Research Report
407

ROCK EVALUATION FOR ENGINEERED FACILITIES

by

D. J. Hagerty
Associate Professor of Civil Engineering
University of Louisville

R. C. Deen
Assistant Director of Research

M. W. Palmer
Research Engineer Assistant

and

C. D. Tockstein
Research Engineer Assistant
Kentucky Bureau of Highways

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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. 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.

Some years ago the value of topographic maps, aerial photographs, pedologic descriptions, and geological surveys in characterizing soil materials was realized. To make this information useful for engineering studies, a serious effort was initiated to obtain data on the engineering properties of various soil groups and associations established on the basis of geological and pedological surveys. 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. This has produced 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. However, a serious gap exists in the association of engineering characteristics with rock units identified on the basis of geological classifications. Therefore, there is a need for the development of a comprehensive evaluation program which permits utilization of existing data and which aids in the procurement of necessary information on engineering characteristics of rock.

SCOPE OF STUDY

The initial work plan included the development of a classification system based on index tests. An investigation of previous works in classification of rock on the basis of index tests showed that a variety of classification systems utilizing many different index tests had been developed. However, this survey showed that no generally applicable system had been developed and that little communication had been established between field investigators, facility designers, and those in charge of construction and maintenance of facilities. Therefore, the initial plan for work was modified to include the development of a comprehensive methodology for evaluation of rock. The development of such an evaluation schema was to include the establishment of an information bank to provide access to collected data by any interested individual. The first step in the development of this rock evaluation program was a survey of the categories of information that have been collected concerning geologic materials, particularly rock strata. On the basis of this investigation of existing data, a method was devised to collect, categorize, and present more extensive data on rock materials. The general schema for the evaluation program was then developed. At the present time, a research effort is continuing to test and verify the validity of the evaluation program which has been developed. A final step in this effort will be a full implementation of the rock evaluation program for project planning in Kentucky.

GEOLOGIC INFORMATION

Any study of rock materials must rely at least in part on a background of geological information. For several hundred years, geologists have investigated rocks of the earth surface, attempting to organize and codify rock units so that the origin, genesis, and transformation of these units can be properly understood. This work is of tremendous significance for engineering studies of rock materials. Earth materials of concern to the engineer exist in a geological environment. These materials possess physical characteristics which are a function of their mode of origin and subsequent geologic processes that have acted upon them. These events in geologic history lead to a particular lithology, to a particular set of geological structures, and to a particular in-situ state of stress. In the planning, design, construction, and maintenance of engineered facilities, geological structures, distribution of rock types, and variations in existing states of stress in rock materials have significant influence. Additionally, a familiarity with local geologic conditions and information is valuable in that results of past studies and investigations can be incorporated into an information system. This local geologic information can be used to insure that tests selected for classification purposes are compatible with the rocks encountered in a study area. Geologic structures and gelogical materials which have exhibited unfavorable characteristics or which are judged to be potential sources of trouble can be quickly located. Moreover, a knowledge of in-situ stresses can be extremely useful in design. Finally, a knowledge of existing geology in an area under study can provide assistance in the planning and conduct of a testing program for a particular project at a particular site.

In the development of the rock evaluation program for the state of Kentucky, in particular, the geology of the state was reviewed and existing geological information was organized and codified to provide easy access for engineers and technicians not well versed in the topic. The authors recommend that such an organization of geological information be carried out as a primary step in the development of any rock evaluation program in other areas.

ROCK CLASSIFICATION

The organization of geologic information as described in the preceding paragraphs illustrates the basic purpose of any rock classification system: the transfer of information on rock properties from laboratory or field investigators to design engineers and contractors. The optimum means for such transfer of information would be the conduct of tests on rock in its native environment to simulate any proposed construction activity. Behavior of the rock under simulated construction conditions could be monitored and predictions concerning behavior during construction and subsequent operation of the prototype facility could be made. However, the expense of large-scale testing of in-situ rock is such that this approach is not economically feasible. For this reason, inexpensive indirect tests are desirable. If such tests can be developed and used to indicate indirectly the behavior of rock materials under actual construction and operating conditions, great economies can be realized not only in exploration and testing but also in design and construction. Considerable success has been attained in the investigation of soil materials, and to a lesser extent in studies of rock materials, using index testing of samples of material taken from a particular site and predicting performance on the basis of test results and a knowledge of differences between the laboratory test conditions and actual field conditions associated with the proposed facility.

The primary difficulty in the use of index tests for rock characterization lies in the fact that very large samples would be required to test a representative mass of material. Discontinuities located at significant spacings and changes in characteristics of material over long distances would require testing of very large specimens. This cannot be done economically. Therefore, evaluation of rock properties on the basis of index tests must always be considered as a superficial investigation limited on the basis of physical and mathematical continuity considerations. Large-scale rock discontinuities and structural features cannot be preserved in laboratory specimens. These discontinuities and inhomogeneities greatly affect rock deformation and failure in the field. A significant degree of uncertainty will always exist in any prediction of field behavior on the basis of index test results. Nevertheless, index tests can serve as useful indicators of rock behavior, especially in the location and preliminary planning stages. For this reason, the authors have given considerable attention to selecting index properties and using such properties in the classification of rock materials. Index tests must be characterized by simplicity, economy, and ease of performance. Additionally, index test results must be reproducible, within reasonable limits, by various practitioners in various locations using standardized equipment and procedures. Most importantly, the test property must be an index of a material or mechanical property which the design engineer can use effectively.

Many geological classification systems for rock have been proposed. In general, these systems emphasize properties and characteristics of intact material and neglect discontinuities and possible sources of weakness in rock masses which are of critical importance in engineering activities. The most widespread geologic classification of rock has been made on the basis of genesis, and rock materials have been divided into igneous, sedimentary, and metamorphic categories. Within these categories, various subclasses have been developed on the basis of petrographic studies which include characterization of the texture and mineralogy of the rock. In addition to genetic and petrographic classifications, geologists have developed chemical classification systems for rock material which are of limited applicability in engineering studies. Basic genetic classifications have been found to be useful when they can be correlated with the engineering properties of the rock materials. However, in general, genetic classifications are not sufficiently specific and quantitative for use in engineering applications.

Physiographers and geomorphologists have developed systems for classifications of landforms which have proven to be useful as indicators of properties and structures in underlying bedrock. Physiographic classification systems of surficial terrain have proven useful in the location, planning, design, and construction of transportation facilities. The general qualitative character of most geological classification systems has been modified to yield a quantitative methodology of terrain description in the Pattern-Unit-Component-Evaluation (PUCE) system developed in Australia. This quantitative terrain evaluation system appears to be a useful transitional step between purely qualitative geologic classifications and quantitative engineering classification systems for rock.

