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Technical Guidelines for the Design and Construction of Shale Embankments

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In 1974, the Office of Research of the Federal Highway Administration initiated a comprehensive research study to investigate the causes of numerous, large-scale failures of shale embankments on major Interstate routes in several eastern states during the early 1970s and to develop appropriate remedies. The U.S. Army Engineer Waterways Experiment Station was to conduct a three phase, five-year investigation of the shale problem and provide the necessary guidelines to build safe and functional shale embankments at a reasonable cost. Phases 1 and 2 were to be completed in one year and provide interim guidelines for the practicing engineer until the comprehensive guidelines could be developed. Phase 1 involved a state-of-the-art survey of design and construction practices in use at that time as well as a survey of existing problem areas. Phase 2 involved a similar survey of evaluation and remedial treatment techniques for existing distressed shale embankments. Accomplishments from Phases 1 and 2 provided the necessary foundation for the development (under Phase 3) of improved design criteria and construction control techniques for both new construction and existing problem areas. The development of the improved guidelines is described, and the highlights of the major research results are presented.

The Federal Highway Administration (FHWA) recently published a comprehensive engineering manual that provides technical guidelines for the design and construction of shale embankments. These guidelines were developed for FHWA by the U.S. Army Engineer Waterways Experiment Station (WES) at Vicksburg, Mississippi. This paper presents the salient points of the manual and also highlights some of the prominent events that preceded the investigation by the WES researchers. Some of the prominent findings that guided the researchers during the early stages of the investigation are also discussed in order to delineate the basis for some of the guidelines that were developed. Many of these guidelines were taken from other federal agencies and some state highway agencies.

The research study was initiated in 1974 as a three-phase investigation. Phases 1 and 2 were conducted concurrently during the first year of the study to provide preliminary guidance to states that were struggling with inadequate guidelines for correcting existing failures, evaluating potential failures, and constructing new shale embankments. Phase 3 involved the evaluation of existing guidelines and the development of improved guidelines for

Figure 1. Excessive settlement in a shale embankment.

designing and constructing highway embankments of shale.

Phase 1 involved a literature search and contacts with state and federal agencies to collect information on current best practices in designing and constructing shale embankments. The results of this phase were reported by Shamburger and others (1). Phase 2 involved a literature search and contacts with state and federal agencies to collect information on current best practices for identifying problem areas, evaluating existing distressed shale embankments, and correction (remedial treatment) techniques for distressed embankments. The results of phase 2 were reported by Bragg and Ziegler (2). Phase 3 involved the major developmental work that formed the basis for the new guidelines, i.e., comprehensive design criteria and construction control techniques for shale embankments. A field testing program was conducted in conjunction with the sampling program to obtain shale materials from actual embankments for the laboratory investigations. The results of the field and laboratory studies were presented in two additional interim reports (3,4) and were used in the final task of developing the guidelines (5).

BACKGROUND

The development of the modern highway system in much of the United States has required the construction of large embankments by using economically available ground materials from adjacent cuts or borrow areas. Technical guidelines for the development of effective design schemes and construction control procedures for soil and/or rock embankments were established long ago and are generally well implemented. However, shale materials do not necessarily behave as soil or rock on such a consistent basis that conventional procedures may be routinely applied to their use as a suitable embankment material.

The lack of appropriate guidelines for using shale in highway embankments became a very serious problem during the height of the Interstate construction program when many large failures occurred as a result of inadequate design and construction procedures. Most of the failures occurred in the form of pavement distress because of excessive settlement; however, a large number of slope-stability problems also occurred. Many of the slope failures required major reconstruction of long embankment sections.

Vertical and lateral movements of shale embankments have also caused tilting, translation, and cracking of bridge abutments plus cracking and distortion of the bridge approach pavements. In many cases, the excessive settlements required jacking of the bridge girders to insert steel shims under the bearing plates. In some extreme cases, horizontal trimming of the superstructure steel was required to relieve pressure on the abutment.

