use of shale in embankments

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Guidelines for the design and construction of soil embankments are sufficiently developed so that unsatisfactory performance of these fills is relatively rare. The same is true for rock fills. However, there are transition materials or "soft rocks" for which placement in large chunks may lead to highly unsatisfactory embankment performance. Shales are a prominent example, for the large pieces may degrade (slake) into soil in service. This soil may in turn sift down into the large voids, resulting in large settlements and even slope instability. The harder and more durable shales can probably be placed as rock fills if certain precautions are taken. The shales of very low durability must be thoroughly degraded at the end of compaction; i.e., they must be treated as soil fills. And a full spectrum of durabilities exists between these limits. The engineer obviously needs a classification system that will establish where, in the possible range of relative durabilities, a potential embankment shale lies. Such a classification for Indiana shales was developed by sampling materials and subjecting them to a battery of durability, stability, and other tests. The durability tests were the standard ones used for mineral aggregates, but were modified in severity to account for the soft rock being evaluated. It was concluded that the desired classification into four groupings, soil-like, intermediate-1, intermediate-2, and rock-like shales, could be accomplished with four simple tests: one-cycle slaking in water, slake-durability on an initially dry sample, slake-durability on a soaked sample, and a modified sodium sulfate soundness test. The paper describes the Indiana shales tested, the tests, and the response of the shales to the tests. It concludes with a flow chart showing how the tests are used to accomplish the shale classification.

•Highway embankments are commonly built with soil and less commonly with rock. However, in either case, design standards and construction specifications are backed with sufficient experience to be applied with confidence. But what do we know about the family of construction materials between soil and rock, i.e., the "soft rocks"?

Soft rocks include all types of mudrock, which is any sedimentary rock containing at least 50 percent silt and clay constituents. Mudrock is thus a general name for all varieties of siltrock, clayrock, mudstone, siltstone, mudshale, silt shale, clay shale, and argillite. Twenhofel (14), Underwood (15), Ingram (9), and Gamble (6) have differentiated among these rocks. Figure 1 shows an example classification. This paper concentrates on the shales.

When shales are used as embankment materials, the engineer tends to view them with suspicion and often recommends conservative design and construction procedures, e.g., fragmenting the material by extra rolling, placing another material between the shale and the atmosphere (encasement), flattening slopes, inserting special drains, and using berms. These procedures have reduced, but not eliminated, instabilities of shale embankments (8). However, the current practice is probably too conservative. Some usable shales are being wasted, and the strengths of relatively high-quality shales are not being used.

Shales can be grouped in the following four categories:

1. Highly susceptible to postconstructional degradation and, when degraded, inferior in performance to normal fine-grained soils (use of these materials in embankments should be restricted);
2. Similar to normal fine-grained soils and usable with common soil design and construction controls if thoroughly degraded in the construction process;
3. Imperfectly degraded in the construction process, only slightly degraded in service, stronger than soils, but not placeable as rock fill; and
4. Difficult to degrade and probably placeable as rock fill (these are intrinsically superior to soil in fills if certain construction problems can be overcome).

This paper reviews the current placement technology for shale embankments and suggests a simple and inexpensive testing program to classify the shales with respect to their use in embankments.

PROBLEMS WITH SHALES AS EMBANKMENT MATERIALS

Potential problems within an embankment constructed with shales include: (a) settlement due to loading, drying, slaking, or thawing; (b) heave caused by wetting or freezing; (c) slope instability; and (d) surface and subsurface erosion. (Slaking is the process through which a material disintegrates or crumbles into small particulate units when exposed to moisture and especially when dried and immersed in water.)

The degree to which soft rocks will demonstrate poor performance depends largely on their service environment, both man-made and natural. For example, unless the material becomes significantly wetter than the placement condition, slaking may not occur. Once exposed to increased moisture, slaking may occur quickly, in many years, or not at all. The practical consequence of the slaking, if it occurs, depends primarily on the relative abundance of large voids in the compacted mass into which the slaked material can settle. The size and frequency of large voids are directly related, in turn, to the abundance of large chunks of shale in the embankment. If large chunks of slaking materials are placed in the embankment, major problems can be anticipated. If, on the other hand, the slaking material is reduced to small pieces in the construction process, the subsequent slaking in service may produce no unacceptable densifications or surface displacements.

