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Soil
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February 21, 1991

SOIL MECHANICS NOTE NO. 13
210-VI

SUBJECT: ENG - DISPERSIVE CLAYS

Purpose. To distribute Soil Mechanics Note No. 13 (SMN-13).

Effective date. Effective when received.

Dispersive clay soils can be a problem for many SCS practices or structures. In appearance, they are like normal clays that are stable and somewhat resistant to erosion, but in reality they can be highly erosive and subject to severe damage or failure. It is important to understand the nature of these materials and to be able to identify them so they can be avoided or treated.

SMN-13 summarizes the properties of dispersive clay soils, discusses the proper way to investigate for them and outlines the ways to test for them in the laboratory or field. Defensive design measures are given and remedial treatments explained.

Filing Instructions. File with other soil mechanics notes with guide material on dispersive soils or on construction with soils.

Distribution. This soil mechanics note will be of interest to soil engineers, design engineers, area engineers, project engineers, engineering geologists and others who may be conducting investigations for designing, or constructing practices or structures where dispersive soils may be found. The initial distribution to each state and NTC is according to requested numbers indicated in a survey for SMN-1 (shown on the reverse side). Additional copies may be obtained by ordering SMN-13 from Central Supply.

EDGAR H. NELSON
Associate Deputy Chief
for Technology

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Engineering Division

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DISPERSIVE CLAYS

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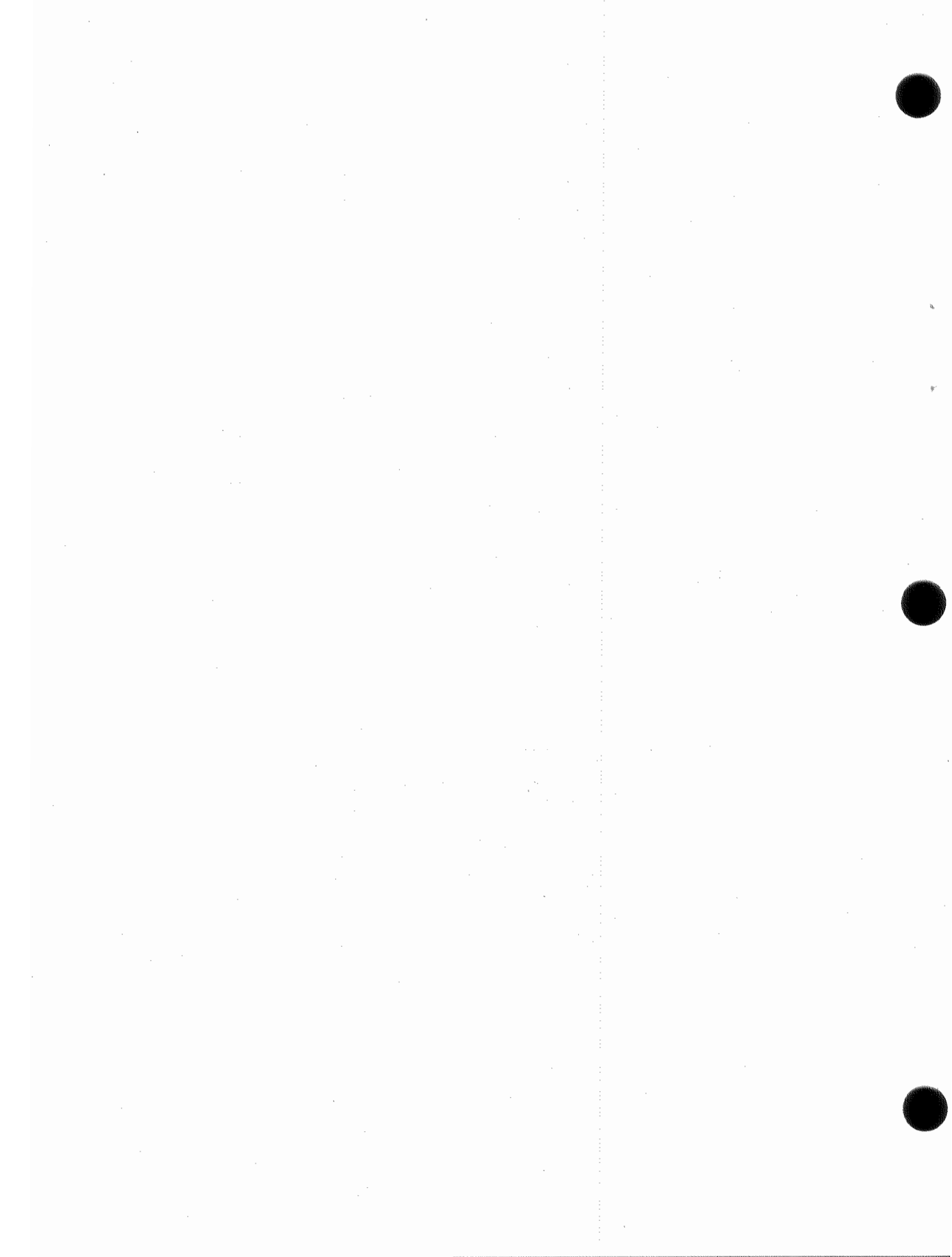


TABLE OF CONTENTS

<u>Description</u>	<u>Page No.</u>
Preface	1
Introduction	1
Origins of Dispersive Clays	2
Sampling and Investigating for Dispersive Clays	3
Tests for Dispersion	5
Engineering Problems Associated With Dispersive Clays	13
Design Measures for Dispersive Clays	17
Construction Considerations	22
Appendix A - References	23

LIST OF FIGURES

<u>Description</u>	<u>Page No.</u>
Figure 1. Outcrop of Dispersive Clay	4
Figure 2. Crumb Test Reactions	7
Figure 3. Pinhole Test Apparatus	10
Figure 4. Chemical Test Data Plot	12
Figure 5. Jughole Features on Embankment	13
Figure 6. Exposed Dispersed Soils in Channel Bank (Squaw Creek Oklahoma)	14
Figure 7. Failed Embankment (Breach)	15
Figure 8. Failed Embankment (Tunnel)	16
Figure 9. Blanket Treatment of Embankment Slopes and Zoning Plan for Dispersive Clays	18
Figure 10. Chimney Filter in Embankment	21



PREFACE

This soil mechanics note was prepared by Danny McCook and Charlie McElroy of the Soil Mechanics Laboratory at Fort Worth, Texas, with review and assistance provided by soils engineers from the other NTC offices.

INTRODUCTION

DEFINITION

Dispersive clays differ from ordinary, erosion resistant clays because they have a higher relative content of dissolved sodium in the pore water. Dispersive clays have a preponderance of sodium in the pore water, whereas ordinary clays have a preponderance of calcium and magnesium cations. Dispersive clays erode as the individual colloidal clay particles go into suspension in practically still water, whereas considerable velocity in the eroding water is required to erode normal clays.

Low plasticity silts and sands are composed of single-grained particles that are much larger than water molecules, and the ionic materials in their pore water are chemically inert. Consequently, the individual particles have little attraction for one another. These soils are highly erodible because of the low inter-particle attraction and relatively low mass of the particles.

Individual soil particles may be detached from a soil mass and carried off by moving water more easily than aggregates of particles. Because dispersive clay particles have much less mass than sand or silt-sized particles and are not aggregated, the clays are much more erodible. The approximate ratio of the mass of the finest sand particle to the mass of a clay particle is 150,000 to 1.

MECHANICAL PROPERTIES OF DISPERSIVE CLAYS

Clays are by definition fine-grained soils that have significant plasticity. They have 50 percent or more by dry weight of particles smaller than the #200 sieve and their liquid limit and plasticity index plot on or above the A-Line on a plasticity chart. Most engineers also consider soils plotting in the hatched zone of the plasticity chart to be clays in discussing dispersion. Typically, dispersive clays are low to medium in plasticity and classify as CL in the Unified Soil Classification System (USCS). Other USCS classes that may also have dispersive clays are the ML, CL-ML, and CH classes. Soils classifying as MH rarely contain dispersive clay fines.

Occasionally, the dispersive characteristics of the clay fines in coarse-grained soils may be of interest. Sands or gravels with dispersive clay fines should be referred to as such, and not called dispersive clays. Some nonplastic or slightly plastic silts can have a low percentage of clay size particles, and one may still be interested in the dispersive characteristics of those clay-size particles occurring in the silt soil. Such soils generally classify as ML in the USCS. These soils should not be termed dispersive clays, however, but rather silts that have dispersive clay fines. Most soil engineers refer to the percentage of particles smaller than 0.005 millimeters as the percentage of clay in a soil.

Standard soil mechanics tests, such as mechanical grain size distribution analyses (gradation) and Atterberg limit tests, do not distinguish dispersive clays from ordinary clays. A special group of tests is needed to identify dispersive clays.

