Research Report
555

THE NEED FOR A SCHEMA FOR THE CLASSIFICATION OF TRANSITIONAL (SHALE) MATERIALS

by

R. C. Deen
Assistant Director

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

offered for publication to the
GEOTECHNICAL TESTING JOURNAL
American Society for Testing and Materials

October 1980

INTRODUCTION

The need for comprehensive information on the characteristics and behavior of earth materials has been recognized for many years, perhaps for as long as significant construction has taken place in and on the surface of the earth. In recent years, however, the magnitude and complexity of engineered construction has greatly increased, resulting in a corresponding increase in the need for information on the engineering properties of soil and rock materials for use in site selection, design, construction, and maintenance of major structures. Probably the most pressing need for such data is for use in preliminary considerations of site selection and design alternatives. Maps and(or) surveys giving the areal distribution of earth materials and their characteristics, together with topographic maps available for many areas, permit much preliminary work on engineered structures to be performed without the engineer ever having to leave his office.

Direct testing of soil and rock can be utilized to furnish necessary information. However, both field and laboratory testing can be extremely expensive, particularly where testing must include applications of stress to large masses of earth material. For this reason, significant technical and economic advantages can be realized through the development of indirect or "short-cut" methods for obtaining indications of the properties and characteristics of geologic materials.

Many agencies have devoted much effort to providing engineering data to supplement information provided by pedological classifications and mapping *(1)*. The correlation of performance data with information on areal distribution and location furnished by geologic and pedologic works has proven extremely valuable in the planning and construction of facilities in and on soil.

In recent years, the size and importance of structures and facilities designed by engineers and architects has greatly increased, resulting in an increased interest in the rock materials underlying surficial soil layers. A clear need has arisen for a program to provide an engineering evaluation of rock materials for the purposes of location, design, construction, and maintenance of engineered facilities.

A variety of rock classification systems utilizing many different index tests have been developed. Table 1 summarizes attributes used in classification systems for use with intact rock samples. Some of those systems are based upon inherent rock characteristics while others are based upon a particular purpose or use of the rock; some are based upon a combination of inherent characteristics and intended uses. A review of existing classification systems indicated that four basic measures -- strength, lithology, anisotropy, and durability

Table 1. Typical Attributes of Intact Rock Sample Classification Systems

Anisotropy
Lithology
Slake Durability
Tensile Strength
Compressive Strength
Density
Drillability
Dry Specific Gravity
Failure Characteristics
Hardness
Hysteresis
Moisture Content
Petrofabrics
Porosity
Seismic Velocity
Shear
Swelling
Tangent Modulus
Texture
Toughness
Unit Weight
Weatherability

-- can be used to characterize the properties of an intact sample.

Testing and classification of intact samples may be sufficient for preliminary planning and location studies, but the design of engineered facilities requires more comprehensive and direct evaluation and testing of in situ rock conditions. To satisfy this need, some sort of in situ classification system is required. Many classification systems involving attributes summarized in Table 2 have been developed. There are relatively few generally applicable in situ classification systems, which, for the most part, have been evaluation schemes used at particular sites for specific purposes (e.g., for tunneling or blasting requirements). It appears the greatest success has been attained by combining the results of tests on intact samples with an analysis of field conditions which tend to govern the behavior of rock materials.

Table 2. Typical Attributes of In Situ Rock Classification Systems

- Rock Quality
  - Bedding Character
  - Joint Frequency
  - Weatherability or Alteration
- Lithology
- Deformation Characteristics
- Velocity Ratio
- Engineering Performance
  - Slope Stability
  - Powder Factor
- Intact Sample Tests
  - Uniaxial Compression
  - Sonic
  - Saturated Sonic
  - Static Modulus
  - Point Loading
  - Slake
- In Situ Tests
  - Seismic
  - Plate Jacking
  - Permeability

TRANSITIONAL MATERIALS

There are many earth materials not readily classified as either soil or rock. These materials, herein designated transitional materials, are composed primarily of clay- and silt-sized particles. On the basis of observer bias, particle-size distribution, mineralogy, and type and degree of bonding between grains, these materials have been assigned several names -- clay shale, shale, siltstone, mudstone, claystone, and marl are but a few.

The study of these transitional materials is of two-fold importance. First, argillaceous (clayey) materials comprise 50 to 75 percent of the sedimentary rock in the earth's crust *(2)*. Because of the prevalence and widespread geographical distribution of these materials, a wide range of properties and characteristics and resulting engineering behavior is expected. A spectrum of compositions has been observed in the primary constituent materials as well as secondary materials such as cementing agents. These transitional materials have also been developed in a variety of depositional environments as well as being subjected to varying stress and tectonic histories. Second, a high percentage of geotechnical engineering problems (slope stability, settlement, bearing capacity failure, etc.) occur in transitional argillaceous materials.

Transitional materials, in general, have low durability, low shear strength, and high swelling or rebound potential *(3)*. The presence of montmorillonites and other expandable clay minerals tend to increase the plasticity characteristics of the material. These wide ranges of mechanical properties make sampling very difficult. Furthermore, the preparation of the specimen may drastically alter the sample. The apparent particle size of cemented material may be a function of the mechanical energy input in testing the specimen *(4, 5)*, chemical treatment of specimens to remove cementing agents may also alter any clay minerals present *(3)*. In addition, spalling of shale, loosening on bedding planes (caused by large temperature fluctuations), and freeze-thaw cycles make critical examination of this material a vital aspect *(6, 7)*.

Several individuals and organizations have expended considerable effort to organize existing data and to test and classify materials which fall in the transitional category. Underwood *(8, 9)*; Fleming, Spencer, and Banks *(10)*; and Gamble *(3)* present excellent comprehensive reviews of previous work.

Early attempts to classify transitional materials were based on geologic considerations. Parameters such as particle size, mineralogy, type and degree of bonding, and breaking characteristics were used in various combinations to categorize the materials.

An early system proposed by Wentworth *(11)* was based on particle size and provided an arbitrary division (1/16 mm) between the argillaceous materials (shale or mudstone) and the remaining clastic (fragmental) sedimentary rocks. Transitional materials were further subdivided by Twenhofel *(12, 8)*. Twenhofel's classification left unresolved the distinction between those transitional materials which behave primarily as soils and those which exhibit rock-like characteristics. Mead *(13)* proposed a classification which differentiated compacted ("soil-like") materials consolidated by the weight of overlying sediments from cemented ("rock-like") materials on the basis of slake resistance (deterioration during wet-dry cycles)*(8)*. That system takes into account bonding in addition to particle size. Other systems were based on type and degree of bonding -- cemented (rock-like) versus compacted (soil-like) *(8, 13, 14)*. Other classification systems founded on slaking behavior have been proposed by Gamble *(3)* and Morgenstern and Eigenbrod *(15)*.

