BUILDING EMBANKMENTS WITH SHALES

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BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT

PURDUE UNIVERSITY AND

INDIANA STATE HIGHWAY COMMISSION

Technical Paper

BUILDING EMBANKMENTS WITH SHALES

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

August 29, 1973

Project: C-36-5J

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The attached Technical Paper "Building Embankments with Shales" was presented at the 1973 Purdue Road School. It has been authored by Messrs. L. E. Wood, C. W. Lovell, Jr., and P. Deo. It was prepared from the Research Report titled "Shales as Embankment Materials" which was presented to the Advisory Board in late 1972.

The Paper is planned for publication in the Proceedings of the Road School and is submitted to the Board for approval of such publication.

Respectfully submitted,

Harold L. Michael
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Associate Director

HLM:ms

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Technical Paper

BUILDING EMBANKMENTS WITH SHALES

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INTRODUCTION

Highway embankments must be built on foundations which do not fail by shearing or settle excessively under the embankment weight. In addition, the embankment must not shear within itself or settle excessively within itself due to its own weight or pavement loadings.

The usual embankment material in Indiana is glacial drift, or soil weathered in place from bedrock. Such materials are placed in relatively thin lifts and compacted with density and (sometimes) moisture control. With the usual compaction specifications and control, and with somewhat conservative side slopes, the performance of soil embankments is predominately satisfactory.

Where the topography is rougher, bedrock is commonly excavated and becomes available for fill. Most of the limestones, dolomites and sandstones so excavated in Indiana are strong and durable enough to be placed in large chunks in a so-called "rock fill". In such a fill, the lifts are thick, and the voids between the rock chunks are large. These voids are choked with fines at the top and sides of the embankment, but inside the embankment a lot of open spaces remain. So long as these rock pieces remain intact, deformations are small within the embankment, because of the friction and interlocking between the pieces.

Although rock fills are much less common than soil fills in Indiana, satisfactory performance is expected from rock fills when built in accordance with current standards and specs. But, what would happen if a rock fill were built of rocks which weathered rapidly in the fill. The rock pieces would become soil, which could in turn fall down into the voids. The cumulative result of this would be at least a lot of settlement of the embankment, and it could lead to a slope failure.

EXAMPLE OF PROBLEM

In December 1971 and January 1972, a slope failure occurred on I-74 near St. Leon in Dearborn County, Indiana. This failure forced the closing of the east-bound lane of the highway. It was located within a compacted fill containing both shale and limestone.

Description of Landslide Area

The failure occurred near the Indiana-Ohio boundary, and about 1-1/4 miles east of the interchange with Indiana State Highway 1 (Figure 1).

Bedrock at this point is in the upper part of the Dillsboro Formation (lower part of the Richmond Group), and is late Ordovician in age. This formation consists of thin beds of shale and limestone. The regional dip is about 6 feet per mile westward, and the beds appear practically horizontal to the naked eye (1). In this region, more than 300 beds of alternating shale and limestone are recorded, with an average thickness of beds about six inches (1).

Natural slopes on these rocks are as steep as 35 percent or about 3 to 1. Gray (1) reports that these slopes show little evidence of instability, and steeper cut slopes also appear to be stable. However, Sisiliano (2) concludes that this general area is the most landslide susceptible in the entire state. Landslides are associated with the residual soils of the area, and occur on natural slopes as well as with embankments and cuts.

Soil cover in the area consists of residual weathered materials on the slopes and glacial till on the broader divides. The till is a strong silty clay. The residual soil consists of limestone slabs