A number of engineering classification systems have been developed for rock materials. Table 1 summarizes attributes used in classification systems for use with intact rock samples. Some of these systems are based upon inherent rock characteristics while others are based upon a particular purpose or use to which the rock is to be put. Some systems 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 -- can be used to characterize the properties of an intact sample. These characteristics are shown in the form of a classification system in Figure 1.

A variety of tests have been proposed as indicators of rock strength. Uniaxial compressive tests have been used in rock classification systems by a number of individuals. Additionally, hardness tests and various penetration tests have been utilized as indicators of rock strength. Compressive strength tests require machined specimens and thus are somewhat costly in terms of sample preparation. Hardness tests appear to be subject to variations in testing techniques. The point-load strength index has been selected herein as a measure of tensile strength; empirical results show excellent correlation between this index and the unconfined compresssion strength of rock materials.

The lithology of rock materials does not have a direct bearing on mechanical properties, but traditional geologic rock names based on the nature of the texture, mineral content, structure, particle size, and cementing matrix yield significant information on the relation between an intact sample and the rock mass from which the sample was taken. A knowledge of rock lithology can provide an intuitive feeling for the character of the rock mass and can suggest mass effects which may be common to certain groups of rocks.

Almost all rock materials show directional differences in their responses to applied stresses and environmental conditions. For this reason, anisotropy of an intact specimen is of significant interest. The authors have selected point-load test results to define the strength anisotropy index as the ratio between maximum and minimum strength values. In general, this ratio is established by performing the point-load test on specimens oriented so that the load first is applied parallel to the planes of weakness in the specimen and then is applied perpendicularly to those planes.

Behavior of rock materials under long-term changes in environmental conditions can be of significant importance to engineering projects. Durability tests have been used to characterize earth materials as soil or rock and to indicate susceptibility of rock material to alteration in a weathering environment. A large number of durability tests have been suggested by other investigators; swell tests and slake-durability tests have been commonly used. The most successful classification scheme for transitional materials with characteristics intermediate between those of true soils and true rock appears to be that developed by Gamble. The authors have modified this work to yield the system shown in Figure 2. This classification system utilizes values of plasticity index and two-cycle slaking durability. All samples with low plasticity index and durability values greater than 95 percent can be considered rock materials.

Intact sample testing and classification may be sufficient for purposes of preliminary planning and location studies, but the design of facilities will require more comprehensive and direct testing of rock materials and will necessitate examination of in-situ 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 by previous investigators. 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 that the greatest success has been attained by combining tests on intact samples with an analysis of field conditions which tend to govern the behavior of rock materials. Upper limits for strength and deformation resistance may be established on the basis of laboratory tests on intact samples, and these values may be reduced (adjusted) on the basis of field tests which show the influence of discontinuities, weathered zones, etc. Rock models have been prepared to allow an assessment of rock behavior under conditions associated with construction and operation of a proposed facility. The basis of these modeling studies has been, in most cases, a comprehensive survey of discontinuities present at the proposed site of a facility. Since joints are the most widespread discontinuities in rock, in-situ classification systems often include a comprehensive joint survey program. On the basis of a review of existing in-situ classification systems, the authors have developed a classification system as shown in Figure 3. This system is designed to incorporate the effects of discontinuities and mass anisotropy on the characteristics and behavior of the rock. The presence of faults and shear zones has been taken into account by considering these discontinuities in the same way as joints.

PROPOSED ROCK EVALUATION SYSTEM

After the development of the classification systems for intact samples and for in-situ conditions, the next step in the development of an evaluation system was the creation of a method for exchange of information. Results of classification programs would be essentially useless if there were no means to make such information readily available in understandable form to engineers and other investigators involved in design and construction activities. Therefore, a system has been developed to provide engineers with a means to obtain information for site selection, facility design, and construction and maintenance planning. The proposed system consists of two phases: an acquisition segment for the collection and collation of data and an application segment wherein collected data can be used in classification programs and can be analyzed with regard to the use of rock materials in various circumstances. A schematic diagram of the proposed rock evaluation program is shown in Figure 4.

The first segment of the program consists of data acquisition. The central feature of this segment is the data bank wherein information from field and laboratory testing as well as from case histories will be stored. The attributes of the data bank are shown in Figure 5. Information storage is to be accomplished under three categories. Category 1 contains information pertient to the location, identification, and natural environment from which the data (sample or case history information) originated. Category 2 is provided for storage of results of visual observations, index tests, and detailed tests of rock mechanical properties. Category 3 is for the storage of information from case histories and performance reports from contemporary construction and also from completed facilities.

Procurement of data for insertion under Categories 1 and 2 of the data bank will involve both laboratory and field testing techniques. The sample identification sheet shown in Figure 6 shows some of the information required. Samples should be selected on the basis of geological considerations and current availability. Samples should be tested at the site immediately after removal from a core barrel or similar device if at all possible. Since this is not practical in all situations, samples can be returned at their natural moisture content and in a undisturbed condition to a laboratory for further testing. The testing sequence in the laboratory should begin with a swell test and a slake-durability test to provide immediate differentiation between soil and rock materials. The remainder of the information for storage in Category 2 of the data bank can be obtained through index testing and refined laboratory or large scale in-situ tests.

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 identification of site or formation investigated can be entered in the data bank so that when a search is made, the existence of this information will be made known to the investigator. That individual can then conduct further searches for the detailed information on previous experience at a given site or in a particular formation.

The data bank will consist of a system of computer files arranged according to the above-mentioned three categories. Computer programming will be used to facilitate storage, retrieval, and use of acquired information. A sample showing the methodology for storage and retrieval of Category 1 information is shown in Figure 7. The same methodology has been followed for Category 2 and Category 3 data. Figures 8, 9, 10, and 11 illustrate the transfer of information to positions on a computer data card.