Recognizing the importance of rock solubility in engineering works, Philbrick *(14)* divided sedimentary rocks into soluble and insoluble categories and combined these with a classification of argillaceous members similar to those of Twenhofel and Mead. Philbrick was somewhat more positive in his approach to the separation of compacted and cemented shales. He proposed a simple test in which the sample was subjected to five cycles of wetting and drying with a 100 N solution of ammonium oxalate or water. Those samples which reduced to individual grains were considered compacted; those unaffected or reduced only to flakes were considered cemented.

Attempts have been made to classify materials solely on chemical or mineralogical composition. Chemical composition alone is insufficient because the transitional materials are very similar in chemical content. Useful information can be obtained, however, from a knowledge of clay minerals present *(8, 16, 17)*. In general, a high percentage of degraded illite or mixed-layer montmorillonite is associated with materials of high swell potential and low shear strength. Conversely, low percentages of the above-mentioned clay minerals or high percentages of kaolinite or chlorite indicate material of greater reliability *(8)*. Factors such as high test cost, time expenditure, and lack of standardized procedures have discouraged the use of mineralogical studies for classification.

Ingram *(18)* suggested breaking characteristics (fissility) useful for classification and identification purposes:

a) three dominant types of breaking characteristics in shales:
   1) massive -- no preferred cleaving direction,
   2) flaggy -- breaks into fragments of varying thicknesses but with the width and length many times greater than the thickness, and

    3) flaky -- splits along irregular surfaces parallel to the bedding into uneven flakes;

b) fissility is associated with a parallel orientation of clay particles;

c) existence of organic matter in the rock tends to increase the tendency toward parallel orientation of clay particles;

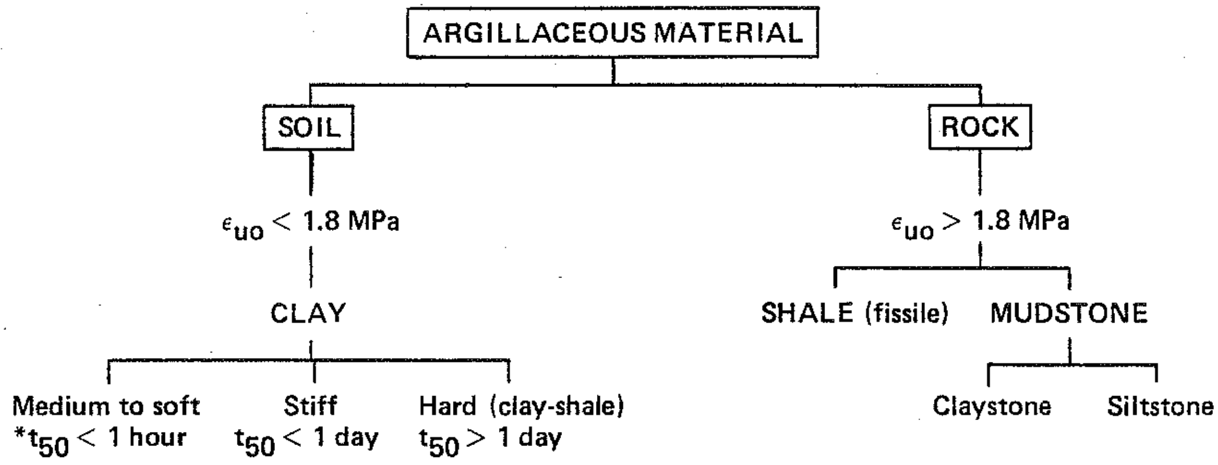
d) most cementing agents cause a decrease in fissility; and

e) moderate weathering increases the fissility of a shale while intense weathering produces a soft, massive clay.

Fissility alone is not of much value in classification since materials in the same stratum exhibit this phenomena to differing degrees.

These classifications provide a geologically oriented evaluation of argillaceous materials; but knowledge of engineering behavior is needed to properly design roads, rock cuts, slope embankments, and tunnels. In the late 1960's, there was a trend to investigate the engineering behavior of transitional materials and to predict the behavior of such materials in their natural environment. Underwood's shale evaluation scheme *(8)* is a predecessor of the "use table". At Philbrick's suggestion *(19)*, Underwood *(9)* divided the evalution scheme with respect to compacted and cemented specimens and supplemented each distinction with additional parametric criteria. For example, compacted material, regarded as soil, was described further by the Atterberg limits. This may be appropriate since the behavior of transitional materials seems to vary with particle size and mineralogy; that is, transitional materials are predominantely composed of fine-grained members with large percentages of clay and silt, and the members are highly overconsolidated *(3)*.

An argillaceous classification system proposed by Elliot and Strauss *(20)* was based on color, quartz content, and a simple self-polishing field test. The sytem was used to classify gray-colored mudstones, siltstones, and sandstones. Unfortunately, this system has not proven useful for other materials. Morgenstern and Eigenbrod *(15)* proposed an engineering classification of argillaceous materials based on results of strength softening tests performed on sandstones, shales, hard clays, and mudstones. Test results indicated the major differentiation between clays and mudstones can be made on the basis of an undrained shear strength of 1.8 MPa (see Figure 1). Those authors also proposed a classification in terms of slaking characteristics.



$^{*}t_{50}$ is the time of softening for a loss of 50 percent of the original strength

Figure 1. An Engineering Classification of Argillaceous Materials Based on Undrained Shear Strength *(16)*.

ENGINEERING CLASSIFICATIONS

It is apparent the foregoing geologically-oriented classifications, while offering qualitative information, are somewhat ambiguous and do not provide quantitative information required for engineering purposes. Recently, investigators have attempted to establish standardized terminology and proposed classifications based on engineering or mechanical properties of transitional materials. Underwood *(8)* delineated several significant engineering properties and probable ranges of values for in situ behavior of shales. He concluded that test results available at the time of his writing were not sufficiently replicable for detailed evaluation. He therefore did not describe test procedures to be used to obtain property values but presented values in broad ranges which could be narrowed as more consistent test results became available.

