Research Report
416

DATA ACQUISITION AND MANAGEMENT FOR ROCK EVALUATION

KYP-64-13, HPR-PL-1(10), Part III

by
M. W. Palmer
Formerly Research Engineer Assistant

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

February 1975

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
DATA ACQUISITION AND MANAGEMENT
FOR ROCK EVALUATION

5. Report Date
February 1975

6. Performing Organization Code

7. Author(s)
M. W. Palmer

8. Performing Organization Report No.
416

9. Performing Organization Name and Address
Division of Research, Bureau of Highways
Kentucky Department of Transportation
533 South Limestone
Lexington, Kentucky 40508

10. Work Unit No.

11. Contract or Grant No.
KYP-64-13

12. Sponsoring Agency Name and Address

13. Type of Report and Period Covered
Interim

14. Sponsoring Agency Code

15. Supplementary Notes
Study Title: Engineering Geognosy

16. Abstract

The primary goal of this thesis was the formulation of an integrated effort to collect, maintain, exchange, and evaluate engineering data on rock materials from a variety of information sources. The proposed rock evaluation program provides a data base of accumulated information by establishing procedures for characterizing rock, from specimen acquisition through indexing, classification and correlation studies of data, and the application of data for site selection, use tables, establishment of design parameters and alternatives, and maintenance of engineered facilities. The co-ordinated evaluation system detailed herein provides guidelines for implementation of an extensive system of data storage and retrieval to investigate the physico-mechanical aspects of both intact rock samples and in-situ rock masses. The exchange of disciplined information would be to the mutual benefit of practicing engineers and research scientists and would advance the study of rock behavior.

17. Key Words
Rock Properties
Data Files
Indexing
Data Management

18. Distribution Statement

19. Security Classif. (of this report)

20. Security Classif. (of this page)

21. No. of Pages

22. Price

CHAPTER I

INTRODUCTION

BACKGROUND

The Council of the International Society for Rock Mechanics, at its 1967 Salzburg meeting, designated a commission to study and report on the most promising areas of research. By February 1969, some four thousand inquiries had been sent to ISRM members and associated institutions concerned with rock mechanics. From an initial list of 21 specific problem areas relating to practical rock mechanics, the commission selected ten priority areas encompassing the original suggestions of the commission and suggestions returned with responses to the inquiries. Further analysis established seven research subjects. The final report (1971) discussed the seven subjects in terms of definition, importance, probability of success, and the best approach to a solution. These seven subject areas were:

a) determination of time-dependent strength and deformation characteristics of rock masses,
b) correlation of mechanical properties with geologic and petrographic data,
c) tunnelling - remote sensing of properties and environmental conditions ahead of the working face,
d) rock mass stabilization,
e) porosity and permeability,
f) evaluation of slope failure characteristics, and
g) measurement of the state-of-stress before and after excavation and construction.

The primary purpose of the present investigation was the formulation of an integrated rock evaluation schema providing a modus operandi from rock sample acquisition, geologic-petrographic-mechanical indexing and classification, through data storage and usage mechanisms coupled with rock performance monitoring to feed back pertinent information into the data storage bank. Included within this systematic evaluation program would also be a means of storing and retrieving case history information -- that is, qualitative information which reflect possible and(or) probable engineering design, construction, and monitoring problems and solutions. The initial report outlining the development and implementation of an overall functional rock program, compiled by Tockstein and Palmer (1974), presented the acquisition and application segments of a rock information system. Specifically, that first report consisted of discussions of the following:

a) Geological Considerations: the geology of Kentucky, including its history, structural features, stratigraphy, and lithology, and present nomenclature;
b) Rock Classification and Index Properties: the concept of mechanical characteristics expressed

as index properties and a state-of-the-art review of classification systems -- both geologic and engineering;

c) Proposed Rock Classification System: tentative intact and in-situ classification systems (Figures I and 2);

d) Proposed Rock Evaluation Schema: a program (Figure 3) to facilitate storage, retrieval, and usage of accumulated information utilizing both an acquisition segment (data bank, field and laboratory operations, and case history information) and an application segment (proposed rock classification system, data usage tables, and monitoring surveillance);

e) Transitional Materials -- Clay Shale, Shale, Mudstone, Claystone, and Other Argillaceous Sediments: a historical categorization of rock-soil differentitation for engineering purposes;

f) Intact Rock Classification Systems: a survey of 17 rock identification systems;

g) In-Situ Rock Classification Systems: a survey of 15 in-situ rock classification systems; and

h) Correlation Parameters: a comprehensive review of index properties, standarized test procedures, and engineering constants relative to rock indexing, classification, and design.

SCOPE

This present treatise extends and further delineates the work of Tockstein and Palmer (1974). This will accomplished in the following chapters herein:

a) CHAPTER II: a complete listing of rock properties obtained from published and some unpublished research data as input data for the data bank component of the acquisition segment of the rock evaluation program. In addition, physiographic, petrographic, and geologic classifications are incorporated.

b) CHAPTER III: introduction to information presently (1974) available concerning transitional materials (strong soil and weak rock) as a basis for a prototype Transitional Material Data Bank. Engineering problems and solutions are addressed in terms of test parameters necessary to either directly aid the design engineer or researcher.

c) CHAPTER IV: statistical interpretation of test results with regard to rock investigations is introduced. In addition, an overview is given of predominant sources of error within a testing program and within various sampling procedures, which in turn determines the numbers of samples to be regarded as being representative of a rock mass.

d) CHAPTER V: data management and theory of operating information systems is discussed with regard to two existing computer "package" programs.

e) CHAPTER VI: basic concepts of rock property correlations and the objective of "use tables" as quantitative design rock models are explained.

f) CHAPTER VII: conclusions and a summary are presented.

	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. Intact Sample Classification System.

	STRENGTH AND DEFORMABILITY - ROCK QUALITY (CONTINUITY)							GROSS HETEROGENEITY		INTACT - IN-SITU REDUCTION FACTOR[a]		LITHOLOGY	
	BEDDING		JOINT SPACING		JOINT FREQUENCY								
CLASS NO.	WORD DESCRIPTION	BEDDING THICKNESS (mm)	WORD DESCRIPTION	SPACING (mm)	WORD DESCRIPTION	JOINTS PER METER	JOINT INFILTRATION MATERIAL[a]	WORD DESCRIPTION	PERMEABILITY (m/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 2. In-Situ Rock Classification System.

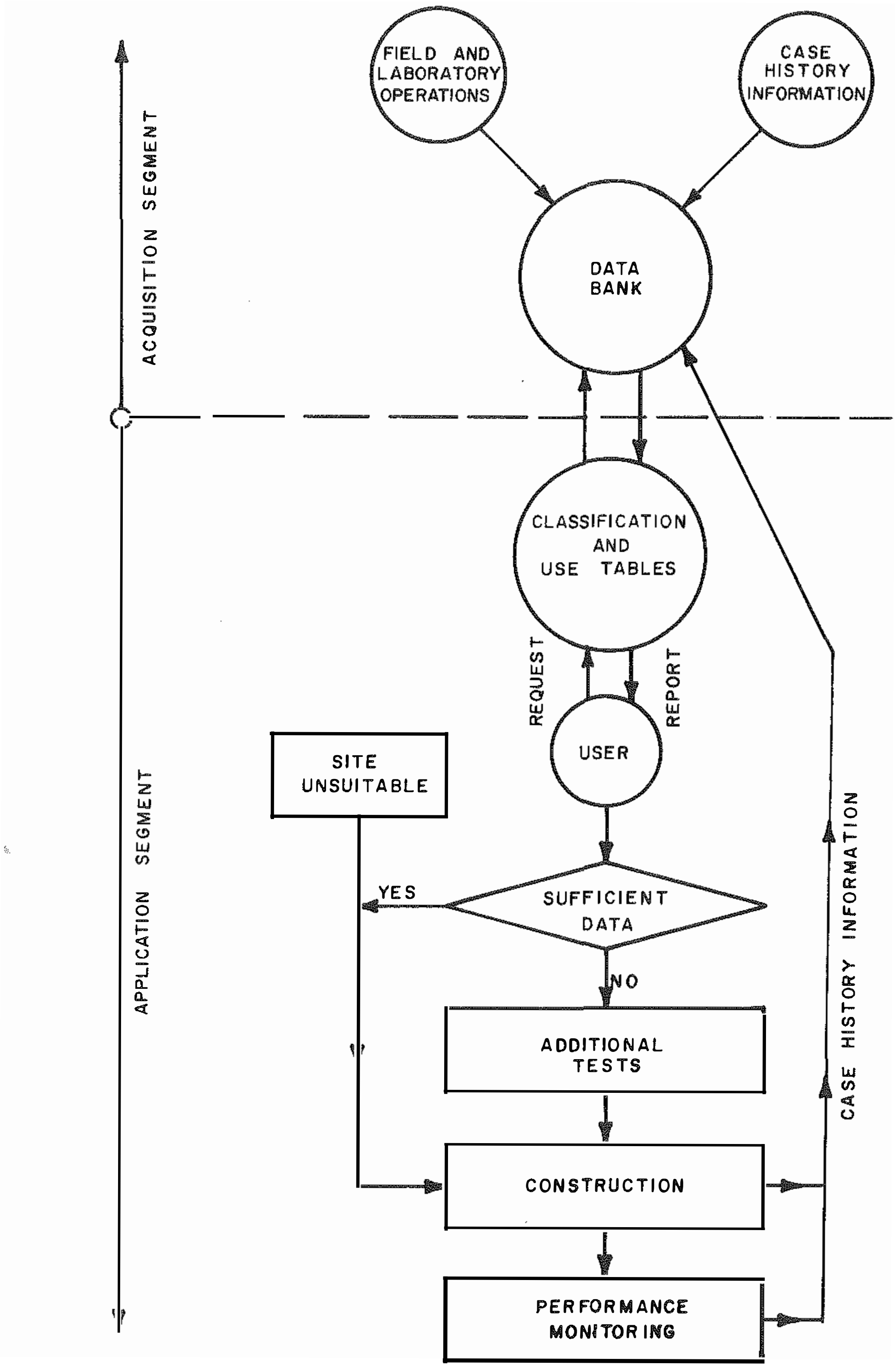


Figure 3. Schematic Diagram of the Proposed Rock Evaluation Schema.

CHAPTER II

DATA BANK

PREVIOUS WORK

As envisioned by Tockstein and Palmer (1974), data bank attributes would consist of three categories of information (see Figure 4):

a) Category 1: information obtained as part of the field acquisition of rock specimens and site description;

b) Category 2: results of visual, index, specific and large scale tests of intact and in-situ rock, and petrographic and mechanical properties; and

c) Category 3: quantitative and qualitative information from previous experience and from performance monitoring.

The first two categories would be a direct result of field and laboratory operations and observations of rock specimens and the rock massif. The third category would encompass both case history information and a rock monitoring program.

A central source of information would be the first step in coordinating efforts of the engineering and scientific communities in seeking available information. Comparatively few systematic approaches of describing and interpreting rock material for engineering purposes have been developed. Results of exploratory probings and subsequent information obtained is vitally important to the rational assessment of the engineering behavior of rock substances (Knill and Jones, 1965). The data bank concept is a means of communication among geologists, engineers, and others. Comprehensive summation of data and interpretation of associated information are means of unifying the fragmentary experience of engineers who have a tendency to rapidly jump from project to project because of the increasing pace of construction activities (Aitchison, 1967). The data bank allows the knowledge gained by construction engineers working in a given area to be recorded in a logical fashion, preserved for other engineers, and eventually used for predicting rock engineering characteristics. The data bank and rock evaluation program should contain a specific niche for every item of relevant engineering knowledge, or at least an indication where such knowledge may be found or stored.

CATEGORY 1: SITE DESCRIPTION

The Sample Identification Sheet and Instructions is the major input mechanism for the Category 1 segment of the data bank. Before establishing the computer file format for the first segment, the "sample location" should be further delineated. To further specify the sample-site location, the sample location input mechanism should include the county name, physiographic region, station number, USGS

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

Figure 4. Data Bank Attributes.

Quadrangle Map Number Designation, and longitude and latitude as a revision to the identification data originally proposed by Tockstein and Palmer (1974).

Transfer of information from the Sample-Site Identification sheet to the Category I subfile is shown diagrammaticaly in Figure 5. The coded designations are fully developed in APPENDIX I.

Site descriptions should also include geophysical investigations and joint surveys. The geological survey described by landform and terrain classifications provides an encompassing view of the folding, faulting, regional geology, and geological history of a site. At specific locations, the joint survey would provide a basis for quantitative observations for the detailing of the strength and deformability (rock quality segment) dependent characteristics of the rock massif which are a part of the in-situ rock classification system.

The geophysical investigative techniques of seismic, gravity, magnetic, and electrical resistivity methods will be discussed as attributes of the CATEGORY 2 section of the data bank. In addition, the geomorphology of a region including a landform classification (Brink, 1967), the P.U.C.E. Terrain Classification (Aitchison and Grant, 1967), and the Joint Survey (Duncan, 1969b) will also be described within the CATEGORY 2 segment.

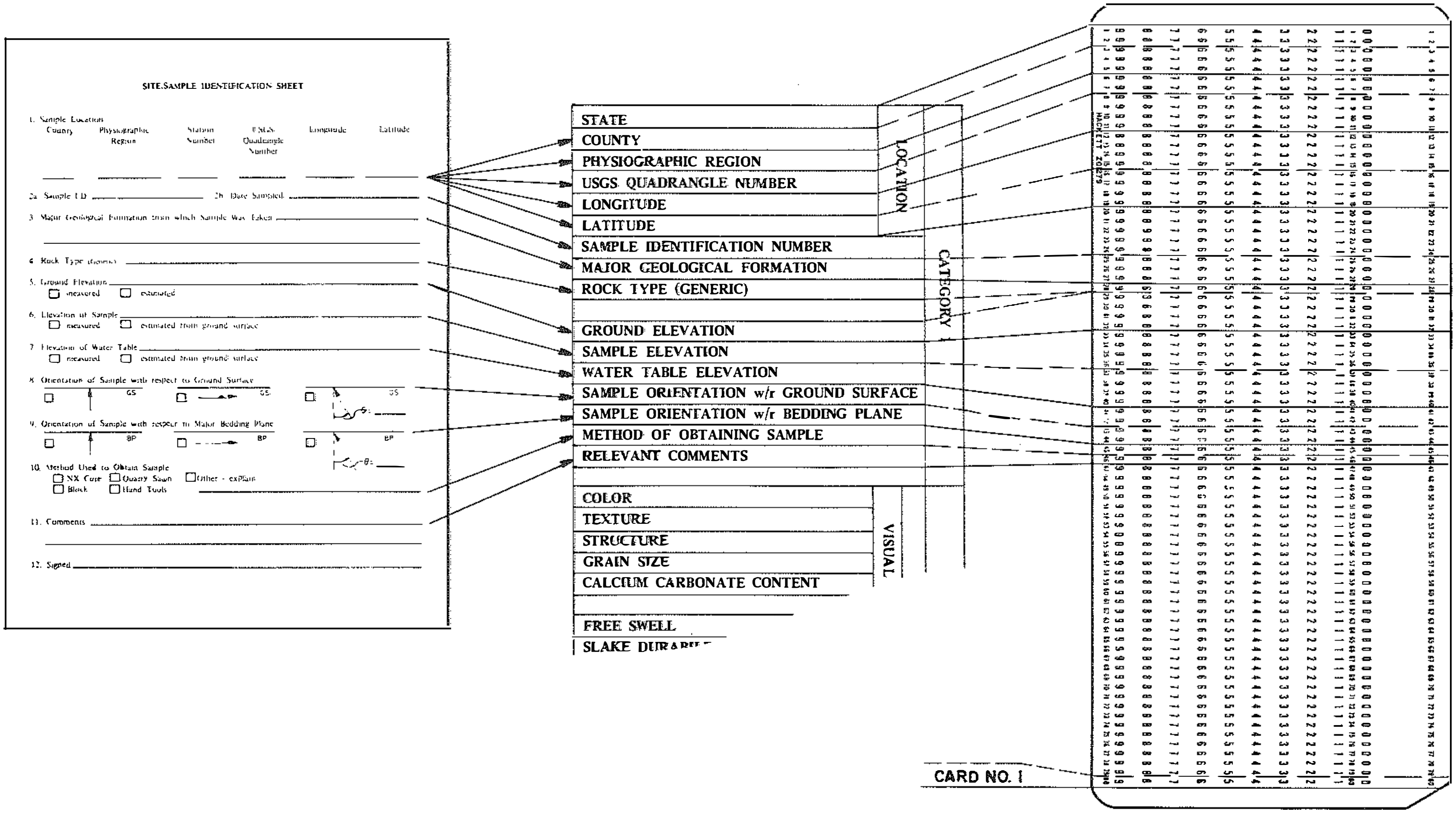
CATEGORY 2: PETROGRAPHIC AND MECHANICAL CHARACTERISTICS

Petrographic and mechanical characteristics of rock are conceptually divided between intact and in-situ rock specimens within the data bank. This separation is necessary both in terms of information storage and the acquisition procedure. There may appear to be too much information within this second category of the data bank. However, establishment of a wide range of test results for a specific rock type is accomplished at a very little extra expense, and the range of rock data saves researchers and construction engineers redundant efforts (Obert and Duvall, 1967). Better descriptors and more meaningful generalizations are needed (Aitchison, 1967). The extensive data bank attributes are designed to provide quantitative data for decision processes and provide an information base to obtain better descriptions and better generalizations for a rock suite. In this manner, a systematic process of information retrieval may be submitted to the community of engineers. The central file system of a data bank should be as inclusive as possible.

Intact Characterization

Petrographic Description

Rock material removed from its environment should be characterized by quantitative and qualitative terminology exclusive of rock mass expressions (Podnieks, et al., 1968). Before performing mechanical property tests, intact specimens should be described by means of a visual examination (Duncan, 1969a). The visual examination should include petrographic and megascopic fabric, color, texture, structure, grain



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 (Generic) ___

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 θ: ___

9. Orientation of Sample with respect to Major Bedding Plane
   ☐ BP ☐ BP ☐ BP θ: ___

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

11. Comments ___

12. Signed ___

Figure 5. Transfer of Information from Sample-Site Identification Sheet to the File Subsystem.

size, and the relative content of calcium carbonate (ASTM C 295). A field description and classification of rock materials developed by Duncan (1969a) was used as a model for the visual examination in this report.

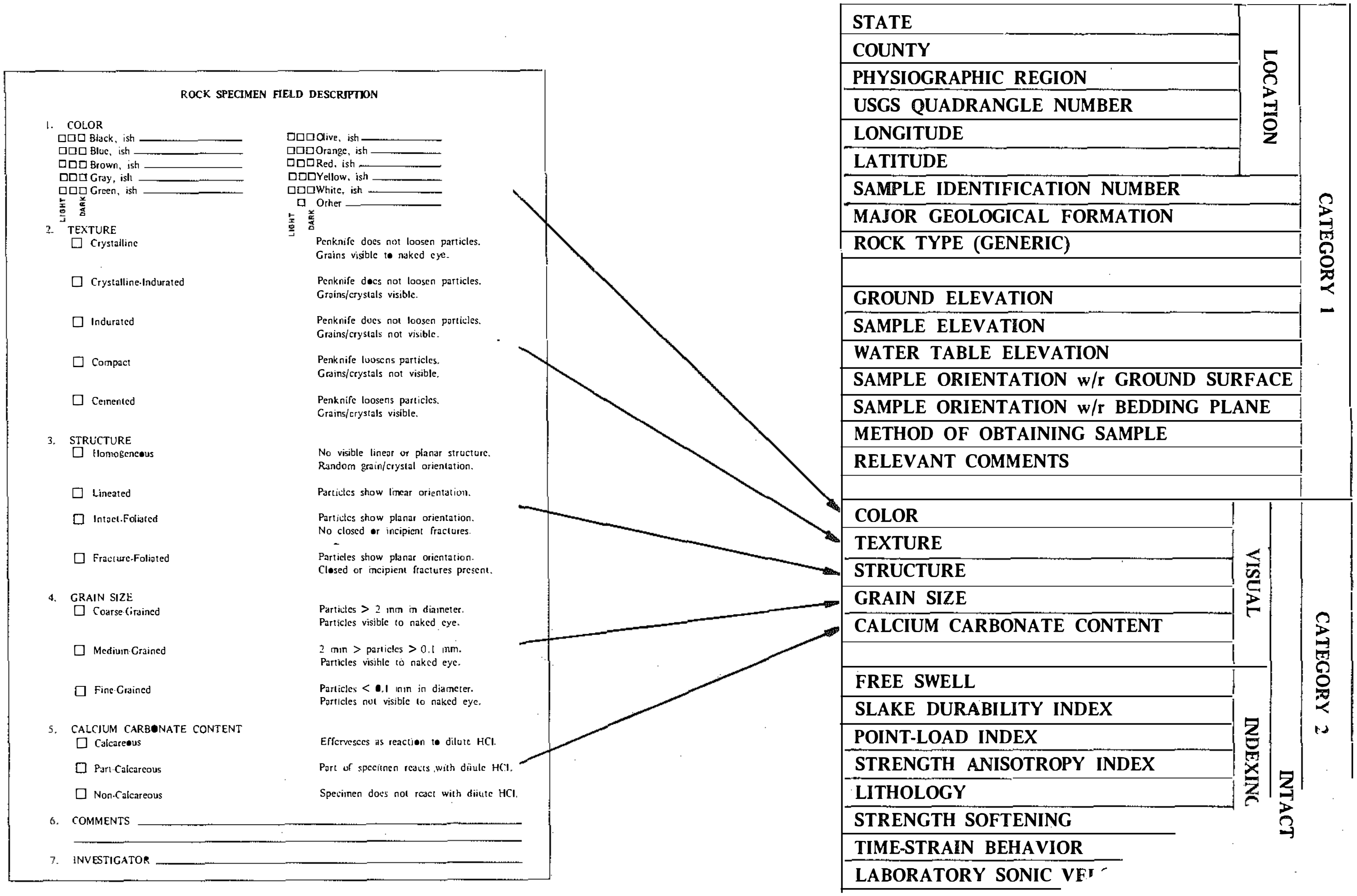
The five components of the field description are fully enumerated in APPENDIX I. The color of rock specimens will be designated by basic colors (black, blue, etc.) or by combinations of colors allowing dark-, light-, and -ish descriptions. Texture will be described by Duncan's crystalline, crystalline-indurated, indurated, compact, and cemented terminology while the structure will be described by one of four terms: homogeneous, lineated, intact-foliated, and fractured-foliated. Intact rock material also will be described in terms of coarse-, medium-, and fine-grained as relative indications of grain size. The relative content of calcium carbonate will be described by terms such as calcareous, part-calcareous, or non-calcareous and is important because calcite is particularly susceptible to weathering or dissolving processes and to varying stress conditions.

To facilitate recording of field descriptions of rock specimens, a "Rock Specimen Field Description" information sheet has been developed. Figure 6 depicts the manner in which information from the field description sheets is transferred to the computer file subsystem.

Different data bank attributes are necessary for transitional materials such that grain size, for example, will be quantitatively described and the testing program will be somewhat different. These differences will be discussed in CHAPTER III.

Classification Indexing

The Intact Sample Classification System (Figure 1) requires four input parameters: point-load index, lithology, strength anisotropy index, and the slake-durability index. The lithology has been previously indicated within the sample-site description. The point-load index (Franklin, 1970; Brock and Franklin, 1972) quantitatively describes the maximum tensile strength of an intact specimen. Since this tensile strength test requires no specimen preparation and there exist good correlations (Reichmuth, 1960; Hobbs, 1967; Reichmuth, 1968; Franklin, 1970) between point-load strengths and directly measured tensile strengths and compressive strengths, the point-load index is a very useful indication of intact rock strength. Anisotropic strength characteristics are indicated by the strength anisotropy index, defined as the maximum strength divided by the minimum strength as obtained with the point-load test (Franklin, 1970 Tockstein and Palmer, 1974). Index values from 1.0 to greater than 20 have been established to indicate isotropic to very anisotropic rock. The last classification parameter, durability, is described by the slake-durability index as the percentage of slaking (Franklin and Chandra, 1971). The free-swell test (Gamble, 1971) is also a good indication of durability and far less difficult to perform than the slake test. Validation of the applicability of the free-swell test for the Kentucky rock suite must be



ROCK SPECIMEN FIELD DESCRIPTION

1. COLOR

☐☐☐ Black, ish ______	☐☐☐ Olive, ish ______
☐☐☐ Blue, ish ______	☐☐☐ Orange, ish ______
☐☐☐ Brown, ish ______	☐☐☐ Red, ish ______
☐☐☐ Gray, ish ______	☐☐☐ Yellow, ish ______
☐☐☐ Green, ish ______	☐☐☐ White, ish ______
LIGHT DARK	☐ Other ______
	LIGHT DARK

2. TEXTURE

☐ Crystalline	Penknife does not loosen particles. Grains visible to naked eye.
☐ Crystalline-Indurated	Penknife does not loosen particles. Grains/crystals visible.
☐ Indurated	Penknife does not loosen particles. Grains/crystals not visible.
☐ Compact	Penknife loosens particles. Grains/crystals not visible.
☐ Cemented	Penknife loosens particles. Grains/crystals visible.

3. STRUCTURE

☐ Homogeneous	No visible linear or planar structure. Random grain/crystal orientation.
☐ Lineated	Particles show linear orientation.
☐ Intact-Foliated	Particles show planar orientation. No closed or incipient fractures.
☐ Fracture-Foliated	Particles show planar orientation. Closed or incipient fractures present.

4. GRAIN SIZE

☐ Coarse-Grained	Particles > 2 mm in diameter. Particles visible to naked eye.
☐ Medium-Grained	2 mm > particles > 0.1 mm. Particles visible to naked eye.
☐ Fine-Grained	Particles < 0.1 mm in diameter. Particles not visible to naked eye.

5. CALCIUM CARBONATE CONTENT

☐ Calcareous	Effervesces as reaction to dilute HCl.
☐ Part-Calcareous	Part of specimen reacts with dilute HCl.
☐ Non-Calcareous	Specimen does not react with dilute HCl.

6. COMMENTS ______

7. INVESTIGATOR ______

Figure 6. Transfer of Information from Rock Specimen Field Description Sheet to the File Subsystem.

established and subsequent correlation coefficients must be calculated to determine the value of substituting the free-swell test for the slake durability test as part of the original classification system. This will be the subject of subsequent investigations. At the present time, it is recommeneded that the free-swell test be performed on all intact specimens. Details of inputing these aforementioned mechanical characteristics are described in APPENDIX I.

Morgenstern and Eigerbrod (1974) have successfully applied a compression softening test to qualitatively differentiate argillaceous material for a transitional material classification system. The specifications are number-coded and enumerated in APPENDIX I.

Failure characteristics are indicated as time-strain behavior under sustained uniaxial loading. Qualitative nomenclature is used to describe elastic, viscous, and visco-elastic material with respect to reference rates of strain (Coates and Parsons, 1966).

The laboratory sonic pulse velocity (Thill et al., 1968), which is part of the in-situ rock classification system strength reduction factor, should be input within the data bank file system at this point. As described by Rinehart, et al. (1961) and Deere and Miller (1966), the propagation velocity test performed on an intact specimen is a good indication of elastic properties.

In addition to the index properties proposed by Tockstein and Palmer, provision is made for storage of other pertinent index test results (Shore scleroscope hardness, Schmidt "L" hammer hardness, unconfined compressive test, tangent modulus at 50 percent ultimate compressive strength, natural moisture content, saturation moisture content, apparent specific gravity, and bulk specific gravity). Secondly, results of less well known index parameters are allocated file space (apparent porosity, apparent void ratio, bulk specific gravity (SSD), degree of saturation, and void index). Thirdly, provision is made for storage of results from those mechanical and(or) physical property tests not included in the above divisions (direct shear tests (Kenty, 1970), triaxial shear tests (Heck, 1970), Los Angeles abrasion test, Deval abrasion test, and the Treton impact resistance test). Finally, provision is made for storage of energy measurements and fracturation criteria (Bernaix, 1969; Krech, 1973). Inclusion of these particular index and property tests are in accord with the ISRM (Franklin, 1970) and the initial work of Tockstein and Palmer (see APPENDIX I).

In-Situ Characterization

Unfortunately, the variability of rock material is such that the above-mentioned identification and testing procedures only indicate a very limited technicalogical evaluation of rock character and engineering problems in rock. A relatively complete rock evaluation schema requires at least minimal in-situ rock competency and rock quality investigations.

Visual Mass Description (Indexing)

Comprehensive assessments of rock massif character throughout all phases of project development must include an examination of the various interactions among the rock material, discontinuities which cause structural weaknesses, and environmental conditions. Initially, rock material can be described adequately by intact specimen indexing and testing. At the same time, short-term environmental constraints may be established (Hamrol, 1961; Iliev, 1968; Podnieks, et al., 1968). A project monitoring program, to be discussed later within this chapter, provides a system for monitoring various time-dependent environmental and state-of-stress conditions which occur during the construction and life of an engineered project. Geological mappings and(or) surveys, landform and terrain classifications, joint surveys, borehole analyses, test pits or shafts, and mechanical testing of in-situ rock are designed to quantitatively and qualitatively depict the discontinuous nature of the rock massif. Essentially, in-situ rock material requires different indexing parameters and testing procedures although the major concern as with intact specimens is the rock strength, deformability, and permeability. In the field, the engineering geologist and(or) foundation engineer are concerned with rock material which signify structural weakness. For most projects concerned with rock mechanics, only a cursory overview of in-situ conditions is economically feasible. Therefore, in-situ descriptive index tests, to a greater degree than tests on intact samples, must be inexpensive, rapid, significant, and simple. The economic consequence of this is that on a given project not all the aforementioned quantitative descriptions of rock structure and discontinuities and subsequent structural conclusions and interpretations can be done. To overcome this problem, the in-situ rock classification system (see Figure 2) is designed to record rock competency with a minimum of time and effort. The primary purpose of geomechanical classifications is to quantify the various engineering parameters and(or) variables for rock and then subject the parameters and(or) variables to a scheme of categorization which will allow allocation of materials into definite engineering groupings or subdivisions. Determinations of rock quality and(or) continuity (bedding thickness, joint spacing, joint frequency, and joint infiltration material), lithology, gross heterogeneity (permeability), and velocity ratio are necessary to adequately indicate geological trends of structural weakness (see APPENDIX I).

Wahlstrom (1973) indicated there is no competency classification system based on digital parameters which may be considered completely adequate. The variety of attributes with respect to shallow tunnels, tunnels at depth, and cut slopes, for example, are such that no one system can predict the necessary design criteria. Subjective appraisal of variables and, to some extent, geological intuition are sometimes required in an engineering classification of geologic materials. Thus, the strength and deformability of in-situ rock as described by rock quality is only a first step in evaluation techniques. As an initial evaluation, the in-situ rock quality is meant to be a general description of the rock massif. In this sense, faults and major joint systems are descriptions of the rock massif in spacial dimensions. However, the in-situ classification system does not characterize faults and(or) joints in terms of orientation. While the orientation of discontinuities is of primary importance in structural considerations at the project site, the actual orientation of the rock massif cannot be used as an indexing property. Instead, the orientation of the rock massif should be incorporated into the rock evaluation schema as an additional item in the data bank. The predominant directions of faults and(or) joints should be incorporated into the evaluation in the form of dip measurements with appropriate bearings. The joint orientation diagram (Duncan, 1969b) is a typical means of recording the information in the field.

With respect to the actual information obtained, results of a joint survey would be preferable to the rock competency description of the in-situ classification. The joint survey, which represents a statistical approach to describing the rock massif, should be performed only by an experienced engineer or geologist. Typically, the joint survey is performed after a geological survey, which would be the backdrop for the detailed quantitative observation (joint survey) at specific locations. Relatively few joint surveys by field operators are anticipated, especially in the actual implementation of the rock evaluation schema. Consequently, the data bank need only indicate by a yes-no file column existence of results of such a survey performed within a particular formation, quadrangle site, or rock type. In addition to such location and descriptive parameters as longitude, latitude, physiographic region, county, rock type, ground elevation, etc. (same information as contained in statements numbered 1, 2, 3, 4, 5 and 7 of the Sample-Site Identification Sheet, Figure 5), Duncan (1969b) suggested that a joint survey should also contain the following information:

a) joint continuity -- joints may be continuous or discontinuous and the degree of discontinuity is measured whenever possible in terms of distance through the rock massif;

b) joint orientation -- the dip or strike;

c) joint spacing -- spacings between adjacent joints;

d) nature of joint surfaces -- qualitatively, joint surfaces may be described as smooth, rough, or apparently keyed, which indicates the relative resistance of rock masses to movement and influences the mass distribution of stresses; impressographs (joint contact test) are used to obtain a "Joint Contact Factor" (actual area of contact expressed as a fraction of the total outline area of a sample);

e) joint width - determined in a large number of measurements using a feeler gauge; width influences the possible extent to which weathering agents may enter the rock mass, the deformation characteristics of the mass, and the movement of ground water in the mass; and

f) infiltration material -- most commonly clay, sand, gravel, or other materials are washed down into the rock massif from the ground surface; a hand vane tester may be utilized in the field to test for the mechanical and physical properties of clay materials for joint thicknesses greater than 18 mm (0.7 in.).

A joint diagram including these various data and the results of any other mechanical or physical property tests, conducted on intact samples and(or) in situ, and any available ground or aerial photographs would complete this storage file. Of the graphical representations of large numbers of joint and(or) fault measurements, the most commonly employed methods are contoured equal-area plots and joint roses (star diagrams). These informational devices are amenable to a system of information storage outside the computer. In summary, the joint survey may indicate an order of magnitude for values of rock mass deformability and compressibility under applied loadings.

Secondary Indexing

Fundamentally, a major concern of in-situ investigations is to somehow quantify the influence of the geologic discontinuities in the rock massif. Physico-mechanical tests and observation techniques should characterize the degree of rock integrity in situ so design parameter values may be established. Rock integrity, or rock quality, in addition to finding use in the in-situ classification system and the joint and(or) fault survey, may be interpreted to indicate deformability by using core indexing to obtain a maximum of information at a project site while the actual core need not be stored indefinitely (Franklin et al., 1971).

A core, at best, is an inadequate sample of conditions hidden from sight (Deere, 1963). For this reason, core logs must be supplemented with selective sampling of important mineralogical and geotechnical horizons. The economic infeasibility of obtaining statistically representative samples of a large project site forces the design engineer to deduce necessary design criteria from whatever sources are available. Therefore, pertinent engineering features observed in rock cores must be carefully and systematically described and recorded in boring logs. In this manner, all engineering operations eventually will be based upon more reliable cost analysis, more adequate problem anticipation, and a better background of equipment response to particular geologic formations.