Excessive vertical settlement and lateral spreading of embankments usually cause severe cracking and dips in the pavement surface that require costly repairs (see Figure 1). There are many reported instances of shale fills experiencing as much as 12-15 in (31-38 cm) of vertical settlement that required intermittent pavement overlays. Many states have spent millions of dollars to overlay pavements that failed because of shale-embankment settlements, and recent pavement condition surveys have identified a number of overlay requirements to restore satisfactory ride quality.

Settlement and associated dips and cracks in the pavement have often been the prelude to the more costly problem of slope failure. Early detection of distress and repair of failed sections of pavement, drainage, and slopes can save costly repairs of major failures.

GENERAL OBSERVATIONS

The failures noted above have been found to be typical of many shale problem areas in the east-central states and other areas from the Appalachian region to the Pacific Coast. In general, the states east of the Mississippi River have had more severe problems with shales in embankments than those west of the Mississippi, probably because the geologic formations in the eastern states are older and the climate is more humid.

The underlying cause of excessive settlement and slope failures in highway shale embankments appears to be deterioration or softening of certain shales with time after construction. Inadequate compaction and saturation are two other primary causes of shale-embankment problems.

Time-dependent shale properties and bedding characteristics must also be considered in evaluating the various schemes for embankment placement. Some shales are rocklike when excavated but deteriorate or soften into weak soil when placed as rock fill. Other shales, often interbedded with limestone or sandstone, break down when excavated, but large-sized, durable rocks often prevent adequate compaction. The difficulties encountered in using shale in highway embankments are often complicated by variations in geology and physical properties of sedimentary rocks, depth of weathering, climate and groundwater conditions, weather, and construction methods.

WES STUDY

Phase 1

A concerted effort was made to compile as much useful information as possible within a short period of time to provide guidance to practicing engineers for dealing with what were then some very pressing problems in connection with shale. Available information was sought on classification and material properties, physical and chemical tests, other design guidelines, construction control procedures, and sampling and testing procedures for in-situ shales and compacted shale mixtures. The following discussion highlights the salient points of the phase 1 report (1).

Figure 2. Apparatus used in slake-durability test.

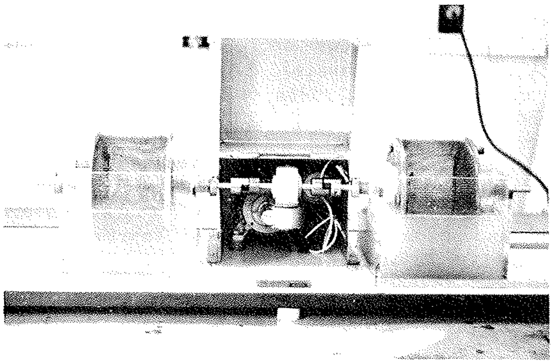


Figure 3. Jar-slake test of oven-dry shale soaked in water.

Occurrence of Shales

An important accomplishment of the first phase of the study was the mapping of the general occurrence of shales in the states studied in relation to the distribution of problem shales. Three sampling units were established for identifying the occurrence of shale: shale predominates, shale subordinates, and nonshale areas.

The WES researchers identified rock-stratigraphic units associated with problem shales and presented a generalized description of their important geologic features (1). A geologic time chart was also developed, and the ages of the formations were grouped geographically. The formational characteristics were analyzed in a similar manner. Distinctions between the younger shales of the western United States and the older formations of the eastern states were also discussed in the phase 1 report (1).

Another significant accomplishment of this phase of the study involved the summarizing of current construction procedures used by highway departments for shale embankments (1). These procedures were divided into three broad categories: preconstruction, construction, and remedial measures.

It was also found that acceptance or rejection criteria for the placement of shale in an embankment differ considerably among the states, varying from fairly rigid measurements to a subjective judgment. The most important decision to make is whether to place shale as soil or rock. Shamburger and others (1) listed processing requirements for each method, cited some noteworthy practices of certain states, and discussed a number of factors that state highway representatives identified as contributing to shale-embankment distress or failure. Most of the cited causes can be linked to one basic problem--the lack of tests and criteria for predicting shale performance with time.

