FINAL REPORT

USE OF DEO'S CLASSIFICATION SYSTEM ON ROCK

by

D. F. Noble
Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A shale from a construction site on Route 23 in Wise County, Virginia, was classified using Deo's classification system, and the usefulness of the classification system was evaluated. In addition, rock that had previously been used in the development of an acid soak test was resampled for use in determining the lowest percentage of concentrated sulfuric acid that would rapidly break down the Millboro type shale.

It was concluded that the Deo classification system would be more effective and useful for working with the ostensibly tough Virginia shales if the tests were run for five cycles and if the physical condition of the tested particles of shale, as determined by observation, was given more weight than the numerical indices as an indicator of the long-term durability of the shale.

It was recommended that the following methodology be adopted by the Virginia Department of Highways and Transportation for identifying Millboro type shales, which are physically tough but will weather in a relatively short time in a wet oxidizing environment.

a. Note the color of the shale.

b. If it is dark (green, gray), then look for iron sulfides.

c. If these are present, then examine the shale for the clay mineral "chlorite".

d. If chlorite is present, then the shale should be considered as having great potential for relatively rapid weathering and should not be used as rock.

Also, it was recommended that black shales should be considered to be nondurable.

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INTRODUCTION

An investigation of the relatively fast deterioration of the Millboro and Brailler shales in a high embankment near Clifton Forge, Virginia, led to the conclusion that the rapid weathering of these shales was caused by a unique set of circumstances that was discussed by Noble (1977). As a part of that earlier study, the testing of these shales progressed from the less rigorous slake and slake durability tests to the more rigorous modified sulfate soundness test described by Deo, Wood, and Lovell (1973) and Chapman (1975), and used by Wood, Lovell, and Deo (1973) in Deo's classification system, to a sulfuric acid soak test that was developed by Noble (1977) to simulate, at an accelerated rate, the type of weathering undergone by these shales. With the writing of the report in 1977, it became apparent that additional work was necessary. The need for a classification system to be used on shales encountered in Virginia was recognized, and it was decided to test Deo's system on Virginia shales. Also the need for the refinement of the sulfuric acid soak test was obvious.

CONCEPT OF DURABILITY

In the discussion of the results in the 1977 report, the term "durability" was used. Because it is a relative term, it seems advisable to define it here. Webster's Dictionary, the unabridged version, provides the definition "able to exist for a long time with retention of original qualities...." This definition uses the concepts of "long time" and "retention of original qualities", which need to be put in a frame of reference for civil engineers. This can be done by referring to the structures they design and build and to a use they make of rock. For structures such as bridges and embankments, a useful life of a hundred or more years would be desirable, while a life of less than fifty years would be undesirable. When an engineer chooses a rock to use as rip-rap, the most important characteristic of the rock is its unchanging nature. It must withstand intense physical and chemical weathering, and thereby maintain its massive size. Thus, a shale with a high degree of durability, suitable for use as rock in the construction of a highway embankment, would be one that maintains its original qualities for over fifty years.

The durability of a rock depends on a combination of its characteristics and the weathering environment. The following are some of the important characteristics:

1. Chemical reactivity
2. Joint sets — their relative orientation, how well developed they are, the spacing between planes
3. Bedding plane spacing
4. Cementation and or the interlocking of grains
5. Orientation of particles
6. Porosity and permeability

All of these characteristics are important in shales.

PURPOSE AND SCOPE

The purpose of the present study was to evaluate the potential of the Deo system (Wood, Lovell, and Deo 1973) for use in classifying a shaley rock located in a cut and embankment in Virginia and to refine the sulfuric acid soak test.

In regard to the classification system, the scope of the study was limited to the shaley rock to be used on Route 23 in Wise County, because (1) the procedure for obtaining shale was dependent upon construction being planned for areas underlain by shale, and (2) no other material was available.

Refinement of the sulfuric acid soak test was limited to determining the lowest concentration of sulfuric acid that would cause rapid deterioration of the Millboro type problem shale.

Through the initial sections of this report, it has been convenient to deal with both subjects of the study under the same heading or subheading. However, it was thought that from this point on considerable confusion would be saved by completing the reporting on the classification system first and then dealing with the work on the sulfuric acid soak test.

EVALUATION OF DEO'S CLASSIFICATION SYSTEM

Materials

During the preliminary engineering and planning stage of a construction project, the Materials Division of the Virginia Department of Highways and Transportation evaluates the engineering properties of the cut and fill materials. If the cut is to be 50 feet (15.24 m) or more deep and is expected to be in quite variable sedimentary rock from near the surface to below the grade line, a rotary core drill is used to extract cores for the evaluation. Based on the geologist's assessment of these cores and of the rock exposed in the vicinity of the cut, the engineer decides how to handle the rock in the construction of an embankment and what slopes to design for the cut. Because the proposed embankment on Rte. 23 in Wise County was to be over 100 feet (30.48 m) high and thus would have great potential for developing stability problems, a core from the cut area was taken to Richmond for testing. Both the slake test and a wet freeze-thaw test were run on specimens of various lithologies taken from the cores.

The remainder of one such core 134 feet (40.84 m) long was shipped to the Virginia Highway and Transportation Research Council to provide shaley rock for classification testing. The initial step in processing the core was to log the lithologies, which is usually a visual procedure that is enhanced by having a fresh rock surface to observe. Because the diamond bit of a core barrel roughens the surface of the core, differences in texture and tones of color are difficult to discern. Breaking the core along its linear axis would have allowed a detailed logging of the lithologies; however, maintaining the core in as large pieces as possible prior to breaking it for samples was desirable. Therefore, logging was based on the appearance of the roughened surface and the hardness of the material as determined by scratching it with a knife.

Three types of rock were identified: (1) siltstone, (2) shale or silty-shale, and (3) interbedded shale and siltstone.

1. The siltstone was identified by its hardness as revealed by the scratching. Frequently, scratching left metal from the knife blade on the siltstone, and the point of the blade was dulled after working the first box of core.

2. The shale was identified by the ease with which it was scratched and by the smoothness of the scratching action, that is, by the lack of any gritty feeling as the scratch was made. Some of the shale was termed silty in that a slight grittiness was noticed during scratching.