Cores may be used to determine lithology, the location and quantitative character of joints and faults, the qualitative character of rock alteration or weathering, the nature of infiltration materials, and ground-water characteristics. Descriptions must be given of the spacings and attitude (dip angle of planar features correlated with frequency of discontinuities) (Deere and Shaffer, 1956). The core hole may also be utilized for a variety of geophysical tests which will be described in the section on geophysical surveys. Core records should consist of a driller's log and a geologic log, as a minimum, and should contain the following information (Deere, 1964; Knill and Jones, 1965; Coon, 1968; Duncan, 1969b;

Franklin, 1970; Lutton and Banks, 1970; Franklin et al., 1971; Wahlstrom, 1973; ASTM C 195-65):

Driller's Log

- a) Mechanical apparatus description and operations
    1. type of drilling equipment
    2. condition of drilling equipment
    3. drilling rate for each rock stratum and each hour
    4. unusual aspects of the drilling operation
- b) Drilling water description
    1. description of appearance
    2. quantity of drill water returning to surface
    3. location of loss and estimated amounts of water lost during drilling operations
    4. temperature of returning drill water
    5. presence of gas bubbles in returning drill water at the collar of the drill hole
- c) Ground-water level
- d) Core recovery
- e) Tendency of the drill hole to deform during the drilling process

Geologic Log (core description)

- a) Sequence of cores as related to depth, temporarily preserved in core box
- b) Core loggings including Deere's rock quality designation and Franklin's fracture frequency
- c) Description of lithology, including mineralogy, results of petrographic examination, and any evidence of alteration
- d) attitude (strikes and dips) and spacings of joints with respect to the direction of coring
- e) Description of joint surfaces, indicating whether they are rough, smooth, or keyed and the degree of localized rock alteration
- f) Apparent (qualitative) toughness, hardness, and coherence as well as obvious porosity, grain size, texture, and variations in grain size, texture, and color
- g) Presence, type, and distribution of argillaceous impurities

All items for the driller's log and the geologic log must be recorded as accurately as possible in order to obtain the maximum information from the boring and to help prevent erroneous conclusions about the character of the rock. In the past, results of exploratory projects were rarely published; consequently, comparatively few systematic methods of describing and interpreting rock data for engineering purposes have been developed, and this has contributed significantly to the difficulty of predicting foundation conditions (Knill and Jones, 1965). Probably the best operating technique of analyzing geological data is a combination of qualitative and quantitative methods in conjunction with accumulated engineering experience.

The fissured condition of rock may be correctly described by the core recovery, the rock quality designation (RQD), the fracture frequency, or the velocity ratio (Coon and Merritt, 1970); these indicators will not suggest the same results for a wide variety of rocks since fracture spacing and fracture infiltration material affect each of the above indices to different degrees. Core recovery, which may be indicated on either the driller's log or the geologic log, is defined as the (percentage) ratio of the length of core obtained from a drilling interval to the length of the total cored interval. Weathered and(or) highly fractured rocks would normally have a low core recovery percentage because these rocks have a tendency to be lost through the washing action of the drilling water and the grinding of low quality rock in the core barrel. Rock quality designation (Deere, 1964; Deere, et al., 1966; Deere, et al., 1967; Merrit, 1968) is basically a modified core recovery percentage. Deere suggested that the RQD be the sum of the lengths of sound and(or) unweathered core pieces 102 mm (4 in.) or more in length expressed as a percentage of the total length of core run. In this manner, broken and chipped fragments are excluded from the RQD (see Table 1). In addition to an indication of the length of core, a description of the end surfaces of each fragment should be given in quantitative terms. Coon (1968), in his investigation of rock quality designations for some 2700 meters (8000 feet) of core, utilized an end surface classification (see Table 2) with a significant degree of success. This will give some indication of the amount of interlocking and, consequently, the apparent angle of shearing resistance along the surfaces.

Coon suggested a "weighted length" to describe rock quality. Two base lengths, 31 mm and 305 mm (0.1 foot and 1.0 foot), were used to describe poor, transitional, and good rock (see Table 3). The weighted length technique disregards the poor category and sums the length of the good rock pieces, as in core recovery calculations. The core pieces within the transitional category are weighted by squaring. In this way, the weighting process indicates the gradual improvement in rock quality from the lower 31 mm (0.1 foot) to the upper 305 mm (1.0 foot) base lengths. The rock quality calculation simply becomes the sum of the squared lengths of "transitional" core plus the lengths of the "good" core divided by the entire length of cored run, expressed as a percent. The advantage of this approach is that it avoids the validity problem of the former techniques. The weighted technique does not depend on the random spacing of core discontinuities to provide a realtively smooth transition from "poor" to "good" rock.

A fracture index or fracture frequency parameter has been defined as the arithmetic average linear size of rock blocks which constitute the total cored rock massif (Franklin 1970). As Franklin pointed out, the fracture frequency may be compared with alternative rock quality measurements such as core

TABLE 1

RELATIONSHIP OF CORE RECOVERY TO ROCK QUALITY

PERCENT CORE RECOVERY	RQD	ROCK QUALITY
< 50	< 25	Very Poor
50 to 75	25 to 50	Poor
75 to 85	50 to 75	Fair
85 to 95	75 to 90	Good
> 95	> 90	Excellent

TABLE 2

CORE END SURFACE CLASSIFICATION SYSTEM
(after Coon, 1968)

CODE	TERM	DESCRIPTION	IDENTIFICATION
1	Fresh	Irregular breaks (may be rejoined with only a hairline separation)	Apparently formed after coring, therefore these surfaces are ignored in all measurements
2	Rounded	Appear as a blunt pencil	Caused by geological discontinuities or breaks during coring
3	Smooth	Apparently fresh surfaces which cannot be rejoined	Thin fractures in rock massif or a separation along bedding and(or) foliation surfaces
4	Weathered (Slickensides)	Smooth to irregular surfaces containing weathering or alteration products or cementing agents	Joints and(or) faults

TABLE 3

WEIGHTED ROCK QUALITY
(after Coon, 1968)

CORE LENGTHS	ROCK QUALITY
< 31 mm	Poor
⩾ 31 mm & ⩽ 305 mm	Transitional
> 305 mm	Good

recovery, RQD, or velocity ratio. Additionally, Franklin has successfully used the fracture index, I_f, versus the point-load strength index, I_s, to classify rock according to the ease of excavation for various highway projects in England. This will be described in detail in CHAPTER V.

Using Wahlstrom's "Core Logging Sheet" as a model, Figure 7 has been prepared as a suggested combination driller's and geologic core log. Utilizing this core information, a rock quality grading classification system for a suite of Kentucky rocks may be established. Designations of rock conditions would be based upon an assessment of a variety of geological characteristics which control the engineering behavior of rock in situ (Knill and Jones, 1965):

a) state of weathering and loss of cohesion,
b) relative compactness of rock,
c) orientation and intensity of fracture sets,
d) relative cleanness of fractures and rock massif, and
e) relative abundance of shale layers.

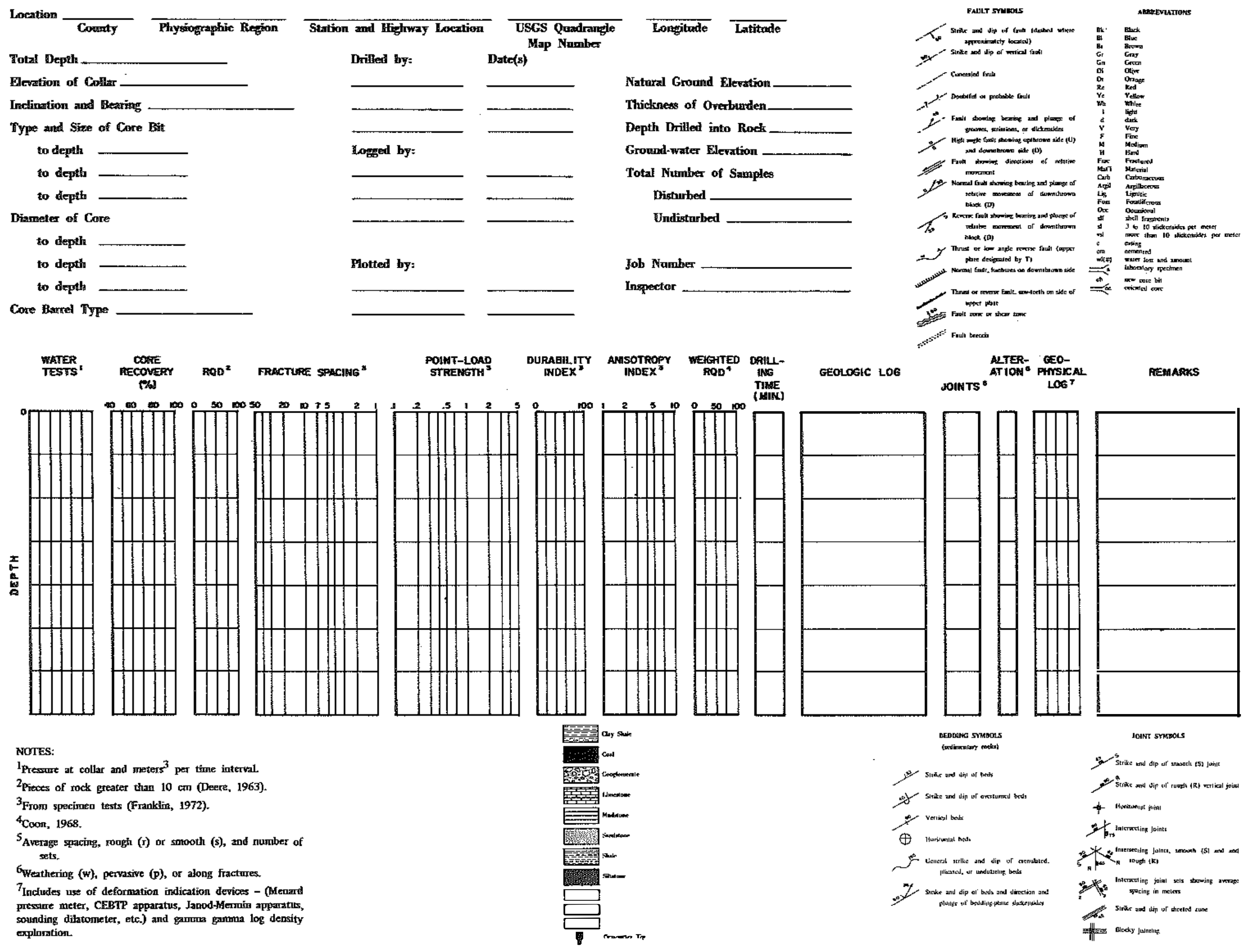
The grading system concept would be a valuable means of predicting excavation requirements.

Hucka (1965) described the use of a type L Schmidt hammer to be used as a means of testing relative rock strength in situ. Statistical data should be made available for interpretation to distinguish rock strength correlations for a standard rock suite.

Geophysical Testing Techniques

Geophysical testing is designed to determine physical characterisitics of earth materials by measuring in-situ electrical and magnetic field variations or the response of earth materials to aritifically induced (external) electrical, radioactive, or elastic-wave fields. Exploration techniques depend to a large extent on the accurate identification of measurable differences in physical quantities (Warrick, 1954; Grant and West, 1965; ASTM D 420). These differences are associated with various differences in the structure or lithology of subsurface rock units. Several aspects of geophysical investigation result in the identification of various anomalies, departures from the average or expected responses obtained by measurement (Wahlstrom, 1973). These anomalies can be interpreted to delineate significant geologic conditions of a particular site. Seismic surveys, in particular, are extremely well suited for the determination of earth material changes with respect to depth when the deeper geologic layers exhibit a higher seismic velocity than the shallow layers. These surveys are used commonly in the determination of the soil-bedrock interface, depth of rock alteration, and location of the water table (Coon, 1968). In terms of engineering investigations, Table 4 identifies the major categories of geophysical investigations.

In the seismic survey, longitudinal (compressional) waves, usually the first to arrive at the detecting instruments, have been utilized almost exclusively in the past. There have been some attempts to utilize



Location ______ County ______ Physiographic Region ______ Station and Highway Location ______ USGS Quadrangle Map Number ______ Longitude ______ Latitude

Total Depth ______ Drilled by: Date(s)

Elevation of Collar ______ ______ ______ Natural Ground Elevation ______

Inclination and Bearing ______ ______ ______ Thickness of Overburden ______

Type and Size of Core Bit ______ ______ Depth Drilled into Rock ______

to depth ______ Logged by: Ground-water Elevation ______

to depth ______ ______ ______ Total Number of Samples

to depth ______ ______ ______ Disturbed ______

Diameter of Core ______ ______ Undisturbed ______

to depth ______

to depth ______ Plotted by: Job Number ______

to depth ______ ______ ______ Inspector ______

Core Barrel Type ______ ______ ______

NOTES:

¹Pressure at collar and meters³ per time interval.

²Pieces of rock greater than 10 cm (Deere, 1963).

³From specimen tests (Franklin, 1972).

⁴Coon, 1968.

⁵Average spacing, rough (r) or smooth (s), and number of sets.

⁶Weathering (w), pervasive (p), or along fractures.

⁷Includes use of deformation indication devices – (Menard pressure meter, CEBTP apparatus, Janod-Mermin apparatus, sounding dilatometer, etc.) and gamma gamma log density exploration.

FAULT SYMBOLS

- Strike and dip of fault (dashed where approximately located)
- Strike and dip of vertical fault
- Concealed fault
- Doubtful or probable fault
- Fault showing bearing and plunge of grooves, striations, or slickensides
- High angle fault showing upthrown side (U) and downthrown side (D)
- Fault showing directions of relative movement
- Normal fault showing bearing and plunge of relative movement of downthrown block (D)
- Reverse fault showing bearing and plunge of relative movement of downthrown block (D)
- Thrust or low angle reverse fault (upper plate designated by T)
- Normal fault, hachures on downthrown side
- Thrust or reverse fault, saw-teeth on side of upper plate
- Fault zone or shear zone
- Fault breccia

ABBREVIATIONS

Bk	Black
Bl	Blue
Br	Brown
Gr	Gray
Gn	Green
Ol	Olive
Or	Orange
Re	Red
Ye	Yellow
Wh	White
l	light
d	dark
V	Very
F	Fine
M	Medium
H	Hard
Frac	Fractured
Mat'l	Material
Carb	Carbonaceous
Argil	Argillaceous
Lig	Lignitic
Foss	Fossiliferous
Occ	Occasional
sff	shell fragments
sl	3 to 10 slickensides per meter
vsl	more than 10 slickensides per meter
c	caving
cm	cemented
wl(#)	water loss and amount
s	laboratory specimen
cb	new core bit
oc	oriented core

BEDDING SYMBOLS
(sedimentary rocks)

- Strike and dip of beds
- Strike and dip of overturned beds
- Vertical beds
- Horizontal beds
- General strike and dip of crenulated, plicated, or undulating beds
- Strike and dip of beds and direction and plunge of bedding-plane slickensides

JOINT SYMBOLS

- Strike and dip of smooth (S) joint
- Strike and dip of rough (R) vertical joint
- Horizontal joint
- Intersecting joints
- Intersecting joints, smooth (S) and and rough (R)
- Intersecting joint sets showing average spacing in meters
- Strike and dip of sheeted zone
- Blocky jointing

Figure 7. Core Log.

TABLE 4

GEOPHYSICAL TECHNIQUES FOR SUBSURFACE EXPLORATION

(after Wahlstrom, 1973)

I. Seismic Methods
  A. Refraction Method
  B. Reflection Method
II. Gravity Methods
III. Magnetic Methods
IV. Electrical Methods
  A. Natural Potentials
  B. Potential Drop (between electrodes)
  C. Distortions (in natural or induced electrical and magnetic fields)
V. Radioactivity Methods

the slower transverse waves (shear waves) in some studies of rock structures. The basis of this survey technique lies in the fact that the velocity of elastic waves depends on the properties of the media through which they pass. These factors include: 1) rock type, 2) degree of lithification, 3) degree of fracturing, 4) amount of weathering, 5) water content, 6) mineral composition, 7) fabric, 8) porosity, and 9) hydrothermal alteration. The velocity of longitudinal waves can be expressed in terms of elastic constants according to the theory of elasticity. The shear wave may be similarly expressed (Ávila, 1966). The most important assumption in these seismic field tests is that the rock massif may be considered a homogeneous, elastic mechanical body despite the discontinuous, heterogeneous nature of the real rock massif. On the basis of this elastic hypothesis, the dynamic modulus of rigidity and the bulk modulus may be determined.

Dynamic rock characteristics (Poisson's ratio, rigidity modulus, and bulk modulus) are algebraically determinable utilizing the compression and shear propagation velocities. In addition, a prediction of the rock material behavior under loading is possible (Bertacchi,et al., 1966; Sinitsyn, 1966). Seismic methods do not in general allow for reliable interpretations concerning anisotropy. The actual procedure involves creating a seismic impulse at a shot point (small explosion or striking hammer) which is transmitted along various paths (depending on material interfaces involved) to geophones (devices which measure ground vibrations). A time-distance graph is plotted on the basis of wave arrival times (of the first impulses) at each geophone. The slope of the plot is related to the seismic velocity in successive media layers and the points of slope change can be used to calculate the depths to boundaries between "velocity" layers.

Variations of the refraction and reflection seismic survey methods are the uphole seismic test and the cross-hole survey (Myska, 1973). The uphole seismic test utilizes an exploratory boring as a shot hole. A geophone is usually placed near the collar of the borehole (to prevent shock-wave or cave-in damage to the instrument) and successive explosions (shots) are set off at various depths. Comparison of successive test results shows the locations of velocity discontinuities. The cross-hole method utilizes one exploratory boring for the origin of shock waves and one or more adjacent borings for the placement of geophones. The wave travel time through the rock measured at the various borings can be used to identify fractures, faults, and joints not encountered in the drill holes. The sensitivity and response time of the geophones determine the precision with which travel times are recorded (Coon, 1968).

Gravity surveys are designed to detect and measure lateral variations in the earth's gravitational field. These variations are associated with near-surface changes in rock density (Rogers, 1973). Such density variations indicate differences in rock type and(or) geologic structure in an area (Clark, 1966). Rock density is a function of compaction, porosity, texture, composition, saturation, alteration, age, and fracturing. In general, a gravimeter, an accelerometer sensitive to 0.01 milligals (10^{-7} m/s^2), is used to identify gravitational anomalies which indicate rock masses with smaller or greater densities than adjacent rock by measuring the vertical component of the gravitational field. A variety of corrections are necessary to properly identify specific anomalies. There exists an inherent ambiguity in gravity survey interpretation because there is no unique source configuration for a specific gravity anomaly. It is necessary to obtain information by other means regarding the depth or density of a particular body in order to make correlations. Corrections are made for the station elevation with respect to an arbitrary datum plane, site latitude, and, if necessary, for the influence of the neighboring topography (Dobrin, 1960; Rogers, 1973). Precision gravity methods require the station elevation be known to 0.03 m (0.1 feet) since gravity varies 0.195 mgal/m (0.06 mgal/ft) for elevation change; the latitude of the station must be known to within 0.01 second (about 15 m (50 feet)) since gravity decreases 0.6 mgal/km (1.0 mgal/mile) with distance away from the equator. These precision limits allow an instrument precision of 0.01 milligal (Rogers, 1973). In addition, a high precision gravity survey requires accurate determination of the bulk density of rock units within a specific area (Sumner and Burnett, 1974). Gravity methods of investigation have found use in the identification of soil-rock interfaces and extensively altered rock zones (Wahlstrom, 1973; Sumner and Burnett, 1974).

Magnetic survey techniques of subsurface exploration depend on the different magnetic susceptibilities of earth materials (Raybould and Price, 1966). Magnetic susceptibility is defined as the ratio of the degree of magnetization to the intensity of the magnetizing force. Susceptibility of a rock to being magnetized in the earth's magnetic field varies directly with its magnetic mineral content (ASTC C 294). Lines of magnetic force in the earth's magnetic field are somewhat distorted by specific substances; ferromagnetic and paramagnetic substances tend to concentrate magnetic force lines while diamagnetic substances (rock salt, anhydrite) tend to disperse these force lines. The value of this technique lies in the fact that most rocks are weakly paramagnetic and demonstrate appreciable and measurable differences in susceptibility. A magnetometer (a balanced magnet) or a dip needle can be used to measure distortions (vertical or horizontal components) in the magnetic field. In addition, magnetometers can operate from the ground or the air, thus enabling aerial magnetic surveillance of a particular region which may be especially useful in initial site selection and(or) reconnaissance studies (Wahlstrom, 1973).

Shallow subsurface investigations may be based on the apparent electrical resistivity between points on the ground. Common rock-forming minerals are considered insulators (resistivity greater than 10^{8} ohm-meter); natural minerals which behave as conductors (resistivity less than 10^{-5} ohm-meter) or semiconductors (resistivity between 10^{-5} and 10^{8} ohm-meter) most probably owe this electrical conductivity to the amount of water present, its salinity, and its distribution (Keller and Frischknech, 1966). Thus, resistivity measurements can be utilized in various subsurface investigations to locate ground-water tables and to identify altered or fractured rock zones.

The natural occurrence of radioactive elements (uranium, thorium, and potassium-40) or any anomalous concentrations of these elements form the basis of radiometric surveys which consist of measurement of gamma radiation. Gamma rays, the most penetrating form of radiation, diminish considerably while passing through only a few centimeters of earth material; thus radioactive elements and their radioactive daughter products must occur in an outcrop to be easily detected (Clark, 1973; Faure, 1973).

Field Testing Techniques

At present, the deformation potential and failure mode of rock masses generally are determined from in-situ tests and joint surveys. Only the most prevalent in-situ testing techniques will be discussed within this introduction to the data bank attributes. Included within this treatment are tests to evaluate the resistance to sliding along pre-existing joints and(or) faults, jacking and plate-loading tests to evaluate the probable deformability of the rock massif, and pressure chamber and borehole deformation tests to evaluate the deformation modulus (Coon, 1968; Goodman, et al., 1968; Duncan, 1969b; Rocha, 1970; Armstrong, 1972). Such operations as overcoring (Merrill and Peterson, 1961; Austin, 1970) to measure in-situ stresses are beyond the scope of this report.

In-situ shear tests (Mellinger and Kenty, 1971) are used to determine the shear strength of continuous laminae of infiltration material, of continuous joint and(or) fault zones within the rock massif, and of the rock massif where joints and(or) faults are discontinuous (Duncan, 1969b; Evdorimov and Sapegin, 1970). Frictional resistance is controlled generally by the mineralogical composition of the rock units (blocks) which form the potential sliding surfaces on either side of joint zones (no infiltration material). This potential sliding (movement) resistance of smooth surfaces is a direct function of the composition, shape, and size of the crystals and(or) grains comprising the mineral aggregate matrix (Loucher and Rieder, 1970). In addition, the method of structural formation affects the nature of joint walls; slight movement on joint planes produces polishing of contact surfaces (slickensides) resulting in low frictional resistance, while the formation of cooling (shrinkage) joints produces contractions resulting in rough and open joints of higher frictional resistance. Random discontinuous joints and(or) faults have a degree of interlocking between individual units resulting in higher shear strength. Thus, potential movement is impeded by frictional resistance and interlocking. Presence of argillaceous infiltration material within joint zones requires the following specific information on the nature of the infiltration material be furnished for design and(or) analysis:

a) quantification of the frictional resistance at the contact between the rock material and the infiltration material and

b) data on the shear strength, cohesion, and angle of shearing resistance of the infiltration material itself.

A portable hand vane tester may be employed to determine the in-situ shear strength of infiltration material with thicknesses greater than 1.8 cm (0.7 inch) (ASTM D 2573). Large projects will require in-situ sliding or shear tests in which a rock unit is encased in concrete, monitored with interconnecting vertical and horizontal gauges, and tangential and normal forces are applied to the mass by means of jacks. Deformation characteristics of the infiltration material can be determined by means of plate or jack loading tests in which a constant load is imposed on the rock massif for a given time. This will be discussed subsequently. As Duncan (1969b) indicated, there are several critical physical and mechanical parameters which influence the sliding resistance of the rock massif:

a) frictional resistance, ϕ_f, between adjoining rock materials which form the walls of the joints (families of continuous joints);
b) shearing resistance, ϕ_m, of the rock massif as a consequence of the frictional resistance between units, the degree of unit interlocking, and the inherent strength of the rock substance forming the units (joints are discontinuous);
c) orientation of the potential movement surfaces with respect to the applied load;
d) shear strength in the rock massif due to keying of rock material;
e) unconfined compressive and shear strengths of rock materials forming protuberances (irregularities) within joint zones;
f) thickness of joint zones (measure of massif compressibility);
g) frictional resistance between the rock material and infiltration material; and
h) shear strength of the infiltration material in joint zones.

The presence of water would affect all of the above parameters.

Failure mode characteristics (sliding resistance) are usually derived from one of three primary conditions:

a) interformational failure may occur when joint infiltration material is present and forms continuous layers;
b) boundary failure may occur where families of planes exist; and
c) failure will occur within a rock massif with random or discontinuous joints.

Uniaxial jacking (Misterek et al., 1974) and plate-loading tests are utilized to determine the extent to which the rock massif will deform under various loading conditions. Many variations of the plate-loading test of rock have been developed since its appearance in this country in 1948 (cf. U.S.B.R., 1948).

These include rigid plate, flexible plate, chamber, radial jacking (Lauffer and Seeber, 1966), cable jacking, and borehole jacking tests (Coon, 1968; Dodds, 1974). In general, the tests consist of loading the surface of the rock in a normal direction and then measuring the resulting deformation. To obtain the most information, emphasis must be placed on obtaining data such as evidence of blast damage, qualitative indications of the rock massif elastic-plastic response, and values of in-situ stress levels, besides the primary data directly concerning the modulus of deformation (Dodds, 1974). Coates and Gyenge (1965) have utilized plate-loading test data to obtain bearing values of relatively weak rock material. Extensive results from in-situ jacking tests indicate the deformation moduli of most rock materials are less than the modulus of concrete. The low in-situ deformation modulus is attributed generally to the discontinuous nature of the rock massif. Most plate-jacking tests are performed in underground openings (Rocha, 1955). However, a few tests have been performed in test pits. The particular size of plate is extremely important since the size determines the validity of the deformation moduli obtained and the particular method of analysis employed. Typically, plates having diameters from 10.3 cm to 91.4 cm (8 to 36 inches) have been utilized. Ideally, the plate should load a significant volume of rock, and therefore, as a minimum requirement, the plate diameter should be equal to several times the average joint spacing (Grimm et al., 1966). Another fundamental parameter is the rigidity of the jacking plate with respect to the rock tested. This determines the choice of analysis as either rigid or flexible plate elastic solutions. In general, plate rigidity is directly related to the plate size; small rigid plates may impose relatively high loads (Gicot, 1948; Talobre, 1961). Small-sized plates may not load a significant volume of rock while large plates are considered semi-rigid or flexible since the stress distribution under these plates is generally non-uniform (Coon, 1968). Several investigators have obtained a uniform stress distribution by placing a rubber pad or an oil-filled metallic cushion between the jack shoe and the mortar-pad-surfaced rock (Rocha, 1955; Shannon and Wilson, 1964; Dodd, 1967). In this manner, the semi-rigid analysis can be eliminated (non-uniform stress distribution), and the data can be analyzed by solutions for flexible plate loading on an elastic medium. Coon (1968) discussed in detail gage types, deformation measurements, site preparation, and testing procedures for jacking tests.

Pressure chamber tests are performed at significant depth, are of extremely large scale, and are expensive. The size factor of these tests is such that they are especially useful in testing rock having large joint spacings. A chamber (confined in three dimensions) is fitted with an impermeable lining which should offer no resistance to the imposing load. This chamber is pressurized (1.38-3.45 MPa (200-500 psi)), usually with water. Resultant rock deformations are measured with diametral or buried deformation gages in the middle one-third of the pressurized chamber (to eliminate end or boundary conditions). Analysis is based on the application of thick-walled cylinder solutions (Deere, et al., 1967). The expense and scale of this test require that its use be limited generally to very large projects where an accurate determination of rock deformation characteristics can result in substantial savings (Coon, 1968).

Surface loading tests include the cable test (Jaeger, 1961; Fergusson, et al., 1964; Deere, 1965; Zienkiewicz and Stagg, 1966) and the tank test (Building Research Station, 1967). The cable test utilizes high-strength steel cables anchored within a boring by either mechanical or grouting techniques. The tank test involves placing a steel tank, filled with water, on a rock surface, with deformation measurements taken in boreholes adjacent to the tank. Neither of these tests is commonly performed.

Exploratory borehole deformation tests (Singh, 1974) are generally miniaturized pressure chamber tests. Depth of exploratory borings for roadbeds should be at least 1.5 meters (5 feet) below the proposed subgrade elevation while borings for embankments should extend below the level of significant influence of the proposed load (ASTM D 420). In areas where drainage may be influenced by either previous water-bearing materials or impervious water-damming materials, borings should extend beyond these materials a sufficient distance to determine those engineering properties relevant to a project design. Advantages of these test techniques are (1) the relatively simple site preparation, (2) measurement of moduli at depth (without the expense of a test adit), and (3) measurement beyond the distressed zone of an adit (Coon, 1968). Disadvantages of these methods of test are that horizontal moduli are measured, since the load is exerted horizontally, and small volumes of rock are affected by the test technique. Several investigators (Duffant and Comes, 1966; Dvorak, 1967) have found that borehole deformation tests indicate higher moduli than other tests and give approximately the same scatter as that of plate-jack tests. Specifically, these tests include the following:

a) the Menard Pressure Meter test (Menard, 1966) -- a cylindrical probe, consisting of three pressure cells of equal size arranged one above the other, is inflated by compressed air or water; the middle cell is utilized for deformation measurements by either feeler gages or by the volumetric method (the extreme (guard) cells increase the vertical length of the loaded area so that deformation measurements are not affected by end effects);

b) CEBTP Apparatus (Mayer, 1963) -- a hollow steel cylinder, axially split into two halves, performs as a plate jack; a pair of oil-filled rubber bags occupy the hollow space in such a manner that changes in oil pressure force the half cylinders apart and an induction extensometer, sensitive to movements of 0.010 cm (0.004 inches) located between the bags, measures the acutal movement of the half cylinders; load on the rock surface is calculated from the pressure in the system;

c) Janod-Mermin Apparatus (Mayer, 1963) -- a hollow steel tube with ring seals at both ends allows pressurization of the hollow space by water; deformations are measured by a pair of transverse extensometers passing through the water seals and contacting the tube sleeve; and

d) Sounding Dilatometer (Kujundzic, 1964) -- a steel cylinder is encased within a rubber envelope, the steel tube is pressurized with water, and resulting deformations are measured by a pair of centrally located extensometers or by measuring the water pumped into the instrument (for soft rocks).

These instrumentation techniques, because of the relatively small volume of rock affected, are subject to local influences of one or more discontinuities. This effect must be assessed to prevent an erroneous evaluation of the massif deformability due to the irregularities of a tested point or length.

Specific information concerning field testing must be retained within an information storage-retrieval system. A separate file external to the computer should be maintained. Such a file would be composed of specifically designed data-information sheets to include parameters discussed herein as well as pressure (at rock face)-deflection graphs, diagrams of apparatus set-up, and the methodology of interpretation. Design of these file sheets is beyond the scope of this report. Essentially, a project must be relatively large to absorb the expense of test site preparation and measurements. Therefore, except for Hoek's field shear-box data and subsequent data (Aufmuth, 1974a), only a coded indication of the existance of these test results will be inserted within the data bank (see APPENDIX I).

Physiographic/Terrain Classification

Three geotechnical classifications of landforms will be briefly discussed under the last attribute of Category 2 information. Beckett and Webster (1962) introduced detailed physiographic classifications. By 1965, investigators had further enunciated principles and standarized terminology for land classification (Brink, et al., 1966). Aitchison and Grant (1967) suggested that the primary function of a land classification system for engineering projects is that of providing a framework for the collection, storage, and retrieval of information. Actual planning and operation phases of an engineering project require that multistage information (different levels of generalization) be utilized to characterize engineering land uses. Although the basic implementation of this system of information management is beyond the scope of the present investigation, a superficial description of various terrain classifications follows:

a) Geotechnical Classification (Jovan and Bozinovic, 1966) -- the bases for these systems is that a terrain unit is the surface manifestation of the lithosphere within the influence zone of a given massif structure. Typically, a terrain unit is a lithological complex which must be considered to have varying mechanical properties with respect to the individual rock masses from which it is derived. The nature of a terrain unit is such that it is a function of composition, spacial distribution, relief, surface and ground waters, climate, vegetation, and anthropogenic disturbances (Stapanovic, 1960).

b) P.U.C.E. (Aitchison and Grant, 1967) -- the Pattern-Unit-Component-Evaluation concerns itself with a four-stage delineation of land masses with characteristic engineering properties (Brink et al., 1966; Grant, 1966). These four stages are the province, terrain pattern, terrain unit, and terrain components, which are also mapping units:

1) Province -- areas of constant geology with no limit of dimension; delineation is provided by regional geology maps and(or) airphoto interpretation (map scale = 1:250,000);
2) Terrain Pattern -- areas of similar airphoto pattern and constant geomorphology (map scale = 1:250,000);
3) Terrain Unit -- areas consisting of a single physiographic feature formed by a characteristic associaton of natural materials with a particular vegetation cover (map scale = 1:50,000); and
4) Terrain Component -- areas of constant rate of change of slope, consistent vegetation associations, and(or) consistent soil or rock profiles measured in situ and extending over an area from less than 4 km^2 (one acre) to more than 260 Mm^2 (one hundred square miles) (not usually mapped).

c) Physiographic Classification (Brink and Partridge, 1967) -- Land Systems are defined (indexed) with respect to a limited number of constituent facets (mapping units) which occur in specific combinations. Variants are defined as mapping units in which the soil or rock profile differs within a land facet occurrence while retaining the same surface form. The Kyalami Land System in South Africa, some 520 Mm^2 (200 square miles), has been successfully mapped utilizing this physiographic classification. In terms of engineering, it was found that certain of the facets repeatedly provided specific construction materials (i.e. granite for subbase material, limestone for coarse aggregate, etc.).

A land mass classification system would have to be stored in a separate file. Only the existence of the classification scheme would be indicated within the data bank.

CATEGORY 3: ENGINEERING EXPERIENCE

The third and final portion of the data bank will contain "historical" information -- previous experience, construction practices, and performance monitoring. All three information composites might be kept in separate files with only the existence of such information being input into the data bank. Previous experience in an area or with a particular formation primarily includes literature references concerning the occurrence of landslides, evidence of tendencies to swell and(or) heave, occurrence of settlement, geologic anomalies, hydrologic problems, problems with slope stability, etc. Specific examples of this literature survey would be information contained in a report by Deen (1968) and a report by

Deen and Havens (1968). Existence of these reports would be cross-referenced by several keywords, by geologic nomenclature/formation identification, by county names, and by longitude and latitude specifications (see Table 5). Keywords should be taken from ASCE's keyword list (1967).

The second type of information input into Category 3 of the data bank involves contemporary construction activities. These are case history studies which furnish information on the success or failure of excavation methods, construction problems encountered within a specific geologic formation or member, sampling difficulties within a specific formation, and positive solutions to engineering problems. This type of information lends itself well to the keyword concept.

Information gained from performance monitoring programs include data on weatherability rate (Floyd, 1967), performance of slopes (Philbrick, 1963), maintenance required for various facility types, and notations of swell, heave, and settlement. Airphoto and ground-photo interpretation and storage is also maintained within this filing system. The keyword concept can also be used to indicate availability of information.

TABLE 5

EXAMPLES OF CROSS-REFERENCING HISTORICAL INFORMATION

Reference: Deen, R. C. (1968), *The Crab Orchard and Osgood Formation; A Case for Slope Instability,* Kentucky Department of Highways, Division of Research, Lexington, 34 p.