Classification and Composition

The major engineering properties considered were plasticity, swell potential, durability, and strength. These properties were related to texture, mineralogy, geochemistry, and rock fabric. The WES researchers concluded that no single test (physical, chemical, or mineralogical) entirely indicates shale suitability and therefore recommended that each shale material encountered in the soil profile be subjected to the following battery of tests: (a) X-ray diffraction, (b) slake durability (see Figure 2), (c) jar slaking (see Figure 3), (d) scleroscope hardness, and (d) pH.

Factors Contributing to Material Degradation

In addition to the nature of its constituents, the suitability of a shale material for use in embankment construction is a function of its geologic history and present-day environment. Geologic age, tectonic history, metamorphism, and the geologic processes of weathering result in shales that possess varying degrees of soundness, strength, and durability.

The postconstruction changes that result from the weathering of shale-embankment material are time dependent and difficult to predict. Since water is the driving force of the weathering process, it is important to have close control of the drainage aspects of the embankment design. It is also helpful to study the material in outcrops and recent exposures to determine an approximate weathering rate from the degree of altered rock and/or soil developed over the fresh material.

Laboratory Examination and Testing Techniques

The testing of shales for use in highway embankments should provide the answer to one very basic question: Should the shale material be treated as a rock or a soil? Other questions to be addressed include the following: (a) What likely forms of deterioration will the shale experience, and (b) what other properties of the shale will influence the embankment design? These three questions relate to the shale's resistance to three basic modes of deterioration, which can be categorized as follows: (a) chemical weathering (breakdown of primary mineral components), (b) physicochemical deterioration (clay mineral hydration, swelling, and dispersion), and (c) physical deterioration (including relation to rock strength and measure of rippability).

The WES researchers subdivided the laboratory testing of shales into three categories: (a) mineralogical and petrological tests (amount and nature of rock constituency), (b) soil-mechanics tests (classification, plasticity, strength, grain size, and moisture density), and (c) durability tests (slaking, soundness, and hardness). Although all are important, the major factor is the degree of durability exhibited by the shale material and how this durability can be expected to change with time.

The WES researchers were unable to confirm a single test that adequately covered the three modes of deterioration. All of the tests investigated suffered from at least one of the following drawbacks: They were not quantitative, experience with them was limited, they were too severe, or they were generally impractical. The tests selected (X-ray diffraction, jar slaking, slake durability, scleroscope hardness, and pH) were based on the following criteria: previous success, general acceptability, time requirements, costs, simplicity of procedure, and indication of shale variability.

Phase 2

One of the immediate concerns was the need for suitable methods of evaluation and remedial treatment of shale embankments that were exhibiting signs of distress. A number of embankments were settling excessively, and many showed signs of imminent slope failure. Determining the likelihood of failure and the appropriate types of remedial measures were paramount problems at the onset of this research. The salient points of the phase 2 report (2) are discussed below.

Evaluation Techniques

When embankment and/or pavement distress reaches the point where routine maintenance procedures are ineffective for stopping or slowing the rate of increase in distress, the extent of the shale-embankment problem should be evaluated. Excessive settlement and surface slides could be indications of marginal stability. These signs of distress could be indications of shale deterioration within the fill, which could eventually lead to large-scale failures of the pavement and embankment slopes (2).

The evaluation process, concerning which the engineer must be knowledgeable, is outlined in the following steps:

1. Historical review, including (a) design details, (b) construction methods used, (c) area geology, (d) foundation conditions, and (e) materials data;
2. Instrumentation plan;
3. Drilling, sampling, and site reconnaissance;
4. Laboratory and in-situ testing;
5. Settlement analysis; and
6. Slope stability analysis.

After gathering the necessary data and performing the appropriate analyses, the highway geotechnical engineer must assess the validity of the information and use it to predict the future performance of the embankment. If settlement is the only problem, a forecast of the amount, rate, and location of future settlements must be made to assist in the planning of remedial treatments. If slope stability is marginal, the factor of safety must be determined and the potential for economical improvement investigated.