CHEMICAL PROPERTIES OF DISPERSIVE CLAYS

Normal clays have a flocculated or aggregated structure because of the electrochemical attraction of the particles to each other and to water. Calcium and magnesium cations predominate in the double layer in normal clays. The balance of electrochemical forces in these soils favors a strong attraction of the particles to one another. This explains these soils' typical cohesive, nonerosive behavior.

Dispersive clays, however, are predominated by sodium cations in their pore water. Because sodium cations have only one positive charge compared to two charges for calcium and magnesium ions, an imbalance in the electrochemical forces occurs in dispersive clays. This imbalance causes particles in a dispersive clay to be repulsed rather than attracted to one another. Consequently, dispersive clay particles tend to react as single-grained particles and not as an aggregated mass of particles.

Because clay particles are very small and have a low mass, the particles are easily detached and transported by water. This explains the extremely low resistance to erosion of these soils. Dispersive clays are much less erosion resistant than even fine, nonplastic silts and sands because of the much smaller mass of the clay particles compared to the silts and sands.

Dispersive clays are most easily eroded by water that is low in ion concentration, such as rainwater. In some instances, dispersive clays are less problematic than expected. This has been attributed to the eroding water being more in balance with the ionic composition of the attached clays and has been especially observed in channel projects where the stream water was similar in chemical composition to the clays in the banks.

ORIGINS OF DISPERSIVE CLAYS

The origin of a particular dispersive clay deposit cannot always be identified with certainty. Experience in an area can give indications of probable contributing causative factors, however. Some observations of SCS engineers' are summarized as follows. Many marine shale formations produce dispersive clays. In Oklahoma, for instance, several lower Permian and middle Pennsylvanian age formations produce dispersive clays soils as residual soils and in the derived alluvial deposits. Examples are the Oscar, Senora, and Wellington formations. Extensive experience in an area is needed to develop enough correlation data to make generalizations regarding specific geologic formations. Because shales may be exposed to such post-depositional influences as saline seepage, leaching of pore-water salts, and seepage from overlying formations containing other salts, the original cation exchange complex of the shales may be altered.

Residual clays developed from weathering of dispersive shale generally are uniformly dispersive deposits. However, alluvial deposits derived from upland dispersive shale formations may not be as uniformly dispersive. Other sediment sources can become mixed with the dispersive shale derived soils, and the resulting alluvial profile may be quite erratic in dispersive clay occurrence. Dispersive clays

occur erratically in most alluvial profiles. Alluvial soil deposits can rarely be correlated by dispersive characteristics either laterally or vertically. Dispersive clays often occur as random lenses or pockets in the profile. This strongly affects the ways in which samples should be collected for testing for dispersive properties.

Weathered loessial soils in parts of Mississippi, Arkansas, Tennessee, and Louisiana are another common type of dispersive clay deposits. The source of the excess sodium cations in these soils has been attributed to the chemical disintegration of sodium or potassium feldspars in these deposits. The Slate Belt physiographic area of North and South Carolina also has dispersive clay deposits. More research is needed to gain better insight into causative mechanisms for dispersive clay deposits.

In some locations, dispersive clays result from salt water discharges, which alter the native soils that were not originally dispersive. This is common in areas of oil field activity.

Fine-grained soils weathered from igneous and metamorphic rocks, as well as soils weathered from limestone are almost never dispersive. However, verification testing is always recommended until experience in the area verifies the absence of dispersive clays.

Mineralogical (x-ray diffraction) analyses have shown many dispersive clays contain a high percentage of smectite, the active clay group containing montmorillonite. The presence of montmorillonite without the influence of a predominance of sodium does not produce dispersive clays, however. Many montmorillonitic clays are not dispersive.

SAMPLING AND INVESTIGATING FOR DISPERSIVE CLAYS

Sampling and testing for dispersive clays should always be a part of investigations for SCS structures unless:

- (1) Extensive experience in an area or region has shown dispersive clays are not present and no problems have been attributed to dispersive clays in the area.
- (2) The project is located in an area where soils are derived from calcium-rich parent materials. Examples are residual and alluvial soil deposits derived from limestone and chalk.
- (3) Only coarse-grained soils that have less than 15 percent clay occur within the project area.

The immediate project area should be examined for at least two physical features that may indicate the presence of dispersive clays. Often, an erosional pattern similar to a "badland" topography occurs when dispersive clays are located at or near the surface and topographic relief has allowed erosive forces to act. Figure 1 shows an outcrop of dispersive clay that depicts this feature characteristic.

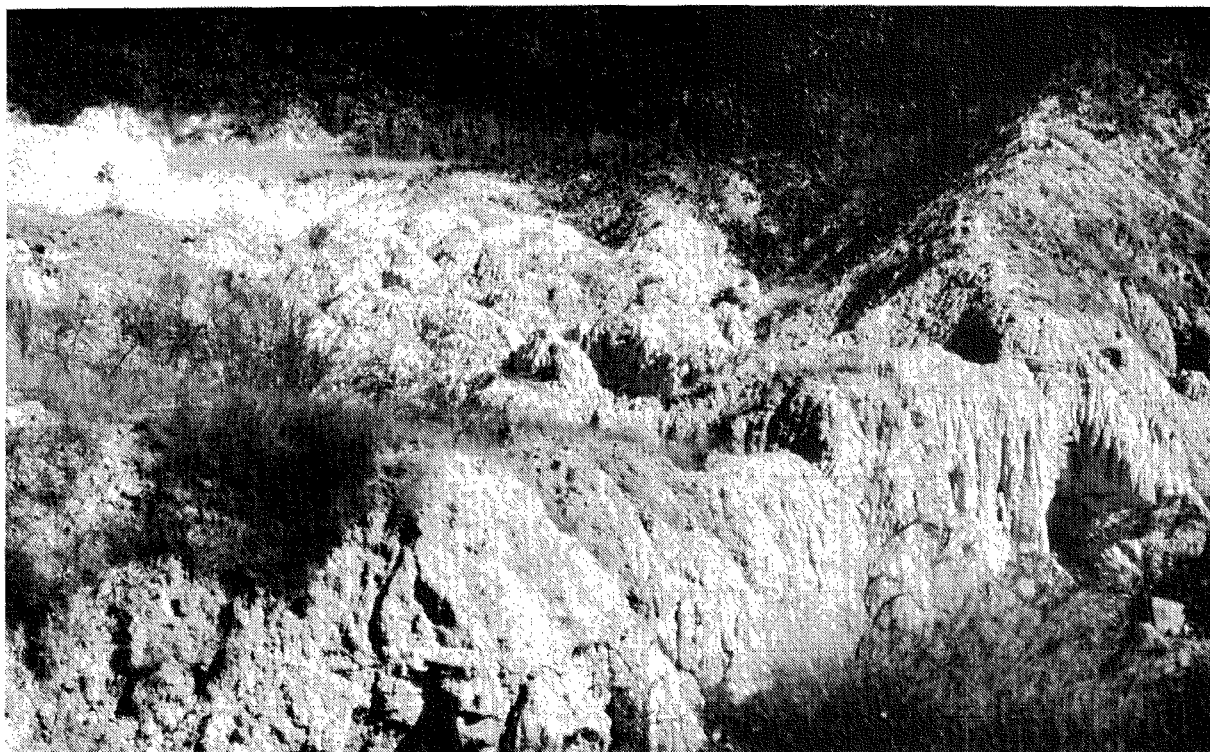


Figure 1. Outcrop of Dispersive Clays.

If topographic relief is not present in an area, these features may not be present. In such cases, no discernible differences between normal and dispersive clays may be noted. Water bodies in the area should be examined to determine if the water remains turbid for long periods. In dispersive clay watersheds, many water bodies remain turbid and rarely, if ever, clear up.

Color is not a reliable distinguishing feature for identifying dispersive clays. Red, gray, brown, and mottled dispersive clays that have no definite color pattern have been observed.

Sampling for dispersion should recognize that dispersive clays often occur as random lenses in soil profiles. A minimum of 30 samples is required to make valid statistical inferences (mathematically). Fewer samples may be useful, but conclusions based on limited data are sometimes misleading. Samples collected for dispersion tests should be relatively small and discrete. When possible, augers should not be used because the auguring process tends to mix layers of soil.

A minimum of 3 to 5 pounds of moist soil should be collected. Samples should never be composited from several drill holes even if color and plasticity indicate similar soils. Also, they should not be composited from a single drill hole. A sample should not be collected to represent over 1 foot of a profile. Mixing of dispersive and

nondispersive samples by compositing often obscures the presence of the dispersive clay lenses in the profile. Wide variations in dispersive characteristics occur within short horizontal and vertical distances in an area.