Specific case histories were compiled concerning roadway slides occurring within the Crab Orchard Formation (Eastern Kentucky) and the Osgood Formation (Western Kentucky). Borings were made in slide areas as well as a complement of laboratory tests focusing on the clay-shales of these formations. Columnar sections describe the surrounding geology and engineering characteristics of shales were discussed as well as field solutions to embankment damming effects and slope instability.

KEYWORDS

Abutments
Active Transitional
    Materials
Atterburg Limits
Case History
Damming Effect
Drainage
Embankment Foundation
Engineering Material
Landslides
Slope Stability
Useful in Practice
X-Ray Diffraction

GEOLOGIC NOMENCLATURE

Borden Formation
Breathitt Formation
Crab Orchard Formation
Irvine Formation
Osgood Formation
Tradewater Formation

Estill Shale Member
Lulbegrud Shale Member
Oldham Member
Plum Creek Member
Waco Member

Bisher Limestone
Boyle Dolomite
Louisville Limestone
New Albany Shale
    (Chattanooga Shale)
    (Ohio Shale)
Sellersburg Limestone

COUNTY NAMES

Bell
Boyd
Breathitt
Clark
Estill
Johnson
Larue
Lawrence
Leslie
Lewis
Magoffin
Nelson
Perry
Powell

Reference: Deen, R. C. and Havens, J. H. (1968), *Landslides in Kentucky*, Landslide Seminar, University of Tennessee, September 18 - 20, 82 p.

Certain characteristics of landslides in Kentucky reoccur repeatedly. Slides in the Tradewater, Breathitt, Kope, Osgood, and Crab Orchard Formations seem to be associated with subsurface seepage waters and the embankment damming effects. Case history information and geologic columnar sections as well as field solutions are presented in this report.

KEYWORDS

Case History
Damming Effect
Drainage
Embankment
Landslides
Seepage
Shales
Slope Stability
Stability Analysis
Useful in Practice

GEOLOGIC NOMENCLATURE

Breathitt Formation
Crab Orchard Formation
Fairview Formation
Kope Formation
Lee Formation
Osgood Formation
Tradewater Formation

Bedford Shale
Berea Sandstone
Bisher Dolomite
Boyle Dolomite
Brassfield Dolomite
Estill Shale
Lulbegrud Shale
New Providence Shale
Ohio Shale

COUNTY NAMES

Bath
Bell
Boyd
Butler
Clark
Estill
Fleming
Harlan
Kenton
Lawrence
Lewis
Nelson
Ohio
Powell
Pulaski
Rockcastle

CHAPTER III

TRANSITIONAL MATERIALS

INTRODUCTION

Earth materials which are not readily classificable as either soil or rock are termed transitional materials (Tockstein and Palmer, 1974). "Soft rock" might well be included within the transitional category since such rock would perform most probably as a soil in various laboratory tests. For example, the non-destructive type "L" Schmidt hammer has shattered specimens of soft rock in laboratory tests (Deere and Miller, 1966). For this reason and because of the associated chemical breakdown of some soft rock-soil types in water, the free-swell test result can be used to differentiate soils and rocks. Earth material having a free-swell value above a specified level will be considered to be a soil; materials demonstrating lower free-swell values can be designated as rock.

A standard compression softening test (Morgenstern and Eigenbrod, 1974) has been used to categorize argillaceous materials as clays or mudstones; this time-dependent strength loss test is proposed to be used to differentiate rock-soil materials. From the point of view of a rock evaluation program (REP), the description or designation of a material as "soil" or "rock" is relatively unimportant. The REP is directed toward the engineering behavior of consolidated earth materials. For these reasons, the engineer is not so much concerned with the labels "clay shale", "shale", "siltstone", etc. (Grabaw, 1920; Twenhofel, 1937; Wilson, 1971), but is concerned with selecting the most appropriate index and design tests for these materials.

An appreciation of the engineering behavior of transitional materials can be obtained by listing major historical difficulties experienced when these materials were encountered in engineering projects. Transitional materials, in general, have low durability, low shear strength, and high swelling or rebound potential (Gamble, 1971). The presence of smectites and other expandable clay minerals tend to increase the plasticity characteristics of the material. These wide ranges of values of mechanical properties make sampling very difficult. For example, a soft seam of mylonite may be washed away with drilling water during coring. Furthermore, the method of preparing 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 (Gipson, 1963; Savage, 1969); chemical treatment of specimens to remove cementing agents may also alter any clay minerals present (Gamble, 1971). In addition, spalling of shale, loosening of this material on bedding planes (caused by large temperature fluctuations), and freeze-thaw cycles make critical examination of this material a vital aspect of highway engineering (Jumikis, 1966; Loubser, 1967).

CLASSIFICATION AND EVALUATION

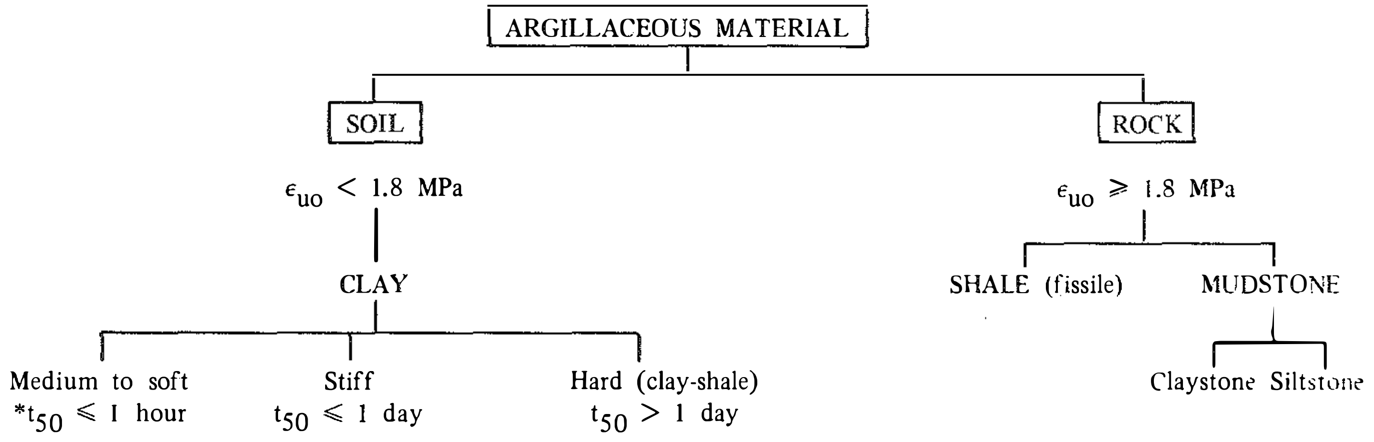
Classifications of transitional materials (Tockstein and Palmer, 1974) have been based on such parameters as particle size (Wentworth, 1922), mineralogy (Clark, 1954; Underwood, 1967; Franklin, 1970), type and degree of bonding -- cemented (rock-like) versus compacted (soil-like) (Mead, 1938; Philbrick, 1950; Underwood, 1967), breaking characteristics (Ingram, 1953), and slaking behavior (Mead, 1938; Gamble, 1971; Morgenstern and Eigenbrod, 1974). 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 sheme (1967) is one of the predecessors of the "use table" rock model (CHAPTER VI). At Philbrick's suggestion (1969), Underwood (1969) divided the evaluation scheme with respect to compact 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 behavior of transitional materials seem to vary with grain size and mineralogy; that is, transitional materials are predominantely composed of fine-grained members with large percentage of clay and silt, and the members are highly over-consolidated (Gamble, 1971).

An argillaceous classification system proposed by Elliot and Strauss (1970) was based upon color, quartz content, and a simple self-polishing field test. The system was used to classify gray-colored mudstones, siltstones, and sandstones. Unfortunately, this sytem has not proven useful for materials of other colors. However, these parameters are included in the Transitional Material Data Bank which is discussed in the next section.

Morgenstern and Eigenbrod (1974) proposed an engineering classification of argillaceous materials based upon 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 8). These authors also proposed a classification in terms of slaking characteristics, which are included in the Transitional Material Data Bank indexing characteristics.

TRANSITIONAL MATERIAL DATA BANK

The proposed data bank attributes for transitional materials is the first prototype of a descriptive system to file results of tests on such materials (see Figure 9). Upon further investigation, the specific tests indicated for input to this data bank may be modified. An in-depth overview of transitional materials was not included in the present investigation. Since only a cursory view of transitional materials was



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

Figure 8. An Engineering Classification of Argillaceous Material.

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/T GROUND SURFACE
				SAMPLE ORIENTATION W/T BEDDING PLANE
				METHOD OF OBTAINING SAMPLE
				RELEVANT COMMENTS
CATEGORY 2	INTACT	PETROGRAPHICS		COLOR
				TEXTURE
				STRUCTURE
				GRAIN SIZE
				SCRATCH HARDNESS
				ACTIVE CLAY AGENTS
				SLICKENSIDENESS
				CONSISTENCY
				HCl REACTION
		INDEXING		FREE SWELL
				SLAKE TEST
				RATE OF SLAKING
				POINT-LOAD INDEX
				ANISOTROPY 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 RESULTS		LAB SONIC VELOCITY
				SHORE SCLEROSCOPE
				UNIAXIAL COMPRESSION
				TANGENT MODULUS @ $\sigma_{ult(50)}$
				NATURAL MOISTURE CONTENT
				SATURATION MOISTURE CONTENT
				DRY APPARENT SPECIFIC GRAVITY
				BULK SPECIFIC GRAVITY
				SSD BULK SPECIFIC GRAVITY
				VOID INDEX
				APPARENT POROSITY
				WATER ABSORPTION
				FINENESS MODULUS
				CONSOLIDATION TEST RESULTS
				FREEZE-THAW TEST
				SODIUM SULFATE SOUNDNESS
				REPEATED DIRECT SHEAR
				DIRECT SHEAR TEST
				TRIAXIAL COMPRESSION
				LOS ANGELES RATTLER
				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 TECHNIQUE
				DIRECT SHEAR STRENGTH
CATEGORY 3				PREVIOUS EXPERIENCE
				CONSTRUCTION PRACTICES
				PERFORMANCE MONITORING

Figure 9. Transitional Material Data Bank Attributes.

undertaken, the data bank is meant to be a model from which further investigations may depart.

A brief description of the CATEGORY 2 segment is included in this section; both CATEGORY 1 and CATEGORY 3 computer specification designs are essentially the same as presented in APPENDIX I and discussed in CHAPTER II.

Petrographic Description

The petrographic description of intact specimens includes color, texture, structure, grain size, scratch hardness, and active clay agents. For computerization, these descriptions could be integer coded into the system; for instance, texture (Podnieks et al., 1968) may be designated as: (0) no input, (1) asphanitic, (2) glassy with microphenocrysts, (3) granular, and (4) phaneritic. Scratch hardness (Leber, 1961) may be designated by: (0) no input, (1) soft, scratched with a fingernail, (2) moderately hard, not scratched with a fingernail, easily scratched with a knife, (3) hard, difficult to scratch with a knife, and (4) very hard, cannot be scratched with a knife. The presence of active clay agents may be indicated by determining clay minerals present or performing "activity" tests and input as: (0) no active clay agents, (1) appreciable presence of montmorillonite, (2) small presence of montmorillonite, (3) appreciable presence of vermiculite, etc. Consistency (Lutton and Banks, 1970) at natural moisture content may be indicated by: (0) no input, (1) soft, easily remolded by fingers, (2) medium, can be broken relatively easily into small pieces, (3) hard, difficult to break into pieces, and (4) very hard, cannot be broken with finger pressure. Plasticity characteristics may be described by knife-cut surfaces as: (0) no input, (1) high gloss, (2) medium gloss, (3) low gloss, and (4) dull.

Intact Indexing

Intact indexing includes the REP intact rock classification test results, Atterberg limits, and some mechanical analysis. Slake durability is not an appropriate test for transitional materials because the material has a tendency to break down and clog the mesh in the revolving drum, thus hampering wear (Franklin and Chandra, 1971). Morgenstern and Eigenbrod (1974) noted a linear correlation between the maximum slaking water content and the liquid limit for argillaceous material. The correlation indicated that, during slaking, materials eventually reach water contents equal to their liquid limits. Thus, input on the amount of slaking can be indicated by the liquid limit and may be integer coded as: (0) no input, (1) very low, $w_L \leqslant 20$, (2) low, $20 < w_L \leqslant 50$, (3) medium, $50 < w_L \leqslant 90$, (4) high, $90 < w_L \leqslant 140$, and (5) very high, $w_L > 140$. The rate of slaking in a two-cycle water immersion test can be described (Morgenstern and Eigenbrod, 1974) by a change of liquidity index: (0) no input, (1) slow, $\Delta I_L \leqslant 0.75$, (2) fast, $0.75 < \Delta I_L \leqslant 1.25$, and (3) very fast, $\Delta I_L > 1.25$. An engineering classification of argillaceous materials (see Figure 8) can be input as the results of a compression strength softening test: (0) no input, (1) mudstone, initial compressive strength > 1.8 MPa, strength loss < 40 percent of original strength, (2) clays, initial compressive strength < 1.8 MPa, strength loss > 60 percent of original strength, (3) hard clays, 50-percent loss of strength within days, (4) stiff clays, 50-percent loss of strength within hours, and (5) medium to soft clays, complete disintengration occurs in less than an hour.

To input the mineralogy of specimens, an appropriate method of identification must be chosen. These methods include differential thermal activity tests, differential gravimetric analysis, x-ray diffraction tests, microscopic (optical and electron) examination, and semi-quantitative spectrographic analysis (Underwood, 1967). After the method is chosen, the investigator must decide which, if not all, chemical constituents should be reported and to what accuracy. Fissility and the presence of laminations (Ingram, 1953) will be input as: (0) no input, (1) massive, (2) flaggy, and (3) flaky.

Atterberg limits tests and hydrometer and(or) sedimentation analyses can be performed after the specimen is broken down by shaving action, grinding, and(or) puliverization. The test procedures should follow ASTM specifications. Additional integer coded input could describe the cementing material: (0) no cementing agent, (1) recrystallization of clay minerals, (2) calcareous, (3) ferruginous, (4) gypsiferous, (5) phosphatic, (6) siliceous, and (9) other. Various inclusions (Jumikis, 1966) would be described as: (0) no input, (1) calcite veins, (2) quartz viens, etc. The last of the intact indexing characteristics included in this prototype data bank is the quartz/feldspar ratio and feldspar freshness (Duncan 1969a).

Intact Physio-Mechanical Test Results

The first 12 parameters, as intact physico-mechanical test results (see Figure 9), are essentially the same as those listed in APPENDIX I. Some parameters have been eliminated (i.e. Schmidt "L" hammer), and many of the test techniques must be altered to some extent (Jumikis, 1966; Lutton and Banks, 1970; Gamble, 1971) for transitional material. Determining the precise test alteration to standard procedures is not within the scope of this investigation.

Consolidation and swell pressure test results (Lutton and Banks, 1970) should include reporting of the following: compression index, C_c; swelling index, C_s; swelling pressure, p_s (from the final load at which no further swelling occurs); time in seconds, t_{50}, for 50-percent rebound for the 1500-MPa (16-tsf) load; and coefficient of compressibility, a_v, in $cm^2/g \times 10^{-4}$ computed for the load sequence between 1500- and, 1-MPa (16- and 0.01-tsf) rebound loads. Resistance to disintegration is indicated by results of a freeze-thaw test and the sodium sulfate soundness test.

Cyclic direct shear tests may be used to determine the residual shear strength according to the procedure of Lutton and Banks; reported results should include a description of the shear surface. Laboratory direct shear tests on weak rock (Mellinger and Kenty, 1971b,c) should be performed at a constant loading rate of approximately 0.4 MPa/min (55 psi/min) and an average rate of displacement of 0.25 mm/min (0.01 in./min). The cohesion, angle of internal friction, and time to failure should be reported and input into the data bank. The shear strength of shale is considered to be its most important property (Jumikis, 1966), and considerable care must be taken to conduct a meaningful test. The triaxial compression test will yield an angle of shearing resistance and a cohesion intercept. An input code is needed to specify the particular triaxial compression test performed. For example, Moretto and Bolognesi (1970) reported the results of three types of triaxial tests:

a) isotropically consolidated triaxial compression tests yielding one Mohr-Coulomb stress circle for each tested specimen; the short-term residual strength is obtained by subjecting specimens to large deformations after the peak value is reached;

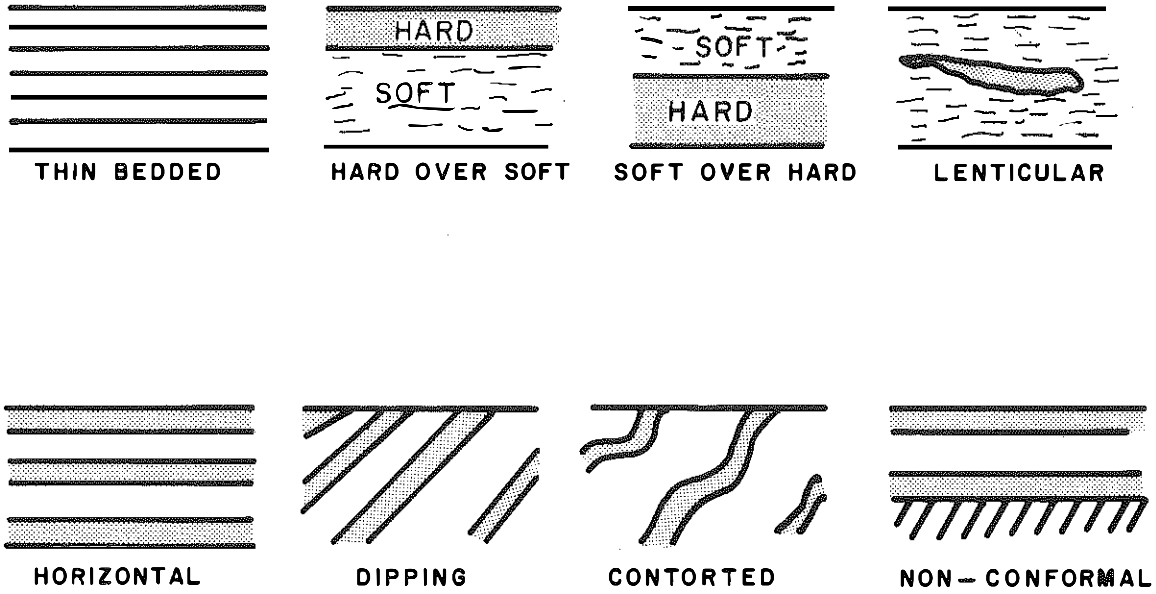
b) multiple-stage triaxial tests yielding three Mohr-Coulomb stress circles for each specimen and three values of the peak strength of the material; in this way, the stress circles are not influenced by the inevitable dispersion of test results that appears when testing apparently "identical" specimens; and

c) multiple-stage triaxial tests yielding four Mohr-Coulomb stress circles and either one or two peak values and two to three residual strength values.

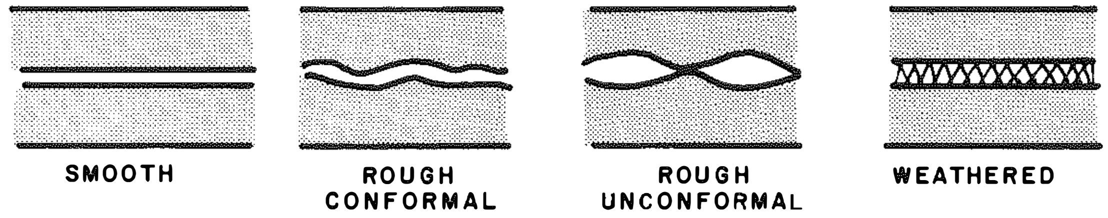
Besides the water-absorption slaking test and the slake-durability test, the Los Angeles rattler and(or) Deval abrasion tests should be conducted to find their applicability to the Kentucky rock suite. If other tests are needed because either the test is too time consuming or the results are not appropriate, there are a wide variety of slaking tests for different times in different laboratory environments: Franklin (1970) -- test conducted using a solution of two-percent sodium hexametaphosphate for 30 minutes and drying time of 1 hour; Badger, et al. (1956) -- specimen is revolved in a drum containing distilled waterr for 30 minutes and washed over a 0.420-, 0.030-, or 0.01-mm sieve; Taylor and Spears (1970) -- specimen placed in de-aired distilled water for 30 minutes, washed and oven-dried; variations include the use of organic liquids (methyl and amyl alcohol, carbon tetrachloride and benzene). Experiments have also been conducted with ultrasonic disaggregation as an index of shale durability (Laguros et al., 1971).

In-Situ Mass Indexing

This segment of the data bank is similar to that detailed in APPENDIX I with the exception of two additional in-situ descriptions. These are descriptions of stratification and bedding interfaces (see Figure 10). The description of the bedding interface (Sowers and Sowers, 1970) gives an indication of the mechanical behavior of in-situ deposits under load. That is, smooth surfaces will slide more readily than rough interfaces in which irregularities match or conform.



STRATIFICATION DESCRIPTIONS



BEDDING AND INTERFACE DESCRIPTIONS

Figure 10. Stratification/Bedding and Interface Descriptions.

The gross heterogeneity measurement obtained by utilizing the Menard Pressure Meter and the in-situ seismic velocity is the same as explained in CHAPTER II.

The orientation or dip of the bedding with respect to the applied loads determines the ensuing stresses, distribution of structural loads, and the tendency for the development of movement (Jumikis, 1966; Sowers and Sowers, 1970). The joint survey, depicting directional joint patterns, joint spacings, and discontinuities, is very often more important than the intact or in-situ strength of the rock.

In-Situ Secondary Indexing

Although the four parameters of in-situ secondary indexing are identical to those of APPENDIX I, namely, core recovery, RQD, fracture frequency, and weighted length index, the field application is significantly different in one very important aspect; these various core computations must be performed immediately upon removal of rock from the core barrel (Gamble, 1971). This is necessary because of the great possibility of "discing" caused by stress relief and(or) wetting/drying. If the calculations are not done immediately, the in-situ secondary indexing parameters will be a function of exposure time and disturbance (to a much greater extent than necessary).

In-Situ Direct Shear Strength

The in-situ direct shear tests of weak rock should follow procedures outlined by Mellinger and Kenty (1971a). In addition, since cyclic direct shear tests have yielded good correlations of residual shear strength with liquid limit for various shales of the upper Missouri River Basin (Fleming, Spencer, and Banks, 1970), it might be beneficial to determine if such a correlation holds for Kentucky rocks.

Category 3

The third category of the transitional material data bank includes previous experience, construction practices, and performance monitoring. Within this category, special attention should be given to measurements of elastic rebound as a result of unloading and(or) stress relief, swelling due to clay mineral hydration or other physico-mechanical reactions, and any chemical alternation of iron sulfides (associated with organic matter) to gypsum, limonite, and other products with resultant volume increase or disruptions of the rock mass.

Omissions

There are some significant omissions from the transitional material data bank. These include specimen surface area, in-situ stresses, crystal growth, Dorey abrasion test results, iron sulfides swelling test, pore pressure, or any indications of Bjerrun's (1967) "recoverable strain energy". Further, no quantitaive method for indicating the cemented-compact material specification need be retained. Distinction between compact and cemented shales may be accomplished utilizing a five-cycle wet-dry test with a 100 N solution of ammonium oxalate or water -- specimens unaffected or reduced only to flakes are termed cemented while specimens reduced to individual grains are termed compacted (Philbrick, 1950). Some measurements which are considered extremely important have not been standardized (for example, specimen surface area). It must be noted again that establishment of this transitional material data bank is a simplified pilot effort, and the mechanics of durability, swelling, and water absorption are functions of such parameters as exchangable ions, particle-size distribution, internal structure, and superimposed load, among others. Further revision may be necessary as results of in-depth studies are incorporated into the rock evaluation program.

CHAPTER IV

STATISTICAL INTERPRETATIONS

SOURCES OF ERROR

Procurement of meaningful data requires a well-defined procedure to measure a physical or mechanical property and specific requirements for the test apparatus. Interpretation of test results, which also requires standardization, is of increasing importance in the field of rock mechanics because of the necessity for index field methods. Limitations of specific measuring techniques is of vital importance because therein lies the test and parameter interpretive limitation (Heuze, 1971).

The measurement process is the application of a specific test method. In general, there are three variability characteristics of a measurement process (ASTM E 177):

a) test method -- involves testing apparatus and an operator to prepare specimens, make and record measurements, and follow test procedures;

b) system of causes -- a system of causes is defined as a collection of factors, such as test apparatus, operator, specimen preparation, field specimen acquisition, and others more difficult to identify, which may cause a variability of measurement; and

c) capability of statistical control -- either the measurements are obtained from an identifiable statistical universe (the realization of a system of causes defines the statistical universe of specific measurements within the measurement process) or an orderly array of statistical universes.

To define statistical characteristics of a measurement process, namely precision and accuracy, the process must be generated by a specific method with a specific system of causes and the process must be capable of a state of statistical control. Generally, the precision of a measurement process is indicative of the degree of mutual agreement between individual measurements from the process. Accuracy refers to the degree of agreement of measurements with an accepted reference level of a specific property; e.g., laboratory sonic velocity. With respect to accuracy, it is far more important to detect and correct an error than merely determine its magnitude. The accepted reference level refers to either the accepted standard value or the actual (or hypothetical) measurement obtained by utilizing a suitable standard method (ASTM E 177).

A consistent deviation from the reference level is known as systematic error. The sources of systematic error lie mainly in the system of causes associated with the measurement process. These causes include the treatment and(or) preparation of test specimens, calibration of instruments, laboratory environment, and interpretation of procedural instructions. Systematic errors may change for reasons difficult to identify. This is especially true for systematic errors associated with individual laboratories, sets of test apparatus, and operators.

In addition to the test method, an experimental determination of a physical and(or) mechanical property requires additional plans and procedures. The experimental technique for determining the precision of a measurement process has an inherent precision which is indicated by the sampling error. Systematic errors due to inadequacies of statistical design or experiment procedural deviations may also be included within this inherent precision problem. Indices of precision include the standard deviation, σ, two-sigma limits (about five percent of the observations from a statistical universe are expected to differ from the average value by more than 2σ), three-sigma limits (less than one percent of all observations from a statistical universe are expected to differ from the average by more than 3σ), difference two-sigma limits, difference three-sigma limits, and indices in percent.

As discussed in the next section, sampling procedures utilized in the field are potential sources of error. In addition, appraisal of intrinsic properties, environmental conditions, and mass response to external forces is associated with potential recording and interpretation errors. As an indication of some of these errors, a brief discussion of some field testing problems follow (Hansagi, 1965; Heuze, 1971):

a) Mass properties from borehole analysis -- comparison of rock mass properties at several sites requires that all boreholes be drilled with the same machine and, whenever possible, the same crew to reduce errors due to the human factor and machine performance.

b) Stress-relief in boreholes -- measurements of stresses in boreholes based upon deformation characteristics require that the mass modulus of deformation be known. The mass modulus of deformation should be determined at, or near, the particular location of stress measurement, and the characterization of the modulus should account for any anisotropic properties of the mass. Typically, estimates of the modulus obtained by laboratory tests on cores in cylindrical pressure cells (cf. Fitzpatrick, 1962) do not give good results since in-situ conditions are not preserved prior to testing nor duplicated during testing. Dilatometers and borehole jacks appear to give more realistic values.

c) Rock Quality Designation -- RQD has been found to correlate best when conditions vary only marginally within the given rock mass. RQD testing procedures require maximum care on the part of the drillers and in their use of equipment; poor performance of either man or machine may affect the spacing and fractures in the recovered core specimens.

d) Mass strength -- one of the most important sources of error in rock mass strength predictions is the size effect; that is, the size of the test sample must be representative of the size of the in-situ prototype. As constraints on the testing, the magnitude and direction of loading should duplicate in-situ stresses, damage to the test specimen must be kept to a minimum, and the water pressure and water content in the specimen must be representative of field conditions (Lane, 1969).

e) Petrofabrics - joint frequency -- regardless of the care taken to perform some type of joint reconnaissance and statistical analysis, if only one major joint remains undetected, then subsequent engineering interpretations may be in error (Terzaghi, 1961; Deere, 1963b).

SAMPLING PROCEDURES

Generalizations made from observations and testing of intact specimens of a given site are, at most, statistical inferences. Confidence in conclusions is directly related to the representative significance of the specific observations and, necessarily, the care in obtaining samples to be tested. Sampling programs include the consideration of the number and location of testing stations, the number of different tests to be performed both in the laboratory and in the field, and the condition of the in-situ mass to be investigated (Friedman, 1963). Sampling accuracy depends to some extent on the experience of the operators and the specific purpose of the investigation (Shergold, 1963). Most importantly, the sampling procedure must be performed in such a manner that all grades of site material are subject to testing and cataloging (Field Sampling Manual, 1960). The size and type of sample required for a site investigation is a function of the specific tests to be performed. ASTM D 420 requires that the size of disturbed and(or) bulk samples for visual classification should be 0.03 to 0.45 kg (2 oz to 1 lb), and for aggregate property tests, samples should weigh 45 to 90 kg (100 to 200 lbs). Analysis begins with the collection of geographically separated specimens. Sample size is also a direct function of the type of site being investigated. For example, ASTM C 295 requires a variety of weights and(or) pieces for the petrographic examination of aggregates for concrete depending upon the type of site. Procurement of intact rock specimens utilizing a diamond core drill should be according to ASTM D 2113.

According to Shergold (1963), sampling aggregate from stockpiles requires eight sample increments taken from a depth of at least 23 cm (9 in.) below the surface of the pile. Patches of segregated material should be avoided. The minimum number and size of sample increments are indicated in ASTM C 295 and are comparable to recommendations of Shergold. These sample increments are throughly mixed to form a composite sample, which is then reduced on a sample divider, or by quartering, to the amount required to be sent to the laboratory (this amount shall not be less than the requirements of ASTM C 295). ASTM D 75 includes a provision that at least three approximately equal increments of aggregate, selected at random from a conveyor belt, bin, or belt discharge, be combined to yield a composite sample whose mass equals or exceeds minimum values.

Sampling rock material directly from a natural outcrop, pit, or quarry face requires special care to ensure that samples are representative of the range of variation encountered within the vein or bed to be sampled. Obvious differences in rock color or texture indicate need for separate sampling, each sample consisting of eight to twelve 10-cm (4-in.) cubes of rock. Where there are no obvious variations in color and texture, not less than 20 cubes should be taken from locations spaced at approximately equal intervals over the height of the outcrop and along the length of the exposure. The spacing of observation intervals is a function of the outcrop extent, that is, the larger the extent of outcrop, the more samples are needed to be representative of the mass. Samples chosen should show no sign of incipient fracture due to unnatural causes; and, unless otherwise specified, the samples should be fresh (previously unexposed) rock (Shergold, 1963).

Steckley, et al. (1973) developed a systematic approach to fragmentation field testing including the following stages: (1) regional test area selection, (2) field site selection, (3) pre-test geologic and fabric investigations, (4) pre-test rock property determination, (5) fragmentation tests (pilot and full-scale), (6) post-test geologic and fabric investigation, and (7) post-test property determination. As part of the detailed pre-test geologic and fabric investigation, oriented samples for rock property determination are collected. The deformational state of the rock in situ is evaluated by detailed mesofabric mapping and core logging. Orientations and densities of joints, faults, bedding planes, etc. are determined and three-dimensional orientations of singular structures (a joint, a fault, etc.) are plotted as a group on equal-area or Lambert-Schmidt nets. Densities are defined as a number of deformation features per unit area of outcrop face. Orientation and density measurements are used to delineate representative areas of the in-situ mass for the collection of oriented samples for the various laboratory tests. A sampling process was recommended by Friedman (1963).

Specimens representing a mass unit must be chosen at random. In particular, a probability sampling plan is necessary to permit the application of probability theory in analyzing test results. Probability sampling plans combine a viable sample selection procedure with an appropriate procedure for grouping and(or) summarizing test results (ASTM E 105; ASTM E 141). Inferences may be made as to universe characteristics and error risks calculated from test results. The sampling plan, which is incorporated in the testing procedure (ASTM E 105), must

a) have an objective procedure for sample selection (using random numbers whenever possible),

b) have an estimate formula (also the standard error of the estimate), and

c) describe the sources of possible bias in the sampling procedure and(or) the estimating formula(s).

Major difficulties involved in probability sampling are the lack of adequate information concerning the pertinent statistical characteristics of the rock mass and the method of specimen acquisition. It must be realized that, regardless of the statistical competency of a particular sampling method, cost or laborous sampling may render the method unusable.

In addition to the above-mentioned procedures, there are specific requirements relative to site information which should be recorded on the Sample-Site Identification Sheet (see Figure 5). In addition, ASTM D 420 requires that rock investigations consist of the following:

a) review of all available information concerning the geologic history and formation of rock and ground-water conditions at the site and immediate vicinity (stored in the data bank: Category 2, In Situ, Physiographic/Terrain Classification; Category 3, Previous Experience and Construction Practices);

b) site investigation of the surface and subsurface materials using test pits, exploratory borings, core drilling, and geophysical methods (stored in the data bank: Category 2, In Situ, Mass Description: Orientation, Joint Survey, Core Borings, Schmidt Hammer Test, and Geophysical Surveys) allowing a determination of the depths to bedrock, water table, and firm foundation material and a general idea of the occurrence and location of structural discontinuities;

c) recovery of representative disturbed samples from the drilling process for laboratory classification tests, for potential construction material evaluation, to complete the intact property matrix of the data bank, and for the determintion of the engineering properties necessary to utilize the specific use table(s) required for a particular project; and

d) evaluation of the performance of existing installations in the immediate vicinity of the site (stored in the data bank: Category 3).

NUMBER OF SAMPLES

Laboratory testing procedures require a representative sample of the site and(or) formation to yield a meaningful measure of the intact property characteristics (Steckley, et al., 1973; Krech, 1973). The question arises, "What is a representative sample?" Beyond this, "How many test pieces of a particular outcrop, formation, or exposure are necessary and sufficient to yield meaningful results?" and "How should the test pieces be made (cut)?" In particular, the specific test must produce sufficient valid experimental evidence with respect to the inherent variability among laboratories, operators, test apparatus, and test specimens to avoid attributing either too much or too little variability to the test method (Mandel, 1964; ASTM E 177).

A representative sample of geologic material is conceptually the minimal amount of material removed from the rock mass, or tested in situ, which will yield an acceptably accurate indication of the particular property being measured. Using only the amount of material so designated as a representative sample, the measured property is delineated within certain confidence limits. The representative sample is actually an index of the geologic formation and(or) outcrop. This index allows strength, durability, anisotropy, lithology, and rock quality to be expressed quantitatively with a minimum number of tests. The variability of some rock properties is so great that many non-destructive tests must be performed on each specimen, with several specimens being required, to yield a representative sample (ASTM D 75). For example, Deere and Miller (1966) recommended that each NX size (54-mm (2 1/8-in.) inside diameter) core specimen be tested at eight points (a quarter turn of the specimen) about each of three circumferences and that the statistical mean of these 24 observations be used to indicate the surface hardness using a Shore Scleroscope. Shergold (1963) has shown that a single sample from a quarry face or a rock outcrop is not sufficient to allow an assessment of rock as aggregate material. A true assessment of the rock requires that a number of samples be tested. The actual number of samples is directly related to the variability of the rock, the tests required, and the experience and discretion of the operator taking the samples. Shergold's investigation demonstrated that at least five samples should be tested for the mean results to be reasonably representative of the rock. "Sample" as used in this context is composed of a mixture of eight separate and distinct shovels of aggregate taken from either a conveyor belt or eight separate truck loads on a given day.

