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Field and In-Situ Rock-Mechanics Testing Manual

Technical Report

October, 1981

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ABSTRACT

Standardized field and in situ rock mechanics testing procedures have been prepared for use in the National Terminal Waste Storage Program. The procedures emphasize equipment performance specifications, documentation and reporting, and Quality Assurance acceptance criteria. Sufficient theoretical background is included to allow the user to perform the necessary data reduction. These procedures incorporate existing standards when possible, otherwise they represent the current state of the art. Maximum flexibility in equipment design has been incorporated to allow use of this manual by existing groups and to encourage future improvements.

Field and In Situ Rock Mechanics Testing Manual

Contents

Field and In Situ Rock Mechanics Testing Manual

1.0 Introduction

1.1 Background.

The National Waste Terminal Storage (NWTS) program includes several rock mechanics testing studies to fully characterize rock at candidate nuclear waste repository sites. Because of the nature of the NWTS program, these rock mechanics studies must fulfill several requirements:

- The studies should provide technically sound, high-quality data.
- Studies conducted by individual groups should be usable by other researchers and be easily integrated into the overall NWTS program.
- The studies should satisfy the data defendability, preservation, and retrievability requirements of the NWTS program.

To satisfy these requirements, standardized rock mechanics test procedures are necessary. Standard procedures are in existence for only a few field and in situ tests, however. Most testing of this type is state of the art, and methods vary considerably between organizations. Therefore, a set of standard procedures incorporating the state of the art of rock testing and oriented toward the NWTS program requirements was commissioned by the Office of Nuclear Waste Isolation (ONWI). This testing manual is the result of that effort.

The manual was prepared by Foundation Sciences, Inc., Portland, Oregon. Accepted standards and procedures, particularly American Society for Testing and Materials (ASTM) and International Society for Rock Mechanics (ISRM), are incorporated wherever possible. Where these are lacking, the procedures are based on the state-of-the-art techniques used by research laboratories, universities, and the geotechnical industry. This manual should be considered a living document. It was the intention of the authors that changes in technology and methodology could be incorporated into these procedures while maintaining the general intent and level of quality.

1.2 Purposes of the manual.

1.2.1 To provide a standard approach for conducting tests. The method of testing can have a significant effect on the data generated by the test. A major purpose of these procedures is to describe in general terms a standard approach for measuring specific rock properties and in situ conditions. These procedures are as flexible as possible while establishing common ground for comparison and evaluation of results.

1.2.2 To establish performance requirements for apparatus. Two important areas in rock mechanics testing that have not received sufficient emphasis in state-of-the-art testing programs are the level of accuracy for measurement of test parameters and the effect of physical measurement errors on the quality of the final data. A primary purpose of these procedures is to establish performance criteria for all relevant equipment and instrumentation, in order to provide high quality data consistent with repository site characterization requirements. Another purpose of these procedures is to identify and minimize the limitations placed on the resulting data by uncertainties due to measurement system error and sample variability. The intent is to provide the person using the data with an idea of how good the data really are.

1.2.3 To establish Quality Assurance acceptance criteria and checkpoints. The results of rock mechanics testing in the NWTS program must be defendable, traceable, and recoverable. These are responsibilities of a Quality Assurance program. The procedures in this manual identify the relevant areas of qualification, verification, inspection, and documentation so that each test can successfully fulfill Quality Assurance requirements.

1.2.4 To define reporting requirements. The potentially widespread application of the results of the testing programs requires that reports be complete, understandable, and usable to workers who may or may not have a background in rock mechanics. The procedures in this manual emphasize reporting requirements in order to produce a document which can stand alone and be correctly applied.

1.3 Limitations of the manual.

1.3.1 Data interpretation and application. The procedures in this manual are designed to produce usable data. The interpretation and application of these data depend on the nature of the project and are highly site specific. More importantly, interpretation and application are in part creative processes which draw heavily on the experience, judgment, and capability of the individual, and are not amenable to reduction to a standard procedure.

1.3.2 Technical expertise. In performing tests as complex and site-specific as field and in situ testing, contingencies will arise which are not and cannot be covered by a procedure. These require an understanding of the physical processes involved in the test, and of the equipment used. The procedure is not a substitute for technical knowledge and experience.