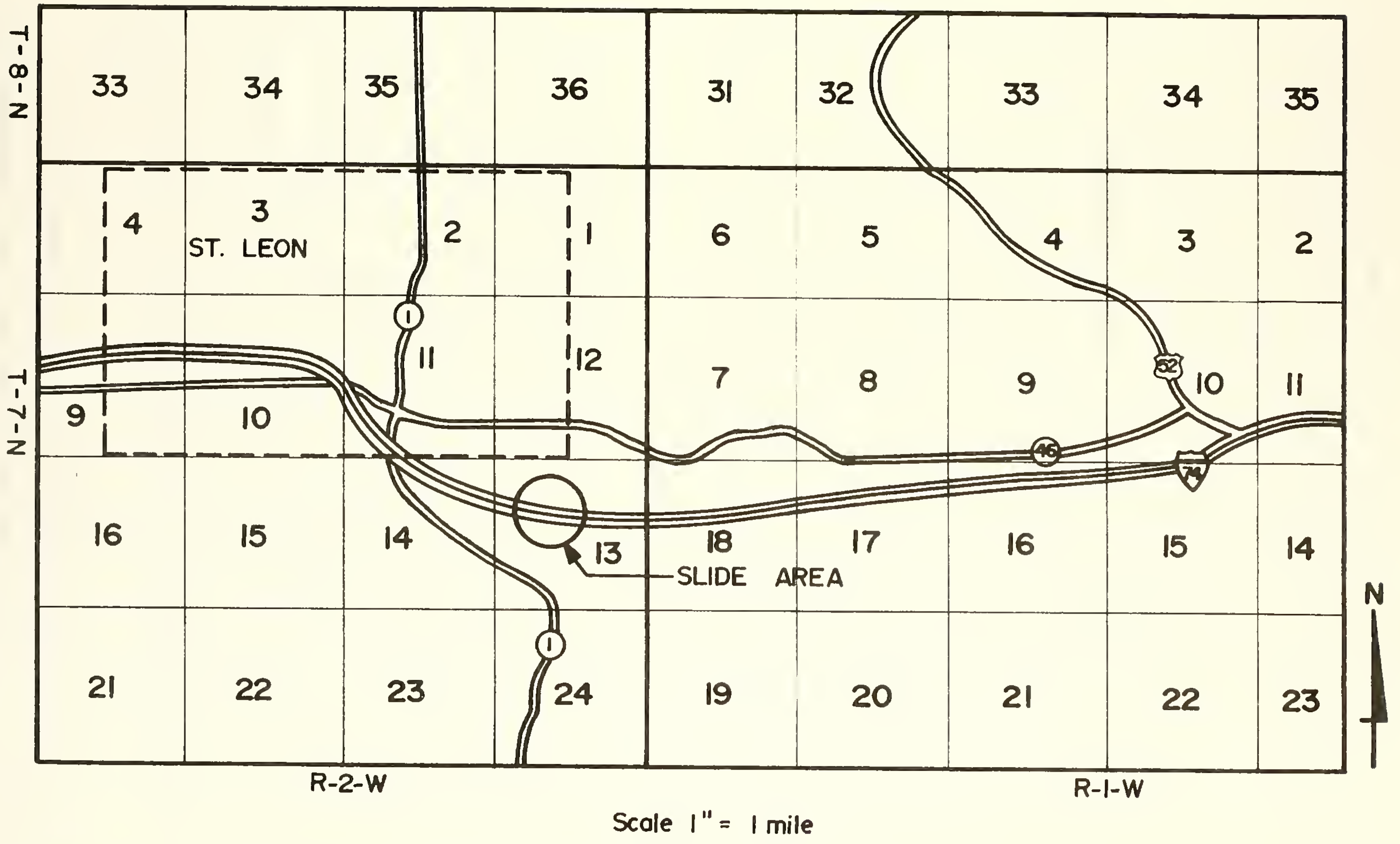


FIGURE 1. LOCATION OF SLIDE AREA.

in a matrix of greenish-brown or yellowish-brown clay, which has weathered principally from shale. The insitu soils tend to have good internal drainage. Cuts in this material may cause landslides (4), and erosion is a serious problem on cut slopes (3).

These soils are heterogeneous. Water movement through them tends to follow irregular pathways of least resistance. One part of the soil may be fairly dry, while another part close by is thoroughly saturated. The most important zone of weakness is immediately beneath the soil at the bedrock-soil interface. The reason for this is that the shale is less permeable than the soil, so that water seeping downward through the soil, as well as water seeping toward the outcrops in beds of limestone, tends to collect and move downslope at the bedrock-soil interface as shown in Figure 2.

Embankment Details

The embankment was constructed during 1961. The fill material consisted of the locally available mixture of limestone, shale, and clay weathered principally from the shale. The construction specifications do not directly refer to the shale or to any special treatment for it. Apparently, the shale was placed in large chunks and was not much reduced in size by compaction. The harder limestone was present randomly and probably protected the shale by bridging, arching or similar load-distribution action. If the fill were constructed as a rockfill the lifts could have been as thick as four feet (5).

The side slopes were 2 to 1. Figure 3 shows a cross section of the embankment after construction and after failure. According to the classification system proposed by the HRB Landslide Committee

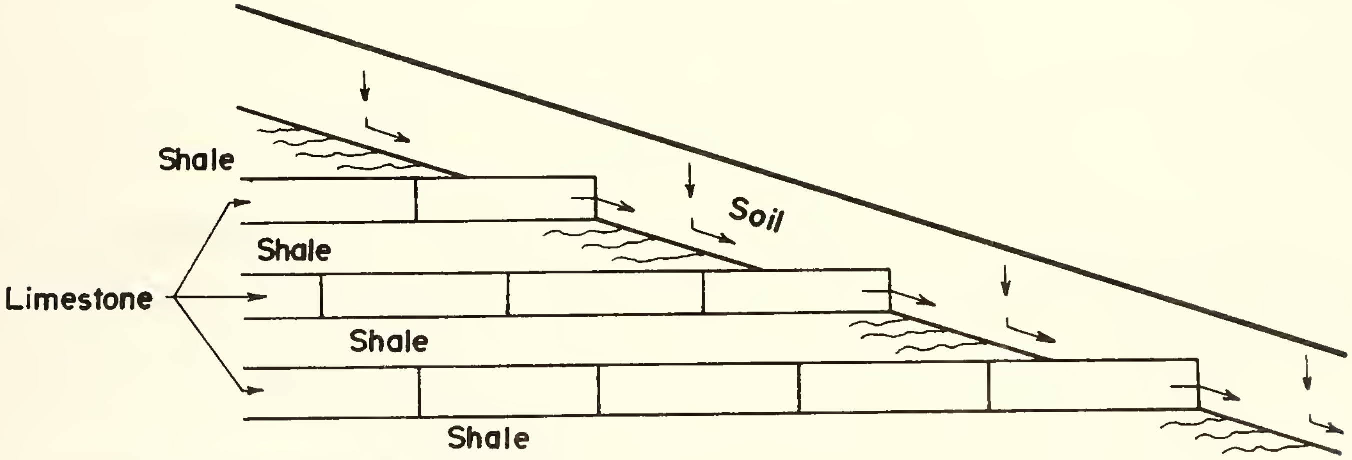


FIGURE 2. MOVEMENT OF WATER AT SOIL-BEDROCK INTERFACE (1).