Use of the information stored in the data bank can be accomplished through the development of specific classification and application programs. However, a generalized classification can be obtained using the systems shown in Figures 1 and 3. 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 12. In this sample table, a number of uses (aggregate, rock fill, etc.) for rock materials are shown. The four indices utilized for classification of rock materials can be quantified in terms of acceptable values for the rock material for use in any one of the given ways shown in the table. If a rock is to be used as aggregate in a highway construction project, acceptable values of the point-load index, lithology, strength anisotropy index, and slake-durability index can be developed. Then, any rock available for use in a particular project as aggregate can be tested, and the test values obtained for that rock can be compared with the ranges of acceptable values shown in the table. In this way, the acceptability of various rock units for use in different ways can be quantitatively evaluated. 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 the rock evaluation program as shown in Figure 4. This figure represents the combination of the acquisition 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 must decide whether or not sufficient data has been obtained for the evaluation of a particular site as the location of a proposed facility. If sufficient data has 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 that design and construction operations are appropriate at this site. If the user decides that an insufficient amount of data is 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. For this reason, performance monitoring data should be returned to the data bank as case history information. Ideally, the proposed rock evaluation program will be a self-sustaining, ever-expanding source of valuable information concerning the engineering properties and behavior of rock materials.

SUMMARY

Rock engineering includes a number of very significant major operations: engineering analysis and interpretation 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 drawn from various professions and disciplines are involved in these facets of rock engineering. To facilitate communication among these individuals and to assist in all facets of rock engineering, a rock evaluation program has been proposed.

This evaluation program is especially useful for the planning, design, and construction of transportation facilities in and on rock. Data on engineering characteristics of rock units are utilized in a 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 properties. 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 has been developed. Data for inclusion in the information bank are derived from laboratory and field testing as well as monitoring of rock behavior during construction and subsequent operations of completed facilities. Current study efforts are directed toward verifying and improving the methodology set forth in this preliminary development of the rock evaluation program. It is hoped that development of this program will be of significant assistance to individuals engaged in rock engineering and, in particular, to individuals concerned with the planning, design, construction, and maintenance of transportation facilities in and on rock.

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TABLE 1

TYPICAL ATTRIBUTES OF INTACT ROCK SAMPLE CLASSIFICATION SYSTEMS

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

TABLE 2

TYPICAL ATTRIBUTES OF IN-SITU ROCK CLASSIFICATION SYSTEMS

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

	TENSILE STRENGTH		ANISOTROPY		DURABILITY		LITHOLOGY	
CLASS NO.	WORD DESCRIPTION	POINT-LOAD INDEX[a] (MPa)	WORD DESCRIPTION	STRENGTH ANISOTROPY INDEX[b]	WORD DESCRIPTION	SLAKE-DURABILITY INDEX[c] (percent)	SYMBOL	WORD DESCRIPTION
1	Very Strong	> 10	Isotropic	1.0 - 1.2	Very Durable	> 50	SS	Sandstone
2	Strong	3 - 10	Slightly Anisotropic	1.2 - 1.5	Durable	25 - 50	SH	Shale
3	Moderately Strong	1 - 3	Moderately Anisotropic	1.5 - 5.0	Moderately Alterable	10 - 25	LS	Limestone
4	Weak	0.3 - 1	Anisotropic	5 - 20	Alterable	5 - 10		
5	Very Weak	< 0.3	Very Anisotropic	> 20	Highly Alterable	< 5		

[a]Point-Load Index = Force at Failure/Square of Distance between Loaded Points in a test method developed by Franklin (1970)

[b]Strength Anisotropy = Maximum Strength/Minimum Strength

[c]Slake-Durability Index = Percent Retained on 2-mm Screen after slaking in a test developed by Franklin and Chandra (1972)

Example: 1 - LS - 2 - 1 indicates a very strong, slightly anisotropic, very durable limestone

Figure 1. Proposed Intact Sample Classification System.

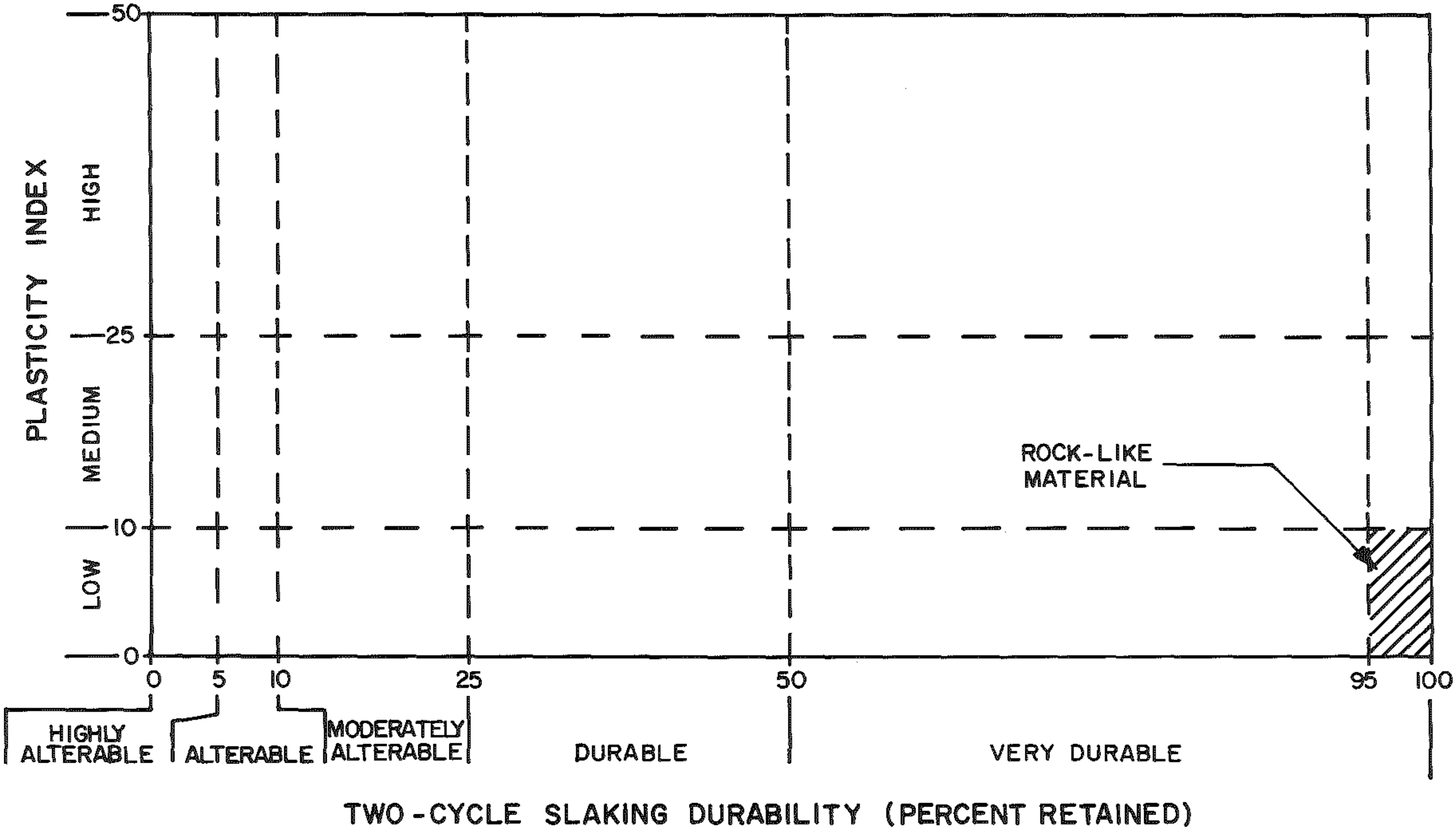

Figure 2. Durability-Plasticity Classification for Shales and Other Argillaceous Rocks.