1.3.3 Equipment specifications. To keep these procedures timely and avoid hardship for testing organizations, no equipment or apparatus has been specified by brand name. Equipment requirements have been approached through performance specifications, to allow workers maximum flexibility. It is not the intent of these procedures to restrict future improvements in testing techniques in any way.

1.4 Acknowledgments.

The authors wish to acknowledge the various organizations involved in rock mechanics testing which have produced testing procedures in the past. In particular, the following supplied background information which was incorporated into this manual:

The American Society for Testing and Materials (ASTM).

The International Society for Rock Mechanics, Commission on Standardization of Laboratory and Field Tests (ISRM).

U.S. Army Corps of Engineers, Rock Testing Handbook (Standard and Recommended Methods).

2.0 Rock mechanics characterization of repository sites

2.1 General.

The primary technical requirements of a nuclear waste repository may be grouped into two broad categories:

- Isolation of the wastes from the atmosphere, from ground water, and from human activity, to prevent dangerous contamination, and
- Retrievability, so that the repository may be operated safely and efficiently.

These requirements cannot be achieved unless the underground openings forming the repository are stable over long periods of time under severe stress and temperature conditions. Rock mechanics studies provide the basic data on material properties necessary to design a stable repository.

2.2 Purpose of rock mechanics.

In situ rock mechanics studies provide basic data on the mechanical and thermal behavior of the candidate rock mass, as well as determining the actual conditions existing at the candidate repository site. This information is of primary importance in designing the size, shape, spacing, and depth of the openings, in designing adequate support systems, and in determining the allowable thermal loading of the repository. Numerical modelling techniques are currently the only way of predicting the behavior of the rock mass on a large scale and over long periods of time; however, the results of such studies are limited by the accuracy of the input rock mechanics data.

2.3 Data required.

The data required for a complete rock mechanics characterization of a repository site may be divided into several groups. It is recognized that some studies required for rock mechanics characterization will also be useful or have their primary application in other areas such as tectonics, seismology, hydrology, etc. The guidelines for geologic and geophysical work contained in the manual are written specifically for rock mechanics uses, to ensure that the minimum required data are obtained. If the data can also be obtained from other studies, such as general site characterization, this is clearly acceptable for rock mechanics studies.

2.3.1 Geometry. The arrangement and extent in space of the materials at the site affects the scope of the rock mechanics testing program and the interpretation of the results. Of particular interest are structural features such as joints and faults which significantly affect the rock mass behavior. The stratigraphy and structure of the site are generally determined by geologic and geophysical exploration. Procedures and guidelines for this phase of the study are contained in Sections A and B of this manual.

2.3.2 Stress. The orientation and magnitude of the existing state of stress in the rock mass are of fundamental importance. Procedures for determining the state of stress are contained in Section C of this manual.

2.3.3 Mechanical properties. Deformational properties and strength of the rock mass will be limiting factors in repository design. Procedures to evaluate these properties are contained in Sections D and E of this manual.

2.3.4 Fluid properties. Existing fluid pressures and the ability of the rock mass to dissipate induced fluid pressure changes are important to the stability of the openings. Procedures for measuring these properties are contained in Section F.

2.3.5 Thermal properties. The thermal properties of the rock mass in situ may differ considerably from those of intact rock due to discontinuities in the rock mass. These properties are particularly important in modelling studies. Procedures for evaluating thermal properties of rock are contained in Section G of this manual.

2.3.6 Support system performance. The performance of support systems is necessary rock mechanics data for designing the repository openings. Procedures to measure the response of a support system to a sustained load are contained in Section H of this manual.

3.0 Error in physical measurements

3.1 Definition of terms.

3.1.1 Accuracy - the deviation of the measurement from the "true" value of the parameter being measured. For example, a pressure gage that reads 102 psi (0.703 MPa) at a known pressure of 100 psi (0.689 MPa) has an accuracy of 2% at that point.

3.1.2 Precision - the ability to reproduce a certain measurement, regardless of the accuracy. For example, if the pressure gage of Section 3.1.1 is read five times and the readings are 102, 101, 102, 102, and 101 psi (0.703, 0.697, 0.703, 0.703, 0.697 MPa), the precision is 1% of the measured value.