Samples collected for dispersion tests must be maintained at their natural water content until tests can be performed. Collected samples should immediately be placed in a good quality plastic bag or container that can be sealed for shipping or holding until tests are performed. Plastic bags that are at least 4 mils thick are recommended to prevent tearing during shipping and handling. The bags should be sealed by folding the tops and taping or tying. SCS Laboratories do not recommend "self-sealing" plastic bags because of their experience with loss of seals during handling and shipping.

Normal SCS procedures for labeling hole numbers and sample numbers, preparing sample lists, and accompanying geologic reports should be used when samples are sent to a soil mechanics laboratory for testing.

TESTS FOR DISPERSION

INTRODUCTION

Four tests are presently used to determine dispersive clay characteristics. These tests are intended only to distinguish between "normal" and dispersive clays. They are not applicable to sands and gravels without clay fines or to nonplastic silts that have few clay particles. Several of these tests or modifications of the tests, can be performed in both the laboratory and the field.

Test procedures are summarized in following sections. Complete test procedures are shown in Soil Mechanics Note SM-8, and some test procedures are covered in ASTM standards as noted in following sections.

CRUMB TEST

Introduction. The crumb test may be performed in the laboratory and the field. Identical procedures are used. This test was developed by Australian scientists investigating the failure of water control structures. The crumb test is the simplest of the four tests used for detecting dispersive clays. Because the test is simple and easily performed, it should probably be performed on every sample collected, either in the field or by the laboratory, if samples are submitted to a laboratory. Crumb tests are often performed during an investigation to supplement laboratory information on samples collected.

Procedure. The test is performed by gently placing a clod of soil about 1/4 to 3/8 inch in diameter into a transparent plastic glass part filled with distilled water. The clod or crumb should be at natural water content unless the soil is very wet. Very wet soils may be air-dried to about their plastic limit before performing the test. Only distilled water can be used. Using demineralized water or other substitutes gives misleading test results. The crumb is dropped at the edge of the glass bottom and left in the glass undisturbed for a minimum of 1 hour. At the end of the waiting period, the clod and water are observed and the presence of any colloidal cloud in the water is evaluated. A second observation is recommended

after a waiting period of 4 hours. Some soils have no reaction after 1 hour, but have a significant reaction after the longer waiting time.

Interpretation. A grade is assigned to the test result using the following criteria:

1 - No colloidal cloud develops. Even though the crumb may slake and particles spread away from the original clod because of this slaking activity, no trace of a colloidal cloud is observed in the water.

2 - A colloidal cloud is observable, but only immediately surrounding the original clod. The cloud has not spread any appreciable distance from the crumb.

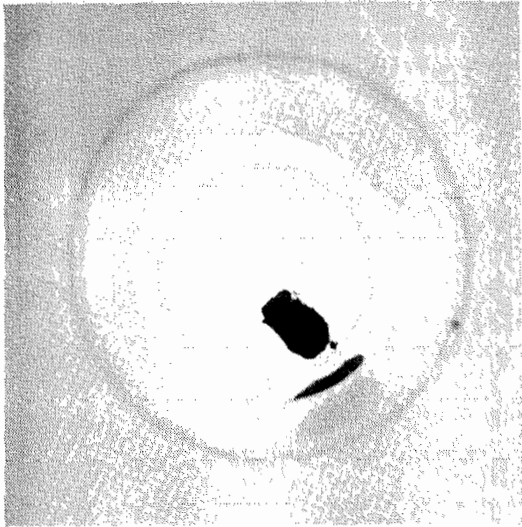
3 - A colloidal cloud emanates an appreciable distance from the crumb. However, the cloud does not cover the bottom of the glass, and it does not meet on the opposite side of the glass bottom from the crumb.

4 - The colloidal cloud spreads completely around the circumference of the glass. The cloud may not completely obscure the bottom of the glass, but the cloud does completely cover the circumference of the glass. In extreme cases, the entire bottom of the glass is covered by the colloidal cloud.

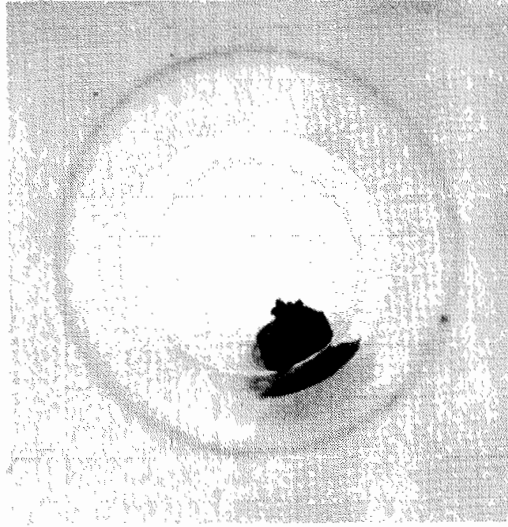
Figure 2 illustrates the four grades of the crumb test.

The crumb test is a good positive indicator for dispersive characteristics, but may be a poor negative indicator. Soils that have a 3 or 4 reaction in this test almost always are dispersive in other tests and in field performance. However, soils that have a 1 or 2 crumb test reaction occasionally are shown to be dispersive in other tests or field performance.

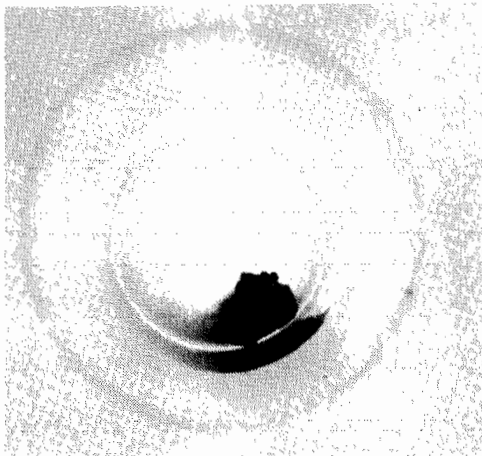
This anomalous behavior has not been satisfactorily explained. It seems to occur most often when soils are tested at a very wet water content. The crumb test should not be relied upon exclusively to test for dispersive clay characteristics unless extensive experience in an area has demonstrated its reliability. This test should be supplemented with the other dispersive clay tests discussed below, together with field performance data.



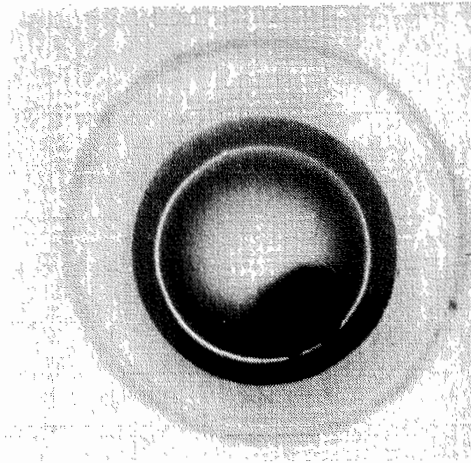
Grade 1 - No reaction



Grade 2 - Slight Reaction



Grade 3 - Moderate Reaction



Grade 4 - Severe Reaction

Figure 2. Typical Crumb Test Reactions

Other. The plastic glass used for the crumb test should be similar to those used by the SCS soils laboratories to have uniformity in testing. It should have a bottom diameter of about 2-1/4 inches, a top diameter of about 3-1/2 inches, and a height of about 2-5/8 inches. The bottom of the glass should have an arch about 1/8 inch high. A clear glass is preferable so that the colloidal cloud can be observed from the side as well as the top. Typical glasses have a fluid capacity of 9 fluid ounces. Similar glasses can be purchased at most grocery or department stores.

SCS DOUBLE HYDROMETER TEST

Introduction. This test is generally performed in the laboratory, but a modified version has been developed for field application. Basically, the test compares the measured percentage of clay in a sample that has been artificially dispersed to that of a companion sample which has no artificial dispersing agent added before measuring the percentage of clay particles in suspension.

Procedure. Detailed test procedures are outside the scope of this soil mechanics note. Refer to ASTM Standard D4221, Standard Test Method for Dispersive Characteristics of Clay Soil by the Double Hydrometer. Soil Mechanics Note SM-8 also has detailed test procedures.

The test measures the percent by dry weight of clay size particles in two clay samples that have been prepared differently. One clay sample is artificially dispersed by adding sodium hexametaphosphate to the sample and thoroughly agitating the suspension. The other sample is only agitated while being vacuum soaked to saturate the sample, and no artificial dispersing agent is added.

The percentage of clay size in each differently prepared sample is measured using a hydrometer. In this test, the percentage of clay size refers to the percent, by dry weight, of a sample that is particles finer than 0.005 millimeters. A value of percent dispersion is defined as follows:

$$\% \text{ Dispersion} = \frac{\% \text{ Clay (0.005 mm) without dispersing agent}}{\% \text{ Clay (0.005 mm) with dispersing agent}} \times 100$$

A modification of the laboratory test is available for field use. This test is the dilution turbidity test. Detailed test procedures are available from SCS Soil Mechanics Laboratories. In this test, the percentage of clay particles in suspension is not measured directly as it is in the double hydrometer test. Rather, the turbidity of two samples, one prepared with a chemical dispersing agent and the other at natural condition, is compared.