Again, depending upon the specific test, different authors have postulated a variety of required sample numbers. Floyd (1967) recommended that a suite of at least ten samples of the same geologic substance should be tested to obtain a significant mean and measure of the dispersion of uniaxial compressive strength values. Hucka (1965) described a method of utilizing the Schmidt Hammer to determine the strength of rock in situ whereby ten hammer impacts were recorded at ten different places on the rock sample. The arthmetic average (mean) of these 100 individual tests was considered to be representative of the strength function of the rock. Control tests for the uniaxial compression in the laboratory are necessary to identify rock strengths below 25 MPa (3000 psi) since the hammer was designed for testing materials with a strength greater than 25 MPa.

Yamaguchi (1970) concluded that ten or more test pieces are required to statistically determine the strength of rock, even if the test specimens are prepared from the same rock block. In his investigation, Yamaguchi tested three kinds of rock; granite, andesite, and sandy tuff (typically hard, medium hard, and soft rock, respectively). Measurements of both compressive and tensile (radial compression Brazilian test) strengths were made. Rock, being a heterogeneous geologic material, requires statistical analysis or a statistical array to describe most of its physical and mechanical properties. It is essential, therefore, that every test specimen be taken at random from the entire population and that enough test pieces be prepared to determine the inherent probability distribution of the property being tested. It is impossible to attain the true mass mean value and the true variation of rock strength utilizing tests on intact samples; but a probable value and its variation is empirically obtainable. Test pieces were prepared from cores utilizing three orientations. The magnitude of the mean, the standard deviation, and the square root of unbiased variances of the test results indicated that it may be assumed that the distribution of the rock strength was approximately normal. The data collected was randomly divided into several groups of five measurements each. Calculated values of the mean strength, square root of unbiased variance, and the 95-percent confidence limits were tabulated and plotted. In addition, the data were rearranged and divided subsequently into groups of 10, 20, 40, 80, and 161 measurements. Graphs of these results indicated that values of mean strength, square root of unbiased variance, and the 95-percent confidence limits all converge to the fixed values obtained using the total number of test pieces of 161. Using the "decision for sample number" technique, which encompasses the above-mentioned concepts, Yamaguchi concluded that ten or more test pieces were required to determine the strength of rock; this is in general agreement with contemporary experience (Coates and Parsons, 1966).

ASTM E 122 contains relatively simple methods for calculating the number of specimens required to represent a geologic material. These formulas enable the investigator to estimate the average of some physical or mechanical characteristic of a specific material. Either the standard deviation or the range of values must be known or assumed. In addition, the investigator must decide what maximum difference, E, between the estimate made from the sample and the result which would be obtained by testing the sample universe will be tolerated. Equations for calculating the sample size from statistical measures are (ASTM E 122-58):

$n = (3\sigma_0'/E)^2$

where n = size of sample,

σ_0' = advance estimate of the standard deviation,

3 = factor corresponding to a probability of approximately three in 1000 that the difference between the sample and the sample universe is greater than E,

E = maximum allowable difference between the sample estimate and the result of testing the sample universe, and

$n = (3\nu_0/e)^2$

where ν_0 = coefficient of variation $= \sigma_0'/\bar{\sigma}_0'$·the advance estimate of the coefficient of variation, expressed in percent (or as a fraction),

e = $E/\bar{\sigma}'$ = the allowable sampling error expressed as a percent (or as a fraction) of σ'; and

$\bar{\sigma}_0'$ = expected value of the characteristic being measured.

It should be noted that irregularity in the distribution (e.g., skew) can alter the probability factor from 3 to either 1.64, 1.96, 2.58, or 2.0 relating to different probabilities. The range, R, of successsive random groups of four, five, eight, or ten observations can be used to obtain an estimate of the standard deviation.

In particular, R/d_2 is an estimate of the standard deviation. ASTM E 122-58 includes tabulated values of d_2 with respect to group size.

CHAPTER V

DATA MANAGEMENT

OPERATING SYSTEMS

An operating system (OS) includes organization of computer programs, subprograms, and(or) program packages (pre-assembled). Data management programs are designed for maximum efficiency in handling large masses of data by providing systematic and effective accessibility for identifying, organizing, storing, retrieving, and cataloging all data, programs, subprograms, and files within the operating system. Processes of the OS allow data sets (named, organized record) to be stored within the management programs and classified according to specific design and(or) installation requirements (i.e., data may be retrieved by geographic areas, physiographic regions, test results, etc.). A well-designed OS permits the operator to execute a sequence of operations with a minimum of manual intervention and data handling. Data sets may be organized in one of four ways to gain access to the stored data (OS Data Management Services Guide, 1973):

a) Sequential -- location of data set is determined by its physical position (punched tape, punched cards, and printed output);
b) Indexed Sequential -- data sets are arranged in keyed (grouped) sequence;
c) Direct -- data interspersed throughout, and addresses are specified directly;
d) Partitioned -- independent groups of sequentially organized records (members), each member has a specific name stored in a directory.

In general, there are two basic approaches to establishing an operating system for data management purposes -- the format is pre-assembled or the format is assembled specifically for a particular need. Pre-assembled operating systems and(or) scientific packages include the BioMedical Program Package (BMD) and the Statistical Package for the Social Sciences (SPSS). Direct-access programming is assembled as part of the operating system with specific design requirements contained within the assembler language.

DIRECT-ACCESS MANAGEMENT CONTROL

Characteristics of direct-access devices include the following:

a) each set of data has a distinct location and an unique address;
b) devices are similar with respect to data recording, data checking, data format, and programming;
c) recording surface of each volume (standard unit of auxiliary storage, i.e., magnetic tape, disk pack, drum, bin in a data cell) is divided into concentric **tracks**;
d) each device has an **access mechanism** (contains read/write heads which transfer data, one head at a time, as the recording surface rotates past them).

The direct-access volume allows any record (data set) to be found and utilized without extensive search routines. Records can be stored either directly or sequentially. Each data set stored on a volume is described by a simple name or combination of names (for further qualification), location, organization, and other control information stored in the **data set label** or **volume table of contents.** Direct-access volumes must use standard labels (a volume label, a data set label, and optional user labels).

Distinguishing between data set locations on the volume is a potential source of error. The operating system, however, provides for automatic cataloging of data sets. The name of the data set is sufficient to retrieve a cataloged data set. If the data set name is qualified, each qualifying noun corresponds to one of the indices in the catalog. For example, the OS finds the data set COUST.PHYREG.MAGEOFO.ROCTYP (each name consists of one to eight alphameric characters, the first of which must be alphabetic) by simply searching a master index to determine the location of the index name COUST (County and State information), by searching that COUST index to find the location of the index PHYREG (Physiographic Region information), by searching that PHYREG index to find MAGEOFO (Major Geologic Formation information), and by searching that MAGEOFO index to find ROCTYP (Generic Rock Type data) to find the identification of the volume containing the data set.

Direct-access volumes are used to store programs, subprograms, the operating system, and data (and for temporary working storage). A volume table of contents (VTOC) is utilized to register each data set and the available space on the volume since one specific storage volume may contain many different data sets and space may be relocated and reused as the need arises. The volume is identified by a volume label (usually stored in Track 0 of Cylinder 0). Seven additional labels located after the standard volume label may be used for further specification and(or) identification. These additional labels enable the operator to specify data acquisition as to geographic location, rock type, formation, and map number for easy access and usage.

BIOMEDICAL COMPUTER PROGRAMS

The BioMedical Program Package (Dixon, 1973) was developed by the UCLA Medical Center and includes programs for commonly required data processing and statistical analyses. Programs are classed in six categories: (1) description and tabulation, (2) multivariant analysis, (3) regression analysis, (4) special problems, (5) time series analysis, and (6) variance analysis.

Input data may be inserted into the BMD system by cards, tapes, or disk. The DATA MATRIX is composed of DATA VALUES; rows are called CASES while columns of the array are called VARIABLES. All parameters are number-coded. Data for both the BMD and SPSS systems are card-punched on a case-wise basis (each case is completed on one or more cards, then the next case begins a new card). The operator must refer to a particular program description (see Table 6) to ascertain which control cards are necessary to initiate that program. The more elaborate analyses of regression, variance, and multivariance require that cases have no missing input variables (the programs assume zeros for all undesignated parameters). Data for a BMD program must begin with a problem card (PROBLM in Columns 1-6) and must have a finish card (FINISH in Columns 1-6) as the last control card. The body of the deck has at least one variable format card (specified arrangement of data) and optional label cards, transgeneration cards (to generate new variables), and some special cards required by special programs.

An interesting variation of the BMD package is possible since the operator may vary the data format (alter the field sequence of variables) for a specific application. VARIABLE FORMAT cards inform the specific program of the data format to be used. The operator must specify the number of cards used to keypunch the variable format on the PROBLM card (Dixon, 1973). Input variable format cards allow the operator to select only those cards which have fields (variables) of interest. In addition, the operator may choose among the fields on each card.

As an example of the keypunch cards necessary to utilize the BMD package, Figure 11 demonstrates a listing of control cards necessary to run program BMD01D, Simple Data Description. The listing does not include the data input deck, which would follow the variable format cards and precede the FINISH card. The output of BMD01D includes the calculation of means, maximum values, minimum values, ranges, and sample sizes. System cards vary from computer installation to computer installation.

The disadvantage of the BMD package for data manipulation required for the Rock Evaluation Schema (Tockstein and Palmer 1974) is that the system of programs are completely independent; they are not compatible in terms of data input or output. Only completely independent problems can be processed.

STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

The Statistical Package for the Social Sciences (SPSS) is a documented, integrated system of computer programs, written in Fortran language, originally designed for the analysis of social science data. As such, the computer program package provides a unified and comprehensive set of procedures designed for data transformation and file manipulation. Statistical routines commonly used in the social sciences have been included in the computer package, including the following subprograms:

a) cross-tabulations (CROSSTABS and FASTABS);

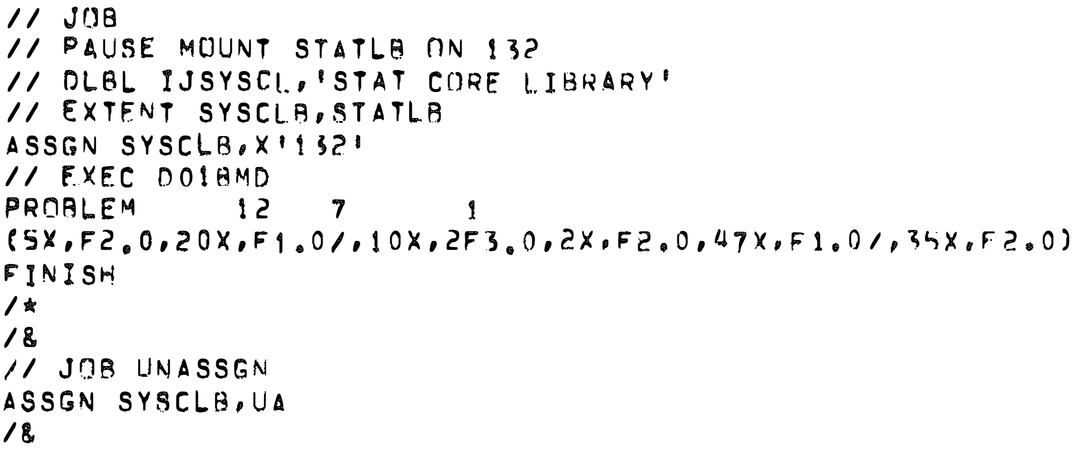
b) bivariate correlation analysis -- Pearson product-moment correlation coefficients (PEARSON CORR), Spearman, and(or) Kendall rank-order correlation coefficients (NONPAR CORR) to measure the linear association of two parameters;

c) partial correlation -- cross-tabulation with control variables (PARTIAL CORR provides the

TABLE 6

SOME BMD PROGRAM DESCRIPTIONS

PROGRAM DESIGNATION	PARSIMONIOUS DESCRIPTION
BMD 01 D	Computes averages and measures of variable dispersion (mean, standard deviation, maximum, minimum, range, and standard error of each variable).
BMD 02 D	Computes simple correlation coefficients, averages, variances, measures of variable dispersion, and scatter plots
BMD 03 D	Computes simple correlation matrix with item deletion (means and standard deviation)
BMD 04 D	Computes alphanumeric frequency count
BMD 05 D	Provides scatter plots or histograms
BMD 06 D	Cases grouped with respect to one variable; summary statistics
BMD 07 D	Groups data; produces histograms; summary statistics
BMD 08 D	Computes two-way frequency tables
BMD 09 D	Produces cross-tabulation (accepts incomplete data)
BMD 01 M	Computes correlation coefficients, eigenvalues, and rank order
BMD 08 M	Performs factor analysis (maximum of 198 variables)
BMD 01 R	Performs simple linear regression (one-way analysis of covariance); least-squares method
BMD 02 R	Performs multiple linear regression; least-squares method
BMD 14 S	Performs a tape sort of BINARY or BCD records
BMD 01 V	Computes an analysis of variance table for one variable



```
// JOB
// PAUSE MOUNT STATLB ON 132
// DLBL IJSYSCL,'STAT CORE LIBRARY'
// EXTENT SYSCLB,STATLB
ASSGN SYSCLB,X'132'
// EXEC D01BMD
PROBLEM      12    7      1
(5X,F2.0,20X,F1.0/,10X,2F3.0,2X,F2.0,47X,F1.0/,35X,F2.0)
FINISH
/*
/&
// JOB UNASSGN
ASSGN SYSCLB,UA
/&
```

Figure 11. BMD10D.

partial-correlation coefficient and the level of statistical significance);

d) multiple regression -- linear relationship between a set of independent parameters and a dependent variable (REGRESSION) allowing prediction of the dependent parameter;

e) factor analysis (FACTOR) -- with and without iteration, Rao's canonical factoring, and alpha and image factoring; these techniques aid in the determination of the degree to which a given parameter or set of parameters is characteristic of a common phenomena;

f) Guttman scaling -- unidimensional, cumulative index (GUTTMAN SCALE) describes interrelationships between three or more parameters;

g) simple frequency distributions (summary statistics) -- arthmetic mean, standard deviation, variance, skewness, kurtosis, mode, standard error, range, minimum, maximum, chi-square, Fisher's exact test, Cramer's V, contingency coefficient, lambda asymmetric, lambda symmetric, Kendall's tau B and C, the gamma statistic, Somer's D, and uncertainty coefficients.

The operator may generate variable transformations, recode variables and(or) parameters, and sample, select, or weight specified observations. The SPSS text (Nie, Bent, and Hull, 1970) is a complete instructional manuscript for the SPSS computer programs and data management. The text is written in sufficiently simple language to make the system easily accessable to operators with little prior computer language or device experience. Processing operations include the classification, sorting, storing, and retrieval of computer coded data.

One of the more important design functions of the SPSS system is that the output resulting from processing a data file through one subprogram may be used directly as the input to another subprogram. This enables a long chain of analysis tasks to be performed easily. In addition, the SPSS can be amplified to include procedures which have not been previously provided. These features, as well as combining values of parameters arithmetically, permit, for example, the calculation of various elastic and dynamic constants using values obtained from the appropriate data bank file system. Data analysis is used to condense information for easy comprehension and interpretation, to describe a body of empirical data, and to search for meaningful patterns or relationships among sets of parameters. Examination of parameter (variable) distribution characteristics is accomplished by any one of three distinct statistical procedures:

a) CONDESCRIPTIVE -- parameters may assume a continuum of values;
b) CODEBOOK -- parameters may assume only a limited number of values; produces elaborate, labeled tables of parameter values including relative frequency and distribution histogram;
c) MARGINALS -- parameters may assume only a limited number of values; produces information similar to CODEBOOK, with the exception of histograms and labeling.

All three subprograms include provisions to calculate the mean, mode, maximum value, standard deviation, and range, at the discretion of the operator.

Subprograms CROSSTABS and FASTABS permit an operator to compile two-way to n-way cross-tabulations of parameters and to compute various data frequency distributions. In particular, CROSSTABS produces a sequence of two-way tables (values of the first parameter on the ordinate and the second parameter values on the abscissa) composed of frequency counts of the number of cases and(or) observations in which the two parameters took each possible combination of values expressed as a percentage for row total, column total, or combinations of these totals. The degree of association of the two parameters with respect to the distribution of frequency counts in the two-way table may be characterized by chi-square, Cramer's V, Kendall's tau B and C, the gamma statistic, and Somer's D. A sequence of two-way tables is generated to handle n-way cross-tabulations. FASTABS operates in a similar manner but can manipulate only numeric input data.

The SPSS system is activated by means of a sequence of control cards (80-column card format). Two important operator functions with respect to control cards are (1) to prepare control cards in the specified format recognizable by the system and (2) to arrange the control cards in the appropriate sequence to perform the operations in the order intended. Data bank attributes (Figure 4) are organized within the SPSS system in a file. The complete file sequence consists of data and the appropriate SPSS control cards:

a) file name;
b) variable list (variables in specific file);
c) subfile (names subfiles, if any, being entered into the file);
d) number of data cases in the file; if the exact number of cases is not known, the keyword ESTIMATED is placed after # OF CASES (not for card input device), and the operator must

choose a number greater than or equal to the actual number of cases -- the system will accept fewer cases than estimated, but not more;

e) input medium used to enter the data (card, tape, disk); and

f) input format statement.

Optional control cards include:

a) missing data values (designate up to three values which are treated as missing),

b) extended variable labels,

c) variable value labels, and

d) variable printing formats.

Most of these cards are included in Figure 12. This figure is a listing of an SPSS sequence application, including control cards and cross-tabulation routine.

Although the SPSS system is not specifially designed as an information retrieval system, features of the program package do allow the SPSS to be used for this purpose. The operator simply creates an SPSS file to be saved (SAVE FILE, on tape) and on specific subsequent runs, a WRITE control card may be inserted into the card deck to obtain general selected parameters from a specific file. Also, specific cases may be omitted and(or) rejected. SPSS performs the required calculations and produces a printed output. The detail of the output report depends on the detail the operator has provided when defining the data file and imposing various options and restrictions on specific statistical programs.

Selection of specific calculations and methods of report presentation is accomplished by the use of task definition cards (see Figure 12). The task definition concept allows the selection and activation of specific statistical programs (CROSSTABS, GUTTMAN, REGRESSION, etc.) by means of procedure cards which name the subprogram desired and indicate the variables (parameters) directly concerned in the statistical calculation. The OPTIONS card specifies optional program processing of missing data and various calculation and printing functions. Since the options available and the corresponding code integer number vary from one subprogram to another, the specific definition of option codes is included within the text of the subprogram routines. The STATISTICS card allows the operator to select specific statistical routines from those available and to have the results reported as output. Like the OPTIONS card, the STATISTICS card coded integer numbers vary from subprogram to subprogram. The PROCESS SBFILES card gives the operator access to different subfiles of the file DATA0110. Calculations of individual combinations of subfiles is easily accomplished by the PROCESS SBFILES card and the subfile names specified within parentheses starting in Column 16 of the computer card format.

Run cards include the optional RUN NAME card, FINISH card, KEYPUNCH card (SPSS assumes the use of an IBM 029 keypunch; if an IBM 026 is used, the KEYPUNCH control card with 026 starting

SYSTEMS CARDS

```
// JOB JIN395        PALMER, MICHAEL W                                    09.17.32
ALLOC F2=0K
// PAUSE MOUNT 9'S PACK ON 137
// ASSGN SYS001,X'137'
// DLBL IJSYS01,'SPSS LABELS',0
// EXTENT SYS001,999999,1,0,20,10
// ASSGN SYS002,X'137'
// DLBL DISKOUT,'SPSS DATA',0
// EXTENT SYS002,999999,1,0,30,50
// DLBL DISKIN,'SPSS DATA'
// EXEC SPSS148
```

DATA DEFINITION CARDS

```
RUN NAME        INPUT DATA
FILE NAME       DATA0113
VARIABLE LIST   ST, CO, PR, MN, LON, LAT, ID, GF, LITHO, GEL, SF, WTE,
                SOG, SOB, MOS, RC, FREE1, COL, TEX, STR, GS, CCC, FREE2,
                FS, SDI, TSI, SAI, LITH, SS, TSB, FREE3, LSV, SSH, SHH, CARD1,
                UCS, TM50, NMC, SWC, ASG, BSG, FREE4, AP, AVR, SSDG,
                DOS, VI, FREE5, DSP, DSC, DST, TSCP, TCSC, LAA, DA, TI,
                FE, CAD, COV, SEFF,
                MC, FREE6, CARD2, BT, JS, JF, JIM, GH, VR, FREE7, JO,
                JSUR, FREE8, CR, RQD, FF, WCL, SH, FREE9, GEOS, FT, LC,
                FREE10, PE, CP, PM, FREE11, CARD3
INPUT FORMAT    FIXED (F2.0,F3.0,F2.0,F4.0,F4.0,F4.0,A5,F3.0,F1.0,F4.1,
                F4.1,F4.1,F2.0,F2.0,F1.0,F1.0,F2.0,F2.0,F1.0,F1.0,F1.0,
                F1.0,F2.0,F2.0,F2.0,F2.0,F2.0,F1.0,F1.0,F1.0,F2.0,F5.0,F3.0,
                F2.0,F1.0/2X,3X,5X,F3.1,F3.1,F2.0,F2.0,F3.2,
                F3.2,F1.0,F2.0,F2.0,F3.2,F2.0,F2.0,F1,0,F2.0,F3.1,F3.1,F2.0,F3.1,
                F2.0,F2.0,F2.0,F3.0,F1.0,F2.2,F3.1,F1.0,F10.0,
                F1.0/2X,3X,5X,F3.0,F3.0,F1.0,F1.0,F1.0,F2.1,F1.0,F5.0,
                F1.0,F4.0,F2.0,F2.0,F2.0,F2.0,F2.0,F4.0,
                F1.0,F2.0,F1.0,F7.0,F5.0,F5.0,F5.0,F4.0,F1.0)

# OF CASES      10
INPUT MEDIUM    CARD
VAR LABELS      ST, STATE NAME/CO, COUNTY NAME/PR, PHYSIOGRAPHIC REGION/
                MN, USGS MAP NUMBER/LON, LONGITUDE/LAT, LATITUDE/
                ID, SAMPLE IDENTIFICATION NUMBER/GF, GEOLOGICAL FORMATION/
                LITHO, LITHOLOGY/GEL, GROUND ELEVATION/SF, SAMPLE ELEVATION/
                WTE, WATER TABEL ELEVATION/SOG, SAMPLE ORIENTATION WRT GROUND/
                SOB, SAMPLE ORIENTATION WRT BEDDING PLANE/
                MOS, METHOD OF OBTAINING SAMPLE/RC, RELEVANT COMMENTS/
                FREE1, UNSPECIFIED AT PRESENT/
                COL, COLOR/TEX, TEXTURE/STR, STRUCTURE/GS, GRAIN SIZE/
                CCC, CALCIUM CARBONATE CONTENT/
                FREE2, UNSPECIFIED AT PRESENT/
                FS, FREE SWELL RESULTS/SDI, SLAKE DURABILITY INDEX/
                TSI, POINT LOAD INDEX/SAI, STRENGTH ANISOTROPY INDEX/
                LITH, LITHOLOGY/SS, STRENGTH SOFTENING/TSB, TIME STRAIN BEHAVIOR/
                FREE3, UNSPECIFIED AT PRESENT/
                LSV, LABORATORY SONIC VELOCITY/SSH, SHORE SCLEROSCOPE HARDNESS/
                SHH, SCHMIDT HAMMER HARDNESS/CARD1, END OF CARD I/
                ST, STATE NAME/CO, COUNTY NAME/ID, IDENTIFICATION NUMBER/
                UCS, UNIAXIAL COMPRESSION STRENGTH/TM50, TANGENT MODULUS AT 50%/
                NMC, NATURAL MOSITURE CONTENT/SWC, SATURATION WATER CONTENT/
                ASG,DRY APPARENT SPECIFIC GRAVITY/BSG, UNIT WEIGHT/
                FREE4, UNSPECIFIED AT PRESENT TIME/
                AP, APPARENT POROSITY/AVR, APPARENT VOID RATIO/
                SSDG, APPARENT SPECIFIC GRAVITY/DOS,WATER ABSORPTION/
                VI, VOID INDEX/
                FREE5, UNSPECIFIED AT PRESENT TIME/
                DSP, DIRECT SHEAR PHI ANGLE/DSC, DIRECT SHEAR COHESION/
                DST, DIRECT SHEAR TIME TO FAILURE/
                TSCP, TRIAXIAL COMPRESSION STRENGTH PHI ANGLE/
                TCSC, TRIAXIAL COMPRESSION STRENGTH COHESION/
                LAA, LOS ANGELES ABRASION TEST/DA, DEVAL ABRASION TEST/
                TI, TRETON IMPACT TEST/FE, FRACTURE ENERGY/CAD, COST ANALYSIS/
                COV, STRENGTH COEFFICIENT OF VARIATION/SEFF, SCALE EFFECT/
                MC, MINERALOGY/
                FREE6, UNSPECIFIED AT PRESENT/
                CARD2, END OF SECOND DATA CARD/
                ST, STATE NAME/CO, COUNTY NAME/ID, IDENTIFICATION NUMBER/
                BT, BEDDING THICKNESS/JS, JOINT SPACING/
                JF, JOINT FREQUENCY/JIM, JOINT INFILTRATION MATERIAL/
                GH, GROSS HETEROGENEITY/VR, VELOCITY RATIO/
                FREE7, UNSPECIFIED AT PRESENT/
                JO, JOINT ORIENTATION/JSUR, JOINT SURVEY/
                FREE8, UNSPECIFIED AT PRESENT/
                CR, CORE RECOVERY/RQD, DEERES ROCK QUALITY DESIGNATION/
                FF, FRACTURE FREQUENCY/WCL, WEIGHTED CORE LENGTH/
                SH, SCHMIDT HAMMER TEST/
                FREE9, UNSPECIFIED AT PRESENT/
                GEOS, GEOPHYSICAL SURVEYS/FT, FIELD TESTING/
                LC, LANDFORM CLASSIFICATION/
                FREE10, UNSPECIFIED AT PRESENT/
                PE, PREVIOUS EXPERIENCE/CP, CONSTRUCTION PRACTICES/
                PM, PERFORMANCE MONITORING/
                FREE11, UNSPECIFIED AT PRESENT/
                CARD3, END OF THIRD DATA CARD
VALUE LABELS    PR (1)BLUEGRASS(2)EASTERN COAL FIELD(3)JACKSON AREA(4)KNOBS
                (5)PENNYROYAL(6)WESTERN COAL FIELD/
                LITHO (1)LIMESTONE(2)SHALE(3)SANDSTONE(4)SILTSTONE
                (5)GRANITE(6)CONGLOMERATE(7)OTHER/
                COL (00)WHITE(10)BLACK(20)BLUE(30)BROWN(40)GRAY
                (50)GREEN(60)OLIVE(70)ORANGE(80)RED(90)YELLOW/
                TEX (1)CRYSTALLINE(2)CRYSTALLINE-INDURATED(3)INDURATED
                (4)COMPACT(5)CEMENTED/
                STR (1)HOMOGENEOUS(2)LINEATED(3)INTACT-FOLIATED
                (4)FRACTURE-FOLIATED/
                GS (1)COARSE(2)MEDIUM(3)FINE/
                CCC  (1)CALCAREOUS(2)PARTLY-CALCAREOUS(3)NON-CALCAREOUS/
                CAD (0)NONE(1)AVAILABLE(2)CLASSIFICATION(3)OTHER/
                MC (1)QUARTZOFELDSPATHIC(2)LITHIC(3)PELITIC-CLAY
                (4)PELITIC-MICA(5)SALINE/
                JIM (1)AIR(2)WATER(3)COHENSIONLESS SOIL(4)INACTIVE CLAY
                (5)ACTIVE CLAY(6)GRAVEL(9)OTHER
```

TASK DEFINITION CARDS

```
MISSING LABELS  FS(0)/SDI(0)/SAI(0)/LITHO(0)/LITH(0)
CROSSTABS       FE BY TSI
OPTIONS         3,5
STATISTICS      1,3
READ INPUT DATA
```

Figure 12. SPSS Sequence Listing for Cross-tabulation.

in Column 16 is necessary to successfully complete the run), PRINT BACK card (to suppress printing of control cards in the report), COMMENT card, DOCUMENT card (only used once during the processing run, this card contains any documenting information within the SPSS file specified by the control name starting in Column 16), and the NUMBERED card (instructs the computer to ignore any information contained in Columns 73 through 80 on control cards; enables the operator to number code cards of a run or put any other comment or documented information in those particular columns).

An SPSS file is composed of two distinct portions: (1) information describing the data (data-definition cards) and (2) the specific data cases. The file is retained on tape by the SAVE FILE control card. After file generation and retention is achieved on tape format, the file is automatically accessible on subsequent processing runs using the GET FILE control card. Data and documenting information within the SPSS file is alterable with respect to labels, missing values, variable transformations, variable recoding, new variable addition, and updating data.

The nature of the data management program utilizing the SPSS system is infinitely variable because of the system's data-modification capabilities, data-selection cards, and the file-modification control cards. Data-modification control cards (RECODE, COMPUTE, IF) allow the operator to modify the existing data file based on existing variables and existing values associated with these variables, temporarily or permanently. Data-selection control cards (SAMPLE, SELECT IF, WEIGHT) enable the operator to select from or bias cases within the file. File-modification control cards (DELETE VARS, KEEP VARS, ADD VARIABLES, WRITE CASES) permit the operator to delete or add data from an existing file and thus is an updating and maintenance function.

The purpose of the data bank matrix is to store results of various tests on rock material and to facilitate specific correlation studies which might be useful to the engineer. The system operator may want to construct a composite index or scale generated from several parameters within the matrix, or the operator may wish to reclassify continuous variables into groupings, or discrete categories, to be used in frequency distribution subprograms or to generate rock index classifications based on the specific parameters so chosen. The COMPUTE and IF control cards permit the operator to generate variable transformations by means of Fortran-type arithmetic and logical statements. For example, the COMPUTE transformation control card can be used to combine two variables within the system file in order to generate a new variable:

```
Column 1        Column 16
↓               ↓
COMPUTE         MODRATIO = TM50/UCS.
```

In this case, the modulus ratio is computed as the ratio of the tangent modulus at 50 percent ultimate strength (TM50) to the uniaxial compressive strength (UCS). The RECODE control card causes values of existing variables to be altered while both the COMPUTE and IF cards cause new variables to be introduced into the matrix file structure.

Data-selection control cards enable the operator to retrieve data from specific cases or grouping of cases contingent upon constraints the operator has established. For example, the SELECT IF control card can be used to obtain specific cases within a particular physiographic region and having a specific generic rock type designation associated with the data:

```
Column 1       Column 16
↓              ↓
SELECT IF      (PR EQ 1 AND LITHO EQ 1).
```

This card and logical expression will retrieve all data catalogued in the Bluegrass Region (PR = 1) and as limestone rock type (LITHO = 1). The operator may wish to exclude a variety of parameters from a particular statistical routine. To generate a subset of variables within the file, the operator may use either the DELETE VARS or KEEP VARS control card, whichever is more economically consistent with the number of variables concerned, in conjunction with the SAVE FILE card. For example, if the operator were interested only in the intact classification results for limestones in the Eastern Coal Region, the following routine might be used (if the data bank is stored on tape):

```
Column 1       Column 16
↓              ↓
RUN NAME       LIMESTONE INTACT INDEXING IN EASTERN COAL FIELD
GET FILE       DATA0110
FILE NAME      INDEXLIM, NEW FILE WITH ONLY INTACT CLASSIFICATION
SELECT IF      (PR EQ 2 AND LITHO EQ 1)
KEEP VARS      FS, SDI, TSI, ASI, LITHO
SAVE FILE
FINISH
```

In addition, new variables can be added to the original SPSS file by means of the ADD VARIABLES control card. Subject to certain constraints (one-to-one correspondence between number and order of cases in system file and new variables, and the total number of variables in the system may not exceed 500), the most critical possible source of error is failure to ensure that the variables being added are added to the proper cases. One means of accomplishing the variable addition into the system file to correspond to the proper cases is by means of the sample identification number (ID) as a reference.

The most serious disadvantage of the SPSS system is that files cannot be read directly by programs outside the system. This would seem to negate the use of other statistical packages or other programs in conjunction with the SPSS files. However, the WRITE CASES procedure does provide access to the SPSS file data in a form readable by all data processing programs. In particular, the WRITE CASES procedure allows the operator to have any or all of the data punched on cards, or written on tape, disk, or another medium of choice. The operator can specify the selection of variables and cases to be output and also the output format. The WRITE CASES procedure is controlled by the WRITE CASES control card followed by a Fortran IV format list in parentheses (list of instructions for writing the data) and a variable list containing the variables to be output. For example, if the operator wants to output the data concerning the in-situ classification system for processing external to the SPSS package, the following procedure may be followed:

```
Column 1       Column 16
↓              ↓
RUN NAME       IN SITU CLASSIFICATION OF LIMESTONES AND GRANITES IN THE
               KNOBS REGION
GET FILE       DATA0110
SELECT IF      ((PR EQ 4) AND LITHO EQ 1 OR LITHO EQ 5)
WRITE CASES    (2(F3.0,2X),3(F1.0,2X),F2.0)BT,JS,JF,JIM,GH,VR
FINISH
```

This deck would output all data concerning the in-situ variables for limestone and granite rock types from the Knobs region.

The SPSS text (Nie, Bent, and Hull, 1970) discusses in detail the various statistical routines available to the operator. These routines include descriptive statistics, table displays, multiple regression analysis, and various scaling features.

CHAPTER VI

DATA MANIPULATION

INTRODUCTION

The rock evaluation program provides an information storage device, the data bank, and an aid to engineering interpretation and a means for making various physico-mechanical parameter correlations. This latter aspect of the REP, raw data manipulation, provides a predictive tool for the engineer user. Laboratory test results and gross massif characterizations can be utilized to predict prototype reactions and structural engineering features of in-situ rock. Causes of rock failures must be investigated on the basis on data in the information bank to fully determine design potentials of rock material and adequate factors of safety. Since rock masses characteristically are heterogeneous, anisotropic, anelastic, discontinuous, and sustain natural stresses that cannot be simulated in laboratory situations, statistical methods of analysis, evaluation, and interpretation must be applied to empirical and observational techniques of rock investigation. Each site and each project must be evaluated as separate units (Judd, 1965). Extrapolation of information from one project to another may well lead to erroneous conclusions. Each design situation involving rock material must be evaluated upon its own merits; however, the data bank can indicate physical property trends, petrographic similarities, or structural similitude if information on a given site is available in both the intact and in-situ categories. Also, site location can be categorized as sources of rock construction materials (i.e., concrete aggregate, riprap, impervious blankets, dam filter material) for construction bidding purposes and for various use tables (see Figure 13).

Data may be manipulated in three distinct ways. Data bank information may be (1) stored for users needing simple data correlations (e.g., fracture frequency verses point-load test results); (2) massaged to define mechanical constants (static modulus of deformation, dynamic modulus of deformation, logarithmic decrement, etc.) thereby setting up temporary information files and design parameters; and (3) used in regression analyses to obtain comprehensive design data.