Remedial Treatment Techniques

From an evaluation of existing state and federal practices and a comprehensive literature search, the WES researchers developed recommendations for correcting problem shale embankments. The methods selected were organized in the following categories: (a) pavement overlay; (b) drainage systems; (c) slope flattening, berms, and buttresses; (d) retaining walls; (e) chemical stabilization; and (f) reconstruction.

Surface and subsurface drainage measures are an integral part of most of these remedial treatment methods. This is especially critical in stabilizing sidehill fill failures, largely because of their susceptibility to infiltration of water from adjacent natural ground.

Phase 3

The objectives of phase 3 were to fill in the gaps identified in the assessment of the state of the art and produce a comprehensive engineering manual of technical guidelines for the design and construction of shale embankments. The scope of the work included laboratory and field investigations and the associated analytic studies to develop the improved guidelines. The following discussion highlights the salient points of the phase 3 reports (3-5).

A major part of the study involved sampling and describing various stratigraphic settings for shale and examining the variability of intrinsic shale properties. A total of 158 samples were collected and thoroughly described (associated test and mineralogical data were included). Emphasis throughout the sampling program was on shales that had a history of poor performance, but some nonproblem shales were also sampled to provide a balance.

Information provided by 15 state highway agencies on lift thickness and service performance for 92 embankments was correlated with index tests on corresponding shale samples (3). The WES researchers also collected undisturbed samples and performed in-situ field tests at six embankment sites in five east-central states. Large chunk samples of the unweathered parent shales used in the embankments were also obtained from the source cut or borrow area. Comparisons between the unweathered shale and the partially deteriorated embankment material were made to estimate the amount of deterioration that occurred during the particular time period of performance (3).

Several test procedures were developed for compaction tests, including a simple test on compacted samples to assess the expected compressibility of saturated shales for use in estimating long-term settlement. This test consists of cyclic soaking and draining under a surcharge load equivalent to the embankment height times the density.

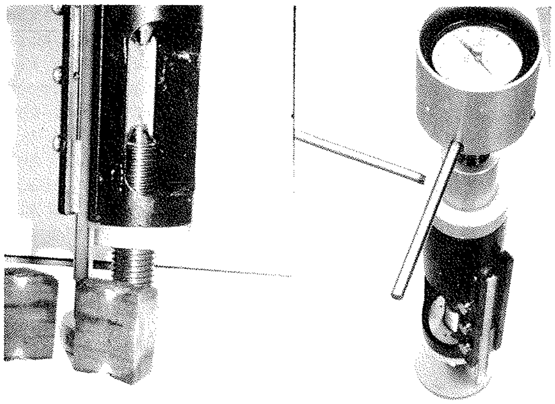
A technical manual (5) was developed from the knowledge gained during the reviews of the best current practices of various state and federal agencies and the basic research conducted at the WES laboratories. The manual is intended to provide technical guidelines for design, construction, and maintenance engineers as well as geotechnical engineers. The manual covers field exploration and sampling of shales, laboratory testing and classification, design features for shale embankments, construction methods and control procedures, evaluation methods for existing shale embankments, and remedial treatment methods for distressed shale embankments. The scope is limited to methods and procedures needed for shale embankments that differ from those normally used for soil or hard-rock embankments. The material covered excludes foundations, cut slopes, and frost action.

General Considerations for Shale Embankments

The successful use of excavated materials from cuts in shale formations for highway embankments requires adequate compaction of all fill materials and sufficient drainage to prevent harmful saturation of the completed embankment. These two main requirements are often difficult to achieve because of the variable stratification of shale formations. Features of shale formations in cuts and other borrow sources have an important influence on the type and extent of design measures (foundation benching, drainage provisions, use of material, compaction requirements, and embankment slopes) and special excavation, placement, and compaction procedures required during construction.

