developing countries. Broad goals for the ultimate impact of the project work are to promote effective use of existing information in the economic development of transportation infrastructure and thereby to enhance other aspects of rural development throughout the world.

In addition to the packaging and distribution of technical information, personal interactions with users are provided through field visits, conferences in the United States and abroad, and other forms of communication.

STEERING COMMITTEE

The Steering Committee is composed of experts who have knowledge of the physical and social characteristics of developing countries, knowledge of the needs of developing countries for transportation, knowledge of existing transportation technology, and experience in its use.

Major functions of the Steering Committee are to assist in the definition of users and their needs, the definition of information products that match user needs, and the identification of informational and human resources for development of the information products. Through its membership the committee provides liaison with project-related activities and provides guidance for interactions with users. In general the Steering Committee gives overview advice and direction for all aspects of the project work.

The project staff has responsibility for the preparation and transmittal of information products, the development of a correspondence network throughout the user community, and interactions with users.

INFORMATION PRODUCTS

The two major products of this project are compendiums of previously published information on relatively narrow topics and syntheses of knowledge and practice on somewhat broader subjects. Compendiums are prepared by project staff at the rate of about 6 per year; consultants are employed to prepare syntheses at the rate of 2 per year. In addition, proceedings of at least 2 international conferences on low-volume roads are prepared and transmitted to the project correspondents. In summary, this project aims to produce and distribute between 20 and 30 publications that cover much of what is known about low-volume road technology.

News about the project work is published in the bimonthly *Transportation Research News*; reprints of these articles are distributed to the project correspondents.

INTERACTIONS WITH USERS

A number of mechanisms are used to provide interactions between the project and users of the information products. Review forms are transmitted with each publication so that recipients have an opportunity to say how the products are beneficial and how they may be improved. Through visits to developing countries, the project staff acquires first-hand suggestions for the project work. Additional opportunities for interaction with users arise through international conferences in which there is project participation and through informal meetings with U.S. students who are from developing countries and who attend the annual TRB meeting.

Foreword and Acknowledgments

This publication is the second in a series of syntheses being produced by the Transportation Research Board's project on Transportation Technology Support for Developing Countries. A list of all project publications that have been completed to date appears on the inside back cover of this book.

It is planned that each synthesis be published first in the English language and that separate French and Spanish versions be published as soon thereafter as the respective translations can be completed.

The objective of the book is to provide useful and practical information for those in developing countries who have responsibility for stage construction of low-volume roads. Feedback from project correspondents will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later syntheses.

Acknowledment is made to Tippetts-Abbet-McCarthy-Stratton, Engineers and Architects, New York, for permission to include figures that have been selected from Reference 17 and reproduced in this publication.

Appreciation is also expressed to libraries and information services that provided reference material that was consulted in preparing the synthesis text. Special acknowledgment is made to the U.S. Department of Transportation Library Services Division and to the Library and Information Service of the U.K. Transport and Road Research Laboratory.

Finally, the Transportation Research Board acknowledges the valuable advice and direction that have been given by the project Steering Committee, and is especially grateful to William G. Harrington, Maricopa County Highway Department, Arizona, Melvin B. Lawson, Illinois Department of Transportation, and Edward C. Sullivan, Institute for Transportation Studies, University of California, Berkeley, who provided special assistance during the development of this particular synthesis.

CHAPTER I

Introduction

GENERAL SITUATION

Many aid programs for developing countries in the past have been oriented toward major development and large individual projects; the emphasis is now on helping the rural poor. Access and transport are prerequisites for integrating rural populations with urban economies. Road access is a popular demand of rural communities partly because of real benefits and partly because roads are believed to be the forerunner of other services. Roads provide wider and more flexible coverage of an area than rail or water and are well suited to serve scattered rural populations.

Rural access is often poor in developing countries. Villages are connected by paths or simple earth tracks that have met the needs of pedestrian and animal traffic in years past, but are not generally suitable for motor vehicles. Unfortunately, few developing countries have sufficient financial resources to provide roads for low volumes of traffic in rural areas. However, in order to provide as much mileage as possible within financial limitations, there is a procedure called **stage construction** that can be followed in the development and construction of low-volume, low-cost roads. Stage construction emphasizes the practical aspects of constructing the most economical and usable road that is adequate to meet the needs of the present and the immediate future. As rural development progresses and traffic volumes increase, the road can be upgraded or improved in stages in response to the greater needs.

STAGE CONSTRUCTION

The term **stage construction** is used to describe the betterment of a road in stages through step-by-step improvements that are usually adequate to meet current needs. Improvement occurs over an extended interval of time as traffic volume or other considerations indicate the need. The various stages of construction may be carried out over a few years' time for local or minor improvements, or may take many years for major improvements to be made. These types of improvements or upgrading are betterments rather than simple routine maintenance.

Stage construction of roads is appropriate for either of two sets of circumstances:

(a) A path or track proves to be no longer suitable because of increased demand that may or may not have been foreseen by the responsible authority. Stage construction could also be appropriate for a track or road that had previously undergone some degree of improvement. Such a road may be determined to be inadequate in surfacing, width, stream crossings, or for other reasons, and would therefore be upgraded.

(b) A road is designed, but it is too costly to be built all at once; it is built in stages. Initially only as much as is necessary to satisfy current transport needs is built. In such a case, each stage should be planned and built in such a way that it can be incorporated as a part of the final project, insofar as that is practical. Of the two sets of circumstances, the first is the more common occurrence.

While the usual requirement is to improve an existing access route, there will occasionally be a need to construct a road where no footpath, track, or road already exists. Decisions must then be made for standards that will be followed for building the new road and for the extent to which the existing alignment should be employed. Typically, the various stages of construction that occur are as follows. In the initial stage, a trail or track is cleared, graded, and drained to provide a road that a vehicle can use in dry weather. Next, a gravel or stabilized surface is added to improve the rideability and to lessen the time that wet weather limits usage. Subsequent stages may include paving fords or building bridges across streams. The final stage would be widening to accommodate increased traffic or placing a bituminous surface that reduces the need for maintenance.

Spot or local improvements to an existing road are also stages of construction, as are easing restrictive or hazardous curves or replacing fords with culverts or bridges. Stage construction may also include combinations or variations of the stages noted above.

Two considerations should not be overlooked. First, each stage must be a usable facility. It should also be protected from excessive deterioration caused by weather and usage. For example, protection from erosion should be built in the same stage of construction as the road or bridge or ford to be protected and should not be deferred until a later stage. Second, when planning or constructing any stage of a project, consideration should be given to each stage being logically utilized or incorporated into a future upgrading. This applies especially to alignment and to the more costly and permanent structures.

There are conditions other than the availability of funds that may sometimes warrant stage construction:

(a) Other government programs may reduce the availability of engineering or qualified supervisory forces.

(b) The equipment needed to build a completed project may be in use elsewhere. Building in stages, especially the initial stages, requires fewer resources.

(c) Construction conditions themselves may sometimes dictate building in stages. Drying wet areas or stabilizing embankments and foundations can often be achieved either by allowing more time or by following more involved construction procedures.

(d) It is also a common practice to delay the placing of permanent surfaces in order to identify and correct soft or unstable areas. Surfacing may thus be delayed for several years and may be done as a separate stage.

This synthesis considers the planning, design, and construction of low-volume roads with emphasis on construction in stages. While some recognition is given to considering the standards or levels of construction to be obtained, the thrust is toward construction practices and procedures and to various factors that enter into a sound but low-cost project. The synthesis does not attempt to include the many technical and detailed procedures that are adequately described in the reference list that follows Chapter IV. Throughout the chapters that follow, references are denoted by bold-face numbers in parentheses. Thus a word followed by **(14)** means that Reference 14 contains more information on the subject under discussion.

CHAPTER II

Planning for Stage Construction

GENERAL

This synthesis will consider two classifications of roads: Class 1 — those with less than 50 vehicles per day (ADT) — and Class 2 — those with between 50 and 400 ADT. These roads are commonly called feeder or tertiary roads, or they may be known by local names such as agricultural, tea, cotton, or coffee roads. Class 1 and Class 2 roads carry low volumes of traffic and normally include both motorized and animal-drawn vehicles as well as bicycles and pedestrians. Typically they are from 5 to 15 km long, but they may include penetration or development roads that sometimes exceed 100 km.

When a decision is made to provide a road, there must also be a decision as to the level of service to be provided. That decision establishes the stage to which the road will be constructed. Factors entering into the level-of-service decision include the amount and types of traffic, the extent to which delays in traffic movement can be tolerated, and the constraints and limitations of funding.

Most Class 1 roads seldom warrant development beyond the graded natural earth stage, while Class 2 roads generally have granular surfaces such as gravel, stabilized soil, or crushed stone. For the higher traffic volumes of Class 2 roads, the surfaces may be waterproofed with bituminous materials. Exceptions to these general ideas can be easily justified by conditions of topography, weather, or maintenance conditions. For example, at least one study conducted in open savannah in Africa has indicated that the transition from an unimproved earth road to an improved gravel road can be justified on the grounds of costs when the average traffic reaches about 40 ADT. Similarly, the transition from an unimproved road to a bituminous road may be justified at 120 ADT, and from an improved gravel road to a bituminous road at 170 ADT**(1)**. These figures also justify a policy of stage construction and ensure that the total transport costs and the capital outlay to achieve them are always minimized.

Two terms are commonly used to describe further the level of service to be provided by low-volume roads. **All-weather surface** describes a road that can be used during all seasons of the year. Streams and rivers can be crossed during normal weather conditions but may be impassable for indeterminate periods during storms or high water. The road may therefore be closed, at least in sections, during those periods. **All-weather road** describes a road that not only can be used in all seasons, but streams and rivers are crossable during and immediately after storms.

A single lane is generally adequate for Class 1 roads and for the lower volumes of Class 2 roads **(2)**. Turnouts should be provided to increase the serviceability of single lane roads of less than 5.5-m roadbed **(3)**. This will permit them to carry greater volumes without undue delays. Two lanes are considered essential when traffic volumes approach the 200 ADT range **(3, 4)**. The number of lanes depends on characteristics of traffic, the number of animal-drawn vehicles in the traffic mix, and national policies.

Low-volume roads can seldom justify extensive costs and manpower during the formal planning stage. It is essential, however, that certain basic information be provided to those responsible for the final product. Knowledge of the conditions and problems peculiar to the specific project can avoid costly mistakes and allow the orderly execution of the work. It is desirable to visit the site and to become familiar with field conditions. Valuable information can be obtained from firsthand knowledge of the particular topographical and climatic conditions. If an existing road is to be improved, the local residents or those responsible for the maintenance of the existing road will often know about any unusual problems. Information on local flooding, useful construction materials, and labor availability can also be obtained from these sources.

ALIGNMENT

If the project is a transition from an earth track to an improved road, the extent to which the existing alignment should be employed is usually not difficult to decide. Generally the alignment of the earth track will follow the ground contour, winding to avoid steep inclines and other local obstacles. It may follow old foot trails. Except in easy country, the layout of the track is not likely to follow a course that is suitable for motor traffic. The first step in road improvement, then, is to improve horizontal and vertical alignment consistent with the design standards that were selected (Table 1). Often the general direction of the old track will be followed, and a deviation from the old track will occur only where a new line is more practical for short distances. Sometimes a different line will be required to avoid major obstacles or to cross streams.

Table 1. Suggested design standards.

Variable	Class 1 Roads			Class 2 Roads		
ADT on opening (Mixed traffic)	under 50			50-400		
Terrain	flat	rolling	mountainous	flat	rolling	mountainous
Design speed (Km/h)	60	40	30	80	65	40
Maximum gradient (%)	6.0[a]	8.0[a]	10.0[a]	6.0	7.0	9.0
Width of surfacing (m)	4.0 to 5.0 depending on design speed			5.5 to 6.2 depending on design speed		
Width of one shoulder (m)	1.0			1.5		
Total width of roadway (m)	6.0 to 7.0			8.5 to 9.2		
Width of bridges (m)	3.5 to 4.0 (single lane)			8.5 to 9.2 for $L \leq 20$ 7.0 to 7.7 for $L \geq 20$		
Vertical clearance (m)	5.0			5.0		
Design-live loading (AASHO or equivalent)	H15-44			HS20-44		
Axle load for pavement design (legal limit) (t)	—			9		
Right-of-way width (m)	25			35		
Surface type (assuming an adequate base)	granular			granular, single- or double-surface treatment		

[a]Some authorities recommend maximum gradients in the range of 7.0, 10.0 and 12.0, respectively, plus some additional increase for short distances.

There are difficult decisions to be made at the stage when a permanent surface is being considered. A permanent surface is likely to fix the alignment for many years to come, so that at this stage it may be appropriate to review the entire route to determine if major diversions are desirable. There may be some justification for relocating the road nearer to material sources, providing better access, or perhaps eliminating some troublesome maintenance problems.

TRAFFIC VOLUME

Some estimate of the volume of traffic to be served is necessary. If only a track or foot trail exists, probably a graded earth road will suffice, certainly as an initial stage. However, there should be some appraisal of present and near-future transport activities in the vicinity. Movements of produce to local government marketing centers or movements to and from local village markets probably will account for most of the activity. Activity, such as increased government services, will also be generated as the result of a road being built. An improved road may encourage the development and transport of some local natural resources such as lumber and cattle. If produce and goods do not currently move by vehicle, some reasonable estimates of volume can be made from loads carried by animals or by head. When all these data are brought together, some concept of the requirements begins to emerge.

Where motorable roads already exist, actual traffic counts can be made and then estimates of growth can be projected. In many countries the ministries responsible for economic or agricultural development maintain information pertaining to potential local development. This information should be considered when estimating traffic growth.

When traffic information has been collected, the data can be compared to the guides given in Figure 1 for the stage to be developed.

RUNOFF AND DRAINAGE

Reliable information on rainfall and runoff is difficult to obtain. Yet, because of the destructive effects, runoff plays a major part in the planning and cost of a project. Lack of data for the immediate areas involved can be a major cause of premature and untimely failure of many otherwise sound low-cost roads. It is possible to economize on some facets of road construction or improvement, but shortcuts that do not account properly for runoff often result in failures that can completely disrupt the use of the road for long periods of time.

The problem is to obtain reliable data on amounts and duration of rainfall, catchment areas, runoff characteristics of the land, and maximum flood levels for the immediate area involved. Valuable information can often be obtained by close examination of the site for evidence of high water in trees and brush alongside streams and for deposits on floodplains. The recollections of local inhabitants may also be helpful. All the information must then be analyzed to estimate the proper sizes for drainage structures.

In considering the stage construction of drainage structures, it must be remembered that the amount of runoff water will be the same regardless of traffic volumes on the road. Therefore drainage structures do not lend themselves to stage construction except for the length of culverts and width of bridges. The size of the water opening must meet the runoff needs regardless of the degree of stage construction being considered. In arid areas where infrequent but intense storms are likely, drainage structures are seldom warranted. Provisions should be made for dips to be placed wherever runoff causes significant erosion. In order to minimize cost during first stage construction, over-the-road flow may be permitted at some locations instead of placing culverts. This is often practical where road surfaces are stable, flow is limited to storm runoff, and erosion is not a problem (6, 7, 8, 9, 13).

SOILS AND MATERIALS

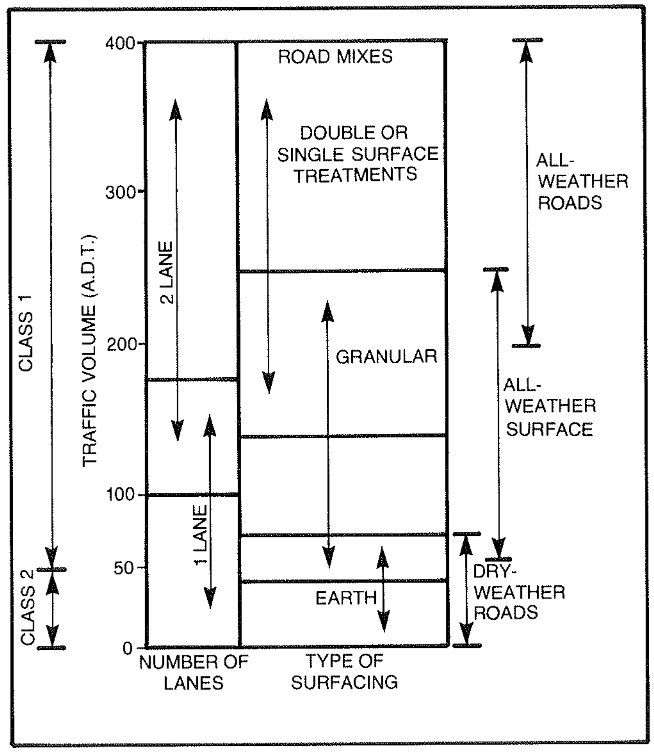
Soils

Most stage construction projects will involve soil handling, whether for building embankments, shaping road beds, or providing drainage. Some knowledge of how the soil will respond to handling is an important consideration in planning the work. Usually the soil immediately adjacent to the road is extracted to form the roadside ditches and is placed in the roadway to form the roadbed. However, if the soils are heavy clay, wet, or exceedingly sticky or hard, it may not be practical to handle them, and in extreme cases they may not be usable.

A review of the soil conditions to determine workability and suitability is highly desirable if not essential. Experienced personnel can usually determine general suitability in the field without making a formal survey. Less experienced personnel may require test assistance from the central laboratory.

A minimum soils survey is usually adequate for a Class 1 road if no difficult problems are evident. However, if soils are poor or if traffic volumes indicate a need for a more advanced stage of construction, more formalized investigation and analysis are required (6, 10, 11, 12). The use and treatment of soils will be discussed in more detail in Chapter IV of this synthesis.

Figure 1. Guide for lane requirements and surfacing types related to traffic volumes.



Other Materials

The availability of other materials needed for the project should be determined before the planning is completed to ensure that they will be available at the site and at the time they are required. In the interest of cost savings, local materials should be used where practical (10). Gravels or granular materials can often be found on or near the roadsides or in local stream beds and flood terraces (11). Local residents will often know what other sources are used for various local needs. Aerial photographs and geological maps may also be helpful in locating likely sources (16).

When gravel, sand, or other granular materials are not available within a reasonable haul distance, cement, lime, or asphalt may be used, if available, to mix with the in situ soils and improve their quality (12).

Local rock has a variety of uses in culvert construction, erosion control, retaining walls, and stream crossings. It also has the advantage of being readily adaptable to labor-based construction methods. Care must be exercised, however, that only durable hard rock is used. Rock that is badly weathered or that deteriorates quickly when exposed to the weather should be avoided. If rock is not available for culvert construction, either concrete or corrugated metal can be used. Corrugated metal is usually an imported item, while cement is usually readily available and often is produced within the country. For smaller culverts concrete is usually less costly; but for larger culverts prefabricated, bolted, corrugated metal culverts may provide an economic advantage over small bridges. The costs for each should be investigated. When concrete pipe culverts are used, they may be produced either at the project site or at a central location and then transported to the project. The advantages and disadvantages of each method of production should be carefully reviewed before deciding which to employ (7). If access to the site is difficult, transporting the cement and the culvert forms may be less costly than transporting the finished culverts. However, this assumes that sand, stone, and water are locally available. It is important to remember that production at the site is usually done under adverse conditions, requires some additional equipment, and employs inexperienced personnel. Close supervision and control are required. Production at a central site, on the other hand, permits closer control with more experienced personnel and should result in a higher-quality product. Production costs may be less at a central site but cost of transport to the project site may be greater, even if the site is easily accessible. Production at the project site has the disadvantage of being limited to producing only those culvert sizes for which forms are available.

Selected local timber may be used for a variety of purposes including structures, piling, and concrete forming. In areas where termites (white ants) are indigenous, timber must be limited to temporary use unless treated. It may be that treatment costs will offset other cost advantages for the use of timber.

CONSTRUCTION METHODS — LABOR-BASED OR EQUIPMENT(15)

Whether the work is to be done by labor-based methods or by maximum use of equipment may very well be decided by government policy. Otherwise the decision depends on the economics of labor versus equipment. Depending on the nature of the individual project, a practical approach will probably involve some mix of the two methods.

The availability of manpower must be determined, as well as availability of equipment and the capability to maintain it. There must also be an appreciation for the nature of the materials and the construction problems involved. Labor-based methods are generally more favorable if (a) the terrain is level or rolling, (b) the soils are light and can be readily handled by hand tools, (c) the quantity of earthmoving is small, and (d) drainage structures are simple. Mountainous or very hilly terrain will usually require more equipment. If the embankments are large, if there is an abundance of hard rock, or if soils are hard, highly plastic, stony, and do not handle well with hand tools, more mechanical equipment is required. A practical balance between labor and equipment might be achieved, for example, when there is a requirement to move embankment or road-surfacing materials for a distance of several kilometers. A dump truck could be loaded by labor, the truck driven to the site and dumped, and the material spread by labor.

The possibility of using local equipment or animal-drawn vehicles for some parts of the work should not be overlooked. Farm tractors fitted with spreader blades can be used for light leveling work, and animal-drawn vehicles can be used for hauling light loads.

Making maximum use of resources that are locally available requires more supervision at the intermediate level. However, there are numerous combinations of labor, road-building equipment, and local equipment that can be used to build a project at minimum costs.

METHOD OF ACCOMPLISHMENT—CONTRACT OR GOVERNMENT FORCES

Planning needs may differ between a project built by contract and one built by public employees, especially for stage construction.

If the work is to be contracted, some form of documented technical specification and formal agreement is required, regardless of how simple the work may be. This document must specify, as a minimum, a description of the work to be done, the quality of the resulting product, and the time for completion. Varying degrees of detail are required depending on the extent and complexity of the work. The aim should be to make the specifications as simple and brief as practical and still maintain the quality of work desired. Procedures must be specified for determining the amount the contractor is to be reimbursed for the work he does. These must be precise and exact, but also simple and practical.