In a discussion of Underwood's paper, Philbrick *(19)* pointed out that the system was aimed at compacted ("soil-like") materials while neglecting cemented ("rock-like") groups. Philbrick suggested the need for a distinction between the two kinds of material, perhaps based on particle size. Underwood *(9)* concurred and suggested separate tables for the compacted and cemented types might be used to advantage. He suggested the addition of Atterberg limits to the compacted material table and a measure of observed slope angles with relation to slope height for the cemented materials. Underwood also pointed out the importance of in situ mositure content as a significant indicator of the probable engineering behavior of shale.

The term "clay shale" has been used to describe compacted transitional materials. Bjerrum *(21)* referred to "overconsolidated clays and clay shales" in his investigation of progressive slope failure. Fleming, Spencer, and Banks *(10)* also used "clay shale" in reference to compacted materials. They applied the terms "claystone" and "siltstone" to cemented materials composed primarily of clay-sized and silt-sized particles.

Results of a study on the behavior of transitional material at five locations in the upper Missouri Basin *(10, 22)* lead to the following conclusions:

a) the principal features determining the engineering behavior of clay shales are the degree of overconsolidation and the lithology, both reflections of geologic history;

b) overconsolidation is related to undesirable engineering behavior such as swelling, high lateral residual stresses, and fissure development;

c) important features of lithology are mineral compositon (especially clay minerals), mechanical composition (particularly the clay-size fraction), presence or absence of any cementing agent, and degree of homogeneity; and

d) other important factors include local geological structure (the presence of relatively stronger or weaker strata may favorably or unfavorably affect the mass), water conditions (materials stable at low moisture contents may be unstable when saturated), and time (progressive failure may occur as a result of bond deterioration).

Design was based on empirical evidence (local site geologic and hydrologic conditions and examination of nearby natural slopes in similar materials). A similar study of slopes in transitional material along the Panama Canal *(23)* reached the same conclusions. Testing used in these studies is applicable primarily to the compacted category of transitional materials. No distinction was made between "soil-like" or "rock-like" materials. It would be convenient, however, when working with index tests and classification systems for rock to establish a limit of sorts, admittedly arbitrary, below which transitional materials would be subjected to index tests applicable to soils and above which such testing would not be required. The limit should be more definitive than those of Mead or Philbrick.

After a thorough review of past experience dealing with transitional materials, Gamble *(3)* contributed the following:

a) To standardize the prevailing geologic terminology, he proposed a geological classification for argillaceous materials (Table 3).

b) The major engineering problems associated with transitional materials are:

   1) low durability -- rapid weathering or slaking in open excavation, differential weathering of slopes and cuts, and slaking or slabbing in tunnels and other underground excavations.

   2) swell, rebound, or stress relief -- common in montmorillonitic shales; caused by relief of overburden pressure, clay mineral hydration, or oxidation reactions of iron sulfides with accompanying volume increase.

   3) low shear strength -- problem in slope stability and foundations; discontinuities are often responsible for low strength zones.

   An informative chart relating variables that affect behavior was also presented by Gamble *(3)* and is reproduced herein as Figure 2.

c) Using apparatus developed by Franklin *(17)*, Gamble tested numerous samples and proposed a classification based on a two-cycle slake-durability test.

d) From correlations of durability index with other characteristics (water content, liquid limit, dry density, plasticity index, and activity ratio), Gamble concluded

Table 3. **Suggested "Geological" Classification of Argillaceous Materials** *(3)*

Unindurated Group	Indurated Group		After Incipient Metamorphism	Metamorphic Equivalents
	Mudrocks (Shales or Mudstones)			
	Breaking Characteristics			
	Massive	Fissile or Shaly		
Silt →	Siltstone	Silty Shale		
Mud[a] →	Mudstone	Shale	→ Argillite →	Slate, Phyllite, or Schist
Clay →	Claystone	Clayey Shale		

[a] Mixture of undetermined amounts of silt and clay with minor amount of sand

Definition of terms:

Indurated -- Rock hardened by pressure, cementation, or heat; includes both compacted and cemented hardened materials.

Massive -- Non-fissile or non-shaly material, breaks in apparently random directions in blocky or irregular shapes.

Fissile -- splits or breaks into flakes, chips, or thin flat pieces approximately parallel to bedding.

Siltstone -- Massive, indurated rock composed predominantly of silt. Often contains small amounts of fine sand, is grittier and usually harder than adjacent claystones or mudstones.

Claystone -- Massive, indurated rock composed predominantly of clay. Smooth to touch.

Mudstone -- Massive, indurated mixture of undetermined amounts of silt and clay, with possible minor amounts of sand.

Silty Shale -- Fissile, shaly, or laminated indurated rock composed predominantly of silt.

Clayey Shale -- Fissile, shaly, or laminated indurated rock composed predominantly of clay.

Shale -- Fissile, shaly, or laminated indurated mixture of undetermined amounts of silt and clay with possible minor amounts of sand.

> that a chart (Figure 3) showing the relationship between plasticity index and slake-durability index provided the best correlation to use as a basis for classification. Rock samples which have low slake-durability values should be subjected to soils classification tests (Atterberg limits or sedimentation-size analysis).

It appears that transitional materials which fall into the low plasticity range and high or very high strength ranges could be safely designated as rock-like (cemented) material and not subjected to soil-type tests. This would provide the distinction necessary to assign a sample to the appropriate testing program.