Degradation of material in the embankment can be controlled by effective drainage or proper encasement of the embankments or both. Even nonslaking materials are weakened and made more compressible by increased moisture. Other shales contain enough expansive minerals to cause significant swelling upon wetting and shrinkage upon drying and potentially harmful effects to the embankment and/or the overlying pavement.

If one is able to assess the general susceptibility of a material to slaking, volume change, and the like in the projected service environment, more rational decisions can be reached in the design and construction processes, thereby increasing the probability that satisfactory service will be produced with economy.

Figure 1. Classification of shale and related rocks.

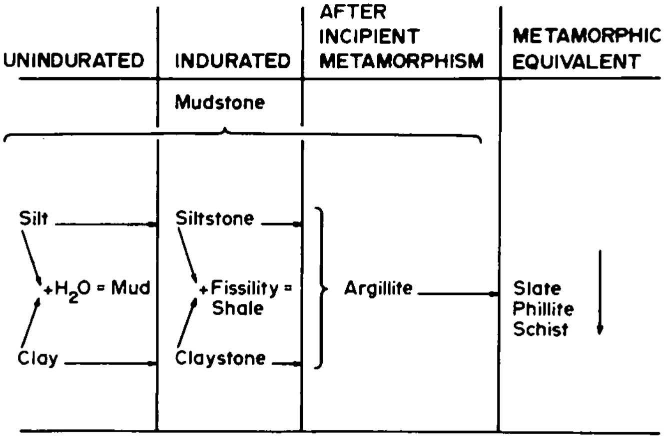
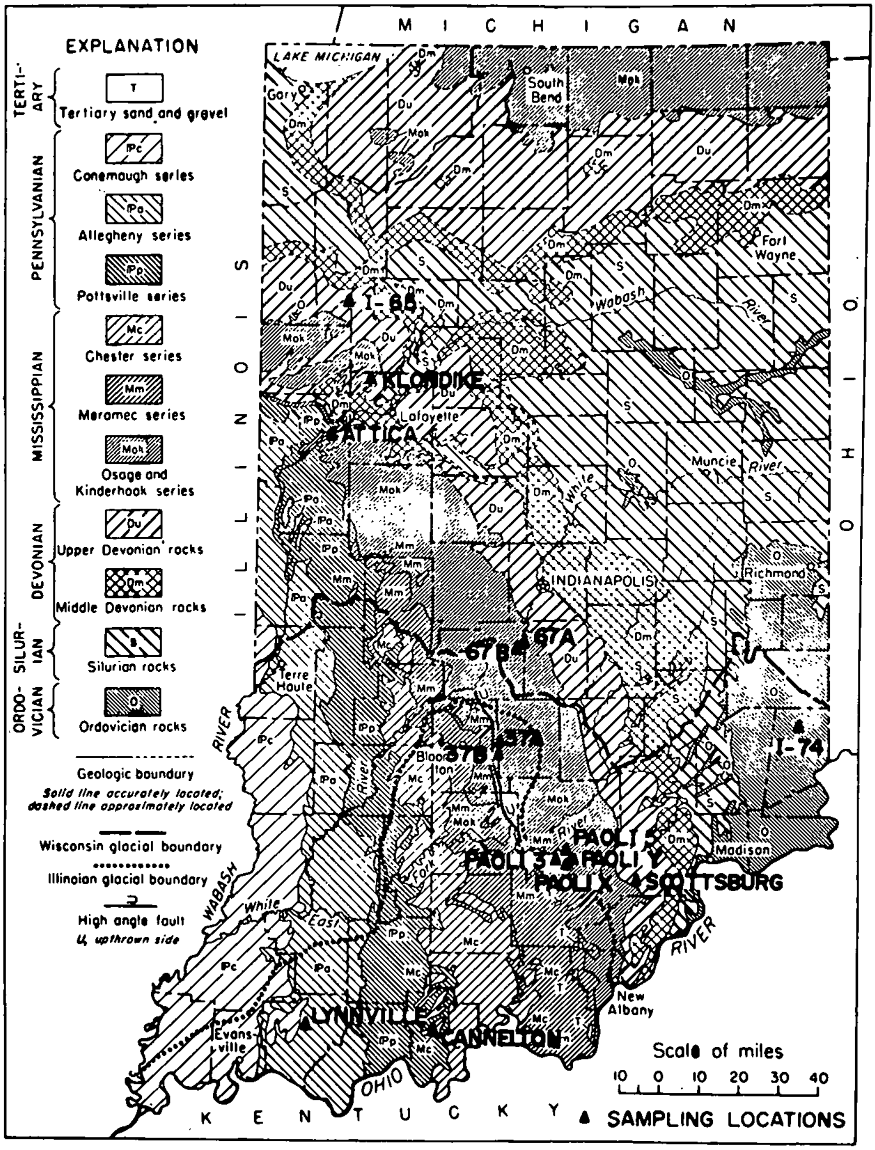