If the work is to be done by public employees, the paper work may be limited to sketches and general instructions. Depending on the ability and experience of the field supervisor, many decisions on construction methods and details may be left to him. If the work is an uncomplicated stage improvement, verbal instructions may be sufficient. For example, the instructions may simply be to "place 15 cm of gravel, 4 m wide, from A to B." Some level of control must be provided, however, to ensure that established standards are maintained and that the project stays within budget limitations.

SCHEDULING THE PROJECT

Time is required to bring together all the materials, manpower, tools, and equipment needed at the work site, and deliveries should be scheduled with the construction season in mind. Rainy seasons that are normally disruptive and damaging can be made to work to the project's advantage if the work is so scheduled. If embankments and drainage have been placed properly, the rains can materially assist in the settlement of the embankments and in the compaction of the surfacing.

If the project is contracted, it is desirable that specifications provide for certain activities to occur within given time frames or by given dates. It is also essential that the contractor be permitted to start work at a time that will make proper scheduling of operations possible.

If the project is built by government forces, the supervisor assumes direct responsibility for many of those scheduling activities that would otherwise have been assigned to the contractor. It is essential, then, that the supervisor be given the authorization to proceed with scheduling activities in sufficient time to start the work by the scheduled starting date. This becomes especially critical where wet seasons are intensive.

CHAPTER III

Design for Stage Construction

GENERAL

Design considerations are illustrated by the following summary remarks that were made at a major conference on low-volume roads.

> A common thought throughout the papers and discussions was that engineers must design low-volume roads from a point of view different from that used in the design of high-volume roads. A primary concern was that techniques should be developed for designing low-volume facilities with a minimum of effort and, certainly, in most cases with the use of meager data . . .
>
> Throughout the sessions the concept of design by using simplified but reasonable techniques constantly reappeared. Economic and environmental considerations make it imperative for the engineer to assume concomitant constraints in design. The principle of design by using what one knows will work, regardless of cost, certainly does not apply to low-volume roads. To paraphrase the Mikado, we must make the design fit the job. (16)

There is some question as to when, if ever, various components of roads should be overdesigned or overbuilt to anticipate future upgrading needs. Building for 20 years in the future is commonly practiced where there are sound data for anticipating future needs. But where reliable forecasts cannot be made or where the need for improvement cannot be foreseen within 20 years, stage development would appear to be the better use of available funds.

Sometimes funding that is available for a specific project may not be available for improvements at a later date and may be used to overbuild the more critical components such as road width and stream crossings. If difficulties are anticipated in providing maintenance after a project is built, it may be better to overbuild initially to provide assurance that the facility will function. The decision of how much to overbuild may be as much a practical consideration as a technical one.

SURVEY

The amount and kind of survey required, like the amount of design, depend on field conditions and what is to be built. If a road is on a new location or follows a foot trail or track, a conventional survey normally follows the general direction of the trail or track. Distances are measured and stations are established. Elevations are determined at the station points, or more frequently if the terrain is irregular or steep. When this information is plotted to scale, an alignment and center-line grade can be established.

If the assignment is to improve an existing well-defined road, a survey may not be required throughout its entire length. If only localized improvement of grades, curves, or drainage is to be made, it may be adequate to provide survey information for only those locations.

The amount of cross-sectioning depends on the nature of the terrain. Hilly and mountainous terrain generally requires more frequent sectioning and for greater widths than flat terrain where there is little change between stations. Cross-sections should always extend beyond the probable points of intersection of the slopes of the natural terrain. The sections should be taken at regular intervals spaced sufficiently close that quantities can be determined with reasonable accuracy. Additional sections are required wherever there are abrupt changes in terrain. Where water courses intersect, profiles should be run far enough in both directions to provide the needed data for the drainage designer.

The stage development of an existing road where alignment and grades are already established generally requires less survey than to develop the road initially.

STRAIGHT LINE PLANS

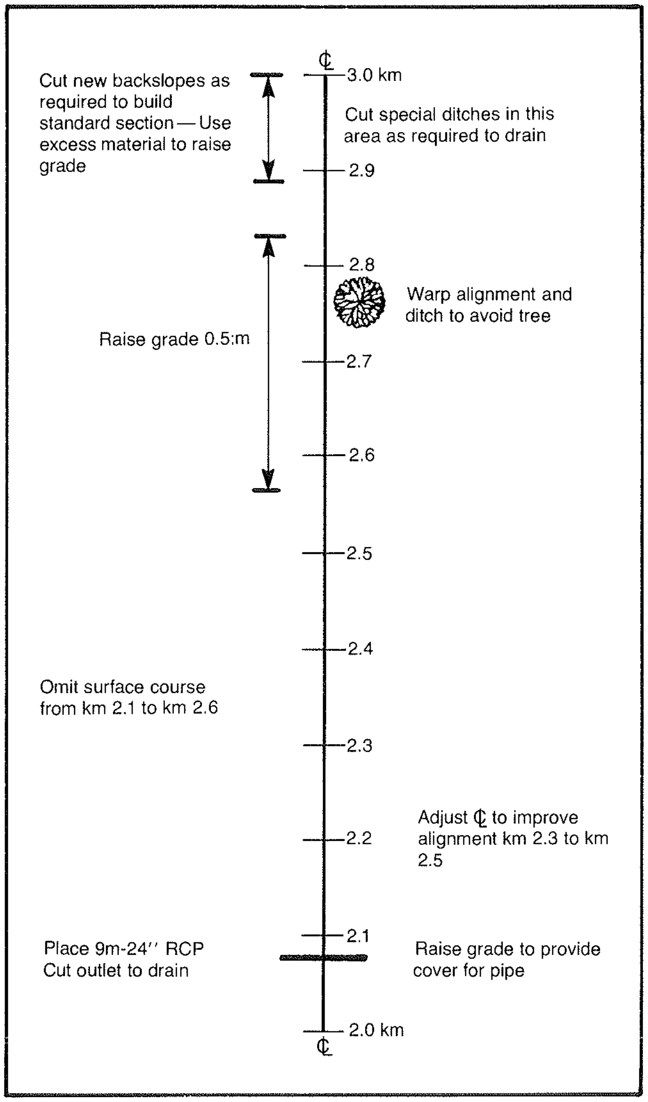
A straight line plan may be adequate when an established road is to be improved. This type of plan is most applicable when no significant changes in grade or alignment are anticipated and when design speeds and traffic volumes are low. The work is usually limited to ditching, minor grade alignment and drainage improvements, or surfacing. It requires a minimum of survey and design and can be used for determining quantities and for building the project. The plan may be developed as follows.

Instead of making a detailed survey the engineer or the designer rides the road to be improved. Distances from the beginning point are noted from the odometer in the vehicle. For control purposes the distance can be correlated with features along the road. The engineer notes work to be done and the corresponding odometer reading, estimating to the nearest tenth. For example, if a culvert is required or an existing culvert is to be extended, the odometer reading and the work are noted; the same process is followed with raising grades, minor changes in alignment, and special ditching. From these notes a straight line plan is prepared that shows odometer readings with appropriate notes for the work to be done. It does not indicate alignment or grade (Figure 2).

The plan is used in conjunction with a typical section. Normal ditching material is placed as a leveling layer on the roadway without changing the grade significantly. If the plan requires a significant grade change, the limits and change in elevation are noted. Depending on the amount, grades may have to be established by survey. When special problems occur, they may require more extensive design considerations.

For stage improvements to existing roads this procedure provides the necessary information at minimum cost. It lends itself to either labor or equipment construction and is equally adaptable to construction by public employees or contractor. It should be noted that this procedure does require a field supervisor to exercise somewhat more judgment than would be required if he were furnished with a more fully engineered

Figure 2. Straight line plan.



plan. But because the design speeds are low, minor grade changes or the easing of curves can normally be "eyed in" without presenting problems. During construction, survey parties may be required for the more exacting work. Otherwise a hand level, ruler, marker, and string are the supervisor's principal tools.

DESIGN STANDARDS

Standards used for the development of low-volume roads should allow for relatively low construction costs. They should provide for a facility that is capable of bearing a potentially higher volume of traffic through stage development unless conditions are such that future traffic growth in the area is not likely to occur. They must also address problems of topography and needs of the users.

Gravel surfaces, animal-drawn vehicles, and other controls will probably prevent these roads from being traveled at high speeds. For these types of roads most developing countries use design speeds of from 60 km/h for flat terrain down to 30 km/h for mountainous terrain. These values are considered adequate for limiting operating conditions, although the greater part of most roads may in fact permit higher operating speeds.

Table 1 shows representative standards used by developing countries and is intended as a guide (5). It should be noted that the guide applies to the final stages of development of Class 1 and Class 2 roads. In order to reduce first costs it may be expedient to build to lesser standards in the initial development stages. As traffic increases, improvements can be made at substandard locations to bring the entire road up to the desired standard.

TYPICAL SECTIONS

The purpose of a typical section is to provide the builder with a clear understanding of the shape, dimensions, and components of the road to be built.

Key considerations in the design of typical sections are (a) sufficient width of riding surface to accommodate the number of vehicles, (b) enough strength in the surface and its underlying materials to support the wheel loads, and (c) adequate drainage to prevent the surface or the roadbed from being eroded or from being softened by prolonged exposure to either surface or subsurface water.

The required width of the riding surface depends on the amount of traffic. Although practices vary throughout the developing countries, a 4-m, single-lane riding surface is generally considered to be adequate for volumes up to 150-200 vehicles per day if turnouts are provided at frequent intervals (400 m maximum) (3). Widths of 6.65 m are common for two-lane Class 2 roads. The capacity of the surface to support the loads depends on the characteristics of the surfacing material, the amount and kind of traffic, and the extent to which the roadbed soil retains its stability as the moisture content changes. Depending on these factors, the typical section should specify the type and amount of material to be placed on the surface. Drainage is obtained by sloping the road surface and by providing ditches alongside the roadway to keep water off the surface and to carry it away from the roadbed.

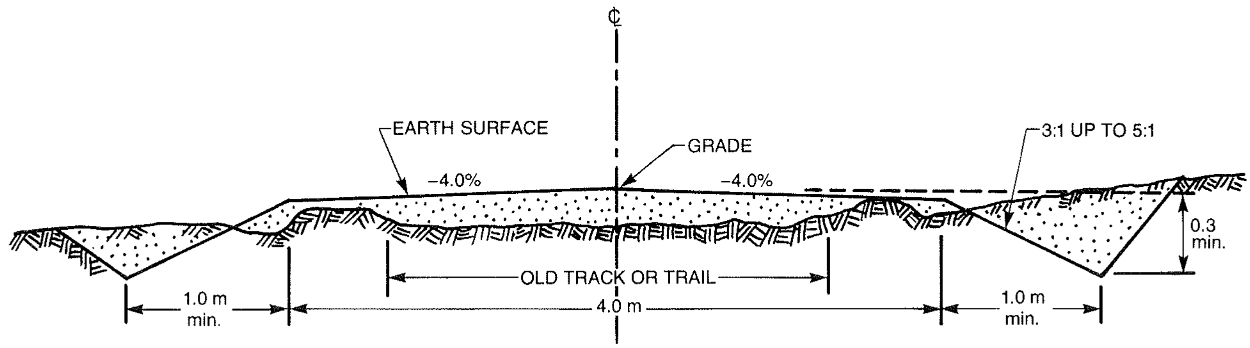
Figures 3 through 8 illustrate commonly used typical sections for Class 1 and Class 2 roads and indicate how they can be applied to the stage development of roads under various conditions. The sketches illustrate single-lane roads with a 4-m surface and no shoulders, and they represent what is generally considered to be a practical minimum for very limited traffic volumes.

Some authorities advocate that the roadbed should be widened initially to permit 0.5-m to 1.0-m shoulders on each side. This adds relatively little cost, provides more stability for road edges, and permits limited vehicle passing. There are also those who advocate, with some justification, that ditches should be placed initially to accommodate a future 5-6 m riding surface with shoulders. For low volumes of traffic, a 4-m riding surface would be placed initially, to be widened through stage development when required. This increases the cost of initial construction, but provides passing space and simplifies subsequent stage development to a two-lane facility. The probability of eventually developing the second lane should enter into this consideration.

The following guides for applying typical sections to the terrain can help to provide longer road life and reduce maintenance requirements:

1. A grade line that is above the adjacent terrain is desirable. A higher grade provides a dryer and therefore stronger roadbed. A stronger roadbed results in less

Figure 3. Stage construction over old track.



Conditions

- Flat terrain
- Road placed on location of old track
- Side ditch material used to form roadbed
- Grade set so that material from ditches is approximately equal to embankment requirements

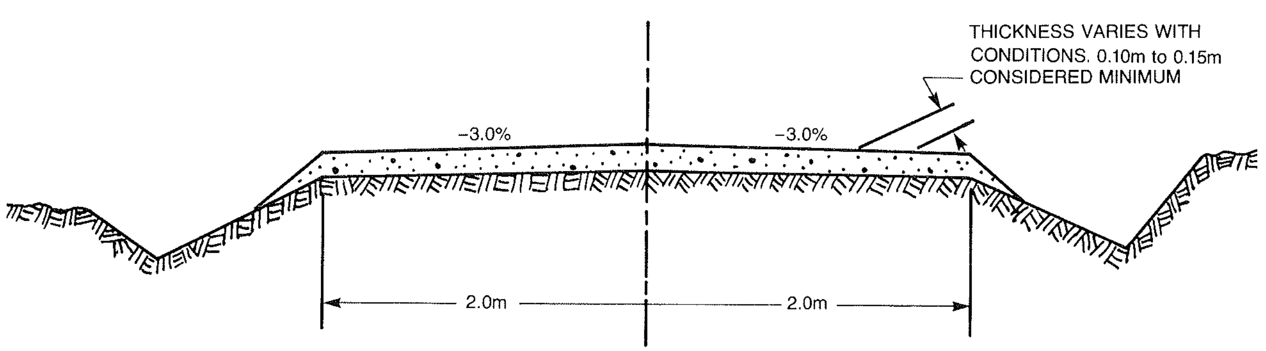
Notes

- Material must be suitable for use
- Groundwater level should not be near surface
- Requires minimum moving of earth
- Adaptable to either labor-based or equipment construction
- Low grade (relative to adjacent terrain) makes roadbed less stable during wet conditions and if ditches are not maintained.

rutting and deformation of the surface. In arid areas, blowing sands are less likely to accumulate on the road, but will accumulate on the downwind side of the embankment.

2. Deeper ditching tends to lower the moisture content of the roadbed and provides greater capacity for water runoff. This may not be possible where grades are flat. Raising the grade line may then be a suitable alternative.
3. Road surface cross slopes of 3-5 percent are desirable. Less than 3 percent slopes tend to permit puddles to form on the surface; the puddles may become potholes under traffic. Slopes greater than 5 percent tend to cause corrugations on the road edges. In general, a tighter surface requires less slope. A slope of 3 percent is adequate for bitumen surfacing, a 5 percent slope is preferable for loose gravels.
4. In cut areas back slopes should be cut as nearly as practical to their natural angle of repose. This angle can usually be determined by observing the natural slopes in the vicinity. Flatter slopes require unnecessary excavation and are not necessarily more stable. Slopes

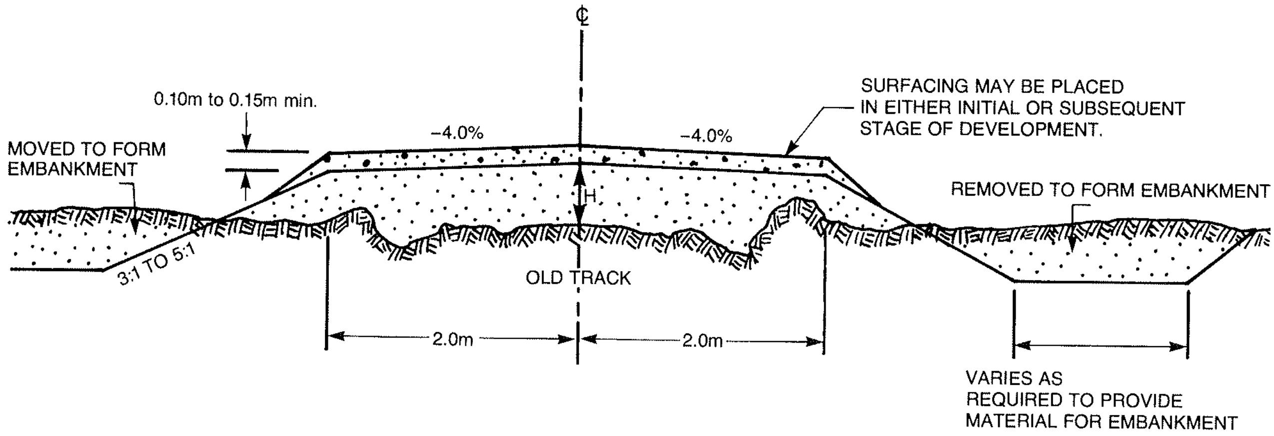
Figure 4. Stage development to all-weather surface.



Notes

- The policy of some countries is to provide all-weather surfaces in the initial construction stage. Others, in order to minimize initial costs, provide such surfaces in a subsequent stage of development.
- If the original soils are of high quality, an all-weather surface may have been provided by that quality. More often, granular soils or gravels must be transported to the site.

Figure 5. Embankment section over old track.



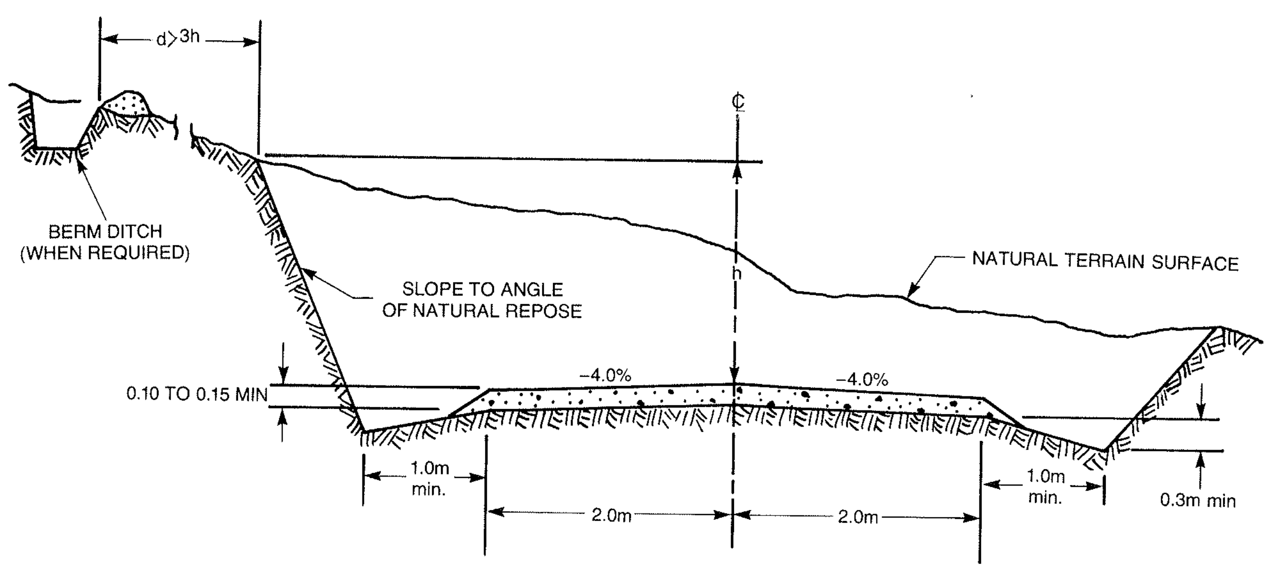
Conditions
- Road placed over old track location
- Flat terrain; high water table or subject to flooding

Notes
- Center line grade set higher to provide dryer roadbed
- Ditch widened to provide material for embankment and to lower water table
- Adaptable to either labor-based or equipment construction
- Dimension H varies depending on flooding level and quality of embankment soil
- More costly but more durable

erode easily if cut too steeply. Erosion causes silting that obstructs drainage and causes excessive maintenance. Steep slopes are also more likely to cause earth slides and sluffing when wet.

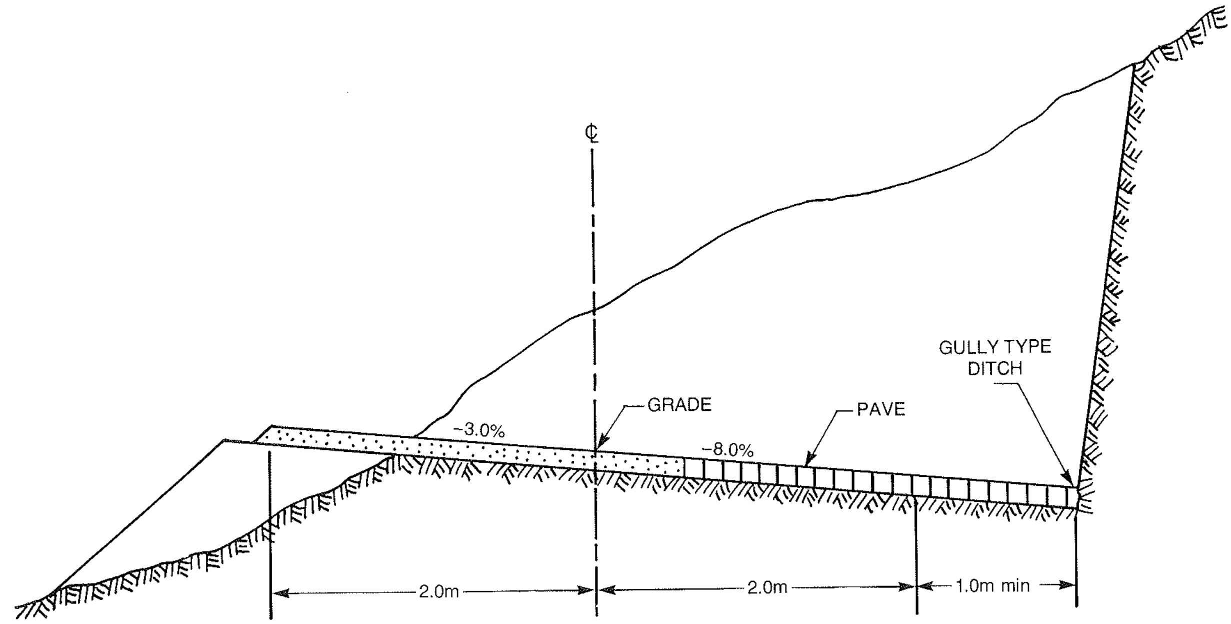
5. In stage development, advantage should be taken of existing road or tracks when fitting the typical section. For example, an existing sunken road may be made to serve as a drainage ditch for one side of the new road

Figure 6. Typical section in cut.