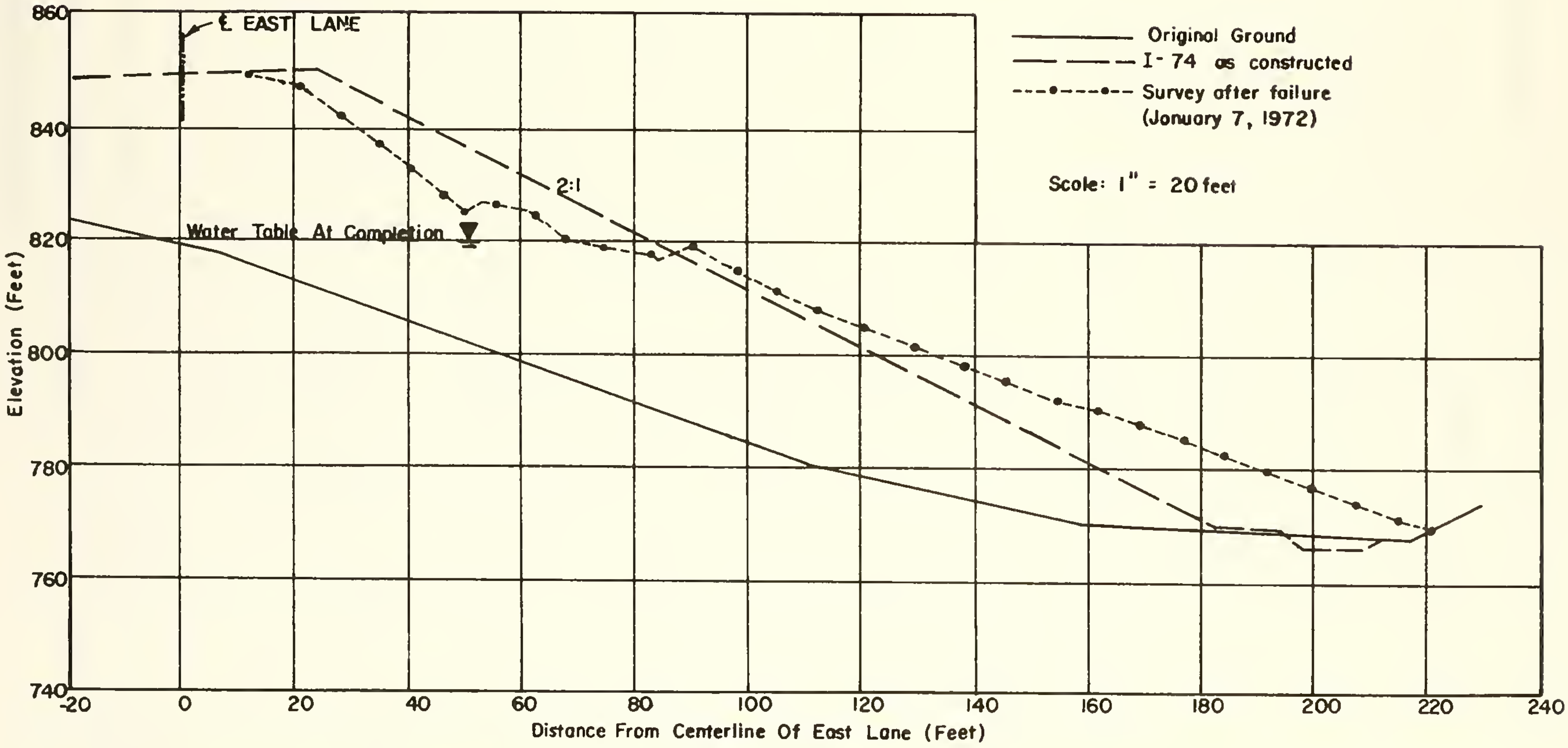


FIGURE 3. CROSS SECTION OF I-74 EMBANKMENT BEFORE AND AFTER SLOPE FAILURE.

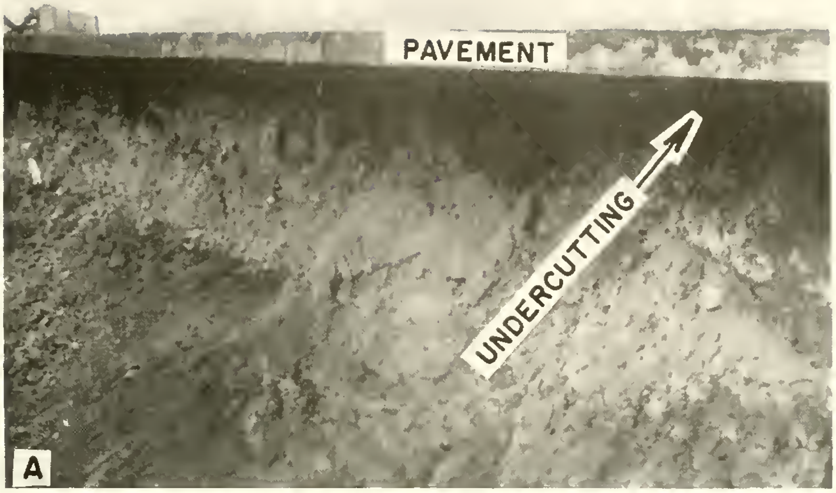
(6), the failure is a (rotational) slump slide. Figures 4(a) and (b) show the photographs of failure zones at two locations. Figure 4(a) shows the main scarp of the slide; the surface is concave upward. Figure 4(b) shows a close-up of the scarp failure surface. Limestone pieces, shale chunks and soil mixtures could be seen here.

Before the failure occurred, the site experienced large settlements, which severely cracked the pavements and locally altered the drainage pattern. Nearby fills along I-74 have also experienced similar settlements, suggesting that they too ultimately will be landslide sites.

SHALES IN INDIANA

Unfortunately, there is a lot of bedrock in Indiana which appears to be quite hard and which may not readily break down in handling and compaction, but which can weather rather rapidly when placed in chunks in the fill. These materials are shales. One way to view shales is as the link between soil and sound rock. Soil embankments are composed of materials of small size, pushed close together by compaction, and with small voids between the pieces. Rock embankments are composed of materials of large size, held "apart" by interlocking, and with large voids between the pieces.

Soil-like shales are those which will surely weather and break down in service. They should be reduced to soil size in the construction process and built into soil embankments. Rock-like shales would weather only slowly, and would be very difficult to break down in the construction process. They probably can be built as rock fills, with special design features to hedge against their somewhat marginal durability.



