Research Report
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A ROCK CLASSIFICATION SCHEMA

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INTRODUCTION

The need for engineering data on earth materials for use in site selection, design, construction, and maintenance of major engineering structures is generally accepted. Probably the most pressing need is for such data to 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, would permit much preliminary work on engineering structures to be done without the engineer ever having to leave his office.

Field and laboratory methods used to obtain engineering data are many and varied and often too expensive to use in preliminary reconnaissance surveys. There is, therefore, a need for the development and use of short-cut methods. Information on the areal distribution of soils and rocks can be inferred from aerial photographs and pedologic and geologic maps and surveys. Some four or five decades ago, when engineering activities were more restricted than they are at the present time and were founded more or less in or on **soil** materials, it was recognized that the pedological soil classification and mapping system could be of great use to engineers. Since that time, many agencies have devoted much effort to providing engineering data to supplement information provided by the pedological classifications and mapping.

In about 1955, the Research Division of the Kentucky Bureau of Highways began a program of adapting existing U. S. Department of Agriculture soils maps for engineering purposes by adding engineering data to the pedological soil series classifications. The Division has provided engineering soils data for numerous samples submitted by the Soil Conservation Service, U. S. Department of Agriculture. Other soils test data are also available from project files of the Division of Materials. As a result, soils profile data have been accumulated and tabulated for use in preliminary site investigations.

In recent years, as the size and extent of engineering structures have increased, the engineer has become more and more concerned about performance relationships between his structures and consolidated earth materials (**rock**). Because extensive areas of the country have been mapped geologically, much information is available concerning the areal distribution of **rock** materials. It would seem, however, that the use of geologic maps could be greatly enhanced for the engineer if engineering test data were provided and could be associated with various geologic formations. Kentucky has a particular advantage in that there is an extensive geologic mapping program, and within a few years, there will be complete coverage of the state with 7-1/2 minute quadrangle maps.

The initial goal of the study reported herein was to devise an engineering classification system for intact rock samples based on simple index tests which could be used to categorize Kentucky surface and near-surface rock types. This system would also provide for the accumulation of engineering test data for use in future site investigations. While conducting the literature survey, several facts became apparent:

1. a large number of rock classification systems -- geologic and technical, general and specific -- already existed;
2. an equally large number of index tests had

been devised; and

3. there was a lack of communication among those involved in specialized areas of rock-related work (geologists, civil engineers, mining engineers, etc.) and, to some extent, among individuals within each field.

It was evident that developing yet another "specialized" classification system with associated index tests would not be a significant contribution. It was decided, therefore, to develop an overall rock evaluation schema which would avoid the undesirable disparate characteristics of narrowness or over-generalization prevalent in many classification systems. It was desired also to develop the program format in such a way that accumulated information could be systematically stored for easy access and use. It was apparent that full development and implementation of a program of this nature would require years of further study and cooperation of many individuals and organizations. Such a program, properly developed and used, would substantially contribute to an advancement, and delineation of the schema and guidelines for its implementation would be a worthy goal.

A first logical step in approaching rock-related problems is the development of a systematic method of data collection. Presently, the only method of rock classification in Kentucky is geologic in nature. Engineering design values are based on empirical experience or building code values that are vague and, in many cases, overly conservative. Only in rare instances are tests actually performed. Lack of a systematic method for recording, cataloging, and storing data results in duplication of effort, loss of valuable information to the engineering community, and inadequate communication between practioners.

A second step is the development of a method of presenting collected data in a form convenient for a variety of uses. Classification systems or data banks are not ends in themselves but only provide a means for organizing existing knowledge, and facilitating interpretations. A method of further quantifying classification parameters with engineering data is needed.

The task of completely delineating, testing, and implementing a rock classification schema of the magnitude suggested is beyond the scope of this paper. It is important, however, that initial groundwork and guidelines for completion of such a program be carefully set forth. Successful completion of the program can be expected through additional studies based on the proposed guidelines. It is the intent of this paper to outline, in descriptive terms, such a rock classification program and provide sufficient guidance for eventual implementation.

The formulation of a viable rock evaluation program requires that the subject material (rock) be defined in a satisfactory manner. Since both intact and in-situ characteristics of rock are important to engineering considerations, rock must be considered both as "rock material" (intact samples), herein defined as a lithified aggregate of mineral particles in varying proportions along with associated voids (pores, microfissures), and as "rock mass" (in situ), which consists of rock material segmented by various forms of discontinuities (joints, bedding planes, faults, etc.) and associated filling materials.

Since it has been suggested that geologic maps provide much useful information for the engineer and that the usefulness of these maps could be enhanced by providing engineering data, the need for a familiarity with geology is evident. 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. To adequately devise a rock evaluation program which will be useful and practical, it is essential to know the location of major structural features in a study area, the distribution of rock types, and the lithologies which have been created during geologic history. Additionally, a knowledge of local geologic nomenclature (Figure 1) is necessary so that information gained from former investigations and past experience can be incorporated into the evaluation system. Information from this base can then be used to

1. ensure that index tests selected for classification purposes are compatible with the range of rock types to be encountered,
2. locate potential trouble areas which are associated with particular types of geologic structures,
3. identify those formations which have exhibited undesirable characteristics (i.e., swelling, solution cavaties, rapid weathering, etc.),
4. evaluate the probable in-situ stresses that have developed during geologic history, and
5. provide an aid in designing a subsurface and testing program to be used for a particular project at a particular site.

ROCK CLASSIFICATION

"Rock Mechanics" may be defined as the study of basic processes of rock behavior and their technological significance. The time scale for these basic