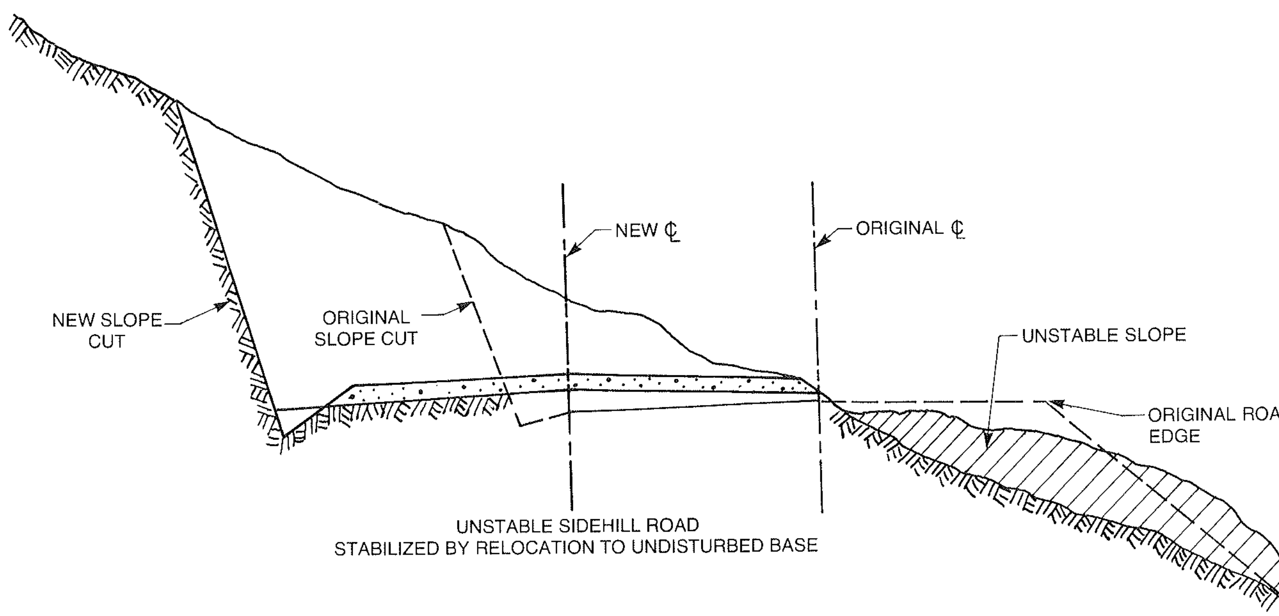
Notes
- Surfacing applied in either initial or subsequent stage
- Labor-based construction less adaptable, depending on volumes

Figure 7. Gully-type ditch on curve (long grade).



Notes
- Limited opportunity to discharge drainage
- To control erosion, pave ditch and road to width required
- Slope full road width toward ditch
- On tangent section break surface slope at ℄

Figure 8. Typical stage improvement in mountainous terrain.



Condition
- Original road placed partly on solid base and partly on unstable fill

Notes
- Road moved into hillside provides firm base
- Same procedure used to ease curves

(Figure 9). An existing compacted roadway may serve as the new road base, provided good drainage is not sacrificed.

6. Widening only one side of an existing road embankment is preferred. When consolidation of the new material occurs, it is then limited to one ridge in the surface. Culvert connections are also reduced (Figure 10).

DRAINAGE

Inattention to simple drainage has caused many low-cost roads to fail. Many poor roads could be turned into good roads by following good drainage practices. Drainage begins by having enough crown or slope (3-5 percent) across the surface to allow quick runoff without scouring or eroding the surfacing material.

From the surface, the flow is to the ditches or down the embankment and away from the road. Ditches should be graded to permit steady flow and to prevent the road from becoming wet and weakened. They should be emptied at the low points in the terrain at every opportunity and thus allow water to leave the roadside area (Figure 11). Water should not be allowed to accumulate along the roadside.

In the case of long sections of road on steep grades, water sometimes overflows the ditches on to the road surface and may run down the road along depressions caused by traffic wheels. Large furrows often open up and make the road impassable. Several ways to correct this problem are as follows:

1. Pave the affected section with stone;
2. Intercept the ditch more frequently with transverse culverts;
3. Build either swales or humps diagonally across the road to divert the water to the ditches (these should be sloped gently so they will not interfere with traffic);
4. Provide larger ditches; and
5. Build narrow channels across the road to collect the water and direct it off. Channels must have a covering that is sturdy enough to carry traffic but open enough to collect water without clogging from surface debris. Paved swales have both the advantages of simple construction and simple maintenance.

Problems are prevented on new roads either by adjusting vertical alignment to discharge accumulated water more frequently, or by providing greater ditch capacity through gully type ditches with paving as shown in the typical section in Figure 7.

Ditches may be constructed in various shapes. The most common is the V-shape, but a trapezoidal shape may be used to provide greater capacity. A flat-bottom ditch (Figure 5) may be used to provide a ready source of borrow material for building the roadbed. The erosion characteristics of different soils may favor one design over another (9).

Figure 9. Sunken track drainage ditch.

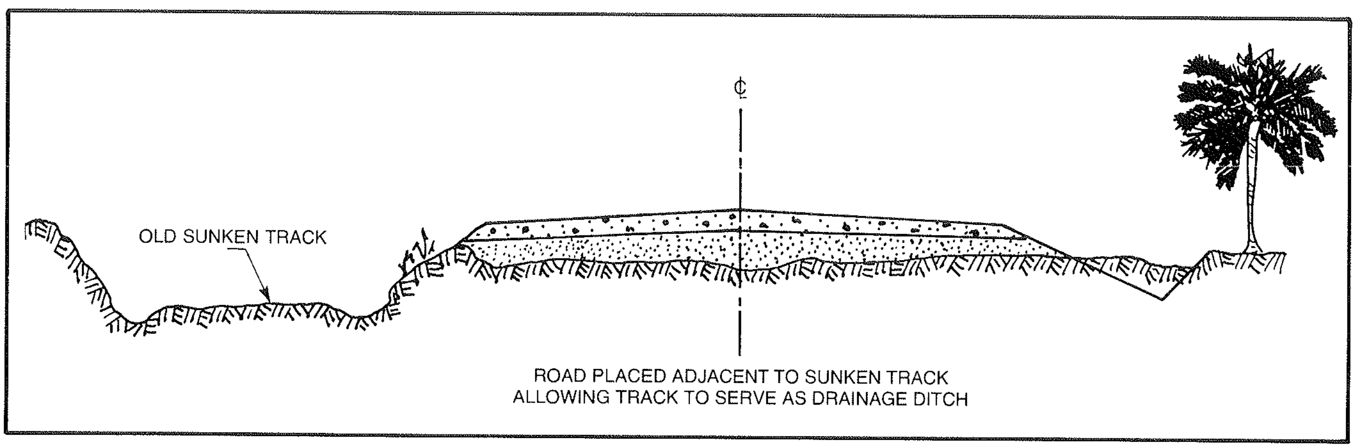


Figure 10. One-side widening of existing road.

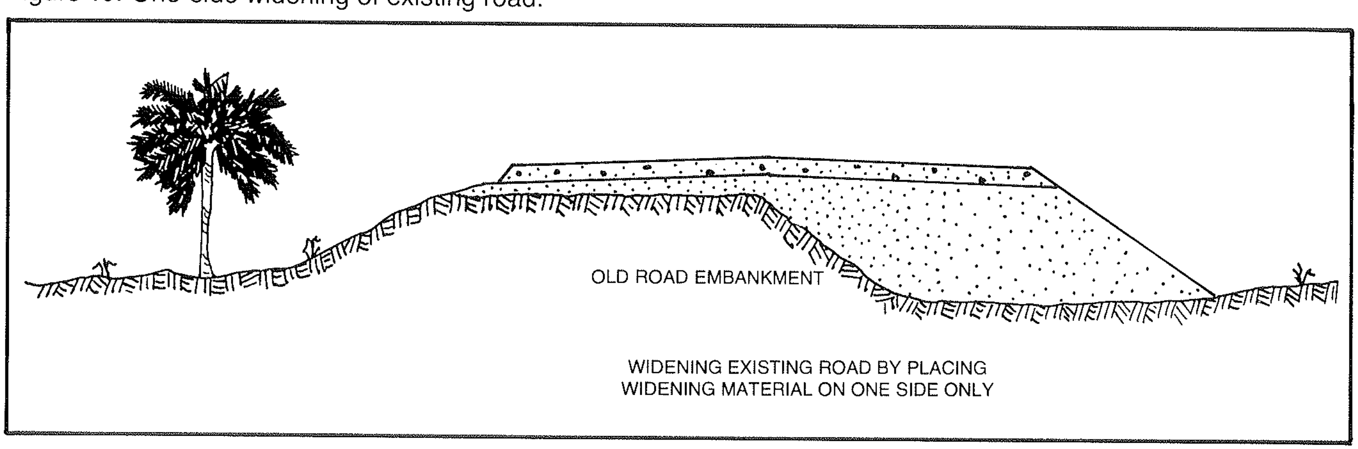
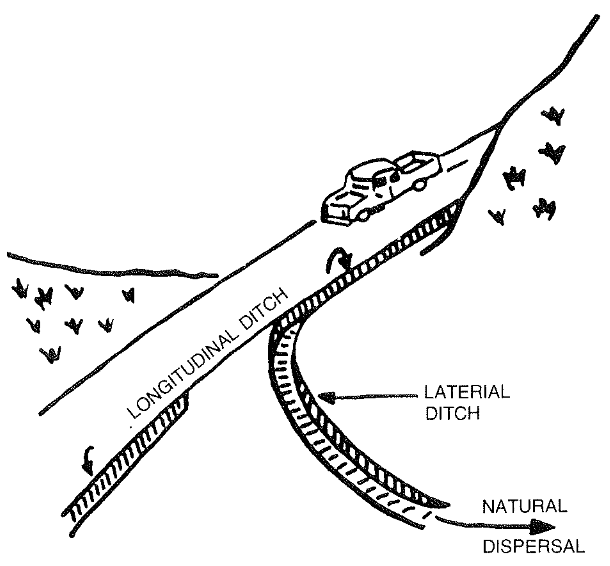


Figure 11. Lateral ditch.



Note
- Common practice for disposal of water in longitudinal ditches is to provide lateral ditches that divert water from the longitudinal ditch

Methods to be employed in ditch maintenance should be recognized in the ditch design. Some designs may lend themselves to either labor maintenance or to equipment maintenance, but not both. On the other hand, a V-shape ditch can be maintained by either labor or equipment.

Lengthy ditches should be avoided by constructing transverse drainage wherever water can be discharged. If the amount of water is too great for the standard ditch shown in the typical section, it should be enlarged. The limitation to this procedure is its cost as compared to the cost of the transverse drainage. In general, it will be cheaper to build transverse crossings than to extend ditches.

Ditches may erode when the grade is too steep. Erosion depends on the velocity of the water and the type of material (**13**). When the material is prone to being eroded, it should be protected. The most economical protection is grass or vegetative cover. Sprigging with creeping, quick-growing, indigenous grass is usually effective. Heavy vine-type vegetation should be avoided because it may clog the ditch and block flow. When vegetation is not adequate, paving with rock and mortared joints may be used. Concrete or cement-stabilized soil surfacing can be used if rock is not available.

Critical grades at which erosion will occur for various types of materials are shown in Table 2. While this table can serve as a guide for the need for erosion protection, better information can be determined by observing conditions in the field, particularly when the work is a further stage development. If scouring or erosion is evident, adequate provisions must be made to prevent reoccurrence after new construction.

Wherever possible, ditches should be laid out without abrupt changes in direction. Ditches are particularly susceptible to erosion at the ends of long cuts where they discharge into natural water courses. It is sometimes necessary to pave the outlet areas in order to prevent damage to adjoining earthworks. If excessive water flows down a hillside to the road, it can be diverted by constructing a berm or intercepting ditch (Figure 6). The ditch should be given as gentle a slope as possible with a minimum of change in direction. If gentle slopes are not practical, ditches should be paved and provisions made for dispersing the force of the water with diversion blocks, or check dams. If the land is stratified and inclined toward the road, an intercepting ditch can easily contribute to a landslide. An interceptor ditch should not be built without adequate investigation.

Table 2. Erosion of Ditches.

Type of Material	Critical Grades (%)
Sandy	1-3
Clay	2-5
Fine gravel	4-6
Soft shale	5 and over

SURFACES

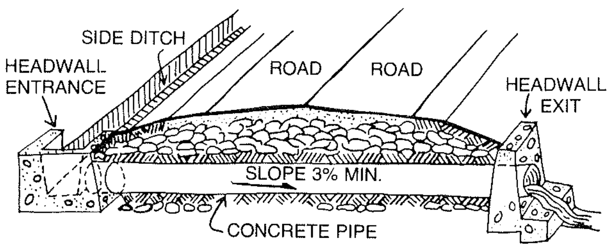
The least costly surfacing for low-volume roads consists of shaped natural earth. Adequacy of this type of surface depends on the characteristics of the soil involved. Most soils provide an adequate surface only when they are dry or slightly moist, but when dry they may also be very dusty. Under very wet conditions almost all soils except sands and gravels become impassable. Earth surfaces can be improved by proper drainage. When graded and drained they are generally considered adequate for Class 1 roads. Earth-surfaced roads can be further improved to provide an all-weather surface by adding materials that are less affected by water. This may be done either during the initial construction or as a stage improvement to an existing road.

The most common practice for providing an all-weather surface is to place an appropriate thickness of gravel or granular material on the road. Suitable materials are often found in stream beds, flood terraces, or in other natural deposits (**6, 11**). The material should contain a sufficient amount of fine-grained binding soils, i.e., silt and clay, to bind the material together on the road surface when compacted. Too little binder results in a loose surface, too much binder results in a soft surface when wet. To provide a good riding surface the maximum size of stones in the material should not exceed about 20 mm (¾ inch). The thickness of material needed to provide an all-weather surface will vary with the quality of the material and the traffic loads to be carried. For low-volume roads, thicknesses of from 10 cm to 20 cm are common.

If material meeting these requirements cannot be found, it may be possible to obtain satisfactory results by mixing materials from two or more locations. A gravel or sand deficient in binder may be found at one location and a binding material at another. Each is hauled to the site and mixed on the road in the correct proportions. Care must be taken to ensure that the selected binding material will mix properly under normal working conditions. When suitable granular or surfacing materials cannot be found, in situ soils are sometimes mixed with lime, cement, or asphalt to provide stability (12).

Bitumen seal coats are often used when traffic volumes reach 140 to 170 ADT, but the volume at which they are justified depends on local conditions. Sometimes seal coats are placed on roads having very little traffic because they eliminate the need for periodic replacing and reshaping of surface materials. They also prevent raveling of stabilized soils, reduce vehicle maintenance costs, and eliminate dust. Seal-coat surfacing may be a single application of bitumen to seal the surface from water and to control dust. More often it consists of one or more applications of bitumen and crushed stone that provide a stronger and more durable riding surface. It should not be assumed that seal coats eliminate future maintenance, since these surfaces will require repairs where localized failures occur. Complete resurfacing may be needed every few years, depending on traffic volumes and local conditions.

Figure 12. Transversal pipes.



Note

- Transversal pipes should be provided at regular intervals to evacuate the water that is running in the ditches (usually lateral ditches are not sufficient); the entrances and exits of the pipes must either be protected from erosion by headwalls or riprapped; under some conditions the pipe may be extended to the toe of slope and the headwall eliminated

CULVERTS

As used in this synthesis, the term **culvert** applies to small drainage structures in which water crosses transversely under the road. The term applies to the commonly used sizes of culvert pipes or their equivalents.

While many features of a road can be upgraded economically as a part of stage development, the size of a culvert cannot. It should be sized and installed correctly as the first step of road development. The sizing should anticipate future changes in land use that might affect runoff. Various methods for determining the proper sizes for culverts are to be found in the literature, but no best method has been developed (7).

While it may not always be practical to make complete drainage studies for low-volume roads, every effort should be made to provide an adequate as well as economical culvert size. Practical information can often be obtained in the field by observing the locations where the culverts are to be placed. Width and depth of the water course, erosion, or evidence of high water are good indications of size requirements. Where improvements to an existing road are involved, the conditions that surround existing culverts can indicate the adequacy of their sizes.

Culverts are generally required at low points in the terrain wherever the road blocks the flow of water. Exceptions include a deliberate decision to provide a ford crossing or a swale, or when small flows are intercepted or diverted by ditches that can carry the water to the next point of crossing. The latter is practical only if the ditches are adequate to contain the flow and the distance to be carried is short. Generally it will be cheaper to place culverts more frequently than to extend or enlarge ditches (Figure 12) (17).

Low points can be determined from project plan sheets that show grade and profile of the alignment. Evidence of flow across the road should be carefully checked in the field to determine actual needs.

CULVERT MATERIALS

Where wood is plentiful and termites or white ants are not indigenous, culverts can be constructed of logs or ax-carved wood. Wood culverts can be constructed quickly, and can thus speed up the road construction and use. In a subsequent stage, wood culverts can be replaced by more permanent construction. Temporary construction of this kind should only be considered if embankments are low, because heavy embankment removal and replacement would be uneconomical.

Local stone is often used for culvert construction where the foundation is good and where the road grade is high enough to provide sufficient cover to spread wheel loads. Stone culverts are usually built with a paved bottom, vertical sides, and a flat arch top. When the culvert span is narrow, reinforced precast concrete slabs spanning rock walls can be used as an alternate to the flat arch top. The slabs can be used as the riding surface. They require less height of embankment over the culvert and can easily be cast on site to the desired size. Both of the above types of culverts make maximum use of local materials and labor.

When local materials are not available, either concrete pipe culverts or corrugated metal pipe culverts are used. They can be used as single culverts or in series when a single pipe is not adequate in size. The concrete pipe may be produced at the site or at a central location and transported to the site. Economics and casting conditions should be reviewed before deciding which method to employ. Corrugated metal pipe is often an imported material, but it has the advantage of being relatively light in weight and can be more easily transported to the site. It can be used on less stable foundations than concrete and is readily assembled by local labor.

Existing culverts should be lengthened with like materials of the same size and without change in the slope of the flow line. Connecting two dissimilar or different sizes of culvert may result in turbulence or a change in water velocity at the joint. Any reduction in slope will cause silt or debris to accumulate.

Culverts generally constrict flood flow and increase velocities to give higher erosion potential on the discharge end. In many instances erosion and scour at these locations are damaging to the road embankment, to the culvert itself, and to the downstream channel. The energy of the high-velocity flow at the outlet should be dissipated to prevent scour. This can be done by placing riprap. If rock is not available, sacked soil cement is a good substitute.

WATER CROSSINGS

Low-volume roads often cross dry stream beds or low water streams by means of fords, dips, and drifts. These crossings are normally used as a first step in the stage construction of a road in order to reduce initial cost. When increased traffic or inconvenience of delays caused by high water justifies the need, the original crossings can be upgraded by construction of bridges or culverts.

In practice the initial crossings are used over long periods of time. The engineer should therefore design and build them for a long life so that they will not be destroyed by heavy storms.

The simplest kind of crossing occurs when a stream with a firm bottom is used as a roadway. The approaches should have gentle grades that do not exceed 5 or 6 percent. The surfacing of the approaches should be gravel or other granular materials that are not affected by wetting produced by traffic.

Less firm stream bottoms can often be made passable by placing rocks in the stream bottom to provide a firm base with a relatively smooth riding surface. The stream will tend to deposit silt on the upstream side and erode the downstream side of any materials placed. It is desirable to widen the crossing on the downstream side to minimize erosion of the crossing area. Fords should follow the bottom of the stream bed as closely as possible so that the natural flow of the current is not altered.

Paved crossings are often built on larger streams and streams with swift currents and deeper water. Rocks are placed to about the height of the normal water level. Concrete is poured over the top and over the sloping sides to provide a paved crossing with a minimum disturbance to the flow of water. In stream beds where erosion is likely, cutoff walls should be built. Rocks should also be placed on the downstream side to dissipate the force of flood water flowing over the surface.

The cross slope of a paved ford should not be crowned but should slope downstream. The elevation of the crossing should permit a thin flow over the surface for a substantial part of the width of the stream when the water is at normal level.

A more serviceable but more costly crossing for continuously flowing streams and shallow rivers is the pierced drift or culverted ford that is designed so that normal flow passes entirely through one or more lines of pipe culverts. A paved surface is built over the culverts. When flood water rises past the tops of the culverts, it flows over the road without damage (8).

In all these types of crossing, gentle approach grades are essential and every precaution must be taken to minimize erosion. To help the traveler during flood waters, markers should be placed to indicate the edges of the crossing. A marker should also be placed at the lowest point on the surface of the crossing to show the depth of water.

BRIDGES

Bridges or culverts often replace ford crossings as the second step in the stage construction of low-volume roads. The new construction usually occurs because traffic has increased sufficiently to justify elimination of delays caused by flood waters, or because flood waters are so violent that lesser crossings cannot be maintained. Bridges may also be widened or strengthened to meet increased needs.

