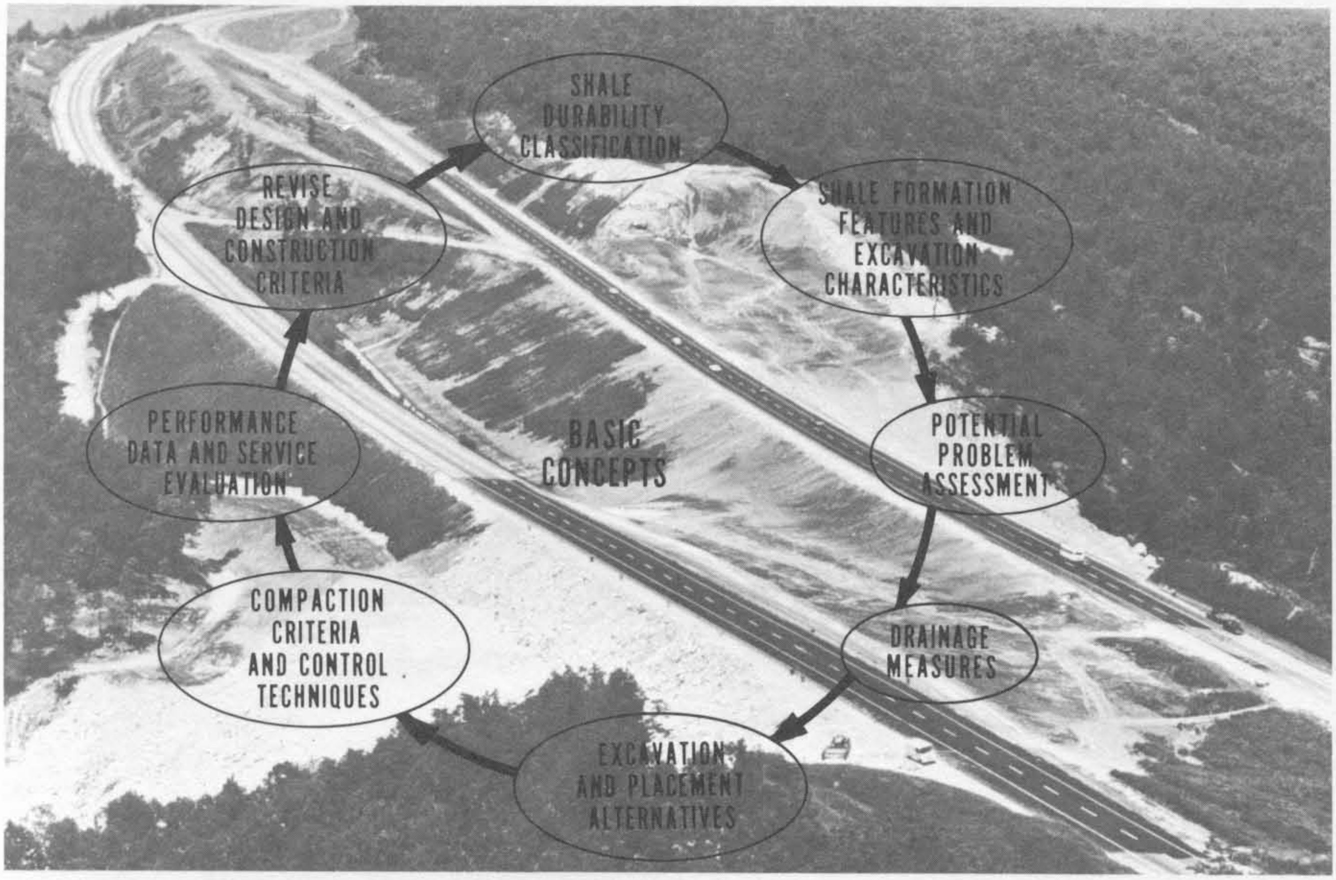
FHWA-TS-80-219

Design and Construction of SHALE EMBANKMENTS: Summary



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U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Offices of Research and Development
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NOTICE

This report was prepared by the Department of the Army Waterways Experiment Station. Mr. W. E. Strohm was the principle investigator.

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DESIGN AND CONSTRUCTION OF SHALE EMBANKMENTS

SUMMARY

INTRODUCTION

The Problem

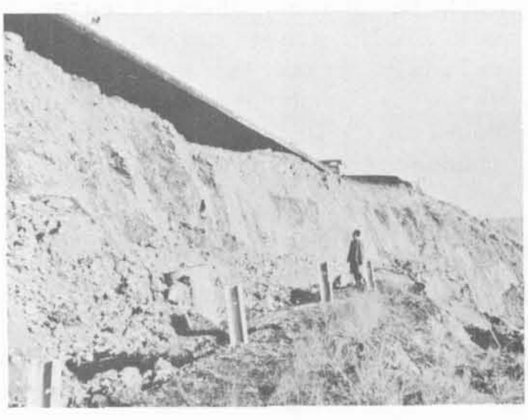
Construction of the modern highway system has required large, high embankments using economically available fill from adjacent cuts or nearby borrow sources. Because of their widespread occurrence, shales and other weak, fine-grained sedimentary rock (siltstone, claystone, mudstone, etc.) were the main source of fill for many embankments from the Appalachian region to the Pacific Coast.

Excessive Settlement. The use of shale materials has caused excessive settlements of 1 to 3 ft (0.3 to 0.9 m) in many embankments. Frequent overlaying and raising of bridge abutments have been required to maintain grade. In some shale embankments continuing settlements have led to large slides. The more severe problems have occurred in the East Central States where the climate is humid.

Costly Repairs. The lack of early remedial treatment often resulted in expensive repairs, amounting to nearly $2 million at one location for three slides where reconstruction required 18 months and numerous lane closures. Prevention of a large slide was often precluded by the lack of suitable techniques for detecting the source of major distress, defining the cause and existing stability, and determining the most appropriate type of remedial treatment.

Underlying Cause. The underlying cause of excessive settlement and slides in highway shale embankments is deterioration of certain shales by infiltrating water with time after construction. Some shales are rocklike when excavated, but when placed as rock fill, slake or soften upon wetting into weak soil. Other shales, often interbedded with limestone or sandstone, break down when excavated, but large-size durable rocks often prevent adequate compaction and large settlements occur upon wetting.

Main Problem. The main problem is determining which shales are durable enough to be placed as rock fill in thick lifts and which shales must be broken down and compacted as soil in thin lifts. The absence of proven criteria for classifying shale durability and predicting the long-term performance has led some highway agencies to adopt a conservative approach where all shale materials are treated as soil.



Local-Level Action

In 1963, a conservative approach of requiring shales to be compacted in 8-in. (0.2-m) lifts was adopted in Ohio after studies of excessive settlements in bridge approach fills and marginal results with stabilization by cement grout. In the early 1970's, following slides on I-74, the Indiana State Highway Commission initiated a cooperative research program with Purdue University. This work led the way in developing criteria for identifying nondurable shales to be compacted as soil from durable shales suitable for rock fill.