ERA	SYSTEM	SERIES		McFARLAN'S NOMENCLATURE	FORMATION			PREDOMINATE ROCK TYPE			PHYSIOGRAPHIC REGION OF OUTCROPPING
Cenozoic	Quarternary	Holocene Pleistocene		Glacial Drift and Loess	Alluvium Loess Continental Deposits			Silts, Gravels, Sands Silts Sands, Silts, Clays			Jackson Purchase Region
	Tertiary	Eocene		Jackson Wilcox	Jackson Claiborne Wilcox			Unconsolidated Sands, Silts, and Clays			
		Paleocene		Midway	Porter's Creek			Clay, Silt, and Sand			
Mesozoic	Cretaceous	Upper		Ripley Eutaw Tuscaloosa	Eutaw Tuscaloosa			Unconsolidated Sands, Gravels, and Clays			
Paleozoic	Pennsylvanian				Western Coal Field	Eastern Coal Field		Western Coal Field	Eastern Coal Field		Eastern and Western Coal Fields
		Upper		Monogahela Conemaugh	Henshaw-Dixon Lisman	Absent Conemaugh (Boyd Co.)		Sandstones, Shales, and Coals Shales, Sandstones, Limestones, Coals	Sandstones, Shales Limestones, Coals		
		Middle		Allegheny	Carbondale	Allegheny (Boyd Co.)		Shales, Sandstones, Coals, Underclays	Sandstones, Shales, Clays		
		Lower		Pottsville	Tradewater Caseyville	Breathitt Lee		Shales, Sandstones, Coals, Underclays Sandstones	Interbedded Shales Sandstones, Siltstones, and Coals Sandstones and Conglomerates		Knobs Region
	Mississippian	Chesterian			Fluorspar Region	West of Arch	East of Arch	Fluorspar Region	West of Arch	East of Arch	Mississippian Plateaus Region
			Upper	Kinkaid Degonia Clore Palestine Menard Waltersburg Vienna Tar Springs	Kinkaid Degonia Clore Palestine Menard Waltersburg Vienna Tar Springs	Leitchfield (Buffalo Wallow)	Pennington	Limestones Sandstones Limestones Sandstones Limestones Sandstones Limestones Sandstones	Interbedded Shales, Limestones, and Sandstones	Shales	
			Middle	Glen Dean Hardinsburg Golconda Cypress	Glen Dean Hardinsburg Golconda Cypress	Glen Dean Hardinsburg Golconda	Bangor Hartselle	Limestones Sandstones Limestones Sandstones	Limestones Sandstones Limestones Sandstones	Limestones Sandstones	
			Lower	Paint Creek Bethel Renault Aux Vases	Paint Creek Bethel Renault Aux Vases	Elwren Reelsville Sample Beaver Bend Paoli	Monteagle (Newman)	Limestones Sandstones Limestones Sandstones	Shales Limestones Sandstones Limestones	Limestones	
		Meramecian		Ste Genevieve St. Louis Salem Warsaw	Ste Genevieve St. Louis Salem Warsaw (Harrodsburg)			Limestones			
		Osagean		Waverly, New Providence, or Borden	Ft. Payne (South) Borden (North)			Cherty Limestones and Shales Interbedded Shales and Siltstones			
		Kinderhookian		Sunbury Bedford	Sunbury Berea Bedford } occur only in east			Shales Sandstones Shales			
	Devonian	Upper		Ohio Chattanooga New Albany	New Albany			Shales			
		Middle		Sellersburg Jeffersonville Boyle	West of Arch	East of Arch		West of Arch	East of Arch		Outer Blue Grass Region
					Sellersburg Jeffersonville	Boyle		Limestones Limestones	Dolomites		
	Silurian	Middle		Louisville Waldron Laurel Osgood Bisher Crab Orchard	Louisville Waldron Laurel Osgood	Bisher Crab Orchard		Limestones Shales Dolomites Shales	Limestones Shales		
		Lower		Brassfield	Brassfield	Brassfield		Dolomites			
	Ordovician	Upper		Richmond	Southwest Blue Grass	Northwest Blue Grass		Southwest Blue Grass	Northwest Blue Grass		
					Drakes	Drakes		Dolomitic Limestones			
						Bull Fork			Shales		
				Maysville	Ashlock			Limestones			
					Grant Lake	Grant Lake		Limestones			
					Calloway Creek	Fairview		Limestones	Limestones		
				Eden	Garrard	Kope		Siltstones	Shales		
					Clays Ferry	Clays Ferry		Shales	Shales		Inner Blue Grass Region
		Middle		Cynthiana Lexington	Lexington Limestone			Limestones			
				High Bridge	High Bridge			Limestones			

Figure 1. Major Surface and Near-Surface Geologic Formations of Kentucky.

processes ranges from millions of years to microseconds, from orogenesis to blasting. Mechanical properties are affected by stress history, anisotropy, inelasticity, size effects, deformability, and others too numerous to mention. Processes of inelastic, elastic, and time-dependent behavior are all natural occurrences in rock.

Testing of rock in its native environment naturally would be the best approach to determination of mechanical properties to use in the design of structures. The expense of such an approach in obtaining necessary parameters is often economically prohibitive. Elimination of direct determination of rock mechanical properties implies that indirect determinations are the next best approach to obtaining values of these properties, at least for preliminary considerations and planning. Concepts of index properties and index tests encompasses these indirect determinations of significant rock mechanical properties.

Index Properties and Tests

Even the most common rock types are composites of highly variable materials. **Intact rock** may be considered to be a solid consisting of a matrix aggregate of minerals, the properties of which are a function of the mechanical properties of the aggregate constituents and the nature of bonding between the aggregate constituents. Intact rock may be sampled and specimens devoid of large scale structural features can be tested.

In-situ rock masses, however, are affected by geological features such as partings, fractures, bedding planes, cleavage planes, chemical alteration and decomposition zones, stress history effects, and environmental changes. Physical discontinuities, present in all rock masses, occur in the form of planes or surfaces of weakness that actually separate blocks of rock material. Mechanical property tests should be conducted on a scale such that a particular test specimen includes these defects in proportion to their presence in the rock mass so as to obtain results which will be representative of behavior of the in-situ mass. As would be expected, size of the specimen that would encompass these geologic conditions would generally be much too large to be tested under laboratory conditions. The obvious solution would be to test the in-situ rock mass; this solution is limited by difficulties encountered in preparing an "area specimen" and applying a necessary and sufficient magnitude of force on undisturbed rock masses. It is necessary to develop and use simple, inexpensive, reproducible indicator tests which predict intact sample rock properties and to forecast rock mass behavior on the basis of index test values and a knowledge of discontinuities and other features present in the rock mass. Development of index tests is an integral part of any rock engineering evaluation scheme. Probably the greatest usefulness of index properties lies in the fact they provide quantitative methods for assigning a particular rock a specific classification independent of the background knowledge and experience of the operator performing the index test. Once a rock has been classified, expected ranges of the values of such mechanical properties as strength, deformability, weatherability, and permeability can be estimated. This allows design parameters to be established and alerts the engineer to potential problems and(or) expected performance.

Complexities involved in even the most superficial overview of rock geognosy require extreme simplification because of physical and mathematical continuity considerations:

1. the scale of rock discontinuities and structural features cannot be preserved in intact laboratory specimens, and thus considerable uncertainty as to the extrapolation of laboratory property values to field situations is inevitable;
2. rock discontinuities and inhomogeneities play a dominant role in terms of rock deformation and failure for both intact and in-situ conditions;
3. "constants" used in simplified mathematical models are statistical functions of these discontinuities and heterogeneities; and
4. discontinuities introduce a probability of unpredictable variations in the geologic conditions which should be considered.

Mechanical properties which are a function of the structural competence of a rock sample may be predicted on the basis of empirical relationships among "index properties" obtained in specific physical-mechanical classification tests.

Except in certain specialized applications, there are no standards to guide the engineer in selecting appropriate indicator tests. Of course, classification tests should be chosen so that, regardless of geologic origin, specimens with similar index properties should exhibit similar mechanical behavior. Obviously, an engineering classification system for intact rock should be based upon index properties statistically related to important physical-mechanical properties of the rock mass. "Index tests" are used for classification purposes and should be distinguished from "design tests," which are usually expensive and may involve considerable complexity because of size requirements and the need to simulate field conditions. In general, an index property should have three characteristics:

1. the test result must be an index of a material (mechanical) property which the design

engineer can use effectively;

2. the test should be simple, inexpensive, and rapidly performed (minimum sample preparation); and
3. test results must be reproducible, within reasonable limits, by various practitioners in various locations using standard equipment and procedures.