The turbidity of the chemically dispersed sample is adjusted by dilution with distilled water until it has the same turbidity as the sample that was prepared without chemical dispersing agent or agitation. A dilution ratio expresses the volume of the diluted sample required to obtain equal turbidity to the naturally prepared sample. If the chemically dispersed sample has the same turbidity as that of the natural sample without dilution, a dilution ratio of 1 is implied. See the following section for interpretations.

Interpretation.

Laboratory Test. If about the same clay size reading is obtained on both samples, the clay soil is naturally dispersed. Based on SCS experience correlating test results and field performance, the following general guidelines have been developed:

- % Dispersion > 60 - The soil is probably dispersive.
- % Dispersion < 30 - The soil is probably not dispersive.
- 30 < % Dispersion < 60 - Other tests are needed to establish whether the sample is significantly dispersive.

Field Test. Dilution ratios obtained in the field turbidity test of 3 or less indicate the soil is probably dispersive. Dilution ratios of 4 or higher indicate the sample is probably not dispersive.

Other. Samples must be maintained at their natural water content from the time of collection until tested. Water used must be distilled. In SCS practice, double hydrometer tests are routinely performed on all samples submitted for dispersive characteristics tests. The test is not applicable to soils that have less than about 12 percent clay size particles. If some uncertainty exists as to whether a sample is dispersive after reviewing results of the crumb test and double hydrometer test, two additional tests are available.

PINHOLE TEST

Introduction. The pinhole test is a direct, or performance, test. The other tests for dispersion are indirect or index tests. Comparison of field performance to pinhole test results have indicated an excellent correlation.

Procedure. Detailed test procedures are outside the scope of this soil mechanics note. Refer to ASTM Standard D4647, Standard Test Method for Identification and Classification of Dispersive Clays by the Pinhole Test, and Soil Mechanics Note SM-8. The following summary discusses general interpretations of the test.

In the pinhole test, a sample of soil at its natural water content is compacted into a plastic cylinder. In some cases an undisturbed sample may be used, and the sample is carved to the dimensions of the plastic cylinder and placed into it. A one millimeter hole is formed in the specimen by inserting a needle of that diameter through the middle of the specimen. The specimen in its container is then placed in a device which has hydraulic connections (figure 3).

Distilled water under specified heads is applied to the inlet of the container, and water is caused to flow under pressure through the hole in the specimen. The test is started with a 2 inch head causing flow through the specimen. Depending on the reaction of the sample, the head may be increased to 7, 15, and 40 inches. Water

flowing through the specimen is carefully observed for turbidity, and the flow rate is closely monitored to determine if the hole in the sample is enlarging by erosion.

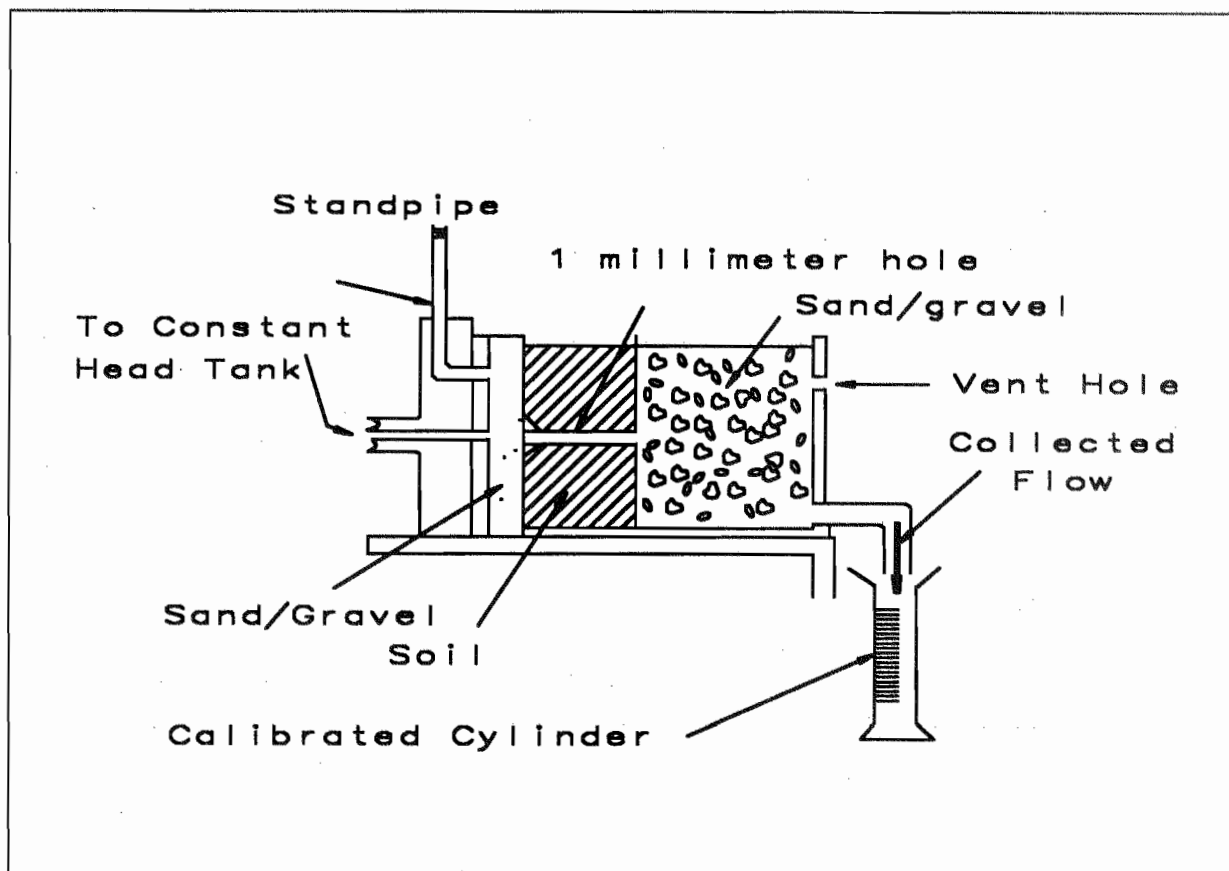


Figure 3. Pinhole test apparatus.

A field version of the pinhole test has been developed. The primary difference between the laboratory and field tests is that heads in the field test are limited to 15 inches, whereas the laboratory test device permits heads of up to 40 inches to be used. Working drawings for constructing a field pinhole test device are in Soil Mechanics Note SM-12.

Pinhole tests are evaluated according to a set of criteria given in the following section.

Interpretation. Dispersive clays will rapidly erode as water flows through the 1 millimeter hole under a 2 inch head. Rapid enlargement of the hole is reflected in an increasing flow rate, and the collected water is turbid. The dismantled specimen has an eroded hole diameter of at least 2 millimeters. Highly dispersive clays fail, or erode excessively, within 10 minutes of flow at the 2 inch head.

Nondispersive, or "normal" clays will not appreciably erode even with flow at heads of 40 inches where velocities in excess of 14 feet per second are involved. The hole of the dismantled specimen has virtually the same diameter as the original sample at the end of the test in such a clay.

Pinhole tests are rated using the following summary of criteria:

D-1 The most severe reaction. The sample rapidly erodes at a head of 2 inches. The pinhole has enlarged to at least twice its diameter. The flow rate exceeds 1.2 milliliters per second after 5 minutes.

D-2 Severe erosion of the hole occurs at a head of 2 inches, but up to 10 minutes is required for the flow rate to increase to more than 1.0 milliliters per second. The eroded hole has a diameter of 1.5 millimeters or greater.

ND-4 The flow rate at a 2 inch head does not exceed 1.0 milliliters per second, but the turbidity of the collected water is at least slightly dark. The hole diameter is less than 1.5 millimeters. At a 7 inch head, if the flow rate is more than 1.4 milliliters per second, classify as ND-4.

ND-3 At a 7 inch head, after 5 minutes of flow, the turbidity is at least slightly dark, the flow rate is at least 1.4 milliliters per second, and the hole diameter is greater than 1.5 millimeters.

ND-2 At a 40 inch head, if any turbidity is observed, classify as ND-2.
Note: Not all samples are tested to a 40 inch head, if evidence of failure occurs at lower heads.

ND-1 No erosion is observed even with 40 inches of head causing flow through the specimen. The collected water remains free of any colloidal cloud.

Other. The pinhole test is usually performed to aid in interpretation of the double hydrometer and crumb test. It is used to verify those indicator test results. When test results of the double hydrometer and crumb test conflict, the pinhole test is useful in arbitrating a decision. In SCS practice, pinhole tests are performed on perhaps 10 to 20 percent of samples submitted.