Features of shale formations in cuts and other

Figure 4. Point-load test equipment.



borrow areas should be considered early in the preliminary design to assess the need for specifying and the feasibility of controlling selective excavation and separate placement and compaction of (a) durable shale and rock in rock-fill lifts (at the base of the embankment and/or outer shells of the embankment) and (b) nondurable shale and soil in thin lifts (or inner sections of embankments). As an alternative, the cost of breaking down all materials during excavation and placement for compaction in thin lifts should be compared with selective excavation and placement to arrive at the best solution. This comparison may be required on a cut-by-cut basis for projects in complex formations. In highly variable formations, unclassified excavation may be justified.

The need for adequate soil and site information to properly design a higway embankment is well established, and procedures are well documented. Some important aspects to remember about shale exploration and sampling are presented in the manual. The basic objective of field exploration and sampling for shale embankments is to define the formation features of each cut and other borrow areas and to obtain samples of different shale layers for durability index tests and natural water content, compaction, and special compression and strength tests. In addition to the usual auger borings, at least two core borings are required in each cut or borrow area to define the depths of the soil and weathered shale and the thickness and inclination of different strata. The coring of shales and layers of harder rock should be extended to a sufficient depth to detect the draining of layers into shale-embankment areas at the fill-cut transition. Measurement of ground-water elevations in core borings can be used to define subsurface seepage that would enter the embankment. Aerial photographs (stereo black-and-white, color, and color infrared) and thermal infrared imagery provide valuable information on geologic conditions, surface drainage channels, exit patterns of subsurface seepage, and springs.

Design Considerations

The most important step in the design of shale embankments is the classification of shales according to their long-term durability (i.e., susceptibility to deterioration). The slake-durability index (6) and jar-soaking index (3) are two simple aids for defining deterioration (but not hardness). The tests can also be used as a field identification aid during construction, when supplemented by a rapid drying technique (i.e., microwave oven). The point-load test (see Figure 4) can also be used as an expedient field index test during construction to identify shales that are susceptible to deterioration, provided the point-load index can be correlated with the slake-durability index during the design stage. Shales classified as mechanically hard and durable can be used as rock fill, whereas shales classified as soft and nondurable need to be compacted as soil in thin lifts. However, intermediate shales classified as hard and nondurable are difficult to distinguish and require special treatment (e.g., a high degree of compaction and isolation from infiltrating water to prevent wetting).

Defining the excavation characteristics of shale formations is also an important requirement for shale embankments. The in-situ hardness of nondurable shales and the amount of interbedding with harder rocks control the excavation methods required to obtain the breakdown necessary for adequate compaction in thin lifts. The breakdown during excavation depends on the amount of ripping or blasting. During placement, further breakdown depends on the weight and type of the compaction equipment used. For example, if heavy tamping rollers that can break down shale and limestone were used during compaction, less breakdown by extra blasting would be required during excavation.

Because of the variability in shale formations and shale durability, special design considerations are necessary to achieve adequate compaction and prevent harmful saturation of embankment materials. The main considerations include foundation benching, drainage provisions, use of material, compaction requirements, and slope inclination.

The design of shale embankments involves four main steps:

1. Assessment of potential problems with shale materials, including consideration of geologic conditions, shale durability, and construction practices;
2. Selection of appropriate design features, material properties, and construction procedures to meet desired settlement and stability criteria;
3. Preparation of plans and specifications, including special provisions and construction control techniques to achieve design criteria; and
4. Development of an appropriate subsurface and/or surface instrumentation plan for monitoring the performance of major embankments.

Construction Considerations

Effective construction of shale embankments requires proper execution and inspection of the following items: (a) foundation preparation, (b) excavation procedures, (c) construction sequence, (d) capabilities of compaction equipment, (e) compaction procedures, and (f) compaction control.