Additionally, index properties may be used to define exactly what constitutes rock within the context of a particular investigation. It would be useful, in many situations, to establish the index property which would delineate "rock" from "soil" or "rock-like" from "soil-like" materials.

A variety of index properties relevant to the mechanical quality of rock masses includes

anisotropy
apparent specific gravity
brittleness
brokenness
core recovery
deformation modulus
degree of alteration
dilatational wave velocity
fracture frequency
hardness (rebound and indentation)
joint extension
modified core recovery (RQD)
Poisson's ratio
porosity
relative absorption
residual shear strength
resilience
secant modulus
slake durability
swelling
tangent modulus
tensile strength
toughness
uniaxial compressive strength
unit weight
void index
water content
weatherability
Young's modulus

Additionally, complete testing of rock material should not be confined strictly to tests of the rock core; valuable information may be obtained within a borehole. Pumping tests, borehole sonic velocity, electrical resistivity, and gamma ray emission logs are useful for stratigraphic and mechanical or physical correlations. Since local or overall displacements limit the utility of an engineering structure, index tests and(or) properties that are indicative of compressibility or displacement should be included in classification systems. However, measures of deformation moduli or mass compressibilities are extremely difficult to obtain and involve complexities (state of in-situ stress, discontinuities, etc.) which are yet to be resolved.

Geologic Classification Systems

From a geologic overview, there exists an almost universal division of rocks with respect to their origin (genesis) into three primary groups:

1. igneous rocks -- rocks formed by cooling of molten magmas or by the recrystallization of older rocks after the application of heat and pressure of such magnitude as to render them fluid;
2. sedimentary rocks -- rocks formed as products of deposition of plant and animal remains, from materials formed by chemical decomposition, and from products of the physical disintegration of pre-existing rocks; and
3. metamorphic rocks -- rocks produced from pre-existing rocks by the effects of heat, pressure, or permeation by other substances.

Each of these primary rock groups have been the subject of individual rock classification systems.

One of the first classifications of igneous rock considered the general composition of the rock. Many authors have modified the original system, but essentially glassy, aphanitic, and granular igneous rocks are described in terms of their proportions of orthoclase feldspar, quartz, plagioclase feldspar, and ferromagnesian minerals. Additional megascopic classification of igneous rock is accomplished on the basis of the degree of visibility of grains (crystals) within a particular rock.

Classifications of sedimentary rocks notably group the rocks into origin, texture, and particle size or composition categories; e.g., detrital, inorganic, and biochemical genetic categories; clastic and nonclastic textural categories, and particle-size classes. Rocks of mixed fabric or composition can be further classified as to predominant constituents -- clays, sands, etc.; e.g. sandy shale, clayey sandstone, or calcareous shale.

Metamorphic rock classifications are generally based upon visible fabric and mineralogy. Foliation or schistosity is conspicuously apparent in metamorphic rocks with the general exceptions of quartzite, marble, dolomitic marble, and hornfels.

Petrographically, the most important properties in terms of a classification system are texture, structure, and mineralogical composition. Because of the lack of agreement among geologists as to exactly which physical features should be included in "texture" and which features should be regarded as "structure", the term fabric has been coined to include both concepts. Texture may be thought of as the size and shape of rock constituents, including accompanying variations of properties. Structure includes distribution and grouping of minerals, which are constituents of rock. Petrological data can aid in predicting mechanical performance (behavior); for example, microfractures detected in quartz crystals in a granite would be significant with respect to strength of granite. Megascopic fabrics in rocks also have been classified with respect to isotropy and anisotropy; e.g., isotropic fabrics and anisotropic fabrics include such subdivisions as linear, planar, intersecting planar, omni-directional planar, folded planar, and composite fabrics.

A chemical classification system is primarily useful only for rock comparison on the basis of chemical activity since, in most chemical classification systems, constituent oxides are reported as percent by weight. It is impossbile, however, to estimate many physical characteristics of a rock from chemical analysis alone since rocks of closely related chemical composition may differ in genesis as well as in texture and mineralogy. However, chemical classifications may be of use in predicting the behavior of rock in certain "chemical" applications (e.g., bituminous concrete mixtures, portland cement mixtures, resistance to chloride attack, expansibility, etc.).

Such descriptive indicators as genesis, petrography, texture, mineralogy, and chemical composition give only vague information concerning the engineering behavior and capabilities of the rock. Geologic classification systems do not give comprehensive information as to rock properties in terms of mechanical behavior of the in-situ rock masses. Geological rock classification systems emphasize the solid constituents of intact rock while an engineering rock classification should consider discontinuities of the rock mass (e.g., pores, cracks, and fissures) because of their great mechanical significance.

Topographic relief is often sufficiently characteristic to be indicative of the geology of the bedrock, even though very few rock exposures may be present. Thus, classification of landforms as they relate to errosional or depositional history and subsurface geology have been developed utilizing aerial photographs, topographic maps, and drainage patterns.

An interesting exception to the qualitative approach of most geological mapping surveys is the Pattern-Unit-Component-Evaluation. Terrain was classified into three major stages; pattern, unit, and component. A geomorphological description was found suitable for a qualitative description of "terrain pattern" while relief amplitudes and stream frequencies were found to be factors suitable for a quantitative expression. A "terrain unit" was descriptively a physiographic unit and was quantified by dimensions of the unit (relief amplitude, length, width, etc.). Finally, the "terrain component" was described by the lithology, soil type, and vegetation association. The quantified terrain component measured in situ identified particle size distribution, strength, permeability, mineralogy, and various dimensions of surface obstacles, vegetation, and relief.

Engineering Classification Systems

Intact Sample Classification

Classification systems based on the physical character of intact rock materials (Figure 2) overcome the problem of irrelevant geologic nomenclature based on a wide range of mineralogical compositions, textures, and weathering conditions occurring in different rock types. Often the mechanical performance of rock material is predicted more rapidly and more accurately by mechanical testing, but usually both visual observations and mechanical tests are required to provide data for design purposes. A rock classification system may be based upon inherent rock characteristics, may be formulated on the basis of the particular purpose for which the rock is to be used, or may be based on a combination of both inherent characteristics and intended usage. An intact rock classification system can form the basis of systematic analyses for the prediction of performance.

There are six characteristics important to rock engineering which should be the basis for a rock engineering classification system:

1. strength,
2. deformability or pre-failure deformation characteristics,
3. lithology,
4. gross heterogeneity or anisotropy,
5. durability or failure characteristics, and
6. rock continuity or mass partings.

These characteristics tend to overlap when used in intact sample and in-situ classification systems. An intact sample system, because of the very nature of specimen size effects, should include the following properties: strength (tensile), lithology, specimen anisotropy, and durability (Figure 3).