(a)

(b)

FIGURE 4. PHOTOGRAPHS OF FAILURE ZONE AT TWO LOCATIONS.

In many parts of Indiana, shales are either exposed at the earth's surface or underlie it at shallow depths that are within the range of engineering considerations. Only shales of the Palezoic Era are present in Indiana, and hence the montmorillonitic clays related to more recent rocks, volcanic activity, and weathering in arid regions are not represented.

Ordovician Age

The oldest geologic system of rocks in Indiana that contains shale is the Ordovician. These rocks are exposed in the southeastern part of the state (Figure 5). The previously mentioned Dillsboro Formation lies within the Ordovician. This formation consists of alternating beds of shale and limestone. At some locations more than five hundred beds of alternating shale and limestone can be observed. The thickness of shale beds varies between one inch and two feet (1).

Limestone in the Dillsboro is argillaceous and shales are calcareous. Common clay minerals present are illite, kaolinite and chlorite (1). Generally these shales are highly fissile, and with repeated wetting and drying, they weather into low strength clay.

Silurian Age

The Silurian System is represented in Indiana by a succession of limestones and dolomites. Silurian rocks are exposed at the surface in the southeastern part of the state. North of the Illinoian glacial boundary, glacial drift of varying thickness covers the bedrock surface. Along certain creeks and river beds, however, the glacial drift has been removed by erosion and the bedrock is exposed. Despite the predominance of carbonate rocks in the Silurian, there are two

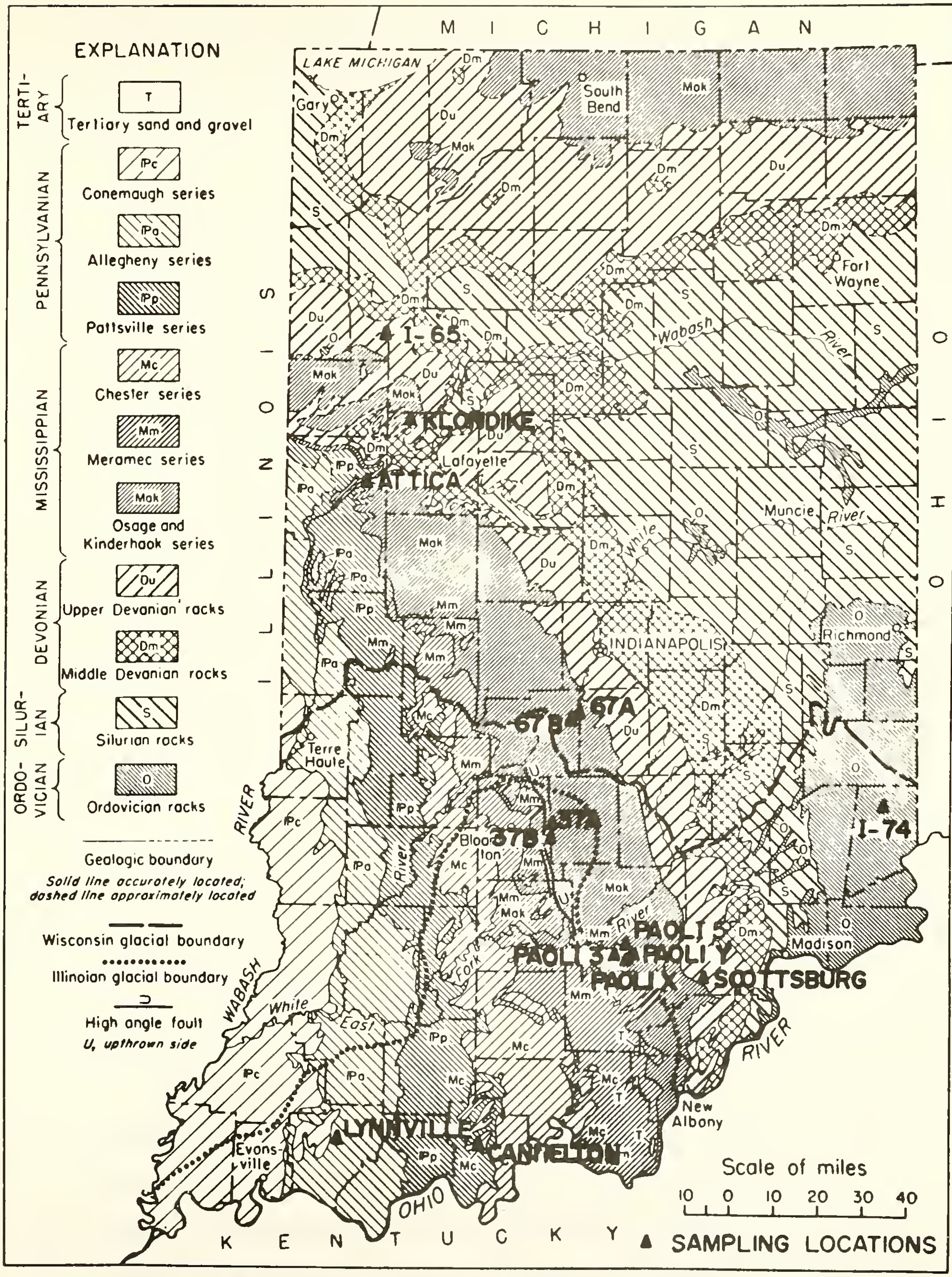


FIGURE 5. BEDROCK GEOLOGY OF INDIANA, AND SHALE SAMPLING LOCATIONS (7).

formations with prominent shale lithologies, the Waldron and the Mississinewa (8).

Devonian and Mississippian Ages

Similar to the Silurian, the Devonian System is also represented in Indiana by a succession of limestones and dolomites. They are exposed at the surface in southeastern Indiana, but are otherwise covered by glacial drift of varying thickness. There is only one shale formation, the New Albany, contained in the Devonian sequence (8).