During the same period, settlement and slide investigation studies and research on causes of distress were underway at various levels of effort in Kentucky, Tennessee, West Virginia, Virginia, Kansas, Oklahoma, and Montana. While suitable methods for repair of slides were being developed, proven techniques for determining the source of distress, existing and future stability, and treatment methods for unstable slopes were not readily available. In addition, many shale formations were suspected and resulted in overdesign with durable shales often treated as soil. In other cases, lack of reliable criteria and tests for defining nondurable shales often resulted in underdesign and inadequate compaction.

Research Program

To provide the highway geotechnical engineer with needed technical guidelines, the Federal Highway Administration sponsored a comprehensive four-year research program in 1974. The three-phase program, accomplished at the U. S. Army Engineer Waterways Experiment Station (WES) was completed in 1978. The results are published in five volumes (Figure 1).

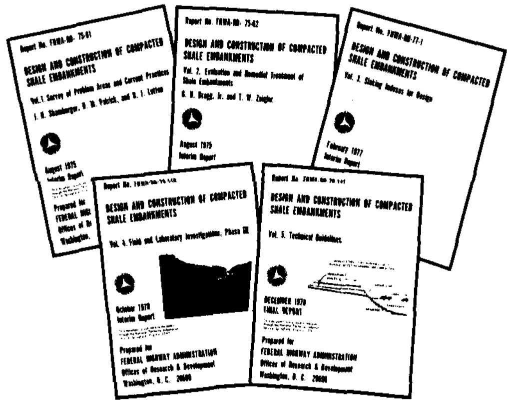


Figure 1. Research Reports.

The technical guidelines draw heavily from the experience of State Highway Agencies, Purdue research, Corps of Engineer work, and WES field and laboratory investigations of selected shale embankments and tests on sampled shales. An advisory group provided valuable guidance during the research work.

Results

Discussions with highway geotechnical engineers of 16 States revealed fewer problems in the Western States where the younger shales were softer and usually compacted as soil in thin lifts. Problem shale formations, especially in the East Central States (Figure 2), were identified by State agencies from past experience. The need for special provisions was recognized in many

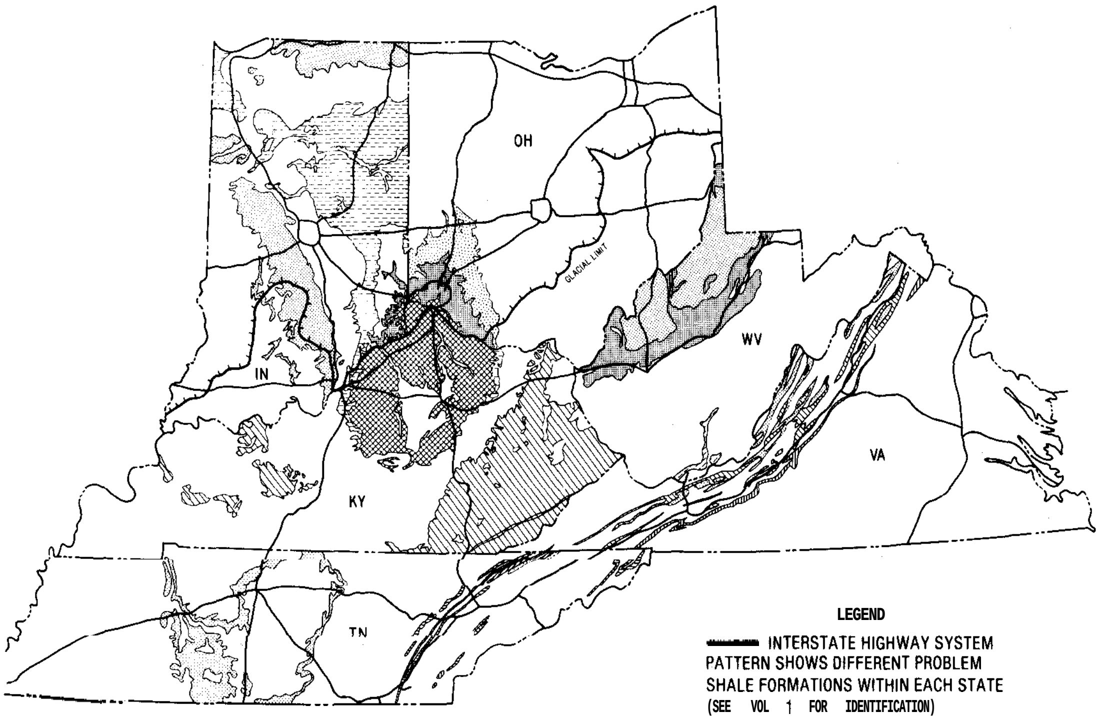


Figure 2. Problem Shale Formations, East Central States.

States. The more severe settlements and slides were related to three main causes:

- Use of nondurable shales as rock fill, which allowed infiltrating surface water or subsurface seepage to progressively slake and soften the shale into small fragments or soft clay.
- Mixing shale and overburden soils with harder rock, which prevented adequate compaction and led to progressive wetting and softening of the fill materials by infiltrating water.
- Lack of adequate benching and drainage of underlying slopes, especially on sidehill locations, which caused a progressive buildup of subsurface seepage in the embankment base and upslope foundation area.

Key Findings. Causes of distress and contributing factors are listed in Table 1. Uncontrolled grading was a major contributor to poor embankment performance. Blasted shale and rock from one cut were often placed in the same lift with overburden soils from another cut. This practice produced random zones of pervious rock and shale, and loose to dense soil. Infiltrating water following erratic paths induced nonuniform settlements. Poor compaction of outer slopes caused shallow slides that progressed into deeper slides with time. Lack of benching at the rear of bridge approach fills, when the remainder of the embankment was constructed, produced weak zones that caused transverse cracking and excessive settlement of the roadway.

Table 1. Key Findings.

CAUSES OF DISTRESS
• Inadequate compaction
• Infiltration and saturation
• Shale deterioration
CONTRIBUTING FACTORS
• Inadequate foundation benching and drainage
• Lack of reliable index tests and criteria for defining nondurable shales
• Difficulties in breaking down hard shales and rock prior to compaction
• Uncontrolled mixing of soil, shale, and large rock in the same lift
• Use of excessive lift thicknesses
• Lack of specific compaction requirements and procedures
• Lake of adequate measures to prevent infiltration of surface water

Good Practices. Controlled grading and the use of test pads to develop compaction procedures were the two main practices that were evident for good embankment performance. Other basic criteria for good shale embankments are:

- Increased use of foundation benching and drainage.

  Define nondurable shale strata in cut sections.

- Increased use of selective excavation and placement to separate nondurable shale from durable shale and rock.

- Increased use of durable hard shale and rock for drainage layers at base and/or in outer sections of embankments.

- Increased compaction of nondurable shale and soil in thin lifts.

- Increased use of impervious layers beneath median and shoulders, paved median ditches, and shoulder curbing to prevent surface water infiltration.

Index Tests. Two index tests, found suitable for identifying nondurable shales, are the slake-durability test and a simple jar-soaking test. With these tests, criteria for classifying shales into the soillike or rocklike category were recommended.

Special Tests. The WES research also developed a soaked-compression index test to predict settlement potential of compacted shale. The soaked compression was related to density and the slake-durability index, and provides the geotechnical engineer a means of estimating the compaction required to minimize settlement.