Tensile Strength -- Since rock strength is an important property, a suitable strength index test is required. Penknife, pick, and hammer tests seldom provide objective, quantitative, or reproducible results. Although unconfined uniaxial compressive tests have been used in rock classification systems, the test requires machined specimens. Hardness tests tend to be strongly influenced by variations in testing techniques. Irregular lump tests have been used successfully by many investigators as a strength indicator. The point load

- 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

Figure 2. **Summary of Typical Attributes of Intact Sample Rock Classification Systems.**

strength index provides a measure of tensile strength, and empirical results show excellent correlation between this index and unconfined compression strength.

Lithology -- Traditional geologic rock names are based on such properties as texture, mineral content, structure, particle size, and cementing matrix. Although these properties provide a better indication of geologic history than of mechanical properties, a rock name may provide a "feeling" for the rock character and suggest mass effects which might be widespread among specific groups of rock.

Specimen Anisotropy -- In general, most rock is anisotropic (measured mechanical properites are a function of specimen orientation). Most elastic sedimentary rocks are slightly to strongly anisotropic in such mechanical properties as thermal conductivity, velocity of elastic waves, electrical conductivity, and fluid permeability. Permeability and the point load test has been applied successfully in the logging of cores. The point load test is used to define the "strength anisotropy index" as the ratio between the maximum and minimum point-load strength indices.

Durability -- Durability refers to the extent of alteration a rock will exhibit under different environmental conditions. Short-term weathering of rock has been measured with various degrees of success by abrasion tests, sulfate soundness tests, absorption tests, slake tests, and swelling tests.

Differentiation between soil and rock materials for classification purposes is important in terms of laboratory procedures to which the materials will be subjected. Several methods for separating compacted (soil-like) materials from cemented (rock-like) materials have been used. Probably the better methods for a measure of durability from an engineering standpoint are swell tests and(or) slake-durability tests. Plots of dry apparent specific gravity versus saturation water content have also been proposed to delineate weak rock and soil materials from "rock-like" cemented and compact rock materials. A qualitative differentiation whereby rock material is that which cannot be sampled by driving a steel sampling tube, whereas most soil material can be so sampled, is susceptible to operator bias. The use of wet-dry cyclic weathering to distinguish among transitional materials has been proposed by many investigators. Thus far, the best method of soil-rock differentiation appears to be a durability-plasticity rating (Figure 4).

In most instances, design parameters necessary for construction projects are unattainable from direct testing of intact samples; most in-situ tests are uneconomical to perform both with regard to time and expense. Rock mapping investigations to determine the behavior of rock in its natural environment, first through an analysis of the current in-situ state of the rock and

	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 3. **Proposed Intact Sample Classification System.**

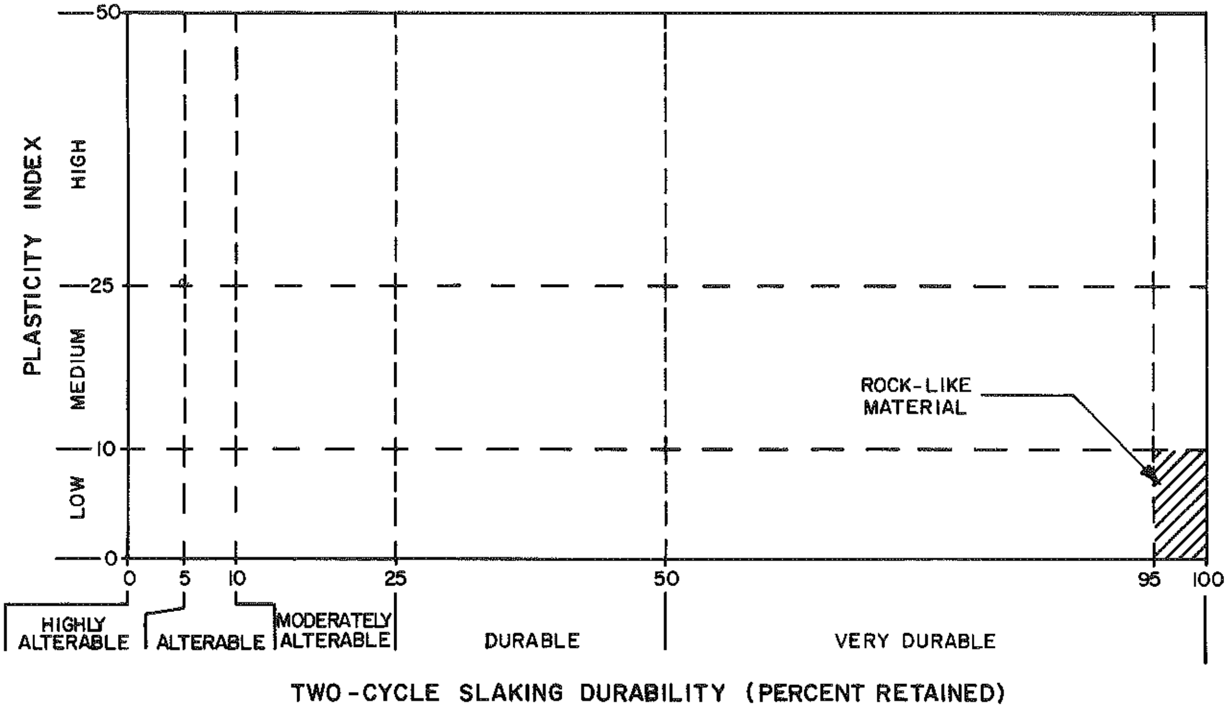

Figure 4. Durability-Plasticity Classification for Shales and Other Argillaceous Rocks (after Gamble, 1971).

second through prediction of the consequences of anthropogenic activities which may occur, require specific testing techniques (procedures): rapid sample preparation and testing, simplicity of testing, portable apparatus for some field testing to obviate deterioration of samples in transit, relevance to rock properties, relevance to engineering problems, and power of discrimination. These should be guidelines to simple, efficient relevant testing without inherent large errors of measurement.

In-Situ Classification Systems

Significant engineering properites of a rock mass can be measured directly in situ (i.e., direct deformation or shear tests, measurements of deformations resulting from environmental alterations, etc.). In most cases, the expense of these tests is prohibitive. Such circumstances warrant use of exploratory tests (for example, borehole logging tests, borehole photography, pumping tests, and geophysical tests) which can be related to engineering properites. Such correlations are the basis for an engineering classification of in-situ rock.

A brief survey of in-situ classification systems (Figure 5) revealed several interesting facts:

1. there are relatively few general in-situ classification systems;
2. in-situ systems have been, for the most part, working site evaluations either for tunneling or blasting requirements or for characterizing a particular site and rock complex;
3. major concerns in existing systems have been rock quality (bedding character, joint frequency, and weathering or alteration), lithology, deformation characteristics, and velocity ratio;
4. some systems utilize laboratory measurements such as unconfined uniaxial compression strength, static modulus, and static sonic velocity on intact specimens; and
5. in-situ tests utilized to a significant degree included seismic velocity, plate jacking, permeability, modified RQD, and borehole analysis tests.

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

Figure 5. Summary of Typical Attributes of In-Situ Rock Classification Systems.