Another important use of the pinhole test is to determine efficacy of chemical amendments for dispersive clays. Soil samples are prepared with a range of treatment rates of a chemical additive, and the pinhole test is used to determine what rate of treatment is necessary to achieve erodibility reduction. Examples of chemical amendments are given in following sections of the TR.

CHEMICAL TEST

Introduction. In this test, a sample of pore water is extracted from a saturated slurry of a soil sample and analyzed for cations at the Lincoln Soil Survey Laboratory. Based on correlations with field performance, a soil's total salt content and the percentage of the cations that are sodium are used to categorize the soil's dispersive characteristics.

Procedure. Detailed test procedures for analyzing soil extracts are given in "Procedures for Collecting Soil Samples and Methods of Analysis for Soil Survey," Soil Survey Investigations Report No. 1, 1984. The test uses an atomic absorption spectrophotometer to determine the total amount of dissolved salts, expressed in milliequivalents per liter, and the amounts of Sodium (Na), Magnesium (Mg), Potassium (K), and Calcium (Ca), in the same units.

This test is strictly a laboratory test, although preparation and obtaining the soil extract could be done in a field situation.

Interpretation. Nondispersive, or "normal," clays are usually predominated by calcium or magnesium cations. Dispersive clays are almost always dominated by sodium cations. An empirical chart was developed by Sherard, *et al*, relating results of this test to observed field performance. The chart is shown in figure 4, below. Data are plotted with total salts in milliequivalents per liter as the X axis and the percentage of total salts that is sodium as the Y axis.

At normal salt concentrations, soils with more than 60 percent of their total salts being sodium are dispersive. Soils with less than 40 percent of their total salts being sodium are usually not dispersive. Soils with 40 to 60 percent sodium are transition in dispersive characteristics. At very low total salt concentrations, higher percentages of sodium may occur in samples and the samples still not have dispersive field behavior. Because so few salts occur in these soils, the influence on the soils' behavior is minimal.

Other. The chemical test is the least frequently performed one of the four dispersion tests run by SCS laboratories. It is useful for arbitrating conflicting test results from the other three tests and in verifying the fundamental nature of a sample. Where possible, field observation should supplement test results to verify their accuracy for a region's soils.

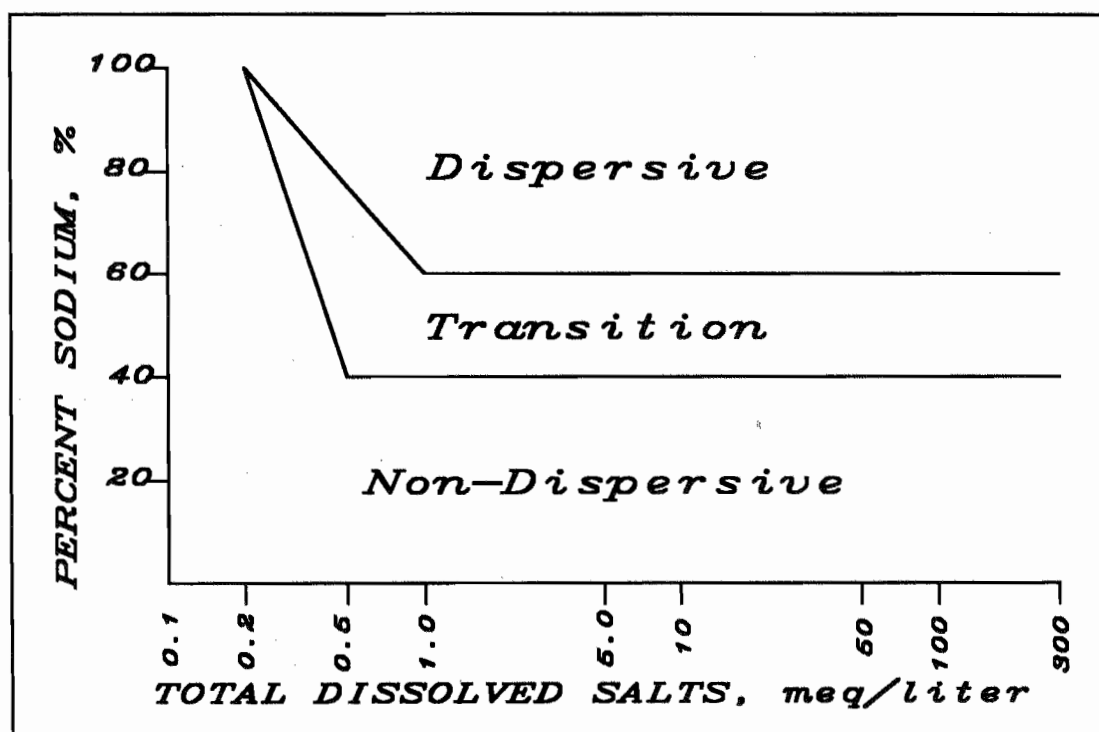


Figure 4. Chart for Plotting Chemical Tests Data

ENGINEERING PROBLEMS ASSOCIATED WITH DISPERSIVE CLAYS

INTRODUCTION

Dispersive clays have contributed to the failure or distress of many SCS structures. These problems range from the complete breaching of flood retarding embankments and grade control structures to severe surface erosion of earth fills. The problems may be placed in two broad categories.

EROSION OF EXTERNAL SOIL SLOPES.

Rainfall and runoff on exposed slopes of dispersive clays can cause severe erosion. Cut slopes in natural soils and slopes of earth fills may both be affected. The erosion often results in severe rilling and gulying on the slopes. In other cases, the erosion results in an unusual appearance referred to as "jugging." This is depicted in the figure below:

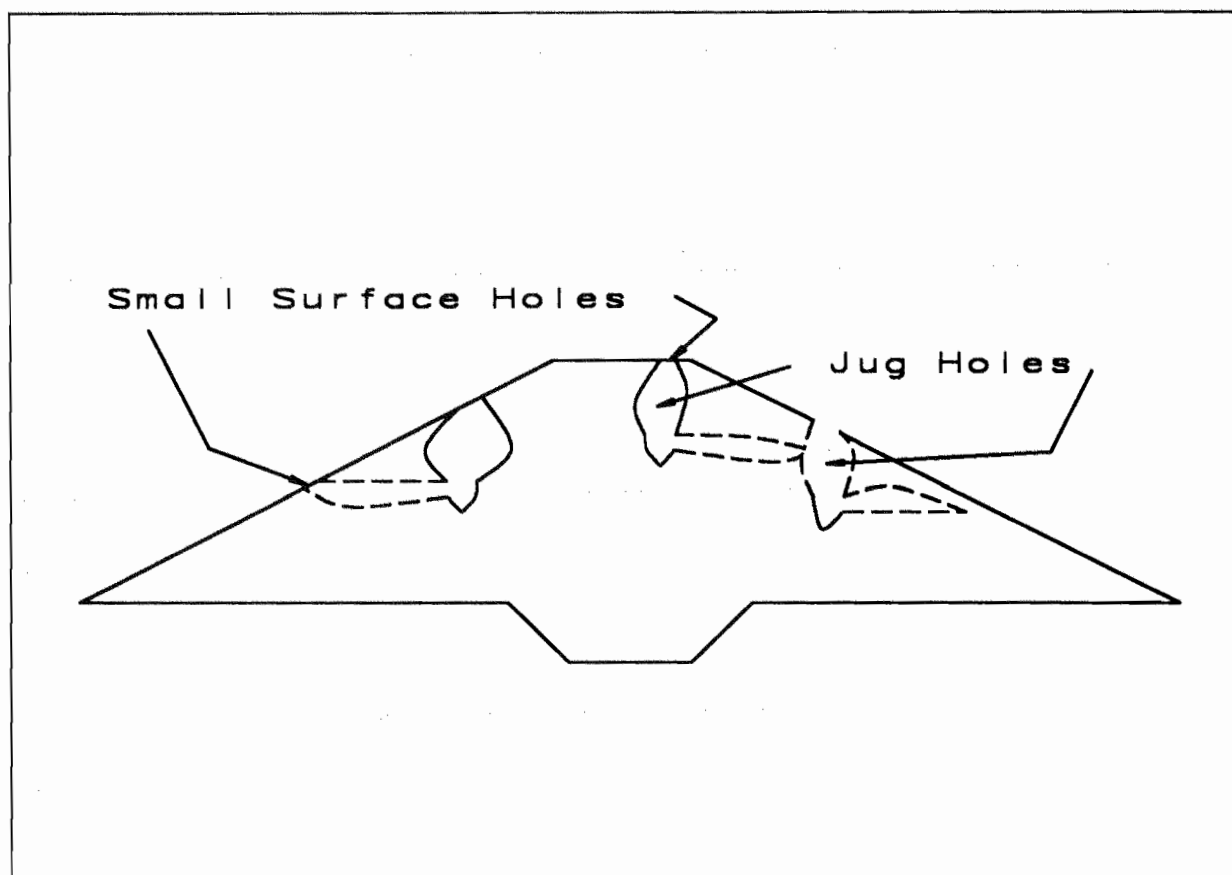


Figure 5. Jug Hole Features on Embankment

The "jugging" pattern is attributed to erosion of drying cracks from the bottom upwards. As the easily eroded clay particles are carried laterally to the slope surface from the bottom of the vertical crack, a tunneling action is initiated. The moist strength of the overlying soils results in the jug shaped holes often observed.