Existing Embankments. Rapid techniques for the evaluation of existing shale embankments includes air photo surveys, ground inspections, and the use of a pressuremeter test to measure in situ strengths of distressed sections. Early application of drainage measures was found to be an economical means of preventing large slides.

Scope of Report

Guidelines for the use of shales in new construction, evaluation of existing embankments, and remedial treatment of distressed shale embankments are briefly described in the remainder of this summary report.

GUIDELINES FOR NEW CONSTRUCTION

The successful use of shales in highway embankments requires adequate compaction in all fill materials and sufficient drainage to prevent harmful saturation after construction. These two main requirements are not easily achieved, especially in shale formations with complex and variable type stratification. Thus, several basic concepts, unique to shale embankments, should be considered in planning new construction.

Basic Concepts

The most important concept in planning highway projects across shale formations is the identification of nondurable shale (siltstone, claystone, etc.) strata. The location and extent of these layers in relation to durable shale and rock layers have a direct influence on the proper use of materials to achieve a stable embankment. For example, thick strata of nondurable shale and sandstone can be excavated separately with the shale compacted as soil in the central portion and sandstone placed as rock fill shells with steep slopes. Hard nondurable shale requires extra blasting during excavation or use of impact equipment on the fill to break down large pieces for proper compaction in thin lifts.

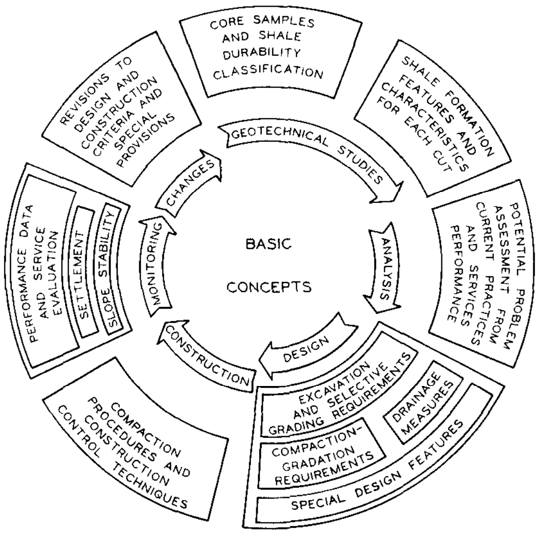


Figure 3. Basic Concepts.

Drainage. Where subsurface seepage feeds into the embankment area, durable rock should be used for a rock fill drainage layer on benched slopes under the fill to prevent harmful saturation and high seepage levels. In shale formations containing steeply dipping layers or thin layers of interbedded shale and limestone, selective excavation and placement are impractical, and all materials need to be broken down during excavation and placement for compaction as soil. In this case, underdrains on benched foundation slopes will require sand or gravel backfill.

Formation Features. The main basic concepts in logical order, as shown in Figure 3, start with the geotechnical investigation to obtain core samples of shales for durability classification and to provide a complete picture of shale formation features in each cut. The features include hardness, thickness, and dip of major strata with depth and seepage conditions below the grade line. Excavation characteristics related to rippability and blasting requirements are important in determining special procedures needed during excavation and placement to break down hard materials and limit the maximum rock size to the specified lift thickness.

Potential *Problem* Evaluation. Information on shale durability classification, shale formation features, and excavation characteristics should be compared with recent design, construction, and service performance experience for similar projects. This process leads to a logical evaluation of potential problem areas and the need for special features, such as extensive foundation benching and drainage, special excavation and placement procedures, and compaction requirements, to meet settlement limitations and stability requirements associated with the allowable risk and type of project. Major embankments in areas of high rainfall may require impervious layers beneath the median and shoulders, pavement subdrains, paved median ditches, and shoulder curbing to prevent surface water infiltration.

Compaction and Control. Field compaction procedures, should be developed from field test pads during construction when experience is lacking for a particular shale formation. Important construction control techniques involve visual inspection and tests to ensure compliance with special provisions, periodic air photos to document construction practices, and visits by the geotechnical staff to solve unforeseen problems.

Monitoring Performance. Major embankments should be monitored after construction to obtain settlement and stability performance data. Evaluation of these data against design measures used and construction procedures will provide a sound basis for revision of design and construction criteria and changes to special provisions for future shale embankments.

Field Exploration and Sampling

During initial studies, all pertinent geologic and soils information available for the project area should be reviewed, and field reconnaissance made to determine the optimum field boring program needed to fill data gaps. Aerial photographs (color, and color infrared photos and thermal infrared imagery) provide valuable geologic information, surface drainage patterns, and subsurface seepage exiting from hillsides along the center line under proposed embankment areas.

Core Borings. At least two core borings, in addition to the usual auger borings, are required in each cut or borrow area to obtain unweathered shale samples and to define soil and weathered shale depths and the thickness and inclination of each major strata of different material (shale, claystone, siltstone, limestone, sandstone, etc.). The core borings should be deep enough to detect seepage layers below grade in cuts that drain towards adjacent embankment areas (Figure 4).

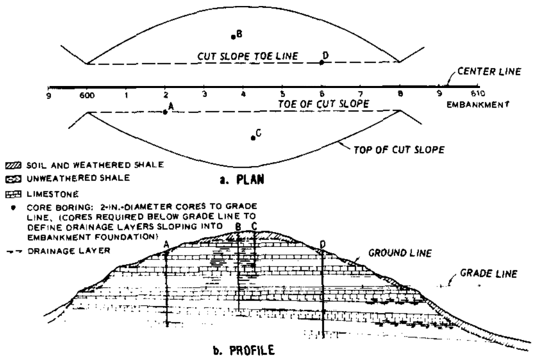


Figure 4. Location of Core Borings.

Shale Testing. Core samples of each major shale layer are needed for durability index tests, natural water content (if cores are sealed when recovered), and compaction tests. Special soaked-compression index tests and strength tests on compacted shale samples may be needed for critical embankments over 50 ft (15 m) high. These test requirements, estimated during the preliminary design phase, may require additional core borings to obtain a sufficient amount of shale cores.

Seepage Conditions. Measurement of groundwater variations before and after heavy rains can be used to estimate the amount of subsurface seepage that would enter the embankment foundation. This information is used for estimating foundation drainage locations and size requirements.

Shale Durability Classification

Selection and testing of shales should be done under the supervision of a geotechnical engineer. Representative unweathered cores of chunk samples from each major shale layer should be tested unless durability and compaction properties have been established for the same shales on another project.

Durability Categories. Major shale strata in each cut along the project need to be classified into the following durability categories:

- Soft nondurable - soillike.
- Hard nondurable - soillike.
- Hard durable - rocklike.

The hard nondurable category is needed to define those shales to be compacted as soil in thin lifts. Thus, hand shales will require extra blasting or processing to break them down for proper compaction.

Index Tests. The two primary tests for durability classification are the jar-slake test and slake-durability test. The simple jar-slake test can be performed on many core pieces as a rapid screening test. Ovendry pieces are soaked in water, and a jar-slake index is assigned using the descriptive behavior noted in the chart. An I_J value of 1 or 2 indicates an obvious soft nondurable shale. Values greater than 2 require slake-durability testing.