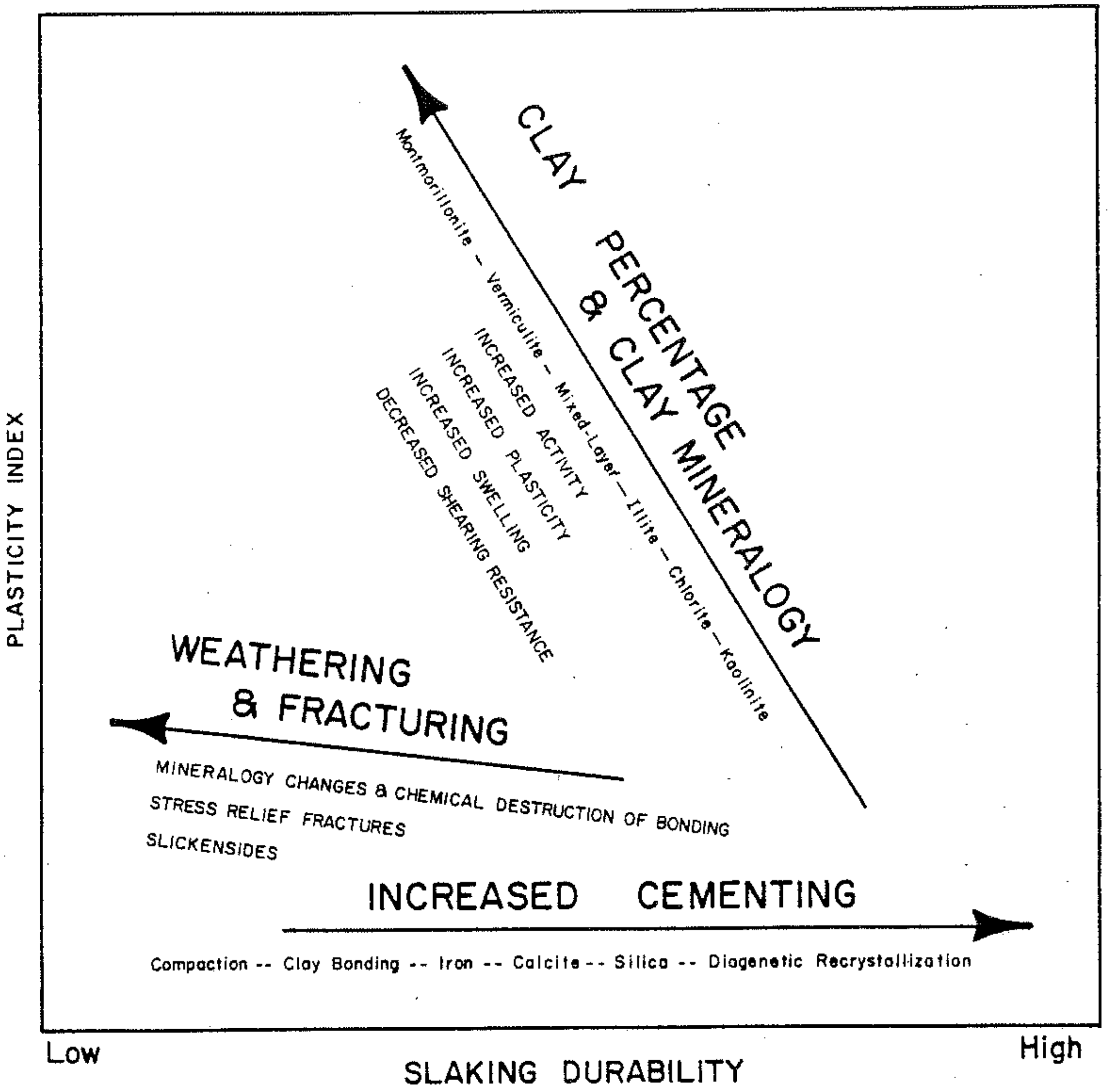


Figure 2. Relationships of Factors Affecting the Engineering Classification of Transitional Materials *(3)*.

An extensive review of classification systems of transitional materials *(24, 25)* evaluated quantitative indices such as natural water content, dry unit weight, minus 2 micron fraction, the Atterberg limits, swell potential, and predominant clay minerals. Among qualitative indices reviewed were color, dry strength, reaction to hydrochloric acid, and slaking behavior. Procedures for preparing transitional materials influence values obtained for some of the quantitative classification indices. The identification of transitional materials as rock-like or soil-like which depend upon plasticity criteria are particularly susceptible in that values of the liquid limit and the portion of minus 2 micron material vary

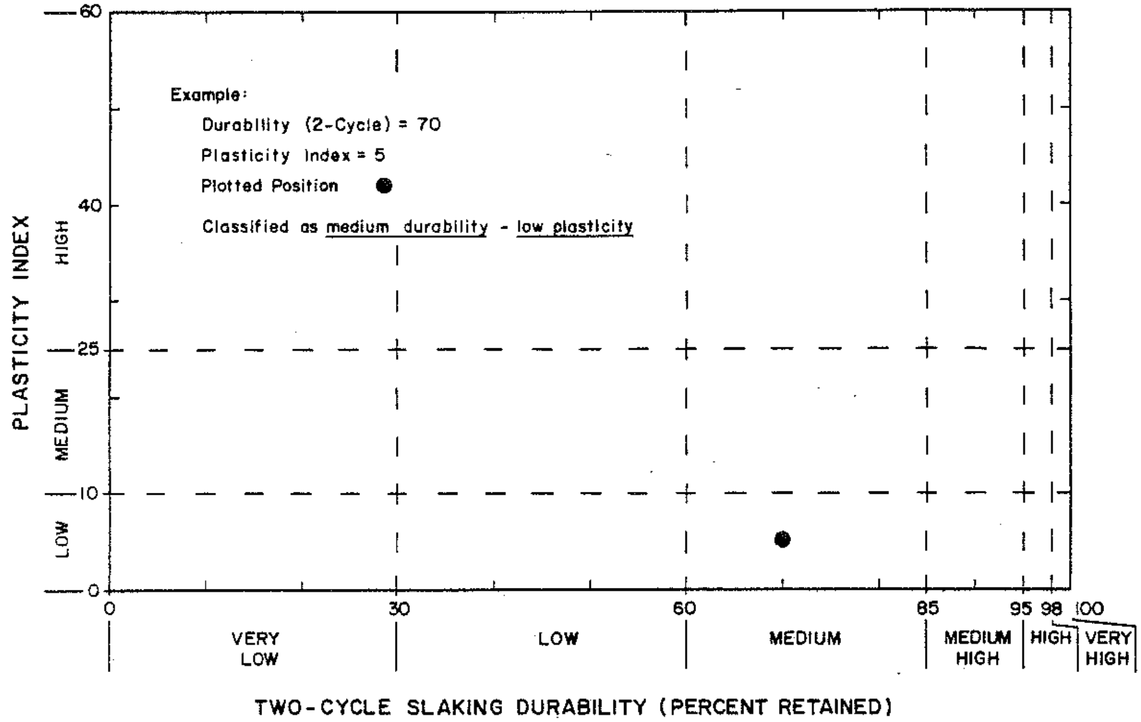


Figure 3. Relationship of Plasticity and Slaking Durability as a Basis for Classification of Argillaceous Materials *(3)*.

with sample preparation techniques. Further study of shale as an embankment construction material *(26, 27, 28)* is summarized in Figure 4.