	STRENGTH AND DEFORMABILITY -- ROCK QUALITY (CONTINUITY)												
	BEDDING		JOINT SPACING		JOINT FREQUENCY			GROSS HETEROGENEITY		INTACT - IN-SITU REDUCTION FACTOR[a]		LITHOLOGY	
CLASS NO.	WORD DESCRIPTION	BEDDING THICKNESS (mm)	WORD DESCRIPTION	SPACING (mm)	WORD DESCRIPTION	JOINTS PER METER	JOINT INFILTRATION MATERIAL[a]	WORD DESCRIPTION	PERMEABILITY (nm/s)	DEGREE OF CORRELATION	VELOCITY RATIO[b]	SYMBOL	WORD DESCRIPTION
1	Very Thin	< 10	Very Close	< 10	Very Low	< 0.3	Air	Very Low	< 1	Excellent	> 0.8	SS	Sandstone
2	Thin	10 - 50	Close	10 - 50	Low	0.3 - 1.0	Water	Low	1 - 10	Good	0.6 - 0.8	SH	Shale
3	Medium	50 - 300	Moderately Close	50 - 300	Medium	1 - 2	Cohesionless Soil	Medium	10 - 100	Fair	0.4 - 0.6	LS	Limestone
4	Thick	300 - 1500	Wide	300 - 1500	High	2 - 4	Inactive Clay	High	100 - 1000	Poor	0.2 - 0.4		
5	Very Thick	> 1500	Very Wide	> 1500	Very High	> 4	Active Clay	Very High	> 1000	Very Poor	< 0.2		

[a]Subject to modification with further testing
[b]Velocity Ratio = In-Situ Sonic Velocity Intact Specimen Sonic Velocity

Figure 3. Proposed In-Situ Rock Classification System.