The most important part of foundation preparation is keying the shale embankment into sloping ground surfaces by using benches and installing drainage measures to intercept all potential subsurface water that may enter the foundation area. Excavation procedures (ripping and blasting) require trial and error to obtain adequate breakdown or fragmentation. In cuts of nearly horizontal thick shale and harder rock strata, each different stratum (classified as soillike or rocklike) should be ripped and/or blasted separately. This procedure will prevent mixing of durable rock with nondurable shale. However, durable (rocklike) shale and sandstone (or limestone) could be excavated together for rockfill sections of embankments. The main criterion is that nondurable shales, especially where interbedded in thin layers with other rock, must be broken down to meet size limits for compaction in thin lifts.

The amount of selective grading depends on the thickness and inclination of different strata in a cut. The geotechnical profiles and typical sections should show the intended use of different strata as soil fill or rock fill. Some stockpiling may be required initially unless soil, weathered shale, and nondurable shale from upper portions of cuts or from bench excavation can be placed directly in the central portion of a through (cross-valley) embankment that has a relatively level foundation. Rock strata for use as rock-fill drainage layers and in the outer sections of embankments can usually be routed directly to the proper location. Placing rock fill indiscriminately in the same lift with soillike shale or in separate lifts across the entire embankment should not be allowed, since the rock fill can act as a reservoir for infiltrating surface or seepage water.

Selective grading may also be required to move large, durable rock out of soillike shale during placement in thin lifts. A dozer equipped with the proper size of rock rake can effectively push large stones to the outer slope. The danger is that large pieces of nondurable shale could be pushed along with durable rock. This danger can be minimized by first breaking down shale pieces with dozer treads or a heavy tamping roller.

To achieve adequate compaction of 8- to 10-in (200- to 250-mm) thick loose lifts of nondurable shales, it may be necessary to use a heavy tamping roller, followed by a vibratory roller, and finally a very heavy [50-ton (4536-kg)], pneumatic-tired roller and a minimum total of six coverages. The speed of compactors should not exceed 3-5 miles/h (4.8-8 km/h).

For durable shales placed as rock fill in loose lifts of a maximum thickness of 24 in (0.6 m), the use of vibratory compactors has proved satisfactory. For clean rock fill, hauling and spreading equipment, when routed uniformly over each lift, may be adequate. The use of rocklike shales in which the amount of soil or fines cannot be controlled should be limited to loose lifts 12-18 in (31-45 cm) thick and should be compacted by using heavy vibratory or pneumatic-tired rollers.

When experience is lacking on the compaction of nondurable shales from a particular formation, test pads should be constructed. Test pads help to determine the applicability of watering and disking in breaking down shales and improving compaction after placement. The suitability of the contractor's compaction equipment and the optimum compaction procedures can also be determined in order to obtain the desired compaction. Developing the best procedure for breaking down oversized shale and rock or raking durable rock out of nondurable shales can also be worked out under test-pad conditions.

For minimum settlement cases, the following procedures may be necessary to achieve adequate compaction. It is generally required that nondurable shales be spread in loose lifts no thicker than 8 in (200 mm) and that oversized pieces be broken down or removed. Four-wheeled, heavy compactor dozers are often used to spread and compact, but they tend to ride over rather than break down hard shale, limestone, or sandstone chunks and slabs. Heavy, tracked dozers, followed by compactors that have square tamping feet with a small contact area, are more effective.

Initial rolling followed by watering of dry shales (by tankers or trucks equipped with spray bars) can also help in breaking down oversized shale pieces. Dry shales that slake readily should be watered and disked as an aid in compaction. The water added should not increase the in-situ water content above the optimum for the shale. A dense layer should be produced by using the following procedure: disking, followed by additional watering (if no "gummy" clods are apparent), then static roller compaction (a minimum of two complete coverages), followed by vibratory roller compaction to bring the total number of coverages to six. The above procedures can be modified on the basis of test-pad results and by using thicker lifts for less stringent requirements on long-term settlements.

Compaction control techniques for shale embankments may include procedural provisions and/or end-result provisions. Specification of lift thickness, allowable oversized rock, watering and disking, compaction equipment, number of coverages, etc., can be used to reduce the settlement potential. In-place density tests can be used to monitor the percentage of compaction.