The bridge site will usually be at or near an existing crossing. It is important, however, that the best possible exact location be selected. The following factors should be considered:

1. The longitudinal center line of the bridge should be at right angles to the direction of the flow of the river.
2. The bottom of the bridge span should be at an elevation above known flooding heights.
3. Piers and abutments should not impede or interfere with the flow of the stream. If interference cannot be avoided, protection must be provided against scouring and the collection and accumulation of debris.
4. Foundations must be on firm bottom, preferably out of reach of flood waters. If the bridge is on piling, the piles must be driven deep enough to be beyond scouring depths and should be protected from the collection of debris.
5. If approaches to the bridge cross a flood plain and require a road embankment, a swale should be built in the profile of the embankment to an elevation lower than the bottom of the bridge beams or girders. This will serve as a relief overflow when flood waters approach the bridge deck level. If the embankment washes out it can be replaced more quickly and at less cost than the bridge. To minimize the chances of the swale washing out, it can be paved and the embankment can be paved or riprapped on the downstream side (13).

The least costly materials to use for construction are generally those that are locally available. Where wood is available and white ants are not indigenous, shortspan wooden bridges are economical and can serve adequately for many years. They can be built by local labor with relative ease. The wood should be treated with preservative to prevent rot. For longer bridge life, footings, abutments, and piers can be built of stone masonry, and wood can be used for beams and decking. Covered bridges have proved to be successful in reducing rot in wooden superstructures. Whenever wood is used for decking, wooden planking should be placed as running strips to protect and preserve the decking. Stone masonry arches, or masonry piers and abutments with steel or concrete beams, are more permanent but are also more costly and require a higher degree of skilled labor. Sometimes site locations or economic considerations may favor reinforced concrete structures. These require engineering design and skilled labor for construction. Their cost can seldom be justified in the initial stages of a low-cost road, but they are often built in later stages to replace fords or drifts.

Widening existing bridges must be undertaken with care. Since widening permits additional loading, the substructure and foundations must be capable of supporting additional loads. Inspections should be made to determine if strengthening or additional support is required before widening. It is often more practical to build an additional bridge immediately adjacent to the first, or to replace the original with a new bridge of the desired width.

Under some conditions it has been found more economical to place corrugated metal plate arch culverts than to build small bridges. These prefabricated curved plates are designed to be assembled at the construction site. They can be transported easily and can be bolted together by local labor at the site. They have the disadvantage of having to be ordered well in advance of installation, and they must also be bolted to a concrete footing. They are generally best suited for deeper gullies or for places where embankments are relatively high.

EROSION

Erosion is a major contributor to the deterioration of roads, especially newly constructed roads. Erosion is often experienced in low-volume roads where the earthwork has not yet stabilized, and may be due to economic conditions that dictate low-cost design and construction, or because the forces of nature and the resulting effects are not fully foreseen by the designer or builder.

An understanding of the process of erosion is necessary as a basis for adequate control measures when locating and designing the facility as well as in its construction.

Soil erosion is caused by rainfall that displaces soil particles on inadequately protected areas. Water running over soil will carry some soil particles away. The rate of their removal is related to the intensity and duration of rainfall, to the volume of water flow, and to the characteristics of the soil particles.

In some areas erosion is caused by wind. Depositions of either water or windborne sediment occur when the velocity is reduced and the carrying capacity becomes insufficient to carry all of its sediment load.

When man has disturbed land by construction, there may be a sudden large increase in erosion. Accelerated erosion is the type that should be controlled during road construction and after the road is completed.

The causes of erosion suggest some basic principles for erosion and sediment control (7). Some of the more important principles, as they would apply to the building or improvement of low-volume roads, are as follows:

1. Construct slopes consistent with soil limitations;
2. Reduce the area of unprotected soil exposure;
3. Reduce the duration of unprotected soil erosion, especially during rainy seasons;
4. Protect soil with vegetative cover, mulch, or erosion-resistant material;
5. Control concentration of runoff;
6. Retard runoff with planned engineering works; and
7. Trap sediment with temporary or permanent barriers, basins, or other measures.

Wherever practical, stream crossings should be made at stable reaches of a stream to avoid meanders that are subject to shifting. Consistent with other requirements, alignment and grade should be blended or fitted to the natural landscape to minimize cuts and fills and to reduce erosion and costly maintenance. Culverts should be located so that the least possible channel change will be required. Care should be taken to protect culvert outlets and channels from severe erosion. Usually rock riprap offers sufficient protection.

Subsurface water is a frequent cause of landslides and other distrubed areas that add to the erosion problem when surface water flows over these areas. The subsurface water can sometimes be intercepted by trenches backfilled with gravel and sand to alleviate such unstable conditions and minimize potential erosion.

Small dams can be placed in a waterway to form reservoirs or basins for detaining water and trapping sediment caused by erosion. They can be temporary or permanent depending on the need.

Grading operations should be conducted in such a way that the area of unprotected soil is kept to a minimum. The work area should be kept well drained and the concentration of water avoided.

In most tropical or subtropical climates and where rainfall is adequate, the growth of natural grass in one season will provide erosion protection for average embankments. Where there is need for greater protection, sprigs of indigenous creeping grasses are often planted. The sprigs should be placed close enough to each other to obtain coverage in one growing season.

When drifting sand presents a problem by covering or obstructing a road, it can be controlled by placing windbreakers on the windward side of the road. A decrease of wind velocity will cause it to deposit its load. Care must be taken to place the windbreaker far enough away to prevent the deposit from being made on the road, but not so far that it is ineffective. Windbreaks are generally effective for a distance that is 10 to 15 times the height of the break.

Windbreaks can consist of any material that will break the wind's force such as slatted fence, trees, brush, or other debris that can be anchored into place.

ENVIRONMENTAL CONSIDERATIONS

While the construction or improvement of low-volume roads is not likely to have appreciable adverse effect on the environment, there are some general practices the road engineer should follow to ensure a minimum of disturbance to the area in which he is involved.

Erosion and the resulting sedimentation are two of the most obvious forms of environmental damage. Good construction practices, such as the disposal of waste material so that it does not affect the watershed, and control of runoff as previously described can reduce this to a minimum. It is important to bear in mind that the damage may extend far beyond that which is visible to the eye. A silted stream, for example, may adversely affect all of those who depend on it as a way of life.

Insofar as possible, objects having local historical, religious, or cultural significance should be avoided. It may sometimes be advisable to modify good alignment to preserve cemeteries, shrines, or individual trees with special local significance. Sources of drinking water or sites for washing clothes and bathing should be disturbed as little as possible. In fact, it may often be possible to improve these or make them more accessible without appreciable costs.

No permanent scars should remain as a result of the construction. Excavation sites or other denuding of the surface should be graded to blend into the adjacent terrain and natural growth should be encouraged.

SPECIFICATIONS

Most countries have specifications for the construction of their major roads. These specifications generally require a higher quality of construction than is economical or necessary for low-volume roads and, if followed closely, tend to increase the cost of low-volume roads beyond the benefits received. It is desirable to be guided by specifications that are geared to low-volume road construction.

If construction is by public forces, it is likely that some form of government guide publication is available for the control and supervision of construction, especially where labor-based construction programs are employed. However, if the government employs a contractor, there must be some form of formal agreement from which the contractor can determine what is to be done and the method by which he is to be reimbursed. These agreements normally include engineering plans or sketches as well as specifications that apply to the quality of the work to be done. They should also include criteria for time and performance of the work, and a firm declaration of any penalty to be charged for nonperformance. In stage construction, work units may be difficult to define or measure. One alternative is to reimburse the contractor on the basis of time and materials required instead of the more common practice of basing payment on the units of work completed. This, however, requires very close and detailed accounting to ensure proper reimbursement for the services rendered.

For low-volume roads the specifications should not be highly technical because the construction is not highly technical. However, it should provide sufficient information to leave no doubt as to the quality of work desired. In some cases the various steps to achieve the desired results may be specified, but the contractor's initiative in utilizing acceptable alternatives should not be restricted. The specifications must also include provisions for controlling the quality of the materials to be used.

CHAPTER IV

Constructing the Project

MOBILIZATION

Materials

Before construction is begun, arrangements should be made for the delivery of materials, tools, and equipment, and for the mobilization of labor. The supervisor would be well advised to have all materials available to him and under his control before they are needed. Delays in equipment delivery can cause interruptions in work that far exceed the time of the actual delays.

A site convenient to the project should be selected for assembling materials and supplies. The site should be well drained and large enough to allow adequate storage space and good traffic circulation and access. Preferably, the site should be located at the half-way point of the project, and it should be readily accessible for incoming deliveries. If the project area is extensive, more than one site may be required. In that case, different materials may be stored at different sites. Construction equipment should be brought to the site in time to check for acceptability and serviceablity prior to its being needed on the job. Proper storage must be provided for fuel and lubricants.

A shelter is usually provided for the supervisor as a base of operations and for maintaining records. A safe place should also be provided for security and storing small items of equipment such as hand tools.

Cement must be stored off the ground and protected from the weather. It is no longer usuable if allowed to become wet (Figure 13). Each site should be provided with the cement necessary for the completion of the work at that site. If more is required than can be properly protected, provision should be made for partial deliveries. Aggregates and sand should be protected from contamination by foreign materials. When handling or stockpiling aggregates, the material should be placed in layers rather than in conical piles. Cones cause the particles to roll and segregate into coarse and fine segments. Segregated aggregate makes poor concrete.

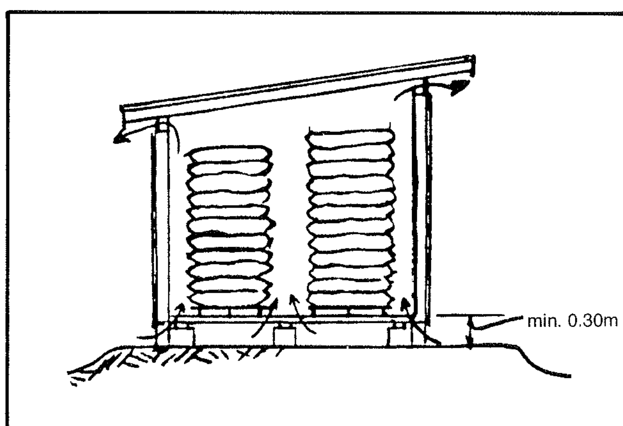
Reinforcing steel should be stored off the ground and, if it is not to be used for several months, should be protected from the weather to minimize rust.

If explosives are required, special consideration must be given to security and safe storage that is well removed from other activities. The amount that is stored should be the minimum required without interrupting the work. Explosive and detonating devices should always be handled separately and must never be stored or transported together. If appreciable quantities of explosives are involved, the storage site either should be surrounded by mounded earth or should be located so that an accidental explosion cannot endanger personnel in the area.

Scheduling

The supervisor should review his project to determine the logical sequence for construction. He should consider how seasons and weather might affect progress; labor requirements must be anticipated. For example, if the project is labor-based, the seasonal availability of labor and training time required must be taken into account. The same considerations apply to the use of local equipment.

Figure 13. Cement storage.



TOOLS AND EQUIPMENT

General

The number and types of tools and equipment required for a road construction project will depend on several factors that include whether government policy demands a maximum use of labor, the nature of the work, local economic conditions, the availability of equipment, and availability of local labor. Some combination of labor-based methods and equipment will probably be found to be most practical.

Hand labor is more productive when soils are easily handled, volumes are small, and hauling distances are short. More equipment is required as soils become more difficult to handle and volumes increase. Long hauling distances and heavy stone or rock removal require heavier equipment. Generally, flat or gently rolling terrain is suited to labor-based construction methods, while hilly or mountainous terrain requires equipment-based methods.

Tools

Labor-based construction requires a variety of hand tools. These include shovels, picks, mattocks, sledges, trowels, wheelbarrows, axes, saws, and machetes. Tool handles, sharpening files, and other miscellaneous articles are required to keep hand tools in good repair. Extra tools should be available for use when something is damaged or when handles are broken. Tool handles are usually available in the local markets and are best replaced by someone who is familiar with that task rather than by the individual user.

In some areas local labor may be more accustomed to local tools that are not universally used. The supervisor must then decide which tool is most appropriate to use. Training in the use of unfamiliar tools may be necessary.

Equipment

Substantial savings can sometimes be realized if local equipment can be used instead of more costly imported road-building equipment. For example, animal-drawn carts or wagons can be used for hauling materials when distances are short, farm tractors with attached blades can be used for spreading loose materials, and soils dug by labor can be loosened by tractors or animal-drawn plows.

When the work is equipment-intensive, the following are normally used:

1. Dump truck — Most useful for transporting loose materials over longer distances than is practical for a wheelbarrow. The number of trucks required will depend on hauling distances, method of loading, and the number of current activities. The number of trucks used should ensure that both loading equipment and trucks are constantly employed.
2. Motor grader — Very versatile, used for moving small quantities of materials over short distances. It spreads, levels, and shapes the earth and materials to form roadbeds or other surfaces. It is used to form ditches and cut and dress slopes. With a scarifier attachment it can loosen hard soils. Its long wheel base makes it ideal for shaping the final road surface to the proper cross slope and grade. One grader is normally adequate for a 10-km project.
3. Roller — Used to compact soils and other surfaces. Several types are used; steel wheel, sheepsfoot, and rubber-tired are most popular. They may be towed or self-propelled. Different types may be more effective for different soils. The best type for all around use is the rubber-tired roller. Other equipment may sometimes be used as a substitute, but the roller is considered essential for good construction even on labor-based projects.
4. Bulldozer — Used to move large volumes of earth for short distances. Its great power is particularly useful for heavy work. It can be used for rough grading, leveling, clearing stumps, and moving large boulders. Its use may be difficult to justify for low-cost roads with light soils and low volumes to be moved. In low-cost road construction there is greater need for the bulldozer in hilly to mountainous terrain than in flat terrain. Tracked bulldozers cannot be used for compaction because the unit weight on the track is too low. A Caterpillar D9 tractor that weighs 95,000 lb has a ground pressure of less than 15 pounds per square inch, while a 10-ton (20,000 lb), three-wheel roller has a compression under the driving wheels of 275 pounds per inch of roller width or more.
5. Front-end loader — Most useful for loading trucks and for moving large volumes of earth for short distances, without trucks. In low-cost construction it is often used primarily for loading trucks at borrow sources. However, it could be used for excavating cuts. It would not normally be used in labor-based construction.

Other miscellaneous equipment may be required, depending on the nature of the construction and the degree to which hand-labor is used. An air compressor and drills may be needed if substantial rock is encountered. Small amounts of rock can be drilled by labor. Pile driving or bridges may also require heavier equipment, but reasonable efforts should be made to substitute less costly methods of construction whenever it is practical to do so.

SITE PREPARATION AND CLEARING

Site Preparation

As early as is practical, the entire project area should be checked for ponding and wet soils. Later construction problems can be prevented if the site is drained or exposed to the sun and wind. Borrow or gravel sources should also be located and prepared for extraction when needed. They may require access roads or clearing and top soil removal.

Staking the Work

The project must be staked for control of the work. The amount and details for staking will depend on what work is to be done. New roads will require staking to locate the centerline, centerline elevations, tops of slopes, and toe of embankments. The information on which staking is based is obtained from the engineering plan and the typical section. A survey crew usually sets the line in the area to be improved. The foreman is given a set of cross-sections and a profile so that the grades can be set as required. String lines are set later to ensure that the material is excavated or dumped and spread to the proper grade and cross-section. Further string lines are required to set ditch grades to drain, especially in flat terrain.

Clearing

Clearing consists of removing the existing vegetation in preparation for excavation and the formation of embankments. Clearing may also be required in areas where ditches are to be dug or borrow sources excavated. As a minimum, a strip measuring about 1 m beyond the top of cuts and the toe of embankments is cleared. Additional widths should be cleared where the line of sight would be obstructed at intersecting roads or around curves. Clearing well back from the road in heavily wooded or wet areas provides exposure to the drying effects of sun and wind that can be beneficial to construction. Road blockage from falling trees can be minimized if the clearing extends 1½ to 2 times the height of tree cover. Greater widths may be desirable in the tropics on the roads with a north-south orientation.

Clearing consists of one or a combination of the following operations, depending on the type of project and the characteristics of the vegetation:

1. Felling trees and cutting shrubs. If the trees are of sufficient size and quality to be marketable, they may be cut to appropriate size for transporting. If not, they may be cut to a size that is convenient for local inhabitants to use and may be given away. Trees should not be left too close to the edges of the tops of slopes because continued weathering often causes them to fall down.
2. Undercutting — disposal of undergrowth, grass, and weeds.
3. Grubbing — removal of tree stumps and roots. Where termites or white ants are not indigenous, stumps that will be covered by 1.5 m or more of embankment may be left in place.
4. Cleaning and burning — cleaning the road area of cleared debris and burning, or otherwise disposing of, what cannot be used. Useful products from the clearing are placed in such a way that they will not obstruct the operation of the drainage or interfere with traffic or construction activities. Of course precautions must be taken to prevent uncontrollable fires.

Clearing is invariably done by hand. The tools used are axes, handsaws, and machetes for the felling, and shovels, mattocks, and grub hoes for the clearing and uprooting. Shovels are used for extracting stumps, and dynamite may be required for large stumps.

Clearing lends itself well to stage construction. It can be done far in advance and independently of other construction activities. For example, some savings in labor and equipment cost can be realized if the local inhabitants are permitted to cut the wood that needs to be cleared for their own use. Because some control of the cutting and removal is necessary, areas or individual trees to be cleared should be identified and authorization given for removal in advance.

Such a program can be undertaken as a separate stage of development to be begun well ahead of actual construction activities and can be included equally well in localized improvements or in major projects.

SOILS

General

After the topsoil has been removed, the excavation and the formation of embankments may proceed. The best roadbeds and embankments are built when the soils involved are known and understood(6).

For low-cost roads, soil is the most common building material and may be the only material. Some soils are perfect for that purpose, and most soils can be improved with proper techniques. Although soil properties vary widely, they can be classified into groups with similar characteristics.

Soils consist of four physical components: gravel, sand, silt, and clay. Natural soils may be composed entirely of one component, but they usually consist of two or more. The main physical characteristic used to identify soils is particle size. Gravel and sand are defined as coarse-grained components; silt and clay as fine-grained components. Any of these may contain varying amounts of organic material that is sometimes defined as a fifth component. Gravel, the largest component, ranges in size from a man's fist to a small pea or bean. It is commonly known, easily recognized, and often found in stream bottoms, relatively free of the other components. Sand, the next largest, ranges in size from a small pea or bean down to about the smallest size the unaided eye can see. It is commonly found along with gravel, and is present in varying amounts in most soils. Silts and clays are too small for the individual particles to be seen by the unaided eye. If the gravel and sand are removed from a soil, silt and clay remain. The clay portion is plastic or putty-like. The silt portion is not plastic and behaves more like extremely fine sand.

Clay may be characterized as low plastic or high plastic. Moist fine-grained soils (silt and clay) that can be formed into ribbons by rolling between the hands are described as clays, although they may contain some silt. The longer the ribbon that can be formed, the more plastic the clay. Ribbons that break into short segments indicate clay that is less plastic and contains more silt. If the soil is dry and lumpy, the more effort required to break the lumps, the more plastic the soil, and the higher its clay content.

A simple test will determine the approximate amounts of each of the components of soil. Place a sample of the soil in a glass jar, filling it to about the one-third point. Add water until it is about two-thirds full and shake vigorously. Allow the material to settle until the water is clear or nearly so. The sand will settle to the bottom and can be distinguished from the silt that will settle on top of the sand. On top of the silt is the clay that is also distinguishable from the silt. The thickness of each layer will indicate its percentage of the total.

The ideal material for road building is one that is mostly gravel and sand with just enough silt and clay to bind it together. The gravel and sand particles will vary from coarse to fine in order to provide interlocking between them. It does not become soft when wet or loose and dusty when dry. The more a soil approaches this standard, the better it is for road building.

Gravels and sands without any silt or clay make good embankments if the embankments can be confined, that is, they can be covered with other materials to hold them in place. They are better if the materials used contain some fine particles to fill the voids between the coarse particles and to bind them together. The silt and clay content may increase without much loss in quality if the soil reamins relatively dry. But as the silt and clay content increases and if the moisture content becomes excessive, the soil becomes less stable.

The same may be said for gravels and sands used for surfacing. Clean gravels and sand (those without any silt or clay) provide good support for wheel loads when confined, but without binder they are quickly displaced by wheel or tire action. If they contain the right amount of binder, gravels and sands are stable and provide good support without displacement. If there is too much binder the soils soften when wet and become dusty when dry.

Soils that are mostly silt and clay generally make satisfactory embankments if they are controlled. If the moisture content at the time the material is placed is not within certain limits, these soils become difficult to handle. If too dry, they are hard to extract and are lumpy; if too wet, they are slippery or may turn to mud. Embankment silt and clay soils may perform satisfactorily while dry, but they become soft when wet, making the in-situ surface of most tracks or unsurfaced roads impassable during wet seasons. This is why it is important to provide adequate drainage adjacent to the roadbeds and to ensure that the drainage functions properly. Those silts and clay soils with greater quantities of gravels or sands are better and are applied to roads to obtain all-weather surfaces.

Soils are found within short distances of each other may vary considerably in composition, and different strata of soil at any one location may also vary. When such variations occur and the variable soils are used for building embankments, the poorer soils should be placed at the bottom and the better soils on top. The pressure of a vehicle wheel on soil decreases with the depth of the soil, so that if the poorer soils are on the bottom they are subjected to less pressure and are less likely to be deformed by the loads. Conversely, the better soils at the top are better able to withstand the more concentrated loads without deformation (Figure 14).

Because of economic considerations, the engineer will seldom have much choice in selecting soils for use in low-volume road construction. He should select the best of those available and make the best use of those that are poor.