3. The interbedded shale and siltstone was designated a separate rock type because the beds were usually 1/2 inch (12.7 mm) or less in thickness and alternated for several tenths of a foot or more. It would have been virtually impossible to separate these layers for testing as discrete lithologic types.

Sampling

The sampling of the core had to be done under two constraints. First, only 8 samples (3 siltstone, 2 shale, and 3 interbedded shale and siltstone) had to represent the entire core. Second, there was not an abundance of the shale and the interbedded shale and siltstone. Fortunately, the constraints tended to compensate for each other. To satisfy the first, rock was taken from various locations in the core to make up a sample. Thus, it was possible to accumulate an adequate sample size of shale and of the interbedded shale and siltstone.

Testing

A flowchart for Deo's classification system is shown in Figure 1. Descriptions of the tests as modified by Deo are in the appendix of the report by Deo, Wood, and Lovell (1973). The full extent of the testing scheme is not illustrated by the flowchart. If a rock type were quite durable and thus was subjected to the entire testing scheme,

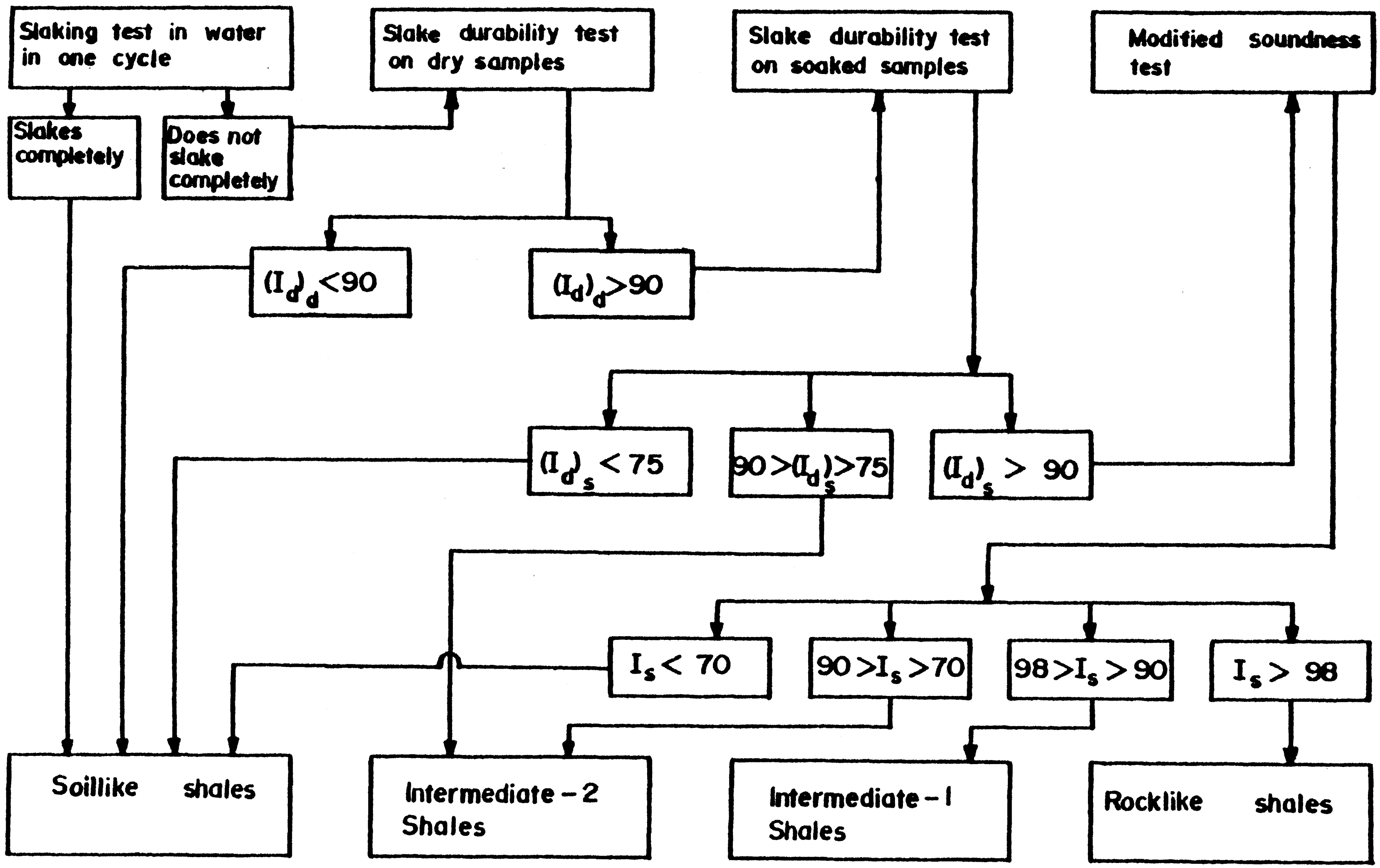

Figure 1. Deo's classification scheme for Indiana shales for embankment construction (Wood, Lovell, and Deo 1973).

6 specimens would be needed for the following tests:

1. Slake test in water for 1 cycle

2. Slake durability test starting with dry rock for 1 cycle and then for a second cycle at 200 revolutions per cycle

3. Slake durability test starting with dry rock for 1 cycle at 500 revolutions

4. Slake durability test starting with water soaked rock for 1 cycle at 200 revolutions

5. Slake durability test starting with water soaked rock for 1 cycle at 500 revolutions

6. Sodium sulfate soundness test starting with dry rock for 5 wetting and drying cycles

The Virginia Department of Highways and Transportation does not routinely run a series of tests on shaley material for embankments. As mentioned earlier, the proposed embankment had considerable potential for failure because of its height and the use of shale or shaley rock. Thus the Materials Division decided to pursue the expedient course of using a slake test and a wet freeze-thaw test organized somewhat as the slake test (5 cycles on individual specimen) to determine the soundness of these rocks.

The slake test was run as outlined in Noble (1977), with the exception that the pH of the soak water was not determined and an extra weighing step was used so that the water content of each of the pieces of rock could be calculated. A description of the slake test as run by the Materials Division is in the Appendix. For the wet freeze-thaw test, specimens taken from throughout the core were put through 5 cycles of freezing and thawing, unless the piece of rock disintegrated, in which case testing was stopped. The pieces of rock were photographed and the number of cracks were noted, as were the condition of the surface and the degree of deterioration.