Using a group of relatively hard to soft Indiana shales, Deo *(29)* proposed a classification scheme for transitional materials for use in embankment construction (Figure 5). His scheme was the result of an extensive laboratory testing program and was based primarily upon the slake-durability test. Chapman *(30)*, also using Indiana shales, performed appropriate tests and classified the shales according to a number of suggested schema which have been presented in the literature. He noted that the slake-durability test (Franklin's method) and simple slaking procedures were useful in classification.

It is apparent from the literature that transitional materials exhibit a wide range of engineering behavior. Further, the many schema suggested for classifying these materials for various purposes are also evidence of the wide variability of such materials. These materials are intermediate in behavior between soil and rock. Therefore, tests which are suitable to classify soils are not adequate for these transitional materials; neither are those tests normally used to classify the more competent rock satisfactory. Because of the variability of these transitional materials and the prevalence of such materials around the world,

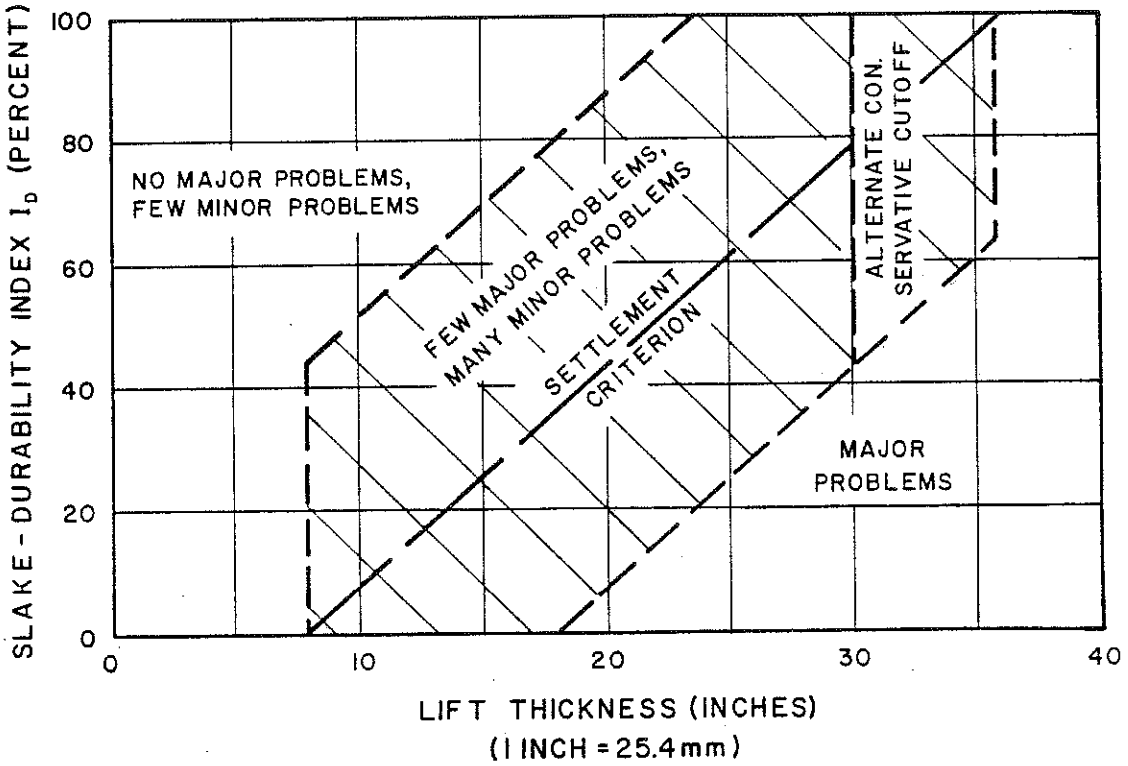


Figure 4. Criteria for Evaluating Embankment Construction on the Basis of the Slaking Behavior of Transitional Materials *(28)*.

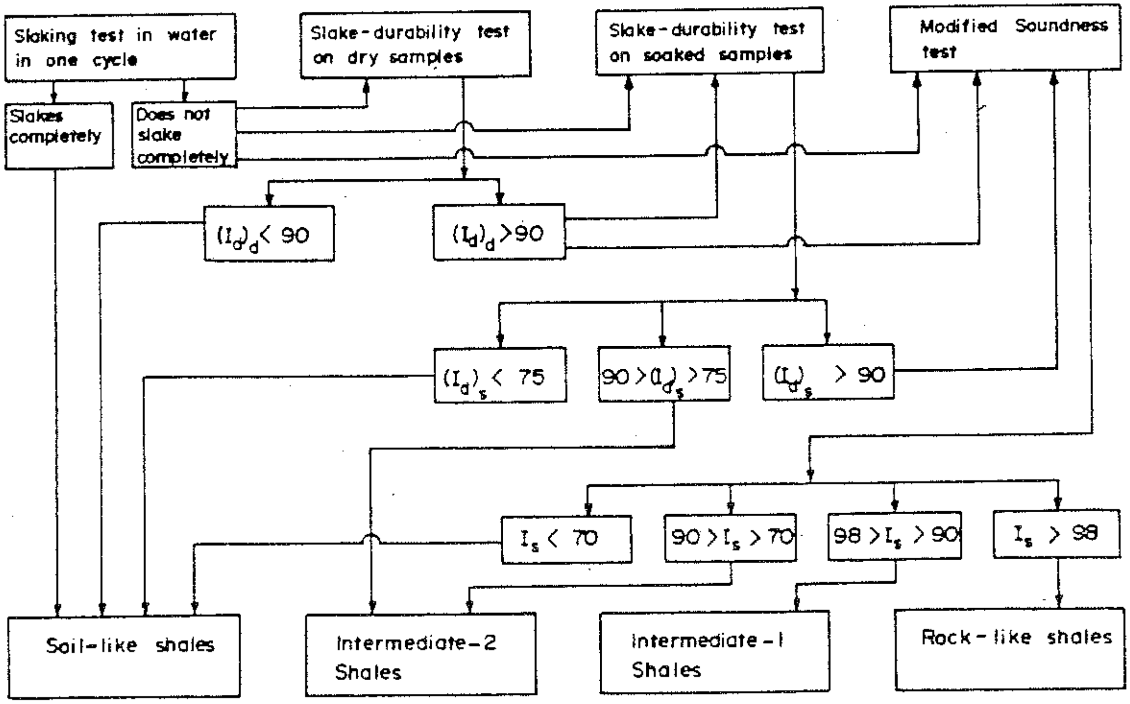


Figure 5. Suggested Classification of Transitional Materials for Embankment Construction *(29)*.

there is an urgent need for a widely acceptable scheme of classifying the materials for engineering design and construction purposes. Such a classification system should be concise and be based upon expected construction and long-term behavior under a wide range of environmental conditions. When the engineer is able to assess the general performance of transitional materials, based upon relatively simple and straightforward testing and classifying procedures, more intelligent decisions can be made in the design and construction of facilities involving those transitional materials.

