IMPROVED ROCK DURABILITY TESTING TECHNIQUES

FOR APPALACHIAN VALLEY FILLS[1]

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Abstract.--The integrity and stability of gravity-placed or end-dumped excess spoil fills in the Appalachians is partially dependent upon placement of durable rock material. Standard durability tests do not adequately discriminate between nondurable and durable rock. Review of recent rock durability research has identified testing procedures and classification systems that may be more applicable to excess spoil fills and the surface mining process. A geotechnical testing program, incorporating the transfer of this recent technology, has been designed by the U.S. Office of Surface Mining Reclamation and Enforcement to allow better prediction of rock durability for a range of overburden materials. An array of rapid, inexpensive rock competency tests are being compared to determine which tests or combination of tests give correlative results which allow accurate prediction of rock durability. Preliminary results from 18 rock samples collected from minesites in Kentucky, Virginia, and West Virginia suggest that tests which measure rock swelling upon water immersion are particularly valuable in predicting the behavior of marginally durable shales. Simple swell tests, when combined with rock strength tests, seem to provide the most efficient discrimination between rocks of similar appearance, but widely varying durability. An additional 84 rock samples collected from 43 minesites in Virginia, West Virginia, Kentucky, and Tennessee are being analyzed to further refine the testing techniques and to investigate the primary mechanisms contributing to slaking.

INTRODUCTION

Excess spoil consists of overburden (soil and rock excavated during the mining operation) not needed to reclaim the disturbed area to the approximate original contour. Before the Surface Mining and Reclamation Act of 1977 (SMCRA), excess spoil structures were constructed with minimal engineering guidance.

Often these structures were placed at locations selected strictly to optimize mining operations. Little thought was given to potential environmental consequences or safety hazards. Since the passage of SMCRA, there has been an increase in the engineering effort directed toward design and construction of excess spoil disposal areas.

In general, methods of placement for excess spoil include: (a) the lift type construction method; (b) the head-of-hollow fill method; and (c) the durable rock (gravity) fill method.

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In the lift method, excess spoil is usually deposited in uniform, horizontal lifts of 4 ft or less and compacted to achieve the desired density. Prior to placement of the spoil in this type of fill, the foundation must be prepared and underdrains installed. According to U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) regulations at 30 CFR Section 817.71(f)(3), the rock comprising the underdrain must be durable (rock that will not slake in water nor degrade to soil material); non-acid or toxic forming; and free of coal, clay or other non-durable material.

An alternative method for excess spoil disposal involves the placement of spoil in lifts at the upper reaches of a watershed. This "head-of-hollow fill" method originated in West Virginia in the early 1970's, and combines the lift-placement technique and a durable rock chimney drain in the center of the fill. The "rock core chimney drain" results from physical segregation of larger rock during spreading of spoil material and lift compaction. All surface and subsurface drainage is to be controlled by this rock core, in order to prevent elevation of the phreatic surface within the fill mass. This type of fill must be placed where the surface drainage entering the core is minimized to prevent a decrease in permeability due to clogging of the rock core by fine particles.

The durable rock fill method consists of dumping spoil to its angle of repose into valleys in a single high lift or several smaller lifts. In existing fills, the lifts range between 50 to over 400 ft in thickness. The front face of the fill is then graded to develop a terraced fill configuration. The material forming the rock fill is generally made up of angular blast rock. According to 30 CFR Section 816.73, the durable rock fill method can only be used if durable rock overburden is present and comprises at least 80 percent by unit volume of the fill. No designed underdrain is required for this type of fill, in as much as the gravity segregation which occurs upon dumping forms a highly permeable zone of large-sized durable rock in the lower one-third of the fill.

The successful performance of excess spoil structures is directly related to the durability of the rock in the fill mass and underdrains. As D.R. Casagrande noted in a public hearing on OSMRE proposed rules concerning spoil in fills:

> "Spoil materials range from hard rocks to clay shales and even soft clay. The range of engineering properties of such materials is enormous. Therefore the proposed rules must be sufficiently conservative to also include the properties of the weakest materials." (Casagrande, 1978).