Figure 2. Bedrock geology of Indiana and shale sampling locations.



CURRENT PLACEMENT TECHNOLOGY

Shales have been treated sometimes as soil and sometimes as rock in embankments. Sherard and others (12) emphasize the importance of proper investigation of these materials and of handling each as an individual problem. Test embankment sections are recommended, where possible.

The various agencies constructing embankments have separate specifications for soils and rocks. However, there may be no fixed specifications for shale or other soft rock embankments. The Indiana State Highway Commission uses shales in embankments with the following provisions:

1. Shales are subjected to thorough breakdown in the process of excavation, hauling, placement, and compaction; i.e., they are treated like soil fill. Occasionally, lift thicknesses are made even thinner than for soil.
2. A nonshale soil encasement of 2 or 3 feet is provided on all boundaries of the embankment.
3. The shale-soil mixture, when treated in the specified manner, is considered to be highly competent, and no other special design features are needed.

Such provisions are normally contained in a special construction specification statement and are often qualitative.

Some agencies, including the Soil Conservation Service in Indiana, use shale in the construction of small dams (13). Durable and nondurable (soil-like) shales are recognized, but there are no quantitative criteria to indicate into which group the shale in question should fall. The Indiana SCS has used durable shales with the following provisions:

1. The maximum size of rock fragments used is 18 inches, provided that such fragments are completely embedded in a matrix of compacted fill;
2. The maximum thickness of rock layers before compaction is 24 inches;
3. Broken shale and limestone mixtures may be used in rock fill;
4. Rock fill has a cover of weather-resistant material of 2 to 4 feet; and
5. A minimum compacted dry unit weight of 112.5 $\mathrm{lb/ft^3}$ was used for two different shales [this number could vary for other shales (13)].

For soil-like shales, the following provisions are suggested:

1. A shale that completely slakes in water in a few (about 10) minutes can also be used in embankment, provided that it is thoroughly broken down to soil during excavation, hauling, placement, and compaction;
2. A minimum encasement of 4 feet of nonshale soil is needed; and
3. The unit weight of the fill should be at least 95 percent of the maximum determined by ASTM D698-66T (3).

With the current state of the art, a considerable amount of judgment may be required at the time of construction, and there is a definite potential for undue conservatism and, occasionally, error on the unsafe side.

ENGINEERING CLASSIFICATION OF SHALES

There is a need to develop a simple and inexpensive testing routine to classify shales with respect to their suitability for use in embankments. With this objective, representative samples of shales were collected from 15 locations within the state of Indiana (Fig. 2). These materials covered a wide behavioral spectrum, from very hard and durable to rapidly weathered into soil.

The tests conducted in the laboratory can be grouped into four categories.

1. Degradation tests measured slaking and other breakdown of the material. Because the standard tests were inappropriate for soft rocks, it was necessary to develop new ones or at least to modify existing ones. This group includes different types of slaking tests (in air, water, and sodium sulfate solution) and abrasion tests.
2. Standard soil identification tests were conducted on thoroughly degraded shales. This group included Atterberg limits, grain size distribution, and X-ray diffraction.
3. Compaction and load-deformation tests, principally California bearing ratios, were performed on as-compacted and soaked samples.
4. Miscellaneous tests included absorption-time, bulk density, and certain breaking characteristics of the materials.