JAR-SLAKE INDEX	
I_J	Descriptive Behavior
1	Degrades into a pile of flakes or mud
2	Breaks rapidly and/or forms many chips
3	Breaks rapidly and/or forms few chips
4	Breaks slowly and/or forms several fractures
5	Breaks slowly and/or develops few fractures
6	No change

In the slake-durability test, ten 3/4- to 1-in. (19- to 25-mm) pieces of ovendry, unweathered shale are placed in a wire-screen drum that is submerged in water and rotated at 20 rpm for 10 minutes (Figure 5).

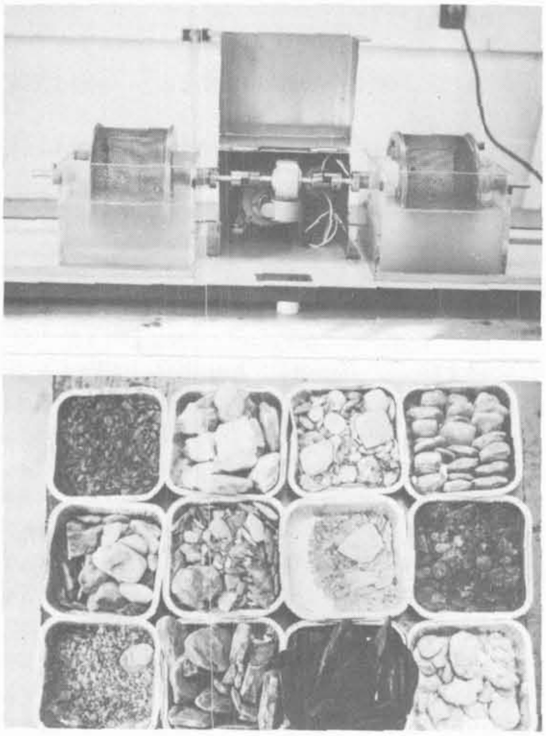


Figure 5. Slake-Durability Apparatus and Different Shales After Testing.

The procedure is repeated on the material remaining in the drum, again after oven-drying. The slake-durability index I_D is the percent of material retained after the two-cycle test.

$$I_D = \frac{\text{Dry wt after 2 cycles}}{\text{Dry wt before test}} \quad 100$$

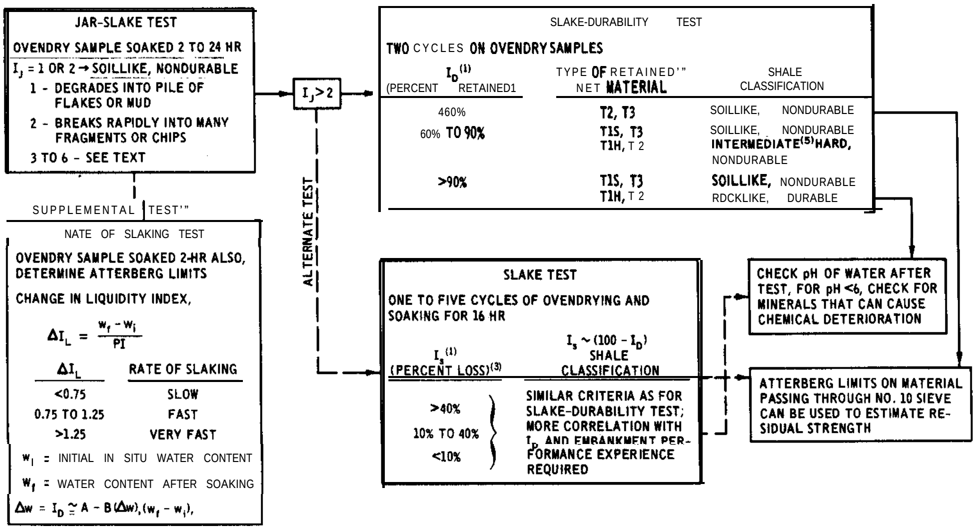
The total test time is about two hours when a rapid means of drying (such as a microwave oven) is used. Low I_D values of 10 to 60 percent indicate low durability, i.e., high susceptibility to deterioration. However, this index does not indicate hardness nor type of breakdown. Since an I_D value near 100 percent for these conditions would be misleading, supplemental letter-number groups are used to denote the condition of the retained wet material.

Classification. Suggested durability classification criteria are shown in Figure 6. A supplemental and an alternate test are included. Although these tests take longer to perform, they each have an advantage. The rate of slaking test can aid in defining hard nondurable shale, and the slake test requires only a glass funnel, beaker, and filter paper.

In all tests, a low pH of the water after testing hard shales indicates an acid shale and possible chemical deterioration by alteration of minerals. For example, the mineralogy of dark shales should be checked for chlorite. Soaking of hard dark shales in a sulfuric acid solution can also be used to define potential chemical deterioration.

Shale Property Tests

Compaction. Shales classified as soillike require compaction tests



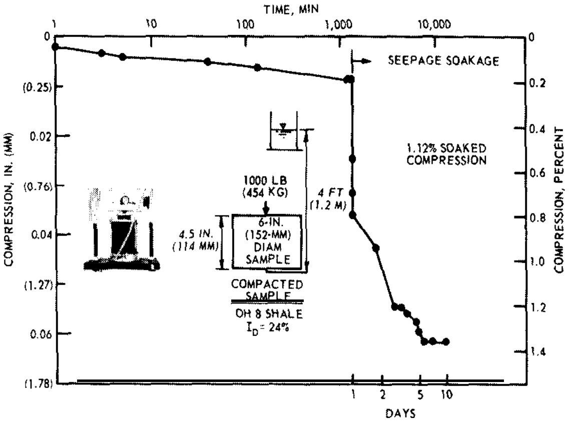
NOTE: (1)DIFFERENT LIMITING VALUES MAY NE JUSTIFIED ON BASIS OF LOCAL EMBANKMENT PERFORMANCE EXPERIENCE.
(2)TYPE T1 - NO SIGNIFICANT BREAKDOWN OF ORIGINAL PIECES.
TYPE T1S - SOFT, CAN NE BROKEN APART ON REMOLDED WITH FINGERS.
TYPE T1H "AND, CANNOT NE BROKEN APART.
TYPE T2 - RETAINED PARTICLES CONSIST OF LANGE AND SNALL "AND PIECES.
TYPE T3 - RETAINED PARTICLES ARE ALL SNALL FRAGMENTS.
"'USING NO. 10 SIEVE (2 MM)
(4)CAN BE PERFORMED ON JAR-SLAKE TEST SAMPLES IF IN SITU NATURAL WATER CONTENT IS KNOWN. PI SENSITIVE TO DEGREE OF PULVERIZATION.
(5)REQUIRES SPECIAL PROCEDURES TO ASSURE GOOD DRAINAGE AND ADEQUATE COMPACTION (95% T-W) FOR LOOSE LIFT THICKNESS UP TO 24-IN. (0.6-M) MAXIMUM.