A SUGGESTED EVALUATION SCHEMA

Suggested field and laboratory attributes of a proposed data bank for transitional materials *(31, 32)* is a preliminary prototype of a descriptive system to file results of tests on such materials (see Table 4). Upon further investigation, the specific tests indicated for input into this data bank may be modified. The data bank would consist of a system of computer files arranged according to three general categories -- identification of sample site, results of tests on or observations of intact and in situ samples and conditions, and case history information. Case history information for inclusion in the data storage system generally cannot be easily quantified. However, a concise version of empirical information can be placed in a coded reference file. The code and the identification of the site or geological formation investigated can be entered in the data bank so that, when a search is made, the existence of this information is indicated. A further search for the detailed information on previous experience at a given site or in a particular formation can then be made.

A storage and retrieval system for compacted shale data was demonstrated by van Zyl, Wood, and Lovell *(33)*. Attributes to describe to characteristics of the shales were suggested. Statistical analyses of data stored in the system were used to indicate typical ranges and expected values of the attributes and parameters. Correlations among various attributes can provide models for predicting parameters difficult to measure from more easily obtained characteristics.

Computer programming would be used to facilitate storage, retrieval, and use of acquired information. Use of the information stored in the data bank would be accomplished through the development of specific classification and application programs. However, a generalized classification can be obtained using the systems suggested by various investigators. For specific purposes such as the analysis of rock formations for suitability in tunneling operations, a more detailed classification system could be developed. In addition to the use of acquired information in the classification of rock materials, a further use of this information can be achieved through the development of a series of use tables. Such a table is shown in Figure 6. Use tables can be developed for particular applications. For example, Franklin developed a diagram showing "ease of excavation" of rock by blasting, ripping, and digging which was essentially a use table. The diagram was based on ranges of point-load index and fracture frequency. Use tables represent quantitative criteria developed from behavioral models of rock masses.

Use tables and the classification system can be combined in the application segment of

Table 4. SUGGESTED ATTRIBUTES OF A DATA BANK FOR TRANSITIONAL MATERIALS

CATEGORY 1

- Location
  - State
  - County
  - Physiographic Region
  - USGS Quadrangle Number
  - Longitude
  - Latitude
- Sample Identification Number
- Major Geological Formation
- Generic Rock Type
- Ground Elevation
- Sample Elevation
- Water Table Elevation
- Sample Orientation w/Ground Surface
- Sample Orientation w/Bedding Plane
- Method of Obtaining Sample
- Relevant Comments

CATEGORY 2

- Intact
  - Petrographics
    - Color
    - Texture
    - Structure
    - Grain Size
    - Scratch Hardness
    - Active Clay Agents
    - Slickensides
    - Consistency
    - HCl Reaction
- Indexing
  - Free Swell
  - Slake Tests
  - Rate of Slaking
  - Point-Load Index
  - Anisotrophy Index
  - Compression Softening Test
  - Mineralogy
  - Breaking Characteristics
  - Liquid Limit
  - Plasticity Index
  - Hydrometer Analysis
  - Sedimentation Analysis
  - Activity Ratio
  - Void Ratio
  - Cementing Material
  - Inclusions
  - Quartz/Feldspar Ratio
  - Feldspar Freshness
- Physio-Mechanical Characteristics
  - Laboratory Sonic Velocity
  - Shore Scleroscope
  - Uniaxial Compression
  - Tangent Modulus at $\sigma_{ult(50)}$
  - Natural Moisture Content
  - Saturation Moisture Content
  - Dry Apparent Specific Gravity
  - Bulk Specific Gravity
  - Saturated Surface Dry Bulk Specific Gravity
  - Void Index
  - Apparent Porosity
  - Water Absorption
  - Finess Modulus
  - Consolidation Test Results
  - Freeze-Thaw Test
  - Sodium Sulfate Soundness
  - Repeated Direct Shear Test
  - Direct Shear Test
  - Triaxial Compression Test
  - Los Angeles Abrasion
  - Deval Abrasion
- In Situ
  - Mass Indexing
    - Rock Quality
      - Bedding Thickness
      - Descriptive Stratification
      - Descriptive Interface
      - Joint Spacing
      - Joint Frequency
      - Joint Infiltration Material
    - Gross Heterogeneity
    - Velocity
- Orientation
- Joint Survey
- Secondary Indexing
  - Core Recovery
  - RQD
  - Fracture Frequency
  - Weighted Length
- Direct Shear Strength

CATEGORY 3

- Previous Experience
- Construction Practices
- Performance Monitoring

CLASSIFICATION ELEMENT	RANGE OF ACCEPTABLE VALUES					
	AGGREGATE	ROCKFILL	ROADWAY SURFACE	STABLE SLOPES	OTHER USES	
Point-Load Index						
Lithology						
Strength Anisotropy Index						
Slake-Durability Index						

Figure 6. Typical Format of a Use Table.

a rock evaluation program as shown in Figure 7. This figure represents the combination of the acquistion segment and the application segment into a total rock evaluation schema. A user can request information from the data bank through a selected classification system and use table. The information retrieved from the data bank can be processed in the classification system and a particular site or a particular rock unit can be evaluated for specific uses. The user must then evaluate the data obtained from the data bank. In general, the user decides whether or not sufficient data have been obtained for the evaluation of a particular site as the location of a proposed facility. If sufficient data have been obtained, these data will allow the engineer to decide whether or not the particular site under investigation is suitable for the proposed activity. If the site is not suitable, it can be abandoned. If the site is suitable, the user can then indicate what design and construction operations are appropriate. If the user decides insufficient data are available on the characteristics of the rock units at a particular site or under a particular stress environment, he may then specify the performance of additional tests to furnish required information. On the basis of these additional tests, the user may decide that the site is unsuitable for the planned activity or he may elect to proceed with design and construction. During construction phases, performance of the rock units at a particular site should be monitored and evaluated. This information can then be returned to the data bank as case history information. After construction is completed, performance of the engineered facility and the rock units adjacent to that facility should be monitored. This performance monitoring also furnishes data which will be valuable in the location, design, and construction of other facilities. Ideally, such a rock evaluation program will be a self-sustaining, ever-expanding source of valuable information concerning the engineering properties and behavior of rock materials.