Durable rock is defined in Federal regulations at 30 CFR Section 816.73(b) as rock which does not slake in water and will not degrade to soil material. A rule-of-thumb used by regulatory authorities is that durable rock achieve an as-tested slake durability index (I_D) of at least 90. The intent of the durability standard is to selectively obtain rock that can withstand surface mining conditions including blasting, handling, compaction, and weathering without significant degradation. The key concern is that, over the long term, a durable rock fill should behave more as a rock mass than as a soil mass. A rock mass is inherently more stable than a soil mass of similar volume because rock has much greater load-carrying capacity and resistance to movement or consolidation than soil. Durable rock fill material has this greater strength because of high intergranular friction and greater resistance to shear stress. Nondurable rock will degrade into soil-sized particles as a result of overburden pressure and moisture absorption, and the drainage system provided by the void space between the rocks may become clogged. The clogging may cause excess pore water pressures to develop that will cause a decrease in the shear strength of the fill material. This decrease in shear strength can cause the failure of the excess spoil structure. Therefore, the correct assessment of the durability of the rock is a critical design factor.

The OSMRE recognizes the need for a suitable rock durability standard. The objective is to select a rapid, inexpensive durability testing standard which will clearly differentiate between durable and nondurable materials, model the effects of surface mining conditions on rock materials, and allow assurance of the long-term stability of properly designed fill structures.

Durability classification systems that involve more than two tests may be uneconomical and are subject to the accumulative effect of mechanical and human errors during testing. Franklin (1970) and Bieniawski (1974) consider the following as necessary prerequisites for any rock classification system employed on a routine basis:

1. System should be based on measurable parameters determinable by relevant tests performed quickly and inexpensively in the field;

2. System should involve only rapid testing techniques due to the potential for large numbers of routine samples;

3. Testing techniques should be simple enough to be carried out by semiskilled field and laboratory staff; and,

4. The range of test result values should allow for a sufficient power of discrimination when applied to the various test samples.

MATERIALS AND METHODS

Samples

The rock samples tested in this study were collected from recently blasted highwalls of surface mines in Kentucky, Virginia, and West Virginia. Eighteen grab samples of freshly blasted rock weighing approximately 100 lb were collected at each site. To facilitate coring during laboratory sample preparation, large, competent blocks of rock were selected. Detailed descriptions of geologic properties and minesite conditions relating to rock durability were made on site, and photographs were taken of the sampled highwall. A dilute hydrochloric acid effervescence (fizz) test for calcareous cementing agents was performed for each sample.

Early to Middle Pennsylvania-age sandstones, shales, and mudstones were sampled for this study. These include overburden and interburden rocks of the Hazard and Peach Orchard Coal zones of the Breathitt Formation in Kentucky; Standiford, Taggart Marker, and Low Splint Coal zones of the Wise Formation in Virginia; and, Freeport and Kittanning Coal zones of the Allegheny Formation, and the Coalburg Coal zone of the Kanawha Formation in West Virginia.

Rock analyses

Geologic materials removed from their in situ environment during the surface mining of coal exhibit changes in physical integrity. Such changes are caused by physical and chemical mechanisms induced by variations in moisture and stress regimes. The rock in fills has been subjected to blasting, handling, compaction, and weathering. Generally speaking, a sedimentary rock that can withstand these processes without significant changes in its original structure can be classified as a durable rock.

When selecting durable rock for fills, one should choose a single test or a combination of tests that best simulate surface mining conditions (Robinson and Ventura 1983). For this study, recent research on rock durability has been reviewed, and testing techniques were selected for application to surface mining rock fills. In order to establish which test or combination of tests best serves as an indicator of sedimentary rock durability, a laboratory testing program was designed to simulate the moisture changes and stress regimes that a sedimentary rock undergoes during the processes of excavation and placement in excess spoil fills. After conducting a wide variety of tests, including Modified Los Angeles Abrasion tests, Modified Slake Durability Index tests, and US Army Corps of Engineers (COE) Accelerated Weathering tests, among others, a simplified testing protocol evolved.

The program presently includes the following tests:

a) Slake Durability Testing, which is currently accepted by OSMRE, includes minor abrasion effects and saturation-desiccation stresses. As defined by Chandra (1970) and Franklin and Chandra (1972), oven-dried samples of rock are placed in a wire mesh drum partially immersed in water. The drum is rotated at 20 rpm for approximately 10 minutes; the sample is then removed, dried, and run through a second cycle.

b) Uniaxial Unconfined Compressive Strength Tests simulate loading stresses in a fill. They are run on rock cores loaded in the direction normal to bedding. Loading is applied to the point of breakage, defined as the maximum stress; constant loading rate of 8,000 lb/min was used.