The testing scheme followed at the Council differed from that developed by Deo for two reasons:

1. It was anticipated that the Virginia shales would have been subjected to a greater intensity of induration than those in Indiana with which Deo worked when he designed his classification scheme, and, therefore, that the Virginia shales would be more durable.

2. There were limited quantitites of shale and interbedded shale and siltstone in the core.

Thus, all the tests at the Council were run for 5 cycles because of the anticipated durability. In addition, only 3 tests were run rather than 6, so that only half the quantity of test material was required.

The tests run at the Council were:

1. Slake test in water for 5 cycles

2. Slake durability test starting with dry rock for 5 cycles at 200 revolutions per cycle

3. Sodium sulfate soundness test starting with dry rock for 5 wetting and drying cycles

These tests were run as outlined by Noble (1977), with the exception that the pH of the slake water was not determined and 10 cycles of the soundness test were never run. As an aid in observing the rate of disintegration, the various specimens were weighed and the indices were calculated after each test cycle.

Results and Analysis

Methods of Handling — Types of Disintegration

A brief discussion of the purpose of testing shales for use in embankments might add meaning to the comparison of the Council's test results with the criteria of Deo's classification system. The purpose of evaluating the durability of shales to be used in embankments is to provide information for judging whether and how these shales can be handled to give satisfactory performance. If handled as rock, the shale will be bulldozed onto the embankment in thick lifts, with no control of compaction; there will be inter-boulder space that is loosely filled with fines, some unfilled voids, and the embankment will have high permeability. If handled as soillike, the shale will be broken into small pieces that will be placed in thin lifts, the shale will be compacted, and the embankment will have minimal permeability. The initial judgment that must be made is whether the shales have the durability of sound rock. Then, if they do not have this durability, what level of effort should be put into breaking and compacting them.

The disintegration of shale by the slaking process may take a variety of forms (severe cracking, disaggregation to discrete particles of silt and clay, flaking, spalling, etc.), all of which indicate that the shale does not have the durability of sound rock in the presence of water and in an unconfined state and thus should not be handled as rock. The type of disintegration that a shale undergoes is important in designing a method for working it into an embankment. A similar rationale can be applied to the results of the slake durability and the modified sulfate soundness tests. Even though these tests give quantified results, it would be wise to consider the nature of the disintegration caused by them when designing an embankment.

Slake Test

All the quantitative results of the Council's testing sequence are presented in Table 1. Table 2 contains a condensation of the observations made after each cycle of the slake test.

Deo's classification system for shales (Wood, Lovell, and Deo 1973) does not utilize the index($\frac{\text{wt. loss}}{\text{orig. wt.}} \times 100$) developed by the Indiana State Highway Commission for the slake test. Thus, the observations presented in Table 2 must be consulted to compare the Council's test results with Deo's system. Deo appears to use the slake test for only 1 cycle because such usage is a quick method of identifying the least indurated shales. As can be seen from the observations made after the first cycle, none of the large particles completely slaked. Thus, Deo's system would move all the samples into the next phase of testing.

Designing for obsolescence is not a part of the philosophy of the civil engineer who is designing a highway system. A useful life expectancy for such structures as bridges and embankments should be expressed in a historical time frame. Hundreds of years of useful service would be desirable; less than fifty years would be undesirable. Therefore, in this study the performance of the Virginia shale in the slake test was considered from the standpoint of its long-range durability.

Inasmuch as the Virginia shales were expected to be relatively durable, 5 cycles of the slake test were run, and the slake indices in Table 1 and the observations in Table 2 should be informative. One of the reasons the observations are interesting is that they were recorded for each of 48 pieces of rock (6 for each of 8 samples). By looking at all

Table 1

Indices From Council's Testing Sequence

Rock Type	Siltstone			Shale		Interbedded Shale and Siltstone		
Sample No.	1	3	8	2	5	4	6	7
Cycle	Slake Index							
1	0.44	0.10	0.017	0.26	0.025	0.008	0.16	0.018
2	0.62	0.19	0.054	0.83	0.11	0.045	0.32	0.08
3	0.66	0.23	0.061	0.86	0.13	0.07	0.35	0.11
4	1.14	0.28	0.076	1.83	0.56	0.18	0.45	0.13
5	1.27	0.35	0.097	1.86	0.64	0.27	0.495	0.20
	Slake Durability Index (200 rev./cycle, dry)							
1	98.3	98.2	99.5	94.6	98.3	99.4	98.6	98.5
2	96.1	96.8	99.1	91.8	98.0	98.0	97.0	96.3
3	95.1	96.6	98.7	86.8	96.9	97.6	96.1	94.3
4	94.5	95.1	98.2	81.7	95.4	97.2	95.5	91.9
5	94.0	94.0	97.8	78.6	93.6	96.9	94.9	89.9
	Modified Sodium Sulfate Soundness Index							
1	98.5	98.9	99.2	60.1	93.1	98.8	95.0	No Sample
2	85.1	98.8	99.1	35.8	93.0	98.7	95.0	
3	82.6	96.0	99.0	29.5	84.2	97.6	88.0	
4	----	95.6	99.0	29.2	73.5	95.8	82.1	
5	----	95.2	98.4	26.9	67.5	95.5	77.7	

Table 2

Observations About the Slake Test (particles A,B,C,D,E, and F for all samples)