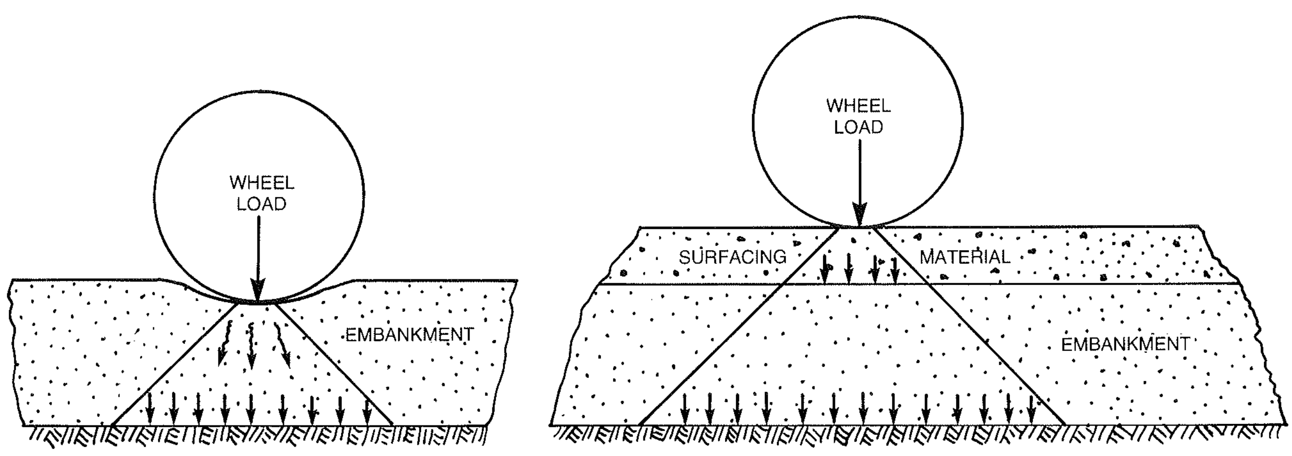
Compaction of Soils

In addition to soil quality, the performance of individual soils as road building materials depends on how they are placed. There is no single factor that produces as much stability in a road formation as does proper compaction. Cost of compaction is moderate, the means for accomplishing it are varied and generally accessible, and the benefits are substantial.

Soil compaction is a mechanical process in which the soil is made more dense, usually by rolling. Compaction makes a soil tighter, denser, stronger, keeps it drier, and minimizes swelling, shrinking, and settlement. The surface of a well-compacted road is stronger, more durable, less likely to form wheel ruts, and less costly to maintain than one on a poorly compacted or uncompacted formation. Five factors are involved in compaction: (1) type of soil, (2) equipment, (3) thickness of soil layer, (4) number of passes of the equipment, and (5) moisture content.

Certain soils are more easily compacted by one type of roller than another (6), but the builder of low-cost roads has practically no choice of soils and seldom a choice of roller. In general, the rubber-tired roller is the most effective with most soils. Steel wheel rollers may be more universally available, but they are less effective for general use. They can be used if the layers to be compacted are thin, but on uneven ground they tend to "bridge" and compact unevenly. They are best used for finishing surfaces. A loaded truck can be used as a substitute for a rubber-tired roller, and in many cases may compact better than the other types of rollers. If a truck is used, care should be taken that the wheel tracks are well distributed over the width of the formation. Sheepsfoot rollers compact clayey soils but are seldom satisfactory for silts and fine sands.

Figure 14. Load distribution in soil.



Notes
- Greatest load pressure is at surface; load spreads as depth increases; place best soils at top, poorer soils at bottom
- In the upper-left diagram, load causes ruts or deformation to road surface because embankment soil provides inadequate support; reasons may be poor soil, poor compaction of embankment, too wet, or combinations of each
- In the upper-right diagram, a surfacing material (usually gravel-sand-clay mixture) has been placed on the same embankment; surface is less susceptible to moisture and supports the load without deformation; when load pressure reaches the embankment the pressure is spread over a larger area and can be supported without deforming the embankment material
- Poor embankment materials and/or heavy loads need thicker surfacing layers
- Both surfacing and embankments provide better support without deforming if compacted thoroughly

Soils should be spread in layers that do not exceed 15-20 cm of thick, loose measurement. Thicker layers are more difficult to compact. The compaction equipment travels longitudinally with the embankment, starting at the edges and working toward the center. There should be an overlap of about one-half the width of the roller on each pass to ensure uniform compaction.

The number of passes required will vary with the soil, its moisture content, the kind of equipment, and the thickness of the soil layer. The average is four to six coverages. Dry soils will require more passes. Excessively wet soils should be given time to dry before compacting because if they are compacted when wet they become spongy and will prevent subsequent layers from being compacted properly.

For each soil there is a moisture content that is best suited for compacting that particular soil. At that degree of moisture, the optimum. moisture content, the highest density can be obtained with the least number of equipment passes. Accurately determining the optimum moisture content involves a rather detailed laboratory test. However, an approximation that is adequate for low-cost construction can be made by the following simple field test.

Fine-grained soils and dirty gravels and sands should be thoroughly damp, not too wet and sticky, and not dry and dusty. They should be damp enough that a ball of soil will sticky together when squeezed in the hand but will not stick to the hand. As a check, drop the ball of soil on a hard surface from a height of 45-50 cm. It should be moist enough that it cracks but does not shatter after striking the surface. If the soil at the work site sticks to the feet or to the equipment it is too wet; when it is dusty, it is much too dry.

Taking advantage of natural conditions can reduce the cost of compacting the soil. In dry weather the soil will usually be at its highest moisture content when it is first excavated. It should be placed and compacted before it dries. The moisture can be increased by sprinkling the soil with water, but this is costly and water is not always available. Soil that is too wet should be permitted to dry in the sun and wind. Drying can be accelerated by loosening the soil for greater evaporation. However, in rainy seasons care must be taken to prevent the soil from becoming even wetter. Wetness can be minimized when storms threaten by shaping the surface to drain and by lightly rolling to provide greater runoff.

Unsuitable Soils

Sometimes roads must pass through areas where the soils are not usable for road construction. Satisfactory results can often be obtained by mixing these soils with varying amounts of lime, cement, or brick dust to improve their stability(12).

Black cotton soil is often encountered in tropical and subtropical climates. This is a highly plastic soil whose volume changes greatly as the moisture content changes. The ill effects of the volume changes can be controlled by insulating the road embankment from the black cotton soil with a layer of sand. About 15-20 cm of sand will stabilize the moisture content of the underlying soil and minimize volume changes. Culverts and other small structures must be similarly insulated with sand layers to prevent volume changes from disrupting the flow profiles.

When acceptable surfacing materials cannot be found, it is sometimes possible to combine soils from two or more sources to produce one that is acceptable. For example, if a granular material is available from one source and a cohesive material from another, and neither is satisfactory by itself, they both may be hauled to the site and mixed in the proper proportions. It is a good idea to lay some trial sections that use varying amounts of each material to determine the best proportions.

Treating soils with additives like cement or lime, or mixing two or more soils together, is costly. The procedure should be avoided unless there are no practical alternatives.

EARTHWORK

Removal of Topsoil

Topsoil normally varies from 10 to 30 cm in thickness, depending on many conditions of growth, soils, and climate. It may not be present in barren, rocky, or eroded areas. It is easily recognized by its darker color as compared to the underlying soil and is generally not suitable for embankments.

Topsoil can be laid aside for later use on the project or may be discarded. It contains nutrients and can be used on slopes to encourage growth and to minimize erosion. Topsoil can also be used to flatten the slopes of embankments. If used as part of the work, it is placed in its final position after the cuts and embankments are constructed and shaped. It should not be stored, even temporarily, where it will contribute to the silting of drainage facilities.

Tracks or old roads often have varying thicknesses of mud or other sediment on their surface or along the roadsides. This is extremely poor material for road building. If the new road is on a shallow embankment and is being placed over the sediment, the sediment should be removed and discarded. If the embankment is greater than 0.5 m, the sediment may be leveled and left in place, provided it is not so thick or soft that it will cause an unstable embankment.

If existing embankments are being widespread, the growth and topsoil on the slopes should be removed before placing additional material. This permits a better bond between the old and the new material.

If the project is labor-based, the removal of the topsoil is done with shovels and mattocks. It is moved to the edge of the road right-of-way beyond the limits of cuts, fills, or ditches, where it is stored. Later it can be moved in wheelbarrows and placed on the slopes or embankments.

If equipment is used to remove topsoil, a motor grader is preferred. The blade of the grader is angled so that a windrow of the topsoil is formed. The windrow may be moved by a front-end loader to the stockpile, or it may be loaded into a truck and hauled away.

A balance between equipment use and labor may be appropriate. The grader would do the more difficult work of loosening or windrowing the topsoil. Labor could then move the loosened material to the stockpile either by truck or wheelbarrow. If a motor grader is not available, a bulldozer can be used and might be preferable under some conditions. The frond-end loader, though less versatile for this purpose, might also be used.

Excavation

After the topsoil has been removed, the roadbed can be formed by cutting high areas, filling low areas, and shaping the roadbed. In flat areas the forming may consist entirely of cutting the ditches and placing the excavated material between the ditches to form the roadbed.

When the work is labor-based, excavation is done with mattocks and shovels, and the material is taken to the embankment area. The laborers must be spaced far enough apart to ensure that they are not accidentally struck by the tools of laborers beside them. Excavation should not cause landslides that would endanger the workers (Figure 15). If the hauling distance is short (under 100 m) the excavated material can be moved by wheelbarrow. For greater distances vehicles are usually required. The hauling distance can be kept to a minimum by balancing the cuts with the fills.

If the project is equipment-intensive, excavation will depend on the kind of equipment that is available and the nature of the construction. The frond-end loader is most versatile and can be used to excavate all but the hardest materials and for loading. A bulldozer can loosen the harder material and can move it short distances. It cannot be effectively used for loading unless through a chute or other arrangement where material can drop into a truck(10). A grader can also loosen and move soil for short distances, but it is less productive for that purpose than the bulldozer. However, it is an extremely versatile piece of equipment for cutting ditches, shaping slopes, and for other fine grading work(7).

The work should be planned to take advantage of gravity rather than oppose it. Workers should load to the low side of the hauling equipment and push materials downgrade rather than upgrade. Excavation should proceed so that the center of the cut remains high enough to assure drainage toward the edges.

Excavation continues until the planned centerline elevation is reached. The roadway is then carefully shaped to the required cross-section. The section can be controlled by stretching a string across the roadway at some selected height above the finished centerline grade. The correct offsets are then measured down to the points of the road formation. Key points are the centerline, the edge of the roadway, the top of the ditch, and the bottom of the ditch.

Finishing and dressing of cut slopes are generally done by hand, using mattocks and shovels, but may be done by grader. Provision of proper slope, removal of excess materials, and compaction of loose areas will minimize the possibility that the slopes will eventually slide down to obstruct drainage (Figures 16 and 17).

If berm ditches are required to prevent excessive erosion of the slopes, they should be excavated before the slopes are finished. Berms should be placed well back from the top of the slope to minimize landslides.

Embankments

General. Low-cost, low-volume roads will generally have low embankments, perhaps less than a meter above the adjoining terrain. Exceptions may occur at cross road culverts, low areas subject to flooding, and in more hilly terrain. The following engineering principles should be applied to embankment construction to make the difference between a good road and a poor one:

1. Start with a firm base;
2. Place fill material in layers of moderate and uniform thickness (15-20 cm);
3. Compact each layer thoroughly; and
4. Control drainage to minimize wet soils both during and after construction.

Firm base. Any wet or soft areas in the alignment should have been corrected by drainage or exposure early in the project.

Figure 15. Hand-labor excavation sequence.

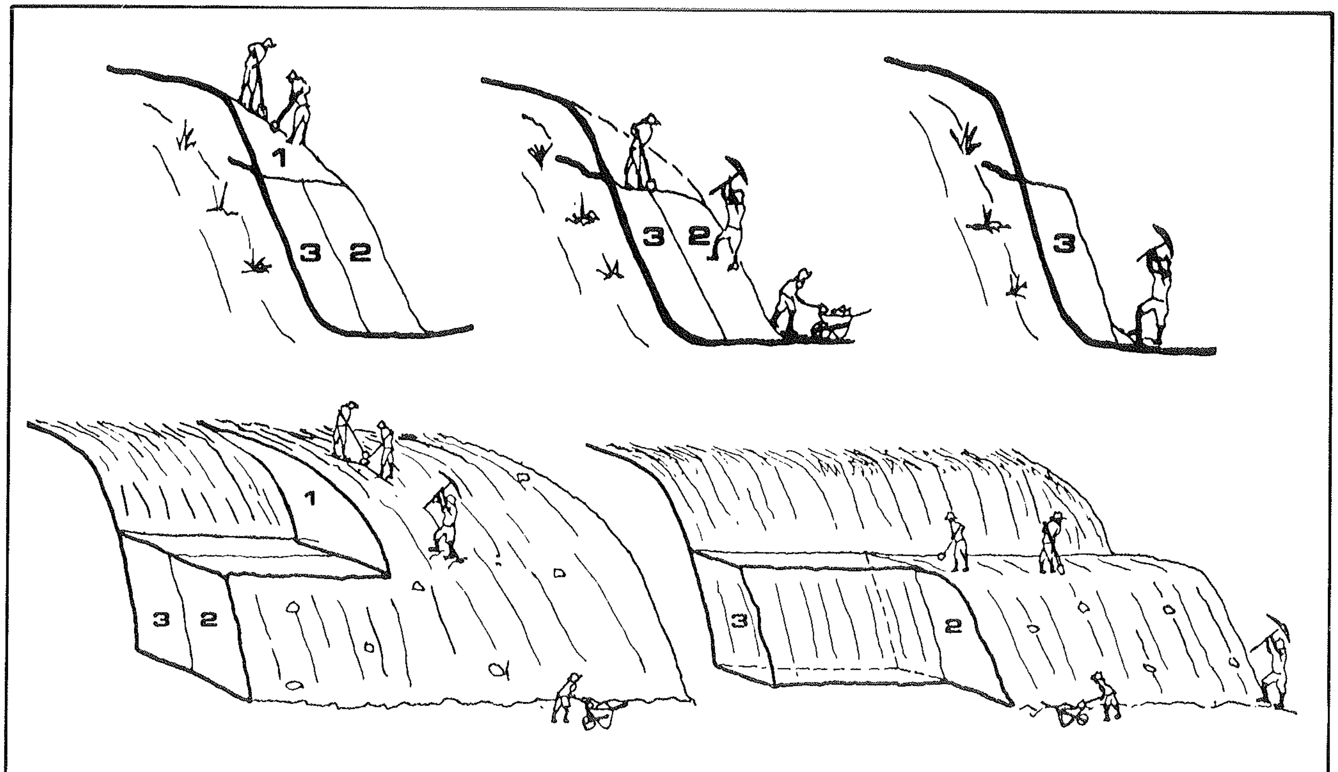
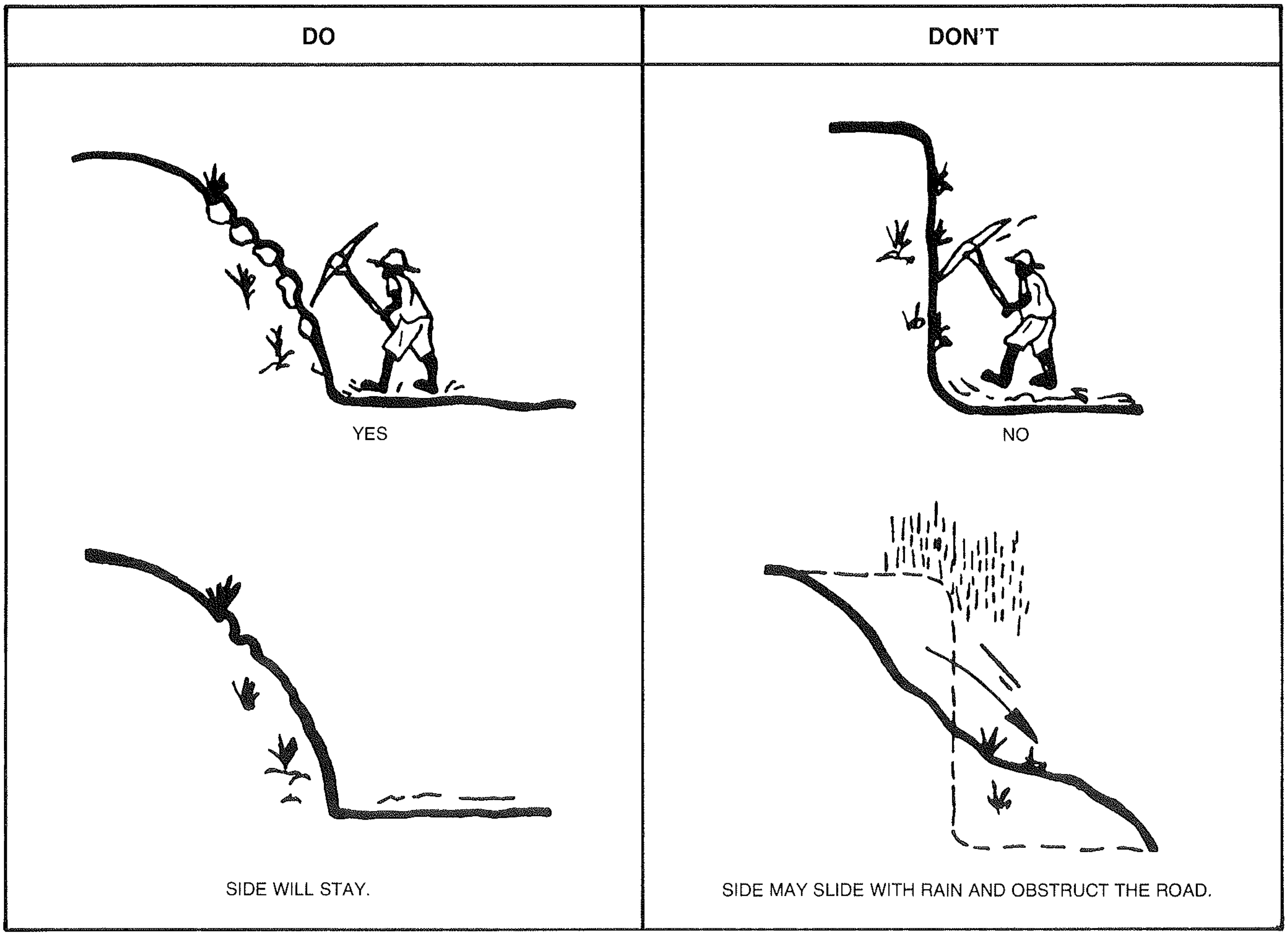


Figure 16. Excavating stable slopes.



By the time embankments are started the base should be firm. Construction will often involve upgrading tracks or unimproved earth roads and with the improved road placed over the old travel area. These tracks or old roads are often sunken below ground level and badly rutted. Discarded material often forms ridges at the sides. Before any embankment material is placed, the old road area should be leveled to a reasonable extent, either with hand tools or equipment such as a grader or bulldozer. If holes or sharp depressions exist, they should be filled and compacted before starting the embankment layers.

Special base conditions. Sometimes embankments must be placed across swamps, marshes, or other unstable soils that are too soft to support them. If the soft material is shallow (less than 0.5 m), it may be practical to remove and replace it with fill material. The weight of higher embankments may simply displace shallow soft materials, resulting in continuing and irregular settlement. The settlement may or may not be objectionable, but leveling the settled road surface from time to time is simply done.

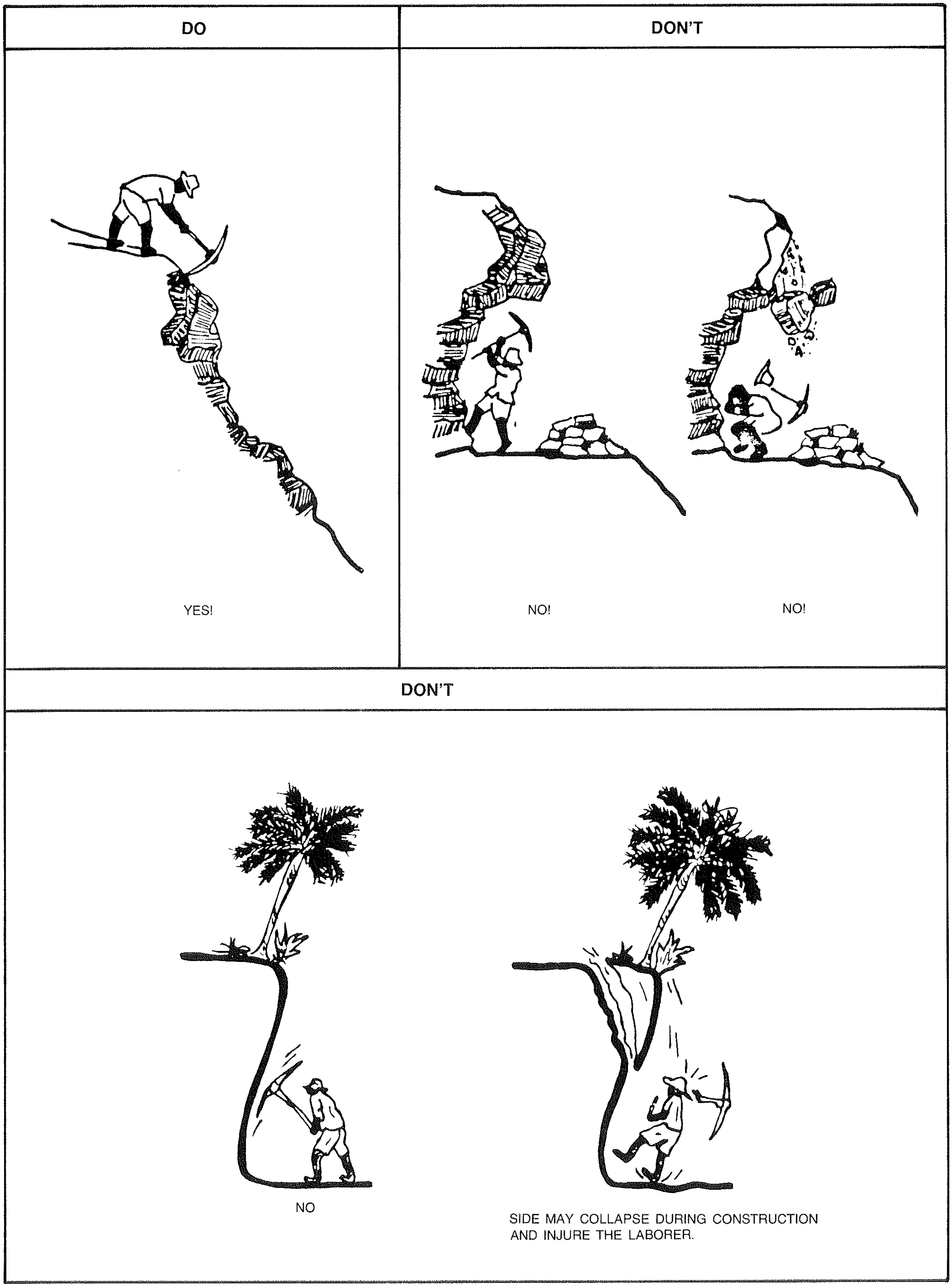
If the material is deep and too soft to support an embankment, it may be crossed by taking the following steps:

1. Place a compact mat of brush, twigs, leaves, or small limbs about 1-2 m thick on the area to be crossed. The width of the mat should be about twice the width of the bottom of the embankment to be placed. Thickness and width can be altered depending on the softness of the swamp.
2. Place on the mat the minimum thickness of embankment material required to provide a working platform.
3. After a few days, place a layer of embankment material not to exceed 0.3 m, and observe the settlement for about two weeks.
4. If the settlement appears reasonably uniform and if no lateral slippage has occurred, add another thin embankment layer. Do not compact any of the layers. Repeat the addition of thin layers at increasing time intervals until the minimum elevation that will allow usage has been reached. If slippage occurs, stop all loading in the slippage area for an extended time period and slow the loading schedule on the remainder.