Figure 6. Recommended Durability Index Tests and Suggested Classification Criteria for Shales Used In Highway Embankments.

to define their optimum water content and maximum density for field compaction control of end result specifications or for developing compaction procedures from test pad construction. The American Association of State Highway Officials (AASHTO) T-99 (Method D) compaction test can be used for shales with oversize particles by scalping plus 3/4-in. (19-mm) material from the test sample. New material should be used for each test point.

Compression. Soaked-compression index tests on compacted samples can provide a relative measure of expected performance for large embankments where settlement of fill materials is of major concern. Compacted samples at different densities are subjected to a vertical pressure equivalent to that for one-half the fill height, then allowed to soak until the measured compression stabilizes. The effect of increase in density and decrease in compression can be related to the slake-durability index and used to evaluate the feasibility of greater compaction in reducing settlements to tolerable limits.

Permeability. Measurements of permeability can also be made during the soaked-compression test. The permeability at a given density provides an indication whether the compacted shale will act as a relatively impermeable barrier to surface water infiltration and also block subsurface seepage water, if foundation drainage measures are not included in the design.



Shear Strength. For special embankments 100 ft (30 m) or higher, shear strength tests on 2.8-in.-(71-mm) diameter compacted shale samples using modeled gradations may be warranted. The results would be needed for stability analyses and possible finite element analyses to predict settlement and lateral deformations.

Data Storage

Consideration should be given to a computerized system of data storage and retrieval for geologic and test data on shales to develop an expanding source of information for future projects. The advantages include reduction of testing for common shale formations and the potential for correlating index properties with compaction and settlement properties, shear strength, excavation characteristics, and service performance.

Potential Problem Assessment

Evaluation. A realistic assessment of potential problems (other than poor foundations) with embankments constructed in shale formations requires a thorough understanding of the causes of distress and the role of contributing factors listed in Table 2.

Judgment. Although a number of problem shale formations have been identified, the influence of construction procedures and the relative importance of factors that contribute to inadequate compaction, saturation, and shale deterioration are not well defined. Consequently, considerable judgment is required in assessing potential problems.

Service Data. A valuable guide can be established if the slake-durability index, lift thickness, compaction procedures, and performance data are collected and correlated. An example of a preliminary correlation between slake-durability index and lift thickness is summarized in Figure 7. The criterion was established using performance experience (mainly settlement) for 83 embankments in 15 States. The choice of lift thickness, say 8 versus 24 in. (0.2 or 0.6 m) for a range of I_D values from 40 to 60 percent in one cut depends on the consequences of post-construction problems and acceptable maintenance costs.

Table 2. Assessment of Potential Problems.

IMPORTANT FACTORS	POTENTIAL PROBLEM CATEGORY MINOR	MODERATE	MAJOR	INFLUENCE OF SPECIAL REQUIREMENTS
Formation Features				
Soil ad weathered rock depth:	Thin, less than 1.5 m	Shallow, 1.5 m	Deep, greater than 1.5 m	Benching depth and need to stockpile
Shale and rock layer thickness:	Less than 0.9 m	0.9 to 1.5 m	Greater than 1.5 m	Feasible use of selective grading
Interbedding of shale and limestone:	None	Few thin beds	Many thin beds	Breakdown of rock for compaction
Dip of layers into fill areas	Horizontal	Five-degree dip	Ten-degree dip	Potential seepage into embankment
Joint spacing:	Wide, greater than 3 m	Medium, 1.5 to 3 m	Close, 0.3 to 1.5 m	Size of excavated rock
Seepage from cut into fill areas:	Low	Moderate	High	Potential wetting of shale embankment
Excavation Characteristics	Easily ripped	Hard ripping	Blasting required	Maximum size of rock and compaction problems
Shale Durability				
Type of breakdown:	Few cracks	Hard pieces	Slakes to soil	Lift thickness and
Classification:	Durable	Durable	Nondurable	compaction requirements
Type Embankment:	cross valley (through)	Skew	Sidehill	Benching and foundation drainage required
Current Design and Construction Practices				
Slope benching and drainage:	Detailed Plans	Not shown in detail	No special requirements,	Type and detail of information on plan drawings
Rock and durable shale for foundation drainage:	Specified on plans	Hard to identify	left to project	and sections
Mixing nondurable shale and soil with rock:	Controlled to prevent	Complex formation	engineer's judgment	Fill processing and control techniques
Field durability classification of shales	Rapid test used	Time-con-test	No reliable method	Identifying nondurable shale on plans and use of rapid field test
Lift thickness and compaction	specified and controlled	Too few inspectors	Uncontrolled	Compaction requirements, procedures, and control techniques
Performance Experience				
Settlements	less than 0.18 m	0.18 to 0.3 m	Greater than 0.3 m	Cost of maintenance versus construction costs
Slope stability	No problem	Shallow slides	Large slides	Cost of repairs or reconstruction and lane closures

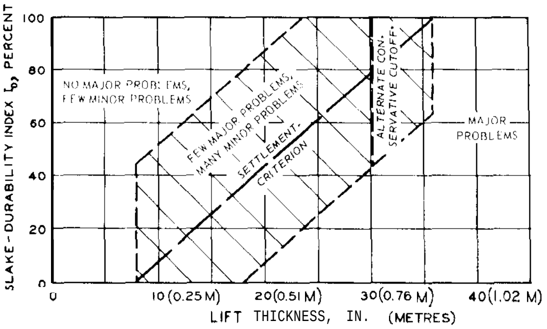


Figure 7. Preliminary Correlation Between Slake-Durability Index and Lift Thickness.

Past Experience. Considerable experience with shale construction projects and a good knowledge of formation geology and excavation characteristics are required to determine, for example, whether normal construction practices will cause undesirable mixing of nondurable shale and soil with rock because of variable stratigraphy and lead to unacceptable settlements, Valuable information on specific projects and regional conditions is contained in State Highway Agency internal reports on slide investigations and repairs and in research reports and published papers by State geotechnical engineers. The greater the detail on geologic conditions and shale durability developed during the project field investigation, the less will be the degree of conservatism required in assessing potential problems and the need for extensive use of special measures.

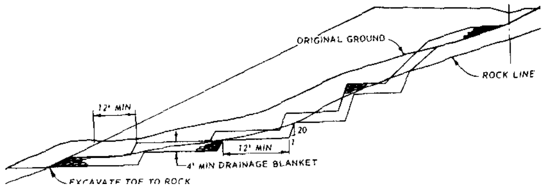
Problem Definition. Problem areas should be well defined before the final alignment is established. Where the final alignment or grade cannot be shifted to avoid or minimize the problem, extensive stabilization measures, such as deep drainage trenches and/or horizontal drains or retaining structures, may be required on hillside locations to avoid a costly failure after construction. Complex geologic conditions in cuts may require extra blasting to reduce all materials to an acceptable size for compaction as soil in thin lifts. In a cut-fill transition area, spring drains, subdrains, and benching may be required to drain excess seepage from pervious strata that are dipping out of the foundation surface.

Along sidehill problem locations deeper than normal borings, rock coring, and sampling may be required over a wider area to define depths of weak materials, stratification sequence, bedding inclination, and groundwater seepage conditions that will affect the stability of the foundation area. In geologically complex cuts, more extensive explorations and sampling may be needed to define stratification sequence, bedding orientation and inclination, spacing of joints, fractures and bedding planes, groundwater depths, and shale durability.