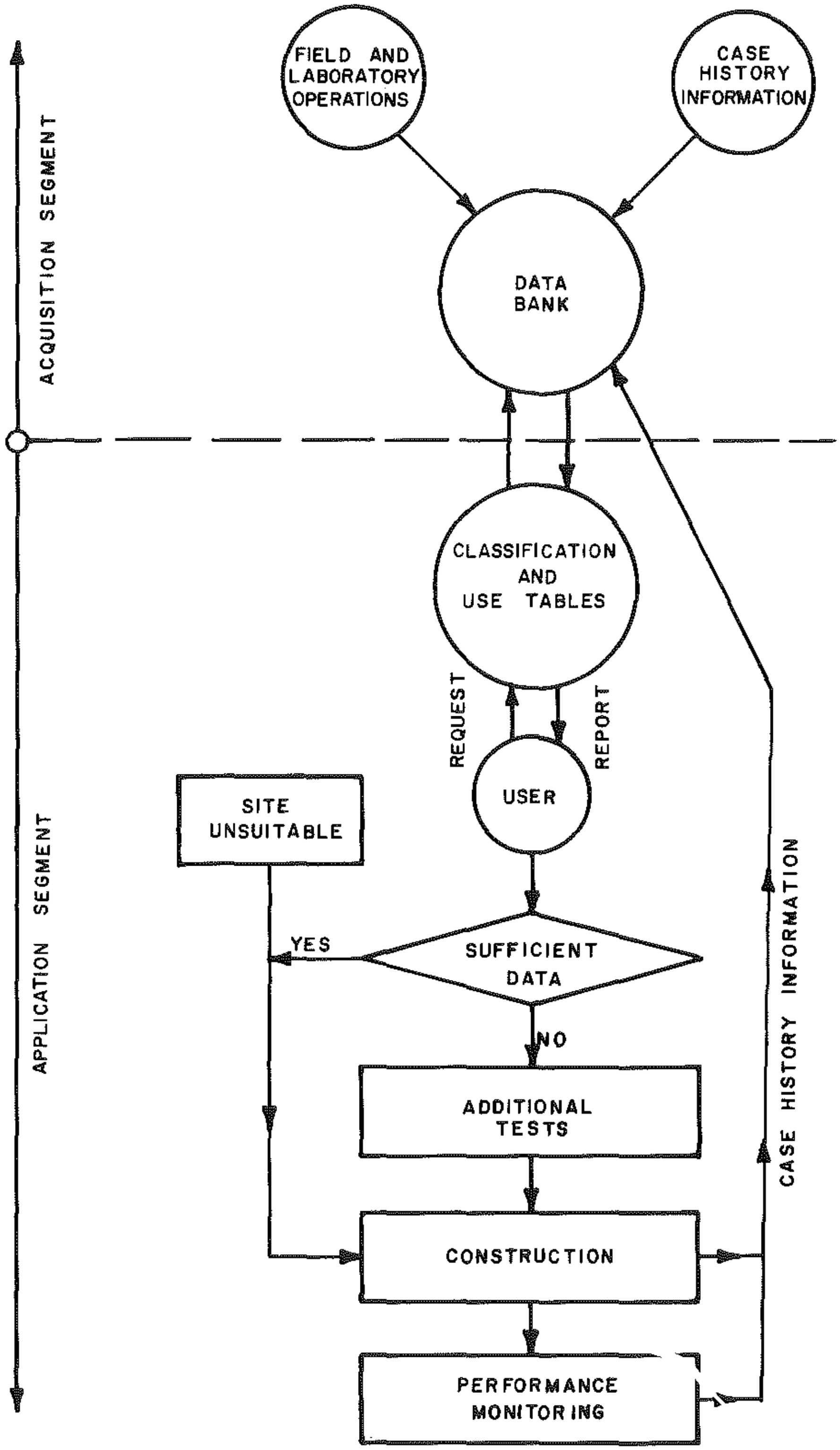

Figure 4. **Schematic Diagram of the Proposed Rock Evaluation Schema.**

Attribute	Subgroup	Group	Class	Category
STATE		LOCATION		CATEGORY 1
COUNTY		LOCATION		CATEGORY 1
PHYSIOGRAPHIC REGION		LOCATION		CATEGORY 1
USGS QUADRANGLE NUMBER		LOCATION		CATEGORY 1
LONGITUDE		LOCATION		CATEGORY 1
LATITUDE		LOCATION		CATEGORY 1
SAMPLE IDENTIFICATION NUMBER				CATEGORY 1
MAJOR GEOLOGICAL FORMATION				CATEGORY 1
ROCK TYPE (GENERIC)				CATEGORY 1
				CATEGORY 1
GROUND ELEVATION				CATEGORY 1
SAMPLE ELEVATION				CATEGORY 1
WATER TABLE ELEVATION				CATEGORY 1
SAMPLE ORIENTATION w/r GROUND SURFACE				CATEGORY 1
SAMPLE ORIENTATION w/r BEDDING PLANE				CATEGORY 1
METHOD OF OBTAINING SAMPLE				CATEGORY 1
RELEVANT COMMENTS				CATEGORY 1
				CATEGORY 1
COLOR		VISUAL	INTACT	CATEGORY 2
TEXTURE		VISUAL	INTACT	CATEGORY 2
STRUCTURE		VISUAL	INTACT	CATEGORY 2
GRAIN SIZE		VISUAL	INTACT	CATEGORY 2
CALCIUM CARBONATE CONTENT		VISUAL	INTACT	CATEGORY 2
		VISUAL	INTACT	CATEGORY 2
FREE SWELL		INDEXING	INTACT	CATEGORY 2
SLAKE DURABILITY INDEX		INDEXING	INTACT	CATEGORY 2
POINT-LOAD INDEX		INDEXING	INTACT	CATEGORY 2
STRENGTH ANISOTROPY INDEX		INDEXING	INTACT	CATEGORY 2
LITHOLOGY		INDEXING	INTACT	CATEGORY 2
STRENGTH SOFTENING		INDEXING	INTACT	CATEGORY 2
TIME-STRAIN BEHAVIOR		INDEXING	INTACT	CATEGORY 2
LABORATORY SONIC VELOCITY		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
SHORE SCLEROSCOPE HARDNESS		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
SCHMIDT "L" HAMMER HARDNESS		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
UNCONFINED COMPRESSIVE STRENGTH		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
TANGENT MODULUS		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
NATURAL WATER CONTENT		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
SATURATION WATER CONTENT		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
APPARENT SPECIFIC GRAVITY		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
BULK SPECIFIC GRAVITY		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
APPARENT POROSITY		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
APPARENT VOID RATIO		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
BULK SPECIFIC GRAVITY (SSD)		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
DEGREE OF SATURATION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
VOID INDEX		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
DIRECT SHEAR PHI ANGLE		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
DIRECT SHEAR COHESION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
DIRECT SHEAR TIME TO FAILURE		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
TRIAXIAL COMPRESSION PHI ANGLE		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
TRIAXIAL COMPRESSION COHESION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
LOS ANGELES ABRASION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
DEVAL ABRASION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
TRETON IMPACT		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
FRACTURE ENERGY		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
COST ANALYSIS DATA		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
STRENGTH COEFFICIENT OF VARIATION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
SCALE EFFECT		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
MINERALOGICAL COMPOSITION		PHYSIO-MECHANICAL RESULTS	INTACT	CATEGORY 2
			INTACT	CATEGORY 2
BEDDING THICKNESS	ROCK QUALITY	MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
JOINT SPACING	ROCK QUALITY	MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
JOINT FREQUENCY	ROCK QUALITY	MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
JOINT INFILTRATION MATERIAL	ROCK QUALITY	MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
GROSS HETEROGENEITY		MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
VELOCITY RATIO		MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
		MASS DESCRIPTION (INDEXING)	IN SITU	CATEGORY 2
JOINT ORIENTATION			IN SITU	CATEGORY 2
JOINT SURVEY			IN SITU	CATEGORY 2
			IN SITU	CATEGORY 2
CORE RECOVERY	CORE BORINGS	SECONDARY INDEXING	IN SITU	CATEGORY 2
RQD	CORE BORINGS	SECONDARY INDEXING	IN SITU	CATEGORY 2
FRACTURE FREQUENCY	CORE BORINGS	SECONDARY INDEXING	IN SITU	CATEGORY 2
WEIGHTED CORE LENGTH	CORE BORINGS	SECONDARY INDEXING	IN SITU	CATEGORY 2
SCHMIDT HAMMER TEST		SECONDARY INDEXING	IN SITU	CATEGORY 2
		SECONDARY INDEXING	IN SITU	CATEGORY 2
GEOPHYSICAL SURVEYS			IN SITU	CATEGORY 2
FIELD TESTS			IN SITU	CATEGORY 2
LANDFORM CLASSIFICATION			IN SITU	CATEGORY 2
			IN SITU	CATEGORY 2
PREVIOUS EXPERIENCE				CATEGORY 3
CONSTRUCTION PRACTICES				CATEGORY 3
PERFORMANCE MONITORING				CATEGORY 3
				CATEGORY 3
				CATEGORY 3

Figure 5. Data Bank Attributes.

SITE-SAMPLE IDENTIFICATION SHEET

1. Sample Location

County	Physiographic Region	Station Number	USGS Quadrangle Number	Longitude	Latitude

2a. Sample I.D. ____________ 2b. Date Sampled ____________

3. Major Geological Formation from which Sample Was Taken ____________

4. Rock Type (Genetic) ____________

5. Ground Elevation ____________
☐ measured ☐ estimated

6. Elevation of Sample ____________
☐ measured ☐ estimated from ground surface

7. Elevation of Water Table ____________
☐ measured ☐ estimated from ground surface

8. Orientation of Sample with respect to Ground Surface
☐ GS ☐ GS ☐ GS $\theta =$ ____

9. Orientation of Sample with respect to Major Bedding Plane
☐ BP ☐ BP ☐ BP $\theta =$ ____

10. Method Used to Obtain Sample
☐ NX Core ☐ Quarry Sawn ☐ Other - explain
☐ Block ☐ Hand Tools ____________

11. Comments ____________

12. Signed ____________

INSTRUCTIONS

1. List sample location descriptors.

2. Sample I. D. will be quadrangle coordinates followed by sequential numbers for each site. Give date sample was obtained.