Never build the embankment higher than the minimum required. As settlement occurs, it can be raised from time to time, but always in thin layers. If loading proceeds too rapidly and slippage occurs, there may be no correction that is economically feasible.

Forming the roadbed with labor. After the topsoil has been removed and major irregularities leveled, the roadway is formed by digging ditches and depositing material in the roadway area (Figure 18). The work is done with mattocks,

Figure 17. Safe slope excavation.



shovels, and wheelbarrows. The material should be placed in layers not more than 15 cm thick across the width of the embankment. The depth of digging can be controlled by placing taut strings from which the depths can be measured; for easy control by the workmen, sticks can be cut to the proper length or marks made on the handles of the digging tools.

For the reasons discussed earlier, each layer placed in the embankment should be compacted. If no roller is available, other means may be improvised. A loaded truck is a possible alternative.

The material made available from forming the ditches may not be sufficient for building the embankment to the desired height. Additional material may be obtained by digging a wider, flat-bottom ditch. This is often done intentionally to provide greater volumes of earth for a higher grade and better ditch drainage. It also tends to lower ground water levels and keep road embankments drier. Additional embankment material can be obtained from cuts or roadside excavations. When nearby sources cannot be located, trucks or other transporting equipment must be used to bring borrow material to the work site.

Forming the roadbed with equipment. Unless there are substantial embankments, the initial work with equipment is "pulling the ditches" with a grader. The grader blade is set to the desired angle and the ditch is cut by proceeding along the alignment at the planned distance from the centerline. The material is bladed toward the center as repeated cuts are made. All material is moved toward the center and spread in thin layers with the blade. The center of the roadway is kept high at all times to maintain drainage. This procedure continues until the ditches are cut to their final depth and the roadway is shaped. The grader tires will provide some compaction but the surface should be rolled to provide uniformity.

If the embankment requires more material than the ditches provide, additional material can be obtained from cut areas on the project or from other borrow sources. Dump trucks bring the material to the embankment. The grader spreads the material over the entire surface to the desired thickness. The amount of spreading required can be reduced by spacing the dumped loads at intervals along the roadway.

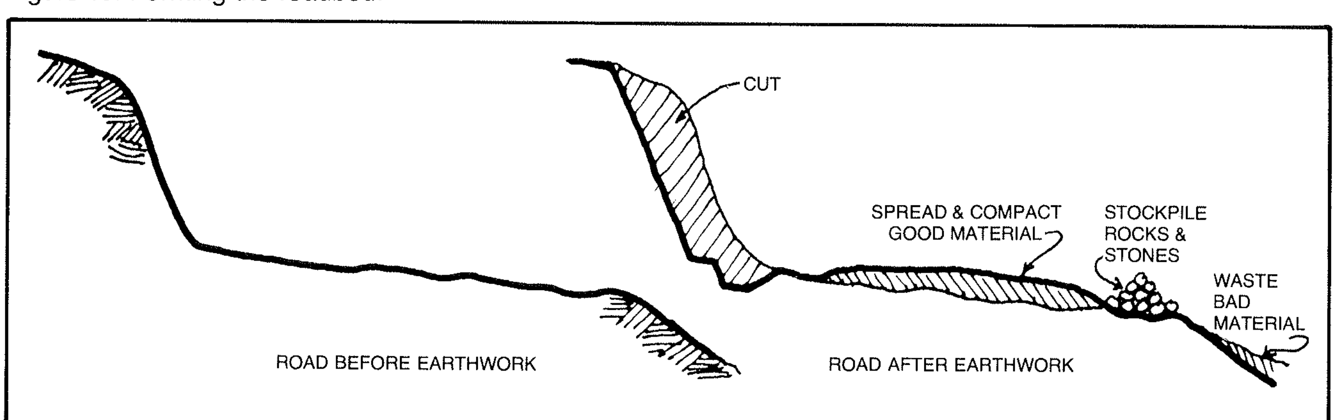
After the material is spread, each layer is rolled by starting at the edges and working toward the center. Each pass of the roller should overlap the preceding pass by about one-half. Unless the soil is too wet, rolling should commence immediately after the spreading and before the material dries out. Varying the paths of the trucks over the embankment as they deliver the material will aid in the compaction, thus reducing the number of rolling passes required. The grader should maintain a smooth even surface until the embankment reaches the desired height, always crowned to drain.

Whether the final surfacing material is to be placed immediately upon completion of the embankment or at some future date, the embankment surface should reflect good workmanship. It should be firm with no soft or spongy areas. The crown should be adequate for runoff without being excessive. The surface should be free of depressions that could retain water. Even a small depression will allow softening of the soil when wet and cause potholes under traffic.

Widening embankments. Stage construction may involve the widening of an existing embankment or the digging of new ditches to provide a wider road. The principles of good construction remain the same. Materials should not be dumped off the side of an embankment to widen an existing embankment. They should be placed in horizontal layers with each layer compacted. This will minimize differential settlement between the embankment and the widening. Old ditches underlying the shallow embankments of the wider road should first be cleaned of any soft or wet material. They should then be filled with well-compacted material before starting to build the new embankment.

Compaction alternatives. Funds available for low-volume road construction may not always provide for compaction equipment. While the advantages of compaction are undeniable, many roads have been built in the past without a conscious effort to compact them. The road builder without compaction equipment should make every effort to provide the best compaction he can by whatever means is at his disposal. The emphasis on embankment compaction should be at the topmost layers. Most critical of all are backfills around culverts that are exposed to erosion from water. Wheeled equipment or travel of any kind provides some compaction. In confined areas hand tamping may be the best that is available.

Figure 18. Forming the roadbed.



ROCK EXCAVATION

Rock excavation is costly and highly specialized. It should be avoided if there are reasonable alternatives such as changing the alignment or grade. When solid rock cannot be avoided, it is usually necessary to blast with explosives. The blasting operation includes the following activities.

Drilling

In this operation, holes are made in the rocks for placing the explosives. This can be done by hand or equipment, depending on the amount to be done and the equipment available.

Placing the Explosives and Blasting

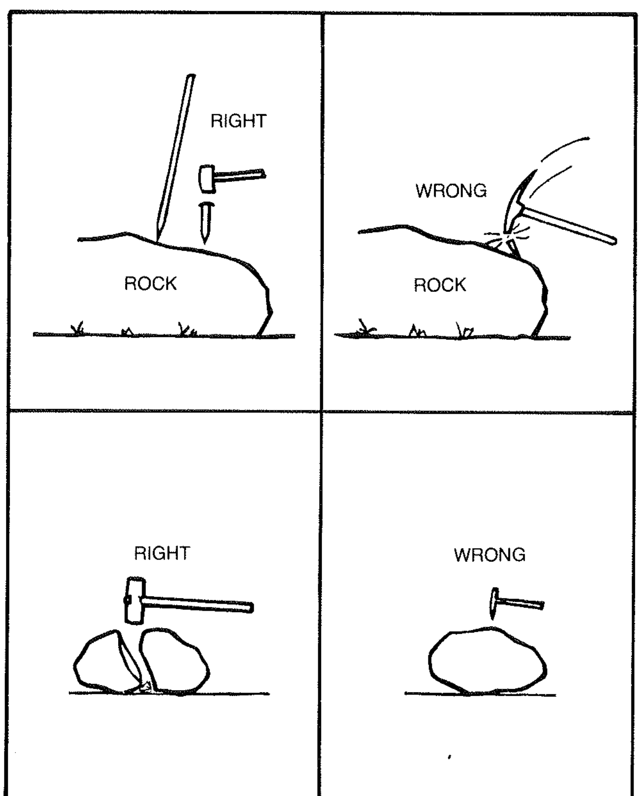
Contrary to drilling, this operation requires the use of skilled workmen. Experience is of the utmost importance in locating the proper drill sites and in loading the holes so that no unnecessary risks are taken with badly placed charges. Improperly placed charges can result in inferior fragmentation that makes road building operations uneconomical. Unless the workmen are well qualified, explosives advisors should be employed. After the explosive has been inserted in the hole and prepared for blasting, all personnel within the blasting area are to be warned of the impending blast by a whistle or other alarm.

Extracting and Loading

Once the blast has taken place, the shattered rock is picked up and loaded for removal. If the fragments are too large they can be broken with mauls or sledge hammers (Figure 19). Excessively large fragments may be a measure of inefficient blasting and may require additional blasting. For short distances wheelbarrows can be used for removal, otherwise dump trucks are used.

The fragmented rock may be used in embankment construction, but only the small fragments should be placed in the uppermost layer. Using large pieces at the surface results in a rough and rocky surface. More rectangular or cubical shaped fragments may be used for building culverts, bridges, or retaining walls, or for surfacing critical sections of roadway. Poorer shaped fragments are useful for erosion protection. Small fragments or chips, even though mixed with soil, can be used in the roadway. The fragments are especially effective in strengthening localized soft or spongy areas.

Figure 19. Breaking rock with hand tools.



Safety

Strict safety measures must be employed to avoid accidents with explosives.

- The fewer men handling explosives, the fewer accident risks.
- Never keep explosives and blasting caps together and never allow the same workman to carry both.
- Allow only one person to carry, connect the wiring, and activate the detonator.
- Work should be assigned according to experience.
- The work party should have exact knowledge of each individual's duties.
- Storage magazines should be entrusted to one man only.
- The magazine should be surrounded with a protecting earth embankment that contains no rock fragments.
- All safety regulations must be observed.

SURFACES

General

Surfacing is a means of providing a more reliable road throughout the year regardless of weather conditions. The surfacing material may be placed either immediately following the construction of the road formation or as a later stage development. Both methods have advantages and disadvantages.

If surfacing material is placed as part of the initial construction, traffic is provided with an all-weather surface immediately. Any further extensive reshaping of the road in preparation for surfacing is eliminated. The greatest disadvantage is the greater initial cost. However, there may also be difficulties in initiating a new project for surfacing at some later date. Some countries include surfacing in the initial work as a matter of policy.

Delaying the surfacing to a later stage of development has the advantage of lower initial costs. Funds are not committed until the need is evident. Such a decision also allows time for the road formation to become more stabilized as it ages. If problems develop they can be corrected before surfacing is placed. Delaying has the disadvantage of not providing as reliable a surface initially. It also requires more extensive preparation for surfacing due to the long-term effects of erosion and traffic.

Staged Surfacing

Preparing an older road for surfacing usually requires much more work than is required for a recently constructed road.

The ditches should be cleaned and the flow lines reestablished. This may require completely new ditching or merely the removal of debris and silt from the existing ditches. Ditch sediment is generally of such poor quality that it should not be placed on the road surface. Ditch outlets and culverts should be cleaned to ensure roadside drainage. Drainage and erosion problems should be corrected. It is likely that the road surface will be misshapen from erosion and years of usage. It should be rehshaped to provide a suitable crown for runoff and then recompacted.

Roadway shaping is done with a motor grader and some labor support. Either a rubber-tired or steel-wheeled roller can be used for compaction. If either graders nor rollers are available, the work can be done with picks, mattocks, and shovels. Local or improvised drags, either tractor- or animal-drawn, can be used to spread the loosened material more evenly along the road. Traffic will provide compaction if the material is moist.

Gravel Surfaces

Before starting the surfacing operation, suitable sources of material must be located. In many areas this may require considerable time and should be started well in advance of when the materials will be needed at the road site. For endurance, a good surfacing material must be stable under both wet and dry conditions and resistant to abrasive traffic action. In addition, the cost for delivery to the road site should be low.

The materials that meet these requirements are mixtures of gravel, sand, silt, and clay. Stability is achieved when the mixture is well graded, i.e., contains a more or less uniform distribution of particles ranging from coarse to fine.

Material sources. The main resources for surfacing materials are stream and river bottoms, terraces, and alluvial fans and sediments. Other deposits occur as a result of the underlying rock (**10, 11**). Very often materials that were used for local improvements may be suitable for reuse as surface material.

Because surfacing materials play such an important part in the performance of a road, they should not be approved indiscriminately. Samples of prospective sources should be subjected to laboratory tests and accepted on the basis of compliance with established specifications (**14**).

Samples for testing can be obtained by digging test pits or from the exposed faces of banks. When obtaining samples from a pit, each change in the soil layers is identified by a change in texture or color. A sample of each is bagged and labeled for location, depth, and thickness of layer, and submitted for laboratory tests. When sampling the face of a bank, a vertical strip of the face is cleaned of vegetable matter and weathered material. A sample is obtained by scraping loose a uniform amount of the bank face from top to bottom or from each stratum if there are appreciable differences in strata. When the tests from these preliminary samples indicate acceptable material, additional sampling should be undertaken to determine the limits of the suitable material and if an adequate quantity is available.

Time and work can be saved if a laboratory unit and trained personnel are available to assist in the search and to make preliminary evaluations.

Excavating the surfacing material. Before the excavation is started, the borrow area is cleared and the topsoil is removed and sectioned for quantity measurement, if measurement is required. In some cases haul roads must be built for access. If the surfacing is to be included as part of the initial construction it should get underway simultaneously with the earthwork so that the finished stretch of road can be protected immediately.

If the work is labor-based, the operation is similar to cut excavation except that the hauling is usually by trucks if appreciable distance is involved. The material is loosened with pickax and shovel and loaded by hand. When the excavation is from a bank, the placement of the truck should be lower than the workmen, thus increasing the work yield. The bank should be dug in steps, while maintaining a stable slope, so that there is no danger to workmen from landslides. If the excavation is from a pit, consideration must be given to drainage. A ramped approach permits access by truck to the pit bottom and increases the work yield. If the work is equipment-intensive, the loading is done by front-end loader.

When the material contains stones that are too large to be placed on the road, the stones should be removed at the source to save hauling. Stones may be removed by passing the material over a slanted screening device that rejects the large stones. The stones roll to one side while the remainder of the material falls through the screen to the truck. This device can be improvised in the field with a simple log or stone structure through which a truck can drive. Heavy reinforcing bars, railroad track, or similar material can be used for the screening. Large stones that are delivered with the surfacing material can be removed from the road surface by labor.

The material is hauled from the source to the road and dumped. The number of trucks required depends on the manner of loading and the haul distance. If all the trucks are the same size, loading and unloading will be more efficient. Immediately after unloading, the material is spread to the full width of the area to be surfaced. It may be spread either by shovel and rake or, if the project is equipment-intensive, by a grader and other equipment. It should be compacted without delay in the manner previously described. The hauling trucks can provide partial compaction by varying their travel over the surface. A fully loaded hauling truck can be used if no roller is available for the final compaction.

To ensure the proper drainage of the finished surface it is important that the planned crown of the road be maintained in the final compacting. The compacted surface should be checked frequently for correct thickness, and adjustments should be made accordingly.

Bituminous Surfacing

A bituminous surface treatment is often applied as a final phase of stage construction when traffic reaches predetermined levels. This type of surface preserves the surfacing materials, eliminates traffic dust, and provides a smoother and faster riding surface that is free from the softening effects of surface water. It consists of one or more coatings of bitumen and crushed stone or gravel aggregate. Clean sand is sometimes used as the aggregate. The aggregate is applied to the existing surface that serves as a base for the surface treatment. Surfaces that are not stable or that consist primarily of silts and clays with poor supporting value when wet are not suitable for surface treatment.

Equipment for bituminous surfacing. Equipment-intensive work requires a grader, water sprinkler, asphalt distributor, broom drag, stone spreader, steel-wheeled or rubber-tired roller (steel-wheeled rollers sometimes crush the aggregate), and dump trucks. Some of this equipment can be eliminated for labor-based work.

Materials. Various bituminous or asphaltic materials may be used depending on climatic conditions and availability. Materials that have previously proven satisfactory under local conditions should be given preference. Depending on local practice, what is available, and the number of coats to be applied, the aggregate should be a clean, hard, crushed gravel, usually ranging in size from 1 to 2.5 cm.

Procedure. The road is brought to the proper shape and grade with the depressions filled and irregularities leveled. This is best done with a grader because even small irregularities are objectionable to vehicles traveling at higher speeds. The surface should then be rolled until it is smooth and tight and wet down if necessary. Any loose material that remains should be removed. Sometimes additional material is required to bring the surface to the proper shape and grade. This material should be placed sufficiently in advance of the final finishing to become fully stabilized.

When the bitumen is applied the surface should be firm, slightly moist, and free of loose material or dust. If the surface is soft, the bituminous surfacing will soon break and disintegrate under traffic. If the surface is loose or dusty, the bitumen will not adhere to the surface. Usually the bitumen is applied with a pressurized, truck-mounted distributor, equipped with spray nozzles for even distribution. The distributor is also equipped with a heater for applying the bitumen at the required temperature, and a measuring device for control of the amount applied. Except for relatively small areas, application of this material by hand is not considered practical.

The bitumen penetrates the road surface and seals it from the softening effects of moisture. It also serves as a binding material to hold the stone that is spread on it before the bitumen begins to set or cure. This may be done with a spreader or by labor with shovels. If a spreader is used, it is attached to the back of a dump truck. The loaded truck is backed over the area to be covered in such a way that the wheels always ride on the stone being spread and not on the bitumen. If the spreading is by hand, the stone is shoveled from piles that have previously been placed at suitable intervals along the sides of the road.

Sufficient stone should be used to cover the surface with one thickness. More than one thickness is wasteful and will be cast to the side by traffic, while less than one thickness fails to provide the intended protection to the surface. Single surface treatments require approximately 25 lb per square yard (13.5 kg/m^2). Double surface treatments use from 35 to 70 lb per square yard (19 to 35 kg/m^2).

After the stone is spread, it should be broomed for even distribution. This can be done with either a drag broom or with hand brooms. The stone is then rolled, preferably with a steel-wheeled roller, to set the stone in the bitumen and to provide a smooth surface.

If a thicker surface is desired for greater durability, additional applications of bitumen and stone are made in reduced amounts. Two or three coatings are common for heavier travelled roads. A pilot car should be used to conduct traffic over the completed surface treatments at a miximum speed of 25 mph (40 km/h) for the first 24 hours after the aggregate is applied. For best long-term results, an additional coating is applied at three- to five-year intervals.

PIPE CULVERTS

General

Constructing culverts involves preparing the site, building or laying the culvert, back filling, and protection from erosion. Sometimes it is necessary to clean or realign the channel at the intake and discharge ends of the culvert to ensure proper flow.

Culverts are normally installed before the road embankment is placed. Where there is no flow during the construction period the embankment may be placed first and a trench excavated for placing the culvert. This is usually a more costly procedure and is to be avoided unless unusual conditions exist.

Culverts may be constructed from local materials such as wood or stone, if they are available. If not, either corrugated metal pipe or concrete pipe is commonly used. Concrete pipe may be produced at the site or it may be manufactured at a central location and transported to the site. Corrugated metal is usually an imported product, but it is lighter than concrete and is more easily transported to the construction site. If the culverts are large, the pipe may be produced in sections that can be nested for transporting and then assembled by bolting the sections together at the site.

Choosing the type of culvert to be placed is normally an economic consideration and will have been decided before the project reaches the construction stage. Locations at which culverts are to be placed are normally a part of the design and are also decided before the construction stage. The supervisor should always be on the alert for additional locations where water would be blocked by the road formation. Such locations require additional culverts unless the blockage can be relieved by minor ditching.

Exact placement of culverts should be decided in the field after examining the flow and channel conditions at each location. A culvert should be placed as part of a continuous channel, and it should alter the natural flow conditions as little as possible. If the grade of the culvert is flatter than the channel, the culvert inlet may fill with sediment. If the culvert grade is steeper than the channel grade, the culvert outlet may cause erosion.

There may be a natural inclination to place a culvert at right angles to the road centerline in order to save materials. This should be done only when the original channel is also at right angles to the road. If the culvert alters the direction of the stream flow, erosion can occur at either end of the culvert. There are greater overall savings if the culvert follows the course of the channel. When this is not possible, a new channel is cut and should be protected from erosion at points where the flow changes direction. If the direction of flow must be altered, it is better to make the change at the discharge end. This assures maximum protection of the embankment against scour and wash.