DATA BANK INFORMATION

A suite of Kentucky rocks must be characterized in terms of a file of values for physico-mechanical properties and observational techniques. This information bank would permit the evaluation of strength and structural properties of rock with minimal sampling. For example, porosity and density characteristics have been related directly to in-situ ultimate compressive strength of carbonate rocks through the use of radioactive isotopes, without sampling (Smorodinov, et al., 1970). These investigators established the following empirical equations, for the rock tested:

$$\sigma_{ult} = 0.88e^{2.85\rho} \qquad 1.55 < \rho < 2.86 \text{ g/cm}^3 \qquad r = 0.91 \pm 0.017$$

$$\sigma_{ult} = 0.95e^{2.55\rho} \qquad \rho < 2.65\ g/cm^3 \qquad r = 0.95 \pm 0.012$$

$$\sigma_{ult} = 2590e^{-0.091n} \qquad 0.11\% < n < 37.4\% \qquad r = 0.81 \pm 0.019$$

$$\sigma_{ult} = 3500e^{-0.108n} \qquad \text{quartz} \qquad r = 0.85 \pm 0.046$$

where σ_{ult} = ultimate compressive strength,
ρ = density,
n = porosity, and
r = correlation ratio.

Such correlations can be accomplished with data bank attributes, and analyses of the Kentucky suite of rocks may be compared to the kind of results shown above. Many correlations of this type, including the integrity-strength classification (fracture index verses point-load strength) applied to rock mappings (Franklin, 1970), are possible utilizing attributes in the data bank.

In addition, a rock quality classification based on tests and observations can form the basis of geotechnical maps indicating local rock quality variations (Cottiss,et al., 1971). A composite index utilizing results from a set of tests and observational techniques can give a better impression of rock quality

CLASSIFICATION ELEMENT	RANGE OF ACCEPTABLE VALUES FOR RIPRAP	
	(after McClure, 1968)	(Smith, et al., 1970)
Uniaxial Compressive Strength	> 500 MPa	
Hardness (Moh's)	⩾ 5.4	
Absorption	⩽ 2.9%	⩽ 2%
Specific Gravity	⩾ 2.62	⩾ 2.5
Freeze-Thaw Test (% loss; 100 cycles)	< 4.7%	
Wet Shot Rattler (% loss)	⩽ 41%	⩽ 40
Sodium Sulfate Soundness (% loss)		⩽ 10
Los Angeles Rattler (% loss)		⩽ 45

Figure 13. Riprap Use Table.

than can one or two separate indices. Cottis, et al. (1971) combined nine coded test results (dry and wet fracture indices, slake loss, apparent specific gravity, porosity, sonic velocity, Schmidt hardness, Brazilian tensile strength, and uniaxial compressive strength) to obtain a relative score of rock quality. These investigators also noted that fracture orientation, roughness, infilling material, and size effects must be considered to characterize the rock mass properly. Franklin, et al. (1971) devised a rock quality diagram (see Figure 14) utilizing fracture index, strength index, and bedding plane spacing. Such composite indices can be coded and formulated easily from data bank attributes. Whether rock quality scores are desired, or results of various intact or in-situ classification systems are needed, data within computer files are easily accessible.

ENGINEERING CONSTANTS AND CORRELATIONS

Data can be massaged to yield various engineering constants and new (not previously in data bank) parameters. For example, compressive strength, static and dynamic moduli, and logarithmic decrements (which characterize the internal friction or damping capacity of a material in terms of rate of vibration decay) can be obtained from rock sonic properties (Avedissian and Wood, 1968; ASTM C 215). For sedimentary rocks (limestones, dolomites, shales, siltstones, and sandstones) tested by Avedissian and Wood, a direct linear relationship was found between the static (E_s) and dynamic (E_d) moduli:

$$E_s = 0.595\ E_d + 0.209 \times 10^6.$$

Least-squares analysis of compressive strength (UCS) data yielded the following:

$$UCS = E_d0.583\ \delta^{-0.127},$$

where δ is the logarithmic decrement.

In general, the percentage variations with respect to measured values of compressive strength were less than 10 percent except in the case of a sandstone (12.7 percent) and a shale (14.3 percent). This equation for compressive strength will give predicted values within ± 10 percent of true values, assuming that there are no structural defects within the specimens.

Sonic tests of rock specimens will also yield the dynamic modulus of rigidity and the dynamic Poisson's ratio (ASTM C 215). These mechanical constants are very often necessary to design. It is therefore very important for a rock evaluation system to include not only the capability to generate these parameters, but also the capability to indicate to some extent the accuracy of these calculations based on results obtained by utilizing good sampling and laboratory procedures.

Other combinations of data bank information may be organized to identify various parameters defined by investigators to characterize rock for classification purposes. Combining compressive strength, UCS, and tensile strength, S_t, Yamaguchi (1969) defined brittleness as

$$B = UCS\ /\ S_t.$$

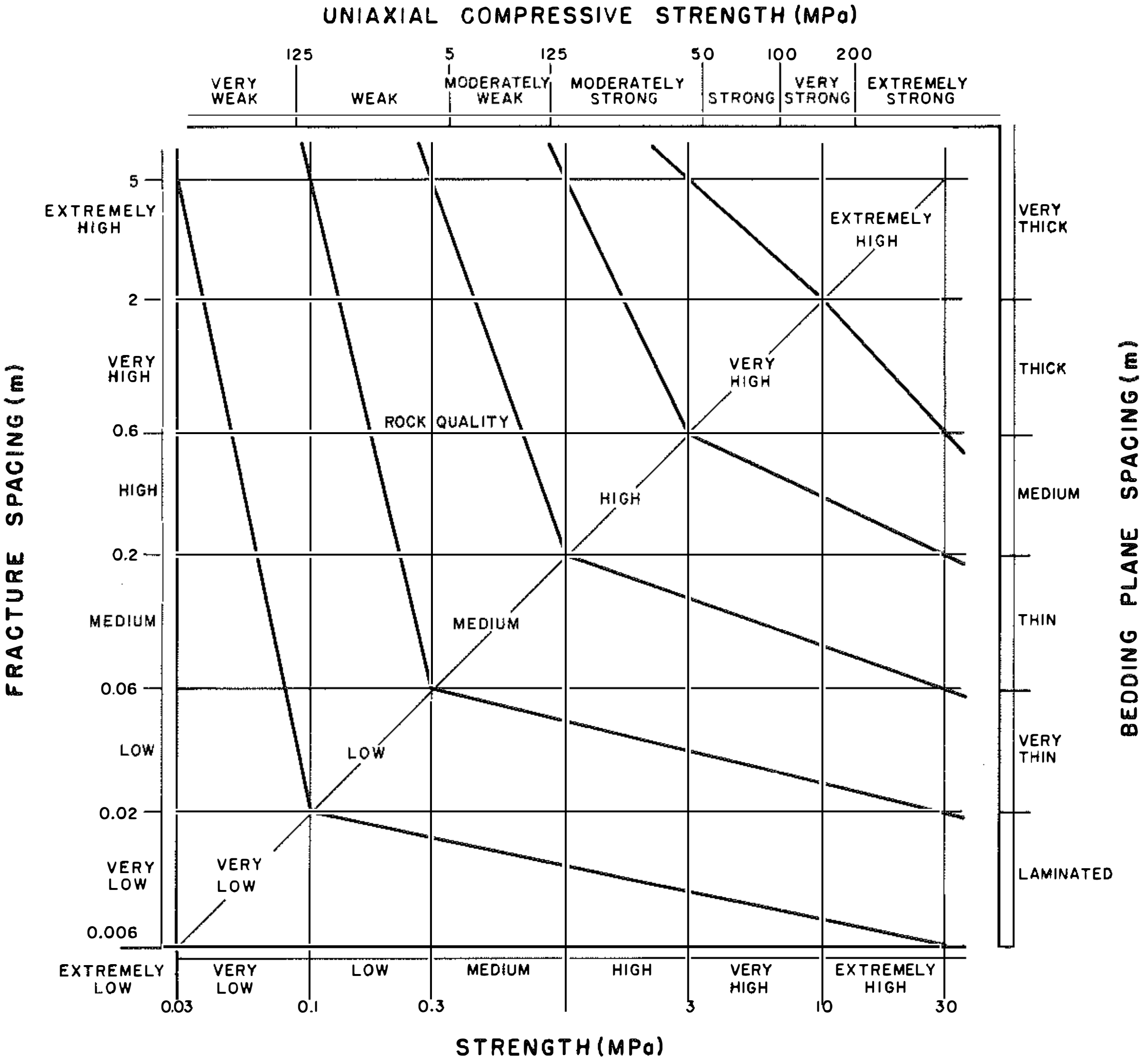


Figure 14. Rock Quality Classification Diagram.

Brittleness was used by Yamaguchi as an indication of intact rock quality. Deere and Miller (1966) established the modulus ratio as an integral part of their intact rock classification system:

$$\text{Modulus Ratio} = E_t \,/\, \sigma_{(ult)}$$

where E_t = tangent modulus at 50 percent ultimate strength and

$\sigma_{(ult)}$ = ultimate compressive strength.

Parameters such as rock density and laboratory sonic velocity have been used to normalize other parameters (Deere and Miller, 1966; Coon and Merrit, 1970) to account for lithologic variations. Temporary computer information files (constants, parameter combinations, and normalization calculations) are one of the more important functions of the data system. Specific correlations relating rock quality designations to in-situ observations and structural needs are a primary goal of the data bank.

DATA ANALYSIS (EXTRAPOLATION)

Regression analysis of input data or generated data is necessary to obtain an evaluation of accuracy in assumed design parameter values. For example, normal stress is plotted against shear stress in laboratory or in-situ shear tests, and linear regression analyses yield the angle of internal friction and cohesion intercept. As a second example, compressive strength can be calculated from Shore sclerscope height, h, as (van der Vlis, 1970)

$$\text{UCS} = 2.55\ (h - 6)\ \text{MPa}.$$

In addition, reduced major axis regression analysis and least-squares analysis are vital methods of determining lines which best fit data for various correlation studies. Reduced major axis analysis has been applied successfully to such correlations as modulus ratio versus RQD ($MR = 0.023\ RQD - 1.32$; $r = 0.544$) and static modulus of deformation versus RQD (Coon and Merritt, 1970) while least-square analysis has been used to extrapolate parameters from strength tests (Mellinger and Kenty, 1971a, b, c; Hobbs, 1967).

CHAPTER VII

CONCLUSIONS

This treatise has described a method and means of collecting, collating, and disseminating information on rock materials and masses. Several categories of investigations have been described.

GEOLOGIC RECONNAISSANCE

A possible shortcoming of the rock evaluation program is the lack of quality control of data/information input into central information storage. A means must be sought to monitor (guarantee) information from various sources so that input data represents results of careful observation and testing and relate to on-site requirements and project needs. One method of data quality control is to accept only data which are accompanied by complete field information (geologic reconnaissance) and specifications of the testing programs followed. These requirements do not in themselves ensure quality data, but they do furnish some insight into modes of data acquisition.

Geologic reconnaissance, preliminary geologic investigation of sites of potential or existing construction, is accomplished by means of literature review, examination of topographic and geologic maps, and reconnaissance surveys (Scroggie, 1952; Gregg and Havens, 1953; Johnson, 1970). Descriptive recorded data should include (1) general geology of area; (2) stability considerations; (3) ground water movement and watershed character; (4) general data on stream characteristics, gradients, outcrops, valleys, sinkholes, erosion conditions, landslides, and seepage and drainage patterns; (5) cursory data on availability of suitable construction materials in the area; (6) logs of test holes (including information on name, structure, texture, color, mineral content, age, origin, relative permeability, gradation, plasticity, and blow counts of material encountered); and (7) data on gross rock conditions (including degree of weathering and degree of cementation). Geologic reconnaissance enables the investigator to forecast the technical feasibility of construction at a given site and the extent of detailed subsurface investigations which will be required. Detailed subsurface investigation utilizing equipment such as core drills and backhoes includes the determination of subsurface conditions and the acquisition of soil and rock specimens for testing purposes. In addition, construction experience and data on performance of existing structures in the general area should be reviewed.

Landform and terrain analysis can furnish some indication of geologic structures and structural constitutents since specific landforms are the direct result of geologic processes. Drainage patterns may be indicative of surface and near-surface materials, topography, and geologic structures. Geologic mappings including delineation of unconsolidated sediments and deposits, texture of surficial deposits, structures of bedrock, observable water tables, unstable slopes, slips, and landslides should be made of the area.

Also, results of airphoto reconnaissance (including color tones, vegetation types, and textural changes) and remote sensing, including infrared techniques, should be part of a well-documented site survey (Hagerty and Coulson, 1974).

Probably the most valuable immediate use for geologic reconnaissance information of the rock evaluation program is in feasibility studies describing construction pre-bid factors and technical feasibility. Pre-bid factors provide necessary information for a cost estimate for foundation and(or) structures in or on bedrock. Contractors primarily are concerned with (1) depth to bedrock, (2) depth of excavation in earth, (3) water levels, (4) nearness to existing structures, (5) sheeting and shoring requirements, and (6) size of construction area (Crimmins, Samuels, and Monahan, 1972). To estimate excavation costs properly, rock should be evaluated for surficial hardness, presence of discontinuities, and generic rock type. For example, in general, igneous rock (granite, basalt) will shatter easily and require less explosive per unit removed than softer rock. Sedimentary rock (limestone, shale) can be ripped and(or) lifted by horizontal blasting, thereby decreasing overall costs, while metamorphic rock (schist, gneiss) is variable in its cost of removal since this rock type includes both hard and relatively soft rocks. Basic knowledge of rock mass defects (bedding planes, foliation planes, joints, faults, solution cavities, schistose planes) is necessary for efficient bidding and performance of any contract in rock work; it is necessary also for efficient subsurface exploration. Costs and hazards of rock excavation depend directly on the gross structure (intact, broken, decomposed) of the mass; most of the gross structure information is recorded in joint surveys, geophysical surveys, and sample-site identification sheets.

ROCK MECHANICS

The science of rock mechanics includes the extensive application of engineering geology and in-situ testing techniques to determine design parameters in the field and the limitations of the earth material to anthropogenic disturbances. The initial stage of application of rock meahanics as a science is concerned with site geology: locating water tables, making borings, drawing cross-sections, finding discontinuities, and examining overburdens (Crimmens, et al., 1972; Deere, 1974). Exploration techniques enable one to assess the character of discontinuities in the context of the surrounding geology. Permeability tests (single- or multiple-hole tests), deformation tests (plate jacking, cable jacking, pressure tunnels), in-situ strength tests (shear box, rock cube tests), and the determination of the in-situ state of stress (by overcoring, flat jack tests) serve to describe the four most important design parameters for most structures founded in, on, or near rock. In-situ tests and geologic descriptions should enable the field engineer to identify and locate foliation shear zones in metamorphic rock (Deere, 1973; Benson, et al., 1974) or bedding plane shear zones (e.g., mud seam, shale-mylonite seam) in the weakest members (underclay, shale, mylonite) of sedimentary rock series (Deere, 1974).

The analysis of anticipated behavior of rock material to permit design and modifications is based upon site geology and pertinent in-situ rock mechanics procedures. This developmental system of prediction involves minimum costs of about $5,000 for the testing and site description program. Large projects or complicated geology would involve costs many times greater. A fully developed system of in-situ investigations is beyond the economic reach of most projects. Instead, engineers utilize intact rock specimens to provide upper limits for design parameters and selected exploration tests and site descriptions (geology) to provide reduction factors to approximately account for natural heterogeneity occurring in materials and environments. Knowledge of site geology, intact test results, field experience, and low cost preliminary investigations are expected to warn the engineer of probable construction hazards and allow him to estimate design parameters (Warrick. 1954).

FUTURE STUDIES

An ongoing effort is underway to write specific computer programs for the REP to include storage, retrieval, and cataloging of data, correlation processes, plotting functions, and empirical curve fitting. Another effort is concentrating on the development of a data use table for aggregate in Kentucky, including parameter specification, test value ranges, chemical degradation, aggregate influence on skid resistance, frost heave, classification of materials, and testing programs. In conjuction with these efforts, another is collecting and organizing specific laboratory and specimen handling procedures to establish a common testing base. With the completion of the Kentucky Aggregate Data Use Tables and associated service monitoring and case history information and the laboratory procedures recommended for performance standards (guide for rock mechanics sampling and laboratory techniques), the initial stages of the REP will be complete.

For rock occurring in Kentucky, extensive laboratory and field investigations are required to determine the adequacy of excavation techniques and specific rock types to be used as construction materials; also, construction and service hazards must be identified. This effort will continue and will be modified as needed by current and future investigations; changing topographic features and humanisitic needs require further information concerning natural deposits, stability analysis, subsurface drainage conditions, and statistical analogues (ASTM E 105) of design, number of samples required, and varying sampling procedures.

There are many investigations which must be monitored for applicability to the REP. Microstructural techniques developed to determine rock fabric parameters on discs and thin sections must continue to be investigated in terms of defect analysis, grain elongation analysis, and mineralogical analysis to correlate petrofabric with physical properties and with possible in-situ adverse structural consequences. Laboratory investigations and interpretation techniques must be related to field investigations within the framework of in-situ stresses and in-situ material strength.

Although not presently included within the data bank attributes, palaeontological investigations may be required where fossils are important for strata identification and correlation. At the proper time, the Sample-Site Identification Sheet also should be modified to retain this information.

Finally, literature surveys of laboratory investigative techniques and intact/in-situ correlations must be kept current to utilize fully developments in rock mechanics. Special emphasis should be placed on gathering information and incorporating information within the data bank concerning such topics as rock failure modes, energy considerations and measurements, and in-situ stress determinations.

REFERENCES

Aitchison, G. D. (1967), *Generalisation and Communication in Modern Soil Engineering,* Keynote Address, **Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering,** Cape Town, South Africa, December, Vol 2, pp 299-305.

Aitchison, G. D. and Grant, K. (1967), *The P.U.C.E. Programme of Terrain Description, Evaluation and Interpretation for Engineering Purposes,* **Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering,** Cape Town, South Africa, December, Vol 1, pp 1-8.

American Society for Testing and Materials (1974), *Standard Definitions of Terms Relating to Natural Building Stones, Standard Method ASTM Designation: C 119-71,* **ASTM Standards, Part 19,** pp 7-10.

American Society for Testing and Materials (1973), *Standard Method of Test for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine, Standard Method ASTM Designation: C 131-69,* **ASTM Standards, Part 10,** pp 87-90.

American Society for Testing and Materials (1973), *Standard Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens, Standard Method ASTM Designation: C 215-60 (Reapproved 1970),* **ASTM Standards, Part 10,** pp 139-143.

American Society for Testing and Materials (1973), *Standard Descriptive Nomenclature of Constituents of Natural Mineral Aggregates, Standard Method ASTM Designation: C 294-69,* **ASTM Standards, Part 10,** pp 202-210.

American Society for Testing and Materials (1973), *Standard Recommended Practice for Petrographic Examination of Aggregates for Concrete, Standard Method ASTM Designation: C 295-65 (Reapproved 1973),* **ASTM Standards, Part 10,** pp 211-220.

American Society for Testing and Materials (1974), *Standard Specification for Dimension Limestone, Standard Method ASTM Designation: C 568-67 (Reapproved 1972),* **ASTM Standards, Part 19,** pp 31-32.

American Society for Testing and Materials (1974), *Standard Specification for Structural Granite, Standard Method ASTM Designation: C 615-68 (Reapproved 1972),* **ASTM Standards, Part 19,** pp 33-34.

American Society for Testing and Materials (1974), *Standard Specification for Building Sandstone, Standard Method ASTM Designation: C 616-68 (Reapproved 1972),* **ASTM Standards, Part 19,** p 35.

American Society for Testing and Materials (1971), *Standard Method of Test for Abrasion of Rock by Use of the Deval Machine, Standard Method ASTM Designation: D 2-23 (Reapproved 1968, withdrawn 1972),* **ASTM Standards, Part 10,** p 412.

American Society for Testing and Materials (1974), *Standard Methods of Sampling Aggregates, Standard Method ASTM Designation: D 75-71,* **ASTM Standards, Part 19,** pp 43-45.

American Society for Testing and Materials (1974), *Standard Recommended Practice for Investigating and Sampling Soils and Rock for Engineering Purposes, Standard Method ASTM Designation: D 420-69,* **ASTM Standards, Part 19,** pp 63-67.

American Society for Testing and Materials (1974), *Standard Definitions and Symbols Relating to Soil and Rock Mechanics, Standard Method ASTM Designation: D 653-67 (Reapproved 1973),* **ASTM Standards, Part 19,** pp 123-140.

American Society for Testing and Materials (1972), *Standard Method for Thin-Walled Tube Sampling of Soils, Standard Method ASTM Designation: D 1587-67,* **ASTM Standard Part 19,** pp 516-518.

American Society for Testing and Materials (1972), *Standard Method for Diamond Core Drilling for Site Investigation, Standard Method ASTM Designation: D 2113-70,* **ASTM Standards, Part 11**, pp 633-635.

American Society for Testing and Materials (1974), *Standard Method for Field Vane Shear Test in Cohesive Soil, Standard Method ASTM Designation: D 2573-72,* **ASTM Standards, Part 19**, pp 317-320.

American Society for Testing and Materials (1974), *Standard Method of Test for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements, Standard Method ASTM Designation: D 2664-67,* **ASTM Standards, Part 19**, pp 322-325.

American Society for Testing and Materials (1974), *Standard Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock, Standard Method ASTM Designation: D 2845-69,* **ASTM Standards, Part 19**, pp 336-343.

American Society for Testing and Materials (1974), *Standard Method of Test for Unconfined Compressive Strength of Rock Core Specimens, Standard Method ASTM Designation: D 2938-71a,* **ASTM Standards, Part 19**, pp 370-371.

American Society for Testing and Materials (1974), *Standard Method of Test for Elastic Moduli of Rock Core Specimens in Uniaxial Compression, Standard Method ASTM Designation: D 3148-72,* **ASTM Standards, Part 19**, pp 400-405.

American Society for Testing and Materials (1973), *Standard Definitions of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases, Standard Method ASTM Designation: E 12-70,* **ASTM Standards, Part 10**, pp 513-515.

American Society for Testing and Materials (1973), *Standard Recommended Practice for Probability Sampling of Materials, Standard Method ASTM Designation: E 105-58 (Reapproved 1970),* **ASTM Standards, Part 30**, pp 186-189.

American Society for Testing and Materials (1973), *Standard Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process, Standard Method ASTM Designation: E 122-72,* **ASTM Standards, Part 30**, pp 220-225.

American Society for Testing and Materials (1973), *Standard Recommended Practice for Acceptance of Evidence Based on the Results of Probability Sampling, Standard Method ASTM Designation: E 141-69,* **ASTM Standards, Part 30**, pp 285-287.

American Society for Testing and Materials (1973), *Standard Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material, Standard Method ASTM Designation: E 177-71,* **ASTM Standards, Part 10**, pp 516-533.

American Society of Civil Engineers **Infromation Retrieval for Soil Engineers,** Vol 93, No. 5, September 1967.

Armstrong, E. L. (1972), *The Stillwater Tunnelling Project of the Bureau of Reclamation,* **Proceedings of the Eighth Canadian Rock Mechanics Symposium,** Toronto, November-December, pp 17-30.

Aufmuth, R. E. (1974a), *A Systematic Determination of Engineering Criteria for Rock,* **Technical Report M-79,** Construction Engineering Research Laboratory, April, 46 p.

Aufmuth, R. E. (1974b), *Site Indexing of Rock, Field Testing and Instrumentation of Rock,* **STP 554,** American Society for Testing and Materials, May, pp 81-99.

Austin, W. G. (1970), *Field and Laboratory Tests for Safety of Dam Investigation at Salt River Project, Arizona,* **Report REC-OCE-70-7**, U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, February.

Avedissian, Y. M. and Wood, L. E. (1968), *Prediction of Compressive Strength of Rock From Its Sonic Properties,* **Proceedings of the Tenth Symposium on Rock Mechanics**, (also **Basic and Applied Rock Mechanics**, edited by K. E. Gray, University of Texas, Chapter 3, pp 55-71).

Ávila, F. P. (1966), *Some Applications of Seismic Field Tests in Rock Media,* **Proceedings of the First Congress of the International Society of Rock Mechanics**, Lisbon, Vol 1, Theme 1, No. 2, pp 3-6.

Badger, C. W., Cummings, A. D., and Whitmore, R. L. (1956), *The Disintegration of Shales in Water,* **Journal of the Institute of Fuel**, Vol 29, pp 417-423.

Beckett, P. H. T. and Webster, R. (1962), *The Storage and Collection of Information on Terrain: An Interim Report,* Military Engineering Experiment Establishment, Christchurch, England.

Benson, R. P., MacDonald, D. H., and McCreath, D. R., (1974), *The Effect of Foliation Shear Zones on Underground Construction in the Canadian Shield,* **Proceedings of the Rapid Excavation and Tunnelling Conference**, San Francisco, California, June, 40 p.

Bernaix, J. (1969), *New Laboratory Methods of Studying the Mechanical Properties of Rocks,* **International Journal of Rock Mechanics and Mining Sciences**, Pergamon Press, Great Britain, Vol 6, pp 43-90.

Bertacchi, P., Carabelli, E., and Sampaolo, A. (1966), *A Contribution to the Use of Geophysical Methods for Investigation of Rock Masses,* **Proceedings of the First Congress of the International Society of Rock Mechanics**, Lisbon, Vol 1, Theme 1, No. 10, pp 45-53.

Bjerrum, L. (1967), *Progressive Failure in Slopes of Overconsolidated Plastic Clay and Clay Shales,* **Journal of Soil Mechanics and Foundation Division**, ASCE, Vol 93, No. SM 5, pp 1-49.

Brink, A. B. A., Mabbutt, J. A., Webster, R., and Beckett, P. H. T. (1966), *Report of the Working Group on Land Classification and Data Storage,* **Report No. 940**, Military Engineering Experimental Establishment, Christchurch, England.

Brink, A. B. A. and Partridge, T. C. (1967), *Kyalami Land System: An Example of Physiographic Classification for the Storage of Terrain Data,* **Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering**, Cape Town, South Africa, December, Vol 1, pp 9-14.

Brook, N. (1970), *A Modified Method of Determining the Protodyakonov Number, and its Correlation with Compressive Strength,* **Proceedings of the Second Congress of the International Society for Rock Mechanics**, Belgrade, Vol 2, Theme 3, No. 34, pp 233-237.

Brock, E. and Franklin, J. A. (1972), *The Point-Load Strength Test,* **International Journal of Rock Mechanics and Mining Scieneces**, Pergamon Press, Great Britain, Vol 9, pp 669-697.

Building Research Station, (1967), *Site Tests for Giant Accelerators,* **Building Research Station News**, Garston, Hertfordshire, England, Vol 2.

Clark, S. P., Jr. (1966), **Handbook of Physical Constants**, Memoir 97, Geological Society of America, New York.

Clark, T. H. (1954), *Shale: A Study in Nomenclature,* **Transactions of Royal Society of Canada**, Vol 48, pp 1-7.

Coates, D. F. and Gyenge, M. (1965), *Testing Techniques for Rock Mechanics,* **STP 402,** American Society for Testing and Materials, pp 19-35.

Coates, D. F. and Parsons, R. C. (1966), *Experimental Criteria for Classification of Rock Substances,* **International Journal of Rock Mechanics and Mining Science,** Pergamon Press, Great Britain, Vol 3, pp 181-189.

Coon, R. F. (1968), *Correlation of Engineering Behavior with the Classification of In-Situ Rock,* University of Illinois, Urbana, Illinois, Ph. D. Thesis.

Coon, R. F. and Merritt, A. H. (1970), *Predicting In Situ Modulus of Deformation of Rock,* **STP 477,** American Society for Testing and Materials, pp 154-173.

Cottiss, G. I., Dowell, R. W., and Franklin, J. A. (1971), *A Rock Classification System Applied in Civil Engineering, Part 1,* **Civil Engineering and Public Works Review,** June, pp 611-614.

Crimmins, R., Samuels, R., and Monahan, B. (1972), **Construction Rock Work Guide,** Wiley-Interscience, John Wiley and Sons, Inc., New York, 241 p.

Deen, R. C. (1968), *The Crab Orchard and Osgood Formations; A Case for Slope Instability,* Kentucky Department of Highways, Division of Research, Lexington, 34 p.

Deen, R. C., and Havens, J. H. (1968), *Landslides in Kentucky,* Landslide Seminar, University of Tennessee, September 18-20, 82 p.

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,** October 18, Clarksville, Indiana, pp 2.1 2.17.

Deere, D. U. (1963a), *Technical Description of Rock Cores for Engineering Purposes,* **Felsmechanik und Ingenieurgeologie,** Wien: Springer-Verlag, Vol 1, No. 1, pp 16-22.

Deere, D. U. (1963b), *Part IV -- Design, Introduction,* **Proceedings of the International Conference on the State of Stress in the Earth's Crust,** edited by W. R. Judd, American Elsevier Publishing Company, Inc., New York, 1964, pp 572-598.

Deere, D. U. (1965), *Rock Mechanics Considerations,* World Trade Center, Consulting Report.

Deere, D. U. (1973), *The Foliation Shear Zone - An Adverse Engineering Geologic Feature of Metamorphic Rocks,* **Journal of the Boston Society of Civil Engineers,** October.

Deere, D. U. (1974), *Rock Engineering,* **Proceedings of the Ohio River Valley Soils Seminar, Rock Engineering,** October 18, Clarksville, Indiana.

Deere, D. U., Hendron, A. J., Patton, F. D., and Cording, E. J. (1967), *Failure and Breakage of Rock,* **Proceedings of the Eighth Symposium on Rock Mechanics,** American Institute of Mining and Metallurgical Engineers, Minneapolis, Minn., pp 237-303.

Deere, D. U. and Miller, R. P. (1966), *Engineering Classification and Index Properties for Intact Rock,* Air Force Weapons Lab Report No. AFWL - TR - 65 - 116, 305 p.

Deere, D. U. and Shaffer, P. (1956), *Plasticity Studies of Till Inturded into Jointed Limestone in Fairmont Quarry, Illinois,* **Transactions of the Illinois Academy of Science,** Vol 49, No. 121.

Dixon, W. J. (1973), **BMD; Biomedical Computer Programs,** University of California Press, Berkeley, California, third edition 773 p.

Dobrin, M. B. (1960), *Gravity Field Measurements and Reductions,* **Introduction to Geophysical Properties,** McGraw-Hill Co., Inc., New York, N.Y., pp 218-241.

Dodd, J. S. (1967), *Morrow Point Underground Powerplant: Rock Mechanics Investigations,* Bureau of Reclamation, Denver, Colorado.

Dodds, D. J. (1974), *Interpretation of Plate Loading Test Results,* **Field Testing and Instrumentation of Rock, STP 554,** American Society for Testing and Materials, pp 20-34.

Dodds, R. K. (1970), *Suggested Method of Test for In Situ Shear Strength of Rock,* **STP 479,** American Society for Testing and Materials, pp 618-627.

Duffaut, P. and Comes, G. (1966), *Stress-Strain Comparative Measuring on a Foundation Material Measured in Place on the Face of an Excavation and on a Borehole Wall,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, pp 399-403.

Duncan, N. (1969a), **Engineering Geology and Rock Mechanics,** Vol 1, International Textbook Company Limited, London, England 252 p.

Duncan, N. (1969b), **Engineering Geology and Rock Mechanics,** Vol. 2, International Textbook Company Limited, London, England, 265 p.

Dvorak, A. (1967), *Determination of Deformation Properties of Rocks in Drillholes by Sounding Deformeter and Comparison with Plate Loading Tests,* **Rock Mechanics and Engineering Geology,** Supplement III, pp 1-10.

Einstein, H., Baecher, G. B., and Hirschfield, R. C. (1970), *The Effect of Size on Strength of a Brittle Rock,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 2, pp 7-13.

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 Stratigaphy and Geology,** Sheffield, 1967, Compte Rendu, Vol 2, pp 715-724.

Evdokimov, P. D. and Sapegin, D. D. (1970), *A Large Scale Field Shear Test on Rock,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 17, pp 117-121.

Faure, G. (1973), *Radiometric Dating,* **SME Mining Engineering Handbook,** edited by Ivan A. Given, Vol 1, pp 4.8 - 4.9.

Fergusson, F. and Lancaster-Jones, P. (1964), *Testing the Efficiency of Grouting Operations at Dam Sites,* **Proceedings of the Eighth International Congress on Large Dams,** Edinburgh, Vol 1, R. 7, Q. 28, pp. 121-139.

Field Sampling Manual (1960), Division of Materials, Department of Highways, Frankfort, Kentucky, 33 p.

Final Report (1971), Commission on "Definition of the Most Promising Lines of Research", International Society for Rock Mechanics, January 20 p.

Fitzpatrick, J. (1962), *Biaxial Device for Determining the Modulus of Elasticity of Stress Relief Cores,* **Report of Investigation 6128**, U. S. Bureau of Mines.

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 I,** U. S. Army Engineer Nuclear Cratering Group, Livermore, California, 93 p.

Floyd, G. T. (1967), *The Engineering Significance of the Relation Between Rock Types and Their Derived Soils,* **Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering,** Cape Town, South Africa, December, Vol 1, pp 121-127.

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.

Franklin, J. A. (1972), *Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-Durability Index Properties,* International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests, Committee on Laboratory Tests, Document No. 2, November.

Franklin, J. A., Broach, E., and Walton G. (1971), *Logging the Mechanical Character of Rock,* **Transactions of the Institute of Mining and Metallurgy, 80,** pp A1-A10.

Franklin, J. A. and Chandra, R. (1971), *The Slake-Durability Test,* **International Journal of Rock Mechanics and Mining Science,** Pergamon Press, Great Britain, 1972, Vol 9, pp 325-341.

Friedman, M. (1963), *Petrofabric Techniques for the Determination of Principal Stress Directions in Rocks,* **Proceedings of the International Conference on State of Stress in the Earth's Crust** (also **State of Stress in the Earch's Crust,** edited by W. R. Judd, American Elsevier Publishing Company, Inc., New York, 1964, pp 450-550), Santa Monica, California, June 13 and 14.

Gamble, J. C. (1971), *Durability-Plasticity Classification of Shales and Other Argillaceous Rocks,* **Ph. D.** Thesis in Geology, University of Illinois, Urbana, Illinois, 161 p.

Gicot, H. (1948), *Mesuies de la Deformabilite du sol de Fondation du Barrage de Rossens,* **Proceedings of the Third International Congress on Large Dams,** Stockholm, Vol 2, R. 56, Q. 9.

Gipson, M., Jr. (1963), *Ultrasonic Disaggration of Shale,* **Journal of Sedimentary Petrology,** Vol 33, pp 955-958.

Giuseppe, B. (1970), *The Shear Strength of Some Rocks by Laboratory Tests,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade Vol 2, theme 3, No. 24, pp 165-172.

Goodman, R. E., van Tran, K., and Heuze, F. (1968), *Measurement of Rock Deformability In Boreholes,* **Proceedings of the Tenth Symposium on Rock Mechanics** (also **Basic and Applied Rock Mechanics,** edited by K. E. Gray, University of Texas, Chapter 19, **pp** 523-555).