In some slopes, only severe rilling is observed. Earthen embankments have been severely damaged by this type of erosion in dispersive clays. Erosion to a depth of 4 feet is not unusual. Jugholes have been observed directly in the crest of embankments, where the energy of eroding water should be small. The severe erosion of embankment soils can be hazardous to a structure that impounds water. Interconnected holes and rills could provide a path for breaching of the embankment at high water levels. Erosion of the slopes of earth fill also poses a hazard to maintenance equipment.

Even the most lush cover of vegetation will not prevent surface erosion on embankments constructed of dispersive clays. Some types of deep-rooted plants may even aggravate the problem.

Erosion of the cut slopes in constructed channels is another common problem associated with dispersive clays. Figure 6 shows a typical channel slope in a dispersive clay deposit. The eroded slopes are unsightly and have a high roughness. Maintenance is hampered, and enlargement of the excavated channel can also be a problem.

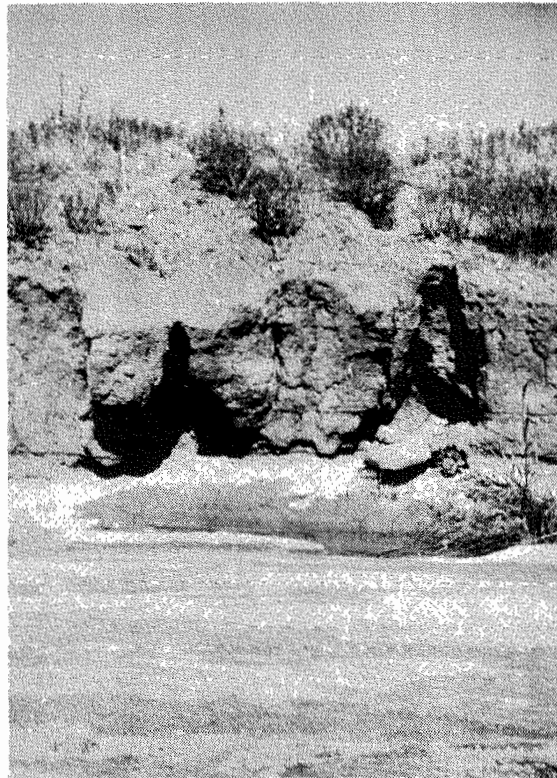


Figure 6. Exposed Dispersive Soils in Channel Bank.

In some instances, test results on soils along a planned channel alignment have indicated badly dispersive clays, but field performance was good. This has been attributed to the influence or interaction of the water in the channels with the clays. This performance has been duplicated by using actual on-site water in the pinhole test rather than distilled water. Even when channel erodibility may not be a problem, rainfall can cause surface erosion of the exposed slopes.

INTERNAL EROSION.

Earth fills constructed of dispersive clays have failed because of internal erosion through cracks or other openings in the fill. Failures usually occur when the fills are first subjected to water storage after or during construction. They are most common when the filling of the reservoir is rapid. Failures have been less frequent when reservoirs fill gradually. Some embankments have failed after surviving an initial filling when later subjected to a higher water head than the initial filling.

These failures usually take the form of an irregularly shaped tunnel through the fill. Often the tunnel caves, and a v-shaped breach is observed. These failures are attributed to the rapid erosion of existing cracks in the dispersed earth fill. Water flowing through the crack rapidly enlarges the crack, and the accompanying failure is sudden and dramatic. Many different earth fills have been damaged because of this phenomenon, including flood retarding structures, grade control structures, side inlet structures, and terraces. Figures 7 and 8 show typical failures.



Figure 7. Failed Embankment Constructed of Dispersive Clays.

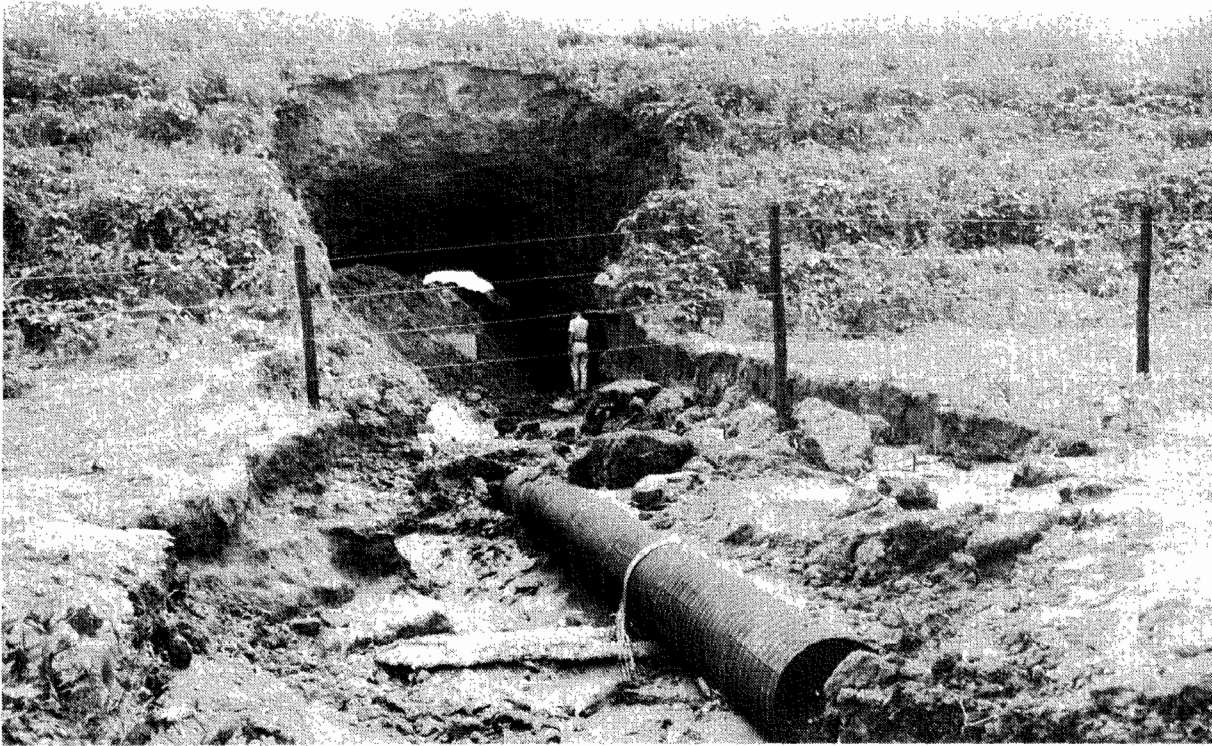


Figure 8. Failed Embankment Constructed of Dispersive Clays.

The cracks through which water flows and erodes the fill may have several causes. The primary causes are desiccation, hydraulic fracturing, and differential settlement. In some cases a combination of these causes may contribute to the cracking. In many instances failures have occurred in the vicinity of conduits extending through the earth embankments. This has been attributed to cracking resulting from differential settlement caused by the conduit and by poor compaction in the vicinity of the conduit. An example is the area under a circular conduit placed in a fill, where soil may not be compacted under the haunches of the pipe.

Soils that are low in plasticity and those compacted to a high density at a low water content are especially vulnerable to cracking.

Another type of internal erosion failure may occur when dispersive clays are associated with concrete and riprap lined channels. Rainfall or overbank flow can enter cracks in the dispersive clays underneath a concrete lining or riprap blanket. Water flowing to an outlet, such as a joint in the concrete lining or openings in the riprap, can lead to internal erosion and enlargement of the crack and undermining of the lining or riprap.

DESIGN MEASURES FOR DISPERSIVE CLAYS

INTRODUCTION

When dispersive clays are detected in a site investigation, several defensive measures can be incorporated into the design. Some of these measures, together with their advantages and disadvantages are summarized below. Most of these design measures can also be used in remedial treatment of damaged structures.

SELECTIVE PLACEMENT

Occasionally, borrow areas on a site may be clearly identified as being completely dispersive clay or nondispersive clays. Where clearly delineated deposits of nondispersive clays can be located nearby, it may be possible to selectively place the soils in an earth fill. Other soil types, such as nonplastic sands or gravels, may also be located and can be selectively placed in a fill.