c) Atterberg Limits Testing is an indicator of the type of clay minerals in the rock and their plasticity. This involves measuring the liquid limit, plastic limit, and plasticity index of the fine grained (minus #40 sieve size) fraction of the rock material.

d) Swell Testing indicates the slaking stress that affects rock when it is removed from its in situ environment in the overburden. This is done by measuring the volume expansion of the cored rock normal to bedding upon immersion in water for a period of 24 hours after oven drying to 105 degrees C. A dial gage is used to measure any dilatancy. Swelling strains are probably the result of expansion due to air breakage along interconnected voids such as microcracks in the rock (Olivier 1979).

e) Jar Slake (Soak) Tests were run to provide a qualitative measure of rock behavior after immersion in water for a 24-hour period. The sample is immersed in a beaker, and observations of any disaggregation are made. As Andrews et al. (1980) state, "...this test might be most closely related to spoil materials located at depth and within a constant humidity or totally saturated environment."; therefore these tests are particularly relevant to the durability of underdrain rock in valley fills.

The above tests were conducted by the COE Ohio River Division Geotechnical Engineering Laboratory under the testing protocol designed by OSMRE. In this discussion, test results for only a limited number of sedimentary rock samples are reported. Thus, any conclusions presented herein should be considered as preliminary until results are available for a wider range of samples currently being tested.

RESULTS AND DISCUSSION

Data from the laboratory testing program are listed in tables 1 and 2. The values obtained in the laboratory for parameters including the swelling strain, slake durability index, unconfined

Table 1.--Atterberg limits data and Deere and Gamble (1971) plasticity classifications for sampled Appalachian shales.

Sample Number	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Plasticity Rating
RR-1	30	21	9	Low
CB-3	33	22	11	Medium
KS-1	30	22	8	Low
KS-2	32	22	10	Low/Medium
AR-1	28	21	7	Low
AR-2	35	27	8	Low
WR-2	36	26	10	Low/Medium
IF-3	35	24	11	Medium
RR-1a	37	22	15	Medium

Table 2.--Swelling coefficients, compressive strengths, slake durability indices, and Franklin and Chandra (1972) and Olivier (1979) classifications for Appalachian rock samples.

Sample Number	Rock Type	Swelling Ratio (DL/L)	Compressive Strength (lb/in^2)	Slake Durability Index (%)	Durability Classification Franklin/ Chandra (1972)	Olivier (1979)
RR-1	Shale	0.0085	11,880	98.5	V.high	M.poor
CB-3	Shale	0.0486	930	94.8	M.high	V.poor
KS-1	Shale	0.0125	2,850	97.2	High	V.poor
KS-2	Mudstone	0.0299	2,210	94.9	M.high	V.poor
AR-1	Shale	0.0020	3,060	95.9	High	M.poor
AR-2	Shale	0.0146	1,670	96.4	High	V.poor
WR-2	Mudstone	0.0142	- -	29.6	V. low	V.poor
IF-3	Shale	0.0280	180	92.1	M.high	V.poor
RR-1a	Shale	0.0010	3,080	95.9	High	Fair
RR-2	Sandstone	- -	14,280	98.3	V.high	Excellent
CB-1	Sandstone	0.0018	6,670	92.5	M.high	Excellent
CB-2	Sandstone	- -	6,050	84.0	Medium	Excellent
KS-1a	Sandstone	0.0004	3,480	95.7	High	Excellent
PH-1	Sandstone	0.0002	4,200	89.1	M.high	Excellent
AR-3	Sandstone	0.0003	6,630	97.9	High	Excellent
WR-1	Sandstone	- -	5,060	96.8	High	Excellent
IF-1	Sandstone	0.0008	5,150	94.3	M.high	Good
CB-1a	Sandstone	0.0006	3,660	96.7	High	Good

- - indicates value too low for accurate measurement.
M. = moderately.
V. = very.
DL/L = ratio of change in sample length to original sample length.

uniaxial compressive strength, and Atterberg limits of the rocks, wherever applicable, were used to classify their durability under the classification systems developed by Franklin and Chandra (1972), Deere and Gamble (1971), and Olivier (1979). None of the rock samples had significant calcareous cement, based on negative fizz test results.