IMPLEMENTATION EFFORTS

A program to accelerate the application of the implementable results of the research project was initiated in June 1979. An executive summary report (7) was developed to provide a condensed version of the five-volume research report. The summary report provides much of the useful information in a brief document that is suitable for easy reference or executive briefing. A series of training workshops was developed for presentation to practicing highway engineers from federal, state, and local agencies. The presentation and explanation of the technical guidelines manual (5) was the focal point of each workshop.

CONCLUSIONS AND RECOMMENDATIONS

Excessive settlement and slope failures of shale embankments are expensive and difficult to correct. It is also impractical to treat all shales as problem materials because the appropriate design measures to preclude failure are too expensive to apply indiscriminately. Since shale is one of the most abundant and troublesome materials that highway engineers must deal with, it is extremely important to have rational guidelines for design and construction. The recently developed technical manual (5) provides the necessary guidance for building satisfactory shale embankments.

The primary causes of large settlements and slope failures in highway shale embankments are inadequate compaction, saturation, and shale deterioration. The first two are typical problems in embankment construction, but few other materials suffer from such a serious deterioration problem. Not all shales deteriorate, and those that do deteriorate at different rates. Some shales are hard, durable rocks, whereas others crumble easily and perform like a soft soil. Between these two extremes lies a wide spectrum of soil behavior.

One of the most important steps in the design of shale embankments is the classification of shales according to long-term durability (i.e., susceptibility to deterioration). The slake-durability index and the jar-soaking index are two simple aids for defining deterioration (but not hardness). Shales for highway embankments should be classified as soillike (nondurable) and rocklike (durable).

Because of the variability in shale formations and shale durability, special design and construction considerations for shale embankments are necessary to achieve adequate compaction and prevent harmful saturation of embankment materials.

The main consideration involves determining which shales can be placed as rock fill in thick lifts and which shales must be placed as soil and compacted in thin lifts. Test pads should be constructed to determine the required procedures (lift thickness, watering, disking, type of compactor, and number of compactor coverages) for each different shale material.

The common persistence and eventual magnification of shale-embankment distress suggest the need for early evaluation and treatment of embankment problems. Existing distressed embankments should be evaluated by performing a systematic review of design, construction, and maintenance records plus a comprehensive field and laboratory investigation to define the cause of distress or failure. The primary consideration in the remedial treatment of shale embankments should be surface and subsurface drainage measures. When other remedial techniques are applied, drainage measures are usually a necessary supplement.

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Stability of Waste-Shale Embankments

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Research conducted by the U.S. Forest Service and Utah State University on the stability of waste-shale embankments is described. Mine-waste embankments can be distinguished from other engineered fills by their variable and loose nature, by the lack of control of gradation and density during construction, and by their deformation tolerance. Stability requirements dictated by government regulations generally focus on the protection of adjacent surface resources rather than on the utility of the embankment. Laboratory and field investigations indicate that waste shales in southeast Idaho have high void ratios, moderate permeability, and low-plasticity fines and are susceptible to collapse settlement on saturation. Commonly occurring slope movements can be classified as slumps, shallow flow slides, and foundation spreading. Fully developed rotational slides are not common in southeast Idaho. The deep slope movements generally result from a reduction in toe support caused by groundwater, excavation, or weak foundation soils. Shear-strength testing of shales at different gradations, durabilities, and moisture conditions indicates that ultimate shearing resistance can be differentiated at two levels that can be related to material conditions. The design of mine-waste embankments should be based on limiting conditions that may include maximum probable precipitation, maximum credible earthquake, saturation or nonsaturation, and index shear-strength parameters. The use of stability charts in design analysis is frequently justified by the simplified nature of the limiting conditions. The emphasis in the design of mine-waste embankments is to control the location of different material types and drainage more than to control slope inclinations.

Surface mining involves the removal and disposal of large quantities of overburden material, much of which is shale. This material is often disposed of in large waste embankments several hundred meters high that vary in volume from several million to several hundred million cubic meters. Until recently, most of these embankments were not engineered. These embankments can be distinguished from highway or earth-dam embankments by the variability