Strength and deformation characteristis of in-situ rock are dependent upon both the physical properties of the intact rock and the number, nature, and orientation of discontinuities in the in-situ rock mass. To evaluate in-situ rock behavior, the engineer first should investigate the physical-mechanical properties of representative intact samples. Then, because the in-situ rock is discontinuous, the engineer should use reduction factors to adjust the "upper limits" defined by a statistical analog of intact samples. Both intact sample properties and discontinuities determine the engineering behavior of the rock mass with respect to strength, deformability, and permeability.

There has been, in recent years, a tendency to characterize a rock mass by means of a rock mass model and(or) a joint survey. The model may be physical, mathematical, or physio-mathematical consisting of three basic parts: consitutent rock material, joints and faults as potential planes of structural weakness, and environmental conditions before, during, and after construction. These three aspects lend themselves to intact sample classification, in-situ classification, and rock monitoring systems as part of the proposed rock evaluation schema. The joint survey is a systematic, statistical procedure by which data are collected to construct the rock mass model. While the use of such techniques as impressographs and coefficient of joint volume decrease are beyond the scope of this research, the use of a modified joint and(or) fault survey is an integral part of the rock quality description within the in-situ rock classification system (Figure 6).

PROPOSED ROCK EVALUATION SCHEMA

A viable rock evaluation program must allow practitioners and researchers to exchange information to their mutual benefit and advancement of the study of rock behavior in general. The practitioner brings performance information and experience to the exchange and receives data on which to base future design and construction procedures. The researcher is provided with a data base from which advancement in behavior prediction can be made. For planning purposes, a program must provide engineers with a sufficient basis for

1. site selection,
2. facility design,
3. construction considerations, and
4. maintenance considerations.

To be universally acceptable, a rock evaluation schema must present general information in such a way that it can be used for many specific purposes. Most importantly, the rock evaluation schema is task oriented. The task is to present a total description of rock -- intact, in situ, and the ensuing environmental effects.

The proposed rock evaluation schema consists of two segments (Figure 7). The central feature of the **acquisition segment** is the data bank. Input for the data bank will come from field and laboratory testing and case history information (i.e., previous experience, contemporary construction experience, and monitoring the performance of completed projects). The **application segment** involves the classification and use of the acquired data for specific purposes. The program is versatile in that classification and use tables for several purposes may be devised and used interchangeably without affecting the acquisition segment of the program.

Acquisition Segment

Data Bank Format

The data bank consists of a system of computer files arranged in three categories (Figure 8) which allow systematic storage and convenient retrieval of accumulated information. Category 1 contains information pertinent to the location, identification, and natural environment from which the sample or information (case histories, performance reports) is(was) taken. Category 2 contains results of visual observations, index tests, and advanced tests for both intact and in-situ rock. Category 3 provides for an indication of the existence of case history reports of previous experience, contemporary construction experience, and information to be derived from rock monitoring

	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 6. Proposed In-Situ Rock Classification System.

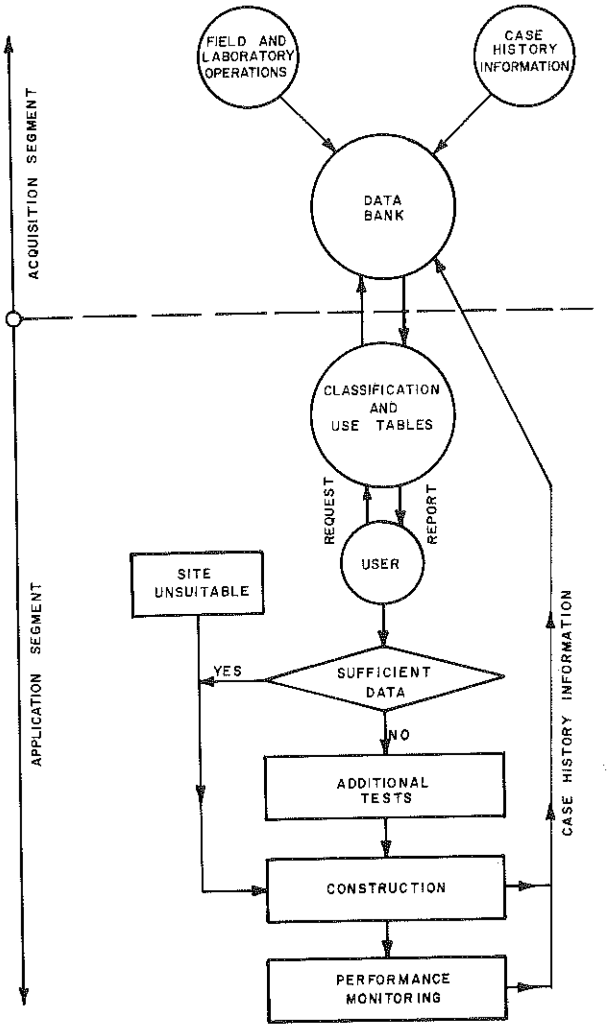

Figure 7. **Schematic Diagram of the Proposed Rock Evaluation Schema.**

programs.

Field and Laboratory Sampling and Testing Data

There is some overlap between field and laboratory methods used to obtain data for Categories 1 and 2 of the data bank. Information for Cateogry 1 (Figure 9) is acquired in the field and provides a description of the sampling site and of the sample type, orientation, and source.

Rock material removed from its environment should be characterized by quantitative and qualitative descriptions. Before performing index or other tests, intact specimens should be described on the basis of a visual examination to include petrographic and megascopic fabric indications of color, texture, structure, particle size, and relative content of calcium carbonate.

Ideally, samples should be tested at the site immediately after removal from the core barrel. This is not practical in all situations, however, because of insufficient qualified personnel, lack of portable equipment, or both. In such cases, samples should be preserved at their natural water content and carefully transported to the laboratory for testing. Testing should always begin with the swell test and the slake-durability test to indicate whether the material is to be treated as a soil or is to be subjected to rock classification.

Unfortunately, the variability of rock material is such that the identification and testing of intact specimens provide only a limited description and(or) indication of rock character and engineering performance. A complete rock evaluation schema requires minimal in-situ competency and rock quality investigations. In-situ rock material requires different indexing parameters and testing procedures even though the major concern, as with intact specimens, is strength, deformability, and permeability characteristics. Tests and observations as indicated in the visual and indexing sections of the intact and in-situ portions of Cateogry 2 (Figure 10) are performed to describe the rock material.

More refined laboratory (direct shear, triaxial, etc.) or large scale in-situ (pumping, plate jacking, etc.) tests may, at times, be required for detailed study of special projects. Information obtained from these tests is also stored in Category 2.

Case History Information

Certain types of empirical knowledge are not easily quantified for inclusion in a data storage system. Such data include information obtained through previous experience in an area or with a particular formation (i.e., occurrence of landslides, swell or heave tendencies, settlement, hydrologic problems, etc.), information obtained from contemporary construction procedures (i.e., success or failure of excavation methods, problems encountered, corrective measures, etc.), and information that can be gained from performance monitoring programs (i.e., weatherability rate, performance of slopes, maintenance required for various types of facilities, notations of swell, heave, and settlement, etc.). Information of this type will be handled somewhat differently. A concise version of the empirical information obtained is to be placed in a coded reference file. The code and identification of the site and(or) formation will be entered in the data bank (Category 3) (see Figure 11) so that, when a search is made, the existence of the information will be made known to the searcher. It is desirable to have or obtain samples for index testing from sites where case history information is available for correlation purposes.