Durability classification of the sampled rock is shown graphically in figures 1 through 3, using single and multiple index classification systems. The single index classification system developed by Franklin and Chandra (1972) uses only the slake durability index test data to assess durability. Slake durability of the rock is assessed by an index, I_D, defined as the percentage retention measured by dry weight after two cycles of testing (fig. 1). This test was adopted by OSMRE as the accepted standard, and thus has been widely used among the coal industry for the selection of durable rock. Figure 1 indicates that, for the rocks sampled in this study, the slake durability test lacks sufficient discrimination to reveal durability differences between sedimentary rocks as disparate as sandstone, shale, and mudstone. Furthermore, the overwhelming majority of sampled rocks are uniformly ranked as highly durable. Several authors have also reported similar problems in the use of the slake durability index as applied to geotechnical projects such as highway or tunnel construction (Duncan et al. 1968, Noble 1977, Olivier 1979, Richardson 1985). Published difficulties with the test include:

1. During testing, some of the more plastic shales may form mudballs, thus rendering falsely high I_D values (Richardson 1985).

2. The test does not differentiate very well between shales (Noble 1977).

3. The test is insensitive to shales which slake into small chips which are larger than the #10 sieve (2 mm) size of the openings in the hardware cloth forming the testing drums" (Duncan et al. 1968, Olivier 1979). This effect was duplicated in shale samples tested in the present study, where high I_Ds of over 90 were attained, yet the shale samples disintegrated into masses of small chips in the soak test (fig. 4). Breakdown of rock into such small soil-like particles in fills may lead to soil-like behavior under the large load factors developed in the fill mass, and fill failure may result.

Additional concerns specific to surface mining were raised by Welsh et al. (1985):

1. The test fails to subject rock samples to the types of physical stresses common to surface mining conditions (impact, heavy abrasion, saturation and desiccation, compaction, etc.).