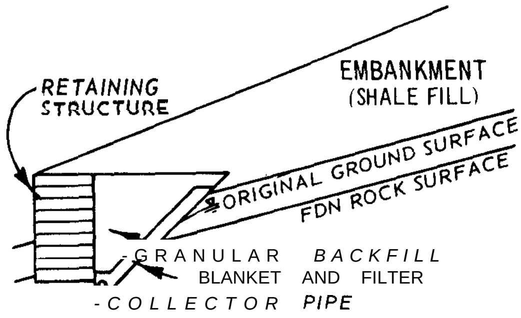
Special Design Measures

Special Features. Special design features especially for problem locations, such as sloping ground on deep weathered material, narrow right-of-way in areas of high fills, and areas of excessive seepage, include the following:

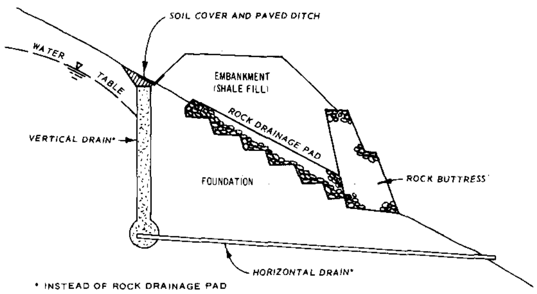
- Foundation benching and rock drainage blanket



- Berms
- Retaining structures
  - Rock buttress
  - Reinforced earth wall
  - Gabion and crib walls

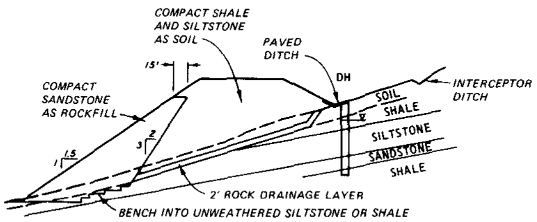


- Drainage measures
  - Underdrains
  - Rock drainage pad
  - Horizontal drains
  - Vertical drains



Drainage. Drainage measures are needed for all retaining structures and require sand or gravel filters of the proper gradation to prevent movement of soil particles out of the shale fill or foundation. Otherwise, clogging of the drains and piping in the fill could cause detrimental settlements. Filter fabrics can be substituted for sand as a filter component between soillike fill and gravel drainage material when sand placement is uneconomical.

Special Provisions. Special excavation, selective grading, foundation benching and drainage, and compaction provisions may be necessary for major embankments to ensure stability and prevent settlement. In areas of deep weathering, stockpiling may be necessary to obtain durable shale and rock for drainage pads at the base of the fill. Special *cross* sections in the plans may be needed to designate the different layers in a cut for use in certain sections of the fill.



Special compaction requirements including types and minimum weight of compaction equipment, maximum lift thickness, number of coverages, and processing procedures may be necessary to achieve require densities for hard nondurable shales. Where experience is lacking for a shale formation, test pad construction should be specified to develop required compaction procedures.

Material Properties. Selection of compaction settlement and strength properties for long-term performance evaluation can be obtained from laboratory tests on compacted samples or estimated from index tests and past experience. An example of settlement related to slake-durability index and the effect of increased density is shown in Figure 8.

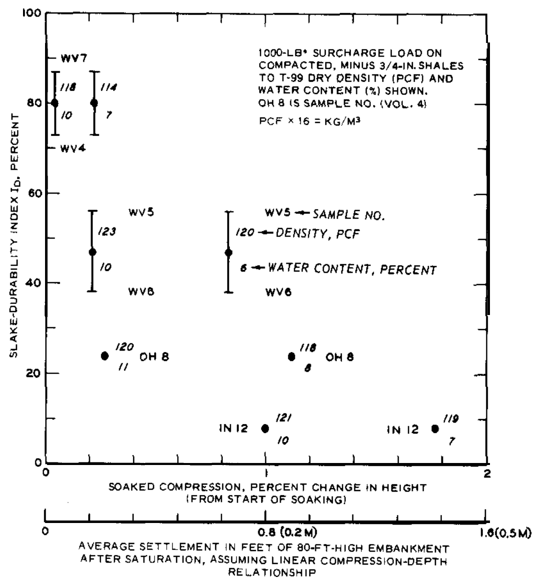


Figure 8. Soaked Compression of Minus 3/4-in. Compacted Shale Samples Related to Slake-Durability Index.

The shear strength needed for a factor of safety of 1.2 is related to slope height in Figure 9.

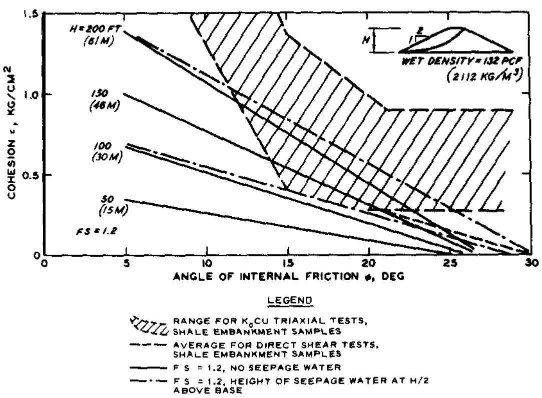


Figure 9. Shear Strengths to Slope Height for FS = 1.2 and 2:1 Side Slopes.

Shales compacted to 95 percent of AASHTO T-99 maximum densities generally will have adequate strength for 2:1 side slopes. Compaction in excess of 95 percent of AASHTO T-99 maximum density may be required for coarse-graded nondurable shales that often develop large strains before the maximum shear strength is developed. Flatter slopes, such as 3:1 side slopes, may be required for bridge approach fills to reduce lateral deformations and associated settlements.

Construction Grading

Grading Sequence. The overall grading sequence is a major consideration in construction of shale embankments to achieve selective excavation and placement as directed by the plans and special provisions. Surface soil, weathered shale, and nondurable shales from cuts and foundation benches need to be compacted in thin, relatively impervious layers in cross-valley fills where foundation drainage is not required or in the central zone of fills above a drainage layer.

Rock, such as sandstone and hard durable shales, needs to be used for drainage layers. These layers are needed on sidehill benched foundation slopes and transverse slopes beneath the cut-fill transition to intercept and drain subsurface seepage.

The usual procedure of placing materials as they are excavated from a cut in the next fill from the bottom up is not suitable for shale embankments.

Preconstruction training of the project engineer staff and inspectors should cover the type and extent of selectively grading and the major items requiring special control as outlined below.

Construction Control

Foundation Preparation. Key items for foundation preparation control are:

1 - Visual inspection to ensure benches are cut into unweathered shale or rock in proper sequence.

2 - Checking durability of rocklike shales used for drainage rock by the simple jar-slake test or point-load test (Figure 10) if preconstruction correlation with slake durability is established.