Mississippian rocks are exposed in a band that trends in a northwest-southeast direction across the approximate center of the state. The oldest rocks (Kinderhook) are at the eastern edge of this band, and the youngest rocks (Chester) are at the western edge. Much of the band of Mississippian rocks is buried by glacial drift.

Pennsylvanian Age

Rocks of the Pennsylvanian System lie west of the Mississippian outcrop, in a belt extending from the Ohio River northward to Lafayette, and then westward to the Indiana-Illinois state boundary. North of the Illinoian glacial boundary, glacial drift of varying thickness covers most Pennsylvanian rocks (8).

Pennsylvanian formations are stratigraphically complex because of common changes from one rock type to another over relatively short distances. In addition, rocks of a specific lithologic type are similar mineralogically from one Pennsylvanian formation to another, making it difficult to distinguish between the formations using lithology alone (8).

Two types of shales are found in Pennsylvanian rocks in Indiana: 1) dark-gray to black, fine grained thinly bedded shale; and 2) light-gray silty thick bedded shale (8).

Pennsylvanian shales have less quartz and feldspar than the shales previously discussed. The common clay minerals are illite, kaolinite and chlorite. They also contain traces of iron (8).

RESEARCH APPROACH

The research reported in this paper involved a study of shales in Indiana with a view to assessing their suitability for use in highway embankments. Indiana shales cover a wide spectrum of behavior from relatively hard and durable ones, to those which will rapidly weather into soil. However they are mostly of relatively low plasticity, and do not exhibit highly expansible characteristics (8).

A principal activity in the research was the modification of existing tests, or development of new tests, for the engineering classification of shales. These tests have to be simple and inexpensive, and yet also be able to rank shales in different embankment-use categories.

Experimental Materials

Sampling sites were selected with the aid of concerned agencies, e.g., the Indiana State Highway Commission (ISHC) and the Soil Conservation Service (SCS). At least 24 potential sampling sites were inspected, and 15 of these were ultimately sampled. The quantity of material acquired varied between 150 and 1500 lb., depending upon the type of material and ease in sampling. Fresh and unweathered samples were desired, and this ordinarily meant taking the material during the cutting of an excavation, or immediately after the completion of the excavation. In some cases the sampling was done with the help of the personnel of the ISHC and the SCS.

The sampling locations are shown on an Indiana state highway map in Figure 6. Sampling locations were also shown in Figure 5, which is the bedrock geology map of Indiana. Ten of the fifteen samples, namely, Klondike, Attica, 67A, 67B, 37A, 37B, Paoli 3, Paoli 5, Paoli X, and Paoli Y are Borden shales of the Osage Series, which is early Mississippian in age (about 330 million years). One, the Cannelton shale, is of the Chester Series, which is of late Mississippian age (about 310 million years). Two, I-65 and Scottsburg shales, are of the New Albany Formation of upper Devonian age (about 350 million years). The Lynnville shale is of the Allegheney Series of middle Pennsylvanian age (about 290 million years). The I-74 shale is of the Dillsboro Formation of late Ordovician age (about 430 million years).

Shales of three sites were used as embankment material in small dams by the Soil Conservation Service (Paoli 3, Paoli 5 and Cannelton). Shales from four locations were used in highway embankments by the Indiana State Highway Commission (I-65, I-74, 37A and 37B).

Shale Tests

A battery of engineering tests was run on all the shales to classify them and predict their engineering performance.

The tests were in four groups:

1. Degradation type tests
2. Soil type standard identification tests
3. Compaction and load-deformation tests
4. Miscellaneous tests.