Application Segment

Use of this segment of the rock evaluation program to obtain information for a specific purpose requires two

COUNTY		LOCATION		CATEGORY 1
PHYSIOGRAPHIC REGION				
USGS QUADRANGLE NUMBER				
LONGITUDE				
LATITUDE				
SAMPLE IDENTIFICATION NUMBER				
MAJOR GEOLOGICAL FORMATION				
ROCK TYPE (GENETIC)				
GROUND ELEVATION				
SAMPLE ELEVATION				
WATER TABLE ELEVATION				
SAMPLE ORIENTATION w/r GROUND SURFACE				
SAMPLE ORIENTATION w/r BEDDING PLANE				
METHOD OF OBTAINING SAMPLE				
RELEVANT COMMENTS				
COLOR		VISUAL	INTACT	CATEGORY 2
TEXTURE				
STRUCTURE				
GRAIN SIZE				
CALCIUM CARBONATE				
FREE SWELL		INDEXING		
SLAKE DURABILITY				
POINT-LOAD INDEX				
ANISOTROPY INDEX				
LITHOLOGY				
LAB SONIC VELOCITY		PHYSIO-MECHANICAL RESULTS		
SHORE SCLEROSCOPE				
SCHMIDT "L" HAMMER				
UNIAXIAL COMPRESSION				
TANGENT MODULUS @ $\sigma_{ult(50)}$				
NATURAL MOISTURE CONTENT				
SATURATION WATER CONTENT				
DRY APPARENT SPECIFIC GRAVITY				
UNIT WEIGHT				
APPARENT POROSITY				
REAL POROSITY				
VOID FILLING				
APPARENT SPECIFIC GRAVITY				
WATER ABSORPTION				
VOID INDEX				
DRY DENSITY				
DIRECT SHEAR STRENGTH				
TRIAXIAL COMPRESSION				
LOS ANGELES ABRASION				
DEVAL ABRASION				
TRETON IMPACT				
FRACTURE ENERGY				
COST ANALYSIS				
STRENGTH COEFFICIENT OF VARIATION				
SCALE EFFECT				
MINERALOGY				
BEDDING THICKNESS	ROCK QUALITY	MASS DESCRIPTION (INDEXING)	IN SITU	
JOINT SPACING				
JOINT FREQUENCY				
JOINT INFILTRATION MATERIAL				
GROSS HETEROGENEITY				
VELOCITY RATIO				
ORIENTATION				
JOINT SURVEY				
CORE RECOVERY	CORE BORINGS	SECONDARY INDEXING		
RQD				
FRACTURE FREQUENCY				
WEIGHTED LENGTH TECHNIQUE				
SCHMIDT HAMMER TEST				
GEOPHYSICAL SURVEYS				
FIELD TESTS				
PHYSIOGRAPHIC/TERRAIN CLASSIFICATION				
PREVIOUS EXPERIENCE				CATEGORY 3
CONSTRUCTION PRACTICES				
PERFORMANCE MONITORING				

Figure 8. Data Bank Attributes.

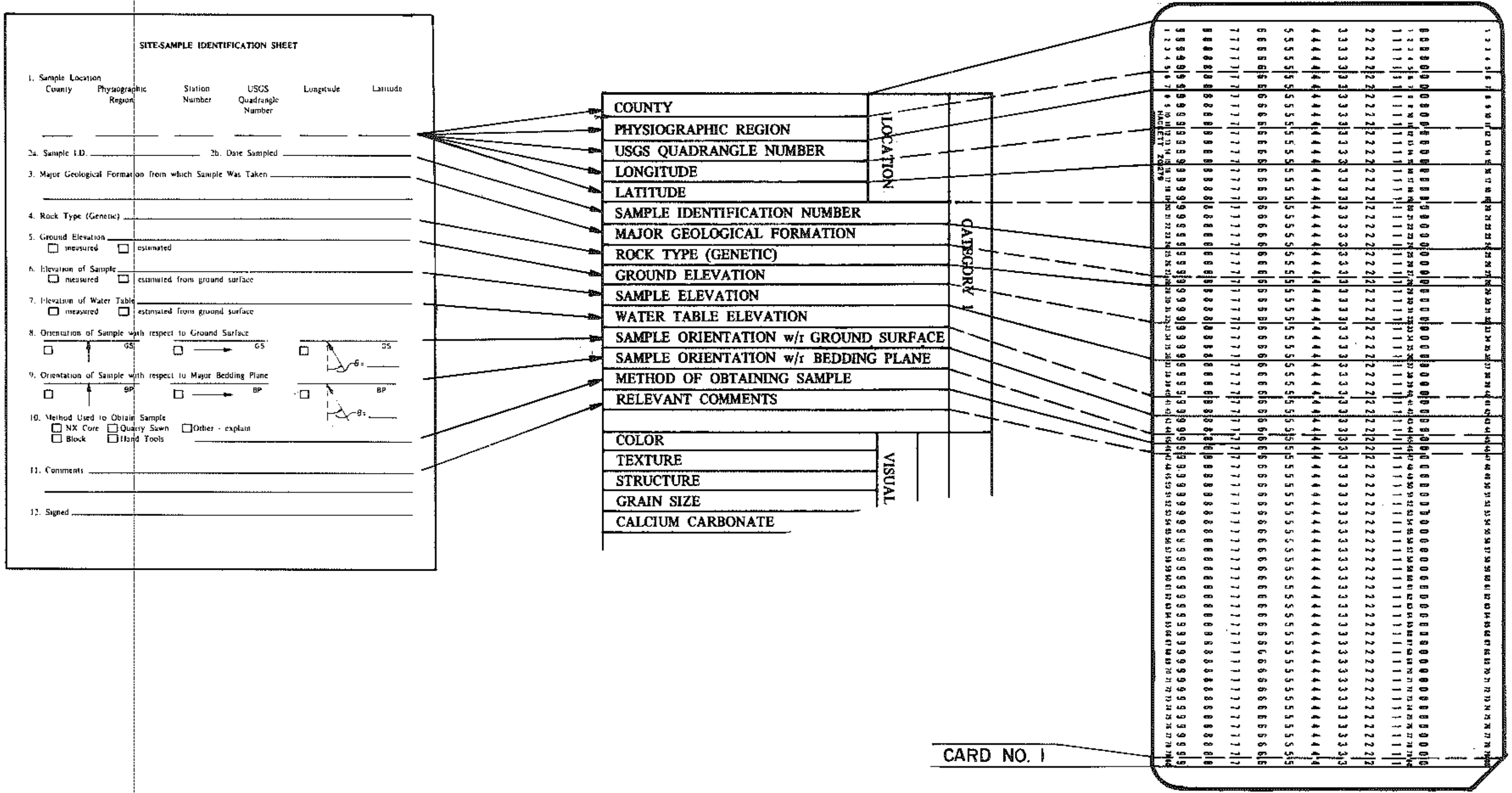

Figure 9. Category 1 (Site and Sample Description) File Subsystem.