Grabaw, A. W. (1920), **General Geology,** Part **I,** D. C. Heath Company, p 210.

Grant, F. S. and West, G. F. (1965), **Interpretation Theory in Applied Geophysics,** McGraw-Hill, New York.

Grant, K. (1966), *Terrain Classification,* Soil Mechanics Section, C.S.I.R.O., Melbourne.

Gregg, L. E. and Havens, J. H. (1953), *Applications of Geology to Highway Engineering in Kentucky,* **Proceedings of the Fourth Annual Symposim on Geology as Applied to Highway Engineering,** February, pp 1-11.

Green, S. J. and Perkins, R. D. (1968), *Uniaxial Compression Tests at Varying Strain Rates on Three Geologic Materials,* **Proceedings of the Tenth Symposium on Rock Mechanics** (also **Basic and Applied Rock Mechanics,** edited by K. E. Gray, Chapter 2, pp 35-54).

Griffith, A. A. (1921), *Phenomena of Rupture and Flow in Solids,* **Phil. Trans. Royal Society,** London, Vol A221 pp 163-197.

Grimm, W., Richter, E. and Rosetz, G. (1966), *A Study of the Deformation and Strength Properties of Rocks by Block Tests In-Situ in Iron Ore Mines,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, pp 457-463.

Habib, P. and Vouille, G. (1966), *Sur la disparition de l'effect de'echelle aux hautes pressions,* **Cr. hebd. Seanc. Acad. Sci.,** Paris, March.

Hagerty, D. J. and Coulson, J. (1974), *Exploration and Testing In Rock,* **Proceedings Of The Ohio River Valley Soils Seminar, Rock Engineering,** October 18, Clarksville, Indiana, pp 1.1-1.18.

Hamrol, A. (1961), *A Quantitative Classification of the Weathering and Weatherability of Rocks,* **Proceedings of the Fifth International Conference on Soil Mechanics and Foundation Engineering,** Paris, Vol II, pp 771-774.

Hansagi, I (1965), *Numerical Determination of Mechanical Properties of Rock and of Rock Masses,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 2, pp 219-223.

Heck, W. J. (1968), *Development of Equipment for Studying Pore Pressure Effects in Rock,* **Proceedings of the Tenth Symposium on Rock Mechanics** (also **Basic and Applied Rock Mechanics,** edited by K. E. Gray, pp. 243-265).

Heck, W. J. (1970), *Suggested Method of Test for Triaxial Compressive Strength of Undrained Rock Core Specimens with Induced Pore Pressure Measurements,* **STP 479,** American Society for Testing and Materials, pp 604-612.

Hendron, A. J. Jr., Mesri, G., Gamble, J. C., and Way, G. (1970), *Compressibility Characteristics of Shales Measured by Laboratory and In Situ Tests, Determination of the In Situ Modulus of Deformation of Rock,* **STP 477,** American Society for Testing and Materials, pp 137-153.

Heuzé, F. E. (1971), *Sources of Errors in Rock Mechanics Field Measurements, and Related Solutions,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 8, pp 297-310.

Hobbs, D. W. (1967), *Rock Tensile Strength and Its Relationship to a Number of Alternative Measures of Rock Strength,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 4, pp 115-127.

Hodgson, K. and Cook, N. G. W. (1970), *The Effects of Size and Stress Gradient on the Strength of Rock,* **Proceedings of the Second Congress of the International Society For Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 5, pp 31-34.

Hoek, E. (1970), *Estimating the Stability of Excavated Slopes in Open-Cast Mines,* **Transactions of the Institute of Mining and Metallurgy,** Vol 79, pp A109-A132.

Hucka, V. (1965), *A Rapid Method of Determining the Strength of Rocks In Situ,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 2, pp 127-134.

Iliev, I. G. (1966), *An Attempt to Estimate the Degree of Weathering of Intrusive Rocks from Their Physico-Mechanical Properties,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 2, No. 3, pp 109-114.

Ingram, R. L. (1953), *Fissility of Mudrocks,* **Bulletin of the Geological Society of America,** Vol 64, pp 869-878.

Jaeger, C. (1961), *Recent British Experience on Underground Work and Rock Mechanics,* **Proceedings of the Seventh International Congress on Large Dams,** Rome, Vol 2, R. 6, Q. 25, pp 167-289.

Johnson, A. I. (1970), *Suggested Method for Geologic Reconnaissance of Construction Sites,* **STP 479,** American Society for Testing and Materials, pp 43-55.

Jovan, S. and Božinovic, D. (1966), *On a Geotechnical Classification of Terrain,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 2, No. 5, pp 121-124.

Judd, W. R. (1965), *Some Rock Mechanics Problems in Correlating Laboratory Results with Prototype Reactions,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 2, pp 197-218.

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.

Keller, G. V. and Frischknecht, F. C. (1966), **Electrical Methods in Geophysical Prospecting,** Pergamon Press, New York.

Kentucky Method 64-601-68, *Sampling of Aggregates for Use as Highway Materials,* 5 p.

Kenty, J. D. (1970), *Suggested Method of Test For Direct Shear Strength of Rock Core Specimens,* **STP 479,** American Society for Testing and Materials, pp 613-617.

Knill, J. C. and Jones, K. S. (1965), *The Recording and Interpretation of Geological Conditions in the Foundations of the Roseires, Kariba and Latiyan Dams,* **Geotechnique,** Vol XV, No. 1, pp 94-124.

Krech, W. W. (1973), *Rock Classification and Rock Property Listings -- Final Technical Report,* US Department of the Interior, Bureau of Mines, Twin Cities, Mining Research Center, ARPA Order No. 1579 Amendment 3, 36 p.

Krech, W. W. and Chamberlain, P. G. (1972), *New Techniques for Rock Fracture Energy Measurements,* presented at the 47th Annual Fall Meeting of the Society for Petroleum Engineers, AIME, San Antonio, Texas, October 8-11, SPE Preprint 4060, 8 p.

Kujundzic, B. (1964), *A Contribution to the Experimental Investigation of Changes Mechanical Characteristics of Rock Massives as a Function of Depth,* **Proceedings of the Eighth International Congress on Large Dams,** Edinburgh, Vol 1, R. 56, Q. 28, pp 1051-1067.

Laguros, J. G., McCasland, W., and Kumar, S. (1971), *Unstable Slopes in Oklahoma,* Fourth Panamerican Conference on Soil Mechanics and Foundation Engineering, Puerto Rico, June.

Lane, K. S. (1969), *Engineering Problems Due to Fluid Pressure in Rocks,* **Proceedings of the Eleventh Symposium on Rock Mechanics,** Berkeley, California.

Lauffer, H. and Seeber, G. (1966), *Measurement of the Rock Deformability with the Aid of the Radial Jack of the TIWAG and Verification of the Measuring Results through the Pressure Shaft Lining of the Kaunertal Power Plant,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 2, pp 347-356.

Leber, W. P. (1961), *Engineering Design -- Presenting Subsurface Information on Contract Plans and Specifications,* U. S. Army Corps of Engineers Manual EM 1110-1-1806, 5 p.

Leeman, E. R. (1964), *Absolute Rock Stress Measurements Using a Borehole Trepanning Stress-Relief Techniques,* **Proceedings of the Sixth Symposium on Rock Mechanics,** University of Missouri, Rolla.

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.

Locher, H. G. and Rieder, U. G. (1970), *Shear Tests on Layered Jurassic Limestone,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 1, pp 1-5.

Lutton, R. J. and Banks, D. C. (1970), *Study of Clay Shale Slopes along the Panama Canal, Report 1, East Culebra and West Culebra Slides and the Model Slope,* **10 CS Memorandum JAX-108**, Department of the Army, Jacksonville District, November, 340 p.

Mandel, J. (1964), **The Statistical Analysis of Experhments,** Interscience Publishers, New York.

Mayer, A. (1963), *Recent Work in Rock Mechanics,* **Geotechnique,** Vol 13, June, pp 108-121.

McClure, C. R. (1968), *Status of Rock Mechanics as Applied to Civil Engineering,* **Proceedings of the Ninth Symposium on Rock Mechanics** (also **Status of Practical Rock Mechanics,** Edited by N. E. Grosvenor and B. W. Paulding, Jr., American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, pp 28-41).

McWilliams, J. (1966), *The Role of Microstructure in the Physical Properties of Rock,* **STP 402**, American Society for Testing and Materials, pp 175-189.

Mead, W. J. (1938), *Engineering Geology of Damsites,* **Transactions of the Second International Congress on Large Dams,** Vol 4, p 183.

Mellinger, F. M. and Kenty, J. D. (1971a), *In Situ Direct Shear Tests of Weak Rock, Test Equipment and Test Procedures,* **Technical Report No.** 3-86, U. S. Army Engineer Division, Ohio River, Corps of Engineers, Foundation and Materials Branch, Cincinnati, Ohio, February, 26 p.

Mellinger, F. M. and Kenty, J. D. (1971b), *Laboratory and In Situ Direct Shear Tests -- Two Clay Shales,* **ORDL Technical Report No.** 3-87, U. S. Army Engineering Division Corps of Engineers, Cincinnati, Ohio, October, 41 p.

Mellinger, F. M. and Kenty, J. D. (1971c), *Laboratory and In Situ Direct Shear Tests -- A Claystone and a Chalk,* **ORDL Technical Report No.** 3-89, U. S. Army Engineer Division, Corps of Engineers, Cincinnati, Ohio, December, 39 p.

Menard, L. (1966), *Use of the Pressuremeter to Study Rock Masses,* **Rock Mechanics and Engineering Geology Journal,** International Society of Rock Mechanics, Vol 4, No. 2, pp 160-177.

Merrill, R. H. (1963), *In-Situ Determination of Stress by Relief Techniques,* **Proceedings of the International Conference on State of Stress in the Earth's Crust**, Santa Monica, California, May.

Merrill, R. H. and Peterson, J. R. (1961), *Deformation of a Borehole in Rock,* **Report of Investigation 5881,** U. S. Department of the Interior, Bureau of Mines.

Merritt, A. H. (1968), *Engineering Classification for In-Situ Rock,* University of Illinois, Urbana, Illinois, Ph. D. Thesis, 156 p.

Misterek, D. L., Slebir, E. J., and Montgomery, J. S. (1974), *Bureau of Reclamation Procedures for Conducting Uniaxial Jacking Tests, Field Testing and Instrumentation of Rock,* **STP 554**, American Society for Testing and Materials, pp 35-51.

Moretto, O. and Bolognesi, A. J. L. (1970), *Shear Strength of Soft Intact Caly and Silty Stones,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 7, pp 39-48.

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, October, pp 1137-1156.

Myska, C. H. (1973), *Down-the-Hole Surveys-Directional,* **SME Mining Engineering Handbook**, edited by I. A. Given, Vol 1, pp 5.63-5.64.

Nie, N. H., Bent, D. H., and Hull, C. H. (1970), **SPSS, Statistical Package for the Social Sciences,** McGraw-Hill Book Company, 343 p.

Norup, W. (1971), *Manual And Author Index, Geodex,* Geodex Soil Mechanics Information Service, Geodex International, Inc. California, 101 p.

Obert, L. and Duvall, W. I. (1967), **Rock Mechanics and the Design of Structures in Rock,** John Wiley and Sons, Inc., New York.

Onodera, T. F. (1962), *Dynamic Investigation of Foundation Rocks In Situ,* **Proceedings of the Fifth Symposium on Rock Mechanics** (also, **Rock Mechanics,** edited by C. Fairhurst, MacMillan Company, New York, 1963, pp 517-533).

OS Data Management Micro Instructions (1973), IBM Systems Reference Library, Order Number GC26-3794-1, second edition, 239 p.

OS Data Management Services Guide (1973), IBM Systems Reference Library, Order Number GC26-374602, third edition, 156 p.

Patterson, M. S. and Weiss, L. E. (1965), *Experimental deformation and folding in Phyllite,* **Bulletin of the Geological Society of America,** Vol 77, April.

Peres Rodrigues, R. (1966), *Anisotropy of Granites, Modulus of Elasticity and Ultimate Strength Ellipsoids, Joint Systems, Slope Attitudes, and Their Correlations,* **Proceedings of the First Congress of the International Society for Rock Mechanics,** Lisbon, Portugal, Vol 1, pp 721-731.

Philbrick, S. S. (1950), *Foundation Problems of Sedimentary Rocks,* Chapter 8 from P. D. Trask's **Applied Sedimentation,** John Wiley and Sons.

Philbrick, S. S. (1963), *Design of Slopes,* **Record No. 17,** Highway Research Board, May, pp 1-12.

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**, pp 348-349.

Pickett, G. (1945), *Equations for Computing Elastic Constants From Flexural and Torsional Resonsant Frequencies of Vibration of Prisms and Cylinders,* **Proceedings of the American Society for Testing and Materials,** Vol 45, pp 846-863.

Podnieks, E. R., Chamberlain, P. G., and Thill, R. E. (1968), *Environmental Effects on Rock Properties,* **Proceedings of the Tenth Symposium on Rock Mechanics** (also, **Basic and Applied Rock Mechanics,** edited by K. E. Gray, University of Texas, Chapter 8, pp 215-241).

Protodyakonov, **M. M.** (1960), *New Methods of Determining Mechanical Properties of Rocks,* International Conference on Strata Control, Paris, Paper C2, pp 187-195.

Protodyakonov, **M. M.** (1962), *Mechanical Properties and Drillability of Rocks,* **Proceedings of the Fifth Symposium on Rock Mechanics** (also **Rock Mechanics,** edited by C. Fairhurst, MacMillian Company, New York, 1963, pp. 103-118).

Raybould, D. R. and Price, D. G. (1966), *The Use of the Proton Magnetometer in Engineering Geological Investigations,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 1, No. 3, pp 11-14.

Reichmuth, D. R. (1968), *Point Load Testing of Brittle Materials to Determine Tensile Strength and Relative Brittleness,* **Proceedings of the Ninth Symposium on Rock Mechanics** (also **Status of Practical Rock Mechanics),** American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York.

Ricker, R., Cook, H., and Pendleton, D. (1965), *Bibliography of Experimental Rock Deformation,* **USAF AFCRL-65-740, Special Report 35,** U. S. Department of Commerce Office of Aerospace Research, second edition.

Rinehart, J. S., Fortin, J. P., and Burgin, L. (1961), *Propagation Velocity of Longitudinal Waves in Rocks,* **Proceedings of the Fourth Symposium on Rock Mechanics,** Bulletin of the Mineral Industries Experiment Station, Pennsylvania State University, p 119.

Rocha, **M.** (1955), *Deformability of Foundation Rocks,* **Proceedings of the Fifth International Congress on Large Dams,** Paris, Vol 3, R. 75, Q. 18, pp 531-559.

Rocha, **M.** (1970), *New Techniques in Deformability Testing of In Situ Rock Masses, Determination of the In Situ Modulus of Deformation of Rock* **STP 477,** American Society for Testing and Materials, pp 39-57.

Rogers, G. R. (1973), *Geophysical Surveys,* **SME Mining Engineering Handbook,** edited by Ivan A. Given, Vol 1, pp 5.24-5.34.

Rosenblad, J. L. (1970), *Failure Modes of Models of Jointed Rock Masses,* **Proceedings of the Second Conference of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 11, pp 75-81.

Ruiz, M. D. (1966), *Some Technological Characteristics of Twenty-Six Brazilian Rock Types,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 2, No. 4, pp 115-119.

Savage, E. L. (1969), *Ultrasonic Disaggregation of Sandstones and Siltstones,* **Journal of Sedimentary Petrology,** Vol 39, pp 375-378.

Schmidt, E. (1951), *Experiments with the New Concrete Test Hammer,* Schweizer Archiv., May.

Scott, J. H. and Carrol, R. D. (1967), *Surface and Underground Geophysical Studies at Straight Creek Tunnel Site, Colorado,* **Record No. 185,** Highway Research Board, pp 20-35.

Scroggie, E. (1952), *Application of Geology to Bridge Foundations,* **Proceedings of the Third Annual Southeastern Symposium on Geology as Applied to Highway Engineering,** February.

Seeger, R. W. and Kent. J. A. (1962), *Conducting A Statewide Survey for Highway Aggergates in West Virginia,* **Engineering Experiment Station Research Bulletin** 28, West Virginia University Bulletin 38 p.

Shannon and Wilson, Inc. (1964), *Report on In-Situ Rock Tests, Dworshak Dam Site,* U. S. Army Engineer District, Corps of Engineers, Walla Walla, Seattle, Washington.

Shergold, F. A. (1963), *A Study of the Variability of Roadstones in Relation to Sampling Procedures,* **The Quarry Manager's Journal,** Great Britain, Vol 47, pp 3-8.

Singh, B. (1974), *Reliability of Dilatometer Tests in the Determination of the Modulus of Deformation of a Jointed Rock Mass,* **Field Testing and Instrumentation of Rock, STP 554,** American Society for Testing and Materials, pp 52-72.

Sinitsyn, A. P. (1966), *Relation Between the Seismic Elasticity Modulus of Rock Foundation and Wave Resistance,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, Theme 1, No. 18, pp 87-90.

Smith, T., McCauley, M. L., and Mearns, R. W. (1970), *Evaluation of Rock Slope Protection Material,* **Record No.** 323 Highway Research Board, pp 6-13.

Smorodinov, M. I., Motovilov, E. A., and Volkov, V. A. (1970), *Determinations of Correlation Relationships between Strength and Some Physical Characteristics of Rocks,* **Proceedings of the Second Congress of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 3, No. 6, pp 35-37.

Sowers, G. B. and Sowers, G. F. (1970), **Introductory Soil Mechanics and Foundations,** third edition, Collier-MacMillian Limited, London.

Spinner, S. and Tefft, W. E. (1961), *A Method for Determining Mechanical Resonance Frequencies and for Calculating Elastic Moduli from These Frequencies,* **Proceedings,** American Society for Testing and Materials, Vol 61, pp 1221-1238.

Steckley, R. C., Podnieks, E. R., Chamberlain, P. G., and Pugliese, J. M. (1973), *Overview of the Role of Geologic Investigation and Rock Property Determination in Fragmentation Field Testing,* **Field Testing and Instrumentation of Rock, STP 554,** American Society for Testing and Materials, 1974, pp 100-115.

Stepanovic, B. (1960), *Fizicke osobine krutih stenskih masa, njihove kategorije i prirodan sistem (Physical Properties of Rigid Rock Masses, Their Classification and Systematization),* Zbornik radova Rudarsko-Geoloskog fakulteta (Belgrade) 6, pp 153-167.

Sumner, J. R. and Burnett, J. A. (1974), *Use of Precision Gravity Survey to Determine Bedrock,* **Journal of the Geotechnical Engineering Division,** American Society of Civil Engineers, Vol 100, No. GT 1, January, pp 53-60.

Talobre, J. (1961), *La Determination Experimentale de la Resistance des Roches D'Appui des Barrages et des Parios de Soutterains,* **Proceedings of the Seventh International Congress on Large Dams,** Rome, Vol 2, pp 12-37.

Taylor, R. K. and Spears, D. A. (1970), *The Breakdown of British Coal Measure Rocks,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 7, pp 481-501.

Terzaghi, K. (1961), *Engineering Geology on the Job and in the Classroom,* **Journal of the Boston Society of Civil Engineers,** April.

Thill, R. E., McWilliams, J. R., and Bur, T. R. (1968), *An Acoustical Bench for an Ultrasonic Pulse System,* **Report of Investigations 7164,** U. S. Department of the Interior, Bureau of Mines, 22 p.

Tockstein, C. D. and Palmer, M. W. (1974), *A Rock Evaluation Schema for Transportation Facility Planning in Kentucky,* Kentucky Bureau of Highways, Division of Research, May, 148 p.

Twenhofel, W. H. (1937), *Report of the Committee on Sedimentation,* National Research Council.

Underwood, L. B. (1967), *Classification and Identification of Shales,* **Journal of Soil Mechanics and Foundations Division,** American Society of Civil Engineering, Vol 93, No. SM 6, pp 97-116.

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, pp 1259-1260.

U. S. Bureau of Reclamation (1948), *Foundation Bearing Tests at Davis Dam,* Standard Research Laboratory Report, SP 18, Denver, Colorado.

Walker, R. D., Larson, T. D., and Cady, P. D. (1970), *Research Needs Relating to Performance of Aggregates in Highway Construction,* **National Cooperative Highway Research Program Report 100,** Highway Research Board, 70 p.

Wahlstrom, E. E. (1973), **Tunneling in Rock, Developments in Geotechnical Engineering,** Elsevier Scientific Publishing Company, Amsterdam, Vol 3.

Warrick, W. A. (1954), *Application of Geology to Highway Engineering as seen by a Highway Engineer,* **Proceedings of the Fifth Annual Symposium on Geology as Applied to Highway Engineering,** March, pp 12-21.

Wentworth, C. K. (1922), *A Scale of Grade and Class Terms for Plastic Sediments,* **Journal of Geology,** Vol 30, pp 377-392.

Wilson, J. L. (1971), *Brown Shale Problems in Eastern Kentucky,* **Proceedings,** Kentucky Oil and Gas Association Thirty-Four and Thirty-Fifth Annual Meetings, 1970 and 1971, edited by D. W. Hutcheson, University of Kentucky, Lexington, Series X, pp 1-33.

Yamaguchi, U. (1970), *The Number of Test-Pieces Required to Determine the Strength of Rock,* **International Journal of Rock Mechanics and Mining Sciences,** Pergamon Press, Great Britain, Vol 7, pp 209-227.

Zdzislaw, G., Jan, C., Stefan, G., and Abigniew, K. (1970), *Laboratory Investigations as the Basis for Determination of a Rock Formation Pressure,* **Proceedings of the Second Conference of the International Society for Rock Mechanics,** Belgrade, Vol 2, Theme 4, No. 47, pp 731-736.

Zienkiewicz, O. and Stagg, K. (1966), *The Cable Method of In-Situ Testing,* **Proceedings of the First Congress of the International Society of Rock Mechanics,** Lisbon, Vol 1, pp 667-672.

APPENDIX I

FILE DEFINITION, FORMAT, AND CODING INSTRUCTIONS FOR ROCK DATA BANK

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 be designated as follows: **QUARTERNARY** 001 Alluvium

002 Loess
003 Continental Deposits

TERTIARY
004 Jackson
005 Clairborne
006 Wilcox
007 Porter's Creek

CRETACEOUS
008 Eutaw
009 Tuscaloosa

PENNSYLVANIAN
Western Coal Field
010 Henshaw-Dixon
011 Lisman
012 Carbondale
013 Tradewater
014 Caseyville

Eastern Coal Field
015 Conemaugh
016 Allegheny
017 Breathitt
018 Lee

MISSISSIPPIAN
Fluospar Region
019 Kinkaid
020 Degonia
021 Clore
022 Palestine
023 Menard
024 Waltersburg
025 Vienna
026 Tar Springs
027 Glen Dean
028 Hardinsburg
029 Golconda
030 Cypress
031 Paint Creek
032 Bethel
033 Renault
034 Aux Vases

West of Arch
035 Elwren
036 Reelsville
037 Sample
038 Beaver Bend
039 Paoli

East of Arch
040 Bangor
041 Hartselle
042 Monteagle

043 Saint Genevieve
044 Saint Louis
045 Salem
046 Warsaw (Harrodsburg)

				047 Fort Payne 048 Borden 049 Sunbury 050 Berea 051 Bedford **DEVONIAN** 052 New Albany **West of Arch** 053 Sellersburg 054 Jeffersonville **East of Arch** 055 Boyle **SILURIAN** **West of Arch** 056 Louisville 057 Waldron 058 Laurel 059 Osgood 060 Brassfield **East of Arch** 061 Boyle 062 Bisher 063 Crab Orchard 064 Brassfield **ORDOVICIAN** **West of Arch** **Southwest Blue Grass** 065 Drakes 066 Ashlock 067 Grant Lake 068 Calloway Creek 069 Garrard 070 Clays Ferry **East of Arch** **Northwest Blue Grass** 071 Drakes 072 Bull Fork 073 Grant Lake 074 Fairview 075 Kope 076 Clays Ferry 077 Lexington Limestone 078 High Bridge 998 Other 999 Not Known
Lithology	LITHO	28	I1	Generic rock type of the sample (ASTM C 119) is indicated as follows: 1 -- limestone (ASTM C 568) 2 -- shale or transitional material (ASTM C 294) 3 -- sandstone (ASTM C 616) 4 -- siltstone (ASTM C 294) 5 -- granite (ASTM C 615) 6 -- conglomerate

				9 -- other (may be further delineated at a future time)
Ground Elevation	GEL	29 - 32	F4.1	Ground elevation at sample site to nearest tenth of a meter.
Sample Elevation	SE	33 - 36	F4.1	Elevation from which sample was taken to nearest tenth of a meter.
Water Table 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)

CATEGORY 2, INTACT SPECIMEN DATA SUBFILE

Part 1[a]

(Data Card No. I)

Color	COL	49 - 50	I2	The hue of the specimen shall be described in terms of ten basic colors: 10 -- black 20 -- blue 30 -- brown 40 -- gray 50 -- green 60 -- olive 70 -- orange 80 -- red 90 -- yellow 00 -- white Other colors can be indicated using combinations of the above code numbers. Using "black" to represent "dark" and "white" to represent "light," the following are examples: dark brown = black + brown = 10 + 30 = 13 light green = white + green = 00 + 50 = 05 greenish yellow = green + yellow = 50 + 90 = 59 grayish orange = gray + orange = 40 + 70 = 47 purple = blue + red = 20 + 80 = 28 (Note that the final zero of the basic code numbers is dropped to obtain the combined codes.)
Texture	TEX	51	I1	1 -- crystalline 2 -- crystalline-indurated 3 -- indurated 4 -- compact 5 -- cemented

Structure	STR	52	I1	1 -- homogeneous 2 -- lineated 3 -- intact-foliated 4 -- fracture-foliated
Grain Size	GS	53	I1	1 -- coarse grained 2 -- medium grained 3 -- fine grained
Calcium Carbonate Content	CCC	54	I4	1 -- calcareous 2 -- partially calcareous 3 -- non-calcareous
	FREE2	55 - 56	I2	Blank (may be designated at a later time)

Part 2

Free Swell	FS	57 - 58	I2	Unconfined swell (Franklin, 1972) input as an integer from 00 to 99, indicating values from 1 x 10^{-3} to 99 x 10^{-3} mm.
Slake Durability Index	SDI	59 - 60	F2.0	Percentage of slaking (Franklin and Chandra, 1971) to nearest percent. Input 100 percent as 99.
Point-Load Index	TSI	61 - 62	F2.0	Tensile strength (maximum value from Point Load Test (Brock and Franklin, 1972)) in units of MPa. Range of allowable input values is 01 MPa to 99 MPa.
Strength Anisotropy Index	SAI	63 - 64	F2.0	Ratio of maximum tensile strength to minimum tensile strength (Point Load Test (Franklin, 1970; Tockstein and Palmer, 1974)). 01 -- isotropic • • • 99 -- extremely anisotropic
Lithology	LITH	65	I1	See Column 28, Cateogry 1.
Strength Softening	SS	66	I1	Strength decrease in compression softening test (Morgenstern and Eigerbrod, 1974) is indicated as follows: 0 -- no data available 1 -- mudstones -- strength lose < 40 percent 2 -- clays -- strength lose > 60 percent 3 -- hard clays -- > 50 percent strength lose within days 4 -- stiff clays -- > 50 percent strength lose within hours 5 -- medium to soft clays -- complete disintegration occurs immediately
Time-Strain Behavior	TSB	67	I1	Time-strain behavior, at 50 percent of unconfined compressive strength, under a sustained uniaxial loading (Coates and Parsons, 1966; Parsons and Hedley, 1966) is indicated as follows: 0 -- no data available 1 -- elastic (creep rate < 2 μm/m/hr) 2 -- viscous (creep rate > 2 μm/m/hr) 3 -- visco-elastic (creep rate ≈ 2 μm/m/hr)

	FREE3	68 - 69	I2	Blank (may be designated at a later time)

Part 3^b

Laboratory Sonic Velocity	LSV	70 - 74	F5.0	Sonic velocity (Thill, et al., 1968) in cps (ASTM D 2845).
Shore Scleroscope Hardness	SSH	75 - 77	F3.0	Rebound hardness measured by the Shore scleroscope tester.
Schmidt Hammer Hardness	SHH	78 - 79	F2.0	Rebound hardness (Hucka, 1965) using Type L Schmidt rebound hammer.
	CARDI	80	I1	1-punch for Card No. 1

CATEGORY 2, INTACT SPECIMEN DATA SUBFILE (Cont'd)
Part 3 (Cont'd)
(Data Card No. 2)

State	ST	1 - 2	12	See Columns 1-2, Card 1.
County	CO	3 - 5	I3	See Columns 3-5, Card 1.
Sample Identification No.	ID	6 - 10	A5	See Columns 20-24, Card 1.
Unconfined Compressive Strength	UCS	11 - 13	F3.1	Unconfined compressive strength (Green and Perkins 1968; Franklin 1972) in units of tenths of GPa (ASTM D 2938).
Tangent Modulus	TM50	14 - 16	F3.1	Tangent modulus at a stress level of 50 percent of the ultimate unconfined compressive strength (Deere and Miller, 1966) in units of tenths of GPa (ASTM D 3148).
Natural Water Content	NWC	17 - 18	F2.0	Natural water content to the nearest percent (Franklin, 1972).
Saturation Water Content	SWC	19 - 20	F2.0	Water content to the nearest percent to fully saturate the sample (Duncan, 1969a; Ruiz, 1966).
Apparent Specific Gravity	ASG	21 - 23	F3.2	ASG = $W_s/V_s\gamma_w$ where W_s = weight of oven-dry sample, V_s = volume of solids plus impermeable voids, and γ_w = density of water.
Bulk Specific Gravity	BSG	24 - 26	F3.2	BSG = $W_s/V\gamma_w$ where V = total volume of sample (solids and voids)(Duncan, 1969a; Ruiz, 1966; ASTM E 12).
	FREE4	27	I1	Blank (may be designated at a later time)
Apparent Porosity	AP	28 - 29	F2.0	Ratio of volume of permeable voids to total volume to the nearest percent (Ruiz, 1966).

Apparent Void Ratio	AVR	30 - 31	F2.0	Ratio of volume of permeable voids to volume of solids plus impermeable voids.
Bulk Specific Gravity (SSD)	SSDG	32 - 34	F3.2	SSDG = bulk specific gravity (saturated surface dry) = $W_t/V\gamma_w$ where W_t = total weight of saturated surface dry sample.
Degree of Saturation	DOS	35 - 36	F2.0	Ratio of natural water content to saturation water content to the nearest percent.
Void Index	VI	37 - 38	F2.0	Degree of saturation of sample to the nearest percent after immersion in water for 1 hour (Franklin, 1972).
	FREE5	39	I1	Blank (may be designated at a later time)
Direct Shear Phi Angle	DSP	40 - 41	F2.0	Angle of internal friction in degrees (Giuseppe, 1970; Mellinger and Kenty, 1971).
Direct Shear Cohesion	DSC	42 - 44	F3.1	Cohesion in units of tenths of GPa.
Direct Shear Time to Failure	DST	45 - 47	F3.1	Time to failure in units of tenths of a minute.
Triaxial Compression Strength Phi Angle	TSCP	48 - 49	F2.0	Angle of internal friction in degrees (Heck, 1968; Moretto and Bolognesi, 1970; ASTM D 2664).
Triaxial Compression Strength Cohesion	TCSC	50 - 52	F3.1	Cohesion in units of tenths of GPa.
Los Angeles Abrasion	LAA	53 - 54	F2.0	Percentage wear (abrasion or wear test) to the nearest percent (ASTM C 131).
Deval Abrasion	DA	55 - 56	F2.0	Percentage lose (abrasion or wear test) to the nearest percent (Ruiz, 1966; ASTM D 2 (withdrawn in 1972)).
Treton Impact	TI	57 - 58	F2.0	Percentage lose (impact test) to the nearest percent (Ruiz, 1966).

Part 4[c]

Fracture Energy	FE	59 - 62	F4.2	Fracture energy from an unconfined compressive test (Krech and Chamberlain, 1972) in units of hundredths of J/cm^2.
Cost Analysis Data	CAD	63	I1	The existence and availability of cost analysis data[c] will be indicated as follows (Bernaix, 1969): 0 -- no information available 1 -- cost analysis data available 2 -- rock classification based on rock properties, generic rock type, and fracture energy is available for a particular physiographic region 3 -- other information available

Part 5[d]

Strength Coefficient of Variation	COV	64 - 65	F2.2	Unconfined (uniaxial) compressive strength coefficient of variation defined as the standard deviation of observed strengths to the mean of observed strengths (Bernaix, 1969).
Scale Effect	SE	66 - 68	F3.1	Ratio of unconfined compressive strength of a 10-mm diameter specimen to unconfined compressive strength of a 60-mm diameter specimen.

Part 6[e]

Mineralogical Composition	MC	69	I1	0 -- no information available 1 -- quartzofeldspathic (acid igneous rocks, quartz sandstones, gneisses, and granulites) -- usually strong and brittle 2 -- lithic/basic (basic igneous rocks, lithic and greywacke sandstones, and amphibolites) -- usually strong and brittle 3 -- pelitic (clay) (mudstones, slates, and phyllites) -- often viscous, plastic, and weak 4 -- pelitic (mica) (schists) -- often fissile and weak 5 -- saline/carbonate (limestones, marbles, dolomites, salt rocks) -- sometimes viscous, often plastic and weak
	FREE6	70 - 79	I10	Blank (may be designated at a later time)
	CARD2	80	I1	2-punch for Card No. 2

CATEGORY 2, IN-SITU DATA SUBFILE
Part 1[f]
(Data Card No. 3)

State	ST	1 - 2	I2	See Columns 1-2, Card 1.
County	CO	3 - 5	I3	See Columns 3-5, Card 1.
Sample Identification No.	ID	6 - 10	A5	See Columns 20-24, Card 1.
Bedding Thickness	BT	11 - 13	F3.0	Bedding thickness to nearest centimeter.
Joint Spacing	JS	14 - 16	F3.0	Average or predominate joint spacing to nearest centimeter.
Joint Frequency	JF	17	I1	0 -- less than one joint per 3 meters 1 -- one joint per 3 meters 2 -- two joints per 3 meters • • • 8 -- eight joints per 3 meters 9 -- nine or more joints per 3 meters

Joint Infiltration Material	JIM	18	I1	0 -- no data available 1 -- air 2 -- water 3 -- cohesionless soil 4 -- inactive clay 5 -- active clay 6 -- gravel 9 - other
Gross Heterogeneity	GH	19	I1	Directional permeability of the massif as measured by the Menard Pressure Meter (Menard, 1966), in units of nanometers per second, as follows: 0 -- no data available 1 -- GH $<$ 1 nm/s 2 -- 1 $\leqslant$ GH $<$ 5 3 -- 5 $\leqslant$ GH $<$ 10 4 -- 10 $\leqslant$ GH $<$ 50 5 -- 50 $\leqslant$ GH $<$ 100 6 -- 100 $\leqslant$ GH $<$ 500 7 -- 500 $\leqslant$ GH $<$ 1000 8 -- 1000 $\leqslant$ GH $<$ 1500 9 -- GH $\geqslant$ 1500
Velocity Ratio	VR	20 - 21	F2.1	Ratio of field seismic velocity to laboratory sonic velocity (Columns 70-74, Card No. 1) (Onodera, 1962).
	FREE7	22 - 25	14	Blank (may be designated at a later time)

Part 2[g]

Joint Orientation	JO	26 - 30	I5	The prevailing joint orientation is recorded as a combination of two intergers (00 to 90) representing the angle of dip of the joint system and three intergers (000 to 360) representing the azimuth of the joint system strike (e.g. a dip of 9° East would be recorded as 09090).
Joint Survey	JSUR	31	I1	Existence of a joint survey is indicated as follows: 0 -- no survey data available 1 -- survey data available
	FREE8	32 - 35	I4	Blank (may be designated at a later time)

Part 3[h]

Core Recovery	CR	36 - 37	F2.0	Ratio of length of core obtained from a drilling interval to the total length of the cored interval, expressed to the nearest percent.
RQD	RQD	38 - 39	F2.0	Sum of the lengths of pieces of sound core 10 cm or more in length expressed as a percentage of the total length of the cored interval (Deere, 1964).
Fracture Frequency	FF	40 - 41	F2.0	Average linear length of rock blocks which constitute the total cored rock massif to the nearest centimeter (Franklin, 1970).