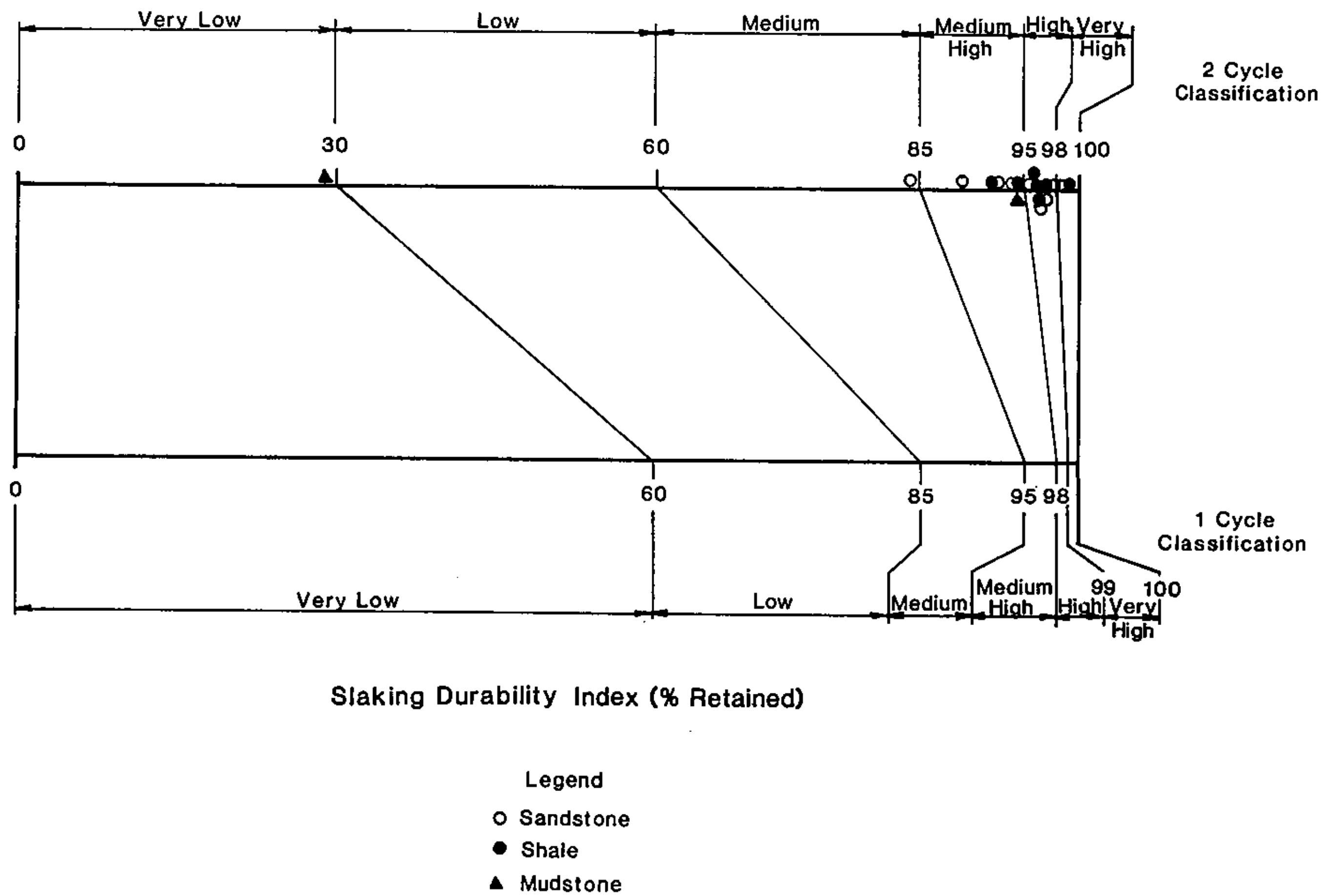


Figure 1.--Classification of Appalachian rock samples under the Slake Durability Index System of Franklin and Chandra (1972).

2. The index does not assess properties of rock samples indicative of rock-like or soil-like behavior.

3. Samples classified as durable in the laboratory exhibit soil-like behavior in the mining process.

Recognizing these problems in using the slake durability test exclusively as a single index measure of rock durability, other classification systems incorporating additional geotechnical tests were compared to the slake durability test standard. Dual-index graphical classification systems developed by Deere and Gamble (1971) and Olivier (1979) were utilized to provide a basis for correlation of durability measures.

The Deere and Gamble (1971) durability classification system is based on the two-cycle slaking durability and the plasticity index of sedimentary rocks. The data from the present study indicate a slightly better resolution between shale, mudstone, and sandstone durability as classified under the Deere and Gamble (1971) system, compared to slake durability testing alone (fig. 2). Sandstones, since they exhibit negligible plasticity, plot at the base of the chart; while shales and mudstones are distributed across the chart by their plasticity values. Gamble (1971) and Deere and Gamble (1971) found from laboratory testing that the plasticity of sedimentary rocks is inversely related to their slake durability. Therefore, higher plasticity values would decrease the rock durability. However, the Deere and Gamble (1971) system makes no attempt to adjust slake durability test rankings based on plasticity values. This classification system suffers from the same problems as the Franklin and Chandra (1972) test because it incorporates slake durability test data.

Olivier (1979) and Duncan (1969) recorded sedimentary rock behavior when it is removed from the in situ environment. Rocks swell and disintegrate as a result of stress relief. This swelling increases as rock absorbs moisture. Olivier (1979), also found that as swelling increases, the uniaxial compressive strength of the rock decreases. The resulting rock durability classification system involves the measurement of two rock properties. The first parameter is the magnitude of rock swelling after a dried sample is immersed in water. The second is the uniaxial compressive strength. Broad categories of "geodurability" ranging from very poor to excellent were assigned by Olivier (1979) based on ratios of compressive strength to swelling coefficient.

Classification of the rocks sampled in the present study using the Olivier (1979) system shows good discrimination between rock types and even between rocks of the same type (fig. 3).