Rock Type	Cycle / Sample	1	2	3	4	5
SILTSTONE	1	A - lrg. crks., flaking started. C - many crks,. rx. disinteg. E - multiple crks. B,D,F - unaffected	A&C - falling apart E - increase in crks. B,D,F - no change	No notable change	No notable change	A - ovoid particle with many crks, hundreds of concave-convex particles C - disintegrated, thousands of thin flakes E - severely crkd., 30-50 particles spalled off B,D,F - at least one crk. each, virtually unaffected
SILTSTONE	3	A - many larg. & med. crks., 3 pieces spalled off. C&F - many cracks B,D,E - unaffected	A,C,F - falling apart B,D,E - no change	No notable change	No notable change	A - 3 lrg. partl. remain (1 1/2 x 1 x 1/2 inches), ovoid partl., thousands of flakes 1/2 inch to clay size C&F - hundreds of partl. concave-convex, max. 1-1 1/4 in. A,C,F - severely distressed B,D,E - unaffected
SILTSTONE	8	A,B,C,D,E,F - unaffected	C - hairline crks. dia. through core. A,B,D,E,F - no change	No change	No change	C - 6 crks. diag. through core. A,B,D,E,F - no change
SHALE	2	A - some hairline crking. B,C,E - some crking, powder on bottom of jar. Rx disinteg. D - vert. & horiz. crks. F - some hairline crks., some sluffing off of pieces.	A,B,C,E,F - came apart when removed from jar. Most damage done in 1st cycle. D - no change	No notable change	No notable change	A&E - severe exfoliation, tens of partl., 1 1/2 x 1/2 to 1/2 x 1/4 inches B,C,F - extremely distressed, hundreds of partl., 3/4 x 1/2 to 1/2 x 1/4 inches, concave-convex some ovoid. D - virtually unaffected
SHALE	5	A - many crks. along joints, flaking, B - many crks., some flaking, clay on bot. C - crks. along joints D - crks along joints, flak. & clay on bottom. E - crking and flaking F - crks. along joints	A,B,C,D,E, F - came apart when removed from jar. Many small pieces.	No notable change	No notable change	A,B,C,D,E,F - severely deteriorated, many concave-convex surfaces, exfoliation mechanism, paper thin edges on most particles, some ovoid shaped particles
INTERBEDDED SHALE & SILTSTONE	4	A,C,E - no crks., minor flaking, some clay on bottom of jar. B - clay on bot., lrg. severe crks. some flaking D - crks. along joints, flaking F - major disinteg., lrg. crks., 1/2 of rx exfoliated.	A,C,E - no change B,D,F - came apart when removed from jar.	No notable change	No notable change	A,C,E - virtually unaffected. B,D,F - tens of particles, exfoliated, each with at least two large particles left.
INTERBEDDED SHALE & SILTSTONE	6	A&D - Many crks. along joints, some pieces breaking off. E - much lrg. scale crking, brking. in chunks and thin sheets. B&C - minor crking. along joints F - unaffected	A,D,E - came apart when moved for drying. B,C,F - no change	No notable change	No notable change	A,D,E - severely distressed, exfoliated, tens of particles, at least one piece (1 1/2 x 1 1/2 x 1 inch) left of each. B,C,F - virtually unaffected.
INTERBEDDED SHALE & SILTSTONE	7	A,B,D,E - unaffected C - horizontal crks., smal. rx. debris on bottom F - minor vert. hairline crks.	A,B,E - no change C - fallen apart D&F - hairline crks.	No notable change	No notable change	A,B,D,E,F - virtually unaffected C - severely distressed, one piece 2 1/2 x 1 1/4 x 3/4 inch, hundreds of particles from 1 1/2 inches to clay size, predominantely concave-convex shapes.

*1 inch = 25.4 mm

of the observations, the initial or early changes, the results of the second cycle, the variability in the test results, the meaning of the variability, and the results of the fifth cycle of slaking can be addressed.

After one cycle of slaking, the only sample for which none of the pieces showed change was sample no. 8. For the other 7 samples, the least that happened was some minor flaking and cracking, and the worst was major disintegration with large cracks. The principal conclusion that can be made based on the results of 1 cycle of slaking is that, since the pieces displaying distress were taken from along the entire length of the core, the thickness of rock represented by the core should not be treated as rock during construction of an embankment that is expected to have a normally useful life.

After the second cycle of slaking, 23 of the 48 pieces came apart. Such a reaction for almost half of the particles reinforces the conclusion made after the first cycle.

No notable change was the principal observation after the third and fourth cycles, because the change that did occur was difficult to either describe or quantify meaningfully in a frame of reference against which the results of succeeding cycles could be compared. Based on the indices in Table 1, it is obvious that for most of the samples most of the quantitative change had taken place by the end of the second cycle. Afterward, not much additional material was lost, though the large particles did become smaller.

The condition of the particles after the fifth cycle of soaking is noteworthy if for no other reason than that only one additional particle from the second cycle through the fifth became severely deteriorated. One particle was noted to have 6 cracks through the core, and 23 particles were either rated as virtually unaffected (the slightest discernible change) or unaffected.

The significance of these observations is that after only 2 cycles of slaking the condition of 23 particles was so poor that a semiskilled observer would likely decide that the material they represented would not perform well in an embankment as normally constructed with rock.

There was no uniformity in the degree of deterioration amongst the particles after one cycle of slaking. This lack of uniformity continued through the fifth cycle, as may be seen in Figure 2. The 6 particles illustrated in Figure 2 were chosen because they represent the final and variable

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8E 6A

5C 3C

2C 1C

Figure 2. Samples after 5 cycles of slake test.

degrees of deterioration observed. From particle 8E down through particles 2C and 1C, the unaffected through the severely deteriorated are shown. Starting with particle 6A, it is considered that the deterioration illustrated was so severe as to warrant banning the material from use in the construction of embankments with rock.

The range of slaking deterioration that shales from all over the United States experience in the presence of water is much greater than the range shown in Figure 2. Deo, Wood, and Lovell (1973) showed a shale that turned to mud (a mass of disaggregated sedimentary particles) in 15 minutes. Such an extreme reaction obviously labels material as being likely to cause problems. However, <u>any</u> significant change in particle size, such as with particle 6A, will cause distress as the slaked particles fall into the voids and reduce the gross volume of the embankment.

In Figure 2, the change in the size of the larger particles from the second cycle through the fifth cycle can be illustrated by comparing the appearance of particle 6A with that of particle 2C. While both particles are shown after the fifth cycle of slaking, particle 2C closely resembled the less deteriorated 6A after only the second cycle of slaking for 2C. Thus, there was a breakdown of the larger particles by the fifth cycle.