All the tests did not yield useful descriptors for classifying the shale. Accordingly, only certain ones were selected for use in the recommended classification system.[1]

TEST RESULTS AND DISCUSSION

Simple Slaking Tests

On the basis of three tests, slaking in air, slaking in water in one cycle, and slaking in water in five cycles, all the sampled shales could be classified into three groups.

Group	Classification	Shale
1	Severely affected by water; significant slaking	Cannelton, I-74, Paoli Y
2	Little affected by water after five cycles	Paoli X, I-65
3	Unaffected by five cycles of water	Paoli 3, Paoli 5, Lynnville, Attica, 67A, 67B, 37A, 37B, Scottsburg, Klondike

Those shales that slake significantly in the five-cycle test should be viewed as nondurable. If used in embankment, they should be accorded special treatment. Groups 2 and 3 perform satisfactorily in these tests, but further examination of their characteristics should be undertaken before design and construction details are specified.

Slake Durability Tests

The values of the slake durability index for dry samples $(I_d)_d$ and for soaked samples $(I_d)_s$ are given in Table 1. An examination of the values reveals the following points.

1. For the shales that 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.
2. For the shales with $(I_d)_d > 85$, $(I_d)_s$ is probably a better measure. If $(I_d)_s$ 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.

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[1] The original manuscript included an appendix that described the procedures for the tests selected. This appendix is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-51, TRB Special Report 148.

3. For shales 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

The results of this test, which seems more effective than others in distinguishing among the harder and more durable shales, are given in Table 2. The values of soundness index I_s range from 0 to 97.2. Inasmuch as this number refers to the percentage retained on the $^5/_{16}$-in. sieve at the conclusion of the test, higher values of I_s refer to more durable shales. When this test was run on a sound, medium-grained limestone, it gave $I_s = 99.2$.

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

1. If $I_s < 20$, 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.
3. Materials having values between 90 and 98 are grouped as intermediate-1 and are probably affected little by weathering. Materials having values between 70 and 90 are termed intermediate-2. Both intermediate types can be superior to soil as embankment materials if given adequate treatment in the construction process.
4. If $I_s > 98$ (none was sampled), the material can probably be treated like a rock.

Compaction and Load-Deformation Tests

Table 3 gives the results at optimum moisture content and standard AASHO effort (2) for all the shales.

The comparisons of the values of as-compacted CBR, soaked CBR, and ratio of soaked to as-compacted CBR show that as-compacted CBR varied between 2.1 and 31.8, soaked CBR between 0.0 and 21.8, and soaked to as-compacted between 0.0 and 0.765. It is noted that, for the three materials showing some slaking in water, the values of soaked CBR are 0.0, 0.4, and 1.1, whereas the as-compacted CBR values are 2.1, 6.1, and 8.0. These data imply an extremely weak embankment, should these shales be saturated in service. [The breakdown of the surcharged shale sample when soaked was sufficient to produce the 0.0 value. (The authors have not seen a 0.0 CBR value reported previously.)]

The values of soaked CBR varied between 0.0 and 76.5 percent of the as-compacted CBR. As this ratio becomes small, a closer examination of the special provisions for the use of the shale is indicated, e.g., complete compaction degradation, special drainage, and encasement.

Swelling Behavior

Swelling after 96 hours of soaking was recorded. The maximum size of shale lumps used was $^3/_4$ inch, and it was thought that a few of the shale pieces might collapse and show a volume decrease upon 96 hours of soaking. However, no such settlement was noted.

For eight of 15 materials, there was almost no axial swell. At standard AASHO optimum moisture for the remaining materials, axial swell was 0.6, 1.0, 2.9, 3.2, 5.2, 5.4, and 7.8 percent. On both sides of optimum moisture content, swell was less than at optimum moisture. Swell also increased with an increase in compaction effort (molding water content constant) and therefore with an increase in dry density. This is similar to fine-grained soil results.

Table 1. Values of slake durability index.

Sample	$(I_d)_d$	$(I_d)_s$
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 2. Results of modified soundness test.

Sample	Percentage Passing $^5/_{16}$-In. Sieve	Soundness Index
Cannelton	100	0
I-74	100	0
Paoli Y	84	16
Paolix 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	94.6
Attica	5.2	94.8
37B	2.8	97.2

Table 3. Results of CBR test at standard AASHO effort and optimum moisture content.