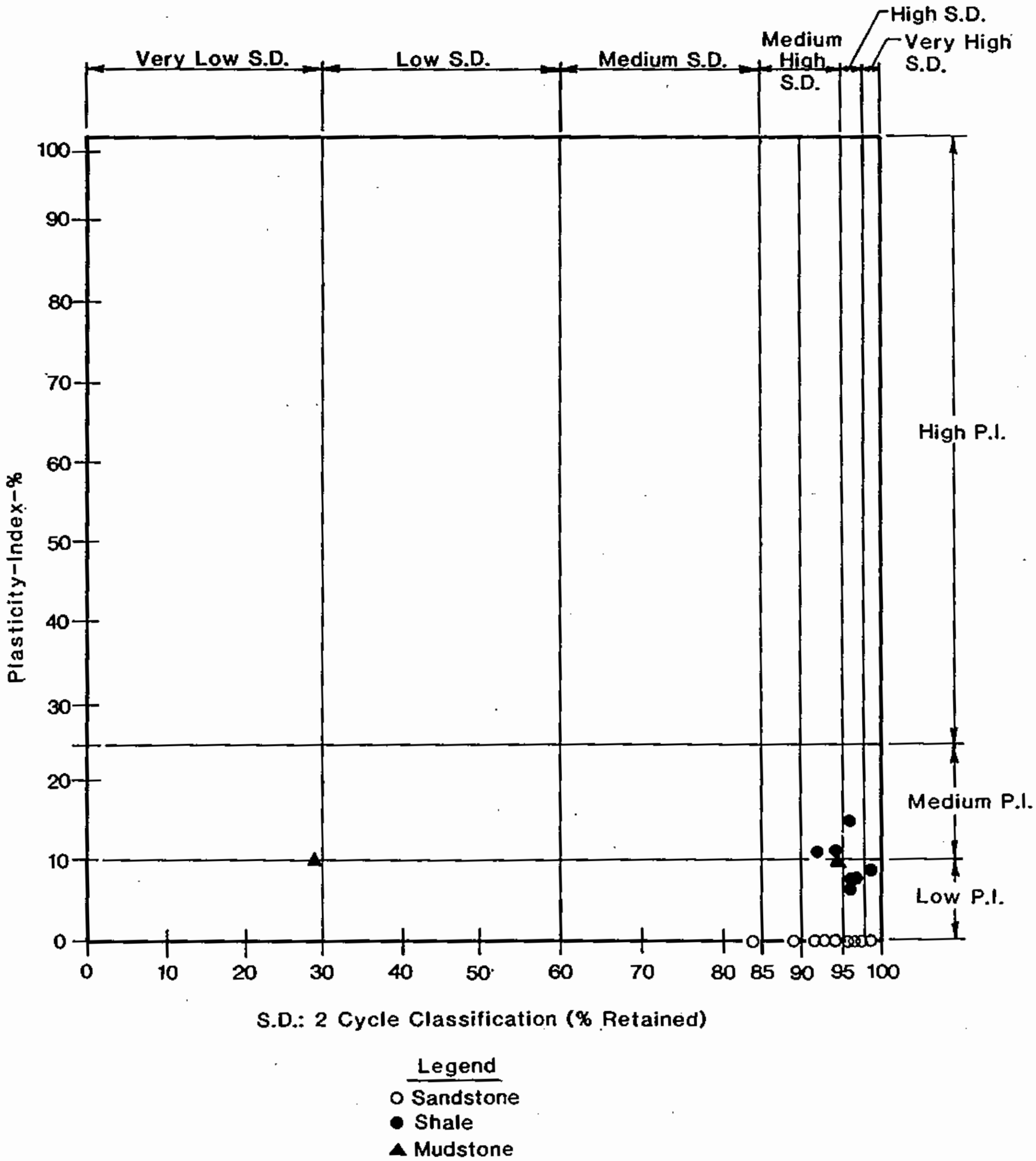


Figure 2.--Classification of Appalachian samples under the Deere and Gamble (1971) System.

Sandstones plotted in the good to excellent geodurability class, while shales ranged from fair to very poor. Mudstones ranked as very poor. The shales plotted into two subpopulations, grouped as moderately poor-fair, and very poor. Such results, if substantiated by further testing of a variety of rock, could be used to distinguish between tougher, more durable shales, and shales and mudstones which should be considered as nondurable.

Results from the soak tests support the Olivier geodurability assessments. Shales with slake durability indices of at least 90 (high durability) were rated as poor in geodurability, and disaggregated into fine, soil-like particles in the soak test (fig. 4). Therefore it appears that for the samples tested, the slake durability testing was not rigorous enough to accurately assess rock durability.

SUMMARY AND CONCLUSIONS

Comparison of the three classification systems indicates that all the systems correlated well in classifying the sampled sandstones as rocks with generally high durability. For shale and mudstone durability, however, the classification systems varied in usefulness. The Franklin and Chandra (1972) slake durability index and the Deere and Gamble (1971) classification system did not effectively distinguish between rock types of different durability. The reliance of these classification systems on the slake durability index test, which has inherent problems identified earlier, is the reason for this failure.