3.1.3 Resolution - the smallest measurement interval which an instrument is capable of reading. For example, if the smallest graduations on a pressure gage are at 10 psi (0.07 MPa) intervals, it is possible to interpolate to the nearest 1 psi (0.007 MPa), thus giving a resolution of 1 psi (0.007 MPa).

3.1.4 Sensitivity - the ratio of instrument output per change in the measured parameter. For example, two different model LVDTs have sensitivities of 10 V per in. and 5 V per in. (25.4 V per cm and 12.7 V per cm).

3.1.5 Systematic errors - reproducible errors introduced by faulty equipment, calibration, or technique. For example, a pressure gage which reads 5% too high introduces a systematic error of 5% into all pressure readings unless this inaccuracy is determined by calibration and the data are corrected. Another example is a technician who always reads the pressure gage 100 psi (0.689 MPa) too high because of parallax errors between the gage needle and scale. Systematic errors can seriously affect the accuracy of a measurement.

3.1.6 Random errors - the fluctuation in the measurement due to the finite precision of the test equipment. For example, the measurement of a constant flow in a permeability test can vary due to the uncertainties in the measurement of volume and elapsed time.

3.1.7 Uncertainty - the combined effect of random errors in a measurement. For a suite of several samples, it is the combined effect of random variations of the average material properties.

3.2 Measurement uncertainties.

When field and in situ tests involve quantitative measurements, each piece of data obtained from the test has an uncertainty associated with it that is the combination of the individual uncertainties of the measurements required to obtain the data. A detailed discussion of uncertainty analysis is highly complex and beyond the scope of this manual. The user is referred to standard statistics texts. However, a few concepts will be defined to provide the background for the error analysis requirements in the procedures.

The basis for uncertainty estimates of measurements is the standard theory of propagation of errors. If a value, y, is a function of several independent measurements:

$$y = f(u,v,x\ldots) \tag{1}$$

The theory of propagation of errors relates the uncertainties of each measurement to the uncertainty of the total measurement by:

$$w_y^2 = \left(\frac{\partial y}{\partial u}\right)^2 w_u^2 + \left(\frac{\partial y}{\partial v}\right)^2 w_v^2 + \left(\frac{\partial y}{\partial x}\right)^2 w_x^2 \ldots \tag{2}$$

where:

w_y = uncertainty of the value of y

w_u, w_v, w_x = uncertainties in measurements of u, v, and x.

As an example, a flatjack test is performed and the in situ modulus, E, is calculated using:

$$E = K \frac{P}{Y} \tag{3}$$

where:

K = a constant depending on the geometry of the flatjack test = 7.14 in this case

P = pressure in flatjack

Y = movement of measuring points.

The test is run at pressures from 0 to 2000 psi (0 to 13.79 MPa). The deformation is linear and totals 0.0023 in. (0.06 mm) at the peak pressure. The following equipment is used in the test:

pressure gage: range: 0 to 5000 psi (0 to 34.48 MPa)
accuracy: 1% of full scale = 50 psi (0.34 MPa, verified by calibration)

deformation gage - Whittemore type
accuracy: $\pm$0.0001 in. (0.0025 mm) (determined by calibration)

The modulus of deformation calculated using Equation 3 is 6.21×10^6 psi (4.28×10^4 MPa). How accurate is that figure?

To calculate the measurement error associated with the modulus value, w_E, Equation 2 is applied to Equation 3:

$$w_E^2 = \frac{K^2}{Y^2} w_p^2 + \frac{K^2 P^2}{Y^4} w_Y^2 \tag{4}$$

where:

w_p = error associated with the pressure gage reading

w_Y = error associated with the deformation reading.

Evaluating w_E at the average pressure and deformation, the uncertainty of the measurement is calculated to be 0.62×10^6 psi (0.43×10^4 MPa). Therefore, the modulus value may be expressed:

$$E = 6.21 \pm 0.62 \times 10^6 \text{ psi } (4.28 \pm 0.43 \times 10^4 \text{ MPa})$$

3.3 Sources of error.

Measurement accuracy is determined primarily by the ability of the researcher to control systematic errors. Precise calibration of test equipment, adequate training of test personnel, control of the test environment to the greatest extent possible, and design of experiments with redundant systems are areas of major importance in performing accurate tests.