Sample	$\gamma_{d\ max}$ (lb/ft^3)	O.M.C. (percent)	As-Compacted CBR	Soaked CBR	$\frac{\text{Soaked CBR}}{\text{As-Compacted CBR}}$	Swell (percent)
Cannelton	107.8	14.8	2.1	0.0	0.0	7.8
I-74	117.9	13.8	8.0	1.1	13.7	5.4
Paoli Y	107.4	16.6	6.1	0.4	6.6	5.2
Paoli X	112.2	12.6	12.0	3.3	25.7	2.9
Paoli 5	117.0	10.1	19.9	6.2	31.2	1.0
Lynnville	115.3	8.7	12.4	7.8	63.0	0.6
I-65	117.8	10.2	21.2	8.3	39.2	3.2
67B	119.7	7.5	29.5	15.8	53.6	0.1
67A	119.0	7.3	28.8	15.3	53.5	0.2
Paoli 3	119.2	7.2	28.2	14.7	52.0	0.2
Scottsburg	118.2	6.9	28.4	14.5	51.0	0.0
37A	119.6	8.2	30.2	18.3	60.5	0.0
Klondike	118.3	10.7	23.4	17.2	76.5	0.2
Attica	117.5	7.2	27.4	19.4	71.0	0.0
37B	119.6	7.1	31.8	21.8	68.5	0.0

Table 4. Fissility characteristics for shales.

Sample	Massive (percent)	Flaggy (percent)	Flaky (percent)	Fissility No.
Cannelton	0	30	70	81
I-74	10	20	70	77
Paoli Y	0	30	70	81
Paoli X	0	50	50	68
Paoli 5	10	40	50	64
Lynnville	20	30	50	61
I-65	0	50	50	68
67B	10	40	50	64
67A	10	40	50	64
Paoli 3	30	40	30	44
Scottsburg	20	40	40	54
37A	30	50	20	38
Klondike	0	50	50	68
Attica	30	60	10	31
37B	30	60	10	31

An increase in swell is identified with a decrease in CBR ratio. If results are compared for those shales that give a swell of 1.0 percent or more, there is a linear trend for reduction in CBR ratio with the increase of swell.

Breaking Characteristics

The percentage by weight having massive, flaggy, and flaky proportions, as determined in the shale breaking characteristics test, is given in Table 4.

Flaky and flaggy are two characteristic conditions of fissility, and therefore a fissility index or number should be some weighted sum of the two; e.g., a fissility number could be proportional to percentage by weight flaky plus a constant times percentage by weight flaggy. The flaggy pieces were heavier than flaky pieces when the same amount of breaking effort was applied. Specifically, the weight of flaky pieces varied between 5 and 100 percent of that of the flaggy pieces, and the average weight of flaky pieces was 0.35 times the average weight of flaggy pieces.

Therefore, the fissility number was defined as the sum of percentage flakiness plus 0.35 times percentage flagginess. The values of fissility number for sampled shales ranged between 31 and 68 and are given in Table 4.

GENERAL DISCUSSION

Several of the degradation tests may be used to distinguish among the various shales. The soaked durability index and the soundness index seem to be valuable for rating shales by their relative durability. They apparently reflect a combined effect of various important characteristics of shale, such as fissility, cementing materials, and amount and type of clay and silt sizes.

Results of compaction and CBR tests on various shales showed a wide range in the values of as-compacted CBR $(\text{CBR})_c$, soaked CBR $(\text{CBR})_s$, the ratio of soaked to as-compacted values R, and the peak density on the standard AASHO compaction curve $\gamma_{d\ \max}$. Higher values of $(\text{CBR})_c$ and $\gamma_{d\ \max}$ indicate stronger shales. The value of $(\text{CBR})_s$ is an indicator of both in-service strength and durability, and higher values indicate more strength and durability. Higher values of R predict more durable shales. The results of the CBR tests correlate satisfactorily with soundness index and fissility number.

The use of fissility number seems to be helpful in categorizing shales. Higher values of fissility number indicate reduced $(\text{CBR})_c$, $(\text{CBR})_s$, and R values. Thus those shales having higher fissility numbers display reduced durability and strength.

On the basis of four simple degradation tests, shales can apparently be classified as

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

The flow chart for classification is shown in Figure 3.