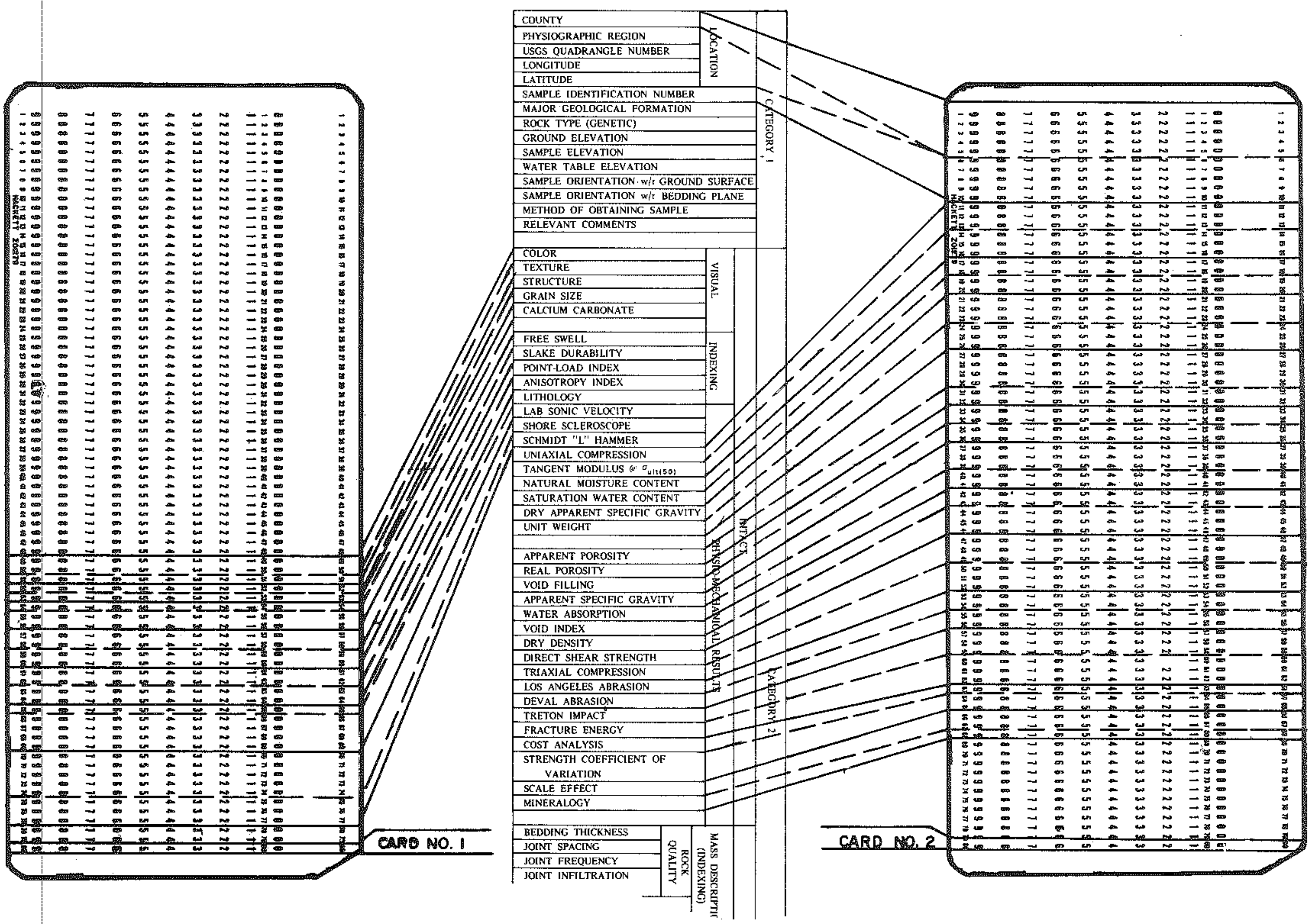

Figure 10a. Category 2 (Intact Sample Data) File Subsystem.