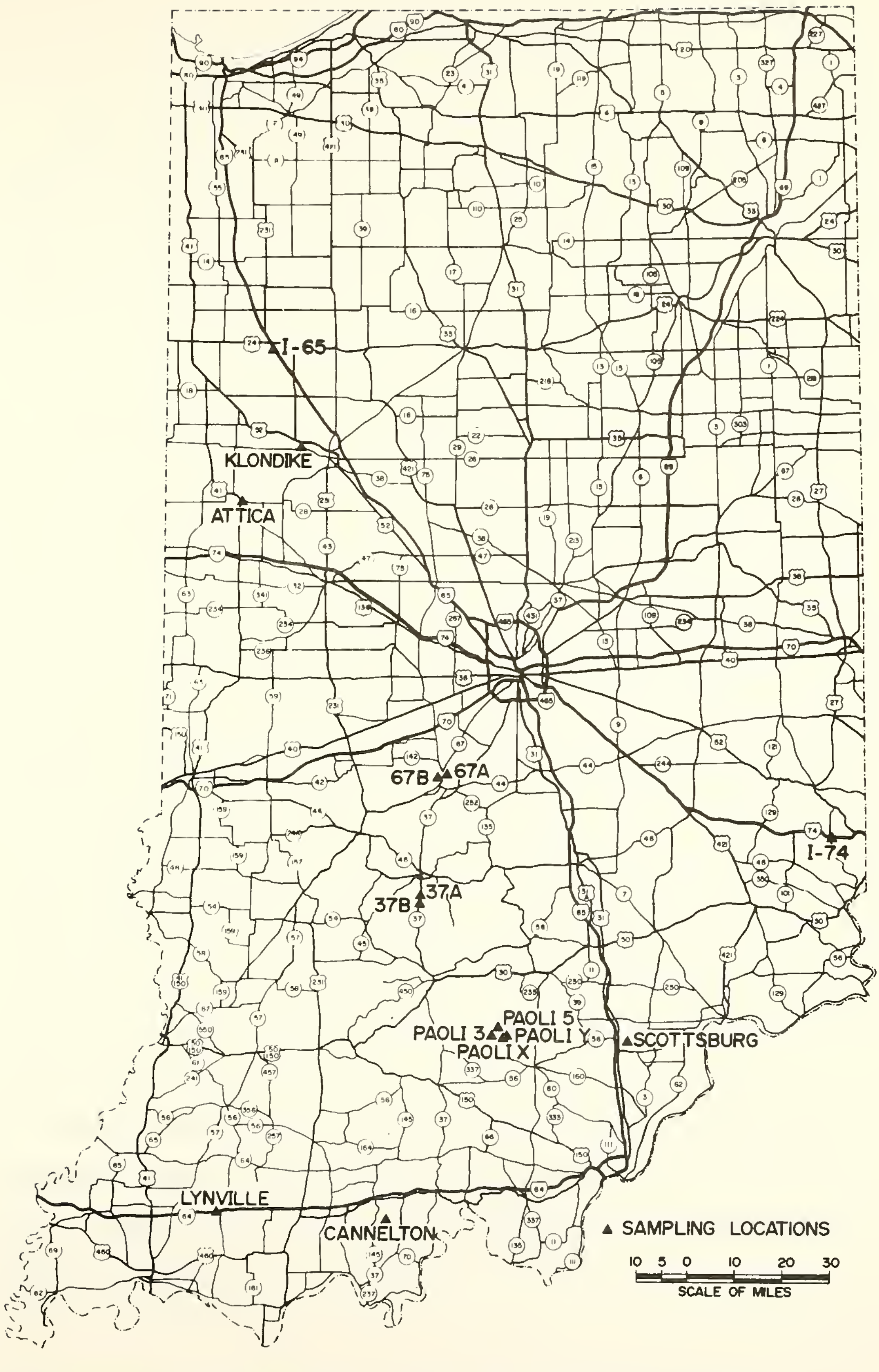


FIGURE 6. HIGHWAY MAP OF INDIANA AND SAMPLING LOCATIONS

Degradation Type Tests

These tests are a measure of the durability of the shales during construction and in the service environment. This group includes different types of slaking tests (in air, water, and a sodium sulfate solution), and mechanical abrasion tests.

Soil Type Standard Identification Tests

These tests were run on powdered shale material to determine the behavior of the shale when and if reduced to the soil size. These tests included Atterberg limits, grain size distribution, and X-ray diffraction.

Compaction and Load-Deformation Tests

Since the embankment materials are placed as a rolled fill, it was desirable to establish some form of the moisture density relationship. Some sort of "strength number" was also needed. Since large pieces of shale may be used in the embankment, the largest practicable laboratory sample was selected. This was the six inch diameter CBR sample and test. CBR values were determined for both as-compacted and soaked samples at different water contents. Swelling after soaking in the CBR mold was also measured.

Test procedures AASHO T 99-61 and T 181-61 were followed for compaction, except that all compaction was accomplished in the CBR mold. Standard AASHO T 193-63 was followed for the CBR testing, with minor modifications.

Miscellaneous Tests

These tests included water-absorption-time characteristics, bulk unit weight, and certain breaking characteristics of the shales.

The breaking characteristics may be the most descriptive feature for shales. These can be classified as massive, flaky-fissile and flaggy-fissile. Fissility is associated with a parallel arrangement of clay particles, and non-fissility with a random arrangement (9). The nature of cementing agents is also an important factor influencing fissility.

Massive rocks have no preferred directions of cleaving and breaking. Most of the fragments are blocky. Flaggy rocks will split into fragments of varying thickness, but the width and length are many times greater than the thickness, and the two essentially flat sides are approximately parallel. Flaky shales split along irregular surfaces parallel to the bedding, and into uneven flakes, thin chips, and wedge-like fragments whose length seldom exceeds three inches. The three breaking types are shown in Figures 7, 8 and 9.

CLASSIFICATION

Key Tests

After considerable testing, it was determined that shales could be suitably rated with only four tests, viz., a slaking test of one cycle in water; a slake durability test on dry samples; a slake durability test on soaked samples; and a modified soundness test.

FIGURE 7. MASSIVE BREAKING TYPE.

FIGURE 8. FLAGGY BREAKING TYPE.

FIGURE 9. FLAKY BREAKING TYPE.

Slaking in One Cycle of Wetting

A broken piece of shale was immersed in water so that it was at least 1/2 in. below the water surface.

After immersion, the shale piece was observed continuously during the first hour; after that, the condition of the piece was checked at two, four, eight, twelve, and twenty four hours. The condition of the piece was recorded as: complete breakdown, partial breakdown, or no change. If the piece seemed intact, the cloudiness of the water was also noted. For any shale which slaked completely or partially, the test was repeated.

Figures 10, 11, and 12 show the extremes of material response in this test. The results of one cycle of wetting are reported in Table 1. It will be seen that only two of the fifteen shales were significantly affected by this test.

Slake Durability Test

The slaking test discussed previously produces rather qualitative results. The slake durability test, on the other hand, measures a weight loss in water which can be expressed as a durability number.

The apparatus was developed by Franklin and others at Imperial College London in 1970 (10). The test procedure was modified to suit Indiana shales. The apparatus, shown in Figures 13 and 14, consisted of a drum of 2 mm mesh, 10 cm inlength and 14 cm in diameter.

FIGURE 10. CANNELTON SHALE BEFORE IMMERSION IN WATER.

FIGURE 11. CANNELTON SHALE AFTER 15 MINUTES OF IMMERSION IN WATER.

FIGURE 12. PAOLI 3 SHALE AFTER 24 HOURS OF IMMERSION IN WATER.

TABLE 1. RESULTS OF SLAKING TEST IN WATER (ONE CYCLE OF WETTING AND DRYING).