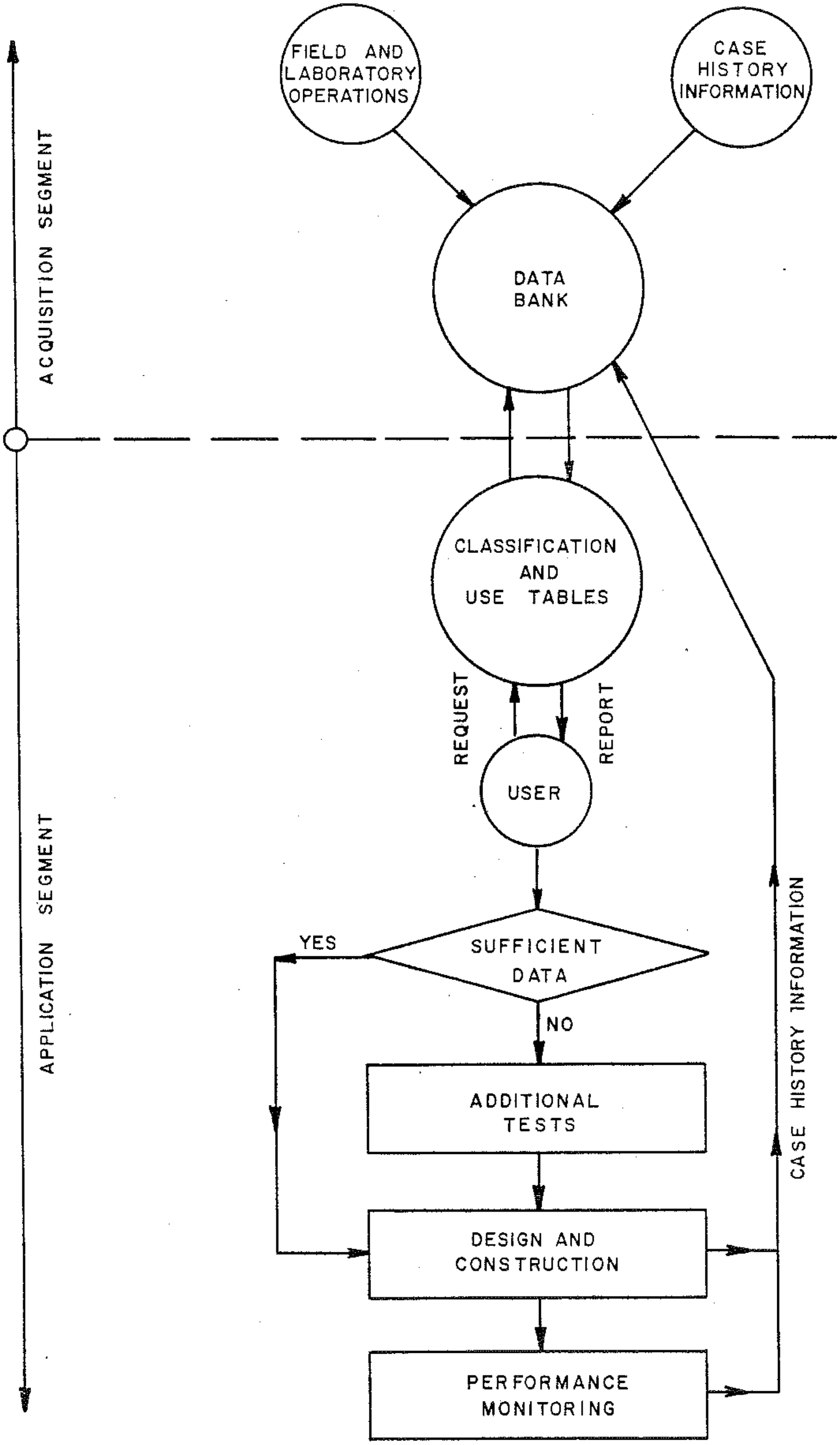


Figure 7. Schematic Diagram of a Suggested Evaluation Schema for Rock.

SUMMARY

Rock engineering includes a number of very significant major operations: engineering analysis and interpretaton of geological information, prediction or determination of engineering properties of rock masses for use in analysis and design, and implementation of completed designs through construction activities in or on rock. Individuals from various disciplines are involved in these facets of rock engineering. To facilitate communication, a rock classification scheme and evaluation program is suggested.

Such a program would be especially useful for the planning, design, and construction of facilities in and on rock. Data on engineering characteristics of rock units can be utilized in a general classification program. The classification program includes characterization of rock units on the basis of tests on intact samples and on the basis of evaluation of in situ rock characteristics and properties. The general classifications can be modified for particular types of projects and use tables can be developed for the evaluation of rock units for use in specific purposes. A computerized system for the storage and retrieval of information is indicated. Data for inclusion in the information bank would be derived from laboratory and field testing as well as monitoring of rock behavior during construction and subsequent operations of completed facilities.