Large numbers of samples are usually required to establish with certainty whether areas or horizons of a borrow area contain dispersive clays. This is especially true in alluvial deposits, which are usually more variable than residual deposits. One can never rely on color or other visual features to distinguish between dispersive and nondispersive soils unless exposed slopes are available for observations. Field and laboratory tests must be used.

One situation where discrete bodies of dispersive and nondispersive clays might be identified is one where a surface horizon of soil has been leached of sodium and is nondispersive, whereas underlying soil horizons are dispersive. Organic matter accumulation in surface horizons can also result in chemical reactions causing the soils to be less dispersive. Another situation in which discrete areas of dispersive soils can be isolated from nondispersive soils is where residual soils in abutments are derived from a different formation than the alluvial soils of the flood plain.

Selective placement of dispersive soils into specified zones of an embankment is feasible only if the above conditions are satisfied. Dispersive clays are generally placed in the interior of earth fills where the zone is not relied upon as a barrier to seepage or internal erosion through cracks. Figure 9 shows an example of a zoning plan utilizing dispersive clays. For selective placement to be feasible, sufficient quantities of nondispersive clays must be located to construct a cutoff and core zone in the earth fill, and for the exposed slopes of the fill.

One should never rely solely upon tests during construction to selectively place dispersive soils. A site must be investigated sufficiently prior to design to be able to estimate the quantities and exact locations of nondispersive soil deposits, as their selection and use is critical to the successful performance of a site.

If nondispersive soils can be located, they may be used to plate the surface of an embankment. Sands or gravels with nondispersive fines have been used to plate embankments. This plating protects any underlying dispersive clays from developing drying cracks and reduces jugging. The surface soils must be protected with quickly established vegetation, however, as they are susceptible to surface erosion because of their low plasticity.

The advantage of this approach is that it is usually more economical than other design measures detailed below. The disadvantage is that a much more extensive site investigation is generally required to assure the option is feasible. Other design measures covered below are usually required to prevent the problem of internal erosion if the remainder of the fill is dispersive clays.

CHEMICAL AMENDMENTS

Several chemical amendments have been used to alter dispersive clays and make them suitable for use on the external slopes of embankments, and for water barrier zones in the embankment. Figure 9 illustrates the use of a treated blanket on the slopes of an embankment as well as zoning of dispersive and nondispersive clays in the interior of the embankment:

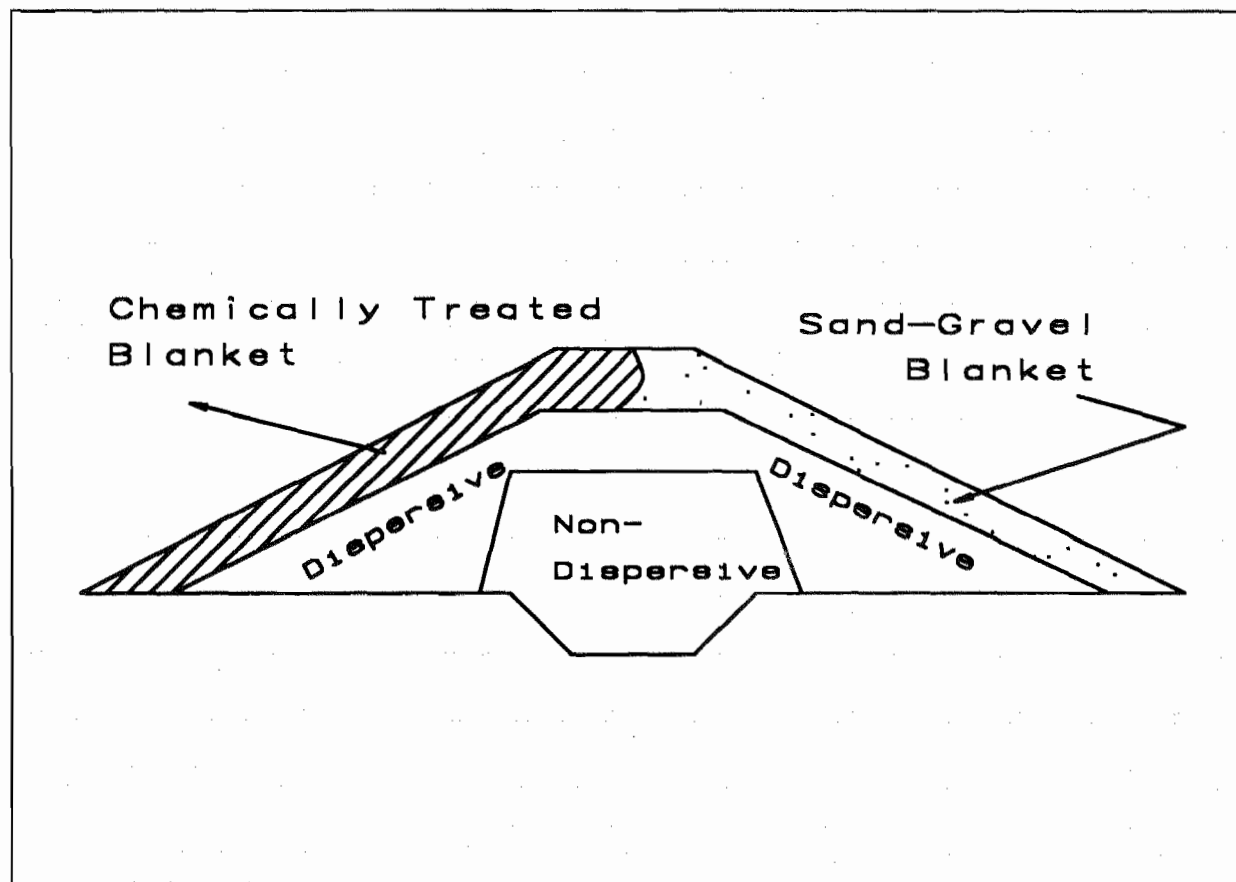


Figure 9. Blanket Treatment of Slopes and Zoning Plan for Dispersive Clays.

Chemicals are added to the dispersive clays at a given rate on a percentage of dry weight basis and then the treated soil is compacted into the embankment. The chemicals used include hydrated lime, alum, fly ash, gypsum, agricultural lime, magnesium chloride, and hydrated lime/agricultural lime mixtures.

The chemical most commonly used to treat dispersive clays on SCS projects has been hydrated lime. Its primary use has been in treating soils to be used as a "blanket" on the exterior slopes of compacted earth fills and on the slopes of excavated channels. Hydrated lime is calcium oxide hydrated with water molecules. When mixed with dispersive clays, the calcium quickly replaces sodium

cations on the dispersive clay particles. An ionic bond is also created as the lime reacts with the silica and alumina in the soil. This reaction is apparently long-lasting. Several SCS projects have been in place for over 20 years with no observable deterioration of the treated soil. Figure 9 shows a combination of zoning of embankment soils and a treated exterior blanket to combat dispersive clays for an embankment.

Usually, laboratory pinhole tests have shown that adding 1 percent of hydrated lime by dry weight to dispersive clays renders the clays nondispersive. Field recommendations then require 2 percent lime to account for the poorer mixing and proportioning in a field situation. For some badly dispersive clays, 1 percent, or even 2 percent in rare cases, has been inadequate to treat the soil. Samples should always be tested using the pinhole test to determine the minimum amounts of chemical amendments.

Another consideration in determining minimum lime requirements for soil to be used as a plate on an embankment is the amount of lime needed to raise the shrinkage limit of the soil to the point that drying cracks cannot develop in the treated soils. Hydrated lime usually significantly affects the Atterberg limits of the soil, and tests are performed at several lime contents to establish this variability. On some projects, as much as 3 percent lime has been added to reduce shrinkage properties of the clay even though pinhole tests indicated that 2 percent lime was adequate to control erosivity.

An alternative treatment is to use a mixture of about 2/3 agricultural lime and 1/3 hydrated lime, applied at the rate of a total lime content of 2 percent by dry weight to the dispersive clay. This equates to slightly less than 1 percent by weight of the hydrated lime. Some favor this mixture over a straight hydrated lime application because the treated soil has a lower pH, which is more conducive to the establishment of vegetation. Soils treated with 2 to 3 percent straight hydrated lime have a high initial pH (over 11.0), and the initial establishment of vegetation may be difficult. One study in Oklahoma indicated, however, that the pH of the treated soil decreased to about 8.0 within 40 days after application. Usually, lush stands of vegetation are established after 2 or 3 years. Agricultural lime by itself has not proven effective in controlling the erosive behavior of dispersive clays.