Sample	Slaking Time	Remarks
Cannelton	8-10 minutes.	Completely breaks down.
I-74	Partial slaking in 24 hours.	About one fourth of material is reduced to thin flakes or very small pieces.
Paoli Y	Negligible slaking in 24 hours.	After 24 hours the piece is still intact. However the water becomes somewhat dirty.
Paoli X; I-65; Paoli 3; Paoli 5; Lynnville; Attica; 67A; 67B; 37A; 37B; Scottsburg; and Klondike	No slaking in 24 hours.	No change in piece or surrounding water after 24 hours.

FIGURE 13. SLAKE DURABILITY APPARATUS.

FIGURE 14. TEST DRUM IN SLAKE DURABILITY APPARATUS.

A motor drive unit attached to the drum was capable of revolving it at a speed of 20 revolutions per minute. The drum was rotated in a water trough which was mounted to the base board.

A sample of ten representative shale pieces, each weighing 50 to 60 gm, was oven dried and placed in the test drum. The drum was now half immersed in the water bath and rotated. Material detached from the pieces passed through the mesh, i.e., became a sample weight loss. The durability number was calculated as the percentage ratio of final to intial dry sample weights.

The durability number for 500 revolutions of the drum was defined as the durability index (I_d). Durability indices were determined both for dry samples, $(I_d)_d$, and for soaked samples, $(I_d)_s$. At least two tests were run for each combination of variables; values reported are averages. As shown in Table 2, the values of $(I_d)_d$ range from 24.0 to 95.0 and those of $(I_d)_s$ range from 0 to 93.6. As these numbers refer to the percent weight retained in the meshed test drum, higher values of I_d refer to more durable shales. For all shales, the soaked values are lower than the dry ones.

Modified Soundness Test

This test measures the degradation of shales when subjected to five cycles of alternate wetting and drying in a sodium sulfate solution. It is more severe than the previously mentioned slaking tests, and is more effective in distinguishing among the harder and more durable shales.

The test was modified from ASTM C 88-63, which is used to determine the resistance of aggregates to disintegration by sodium sulfate or magnesium sulfate. The standard test uses a fully saturated solution, but this is too severe for shales, and after a series of trials, the saturation was reduced to 50%.

The Soundness Index, I_s, was defined as the percent retained by weight on the 5/16 in. sieve. Durability is considered to increase with increase in I_s value. As shown in Table 3, the values of soundness index (I_s) range from 0 to 97.2.

TABLE 2. VALUES OF SLAKE DURABILITY INDEX FOR DIFFERENT SAMPLES.

Sample	Slake Durability Index Dry Sample, $(I_d)_d$	Slake Durability Index Soaked Sample, $(I_d)_s$
Cannelton	24.0	0.0
I-74	63.0	24.5
Paoli Y	86.1	56.2
Paoli X	88.8	68.7
Paoli 5	93.8	89.1
Lynnville	93.8	87.2
I-65	93.2	78.5
67B	93.8	90.1
67A	94.9	90.3
Paoli 3	94.5	91.0
Scottsburg	94.0	91.1
37A	94.8	93.6
Klondike	94.2	91.2
Attica	95.0	93.5
37B	95.0	93.6

TABLE 3. RESULTS OF MODIFIED SOUNDNESS TEST

Sample	Percent Weight Passing 5/16 in. Sieve	Soundness Index, I_s (Percent Weight Retained on 5/16 in. Sieve)
Cannelton	100	0
I-74	100	0
Paoli Y	84	16
Paoli X	69	31
Paoli 5	28	72
Lynnville	14	86
I-65	19	81
67B	17	83
67A	16	84
Paoli 3	16	84
Scottsburg	15	85
37A	5.5	94.5
Klondike	5.4	94.5
Attica	5.2	94.8
37B	2.8	97.2

Performance of Indiana Shales

Simple Slaking Test

On the basis of the first test, viz., slaking in water in one cycle, all the shales could be classified into two groups.

1. Shales which are somewhat affected by water; only Cannelton, I-74, and Paoli Y are in this category.

2. Shales which appear totally unaffected; Paoli X, Paoli 3, Paoli 5, Lynnville, Attica, 67A, 67B, 37A, 37B, I-65, Scottsburg and Klondike fall in this category.

Those shales which slake significantly in the one cycle test should certainly be viewed as non-durable. If used in embankment, they should be accorded very special treatment. Group 2 performed satisfactorily in this test, but further examination of its characteristics should be undertaken before specifying design and construction details.

Slake Durability Tests

An examination of the values of durability index on both dry and soaked samples from Table 2 reveals the following points.

1. For the shales which completely or partially slake in water, the slake durability index for dry samples also predicts a severe degradation in water. This is true for the Cannelton and I-74 shales. On the basis of Tables 1, 2 and 3, an $(I_d)_d \leq 85$ would represent shales which are probably non-durable.

2. For the shales which have an $(I_d)_d > 85$, the $(I_d)_s$ is probably a better measure. If the $(I_d)_s$ is between 0 and 50, the material is highly susceptible to breakdown in water. An $(I_d)_s$ between 50 and 70 represents an intermediate susceptibility to water.

Values between 70 and 90 represent materials with fair to good relative durability.

3. For materials with $(I_d)_s$ values greater than 90 (or perhaps even 85) the test does not distinguish sufficiently among the materials, and other tests are needed if such distinction is desired.

Modified Soundness Test

By comparing the values of Table 3 with those of Table 2, the soundness test seems to be more effective than the other tests in distinguishing among the harder and more durable shales. Although the test does not simulate weathering actions, it seems to relate well to the effects of weathering, e.g., wetting and drying, freezing and thawing.

On the basis of this test, various groupings of materials are suggested:

1. If I_s is less than 20, the material is very susceptible to weathering, and should probably be treated like a fine grained soil.

2. If I_s is between 20 and 50 (perhaps even 70), the material has a relatively high susceptibility to weathering and the material should probably still be treated as a soil.