REFERENCES

1. Deen, R. C. (1959), *An Engineering Soil Survey of Fayette County, Kentucky,* **Bulletin No. 213,** Highway Research Board, Washington, D. C., pp 12-27.
2. Leet, L. D., and Judson, S. (1971), **Physical Geology,** fourth edition, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
3. Gamble, J. C. (1971), *Durability-Plasticity Classification of Shales and Other Argillaceous Rocks,* Ph. D. Thesis in Geology, University of Illinois, Urbana, Illinois.
4. Gipson, M., Jr. (1963), *Ultrasonic Disaggregation of Shale,* **Journal of Sedimentary Petrology,** Vol 33, Society of Economic Paleontologists and Mineralogist, Tulsa, Oklahoma, pp 955-958.
5. Savage, E. L. (1969), *Ultrasonic Disaggregation of Sandstones and Siltstones,* **Journal of Sedimentary Petrology,** Vol 39, Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma, pp 375-378.
6. Jumikis, A. R. (1966), *Some Engineering Aspects of Brunswick Shale,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 2, No. 1, pp 99-102.
7. Loubster, M. M. (1967), *Shale in Road Foundations,* **Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering,** Cape Town, South Africa, December, Vol 1, pp 129-134.
8. Underwood, L. B. (1967), *Classification and Identification of Shales,* **Journal of Soil Mechanics and Foundations Division,** American Society of Civil Engineers, Vol 93, No. SM 6, New York, pp 97-116.
9. Underwood, L. B. (1969), *Closure - Discussion. Classification and Identification of Shales,* **Journal of Soil Mechanics and Foundations Division**, American Society of Civil Engineers, Vol 95, No. SM 5, New York, pp 1259-1260.
10. Fleming, R. W., Spencer, G. S., and Banks, D. C. (1970), *Empirical Study of Behavior of Clay Shale Slopes,* **NCG Technical Report No. 15,** Vol 1, US Army Engineer Nuclear Cratering Group, Livermore, California.
11. Wentworth, C. K. (1922), **Geology,** by W. C. Putnam, Oxford University Press Inc., New York.
12. Twenhofel, W. H. (1937), *Report of the Committee on Sedimentation,* National Research Council, Washington, D. C.
13. Mead, W. J. (1938), *Engineering Geology of Damsites,* **Transactions of the Second**

International Congress on Large Dams, Vol 4, US Government Printing Office, Washington, D.C., p 183.

14. Philbrick. S. S. (1950), *Foundation Problems of Sedimentary Rocks,* Chapter 8 from P. D. Trask's **Applied Sedimentation,** John Wiley and Sons, Somerset, New Jersey.
15. Morgenstern, N. R., and Eigenbrod, K. D. (1974), *Classification of Argillaceous Soils and Rocks,* **Journal of the Geotechnical Engineering Division,** American Society of Civil Engineers, Vol 100, No. GT 10, New York, pp 1137-1156.
16. Franklin, J. A., and Chandra, R. (1971), *The Slake-Durability Test,* **International Journal of Rock Mechanics and Mining Science,** Pergamon Press, 1972, Vol 9, London, pp 325-341.
17. Franklin, J. A. (1970), *Observations and Tests for Engineering Description and Mapping of Rocks,* **Proceedings of the Second Congress of the International Society of Rock Mechanics,** Belgrade, Vol 1, Theme 1, No. 3, pp 11-16.
18. Ingram, R. L. (1953), *Fissility of Mudrocks,* **Bulletin of the Geological Society of America,** Vol 64, Boulder, Colorado, pp 869-878.
19. Philbrick, S. S. (1969), *Classification and Identification of Shales: Discussion,* **Journal of the Soils Mechanics and Foundations Division,** American Society of Civil Engineers, Vol 95, No. SM 1, New York, pp 348-349.
20. Elliot, R. E., and Strauss, P. G. (1970), *A Classification of Coal Measures Rocks Based on Quartz Content,* **Proceedings of the Sixth International Congress on Carboniferous Stratigraphy and Geology,** Sheffield, Vol 2, pp 715-124.
21. Bjerrum, L. (1967), *Progressive Failure in Slopes of Overconsolidated Plastic Clay and Clay Shales,* **Journal of Soil Mechanics and Foundations Division,** American Society of Civil Engineers, Vol 93, No. SM 5, New York, pp 1-49.
22. Fleming, R. W., Spencer, G. S., and Banks, D. C. (1970), *Empirical Study of the Behavior of Clay Shale Slopes,* NCG Technical Report No. 15, Vol 2, US Army Engineer Nuclear Cratering Group, Livermore, California.
23. Lutton, R. J., and Banks, D. C. (1970), *Study of Clay Shale Slopes along the Panama Canal, Report 1, East Culebra Slides and the Model Slope,* **10 CS Memorandum JAX-108,** Department of the Army, Jacksonville District, November.
24. Heley, W., and MacIver, B. N. (1971), *Development of Classification Indexes for Clay Shales,* Technical Report S-71-6, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

25. Townsend, F. C., and Gilbert, P. A. (1974), *Residual Shear Strength and Classification Indexes of Clay Shales,* Technical Report S-71-6, Report 2, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
26. Shamburger, J. H., Patrick, D. M., and Lutten, R. J. (1975), *Survey of Problem Areas and Current Practices,* Vol 1, **Design and Construction of Compacted Shale Embankments,** Federal Highway Administration, FHWA-RD-75-61, Washington, D.C.
27. Bragg, G. H. Jr., and Zeigler, T. W. (1975), *Evaluation and Remedial Treatment of Compacted Shale Embankments,* **Vol 2, Design and Construction of Compacted Shale Embankments,** Federal Highway Administration, FHWA-RD-75-62, Washington, D.C.
28. Lutton, R. J. (1977), *Slaking Indexes for Design,* Vol 3, **Design and Construction of Compacted Shale Embankments,** Federal Highway Administration, FHWA-RD-77-1, Washington, D. C.
29. Deo, P. (1972), *Shales as Embankment Materials,* Joint Highway Research Project, Purdue University, West Lafayette, Indiana.
30. Chapman, D. R. (1975), *Shale Classification Tests and Systems: A Comparative Study,* Joint Highway Research Project, Purdue University, West Lafayette, Indiana.
31. Deen, R. C., Tockstein, C. D., and Palmer, M. W. (1974), *A Rock Classification Schema,* **Proceedings of the Ohio River Valley Soils Seminar -- Rock Engineering,** Kentucky Soils Group, Lexington, Kentucky, pp 2.1 - 2.17.
32. Hagerty, D. J., Deen, R. C., Palmer, M. W., and Tockstein, C. D. (1975), *Rock Evaluation for Engineerer Facilities,* **Record 548,** Transportation Research Board, Washington, D. C., pp 16-23.
33. van Zyl, D. J. A., Wood, L. E., and Lovell, C. W. (1978), *Storage, Retrieval, and Analysis of Compacted Shale Data,* **Record 690,** Transportation Research Board, Washington, D. C., pp 14-22.