The advantages of using hydrated lime to treat dispersive clays are that the method has a long successful history and that the plasticity of the treated clay is reduced. The disadvantages include the cost of the raw material, hydrated lime, and the processing and curing methods are costly. Curing of clays after mixing with lime is necessary to reduce the brittleness of the compacted fill. Soils are generally cured for a minimum of 48 hours before transporting and compacting into a fill. Also, greater amounts of water are needed for the curing process, especially if quick lime is used instead of hydrated lime. Another disadvantage of hydrated lime is the increase in the pH of the treated soil and the attendant difficulty in initial vegetation establishment.

Quick lime is sometimes used instead of hydrated lime and may be more readily available in some locations. Because of its caustic properties, quick lime generally is used in pelletized form or as a slurry, rather than powdered form. Pelletized quick lime is slightly more difficult to incorporate and mix intimately than hydrated lime, which is a fine powder. More water is required to complete the reaction of quick lime than hydrated lime. Greater safety precautions are necessary when handling quick lime because of the hazard created by the heat generated when the

lime reacts with water. Some of these objections are handled by using a slurry prepared from quick lime.

Both granular and liquid alum ($AlSO_4$) have also been used to treat dispersive clays on several SCS projects. Soils can be immediately compacted after mixing with alum, with no curing period, because alum does not strongly affect the plasticity or brittleness of the soils. This is an advantage in that the processing costs are reduced, but a disadvantage in that the tendency of the clays to crack is not reduced with the alum.

Another disadvantage to the use of alum to treat dispersive clays is that less history and documentation of field performance is available to testify to its efficacy. On many soils, alum added at the rate of 0.5 percent by dry weight has been adequate to render dispersive clays nonerosive in the pinhole test.

Fly ash is a waste product from the burning of coal at many power plants. Laboratory pinhole tests have shown that the addition of 4 to 6 percent by dry weight of fly ash to dispersive clays generally renders the soils nonerosive. The planned source of fly ash should be tested when contemplating using fly ash because the composition of fly ash varies considerably with the type of coal burned to produce it. Fly ash does not materially affect the plasticity of the treated soil.

Laboratory pinhole tests have not shown gypsum ($CaSO_4$) to be very effective in treating dispersive clays. However, several field trials have shown some beneficial effect. Unfortunately, these field trails are not well documented, and the use of gypsum at this time should still be regarded as somewhat experimental. Laboratory pinhole tests should be useful in determining the approximate minimum amounts of gypsum.

Other additives, such as magnesium chloride, have been considered. Pinhole tests on dispersive clays treated with this chemical have shown it to be effective. The primary questions concerning this and other chemicals that have few field trials is whether they have adequate longevity and how they may affect subsequent establishment of vegetation.

SAND CHIMNEY FILTERS

The most effective design measure for preventing internal erosion of earth fills that impound water is a sand chimney filter. Extensive laboratory tests have demonstrated the effectiveness of a clean sand filter in preventing internal erosion through cracks even in highly dispersive clays. Numerous field installations have also attested to the efficacy of a sand filter zone in a dispersive clay dam.

Eroding water flowing through a crack in a dispersive clay carries particles of the eroding soil to the sand filter interface. Rapid plugging of the flow results as particles build up on the face of the filter. The sand filter must not have the potential to sustain an open crack within itself for it to be effective. Where severe cracking is possible, a downstream section of a coarser filter material can be advisable. This coarse filter would be more likely to fill a large crack than the sand zone.

A sand chimney filter is usually designed as a vertical zone in an embankment. It is generally about 2 to 3 feet wide and extends below any excavation. The chimney filter zone is usually carried upwards in a fill to the elevation of the planned maximum water storage height. For many soils, ASTM C-33 fine concrete aggregate gradation sand is satisfactory for this purpose. Detailed procedures for designing sand filters are given in Soil Mechanics Note SM-1. Figure 10 illustrates a chimney filter zone in an earthen embankment.

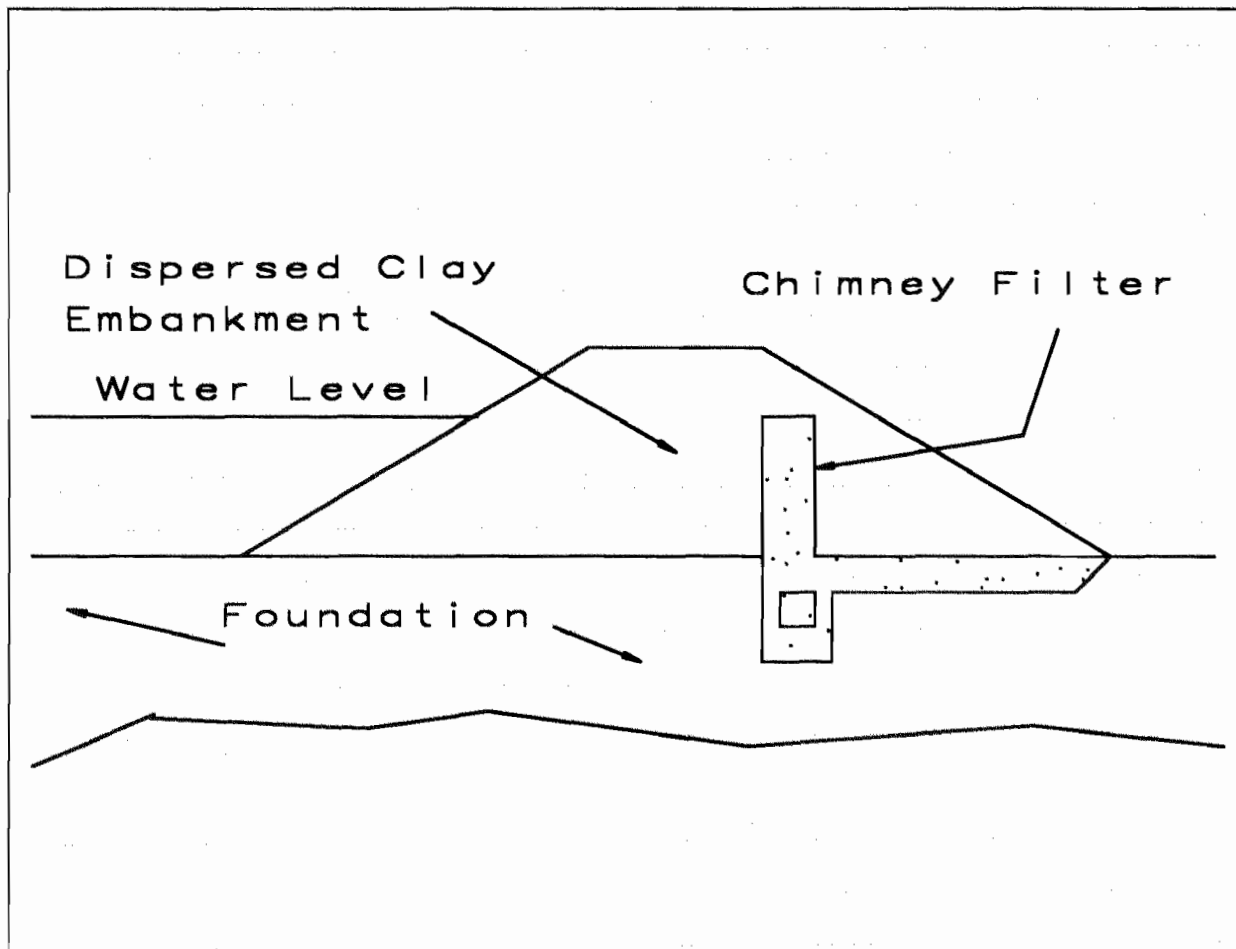


Figure 10. Chimney Filter in Embankment of Dispersive Clay

A critical area for crack development is in the vicinity of conduits passing through earth fills. Sand diaphragms surrounding the conduits are required for all embankments falling under TR-60 guidelines. In all embankments constructed using dispersive clays, this design is important, because many small grade control structures have failed as a result of internal erosion through soils surrounding the pipes.

CONSTRUCTION CONSIDERATIONS

INTRODUCTION

Other procedures that can alleviate problems with dispersive clays are included in the following sections. Where dispersive clays are the only source for embankment fill construction, all precautions possible should be followed.

EMBANKMENT CONSTRUCTION

Compacting soils to as high a water content and as low a dry density as possible while retaining the necessary shear strength and compression characteristics is advisable with dispersive clay soil embankments. This improves flexibility and reduces the potential for developing cracks through a fill.

Take special care to avoid drying cracks that might occur during interruptions of fill placement in hot, dry weather. Always thoroughly scarify and wet the preceding fill surface before adding additional fill.

FOUNDATION PREPARATION

Shape foundation surfaces to as flat a slope as practical before construction. All slopes transverse to the centerline of the fill should be 3 to 1 or flatter if possible. This is especially applicable to stream channel banks and such excavations as those made for installing conduits. Steeply sloping bedrock surfaces beneath embankment fills are especially dangerous because of the potential for differential settlement.

APPENDIX A

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