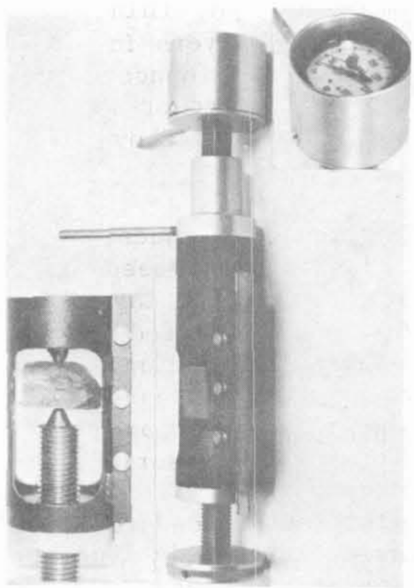


Figure 10. Point Load Tester.

3 - Preventing excess fines in drainage rock.

4 - Ensuring adequate filter zone on top of rock drainage layer by surface degradation under dozer tracks or use of carefully installed filter fabric.

5 - Proper installation of fabricated bench drains and spring drains.

Excavation Procedures. Control of excavation requires the following:

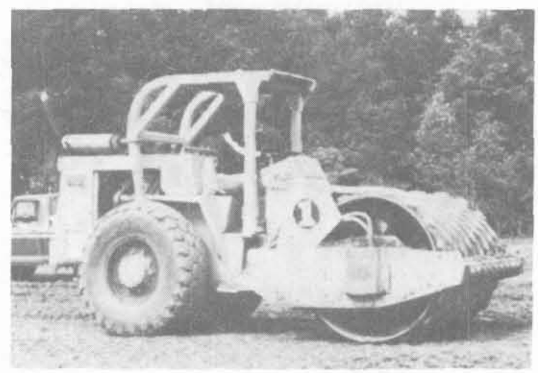
1 - Adequate fragmentation or ripping of nondurable shale for proper compaction.

2 - Separate excavation of different layers and routing to designated parts of fill as required by special provisions.

3 - Checking durability classification of shales.

Compaction Equipment Capabilities. Compaction equipment should be checked to ensure:

1 - Proper types and weight for further breakdown of nondurable shales and compaction to required densities for lift thickness allowed.



2 - Sufficient amount of compaction equipment to keep up with fill placement rate.

KEY COMPACTION CONTROL TECHNIQUES

- Visual inspection:
  - Material type, gradation, fill processing
  - Type and number of compaction machines
    - Maximum speed
    - Number of coverages
- Lift thickness measurement
- Moisture-density testing
- Geotechnical staff visits

Compaction Procedures. Proper compaction for shales require the following steps:

1 - Following established practices for test pad construction and testing when used to establish procedural-type compaction requirements.

2 - Breaking down or removing excess large rock from shales compacted as soil.

3 - Disking and adding water as required for proper compaction of shales.

4 - Checking for proper types of equipment and number of coverages established by special provisions or test pad results.

Compaction Control. Control for adequate compaction involves:

1 - Checking material type, lift thickness, water content, and density for end result provisions.

2 - Checking compaction equipment type, weight, lift thickness, number of coverages, and maximum speed for procedural-type provisions.

Construction of Special Features

Frequent inspection of special feature construction is needed to ensure that critical items listed below are accomplished.

1 - Foundation shear trenches and underdrains: (a) construction in segments to prevent slides in weak foundation materials, and (b) proper type of drainage and filter materials and compaction of backfill.

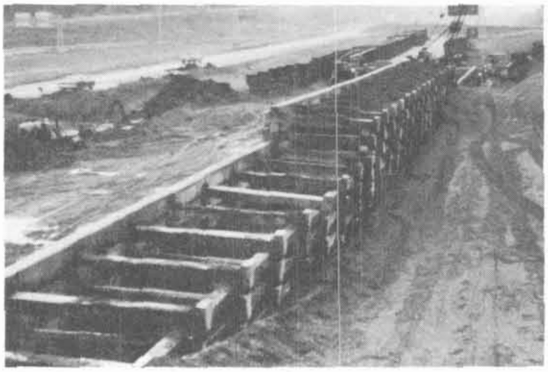
2 - Berms: adequate foundation benching and drainage and proper compaction.

3 - Buttresses: use of hard, durable rock and adequate filter materials along base and behind the buttress to prevent erosion of fill into rock and clogging of drainage paths.

4 - Reinforced earth walls: use of free draining backfill materials (clean sands or gravelly sands).

5 - Gabion or crib walls: use of clean stone backfill and proper filter zone behind wall to prevent erosion of

embankment fill into rock and clogging of drainage paths.



Frequent coordination is required between the geotechnical and construction staffs to solve unforeseen problems such as less than anticipated quantities of durable rock for drainage layers, need for additional test pads to resolve compaction problems, or difficulties in classifying the durability of shale strata.

Construction Records

Construction records with specific information on actual procedures and compaction equipment used, photographs, and test data are valuable sources of materials. The records can be used with long-term performance results to achieve optimum requirements for drainage measures, compaction procedures, and control techniques for future construction at a minimum cost.

Post Construction Monitoring

Monitoring of critical shale embankments should be considered for two reasons:

- To detect as soon as possible distress and apply corrective measures.
- To verify predicted performance and provide data for selection of optimum criteria for economical construction of future shale embankments.

Settlement is a major problem, and embankments over 50 ft (15 m) high with low margins of safety should have roadway settlement surveys two to three times a year. Settlement increases would warrant a geotechnical investigation to define the cause.

Major embankments higher than 50 ft (15 m) may warrant additional observations. Installation of piezometers may be needed for seepage detection. Inclinometer surveys may be necessary to detect lateral movements and possible slope failure.

EVALUATION OF EXISTING SHALE EMBANKMENTS

Early Detection of Distress

Early detection of distress in shale embankments is important in preventing a large slide. One means of detecting distress is by periodic low-level aerial color photography. Color photographs for many miles of a highway can be quickly scanned for telltale signs of embankment distress such as pavement overlays, cracks along pavement and shoulders, misaligned guardrail, shoulder and slope sloughing, erroded slopes and surface drains, and seepage areas indicated by unusual plant growth. Selected embankments can then be inspected on the ground, and the seriousness evaluated.

Distress, in the form of continuing settlement, cracking along pavement edges and shoulders, small shoulder slides, and slope sloughing, has often developed within 1 to 10 years into a large slide requiring expensive reconstruction, especially along sidehill locations. In many cases, the distress has been handled at the District level by maintenance forces without the assistance of the State geotechnical staff until a problem reaches major proportions.

Several States are cataloging distressed shale embankments and assigning priorities according to the seriousness of distress and consequences of failure. The States have established a continuing program of limited field investigations to evaluate the distressed embankments in order of priority and available funds.

Cause of Distress

The primary cause of shale embankment distress is saturation and progressive softening and deterioration of nondurable shales (often mixed with rock and soil) by surface water and/or subsurface seepage that enters the embankment during periods of prolonged rainfall. Because of the heterogeneous mixture of shales, rock, and soil in many shale embankments, infiltrating water follows erratic flow paths, depending on the relative porosity of different layers and the pattern of cracks caused by settlement and deformation. Consequently, it is often difficult to define the pattern of infiltration, location of soft shale or soil zones, and the extent of distress without extensive subsurface investigations.