3. Enter the geological formation name, if known. If questionable, follow name with a question mark. If unknown, leave blank.

4. Generic term (i.e. limestone, sandstone, shale, granite, etc).

5. Indicate elevation to nearest foot (0.3 meter). Mark whether measured or estimated from a topographic map.

6. Indicate sample elevation to nearest foot (0.3 meter). Mark whether measured from ground surface or estimated.

7. Indicate water elevation, if determinable. Mark whether measured from ground surface or estimated.

8 - 9. Sample should be marked with a vertical arrow (↑) to indicate the top surface. Mark the appropriate block which relates this arrow to the surface in question. If on skew, indicate the approximate angle.

10. Check proper box. If other, explain briefly.

11. Include additional information which may be significant, i.e. general condition of rock at site (weathered, fractured, extensive joint systems, joint filling, solutioning, water seepage, etc.)

12. Name and signature of individual obtaining the sample.

Figure 6. Site-Sample Identification Sheet and Instructions.

CATEGORY 1, IDENTIFICATION DATA SUBFILE
(Data Card No. 1)

ATTRIBUTE	ATTRIBUTE CODE	LOCATION (COLUMN)	FORMAT	INSTRUCTIONS AND REMARKS
State	ST	1 - 2	I2	List the names of the states alphabetically and assign numbers sequentially from 01 through 50. Code number for Kentucky would be 17.
County	CO	3 - 5	I3	List the names of the counties within a state and assign numbers sequentially from 001.
Physiographic Region	PR	6 - 7	I2	Physiographic region from which the sample was obtained: 01 Purchase 02 Western Coal Field 03 Western Pennyroyal 04 Eastern Pennyroyal 05 Knobs 06 Outer Bluegrass 07 Inner Bluegrass 08 Eastern Coal Field
USGS Map	MN	8 - 11	I4	USGS number of geologic quadrangle map which encompasses the sample site. Examples: No. Map Name 0246 Kirsey 0763 Lovelaceville 1025 Addyston 0000 Crofton (map not published)
Longitude	LON	12 - 15	I4	Longitude of the sample site will be described in terms of degrees and minutes. Seconds of longitude will be rounded to the nearest minute. Examples: 82° 34' 17" = 8234 86° 06' 47" = 8607 89° 15' 15" = 8915
Latitude	LAT	16 - 19	I4	Latitude of the sample site will be described in the same manner as longitude.
Sample Identification No.	ID	20 - 24	A5	Columns 20-21 -- Last two digits of the year in which the sample was obtained. Column 22 -- Month in which sample was obtained: 1 -- January 2 -- February • • • 9 -- September 0 -- October N -- November D -- December Columns 23-24 -- Specimen number.
Geological Formation	GF	25 - 27	I3	Major geological formation from which the sample was obtained will [illegible]
				Ground elevation at sample site to nearest tenth of a meter.
		[illegible] - 36	F4.1	Elevation from which sample was taken to nearest tenth of a meter.
Elevation	WTE	37 - 40	F4.1	Elevation of water table to nearest tenth of a meter.
Sample Orientation	SOG	41 - 42	F2.0	00 to 90 indicates the angle between the sample axis and the ground surface to the nearest degree.
Sample Orientation	SOB	43 - 44	F2.0	00 to 90 indicates the angle between the sample axis and the major bedding plane to the nearest degree.
Method of Obtaining Sample	MOS	45	I1	1 -- NX core 2 -- block sample 3 -- quarry sawn 4 -- hand tools 9 -- other (may be further delineated at a future time)
Relevant Comments	RC	46	I1	0 -- no comments 1 -- relevant comments available
	FREE1	47 - 48	I2	Blank (may be designated at a later time)

Figure 7. Portion of Coding Instructions for Category 1 File Subsystem.