3a. Materials having values between 90 and 98 are grouped as "Intermediate-1", and are probably little affected by weathering.

3b. Materials having values between 70 and 90 are termed "Intermediate-2". Both intermediates can be superior to soil as embankment materials, if given adequate treatment in the construction process.

4. If I_s is greater than 98 (no such materials were sampled), the material can probably be treated like a rock.

Proposed System

On the basis of 4 simple degradation type tests, Indiana shales can apparently be classified in the following four groups;

1. Rock like shales
2. Intermediate-1 shales
3. Intermediate-2 shales
4. Soil like shales.

The flow chart for classification is shown in Figure 15.

Based upon the experimental data generated by this study, it is possible to make certain qualitative statements about the strength and durability of these shales in embankments. "Soil like" shales are non-durable and weak. They should be thoroughly broken down, and thinner lifts than normally used for soil may be needed. An effective encasement with non-shale soil is probably needed. For the two intermediates, specifications should generally vary between those for soil and those for rock fills. Bigger chunks can be used. For the "Intermediate-2" shales, it is probably necessary to undertake thorough degradation, implement special density control, and specify encasement.

At the present time, the Indiana State Highway Commission has expanded this study to catagorize additional shales brought into their central laboratory, and also to improve the various test limits proposed in the classification flow diagram (Figure 15).

ACKNOWLEDGMENTS

The work reported herein is covered in greater detail in the Purdue Ph D thesis by Dr. P. Deo entitled "Shales as Embankment Materials", dated December 1972. The thesis is also printed (under the same title and date) as "Joint Highway Research Project (JHRP)

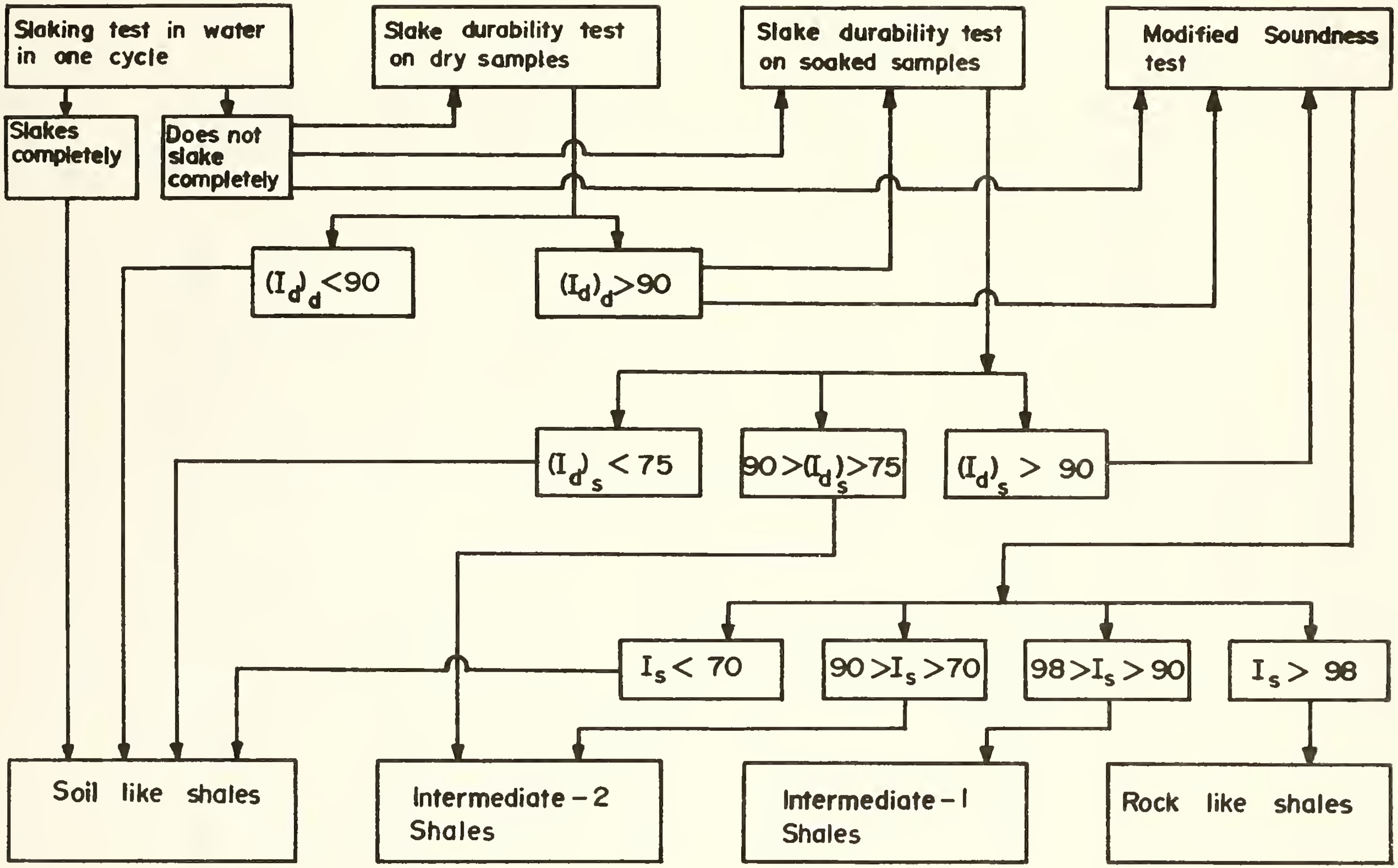


FIGURE 15. PROPOSED CLASSIFICATION OF INDIANA SHALES FOR EMBANKMENT CONSTRUCTION.

Report No. 45". Funds for the study were supplied by the Indiana State Highway Commission (ISHC) through JHRP. Personnel from the Division of Materials and Tests, ISHC, were most helpful throughout the study.

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