It is of special interest to note that for 4 of the 8 samples, (1, 3, 4, and 6) 3 of the 6 particles were rated as being virtually unaffected and the other 3 as being severely deteriorated. Of the 12 particles in samples 2 and 5 combined, only 1 was unaffected. Samples 7 and 8 each had 5 unaffected particles and only 1 that was severely distressed. Based on the lithologic types, the siltstone would be expected to be unaffected, while the combination shale and siltstone might experience variable degrees of distress (more than for siltstone but less than for shale), and the shale would be expected to show severe distress. Of the 4 samples showing the greater variability, 1 and 3 were siltstone and 4 and 6 were interbedded shale and siltstone. The 2 shales (2 and 5) showed the greatest deterioration, while a siltstone (8) and an interbedded shale and siltstone (7) showed the least. Thus, 3 samples reacted as expected and 5 did not. The variableness of the distress is a commentary on the difficulty of identifying the lithologic types as was done in this study, and possibly on the importance of the amount of clay in the coarse-grained lithologic types.

The fact that after the fifth cycle the larger pieces left from the deterioration of the original particles were ovoid in shape while the smaller pieces that had broken off were concave-convex (petal or sickle), and often with paper thin edges, indicated that the distress occurred through exfoliation. Probably, this resulted from the clay minerals increasing in size through the adsorption of water. A zone of weakness developed along the contact between the wetted and unwetted clay particles and the wetted portion broke off.

To restate the conclusion presented after the discussion of the results of the first cycle, if the nondurable rock cannot be separated from the durable rock, then the mass of rock represented by the core tested should not be used in embankments constructed as with rock.

Slake Durability Test

In Deo's classification system as detailed under the preceding section, the slake durability test was set up to be run for 2 cycles, each of 200 revolutions per 10 minutes and for one 500 revolution-25 minute cycle. However, the diverse nature of shales and the purpose of testing them may suggest a different regimen for shales with different physical characteristics. Therefore, the relatively tough shale from Wise County was started oven dry and was run for 5 cycles of 200 revolutions per 10 minutes. The slake durability indices for each cycle are in Table 1.

The indices for the second cycle are all greater than 90 and, according to Deo's criteria, those rocks should be moved into the next series of tests. Only the index (91.8) for sample 2, a shale, was close to the lower limit of 90.

Even after 5 cycles of wetting and tumbling only 2 samples had indices below 90. Thus, according to the slake durability indices, 6 of the samples seemed to be relatively durable, while 2 (nos. 2 and 7) would be rated as nondurable. There was little disparity between the observations made after the fifth cycle by the technician and the principal investigator. Based on the degree of rounding, fracture, and breakage, it was concluded that samples 1 and 4 were durable, that 3, 6, and 8 were relatively durable, and that 2, 5, and 7 were nondurable. Photographs of samples 4, 3, and 5, taken before and after the testing and representative of the three degrees of durability, are presented in Figure 3.

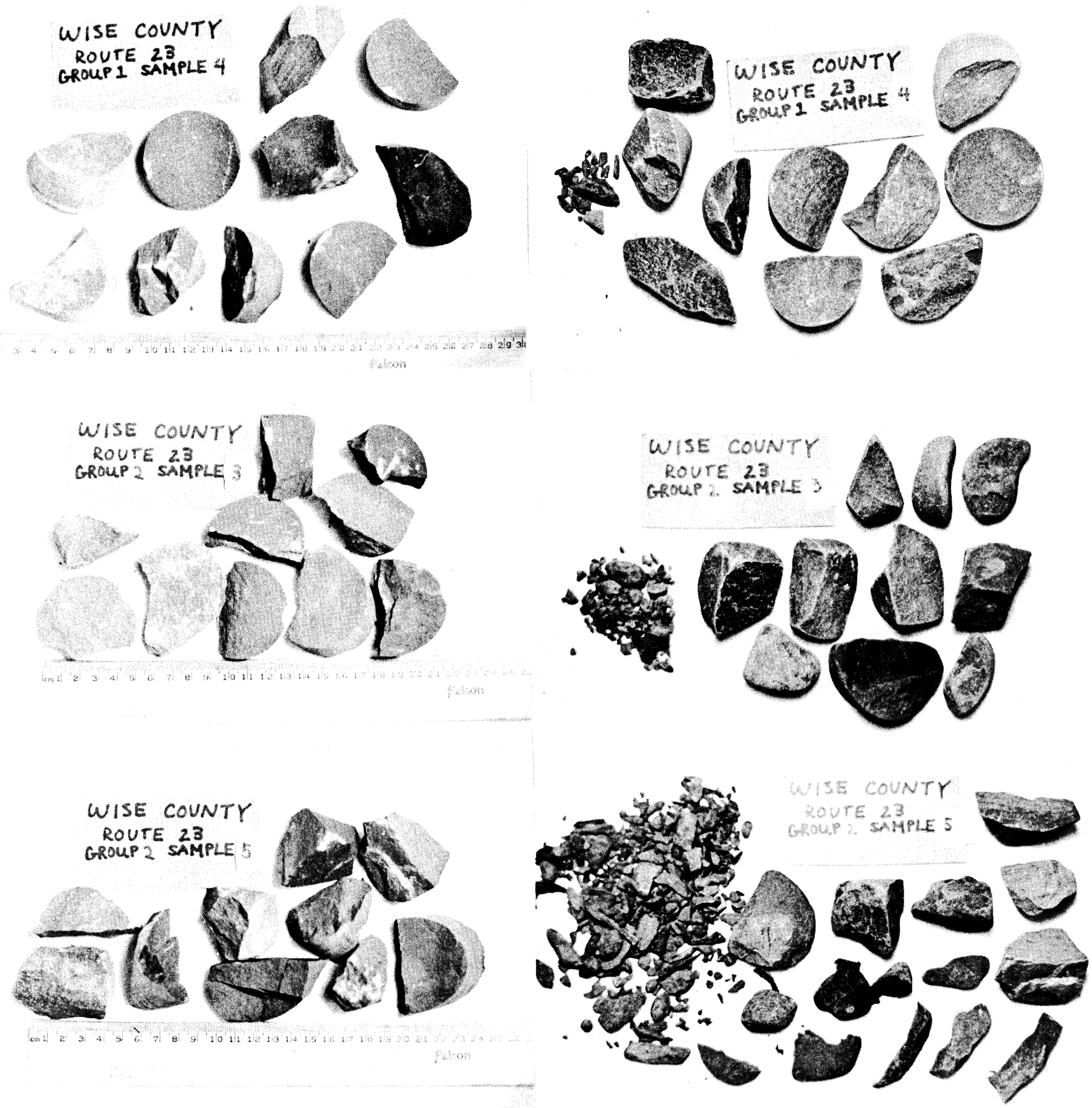

Figure 3. Samples before (on left) and after 5 cycles of slake durability test.