Random errors primarily reflect the limitations of the test equipment. Certain environmental factors, such as radio interference or vibration, can also influence measurements in quite random ways. Careful experiment design and environmental control are the two primary means of minimizing random errors.

4.0 Test equipment performance verification

4.1 Definition of terms and concepts.

4.1.1 Performance verification. The procedures in this manual specify certain accuracies, resolutions and other requirements for the equipment used in the tests. Performance verification means demonstrating that the equipment does indeed perform within the required specifications. The demonstration must be conducted according to standard, accepted, defendable procedures. In general, calibration of the equipment is the method of performance verification.

4.1.2 Calibration. Calibration means subjecting a piece of equipment to a change in the parameter of interest by means of a known input and monitoring the actual output. The variation between the input and output is used to calculate the correct reading of a measured value in an actual test. Alternatively, the calibration can verify that the equipment performance is within a certain acceptable limit of error which will be used when evaluating the test data.

4.2 Standards.

During calibration, the equipment is effectively being measured against a known standard. Clearly, the accuracy of the standard will be the limiting factor in the calibration. The most accurate standards are maintained by the U.S. National Bureau of Standards (NBS).

Not all equipment, of course, can be calibrated directly against NBS standards. Most equipment is calibrated against standards that are traceable to NBS standards. This means that the standard was calibrated against another standard which was calibrated against another standard and so forth until the last standard is the NBS standard. Traceability to NBS is the best practical way to ensure a minimum level of accuracy in the equipment calibration.

All calibration of equipment used in these procedures shall be against standards traceable to NBS, unless otherwise stated.

4.3 Performance specifications.

4.3.1 Specific requirements. Specific performance requirements for equipment are listed in each test procedure.

4.3.2 Manufacturer's specifications. When specific requirements for certain equipment are not stated in the procedures, the performance specifications supplied by the manufacturer shall be the basis for performance verification. This is particularly relevant for electronic equipment, such as voltmeters and oscilloscopes. This type of equipment is generally calibrated before it leaves the factory. The manufacturer can recommend the time intervals and procedures for re-calibration.

4.4 Error estimates.

As discussed in Section 3.2, the accuracy of a piece of equipment influences the error associated with the data. The error contributions from several pieces of equipment in a test setup can be estimated by performing a propagation of error analysis on the system, similar to that in Section 3.2. Not all instrument uncertainties contribute the same amount to the final error, and the accuracy of the test can often be improved by upgrading those pieces of equipment which control the error, or by improving their calibration.

4.5 System calibrations.

Because of the complex nature and possible interaction of error-producing factors in a test system, calibration of the entire system is preferred where possible to produce a more accurate error estimate. For example, calibrating a cross-hole seismic velocity test system in materials of known properties is preferable to performing a propagation of error analysis on individual pieces of electronic equipment.

4.6 Specific calibration procedures.

(Specific calibration procedures will be included at a later date.)

5.0 Statistical methods

5.1 Rock mass variability.

No two rock masses will give the same results when tested, even if they are located adjacent to each other in uniform rock, because of differences in composition, history, and structures such as fractures and pores. The results of tests in a single rock mass, then, will show a range of values. When applying these results, the uncertainty due to this variability must be appreciated as well as the measurement error of the individual data points. To quantify the uncertainty due to rock mass variability, the following statistical methods are useful.

5.1.1 Average. The average, $\overline{X}$, for a group of data is calculated using:

$$\overline{X} = \frac{1}{N} \sum_{i=1}^{N} X_i \qquad (5)$$

where:

N = number of data points

X_i = values of individual data points.

For example, flatjack tests are conducted at five locations in a test adit in dolomite and the results are 5.82, 6.24, 6.39, 5.98 and 6.15 X 10^6 psi (4.01, 4.30, 4.40, 4.12 and 4.24 X 10^4 MPa). The average value is 6.12 X 10^6 psi (4.22 X 10^4 MPa).

5.1.2 Range. The range of the data is expressed by the lowest and highest values. Thus, the range of the data in Section 5.1.1 is 5.82 to 6.39 X 10^6 psi (4.01 to 4.40 X 10^4 MPa).