Before the culvert is placed, a smooth firm bedding should be prepared at the proper grade, altering the natural flow line as little as possible. If the stream is flowing, it may be necessary to relocate the flow temporarily in order to prepare the base or to place the culvert.

Building the Culvert

Wood. Where wood is plentiful, logs or ax-carved wood can be used. Wooden culverts should be considered as an expedient and not as permanent construction. Wood is sometimes used in order to gain access to the area for construction purposes and serves until the permanent culvert materials are available. In subtropical and tropical climates rot and insect damage make wood short lived. In temperate and dryer climates log culverts have been known to last many years.

Stone. Stone culverts are often built where stone is locally available. They are simple to construct and do not require highly skilled labor. Necessary materials are limited to stone, cement, sand, and water. They are best suited to sites where channels are well-defined.

Stones are selected and cut, if necessary, with a stone mason's hammer. A floor of stone with mortared joints is laid to the proper grade. Walls are built to the appropriate height. The top may be constructed as a flat arch if the span is not excessive and the road grade permits. If not, reinforced concrete slabs may be cast and laid across the tops of the walls. When the grade is low and when spans are not excessive, these slabs may be used as the riding surface without cover.

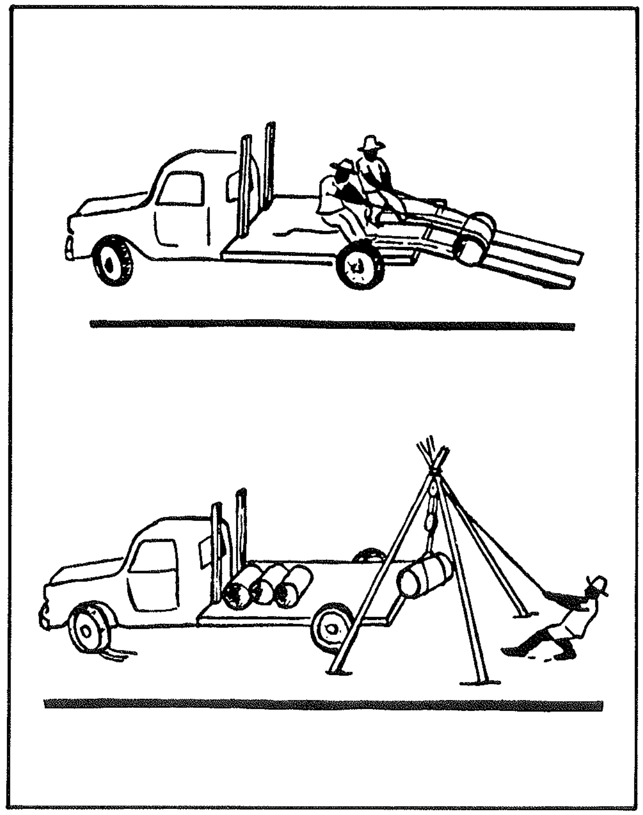
Concrete Pipe

When concrete pipe is produced at the site, care must be exercised to ensure a good quality product. Not only must the ingredients be properly proportioned and mixed but great care must be given to proper curing. The initial curing is obtained by keeping all the surfaces of pipe completely moist for a minimum of three days. This is done either by covering with moist burlap, by flooding, or by spraying. Hand spraying is usually not effective because of the tendency to allow the surfaces to dry before the next spraying.

The pipe should not be handled nor moved until it has aged for a minimum of seven days under favorable curing conditions. For less favorable conditions the aging time should be extended.

Reasonable care must always be used to prevent damage to the pipe during transporting and unloading. The pipe should not be dropped from a truck nor rolled down an embankment (Figure 20).

Figure 20. Handling concrete pipe.



Installing concrete pipe culverts. The load that the pipe will support as a culvert is determined to some extent by the way it is bedded. The least effective bedding results when the pipe is simply laid on the ground surface. A much more effective bedding is obtained when the earth is shaped to fit the lower part of the pipe for about one-half the diameter of the pipe (Figure 21). If the bottom of the pipe bed is rock or hard clay, a space below the pipe should be excavated and replaced with 10-15 cm of sand or compacted granular material. The pipe should never be laid directly on the rock.

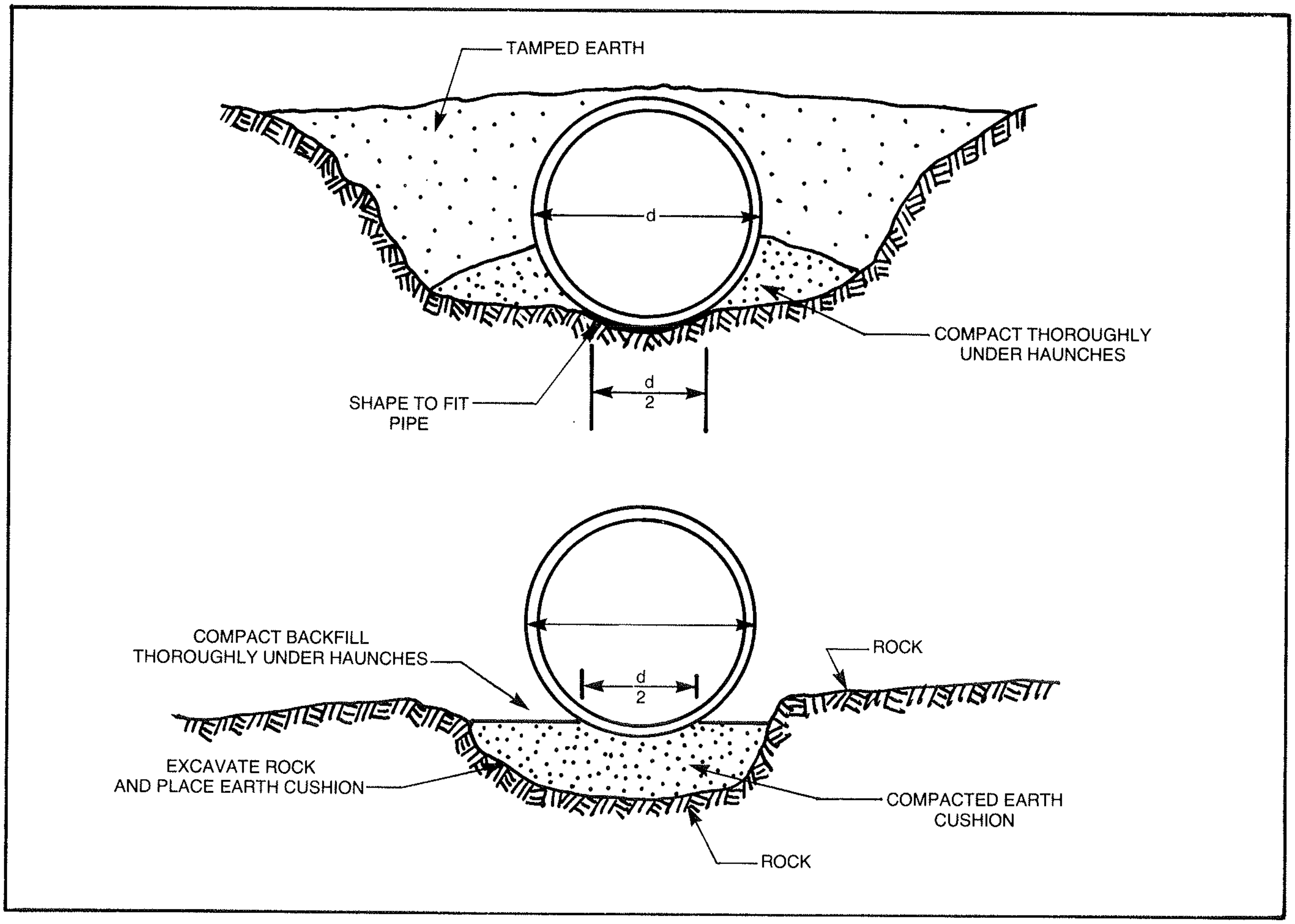
Concrete culvert pipe is made with a groove or recess on one end and a corresponding tongue on the opposite end. When the pipes are joined, the tongue enters the groove of the adjoining pipe to form an overlapping and smooth connection. The joints are sealed with cement mortar consisting of one part cement and not more than two parts of fine clean sand. Joints should be constructed so that the flow will not leak out of the pipe and so that water or sand will not seep into the pipe. Seepage may cause erosion under the pipe and eventually cause failure or blockage of the culvert.

The first pipe is laid on the downstream end with the groove upstream. The grooved end should be cleaned with a wet brush and the bottom half spread with mortar. The mortar will not adhere to a dirty or dusty surface, and will crack and break away if the surface is dry. A shallow excavation should be made underneath the end of the pipe at the joint. The excavation should be filled with mortar that will bed the joint of the first and second pipe. The tongue end of the second pipe is fitted into the groove end of the first pipe until the mortar is squeezed out into the inner and outer surfaces. The inner surface at the joint is then brushed smooth. The outer surface is covered with a bed of mortar. This procedure is repeated until the entire length of culvert is laid. The joints should be kept moist until the mortar has cured. Twenty-four hours is considered a minimum curing time (Figure 22).

If existing culverts are being extended as part of a staged widening improvement, extra care must be taken to ensure that the culvert extension is on a firm base and on the same line and grade as the original culvert. Before any extensions are placed, the original culvert should be checked to see that it is free of obstructions or debris and that the joints are tight.

Backfilling concrete pipe culverts. Backfill around the pipe should be fully compacted because of the susceptibility of backfill to erosion damage and future settlement. If backfill is carefully done, the culvert will be protected from misalignment or damage to the joints (Figure 23). The backfill material should be good clean earth, preferably granular, and should be free of lumps, boulders, roots, or excessive organic material. It should be placed on each side of the pipe with shovels

Figure 21. Bedding concrete pipe.



in layers not exceeding 10-cm loose thickness and should be thoroughly compacted with hand tamps (pneumatic tampers may be used if available). To be effective, hand tamps should not exceed about 150 cm² in size. Care should be taken to place and compact the material around the lower surfaces of the pipe in order to provide adequate support and distribution of loads. After each layer is compacted, additional layers are placed and compacted, keeping each side approximately even, until the pipe is covered by at least 10 cm of material. A minimum of 30 cm of material is desirable for cover between the top of pipe and the road surface, but the cover should always be adequate to protect the pipe from damage (Figure 24).

The supervisor should keep in mind that the greatest density is obtained when the material is at optimum moisture content, somewhere between very wet and very dry. Puddling or water flooding for consolidating the backfill is recommended only for very sandy or gravelly materials.

Figure 22. Mortaring concrete pipe.

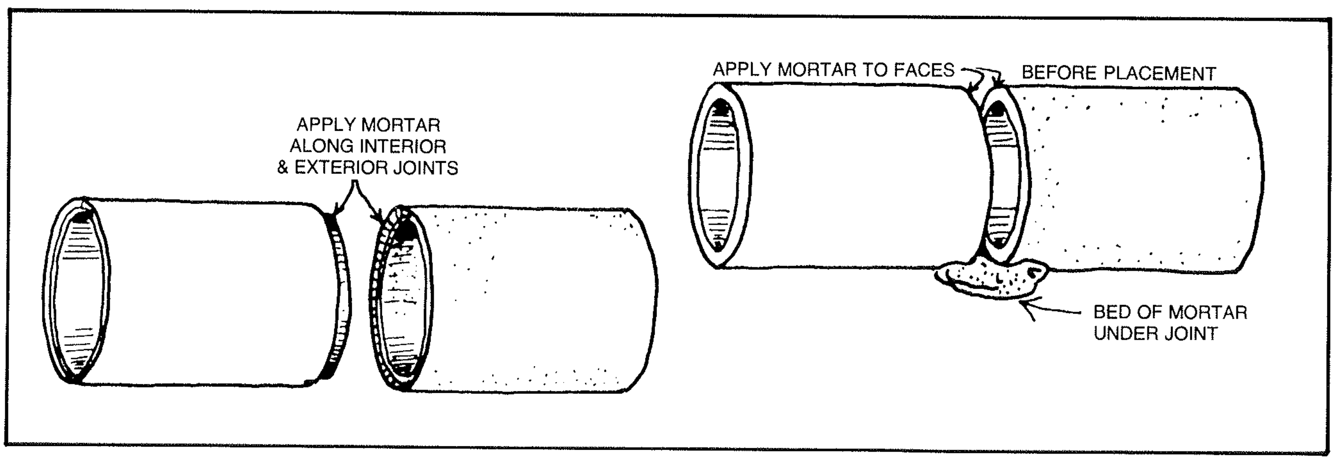
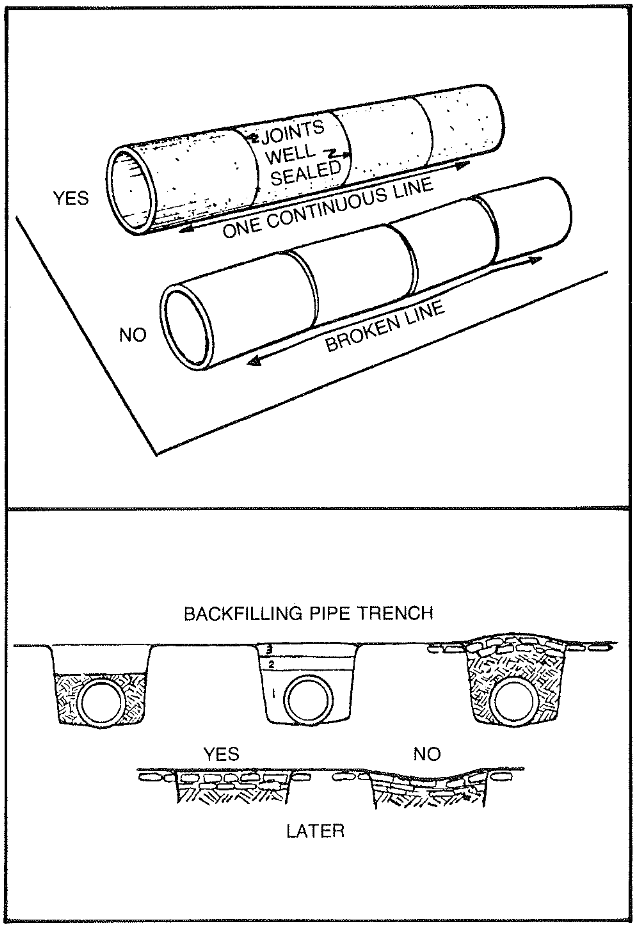


Figure 23. Concrete pipe alignment and backfill.



Corrugated Metal Pipe

Corrugated metal pipe is sometimes preferred for constructing culverts because it is light in weight, less subject to damage in handling, and easy to assemble using common labor. It is also more adaptable for use in soft terrain than concrete or stone. It is furnished in variety of lengths that can be joined together with bands that provide a tight, durable joint. The pipe should be long enough to prevent the embankment from slumping into exposed culvert openings. In many instances, particularly in mountainous terrain, the pipe can be extended to carry water well away from the embankment. If cross-sections of the road are not available, the culvert length may be determined by adding four times the height of the fill to the width of the roadway, measured from the top of slope to top of slope. This formula is based on an embankment slope of 2:1 if the culvert is at a right angle to the centerline of the road.

Installing corrugated metal pipe. All the requirements of channel preparation for concrete pipe apply equally to corrugated metal pipe. The difference is that metal pipe can be placed more quickly and more easily than concrete.

One of the most important phases of installation is the placing and compacting of backfill material around the pipe. Side support must be provided so that it will carry the fill and live loads without excessive deflection. Side support can be obtained only by adequate compaction of good fill material around the pipe. Material should be placed and compacted with care under the haunches of the pipe and should be brought up evenly and simultaneously on both sides. Thickness of the layers and methods of placing and compacting are as described for concrete pipe. The backfilling procedure should continue until the material is at least 30 cm above the top of the pipe. This should also be the minimum cover between the top of the pipe and the road surface.

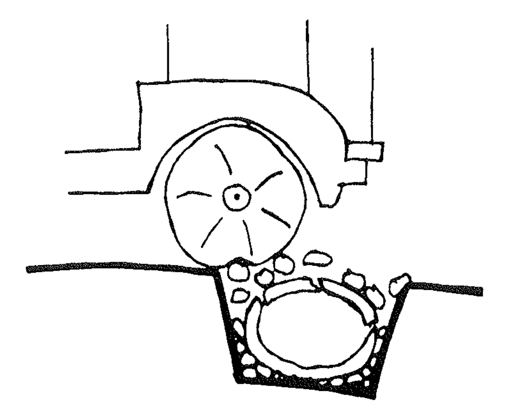
Where multiple lines of pipe are to be installed, they should be spaced far enough apart to permit thorough tamping of backfill between and around each pipe. A rule of thumb for spacing is at least one-half the pipe diameter or 1 m apart, whichever is less.

If heavy equipment is allowed to pass over the culvert during construction, the cover should be at least 1.3 m because the equipment may generate high impact and subject the pipe to extremely heavy damaging loads. Excess cover may then be removed before surfacing.

Erosion Protection

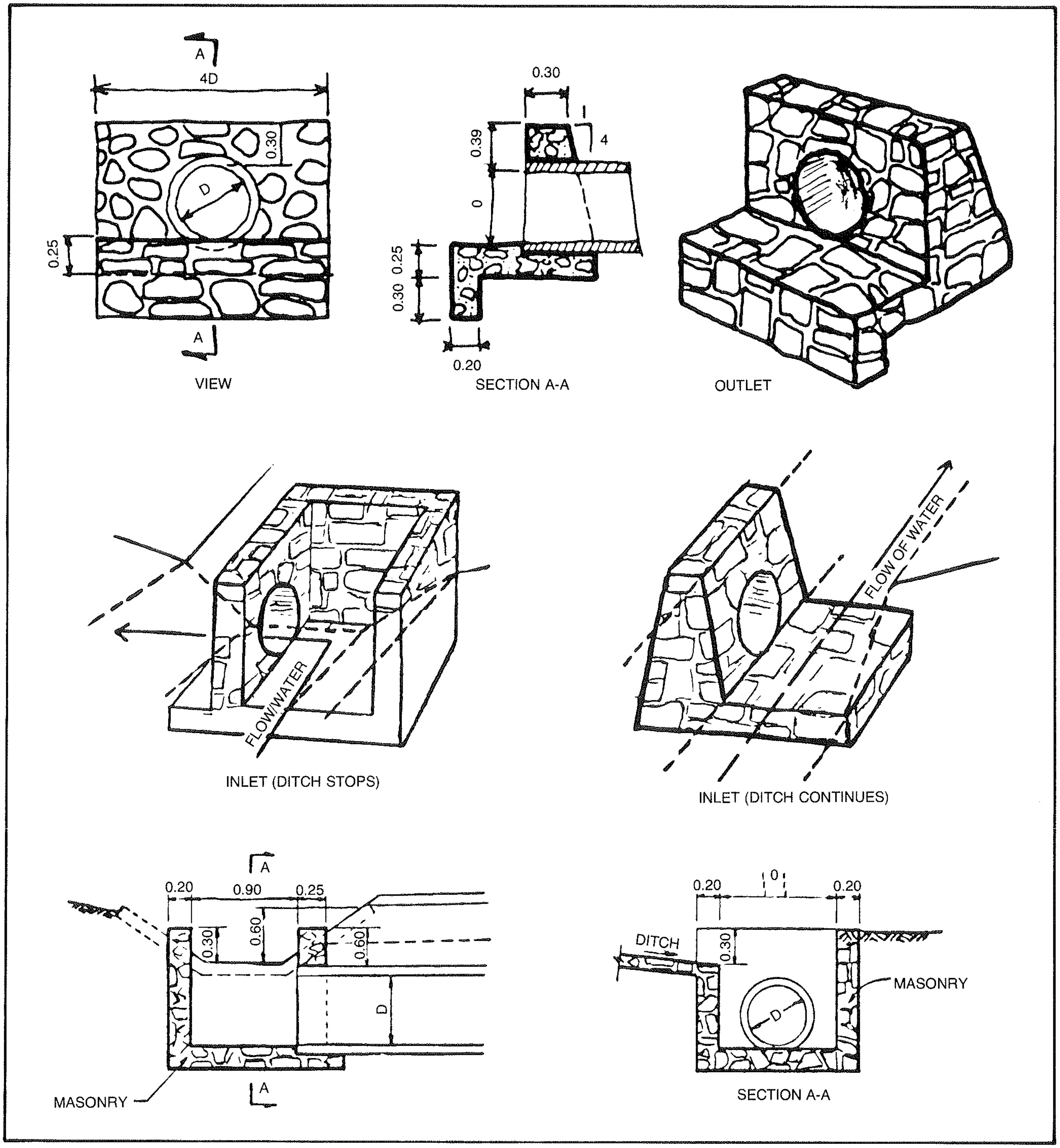
Culverts and the immediate area surrounding them are the most likely components of the entire road to suffer from storm damage. Culverts are placed where the water flow is most concentrated and constricted, but economic considerations seldom permit culverts to be designed for the worst possible condition. Therefore, there may be times when the intake area, the discharge area, the embankment adjoining the culvert, and the culvert itself are all subject to damage and washouts. To minimize this possibility, the flow should be impeded as little as possible. Backfill should be thoroughly compacted around culverts to prevent seepage through the embankment. When the water flow through the culvert is swift, embankments should be protected and headwalls provided (Figure 25). Aprons should be built at the discharge end of culverts to dissipate water energy, cut-off walls should be built to prevent scour, and riprap should be placed at points of potential scour. Areas that are not subject to intensive scour can be protected by grass cover. For quick growth in tropical or subtropical areas, sprigs of grass may be planted instead of seed. For greater protection, riprap consisting of hard, durable rock, at least half of which is as large as can be conveniently carried by labor, may be hand placed. Where

Figure 24. Concrete pipe cover.



NO VEHICLES SHOULD BE ALLOWED TO DRIVE OVER PIPES BEFORE BACKFILLING AND COMPACTING THE TRENCH.