It was stated earlier that the slake test was the least rigorous of the tests employed, that the slake durability test was more rigorous than the slake, and that the modified sulphate soundness test was even more rigorous. Presently, the first two tests are compared.

The index for the slake test is the ratio of the weight lost to the original weight times 100, while the index for the slake durability test is the ratio of the weight retained to the original weight times 100. If the results of both tests are looked at in terms of the weight lost, the slake durability test appears to be more severe than the slake test in that its indices would be between 5 to 50 times greater than those of the slake test. Such a result is not unexpected because physical energy is put into the durability test by the tumbling action.

However, another method of assessing the effect of these tests is to observe the physical condition of the particles after the testing as was done for the slake test. A total of 160 particles made up the sample for the slake durability test. Only 20 were rated as severely distressed, 119 had only their edges rounded, and 21 were considered to be well rounded. After 5 cycles of the slake test, 50.0% of the particles were severely distressed. A comparison of these results with those of 5 cycles of the slake durability test, where only 12.5% of the particles were rated as severely distressed, suggests that the slake test was the more rigorous.

If adsorption of water by the clays causes the distress resulting from the slake test, as was suggested earlier, then the greater rigor of the slake test can be explained by the longer time that the particles spend in water. Because the rock being tested is physically tough and the particles, after being prepared for testing, have relatively sharp edges, the rocks are susceptible to the abrasion and impact that occur during the slake durability test, and thus considerable material is lost in the form of very small chips as the edges of the large particles are rounded. Nevertheless, with 10-minute cycles, the particles are exposed to water for a total of only 50 minutes. Compared to the 120 hours of immersion for the slake test, 50 minutes is a short time. Prolonged immersion is needed so that the water can penetrate the pores of the rock and react with the clay particles. Because of the moderate porosity and low permeability of shaley rocks, it takes more time than elapses in the slake durability test for the water to penetrate the pores.

Modified Sodium Sulfate Soundness Test

The modified soundness test is reputed to be the most rigorous of the tests that were run. The mechanism by which it attacks shaley rock is not certain. The most plausible mechanism is that during soaking the sulfate solution moves along the cracks and other planes of weakness, and the crystallization of the sodium sulfate along those planes during drying tends to force segments of the rock apart. Less plausible, but possible, is that the sulfate radical reacts with some of the colloids that may be present to form compounds of greater volume than the original material, or that the sodium exchanges with the interlayer cations of the clays and increases their volume through altering their ability to hold water.

The index for the modified sulfate soundness test is the weight of specimen remaining on the 5/16 inch (8.0 mm) screen divided by the original weight of the specimen times 100. While the index is a legitimate measure of durability, it seems a more appropriate measure of the durability of rock that might be used as aggregate than of rock that is being considered for use as boulders in the construction of embankments. On the other hand, if a rock were rated as nondurable, then the size fraction to which it is easily broken down becomes of interest, because physical breakup and good compaction are one method of handling a shale that weathers readily once disturbed. On the basis of this reasoning, and after looking at how Deo's system rates a rock, the disintegration of just the 3/4 to 1/2 inch (19.0 to 12.7 mm) size fraction was examined.

The indices for the modified soundness test are in Table 1. They are the average of 3 specimens per sample run through 5 cycles, except that sample 2 had only 2 specimens, sample 6 had only 1 specimen, and the supply of sample 7 was exhausted by the time the sulfate soundness test was run.

According to Deo's classification system, only sample 8 would be considered rocklike, samples 3 and 4 would be intermediate-1, samples 1 and 6 would rate as intermediate-2, and samples 2 and 5 would rate as soillike.

With the introduction of the terms "intermediate-1" and "intermediate-2", it seems advisable to look at how Deo, Wood, and Lovell (1973) used them. Intermediate-1 is close to rocklike and intermediate-2 is close to soillike. Thus, intermediate-1 shales might be mixed with rocklike shales in an embankment. When using intermediate-2 shales, "it is probably necessary to have better density control and to employ an encasement." Intermediate-2 shale should never be mixed with rocklike shale because the two materials will degrade quite differently in service and may cause major problems. A comment particularly pertinent to the shales in Virginia, because of their sequentially and frequently changing lithologies, is that "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."

The relative size of the materials used in the construction of embankments with rock as compared to that of materials observed in the disintegration of shales is important. In Virginia, the maximum size of the boulders used in rock construction is measured in feet, while the particles used in the laboratory tests are measured in inches or fractions of an inch. The spacing of some of the planes of weakness in a shale may vary from inches to feet. The more closely spaced the planes of weakness, the smaller the pieces that the boulders may break into. If the boulders are measured in feet, then the voids will be of comparable dimensions, and any breakdown of a specimen that is measured in inches or fractions of an inch is important because it can easily be accommodated in the voids. Therefore, the effect of the soundness test on the 3/4 to 1/2 inch (19 to 12.7 mm) size fraction should be observed.

As the larger size fraction breaks down, there is no way of knowing whether the pieces are retained on the 5/16 inch (8.0 mm) screen, and in one sense this question is not important. The fact that particles 3/4 to 1/2 inch (19 to 12.7 mm) in size do break down is important, as is the extent of that breakdown. Thus, the more extensive breakdown of the larger size fraction than of the total specimen, which did occur, is significant. The indices for the larger size fraction are in Table 3. Because Deo's criteria apply to the breakdown

Table 3

Indices For the 3/4 to 1/2 Inch (19.0 to 12.7 mm) Size Fraction For The Modified Sulfate Soundness Test

Rock Type	Siltstone			Shale		Interbedded Shale and Siltstone		
Sample No.	1	3	8	2	5	4	6	7
Cycle								
1	91.4	94.4	93.7	46.1	72.9	98.2	81.3	No Sample
2	82.0	94.0	90.0	30.2	72.4	97.9	81.2	" "
3	79.3	89.4	87.7	20.1	60.8	94.4	58.0	" "
4	77.9	88.9	87.5	17.8	43.0	91.3	48.9	" "
5	76.5	86.9	86.5	16.7	36.2	89.6	43.8	" "

of the entire specimen, they are not applied to the indices in Table 3. Nevertheless, an inspection of these numbers suggests that samples 2, 5, and 6 have a strong tendency to break down, that sample 1 is far from sound, and that samples 3, 4, and 8 show a definite tendency to break down, but are the three toughest of the 7 samples tested.