Weighted Core Length	WCL	42 - 43	F2.0	Ratio of the sum of core pieces > 30 cm in length plus sum of the squares of core pieces < 30 cm but > 3 cm in length to the total length of the core run, expressed to the nearest percent (Coon, 1968).
Schmidt Hammer	SH	44 - 45	F2.0	Mean of at least ten trails on a prepared surface (Hucka, 1965).
	FREE9	46 - 49	I4	Blank (may be designated at a later time)

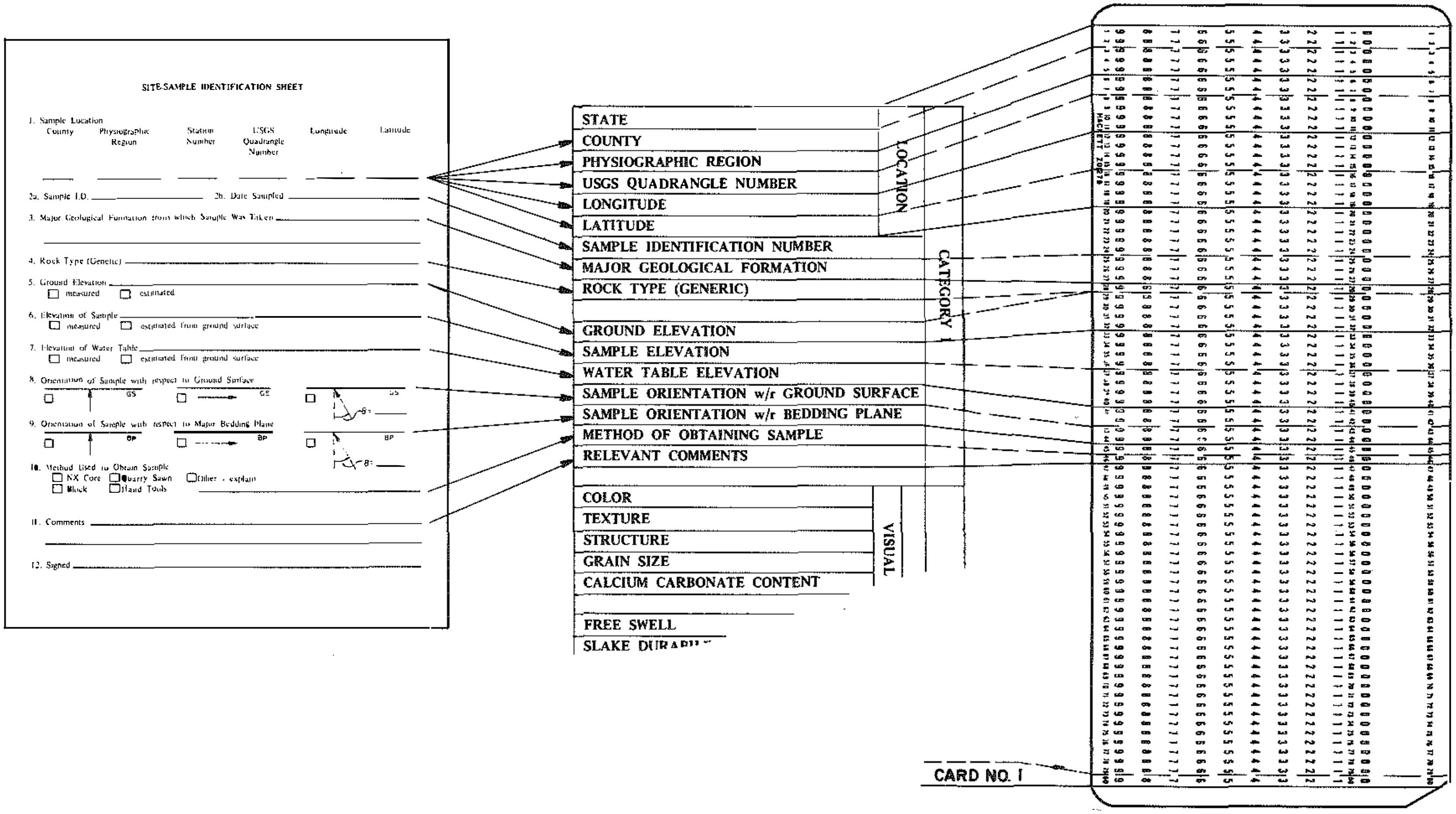
Part 4[i]

Geophysical Surveys	GEOS	50	I1	Existence of a geophysical survey is indicated as follows: 0 -- no geophysical survey 1 -- refraction seismic survey 2 -- reflection seismic survey 3 -- combination of 1 and 2 4 -- gravity survey 5 -- magnetic survey 6 -- electrical survey 7 -- radioactive survey 8 -- all of the above 9 -- limited data
Field Tests	FT	51 - 52	I2	Existence of field test data is indicated as follows: 00 -- no field test data available 01 -- sliding test 02 -- shear test 03 -- uniaxial jacking test 04 -- plate loading test 05 -- percolation test 06 -- tank test 07 -- cable test 08 -- borehole deformation test 99 -- other
Landform Classification	LC	53	I1	Existence of landform classification data is indicated as follows: 0 -- no data available 1 -- Terrain Classification (Stepanovic, 1960; Jovan and Božinovic, 1966) 2 -- PUCE (Aitchison and Grant, 1967) 3 -- Physiographic Classification (Brink and Partridge, 1967) 4 -- Landform Classification (Wahlstrom, 1973). 9 -- other
	FREE10	54 - 60	I7	Blank (may be designated at a later time)

CATEGORY 3, CASE HISTORY SUBFILE[j]
(Data Card No. 3)

Previous Experience	PE	61 - 65	I5	Existence of data on previous experience is indicated as follows: 00001 -- no data available 00002 -- data related primarily to physiographic regions 00003 -- data related primarily to rock types 00004 -- data of a general nature

Construction Practices	CP	66 - 70	I5	Existence of data concerning construction practices is indicated as follows: 00001 -- no data available 00002 -- data related primarily to physiographic regions 00003 -- data related primarily to rock types 00004 -- data of a general nature
Performance Monitoring	PM	71 - 75	I5	Existence of data on performance monitoring is indicated as follows: 00001 -- no data available 00002 -- data related primarily to physiographic regions 00003 -- data related primarily to rock types 00004 -- data of a general nature
	FREE11	76 - 79	I4	Blank (may be designated at a later time)
	CARD3	80	I1	3-punch for Card No. 3



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 (Generic) ____________

5. Ground Elevation ____________
☐ measured ☐ estimated

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

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

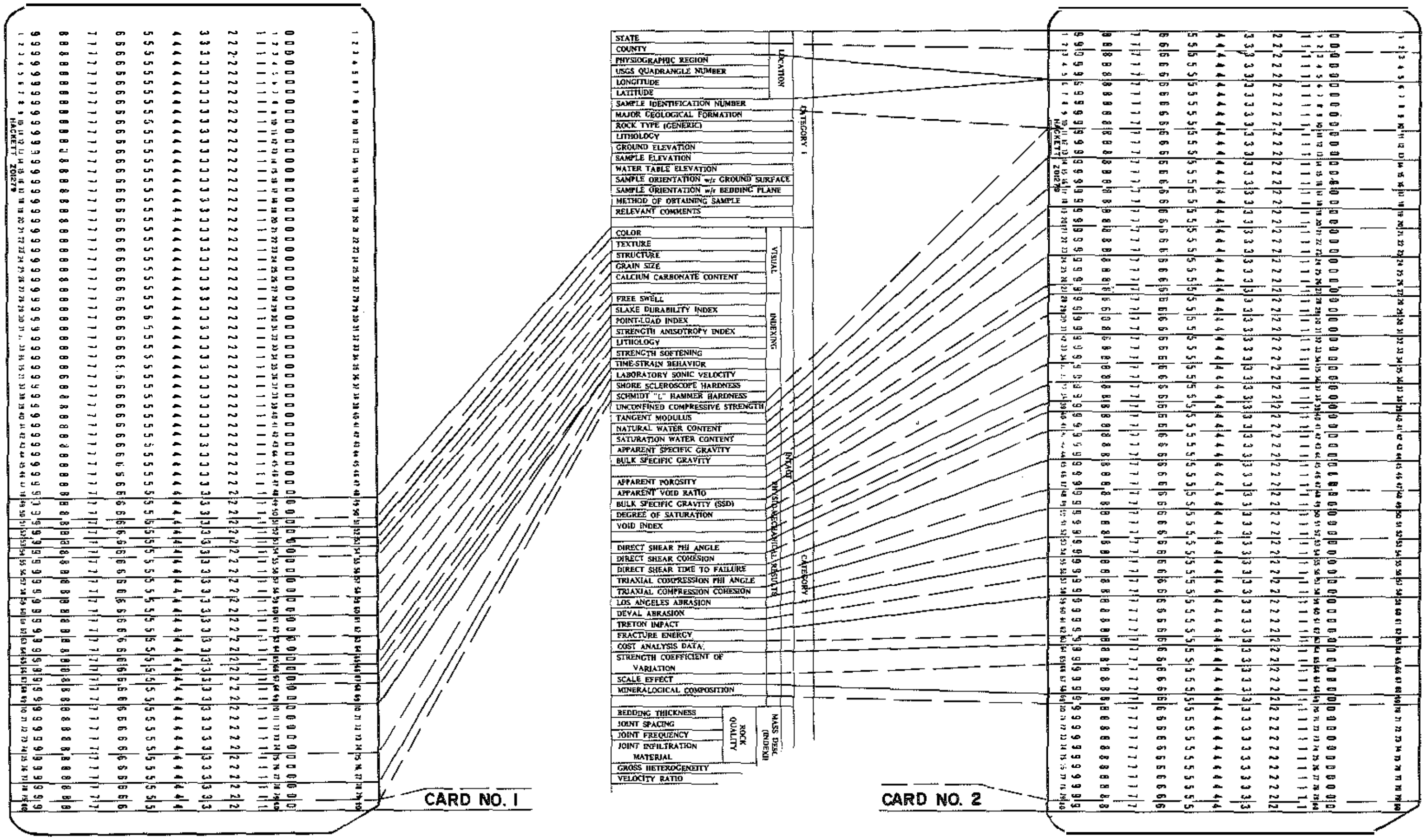
8. Orientation of Sample with respect to Ground Surface
☐ GS ☐ GS ☐ GS θ= ______

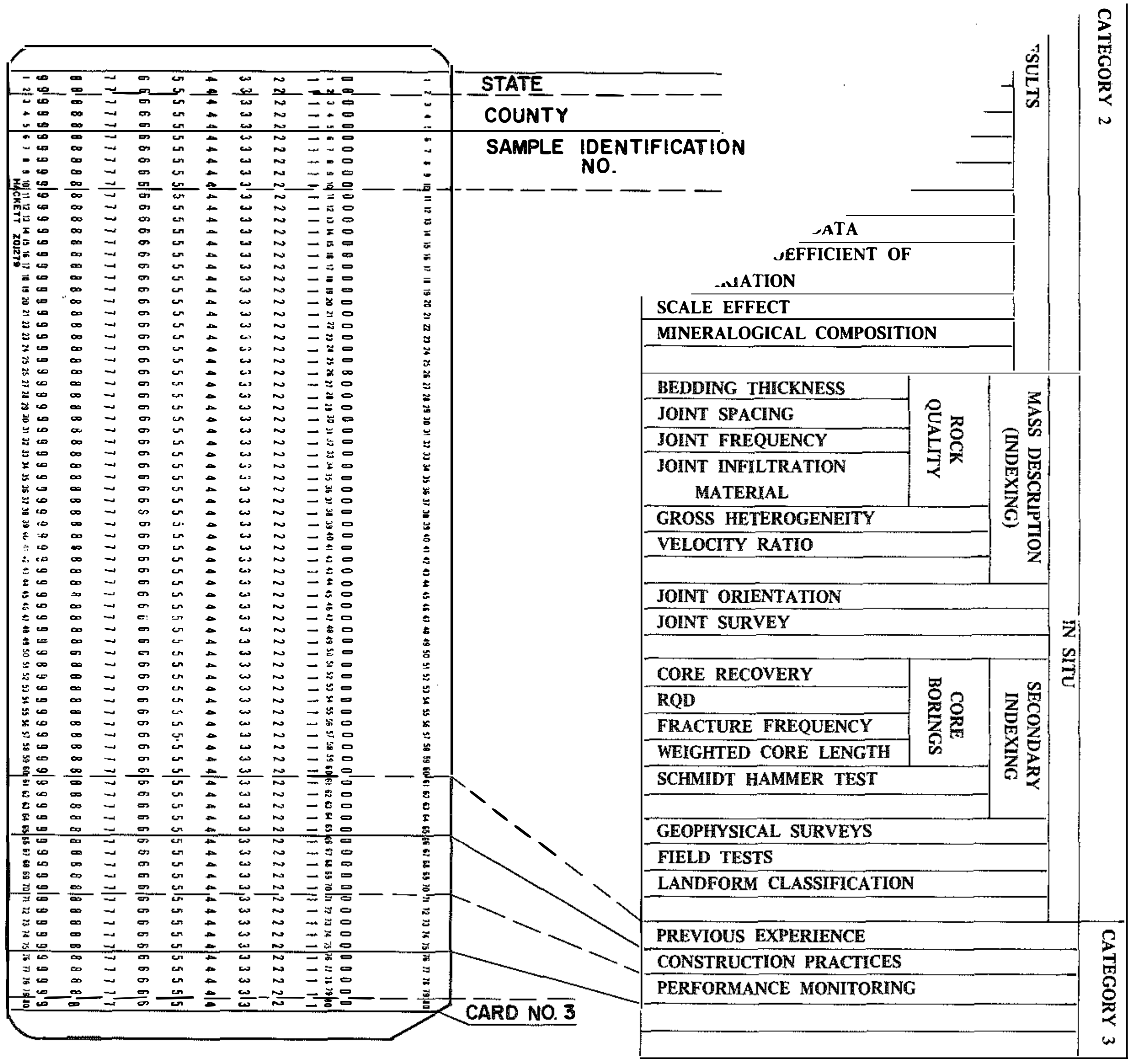
9. Orientation of Sample with respect to Major Bedding Plane
☐ BP ☐ BP ☐ BP θ= ______

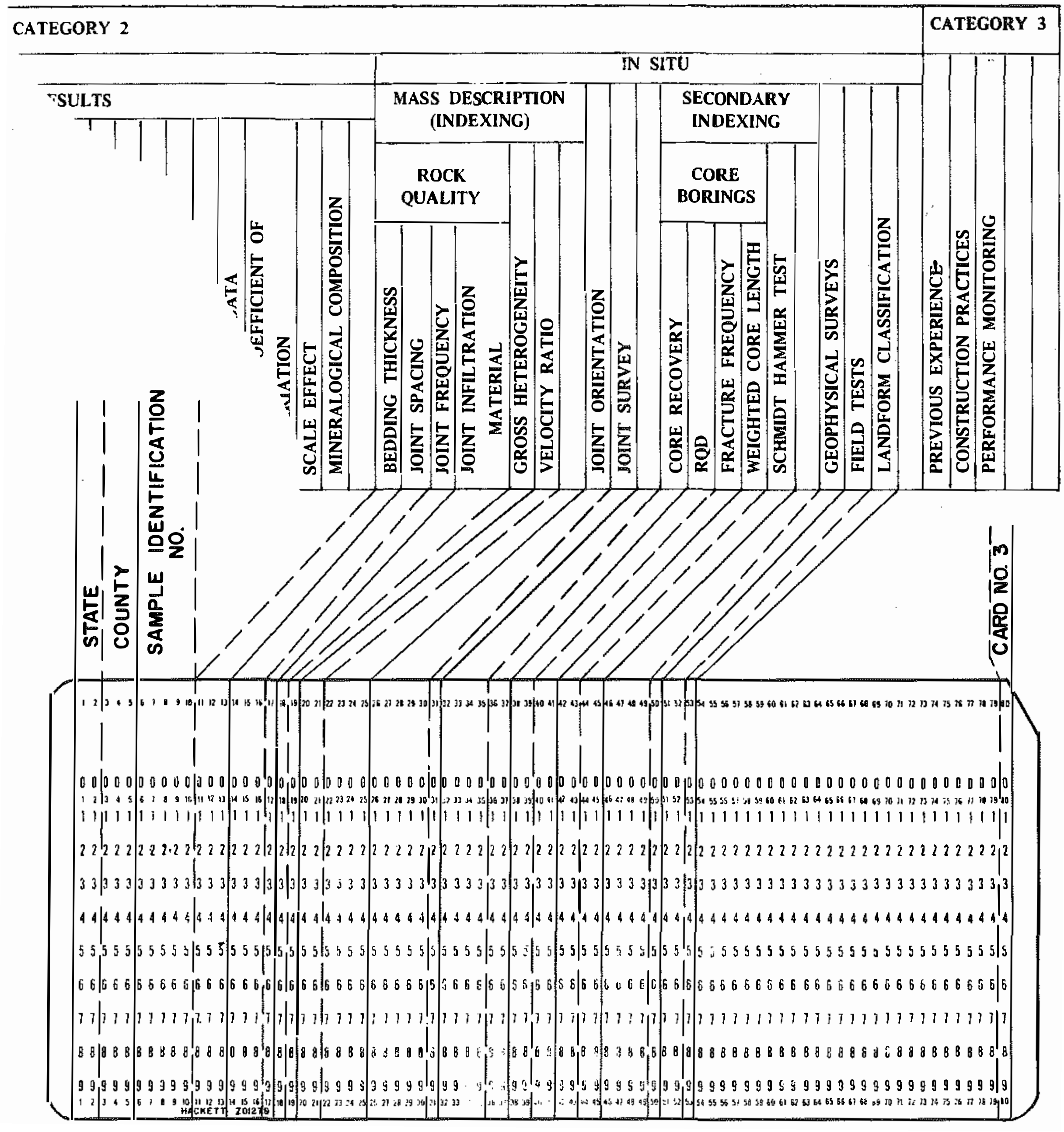
10. Method Used to Obtain Sample
☐ NX Core ☐ Quarry Sawn ☐ Other - explain
☐ Block ☐ Hand Tools ____________

11. Comments ____________

12. Signed ____________


STATE
COUNTY
PHYSIOGRAPHIC REGION
USGS QUADRANGLE NUMBER
LONGITUDE
LATITUDE
LOCATION
SAMPLE IDENTIFICATION NUMBER
MAJOR GEOLOGICAL FORMATION
ROCK TYPE (GENERIC)
LITHOLOGY
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
CATEGORY I
COLOR
TEXTURE
STRUCTURE
GRAIN SIZE
CALCIUM CARBONATE CONTENT
VISUAL
FREE SWELL
SLAKE DURABILITY INDEX
POINT-LOAD INDEX
STRENGTH ANISOTROPY INDEX
LITHOLOGY
STRENGTH SOFTENING
TIME-STRAIN BEHAVIOR
INDEXING
LABORATORY SONIC VELOCITY
SHORE SCLEROSCOPE HARDNESS
SCHMIDT "L" HAMMER HARDNESS
UNCONFINED COMPRESSIVE STRENGTH
TANGENT MODULUS
NATURAL WATER CONTENT
SATURATION WATER CONTENT
APPARENT SPECIFIC GRAVITY
BULK SPECIFIC GRAVITY
APPARENT POROSITY
APPARENT VOID RATIO
BULK SPECIFIC GRAVITY (SSD)
DEGREE OF SATURATION
VOID INDEX
DIRECT SHEAR PHI ANGLE
DIRECT SHEAR COHESION
DIRECT SHEAR TIME TO FAILURE
TRIAXIAL COMPRESSION PHI ANGLE
TRIAXIAL COMPRESSION COHESION
LOS ANGELES ABRASION
DEVAL ABRASION
TRETON IMPACT
FRACTURE ENERGY
COST ANALYSIS DATA
STRENGTH COEFFICIENT OF VARIATION
SCALE EFFECT
MINERALOGICAL COMPOSITION
PHYSIO-MECHANICAL RESULTS
INTACT
CATEGORY 2
BEDDING THICKNESS
JOINT SPACING
JOINT FREQUENCY
JOINT INFILTRATION MATERIAL
ROCK QUALITY
GROSS HETEROGENEITY
VELOCITY RATIO
MASS DESC (INDEX)
CARD NO. I
CARD NO. 2
HACKETT Z01279


STATE
COUNTY
SAMPLE IDENTIFICATION NO.
CARD NO. 3
HACKETT 201279
CATEGORY 2
SULTS
ATA
OEFFICIENT OF
IATION
SCALE EFFECT
MINERALOGICAL COMPOSITION
BEDDING THICKNESS
JOINT SPACING
JOINT FREQUENCY
JOINT INFILTRATION MATERIAL
ROCK QUALITY
GROSS HETEROGENEITY
VELOCITY RATIO
MASS DESCRIPTION (INDEXING)
JOINT ORIENTATION
JOINT SURVEY
IN SITU
CORE RECOVERY
RQD
FRACTURE FREQUENCY
WEIGHTED CORE LENGTH
CORE BORINGS
SCHMIDT HAMMER TEST
SECONDARY INDEXING
GEOPHYSICAL SURVEYS
FIELD TESTS
LANDFORM CLASSIFICATION
PREVIOUS EXPERIENCE
CONSTRUCTION PRACTICES
PERFORMANCE MONITORING
CATEGORY 3


CATEGORY 2
CATEGORY 3
IN SITU
ˇSULTS
MASS DESCRIPTION (INDEXING)
SECONDARY INDEXING
ROCK QUALITY
CORE BORINGS
.ATA
ƲEFFICIENT OF
..IATION
SCALE EFFECT
MINERALOGICAL COMPOSITION
BEDDING THICKNESS
JOINT SPACING
JOINT FREQUENCY
JOINT INFILTRATION MATERIAL
GROSS HETEROGENEITY
VELOCITY RATIO
JOINT ORIENTATION
JOINT SURVEY
CORE RECOVERY
RQD
FRACTURE FREQUENCY
WEIGHTED CORE LENGTH
SCHMIDT HAMMER TEST
GEOPHYSICAL SURVEYS
FIELD TESTS
LANDFORM CLASSIFICATION
PREVIOUS EXPERIENCE
CONSTRUCTION PRACTICES
PERFORMANCE MONITORING
STATE
COUNTY
SAMPLE IDENTIFICATION NO.
CARD NO. 3
HACKETT Z01279

APPENDIX II

COMMENTS ON ROCK DATA BANK FILES

COMMENTS ON
ROCK DATA BANK FILES

[a]Part 1 of the Category 2 Subfile provides for the recording of the field description of rock specimens using visual observations, a penknife blade, and dilute hydrochloric acid. Comprehensive definitions of various descriptive terms used in this subfile may be found in Figure 6.

[b]Secondary indexing and testing include the determination of commonly used engineering parameters which have been used by others with some degree of success for various purposes. These include tests for hardness, moduli, water contents, specific gravities, and unit weights, etc. Tertiary indexing includes tests for porosity, degree of saturation, and void index, etc. Quaternary tests results include data on strength and abrasion parameters.

[c]To obtain more meaningful laboratory measures of intact rock characteristics, engineers have turned to direct rock fracture energy measurements (Krech, 1973). Eventually, these techniques may prove to be very useful for describing the behavior of jointed rock masses.

Energy consumed in the process of rock fragmentation was measured directly by controlling laboratory tests (Krech and Chamberlain, 1972) in such a way that Griffith (1921) cracks extend under stable conditions. The potential energy within the system is controlled allowing an incremental energy source to create new cracks. The Bureau of Mines adopted the term "Fracture Energy" to include surface energy and all other necessary energies associated with the generation of a unit area of new rock surface (crack). Krech (1973) has proposed that the fracture energy of an intact specimen is a basic rock property which can be measured in the laboratory. The measureable quantities are the external forces applied to the rock specimen and the displacement caused by those forces. In particular, stresses and strains within the specimen are unimportant for Griffith's energy balance hypothesis, i.e., a crack will extend as long as the potential energy available to the crack is greater than the surface energy required to restrain cracking.

To obtain a sufficient data base upon which to either classsify rock or utilize rock model studies for excavation problems, Krech (1973) has proposed a framework for quantitative horizontal boring classification and a systematic flow of information from the rock physico-mechanical property data (strength, fracture energy, density, hardness, abrasiveness (silica content), joint properties) to project cost analysis. Project cost optimization requires such informational divisions as "laboratory test results", "field test results", "weighted geologic factors" (manpower efficiency, boring rate, and machine efficiency), "operational factors" (crew efficiency, machine efficiency, etc), "support requirements", "management requirements", and finally and "optimum project cost".

Analysis of all input data is required to properly assess the interaction of rock properties and personnel and machine parameters associated with different excavation techniques. For the present time, the Data Bank will contain only the qualitative information indicating the existence or non-existence of excavation input information, as described above. If a study has been completed in a study area, it will, for the present time be catalogued under separate cover and file and be cross-referenced by physiographic region, excavation techniques, and fracture energy.

[d]Fracturation criteria and comparative rock studies encompass the quantitative evaluation of the system of fractures using three distinct phenomena (Bernaix, 1969):

(1) scatter of mechanical strength tests,
(2) scale effect, and
(3) variations of permeability under stress.

The existence of fracture sets is manifested in a variety of physical phenomena from anisotropy and variations of Poisson's ratio under load to the variation of sonic velocity under stress. Also, various curvature anomolies of compressibility, hysteresis, and curve tightening of transverse and longitudinal deformations indicate the presence of fractures. The usefulness of studying fracturation on a laboratory scale is that some information may be obtained which can be interpreted on the scale of the rock massif (Paterson and Weiss, 1965; Bernaix, 1969).

Analyzing strength test results of Habib, et al. (1966), Bernaix demonstrated that the scatter of test values is linked to the discontinuous nature of the rock specimens and that high initial deformations tend to diminish or disappear completely when a high confining stress forces rock discontinuities tightly together. Both data scatter and size effects reflect the heterogeneity of the fracture system in the rock; scatter reflects the random aspects of sampling procedures (with respect to number of discontinuities within the sample and direction of these discontinuities relative to the applied forces) while scale effect reflects the fact that the probability of encountering a major structural defect increases as the specimen size increases and that there is a decrease in strength with increased specimen size (Einstein et al., 1970; Hodgson and Cook, 1970).

Empirical results by Bernaix have indicated that the coefficient of variation, σ/M (M = arithmatic mean of observed strengths and σ = the standard deviation of observed strengths), is sufficiently reliable to be regarded as a characteristic parameter of rock behavior. In addition, this coefficient of variation was found to be associated with the intensity of the fracturation of the various rocks which have been investigated (Malpasset gneiss, limestone with stylolitic joints, miliolite limestone, and biotite and muscovite gneisses).

In a comparison of various specimen diameters (10, 36, and 60 mm), retaining a slenderness (aspect) ratio of 2 for each specimen, Bernaix noted that a single parameter might well be used to describe quantitatively the scale effect to some degree. This parameter is the ratio of the unconfined compressive strength of a 10-mm diameter specimen to the strength of a 60-mm diameter specimen of the same material. Like the coefficient of strength variation parameter, the scale parameter is directly associated with the intensity of rock specimen fracturation. Empirically, this scale parameter decreases in value when the intensity of the fracture system decreases (sub-lithographical limestone with stylolitic joints and(or) biotite and muscovite gneiss); the parameter decreased to a value of 1 for miliolite limestone (the scale effect is non-existent for this rock). With further study utilizing a Kentucky base suite of rocks, these two parameters may well establish a fracture function-intact rock classification system for at least one generic rock type, if not all that are found in the state.

[e]The last portion of the intact specimen subfile is concerned with a relatively important rock characterisitic, especially with respect to weak rock and transitional materials (Tockstein and Palmer, 1974). This characteristic, mineralogy, is extrrmely important in describing the engineering properties of clay-shales. Information for transitional materials must contain an extensive delineation of the mineralogical compositon of laboratory specimens. This delineation (content percentage) is not as important for sandstones, limestones, and granites. Rock within the transitional material group should be described not only by the mineralogical content, but, minimally, by such indices as quartz/feldspar ratio, feldspar freshness, freshness of dark minerals, and fissility and texture. These indices are provided for in a separate subfile. Only five categories of mineralogical assemblage occur with sufficient frequency to justify consideration by the engineer. These five assemblages will be indicated in the subfile.

[f]Characterisitics used in the in-situ rock classification system envisioned by Tockstein and Palmer (1974) will be inserted into the data files in this segment. The rock mass description for indexing purposes is based on rock quality (bedding thickness, joint spacing, joint spacing, joint frequency, and joint infiltration material), gross heterogeneity, and velocity ratio.

[g]The orientation of the discontinuities present in the rock massif is of primary importance in structural evaluations at a particular project site, but it may not be considered to be an indexing property. Therefore, the major or predominant joints and(or) faults of a massif block will be recorded on a field Joint Orientation Diagram, to be stored in a separate external file with the joint survey. The nature of a diagramatic joint survey precludes its inclusion within a limited computer data file; merely the existence of a joint survey for a rock formation and(or) project site will be included. If a joint survey has been performed, it should be kept in an unique file and cross-referenced by physiographic region, rock type, longitude and lattitude, and county. The joint survey should contain ground and(or) aerial photographs, contoured equal-area plots, or joint roses and the various parameters indicated by Duncan (1969b).

[h]Secondary indexing information is arbitrarily designated to include core boring rock quality information and Schmidt hammer test results. Rock Quality is measured and input as core recovery percentage, RQD, fracture frequency, and weighted core length percentage. Results of a systematic study of the rock core and information obtained from the boring process is maintained in a log file. This file is a combination of the driller's log and the geologic log containing such information as core lithology, joint and(or) fault location, rock alteration, and infiltration material (see Figure 7). In addition to the core information contained on a standard log sheet, items such as the temperature of returned drill water, presence of gas bubbles, tendency of the drill hole to deform during the drilling process, water lost during the drilling operation, and a core end-surface classification should be maintanined on an auxillary sheet within the log file.

As reported by Hucka (1965), the Schmidt test hammer (cf. Schmidt, 1951) can be successfully employed to measure the strength of rock in situ. Variability of test results for a given rock may be decreased if the rebound surface is relatively flat and regular (the rock surface is generally cut with a chisel and ground by hand with a carborundum wheel) and at least 10 readings are averaged (Hucka, 1965). If the rock strength falls below 250 kg/cm^2, it is necessary to perform uniaxial compression laboratory tests for comparison since the hammer is designed for testing materials with a strength greater than 250 kg/cm^2.

[i]The last segment of this data subfile includes indications of various geophysical surveys, large scale field tests, and physiographic/terrain classifications. In each of these classes of information, a coded integer will be used to indicate the existence of information and, to some degree, the type of information to be found in appropriate external files.

Geophysical investigations yield valuable information concerning subsurface geological conditions. These investigative techniques require the accurate identification of measurable differences in physical quantities (Grant and West, 1965; Scott and Carroll, 1967) associated with various differences in the structure or lithology of rock units. Subsurface exploration techniques include seismic, gravity, magnetic, electrical, and radioactive methods. A large number of parameters, as well as particular operating techniques within each type of geophysical survey, require that a separate external file be maintained.

Field tests generally are large scale or highly specialized tests which are only performed under special economic and engineering conditions because of the time, effort, and money involved. A construction project must require a strength or deformability parameter with a great deal of accuracy before large-scale field tests may be employed. Large-scale field tests include in-situ shear tests, uniaxial jacking tests (Misterek, et al., 1974), plate loading tests (rigid plate, flexible plate, chamber, radial jacking, cable jacking, and borehole jacking), percolation tests, cable tests, and exploratory borehole deformation tests. Exploratory borehold deformation tests include the Menard Pressure Meter test (utilized to quantify "Gross Heterogeneiry"), the CEBTB Apparatus test (Mayer, 1963), the Janod-Mermin Apparatus test (Mayer, 1963) and the Sounding Dilatometer test (Kujundzic, 1964).

Physiographic/terrain classification of landforms include the Terrain Classification System (Jovan and Božinović, 1966), the PUCE System (Aitchinson and Grant, 1967), and a Physiographic Classification (Brink and Partridge, 1967). Another extensive classification of landforms is presented by Wahlstrom (1973).

Since the data in this part of the subfile is maintained under separate cover in external files, the information should be cross-referenced with physiographic regions, rock types, county and location coordinates.

[j]The third category of information to be stored within the Rock Data Bank is an indication of the availability of data and reports on case histories. In particular, the information is grouped within three basic subdivisions: previous experience, construction practices, and performance monitoring. "Previous Experience" comprises a literature survey with abstracts and keyword cross-reference descriptions (see Table 5 alluding to such information as geologic anomalies, slope instability, tendencies to swell and(or) heave, etc. An external, continually up-dated file of empirical information should be created. Because "Construction Practices" information will overlap the case history data, it has been incorporated into this subfile. Finally, "Performance Monitoring", a combination of case history measurements and

monitoring of specific engineering construction behavior, is included. A "Performance Monitoring File" will contain a means of continually up-dating field monitoring of specific geologic formations, blasting techniques within specific rock types, rock alteration processes, etc. Field measurement and photography techniques would constitute primary data sources.