Figure 25. Construction of headwalls.



rock is not available, a mixture of cement and soil placed in jute bags can be used either for slope protection or as headwalls. A mixture of 10-15 percent by weight of cement to soil is usually adequate for obtaining a hard material that is resistant to erosion. It may be a good idea to experiment with mixes of the soils involved to determine the most economical mix.

A frequent cause for unsatisfactory performance or culvert failure is the accumulation of water-borne debris. If this problem is anticipated, provisions can be made for its control(7).

LOW WATER CROSSINGS

Fords, dips, or drifts are relatively economical to build. They compensate to some extent for the inconvenience of delays caused by highwater. Fords are generally built across shallow or seasonal streams and rivers by placing a concrete slab across the bottom of the stream bed. Great care must be taken to ensure that the concrete slabs are not quickly destroyed by the erosive forces that accompany swift water. The amount of concrete used can be lessened with maximum use of available stone.

Due to their riding characteristics, fords do have a noticeable influence on traffic. Unless fords and approaches are built with gently sloping grades, they may constitute an obstacle that can force a driver to reduce speed abruptly. The alignment should always follow the contour of the topography, and approaching roads should be surfaced with material that will remain stable when wet. In order not to alter the natural flow of the current, these crossings should follow the stream bed as closely as possible. Thickness of the concrete paving should take into account the speed of flow and the nature of the materials carried by the stream during flooding.

In some stream beds, erosion becomes an important factor because of the swift flow or the type of material in the stream bed. At these locations fords should include paved aprons as well as cut-off walls to prevent the structure from being undermined and destroyed. Cut-off walls may not be necessary on less violent streams because many stream bottoms tend to build up to the level of the crossing on the upstream side. Erosion on the downstream side can be controlled or reduced by placing large rocks in the stream bed on the downstream side (Figure 26). Where rock is not available, more costly concrete construction may be employed. Where erosion from an occasional storm is so great as to require very deep cut-off walls, it may be appropriate to omit them and make repairs when required instead of making a large initial investment(8).

REINFORCED CONCRETE BRIDGES

General

Reinforced concrete structures require comprehensive engineering for their design as well as technical skills for their construction and are not usually built on low-cost roads. However, in some locations where streams are swift or deep or where other materials are not available, reinforced concrete may be the only practical means of providing a crossing.

Materials and Equipment

The materials and equipment required in addition to those normally used for low-cost road construction are reinforcing steel, lumber and nails for forms, and a concrete mixer.

Foundations

Foundations are carefully staked out in accordance with the plans. Excavation for the footings is one of the most critical steps in bridge construction. While preliminary specifications on footing conditions may have been made, conditions are frequently different from those shown on the plans. The footing must be based on a soild foundation. Solid rock is excellent, dense sands and gravels are good, and hard clays are generally acceptable.

The bottom of the excavation should be horizontal. Footings can be stepped where sloping rock occurs. When the quality of the foundation material is in doubt, a bridge or foundation engineer should be consulted.

Pilings are driven when the foundation material is too soft to support the load of the structure without settlement. Normally the need for pilings will have been determined from subsurface investigations prior to the design(6). The piles are driven by a piledriver until they can be driven no deeper(8). The piles are then cut off at the footing level and serve to carry the footing load. After the foundation has been prepared the concrete footing can be poured.

Forms and Falsework

Forms contain the plastic concrete and provide shapes for the structure components. They are usually built with lumber or plywood but other materials may be used. They must be sturdy enough to retain the proper shape after being filled with wet concrete, and tight enough that water or mortar will not leak through. Any dirt or other foreign material, including ponded water, must be removed from the forms before placing the concrete. The inside surfaces of the form work should be oiled to permit ease of stripping.

Falsework is used to brace the forms and to hold them in place. The falsework is supported by mud sills when the ground is firm or by piles if the ground is soft. Care should be taken that the falsework and its supports are not exposed to damage or movement from flooding or erosion. Bracing should be adequate to prevent movement from water or excentric loading while the forms are being filled. If wedges are used to adjust the settlement of forms, they should be double and made of hard wood.

Sufficient markers should be provided to indicate any settlement of forms that might occur during the placing of the wet concrete. Adjustments must be made before the concrete has taken its initial set. If adjustments are made after the concrete has set, the concrete may be permanently damaged.

Reinforcing Steel

Reinforcing steel rods are placed in the forms to take the tensile stresses developed by loads on the structual members. The sizes of the rods and the locations for placing them should be carefully designed beforehand. Rods should be placed strictly in accordance with that design.

Reinforcing steel should never be stored on the ground, nor where it is likely to be damaged or bent by equipment. Any heavy rust, grease, or dirt that might interfere with bonding between steel and concrete must be removed before the rods are placed in the forms. The rods must be firmly supported to provide the proper distance from the surfaces and to ensure that they will be held in place when the concrete is poured. Immediately before placing any concrete in the forms, the steel should be checked to see that it is placed exactly as shown on the plan, including the proper overlap at all splices.

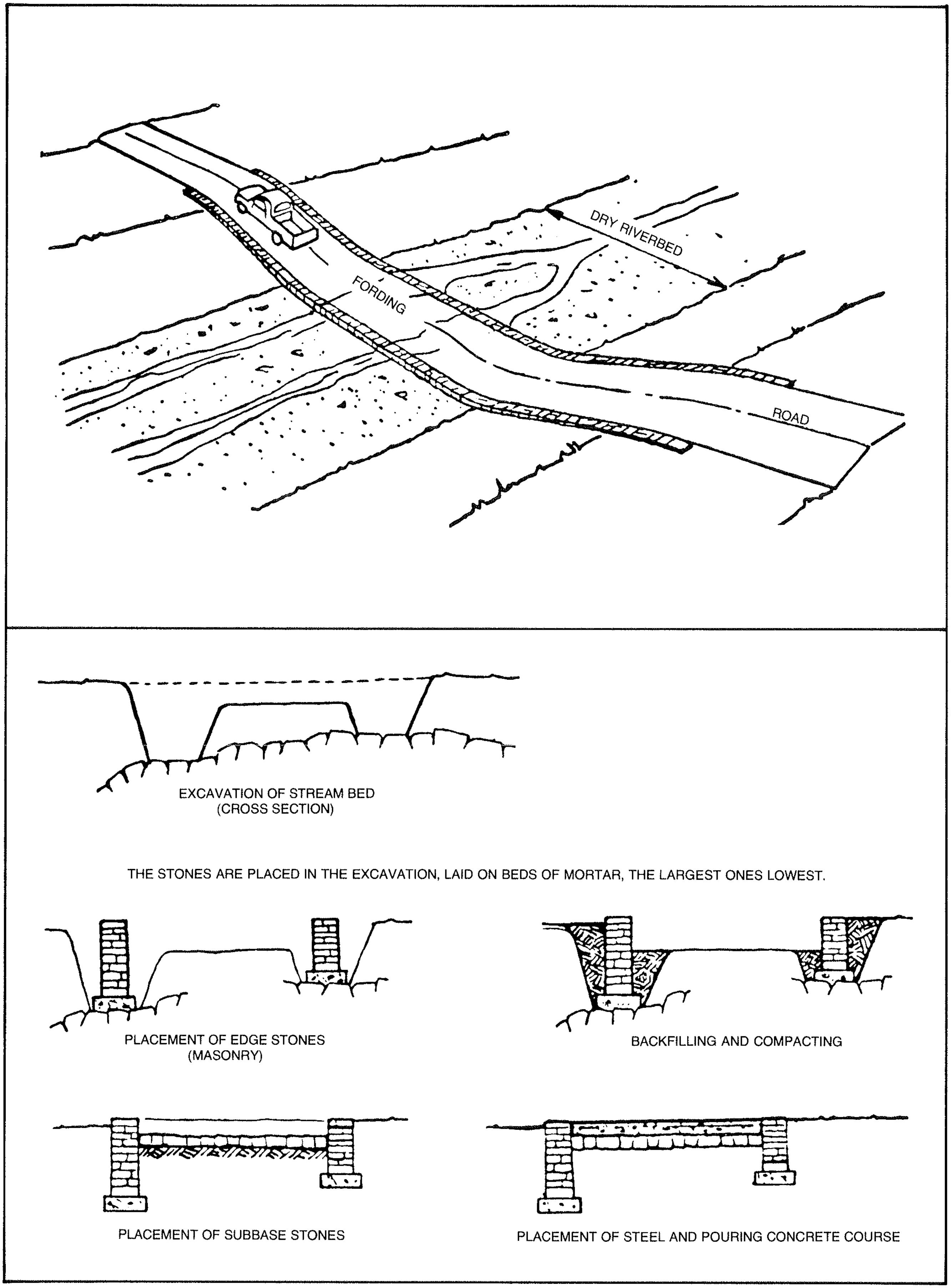
Concrete

Proper proportions of cement, aggregate, and water for the concrete are mixed with a concrete mixer. Water content should be carefully controlled. The mixed concrete should be just fluid enough that it can be placed in the forms and around the reinforcement without leaving voids, but stiff enough so that it will not flatten. If the water content is increased, the strength of the concrete decreases. Excessive water will also cause segregation of the aggregate from the mortar.

Handling and Placing the Concrete

Concrete is moved from the mixer to the forms with wheelbarrows or other containers. Constant attention should be given to its consistency and the method of spreading and working.

Figure 26. Low water crossing.



Segregation of the aggregate should be avoided and the finished product should be well consolidated. It should be free from surface cavities that result from the trapping of air or water along the forms. Spading of the concrete along the vertical forms will usually release the air and water bubbles. Forms should be watched closely for leaks, and any that are found must be caulked immediately.

The concrete should not be dumped indiscriminately through the reinforcement, nor should it be deposited continuously at one point and forced to flow for considerable distances. The work should proceed by dumping succeeding batches in such a way that the concrete will flow along and under the reinforcement. It should then be spaded into the preceding batch to ensure continuity. The last concrete discharged from the mixer will usually contain an excess of coarse aggregate. This should be placed in the forms in such a way that it will mix with concrete containing an excess of mortar. The concrete should be spaded immediately on dumping but should not be overworked to the point that excessive mortar or water rises to the top. Once a concrete pour is started, it must continue until it is finished or until a predetermined construction joint is reached.

When placing concrete in foundations it is sometimes impractical to remove all the water in the foundations. In such cases, it is best to start the placing of the concrete in one corner and continue until it is well above the water surface. The concrete should displace water as it moves forward with as little disturbance as possible. Concrete should never be deposited in running water.

Curing the Concrete

Proper curing of concrete is controlled by humidity, temperature, and protection against disturbance. Temperature is not a factor than needs control until it approaches the freezing point. The concrete then requires protection. Newly placed concrete in structures should be kept continuously moist for a minimum of seven days. When wooden forms are used they should be wetted frequently to prevent opening of cracks that would permit loss of moisture from the concrete.

Concrete must not be distrubed nor loaded while it is curing. Partially cured concrete may suffer permanent damage if disturbed.

Removing Falsework and Forms

Forms and falsework must not be removed until after curing has occurred and the concrete has gained the necessary strength. Strength requirements vary with the function of the concrete member involved. The forms on vertical surfaces carrying no load may usually be removed after two day's curing. Beams, decks, and other load-carrying members should be given at least 14 days; 28 days of curing are usually required before live loads are permitted.

All forms should be stripped carefully to prevent damage to the concrete. Any honeycombed or damaged areas should be repaired immediately after stripping.

CYCLOPEAN CONCRETE

Cyclopean concrete is an economical but poorer quality concrete masonry. It is sometimes used to build simple structures that do not require the strength or the appearances of normal concrete. It can be used to build low headwalls, wingwalls, low retaining walls, low abutments, piers, and other similar structures. It requires a minimum of cement and makes maximum use of local materials and labor.

Random-sized rocks or boulders are placed in position, or within rough form work, and the voids are filled with mortar or small aggregate concrete mix. The random stone is generally limited to not more than 50 percent of total volume. Filling large voids with smaller stones will reduce the amount of concrete or mortar required. Care must be taken to ensure that the mortar fills the remaining voids sufficiently. In order to obtain a bond between the stones and the concrete the stone surfaces should be moist. As with all structures, the foundations must be soild and not subject to differential settlement. This type of construction is limited in its usefulness. It is best suited to vertical loads and can withstand only limited horizontal thrusts.

DRY STONE RETAINING WALLS

In mountainous terrain roadways must often be supported by retaining walls. One of the least costly types of walls to build is a dry stone wall (Figure 27). Dry stone walls contain no mortar to hold the stones together. Stone or rock is normally available in mountainous areas, and no other materials are required except earth and stone backfill. Work crews experienced in paving ditches and building drainage headwalls are normally capable of building dry retaining walls.

The wall is constructed before the road embankment is placed. Excavation may be required to ensure a firm footing and should be on previously undisturbed ground. If excavated materials are suitable for backfilling, they should be piled next to the excavation for reuse. The bottom of the excavation should be well compacted before the bottom course of stone is placed.

The wall should be constructed so that the stones are in contact with each other and so that their longest dimension is perpendicular to the embankment. Larger stones should be placed at the bottom of the wall. Voids between the large stones must be filled with small stones.

After completion of the wall the excavation should be backfilled and compacted with 10-15-cm thick layers of soil. The fill immediately behind the wall should consist of stones that facilitate drainage.

GABIONS

Gabions are wire mesh containers, either cylindrical or basket shaped, that are filled with rock. They can be placed to act as retaining walls, to control erosion, or to serve other uses (Figure 28). Where rock is available, they are economical to install and lend themselves to maximum use of hand labor.

MAINTENANCE

A road built in stage development lacks many of the features of a fully completed project. Some features that would ensure minimum maintenance and long life for the road are omitted. Only these essentials are provided that are necessary to satisfy the immediate transportation needs.

Once built, the road will probably be required to serve in its newly developed stage long beyond the time originally intended, regardless of increasing traffic needs. At the same time, hard-pressed economies are often unable to provide

Figure 27. Dry stone retaining walls.

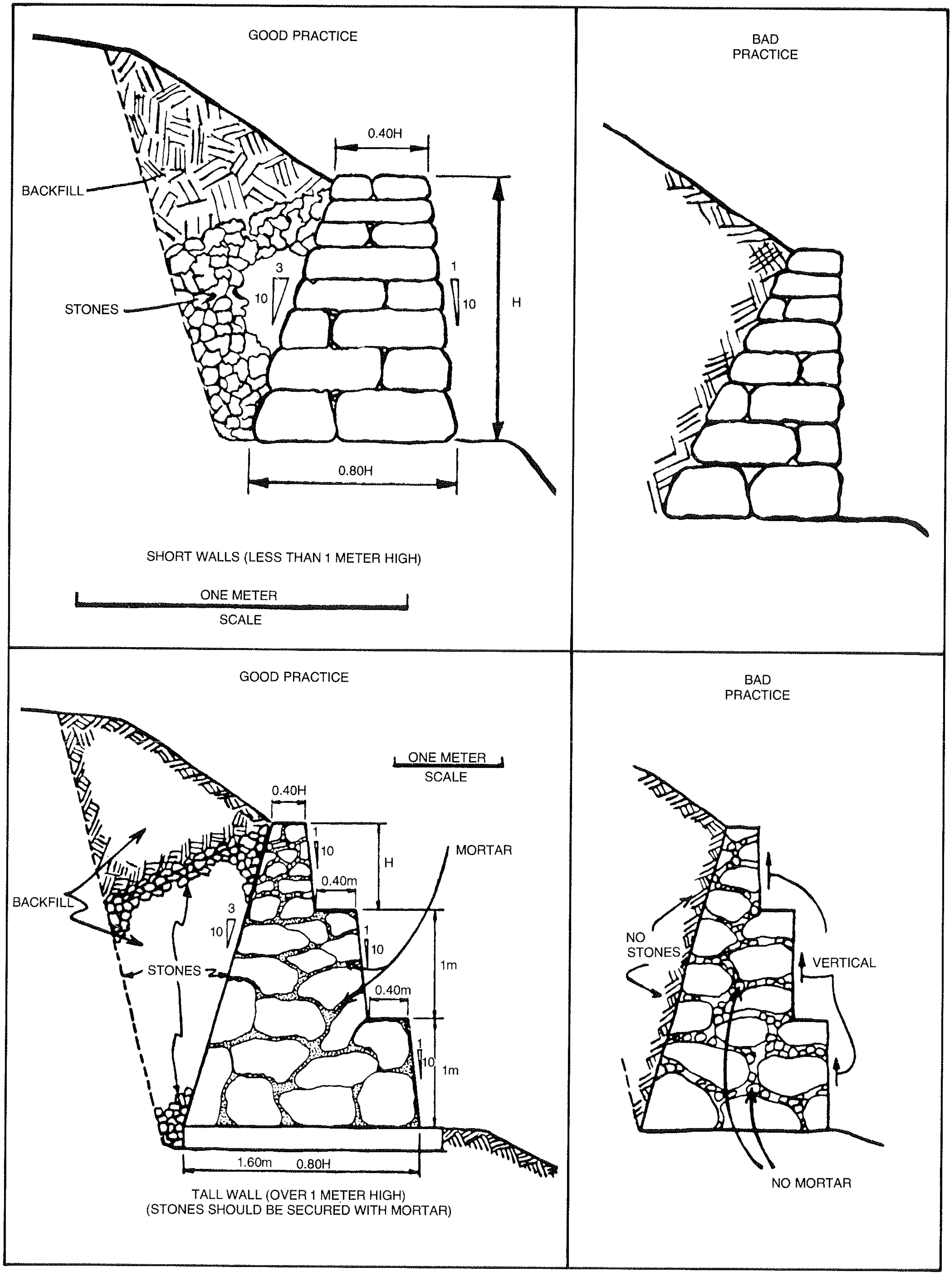
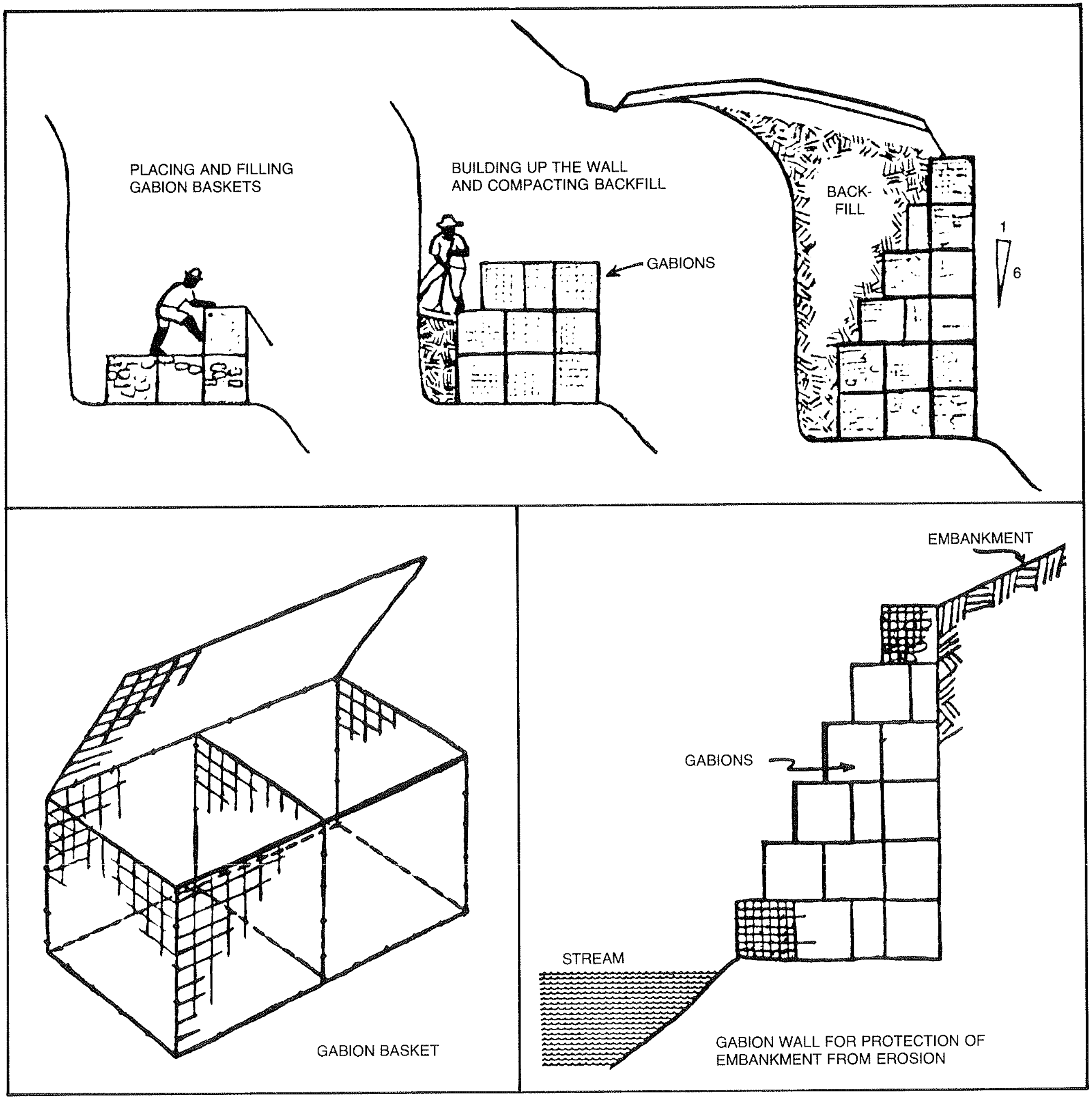


Figure 28. Use of gabions.



the continuous maintenance that every road requires from the day it is built. It is highly desirable that the road be inspected for preventative maintenance at its completion. Small problems that are detected and corrected early can reduce future maintenance costs and extend the life of the road considerably. Many corrections are best noted following the first rainy season after the substantial completion of the project.

Particular attention should be given to correction of excessive surface scouring, excessive side-hill runoff, ditch and channel blockage, to the need for additional culverts, and to scouring or erosion in the vicinity of culverts, drifts, or bridges. The most common problems are associated with water erosion. The most common correction is to provide proper drainage.

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