5.1.3 Standard deviation. The standard deviation, s, for group of data is a measure of the variation of each data point from the average:

$$s = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \overline{X})^2}{N-1}} \qquad (6)$$

In practice, s is more easily calculated from the algebraically equivalent form of Equation 6:

$$s^2 = \frac{N\sum_{i=1}^{N} X_i^2 - (\sum_{i=1}^{N} X_i)^2}{N(N-1)} \qquad (7)$$

The standard deviation of the data in Section 5.1.1 is 0.22 X 10^6 psi (0.15 X 10^4 MPa).

5.1.4 Uncertainty. The uncertainty of the data is an estimate of the expected values of more tests conducted in the same rock mass. Uncertainties are evaluated with various degrees of confidence based on probability theory and on assumed distribution of the data. In most rock mechanics testing, the individual data points can deviate from the average by any value because of the complexity of the material and the test procedures. However, large deviations are relatively less frequent than smaller deviations. In this case, the data is assumed to have a normal distribution of values about the average.

The uncertainty of the test data, U, is calculated by:

$$U = t \frac{s}{\sqrt{N-1}} \tag{8}$$

where:

s = standard deviation
N = number of tests
t = confidence coefficients for the Student's t distribution,* from Table 5.1.

For the data given in Section 5.1.1, the number of degrees of freedom (N-1) is 4. Thus, the confidence coefficient is 2.13 at the 95% level. Using the standard deviation calculated above, the uncertainty is 0.24×10^6 psi (0.16×10^4 MPa). The average modulus value for the sample suite may then be written:

$$E = 6.12 \pm 0.24 \times 10^6 \text{ psi } (4.22 \pm 0.16 \times 10^4 \text{ MPa})$$

This means that if more tests were conducted in the same rock mass, the average modulus values of other test suites would have a 95% probability of falling within the range of 5.88 to 6.36 X 10^6 psi (4.06 to 4.38 X 10^4 MPa).

5.2 Group correlation.

If groups of tests have been conducted at several locations within a single formation, it may be of interest to determine whether differences in results are due to sampling uncertainties of a single material, or whether they represent distinct mechanical variations in the rock. To compare two groups, a confidence coefficient, t, is calculated from the statistics of the groups using:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{(N_1-1)s_1^2+(N_2-1)s_2^2}} \sqrt{\frac{N_1 N_2 (N_1 + N_2 - 2)}{N_1 + N_2}} \tag{9}$$

*The Student's t distribution is similar to the standard normal distribution, approaching it as the number of tests approaches infinity.

TABLE 5.1[1]

Confidence Coefficients for Student's t Distribution

Degrees of freedom (N-1)	t, at confidence level 99%	95%	90%
1	31.82	6.31	3.08
2	6.96	2.92	1.89
3	4.54	2.35	1.64
4	3.75	2.13	1.53
5	3.36	2.02	1.48
6	3.14	1.94	1.44
7	3.00	1.90	1.42
8	2.90	1.86	1.40
9	2.82	1.83	1.38
10	2.76	1.81	1.37
11	2.72	1.80	1.36
12	2.68	1.78	1.36
13	2.65	1.77	1.35
14	2.62	1.76	1.34
15	2.60	1.75	1.34
16	2.58	1.75	1.34
17	2.57	1.74	1.33
18	2.55	1.73	1.33
19	2.54	1.73	1.33
20	2.53	1.72	1.32
21	2.52	1.72	1.32
22	2.51	1.72	1.32
23	2.50	1.71	1.32
24	2.49	1.71	1.32
25	2.48	1.71	1.32
26	2.48	1.71	1.32
27	2.47	1.70	1.31
28	2.47	1.70	1.31
29	2.46	1.70	1.31
30	2.46	1.70	1.31
40	2.42	1.68	1.30
60	2.39	1.67	1.30
120	2.36	1.66	1.29
∞ (normal distribution)	2.33	1.65	1.28

[1] Adapted from Miller, I. and Freund, J.E., 1965, Probability and Statistics for Engineers, Prentice-Hall, Inc., New Jersey, p. 399.

where:

$\overline{X}_1$ = average value of group 1

s_1 = standard deviation of group 1

N_1 = number of tests in group 1

$\overline{X}_2$ = average value of group 2

s_2 = standard deviation of group 2

N_2 = number of tests in group 2.

The confidence level for the value of t calculated from Equation 9 is found from Table 5.1. The degrees of freedom in this case are equal to $N_1 + N_2 - 2$. The confidence level is the probability that the two groups of tests are significantly different.