RECOMMENDATIONS AND SUGGESTED CONSTRUCTION PRACTICES

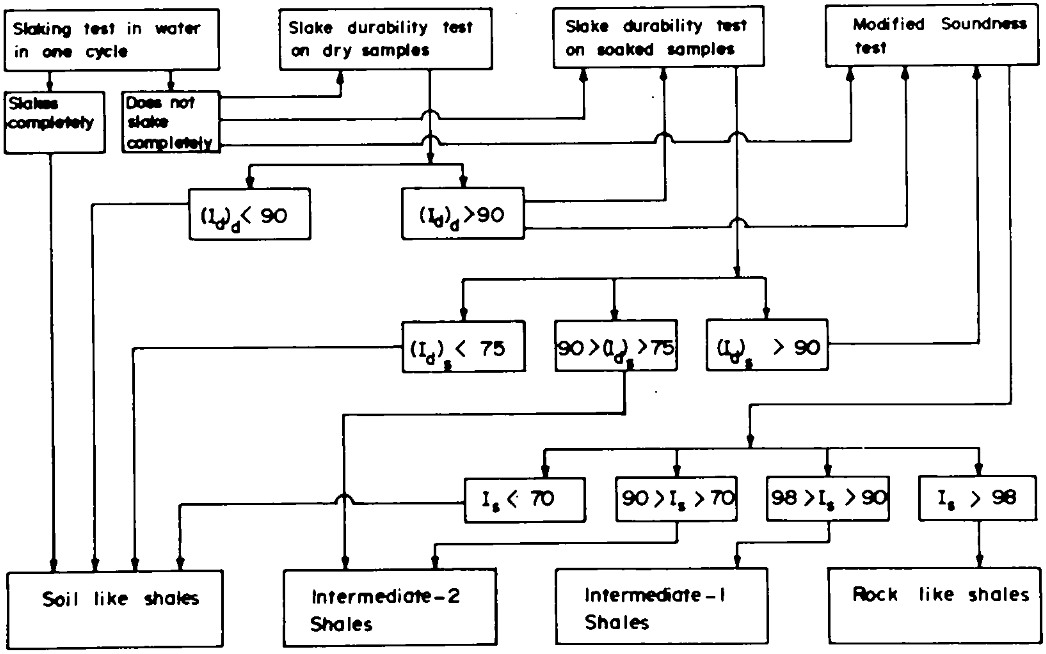
When shale is considered as a construction material in embankments, it should be viewed as a special material, i.e., something between soil and rock. It should be classified in accordance with its probable behavior in the embankment. Before actually specifying use of this type of material, the following steps are recommended.

1. Review the design and construction standards and specifications that would apply if the embankment material were (a) an average fine-grained soil or (b) an average sedimentary rock; i.e., consider the limits for the real material, which is generally intermediate.
2. Study the proposed fill material to determine whether it is homogeneous or a mixture of unlike materials, e.g., shale and limestone. There are special hazards in the latter case, and special attention is required.
3. Perform the slake durability and modified soundness tests. Classify the material in one of the four groups suggested (Fig. 3).

For the different groups of shales, the following construction practices are suggested by the authors. (These opinions were derived intuitively on the basis of observations, but without actual field tests.)

1. If the material is soil-like, it should be thoroughly broken down before use, and thinner lifts than normally specified for soil may be needed. Expansive characteristics for the shale should also be determined. (Axial swell in the CBR test is a good descriptor.) If the shale powder shows more swelling than that of ordinary clays, it should be accorded the special treatment given an expansive soil embankment, including an effective encasement of nonshale material.
2. For intermediate-1 and intermediate-2 shales, specifications should generally vary between those for soil and those for rock fills. Bigger chunks can be used. In intermediate-2 shales, it is probably necessary to have better density control and to employ an encasement.
3. A mixture of durable and nondurable material should not be used in an embankment; e.g., never mix a rock-like with intermediate-2. The two materials will degrade quite differently in service, causing potentially major problems. Only top-quality intermediate-1 or rock-like shales should be mixed with limestone or sandstone.
4. If it is not possible to separate good and bad shales, then the whole material should be treated like soil, i.e., be thoroughly broken down.

Figure 3. Proposed classification of shales for embankment construction.



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