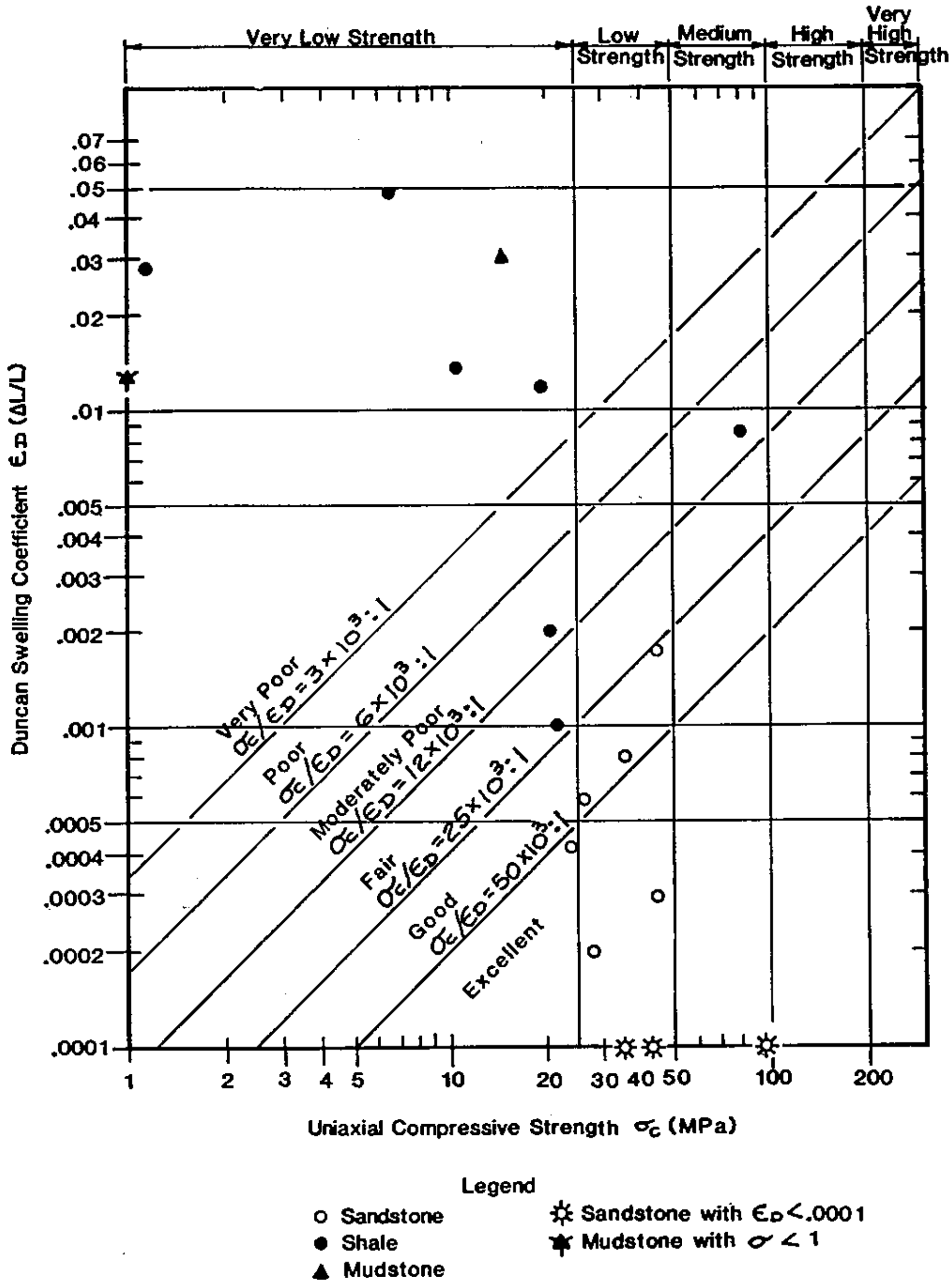
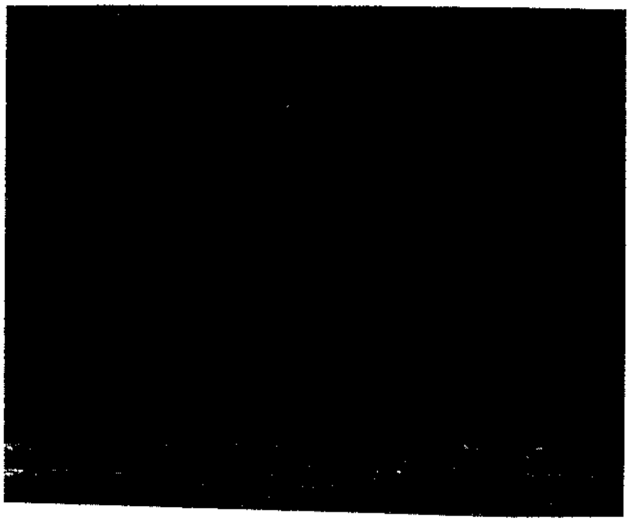


Figure 3.--Classification of Appalachian rock samples under the Olivier (1979) Geodurability System.