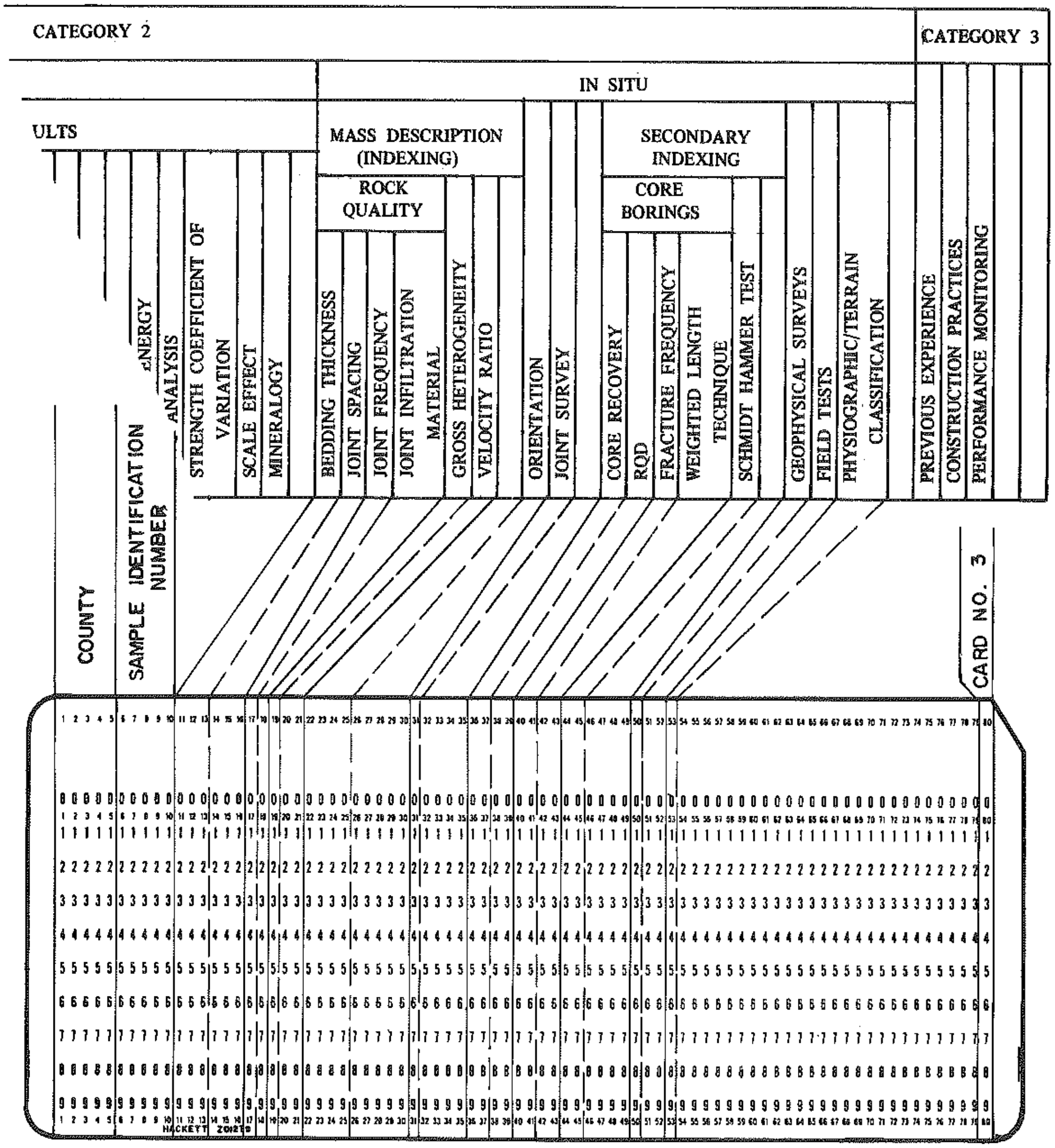

Figure 10b. Category 2 (In-Situ Data) File Subsystem.

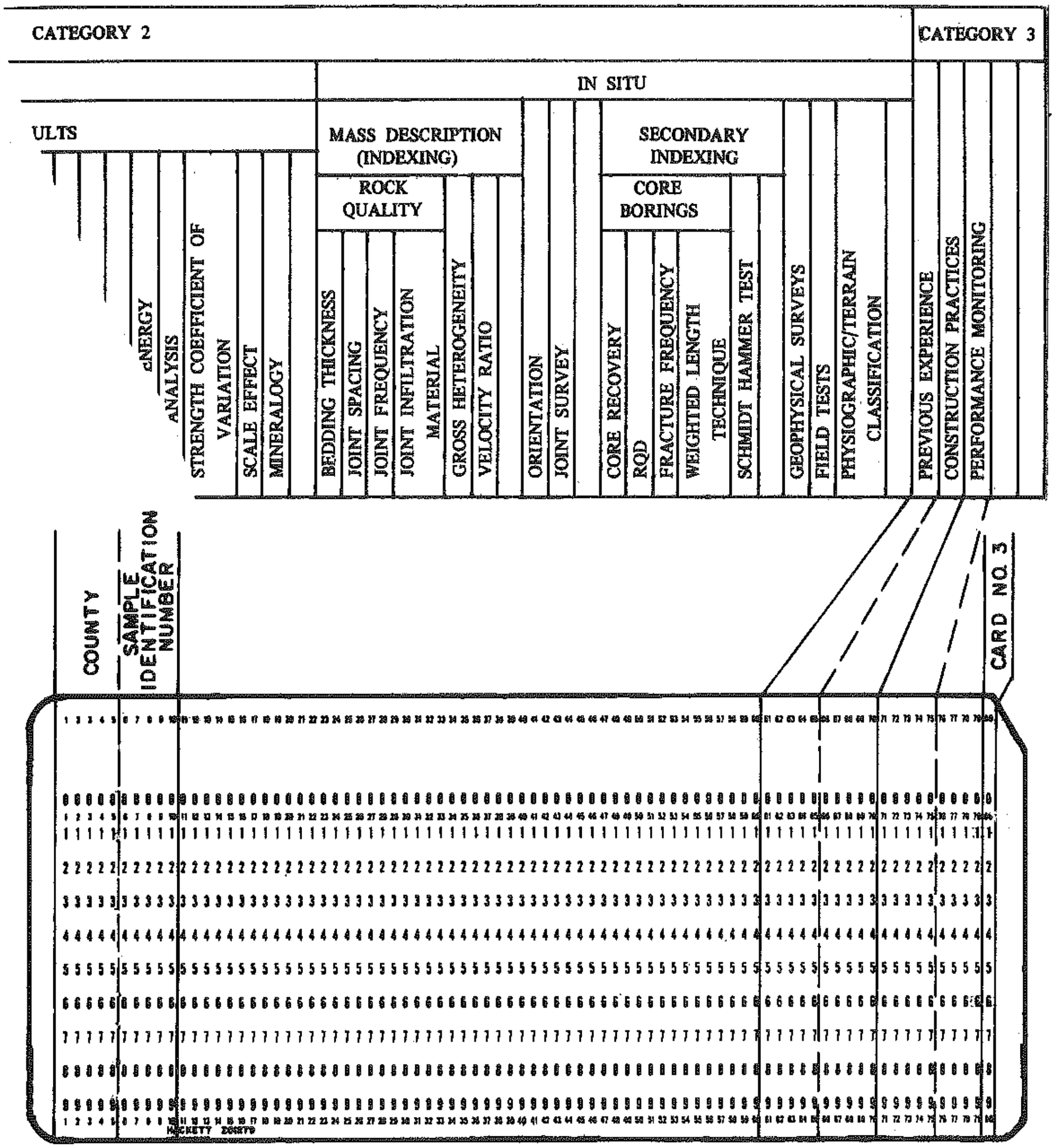

Figure 11. Category 3 (Case History Data) File Subsystem.

preliminary steps. First, the classification system must be adapted (ranges of properties for each parameter or the parameters themselves changed) depending on the intended use. Second, an use table (Figure 12) encompassing applications relevant to the intended use must be developed and appropriate ranges of the index parameters determined. An use table provides a rock model for a particular situation. For example, a specific use table would indicate the minimum values of parameters necessary to implement a design criteria while the data bank is a systematic accumulation of physico-mechanical rock characteristics which will eventually enable a total description of the rock. The program itself is very versatile due to the fact index parameters used in the acquisition segment are standardized to a great extent. Therefore, any classification system that uses these standard parameters can be used with it.

Once the classification system and use tables have been established, use of the accumulated data is quick and convenient. The data may be used to obtain statistical information of a specific geological formation and(or) to obtain specific information about a particular site. A request for data is input into the system; a detailed report of all available information is returned. Using this information in conjunction with classification and use tables, a decision is made that

1. there is suffucient information available for the particular design requirements,
2. the site or formation is not suitable for the intended purpose, or
3. the site or rock formation appears feasible but further investigations are needed to obtain design parameters.

The value of the schema depends upon the amount and quality of information which is fed into the system. Information gained during and after construction and monitoring should be fed back into the data bank for retention and future reference. In this way, the program becomes self perpetuating.

SUMMARY

The scope of rock engineering encompasses at least three major concepts: engineeing interpretation of geological considerations, determination of engineering properties of in-situ rock masses for analysis, and application of these analyses to designs related to rock masses. To facilitate communication among various professions associated with rock engineering, a rock evaluation schema has been proposed in which engineering data are inserted into a classification system wherein the data are evaluated in terms of specific needs. Input data are derived by means of completed and future testing, project construction experience, and monitoring designed to quantify environmental effects on the performance of engineered facilities. To aid in this endeavor, both an intact rock sample classification system and an in-situ rock mass classification system have been designed. In addition, the usage table concept in which ranges of acceptible engineering parameters are developed for use in designs using rock as an engineering construction material has been suggested.

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 Use Table.

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