Evaluation

The major objective in evaluating the future behavior of distressed shale embankments is to determine whether settlements will eventually stop or will continue and develop into a large slide. The first step should be a thorough field evaluation by a geotechnical engineer to determine the surface extent and seriousness of the distress and the probable effectiveness of immediate remedial measures in reducing further distress.

An immediate measure that is usually inexpensive is improvement of surface drainage to reduce infiltration. Other steps in the evaluation process for major embankments include the following:

- Review of available information on (a) the stratification and attitude of bedding at the cut-fill transition and uphill of sidehill embankments, (b) groundwater seepage patterns, (c) placement sequence and amount of mixing of different materials during construction, (d) quantity and durability of shales placed in the embankment, and (e) past experience with similar embankments in the same formation and local area to establish possible seepage sources and locations of weak zones.

- Periodic roadway center-line and cross-section elevation surveys to monitor the rate of settlement and lateral deformation with time.

- Disturbed sample borings to define the depth and thickness of predominant types of materials (i.e., shale, shale chunks and clay soil, soft shale with some limestone, limestone with few shale chunks and sandstone); type and amount of shale deterioration (e.g., softened into clay, fragmented into hard silty chips and gravel sizes, or friable clayey chunks); location of wet or saturated zones; and type of foundation material (e.g., sandstone drainage layer, thick weathered shale, hard shale, and limestone strata).

- Installation of piezometers and/or slope inclinometer casing in selected borings to monitor groundwater levels (or pore water pressures from piezometers) and lateral movements and development of a slip zone.

- Logging of selected borings with portable nuclear moisture density equipment to locate wet, low density zones.

- In situ pressuremeter tests and/or undisturbed sampling and laboratory testing to estimate shear strengths for evaluation of stability.

The scope of the field investigation and monitoring program depends on the type of available information and experience in the area. The results of the evaluation should provide necessary information for decisions on the need for remedial measures and the selection and design of appropriate treatment methods.

EXAMPLE CRITERIA FOR TREATMENT ACTION

TYPE OF DISTRESS	EMBANKMENT CONDITIONS	ACTION NEEDED
Settlement minor (<0.3 m)	Good surface drainage, no cracks or signs of slope instability	Continue to monitor
Excessive settlement (>0.3 m)	Eroded ditches; drainage inlets above median surface; embankment does not contain soft clay, wet zones, or high groundwater; no signs of slope instability	Repair and improve surface drainage, overlay and continue to monitor
Excessive settlement (>0.3 m)	Same as above but embankment contains soft wet zones or high groundwater, cracks exist along shoulders and slope instability is apparent	Design and install drainage measures, evaluate stability and select major treatment alternatives

REMEDIAL TREATMENT OF DISTRESSED EMBANKMENTS

Drainage Measures

The primary consideration in remedial treatment of shale embankments should be surface and subsurface drainage methods. Drainage methods are an integral part of most remedial treatment methods. Remedial treatment plans should include surface treatment and drains designed to minimize infiltration of surface water. Subsurface drainage is essential in treatment of side-hill and transitional fills. Certain types of subsurface drains can be rapidly installed (i.e., horizontal drains and pumped vertical wells) and are used when temporary (or emergency) support is required. Early installation of subsurface drains, when feasible, can halt embankment distress and prevent an extensive failure. Proven remedial measures are:

- Drainage
  - Surface drains (repairs and additions)
  - Horizontal drains
  - Vertical drains (upslope of embankment)
  - Trench drains at embankment toe
  - Pumped wells (temporary)
  - Drainage blanket (under reconstructed embankment)
- Impervious layer beneath shoulders and median
- Slope-flattening
- Berms
- Shear trenches
- Retaining structures

Measures for Unstable Slopes

Remedial treatment, in addition to drainage methods, will often be necessary when significant improvement in slope stability is required. Primary consideration should be given to constructing berms. Retaining structures for supporting slope-flattening or berm fills should be considered where right-of-way and/or suitable borrow materials are limited. As a special type of retaining method one or two rows of closely spaced piles can be rapidly installed as a temporary or permanent support (when properly designed and required to maintain traffic).

Where embankment distress is caused largely by foundation shear failure, foundation shear trenches may be required to supplement slope-flattening or berm fills.

Embankment reconstruction involving combinations of material replacement, flatter slopes and berms, and shear trenches should be considered where large settlements, shear displacements, and/or shale degradation have severely weakened embankment and/or foundation materials.

Specialized stabilization methods, including cement grouting and other cement, lime, and chemical treatments, may be successful under certain conditions. Cement grouting should be considered when embankment settlements have been attributed to a high percentage of interconnected voids. Other cement, lime, or chemical treatments should be considered only on a trial basis at selected sites where risk of failure is minimal and substantial savings over more conventional remedial treatment methods can be realized. Expert guidance is required in design and application of these methods.

Design Considerations

Design of remedial treatment alternatives should be based on sound geotechnical engineering principles, combined with engineering experience, judgment, and ingenuity. Design investigations should include a review of site evaluation data, past experience, and stability analyses based on in situ strengths.

As an essential feature in the design of economical and effective remedial treatment plans, stability analyses aid in determining the significance and interaction of design variables and provide a quantitative basis for designing remedial treatment methods consistent with engineering judgment and experience. Furthermore, these analyses should be conducted in the design of permanent or temporary support (including temporary stability of slopes excavated in construction of permanent remedial treatment). Acceptable factors of safety can vary, depending on the accuracy and confidence in design parameters and the consequence of failure. Factors of safety for permanent remedial treatment range from 1.25 to 1.5 and from 1.1 to 1.3 for temporary support.

Construction Control

Repair or reconstruction of shale embankments requires constant inspection to ensure compliance with design requirements. Important items for inspection include the following:

- Proper type materials for drainage and filter layers, trench backfill, berms, and retaining structures such as reinforced earth, gabion, and crib walls.

- Adequate compaction of backfill, berm fill, and fill for retaining structures.
- Spacing and depth of horizontal drains and vertical drains.
- Proper type and placement of drainage backfill for vertical drains and wells.

It is particularly important that shear trenches or trench drains at the embankment toe be constructed in short segments without delay to prevent back slope slides into the excavation before backfilling is started.

Treatment Monitoring

A plan for monitoring and maintenance should be implemented following repair or reconstruction. The following items should be observed and additional remedial treatment or maintenance applied as necessary:

- Embankment settlement and lateral deformation.
- Pavement distress and surface cracking.
- Erosion and cracking of embankment slopes.
- Function and discharge from surface and subsurface drains.
- Groundwater table elevation and embankment and foundation pore water pressures.

The intensity of site monitoring will depend on site conditions, risk of failure, and critical factors in the remedial treatment design. It is particularly important to check and maintain the operation and effectiveness of subsurface drainage installations to ensure that groundwater levels and pore water pressures do not exceed safe values determined from design stability analyses. Site monitoring and maintenance plans should be modified periodically based on accumulated data.

FUTURE DIRECTION

The future direction in design and construction of shale embankments should be based on service performance. Refinements in shale durability classification criteria, use of selective grading, extensive benching and drainage measures, and procedural-type compaction provisions based on test pads can best be achieved by evaluation of embankment performance within each State. The ultimate goal should be development of optimum criteria for economical design and construction of stable shale embankments.

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