The rate at which a rock disintegrates is of interest. However, there was no specific pattern to the breakdown of these shales by the cycle of testing, and the subject will not be discussed further.

The modified sodium sulfate soundness test, as it would be used by Deo, differentiated rather moderate differences in the samples' sensitivities. One sample was rated as rocklike, 2 were intermediate-1, 2 were intermediate-2, and 2 were rated as soillike.

Based on the size of rock boulders used in the construction of embankments, the size of the voids, the size of the particles created as some of the boulders disintegrate, and the degree of disintegration experienced by the larger size fraction in the soundness test, it appears that little, if any, of the rock tested for this study should be considered as being rocklike.

Conclusions and Recommendations — Deo's System

A brief review of the results of using Deo's classification system, sequence of tests, and criteria, on the Wise County shale should aid an understanding of the conclusions.

Slake Test — None of the particles was completely slaked. Therefore, the slake durability test should be run on these shales.

Slake Durability Test — After the second cycle, all of the indices were greater than 90. Therefore, the sulfate soundness test should be used on these shales.

Sodium Sulfate Soundness Test — Two samples of the rock were rated soillike and two were rated intermediate-2. Thus, Deo would suggest that half of the samples be treated like soil and should thus be thoroughly degraded and compacted.

Inasmuch as the various types of rock could not be separated during excavation and handled differently, Deo would suggest that all of the rock should be treated as if it were soillike. Deo's suggested treatment is satisfactory and is the treatment that this researcher would have suggested, but would have based the suggestion on different criteria. Thus, Deo's classification system is not recommended for use in Virginia without modification.

Modificatuon seems to be appropriate because some of the rationale presented in the results and analyses is particularly pertinent to the consideration of Virginia shales. Deo's criteria were established for shales found in Indiana and so they should not be expected to be appropriate for the shales found in Virginia. Consideration of the type of shale, the nature of the mechanism of deterioration, and the relative sizes of the voids and of the particles that flake off during deterioration suggests that different criteria should be used.

Observations and judgments have the weakness of possibly being more subjective than is desirable. However, making observations and judgments based on the following criteria is recommended. Rocks that undergo significant distress during the testing program in the form of wide open 0.02 to 0.04 inch (0.5 to 1.0 mm) multiple cracks through the particle, or numerous flakes spalled off the main particle, or numerous fine cracks along the bedding planes such that the particle appears to swell and lose its shape, or that break into three or four smaller particles should be considered to be nondurable. If a rock does not show any signs of distress, it may be classified as being rocklike.

Thus it is recommended that a modified version of Deo's classification system be adopted for use in Virginia when shales are encountered in the preliminary engineering investigations. It is thought that the modifications are necessary because of the toughness of these shales in situ. Especially since this toughness is probably more a result of the physical regimen (heat and pressure from burial and folding) that the rock has been subjected to than the mineralogy of the rock. Yet, because of the mineralogy of these shales, they will eventually respond to the drastic change in environment that results from excavation by breaking down into soillike particles and cause distress to an embankment long before it attains its expected useful life.

The modifications of Deo's classification system should be as follows:

1. Run as many as 5 cycles of each test, if no change in the condition of the particles is noted.

2. Use Deo's indices, but assign them less weight than accorded observations based on the degree and nature of the distress outlined above.

REFINEMENT OF THE SULFURIC ACID SOAK TEST

As has been noted, when an embankment constructed with shale according to specifications for construction with rock failed in a relatively short time, work was begun to find or develop a test that would identify the Millboro type problem shale that was used. Inasmuch as the deterioration of the shale seemed to result from the oxidation of the sulfur in the iron sulfide in the shale-producing sulfuric acid, which would attack the mineral chlorite and thus accelerate the breakdown of the shale, a sulfuric acid soak test was designed. Shale was soaked in solutions of concentrated sulfuric acid of 0, 25, 50, and 75 percent. The effect on the shale was monitored by observation and by chemical and X-ray diffraction testing.

The concentration of acid that had the greatest effect was 25 percent. To establish the lowest concentration of sulfuric acid that would cause severe distress for the shale, the work reported here was undertaken.

Materials

Shale was obtained from sites as close as possible to those that had previously been sampled and described by Noble (1977).

Testing and Mode of Analysis

The testing was done as described by Noble (1977), with the exception that the solutions of concentrated sulfuric acid were 5, 10, 15, 20, and 25 percent and no chemical or X-ray diffraction analyses were run. Inasmuch as any test adopted for use in the field would have to be a simple one, the analysis consisted of observing the changes that occurred in the particles of shales. Observations were made by a technician every day from the 1st through the 16th day of soaking. Starting with days 17 and 18, observations were not made on the weekends, but were made only during the 5 workdays until the particles had soaked for 56 days. The principal investigator examined the particles after completion of the 56-day soak period.

Results and Analysis

Both observers agreed that the 25 percent solution of concentrated sulfuric acid caused the most severe degree of deterioration and was the fastest acting of the solutions. After 3 days of soaking, all of the samples in the 25 percent solution except sample 1 had been singled out for comment about the amount of cracking or some other reaction experienced by them that was different from what happened to the particles from those samples that were soaking in the less concentrated solutions of acid. At the completion of the soaking period, the particles in the 25 percent solution had experienced the most distress. Most of these maintained a semblance of their initial shape despite being so severely cracked that they looked like either a sheaf of paper or a stack of miniature 2 x 4's. Specimen 3p25 was so severely distressed that it bore no resemblance to its original shape but looked somewhat like a mass of oatmeal.

The acid seemed to attack the rock along the planes of weakness found in most sedimentary rocks; that is, along the bedding and joint planes. The particles that had very thin beds with moderately spaced joints took on the appearance of a sheaf of paper, while the particles that had somewhat equally spaced bedding and jointing looked like sheets of plywood or stacks of miniature 2 x 4's.