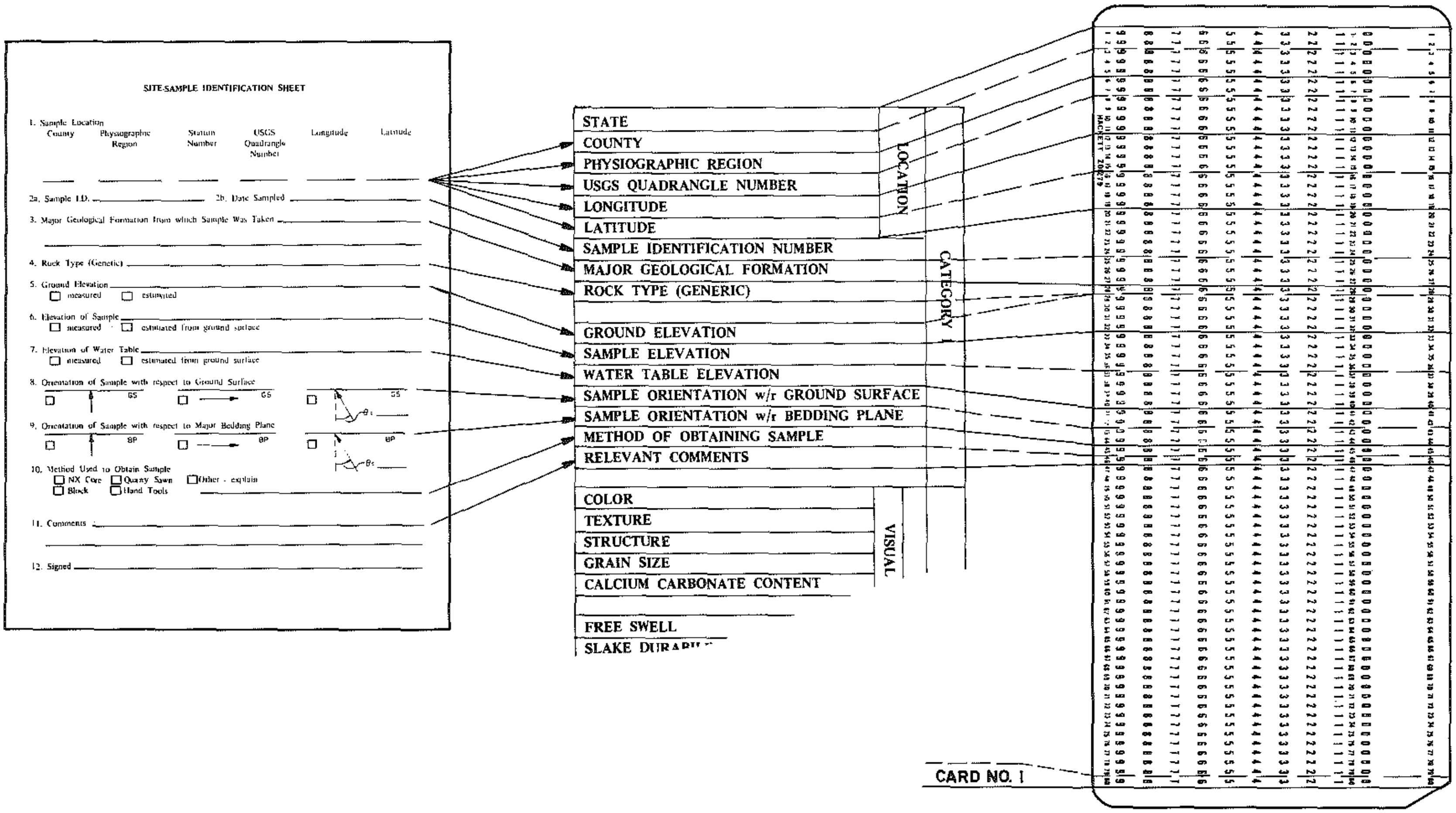

Figure 8. Category 1 (Site and Sample Description) File Subsystem.

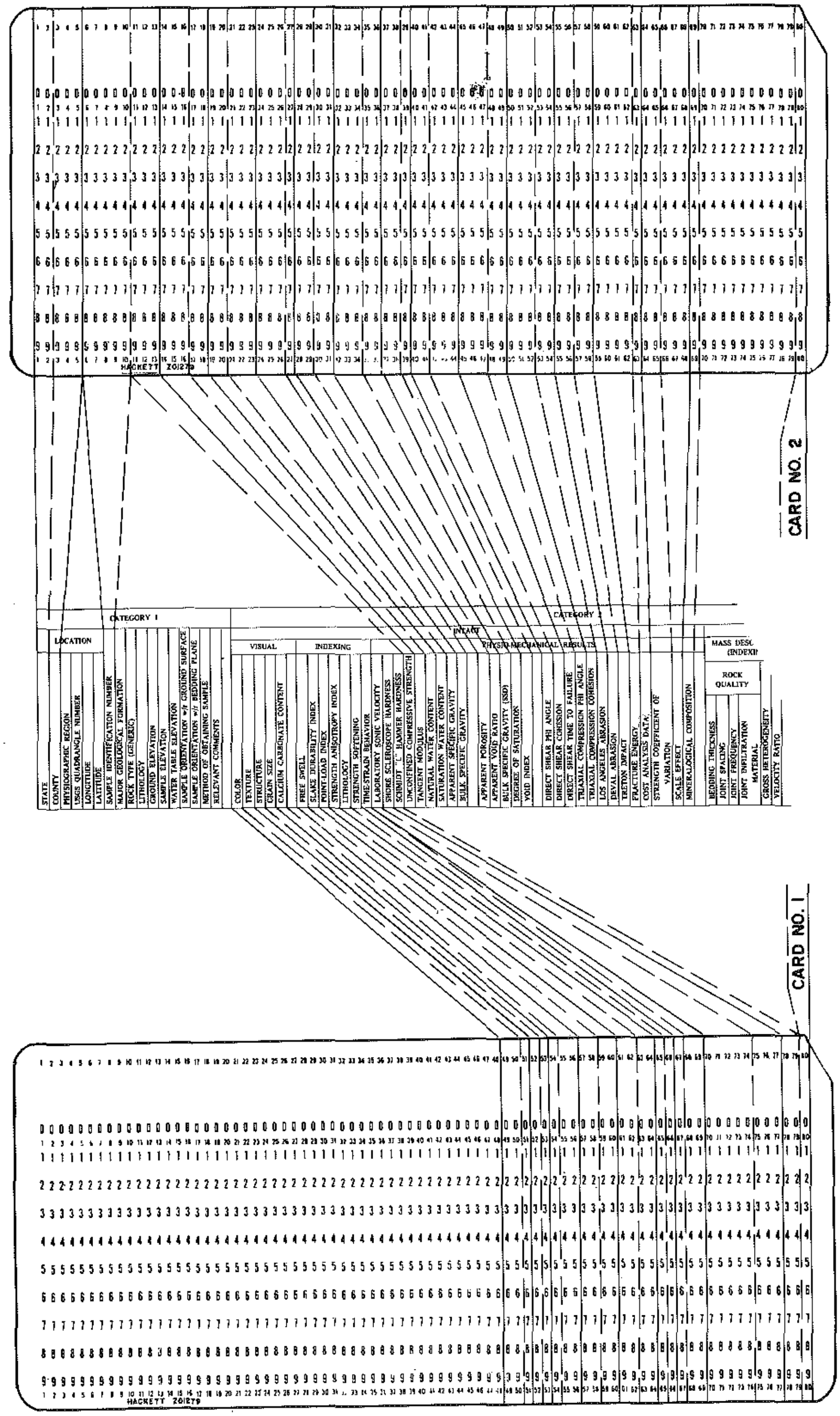

Figure 9. Category 2 (Intact Sample Data) File Subsystem.