APPENDIX III

SPSS DATA PROCESSING
(Version Four)
(After Nie et al., 1970)

I. DATA: Brokenness-Strength Classification Diagram applied to rock mapping. Franklin (1970).

A. Task Definition Card: CROSSTABS

Subprogram CROSSTABS is designed to give a complete representation of the frequency occurrence of specific data points in tabular form:

```
CROSS TABS     FF BY TSI
OPTIONS        3,5
STATISTICS     ALL
```

```
STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES, VERSION OF 02/01/72                  11/20/74

                   RUN NAME        INPUT DATA
                   FILE NAME       DATA0110
                   VARIABLE LIST   ST, CO, PR, MN, LON, LAT, ID, GF, LITHO, GEL, SE, WTE,
                                   SOG, SOB, MOS, RC, FREE1, COL, TEX, STR, GS, CCC, FREE2,
                                   FS, SDI, TSI, SAI, LITH, SS, TSB, FREE3, LSV, SSH, SHH, CARD1,
                                   UCS, TM50, NMC, SWC, ASG, BSG, FREE4, AP, AVR, SSDG,
                                   DOS, VI, FREE5, DSP, DSC, DST, TSCP, TCSC, LAA, DA, TI,
                                   FE, CAD, COV, SEFF,
                                   MC, FREE6, CARD2, BT, JS, JF, JIM, GH, VR, FREE7, JO,
                                   JSUR, FREE8, CR, RQD, FF, WCL, SH, FREE9, GEOS, FT, LC,
                                   FREE10, PE, CP, PM, FREE11, CARD3
                   INPUT FORMAT    FIXED (F2.0,F3.0,F2.0,F4.0,F4.0,F4.0,A5,F3.0,F1.0,F4.1,
                                   F4.1,F4.1,F2.0,F2.0,F1.0,F1.0,F2.0,F2.0,F1.0,F1.0,F1.0,
                                   F1.0,F2.0,F2.0,F2.0,F2.0,F2.0,F1.0,F1.0,F1.0,F2.0,F5.0,F3.0,
                                   F2.0,F1.0/2X,3X,5X,F3.1,F3.1,F2.0,F2.0,F3.2,
                                   F3.2,F1.0,F2.0,F2.0,F3.2,F2.0,F2.0,F1.0,F2.0,F3.1,F3.1,F2.0,F3.1,
                                   F2.0,F2.0,F2.0,F3.0,F1.0,F2.2,F3.1,F1.0,F10.0,
                                   F1.0/2X,3X,5X,F3.0,F3.0,F1.0,F1.0,F1.0,F2.1,F4.0,F5.0,
                                   F1.0,F4.0,F2.0,F2.0,F2.0,F2.0,F2.0,F4.0,
                                   F1.0,F2.0,F1.0,F7.0,F5.0,F5.0,F5.0,F4.0,F1.0)

IGNORING INDEFINITE REPETITION, THE INPUT FORMAT PROVIDES FOR  88 VARIABLES.   88 WILL BE READ.
IT PROVIDES FOR  3 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   80 'COLUMNS' ARE USED ON A RECORD.

                   # OF CASES      10
                   INPUT MEDIUM    CARD
                   VAR LABELS      ST, STATE NAME/CO, COUNTY NAME/PR, PHYSIOGRAPHIC REGION/
                                   MN, USGS MAP NUMBER/LON, LONGITUDE/LAT, LATITUDE/
                                   ID, SAMPLE IDENTIFICATION NUMBER/GF, GEOLOGICAL FORMATION/
                                   LITHO, LITHOLOGY/GEL, GROUND ELEVATION/SE, SAMPLE ELEVATION/
                                   WTE, WATER TABEL ELEVATION/SOG, SAMPLE ORIENTATION WRT GROUND/
                                   SOB, SAMPLE ORIENTATION WRT BEDDING PLANE/
                                   MOS, METHOD OF OBTAINING SAMPLE/RC, RELEVANT COMMENTS/
                                   FREE1, UNSPECIFIED AT PRESENT/
                                   COL, COLOR/TEX, TEXTURE/STR, STRUCTURE/GS, GRAIN SIZE/
                                   CCC, CALCIUM CARBONATE CONTENT/
                                   FREE2, UNSPECIFIED AT PRESENT/
                                   FS, FREE SWELL RESULTS/SDI, SLAKE DURABILITY INDEX/
                                   TSI, POINT LOAD INDEX/SAI, STRENGTH ANISOTROPY INDEX/
                                   LITH, LITHOLOGY/SS, STRENGTH SOFTENING/TSB, TIME STRAIN BEHAVIOR/
                                   FREE3, UNSPECIFIED AT PRESENT/
                                   LSV, LABORATORY SONIC VELOCITY/SSH, SHORE SCLEROSCOPE HARDNESS/
                                   SHH, SCHMIDT HAMMER HARDNESS/CARD1, END OF CARD 1/
                                   ST, STATE NAME/CO, COUNTY NAME/ID, IDENTIFICATION NUMBER/
                                   UCS, UNIAXIAL COMPRESSION STRENGTH/TM50, TANGENT MODULUS AT 50%/
                                   NMC, NATURAL MOSITURE CONTENT/SWC, SATURATION WATER CONTENT/
                                   ASG,DRY APPARENT SPECIFIC GRAVITY/BSG, UNIT WEIGHT/
                                   FREE4, UNSPECIFIED AT PRESENT TIME/
                                   AP, APPARENT POROSITY/AVR, APPARENT VOID RATIO/
                                   SSDG, APPARENT SPECIFIC GRAVITY/DOS,WATER ABSORPTION/
                                   VI, VOID INDEX/
                                   FREE5, UNSPECIFIED AT PRESENT TIME/
                                   DSP, DIRECT SHEAR PHI ANGLE/DSC, DIRECT SHEAR COHESION/
                                   DST, DIRECT SHEAR TIME TO FAILURE/
                                   TSCP, TRIAXIAL COMPRESSION STRENGTH PHI ANGLE/
                                   TCSC, TRIAXIAL COMPRESSION STRENGTH COHESION/
                                   LAA, LOS ANGELES ABRASION TEST/DA, DEVAL ABRASION TEST/
                                   TI, TRETON IMPACT TEST/FE, FRACTURE ENERGY/CAD, COST ANALYSIS/
                                   COV, STRENGTH COEFFICIENT OF VARIATION/SEFF, SCALE EFFECT/
                                   MC, MINERALOGY/
                                   FREE6, UNSPECIFIED AT PRESENT/
                                   CARD2, END OF SECOND DATA CARD/
                                   ST, STATE NAME/CO, COUNTY NAME/ID, IDENTIFICATION NUMBER/
                                   BT, BEDDING THICKNESS/JS, JOINT SPACING/
                                   JF, JOINT FREQUENCY/JIM, JOINT INFILTRATION MATERIAL/
                                   GH, GROSS HETEROGENEITY/VR, VELOCITY RATIO/
                                   FREE7, UNSPECIFIED AT PRESENT/
                                   JO, JOINT ORIENTATION/JSUR, JOINT SURVEY/
                                   FREE8, UNSPECIFIED AT PRESENT/
                                   CR, CORE RECOVERY/RQD, DEERHS ROCK QUALITY DESIGNATION/
                                   FF, FRACTURE FREQUENCY/WCL, WEIGHTED CORE LENGTH/
                                   SH, SCHMIDT HAMMER TEST/
                                   FREE9, UNSPECIFIED AT PRESENT/
```

```
                GEOS, GEOPHYSICAL SURVEYS/FT, FIELD TESTING/
                LC, LANDFORM CLASSIFICATION/
                FREE10, UNSPECIFIED AT PRESENT/
                PE, PREVIOUS EXPERIENCE/CP, CONSTRUCTION PRACTICES/
                PM, PERFORMANCE MONITORING/
                FREE11, UNSPECIFIED AT PRESENT/
                CARD3, END OF THIRD DATA CARD
VALUE LABELS    PR (1)BLUEGRASS(2)EASTERN COAL FIELD(3)JACKSON AREA(4)KNOBS
                (5)PENNYROYAL(6)WESTERN COAL FIELD/
                LITHO (1)LIMESTONE(2)SHALE(3)SANDSTONE(4)SILTSTONE
                (5)GRANITE(6)CONGLOMERATE(7)OTHER/
                COL (00)WHITE(10)BLACK(20)BLUE(30)BROWN(40)GRAY
                (50)GREEN(60)OLIVE(70)ORANGE(80)RED(90)YELLOW/
                TEX (1)CRYSTALLINE(2)CRYSTALLINE-INDURATED(3)INDURATED
                (4)COMPACT(5)CEMENTED/
                STR (1)HOMOGENEOUS(2)LINEATED(3)INTACT-FOLIATED
                (4)FRACTURE-FOLIATED/
                GS (1)COARSE(2)MEDIUM(3)FINE/
                CCC  (1)CALCAREOUS(2)PARTLY-CALCAREOUS(3)NON-CALCAREOUS/
                CAD (0)NONE(1)AVAILABLE(2)CLASSIFICATION(3)OTHER/
                MC (1)QUARTZOFELDSPATHIC(2)LITHIC(3)PELITIC-CLAY
                (4)PELITIC-MICA(5)SALINE/
                JIM (1)AIR(2)WATER(3)COHENSIONLESS SOIL(4)INACTIVE CLAY
                (5)ACTIVE CLAY(6)GRAVEL(9)OTHER
MISSING LABELS  FS(0)/SDI(0)/SAI(0)/LITHO(0)/LITH(0)
CROSSTABS       FF BY TSI
OPTIONS         3,5
STATISTICS      ALL
READ INPUT DATA
```

Output:

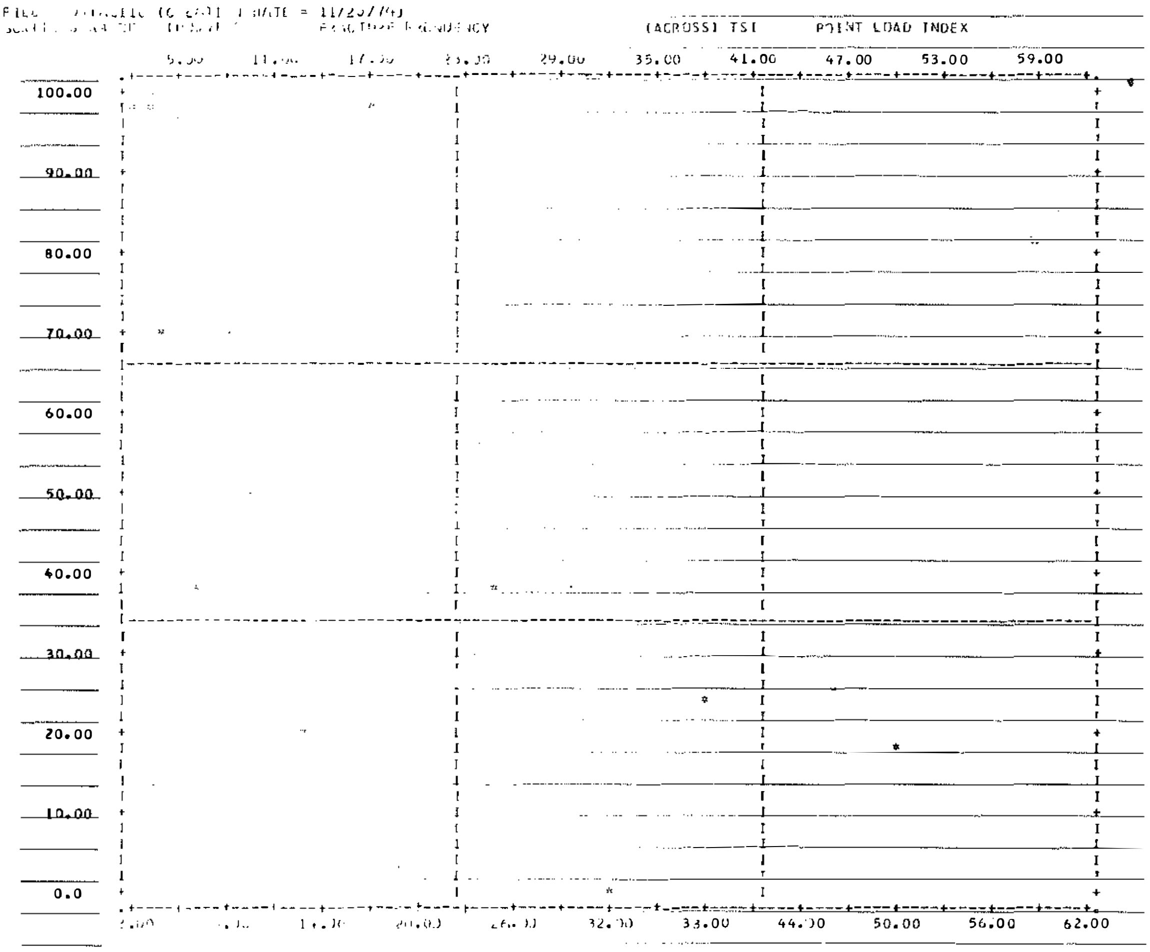
```
FILE     NONAME  (CREATION DATE = 11/20/74)

* * * * * * * * * * * * * * * * * *   C R O S S T A B U L A T I O N   O F   * * * * * * * * * * * * * * * * *
    FF          FRACTURE FREQUENCY                                BY   TSI        POINT LOAD INDEX
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  PAGE   1 OF   1

                  TSI
        COUNT   I
        COL PCT I                                                                                             ROW
                I                                                                                             TOTAL
                I    2.00I    3.00I    4.00I    6.00I   13.00I   17.00I   25.00I   32.00I   38.00I   50.00I
FF      --------I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
         0.0    I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     1  I     0  I     0  I     1
                I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        15.00   I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     1  I     1
                I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I 100.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        20.00   I     0  I     0  I     0  I     0  I     1  I     0  I     0  I     0  I     0  I     0  I     1
                I   0.0  I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        24.00   I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     1  I     0  I     1
                I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        33.00   I     0  I     0  I     0  I     1  I     0  I     0  I     0  I     0  I     0  I     0  I     1
                I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        39.00   I     0  I     0  I     0  I     0  I     0  I     0  I     1  I     0  I     0  I     0  I     1
                I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        70.00   I     0  I     0  I     1  I     0  I     0  I     0  I     0  I     0  I     0  I     0  I     1
                I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   0.0  I   10.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        95.00   I     1  I     1  I     0  I     0  I     0  I     1  I     0  I     0  I     0  I     0  I     3
                I 100.0  I 100.0  I   0.0  I   0.0  I   0.0  I 100.0  I   0.0  I   0.0  I   0.0  I   0.0  I   30.0
               -I--------I--------I--------I--------I--------I--------I--------I--------I--------I--------I
        COLUMN        1        1        1        1        1        1        1        1        1        1        10
         TOTAL     10.0     10.0     10.0     10.0     10.0     10.0     10.0     10.0     10.0     10.0     100.0

CHI SQUARE =     69.99994 WITH   63 DEGREES OF FREEDOM
CRAMER'S V =     1.00000
CONTINGENCY COEFFICIENT =      0.93541
KENDALL'S TAU B =     -0.50885
KENDALL'S TAU C =     -0.59429
GAMMA =    -0.61905
SOMERS'S D =     -0.57774
```

B. Task Definition Card: SCATTERGRAM

Subprogram SCATTERGRAM (Version 4) is designed to give a one-page graphical representation of input data points for given pairs of variables:

```
SCATTERGRAM    FF with TSI
OPTIONS        7
STATISTICS     ALL
```

Output:



```
STATISTICS..

CORRELATION (R)-      -0.67713      R SQUARED      -     0.45851     SIGNIFICANCE    -     0.01574
STD ERR OF EST -      29.54931      INTERCEPT (A)  -     79.88994    SLOPE (B)       -    -1.53631
PLOTTED VALUES -      10            EXCLUDED VALUES-     0           MISSING VALUES  -     0

********* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

II. DATA: Relationship between ultimate compressive strength and porosity for a group of carbonate rocks, Smorodinov et al. (1970).

A. Task Definition Card: CONDESCRIPTIVE

Subprogram CONDESCRIPTIVE is designed to compute descriptive statistics for continuous data:

```
CONCESCRIPTIVE      USC, AP
STATISTICS          ALL
```

Program:

```
RUN NAME        INPUT DATA
FILE NAME       DATA0110
VARIABLE LIST   ST, CO, PR, MN, LON, LAT, ID, GE, LITHO, GEL, SE, WTE,
                SOG, SOB, MOS, RC, FREE1, COL, TEX, STR, GS, CCC, FREE2,
                FS, SDI, TSI, SAI, LITH, SS, TSB, FREE3, LSV, SSH, SHH, CARD1,
                UCS, TM50, NMC, SWC, ASG, BSG, FREE4, AP, AVR, SSOG,
                DOS, VI, FREE5, DSP, DSC, DST, TSCP, TCSC, LAA, DA, TI,
                FE, CAD, COV, SEFF,
                MC, FREE6, CARD2, BT, JS, JE, JIM, GH, VR, FREE7, JO,
                JSUR, FREE8, CR, RQD, FF, WCL, SH, FREE9, GEOS, FT, LC,
                FREE10, PE, CP, PM, FREE11, CARD3
INPUT FORMAT    FIXED (F2.0,F3.0,F2.0,F4.0,F4.0,F4.0,A5,F3.0,F1.0,F4.1,
                F4.1,F4.1,F2.0,F2.0,F1.0,F1.0,F2.0,F2.0,F1.0,F1.0,F1.0,
                F1.0,F2.0,F2.0,F2.0,F2.0,F2.0,F1.0,F1.0,F1.0,F2.0,F5.0,F3.0,
                F2.0,F1.0/2X,3X,5X,F3.1,F3.1,F2.0,F2.0,F3.2,
                F3.2,F1.0,F2.0,F2.0,F3.2,F2.0,F2.0,F1.0,F2.0,F3.1,F3.1,F2.0,F3.1,
                F2.0,F2.0,F2.0,F3.0,F1.0,F2.2,F3.1,F1.0,F10.0,
                F1.0/2X,3X,5X,F3.0,F3.0,F1.0,F1.0,F1.0,F2.1,F4.0,F5.0,
                F1.0,F4.0,F2.0,F2.0,F2.0,F2.0,F2.0,F4.0,
                F1.0,F2.0,F1.0,F7.0,F5.0,F5.0,F5.0,F4.0,F1.0)

IGNORING INDEFINITE REPETITION, THE INPUT FORMAT PROVIDES FOR  88 VARIABLES.   88 WILL BE READ.
IT PROVIDES FOR  3 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   80 'COLUMNS' ARE USED ON A RECORD.

                # OF CASES      10
                INPUT MEDIUM    CARD
                MISSING LABELS FS(0)/SDI(0)/SAI(0)/LITHO(0)/LITH(0)
                CONDESCRIPTIVE UCS,AP
                STATISTICS      ALL
                READ INPUT DATA
```

Output:

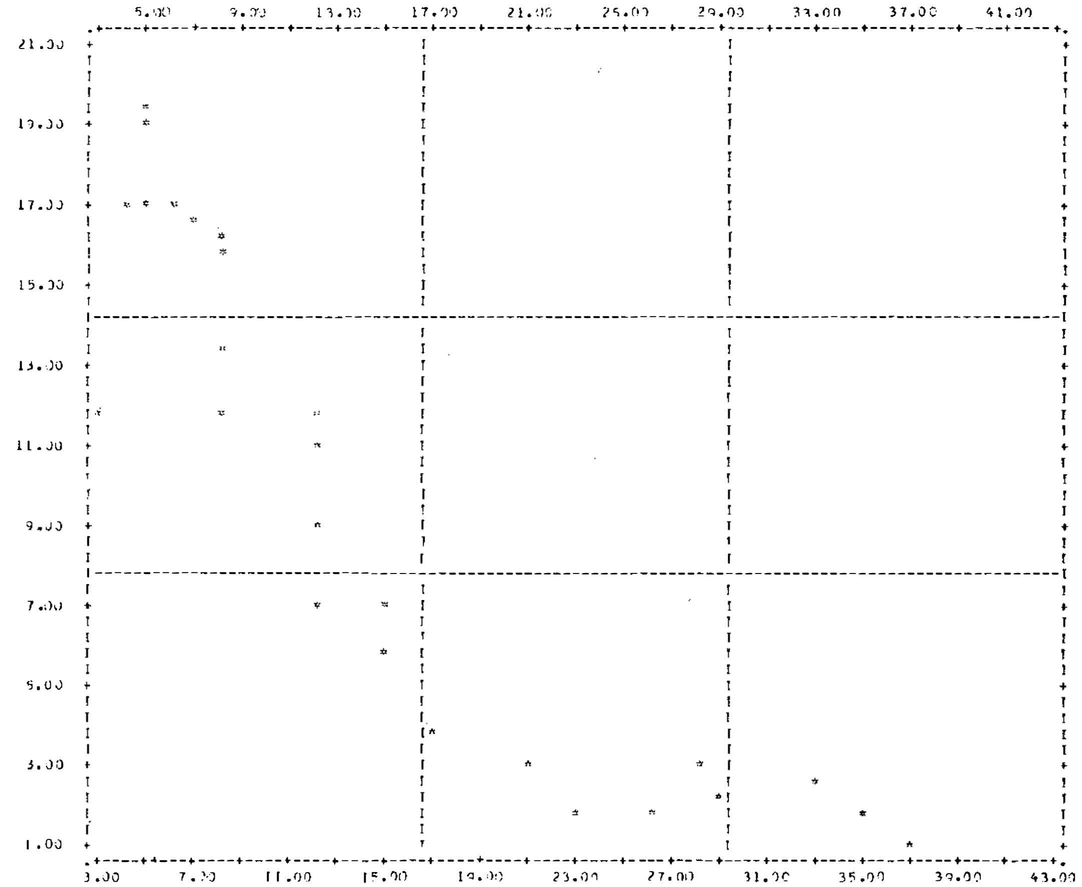
```
VARIABLE   UCS

MEAN               2.840          STD ERROR       0.438         STD DEV         1.384

VARIANCE           1.916          KURTOSIS        0.755         SKEWNESS        1.145

RANGE              4.800          MINIMUM         1.200         MAXIMUM         6.000

VALID    OBSERVATIONS -      10
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   AP

MEAN              26.400          STD ERROR       2.353         STD DEV         7.442

VARIANCE          55.378          KURTOSIS       -1.160         SKEWNESS       -0.106

RANGE             22.000          MINIMUM        15.000         MAXIMUM        37.000

VALID    OBSERVATIONS -      10
MISSING OBSERVATIONS -        0
```

B. **Task Definition Card:** SCATTERGRAM

SCATTERGRAM USC WITH AP
OPTIONS 7
STATISTICS ALL

Output:

```
SCATTERGRAM OF    (DOWN) UCS                                        (ACROSS) AP
```



```
STATISTICS..

  CORRELATION (R)-         -0.88824       R SQUARED        -         0.78897        SIGNIFICANCE    -         0.00001
  STD ERR OF EST -          2.98533       INTERCEPT (A)    -        17.82982        SLOPE (B)       -        -0.54029
  PLOTTED VALUES -         26             EXCLUDED VALUES-           0              MISSING VALUES  -         0

                 ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

C. Task Definition Card: PEARSON CORR

Subprogram PEARSON CORR is designed to compute zero-order product-moment correlation coefficients. Pearson product-moment coefficients indicate the amount of spread about the linear least-squares equation:

```
PEARSON CORR   UCS WITH AP
OPTIONS        3,4
STATISTICS     ALL
```

Program:

```
STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES, VERSION OF 02/01/72                11/18/74

                              RUN NAME        INPUT DATA
                              FILE NAME       DATA0110
                              VARIABLE LIST   ST, CO, PR, MN, LON, LAT, ID, GF, LITHO, GEL, SE, WTE,
                                              SOG, SOB, MOS, PC, FREE1, COL, TEX, STP, GS, CCC, FREE2,
                                              FS, SDI, TSI, SAI, LITH, SS, TSM, FREE3, LSV, SSH, SHH, CARD1,
                                              UCS, TM50, NMC, SWC, ASG, PSG, FREE4, AP, AVR, SSDG,
                                              DDS, VI, FREE5, DSP, DSC, DST, TSCP, TCSC, LAA, DA, TI,
                                              FF, CAD, COV, SEFF,
                                              MC, FREE6, CARD2, BT, JS, JF, JIM, GH, VR, FREE7, JO,
                                              JSUP, FREE8, CR, RQD, FF, WCL, SH, FREE9, GEOS, FT, LC,
                                              FREE10, PF, CP, PM, FREE11, CARD3
                              INPUT FORMAT    FIXED (F2.0,F3.0,F2.0,F4.0,F4.0,F4.0,A5,F3.0,F1.0,F4.1,
                                              F4.1,F4.1,F2.0,F2.0,F1.0,F1.0,F2.0,F2.0,F1.0,F1.0,F1.0,
                                              F1.0,F2.0,F2.0,F2.0,F2.0,F2.0,F1.0,F1.0,F1.0,F2.0,F5.0,F3.0,
                                              F2.0,F1.0/2X,3X,5X,F3.1,F3.1,F2.0,F2.0,F3.2,
                                              F3.2,F1.0,F2.0,F2.0,F3.2,F2.0,F2.0,F1.0,F2.0,F3.1,F3.1,F2.0,F3.1,
                                              F2.0,F2.0,F2.0,F3.0,F1.0,F2.2,F3.1,F1.0,F10.0,
                                              F1.0/2X,3X,5X,F3.0,F3.0,F1.0,F1.0,F1.0,F2.1,F4.0,F5.0,
                                              F1.0,F4.0,F2.0,F2.0,F2.0,F2.0,F2.0,F4.0,
                                              F1.0,F2.0,F1.0,F7.0,F5.0,F5.0,F5.0,F4.0,F1.0)

IGNORING INDEFINITE REPETITION, THE INPUT FORMAT PROVIDES FOR  98 VARIABLES.   98 WILL BE READ.
IT PROVIDES FOR  3 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   80 'COLUMNS' ARE USED ON A RECORD.

                              # OF CASES      27
                              INPUT MEDIUM    CARD
                              MISSING LABELS  FS(0)/SDI(0)/SAI(0)/LITHO(0)/LITH(0)
                              PEARSON CORR    UCS WITH AP
                              OPTIONS         3,4
                              STATISTICS      ALL
                              READ INPUT DATA
```

Output:

```
FILE    DATA0110 (CREATION DATE = 11/18/74)

             VARIABLE          CASES                MEAN              STD DEV

             UCS                  26              9.6423               6.3673
             AP                   26             15.1538              10.4678



FILE    DATA0110 (CREATION DATE = 11/18/74)

VARIABLES                CASES   CROSS-PROD DEV   VARIANCE-COVAR     VARIABLES              CASES   CROSS-PROD DEV   VARIANCE-COVAR

UCS       AP                26       -1480.0679         -59.2027



FILE    DATA0110 (CREATION DATE = 11/18/74)

- - - - - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - -

VARIABLE             VARIABLE             VARIABLE             VARIABLE             VARIABLE             VARIABLE
PAIR                 PAIR                 PAIR                 PAIR                 PAIR                 PAIR
--------             --------             --------             --------             --------             --------

UCS       -0.3882
WITH      N(   26)
AP        SIG  .001

                         A VALUE OF 99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

D. Task Definition Card: NONPAR CORR

Subprogram NONPAR CORR is designed to compute Spearman and(or) Kendall rank-order correlation coefficients:

NONPAR CORR UCS WITH AP
OPTIONS 3,4,6

The keyword WITH may be omitted to obtain all possible correlation coefficients from a given variable list.

Program:

```
STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES, VERSION OF 02/01/72                              11/24/74

                        RUN NAME        INPUT DATA
                        FILE NAME       DATA0110
                        VARIABLE LIST   ST, CO, PR, MN, LON, LAT, ID, GF, LITHO, GEL, SE, WTE,
                                        SDG, SDB, MOS, RC, FREE1, COL, TEX, STR, SS, CCC, FREE2,
                                        FS, SDI, TSI, SAI, LITH, SS, TSB, FREE3, LSV, SSH, SHH, CARD1,
                                        UCS, TM50, NMC, SWC, ASG, BSG, FREE4, AP, AVR, SSDG,
                                        DDS, V1, FREE5, DSP, DSC, DST, TSCP, TCSC, LAA, DA, TI,
                                        FE, CAD, COV, SEFF,
                                        MC, FREE6, CARD2, BT, JS, JF, JIM, GH, VR, FREE7, JO,
                                        JSUR, FREE8, CR, RQD, FF, WCL, SH, FREE9, SEDS, FT, LC,
                                        FREE10, PE, CP, PM, FREE11, CARD3
                        INPUT FORMAT    FIXED (F2.0,F3.0,F2.0,F4.0,F4.0,F4.0,A5,F3.0,F1.0,F4.1,
                                        F4.1,F4.1,F2.0,F2.0,F1.0,F1.0,F2.0,F2.0,F1.0,F1.0,F1.0,
                                        F1.0,F2.0,F2.0,F2.0,F2.0,F2.0,F1.0,F1.0,F1.0,F2.0,F5.0,F3.0,
                                        F2.0,F1.0/2X,3X,5X,F3.1,F3.1,F2.0,F2.0,F3.2,
                                        F3.2,F1.0,F2.0,F2.0,F3.2,F2.0,F2.0,F1.0,F2.0,F3.1,F3.1,F2.0,F3.1,
                                        F2.0,F2.0,F2.0,F3.0,F1.0,F2.2,F3.1,F1.0,F10.0,
                                        F1.0/2X,3X,5X,F3.0,F3.0,F1.0,F1.0,F1.0,F2.1,F4.0,F5.0,
                                        F1.0,F4.0,F2.0,F2.0,F2.0,F2.0,F2.0,F4.0,
                                        F1.0,F2.0,F1.0,F7.0,F5.0,F5.0,F5.0,F4.0,F1,0)

IGNORING INDEFINITE REPETITIONS, THE INPUT FORMAT PROVIDES FOR  88 VARIABLES.   88 WILL BE READ.
IT PROVIDES FOR  3 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   80 'COLUMNS' ARE USED ON A RECORD.

                        # OF CASES      26
                        INPUT MEDIUM    CARD
                        MISSING LABELS  FS(0)/SDI(0)/SAI(0)/LITHO(0)/LITH(0)
                        NONPAR CORR     UCS,AP
                        OPTIONS         3,4,6
                        READ INPUT DATA
```

Output:

```
FILE   DATA0110 (CREATION DATE = 11/24/74)

- - - - - - - - - - - - -   K E N D A L L   C O R R E L A T I O N   C O E F F I C I E N T S   - - - - - - -

VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE
PAIR                  PAIR                  PAIR                  PAIR                  PAIR                  PAIR
--------              --------              --------              --------              --------              --------


UCS       -0.8275
WITH      N(   26)
AP        SIG .001


                  A VALUE OF 99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
1.0000000-0.8275445


0.8275445 1.0000000

FILE   DATA0110 (CREATION DATE = 11/24/74)

- - - - - - - - - - - - - -   S P E A R M A N   C O R R E L A T I O N   C O E F F I C I E N T S   - - - - - - -

VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE
PAIR                  PAIR                  PAIR                  PAIR                  PAIR                  PAIR
--------              --------              --------              --------              --------              --------


UCS       -0.9307
WITH      N(   26)
AP        SIG .001


                  A VALUE OF 99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
1.0000000-0.9306996


0.9306996 1.0000000
```

III. DATA: In-situ direct shear test results of Selma Chalk at Jones Bluff Lock and Dam, Mellinger and Kenty (1971).

Task Definition Card: SCATTERGRAM

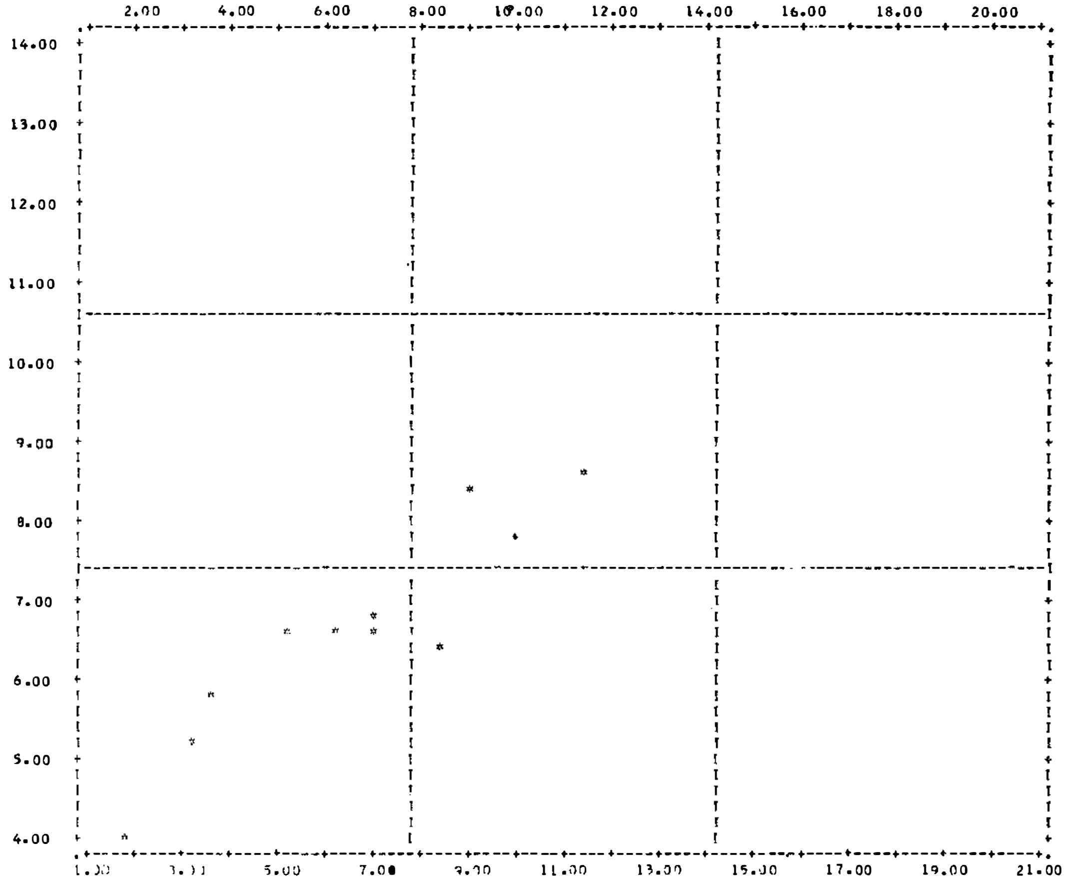
The subprogram SCATTERGRAM is utilized to plot and compute the vertical-scale intercept of direct shear and triaxial shear test results. The READ statement is not used in this computation; instead, shear stress and normal stress are input into the SPSS system to obtain the cohesion intercept and phi-angle to be stored in the data bank:

Program:

```
STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES, VERSION OF 02/01/72                    11/18/74

                        RUN NAME          DIRECT SHEAR RESULTS
                        FILE NAME         DSR1
                        VARIABLE LIST     SS, NS
                        VAR LABELS        SS, SHEAR STRESS/NS, NORMAL STRESS
                        INPUT FORMAT      FIXED (2F6.2)

IGNORING INDEFINITE REPETITION, THE INPUT FORMAT PROVIDES FOR   2 VARIABLES.    2 WILL BE READ.
IT PROVIDES FOR  1 RECORDS ('CARDS') PER CASE.  A MAXIMUM OF   12 'COLUMNS' ARE USED ON A RECORD.

                        # OF CASES        10
                        INPUT MEDIUM      CARD
                        SCATTERGRAM       SS WITH NS
                        OPTIONS           7
                        STATISTICS        ALL
                        READ INPUT DATA
```

Output:

```
DIRECT SHEAR RESULTS

FILE   DSR1      (CREATION DATE = 11/18/74)
SCATTERGRAM OF   (DOWN) SS         SHEAR STRESS                        (ACROSS) NS        NORMAL STRESS
```



```
DIRECT SHEAR RESULTS

STATISTICS..
  CORRELATION (R)-        0.91526     R SQUARED       -       0.83770     SIGNIFICANCE    -         0.00010
  STD ERR OF EST -        0.57223     INTERCEPT (A)   -       4.00164     SLOPE (B)       -         0.41683
  PLOTTED VALUES -       10           EXCLUDED VALUES-        0           MISSING VALUES -          0

                       '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```