The degrees of deterioration observed were rated as minor, moderate, or major. The ratings are listed in Table 4 for those times when there was a change in the rating for any sample. For most of the samples, significant changes in the degree of deterioration occurred throughout the first 4 days of soaking. Thereafter, the changes were slower and it was not until after the 9th day of soaking that any of the ratings changed because the degree of deterioration was noticeably increased in one of the more resistant samples.

Conclusions

The sulfuric acid soak tests have shown that a strong solution of the acid will break down the Millboro shale, which appears rocklike when fresh, in a short time. In particular, the solution of 25 percent concentrated sulfuric acid was the fastest acting of the 8 percentages (ranging from 0.0 to 75 percent) of concentrated acid used in this and an earlier study, and it caused the most severe distress in the 8 samples of Millboro type shale. However, the testing program was not designed to show that the Millboro type shale was the only one that sulfuric acid would break down. Therefore, the test cannot be used to identify the Millboro type.

The importance of showing that sulfuric acid can break down the Millboro shale is that the acid should be produced by oxidation of the sulfur in the iron sulfide associated with the Millboro shale. Thus, when the Millboro is excavated and exposed to oxygen and percolating water, it can be anticipated that sulfuric acid will be produced and that it will accelerate weathering of the shale.

Table 4

Rating of Degree of Deterioration as Evaluated From Observations

Days Soaked / Sample	1/3	1	2	3	4	9	28	56
1	Minor	Minor	Mod. +	Mod. +	Major	Major	Major	Major
2	None	Minor	Mod.	Major	Major	Major	Major	Major
3	Mod.	Major	Major	Major +	Major +	Major +	Major +	Major +
4	None	Minor	Mod.	Major	Major	Major	Major	Major
5	Minor	Mod.	Mod.	Mod. +	Major	Major	Major	Major
6	None	Minor	Minor	Minor	Minor	Minor +	Major	Major
7	None	Minor	Minor	Minor +	Minor +	Minor +	Mod.	Mod.
8	None	Minor -	Minor	Mod.	Mod. +	Mod. +	Mod. +	Major

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RECOMMENDATIONS

A specific shale in a given environment is unique, because the principal mineralogical component of a shale is a clay mineral or, more probably, an assemblage of clay minerals, and clays are extremely sensitive to their environment and to changes in that environment. Therefore, to anticipate how a shale will react when used as a construction material, as in an embankment, it is important to know —

1. the nature of the depositional environment (oxidizing or reducing),
2. the mineralogical assemblage,
3. the clay mineral assemblage, and
4. the nature of the environment that the shale is to be placed in (wet-dry, high-low permeability, oxidizing or reducing).

Thus, it is recommended that a methodology, rather than a test for identifying a Millboro type shale, be adopted by the Virginia Department of Highways and Transportation for use in the preliminary engineering procedure. The methodology is as follows:

a. When dark colored (green, gray) shales are to be excavated and used in a structure, they should be examined to see whether any iron sulfide is present.

b. If iron sulfide is present, the clay mineral assemblage should be determined.

c. If chlorite is present, the shale should be considered as having great potential for relatively rapid weathering and should not be used as rock.

The black coloration results from the presence of organic carbon, which indicates that free oxygen was absent from the mass of sediment that became shale (Tourtelot 1979). Pyrite (iron sulfide) forms in such conditions (anaerobic); thus black shales contain pyrite. When they are exposed to the oxygen rich environment of the earth's surface, the iron and sulfur in the pyrite oxidize. The iron oxide mineral thus formed has a larger volume than the pyrite and causes deterioration of the shale by enlarging the cracks in which it crystallizes.* Therefore, black shales and like materials that contain pyrite should be considered nondurable.

Inasmuch as three methods by which three different types of nondurable shales (poorly indurated shale that is physically sensitive to water, dark shale that may be chemically reactive when exposed to water and oxygen, black shale that is chemically reactive when exposed to water and oxygen) can be identified have been recommended, it is also recommended that the literature be searched for construction methods for handling nondurable shales so that they do not have to be wasted. Further, it is recommended that embankments constructed of such materials be instrumented so that they may be monitored to obtain information that will help in the handling of other such materials.

*Eugene Rader 1982: personal communication.

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APPENDIX

STEPS IN RUNNING SLAKE TEST

1. Choose 6 specimens for each sample (approx. 150 grams each).

    A. Place metal tag with each specimen and record number on test report. Keep tag with specimen throughout test.

    B. Record depth of each specimen on test report.

    C. Place each specimen in a separate moisture can and dry in oven to obtain a constant weight.

2. Lightly brush or wipe off dust, discarding any chips that can easily be broken off with fingers.

    A. Weigh remaining piece.

        1. Record weight on test report (entry marked "Original Wt.")

    B. Place specimen on no. 10 sieve

        1. Place appropriate I.D. slip and tag on screen with specimen.

        2. Take picture.

    C. Place specimen in jar and cover with approx. 0.5 inch of demineralized water.

        1. Soak specimen for 24 hours.

3. Pour over no. 10 screen.

    A. Separate particles and place I.D. slip and tag on screen.

    B. Take picture if needed.

    C. Pour +10 particles in dish and weigh at surface dry condition.

        1. Record weight on test report for calculating percentage moisture (wet wt. + dish).

    D. Dry in oven at 105°C. (221°F.) for minimum of 24 hours.

4. Weigh specimen and record on test report for calculating percentage moisture (dry wt. + dish).

   A. Pour and separate particles over no. 10 sieve.

      1. Place I.D. slip and tag on screen with specimen.

      2. Take picture if needed.

   B. Weigh +10 particles and record on test report as "Wt. after 1st. cycle."

5. Place +10 particles (from 4.B above) in jar with tag.

   A. Cover with 0.5 inch of demineralized water.

   B. Soak for 24 hours — do not shake.

6. Pour over no. 10 sieve.

   A. Separate particles and place I.D. slip and tag on screen.

   B. Take picture if needed.

   C. Pour +10 particles in dish and dry in oven at 105°C. (221°F.) for minimum of 24 hours.

7. Pour over no. 10 screen.

   A. Separate particles and place I.D. slip and tag on screen.

   B. Take picture if needed.

   C. Weigh +10 particles and record on test report as "Wt. after 2nd. cycle."

      For cycles 3, 4, and 5 repeat steps 5, 6, and 7.