The Olivier (1979) classification system shows promise as a more accurate measure of rock durability, particularly for rock materials of marginal durability, such as shale. Correlation with soak test results indicates that the swell and compressive strength tests measure factors which are pertinent to the original concerns regarding rock durability in surface mining valley fills.

Further testing will be performed at COE laboratories to assess the reproducibility of results utilizing a testing protocol including swell, compressive strength, and soak tests on 84 additional rock samples from 43 minesites in Kentucky, Tennessee, Virginia, and West Virginia, and to compare these assessments with those from the slake durability index test. Point load testing results will be compared to uniaxial compressive strength testing, for possible interchangability of these rock strength tests. The geodurability rankings in the Olivier (1979) system will be modified to reflect experience gained through the testing of Appalachian rock material to better assess the durability of rock placed in excess spoil fills.



Sample K S-2 before Soak Test.

Sample K S-2 after 24-hour Soak.

Figure 4.--Qualitative soak test result for Appalachian shale sample.

LITERATURE CITED

Andrews, D. E., Withiam, J. L., Perry, E. F., and H. L. Crouse. 1980. Environmental effects of slaking of surface mine spoils: eastern and central United States. Bureau of Mines, U.S. Department of the Interior, Denver, CO. Final Report, 247 pp.

Bieniawski, Z. T. 1974. Geomechanics classification of rock masses and its application in tunneling. Proceedings of the 3rd International Congress on Rock Mechanics. Denver, CO. Vol II, pp. 27-32.

Casagrande, D.R. 1978. Presentation at Public Hearings. October 26, 1978. Submitted as written comments on the letterhead of Casagrande Consultants, October 27, 1978. 3 pp. with 4 page attachment.

Chandra, R. 1970. Slake durability tests for rocks. Master's Thesis, Imperial College, London University. London., 55 pp.

Deere, D. U., and J.C. Gamble. 1971. Durability-plasticity classification of shales and indurated clay. Proceedings of the 22nd Annual Highway Geological Symposium, Norman, OK. pp. 37-52.

Duncan, N. 1969. Engineering geology and Rock mechanics. 252 pp. Leonard Hill, London.

Duncan, N., Dunne, M.H., and S. Petty. 1968. Swelling characteristics of rocks. Water Power. May 1968:185-192.

Franklin, J. A. 1970. Observations and tests for engineering description and mapping of rocks. Proceedings of 2nd International Congress on Rock Mechanics, Belgrade, Vol. 1, pp 1-3.

Franklin, J. A., and R. Chandra. 1972. The slake durability test. Int. J. of Rock Mech. and Min. Sci. 9:325-341.
http://dx.doi.org/10.1016/0148-9062(72)90001-0

Gamble, J. C. 1971. Durability-plasticity classification of shales and other argillaceous rocks. Ph. D. Thesis, University of Illinois, 161 pp.

Noble, D.F. 1977. Accelerated weathering of tough shales, final report. Virginia Highway and Transportation Research Council. Charlottesville, VA. No. VHTRC 78-R20. 38 pp.

Olivier, H. J. 1979. A new engineering-geological rock durability classification. Engr. Geol. 14: pp. 255-279.
http://dx.doi.org/10.1016/0013-7952(79)90067-X

Richardson, D.N. 1985. Relative durability of shale - a suggested rating system. Proceedings of the 36th Annual Highway Geology Symposium. Clarksville, IN. pp. 105-138.

Robinson, M. K., and J.D. Ventura. 1983. Disposal of excess spoil: durable rock fills. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, pp. 179-187.

United States Code of Federal Regulations. 1987. Title 30, Mineral Resources, Chapter VII, Enforcement, Department of the Interior. Section 817.71, pp. 277-278.

Welsh, R.A., Robinson, M.K., and L.E. Vallejo. 1986. Evaluation of durability testing techniques for rock underdrain material used in Appalachian surface coal mining valley fills. Proceedings of the International Symposium on Flow-Through Rock Drains. Cranbrook, BC. pp. 83-93.