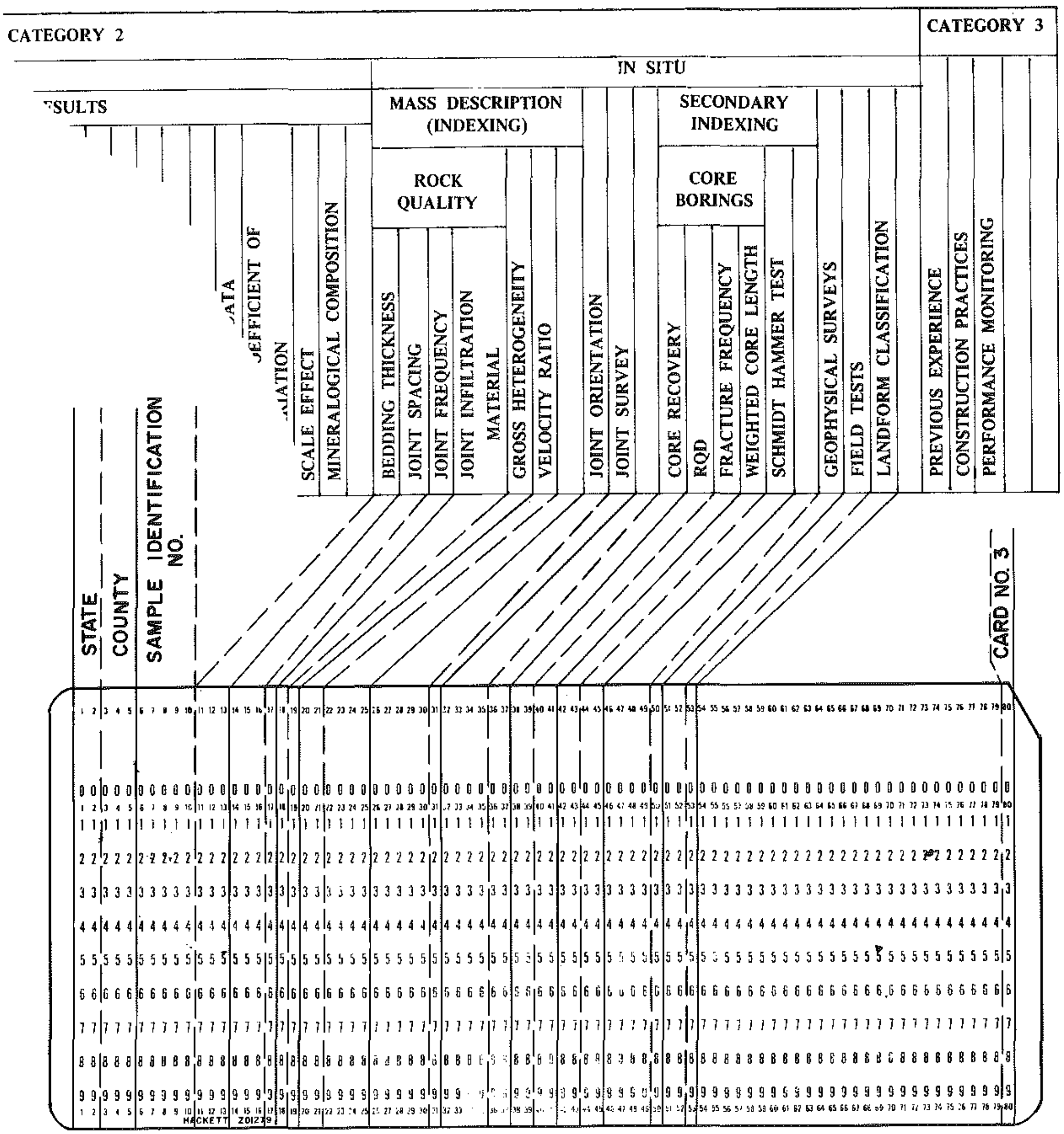

Figure 10. Category 2 (In-Situ Data) File Subsystem.

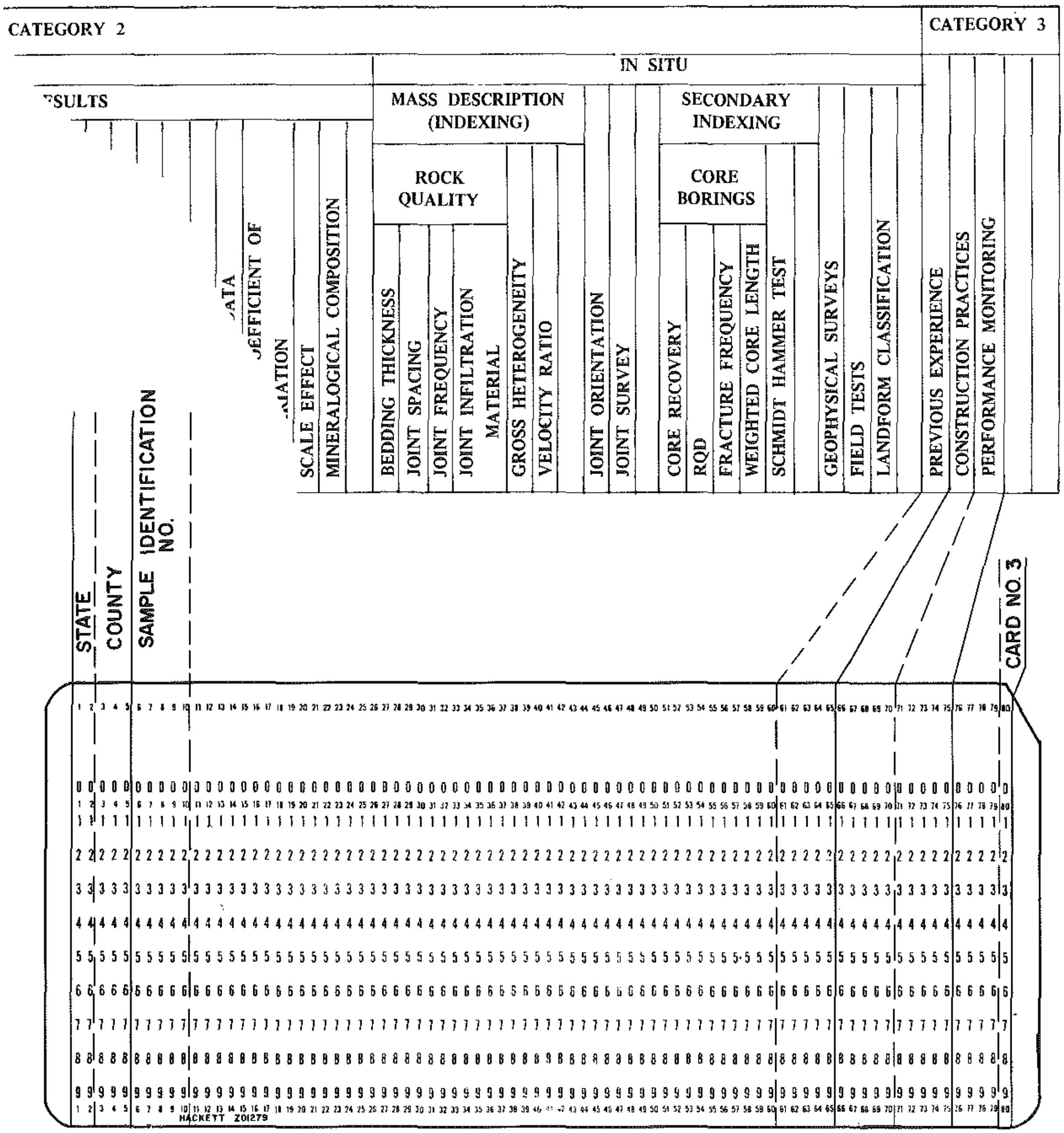

Figure 11. Category 3 (Case History Data) File Subsystem.

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 12. Typical Format of a Use Table.