For example, modulus of deformation was measured in two groups of boreholes several thousand feet apart in the same rock formation. The following statistics are found for each group:

$\overline{X}_1 = 4.35 \times 10^6$ psi (2.99×10^4 MPa)

$s_1 = 0.51 \times 10^6$ psi (0.35×10^4 MPa)

$N_1 = 5$

$\overline{X}_2 = 5.54 \times 10^6$ psi (3.82×10^4 MPa)

$s_2 = 0.82 \times 10^6$ psi (0.56×10^4 MPa)

$N_2 = 8$

The t value calculated from Equation 9 is 2.89. For 11 degrees of freedom, the t value at the 95% confidence level is 1.80. Therefore, it is more than 95% probable that materials of distinctly different modulus are present in the two groups of boreholes.

5.3 Comparisons.

The uncertainty due to rock mass variability should be compared to the error of an individual measurement. The rock mass variability uncertainty should be significantly larger than the measurement error (at least 2 to 3 times) to allow comment on the rock mass. If not, the test system should be improved until the measurement error decreases sufficiently.

6.0 Quality Assurance

6.1 Purpose.

6.1.1 Conformance to standards. The Quality Assurance program is intended to ensure that the actual testing program satisfies the requirements and specifications established in these procedures. The specific tasks involved in implementing the program are discussed in Section 6.2.

6.1.2 Documentation. Documentation is a key part of the NWTS program. An effective Quality Assurance program will monitor project documentation so that the following requirements are satisfied.

6.1.2.1 Traceability. The history of each rock sample and piece of test equipment should be completely recorded. For rock samples, the history from initial recovery, logging, and storage through shipping, preparation, and testing must be available to verify the identity of the sample and allow evaluation of the test results in light of its previous history. For equipment, a history from manufacture through calibration and testing, with emphasis on repairs or modifications, should be available to aid in evaluating equipment performance.

6.1.2.2 Defendability. Test program documentation should provide a clear account of what equipment was used, how the test was performed, and how the results were derived. In this way, verification that the test program was conducted in accordance with recommended procedures and specifications can be provided at any time.

6.1.2.3 Preservation. A complete set of documents on the testing program should be preserved separately from the working and reporting copies, so that no test information is lost.

6.1.2.4 Retrievability. The documentation should be organized and stored conveniently so that any piece may be easily recovered upon request.

6.2 Primary tasks.

6.2.1 Personnel prequalification. The primary personnel involved in field and in situ rock mechanics testing are the Test Supervisor (or Field Engineer, etc.) and the Technicians. Among other things, the Test Supervisor directs the overall field operations, selects the test locations, inspects the test setup and equipment, evaluates the measurements, and trouble shoots where necessary. The Technicians assemble equipment and perform the test. The Quality Assurance program should establish and verify qualifications for each type of position. In general, the Test Supervisor should have performed the test previously, be able to reduce the data, have a good understanding of the theory and applications of the data obtained from the test, and be familiar with the equipment used. The Technicians should understand the purpose of each piece of test equipment, be able to assemble and operate the test equipment, understand the purpose of the data in general, and be thoroughly familiar with the test procedure. The Quality Assurance program can verify these qualifications by written and oral testing of candidate test personnel, by testing the candidate's ability to assemble and operate the equipment, and by evaluating the candidate's background.

6.2.2 Instrument calibration certification. The Quality Assurance program should verify that all equipment calibration and performance verification is conducted according to accepted procedures and that the standards are traceable to NBS as appropriate. Calibration certificates are generally issued identifying the piece of equipment, the calibration standard and its NBS traceability, the calibration data or results, and the time interval for which the calibration is acceptable. A complete set of calibration certificates should be maintained by Quality Assurance personnel.

6.2.3 Inspection during testing. Quality Assurance personnel should inspect the test setup prior to the start of any new type of test, and periodically thereafter, to verify that the correct equipment and procedure are being used. Deviations from standard procedures or equipment should be documented, justified and approved by technical personnel before the test proceeds.

Procedure GT-A.1

Guidelines for Presentation of Geologic Maps

1.0 Introduction

1.1 Objective of the guidelines.

Several types of geologic maps may be used in a site characterization study, presenting different data or interpretations. Each map, however, must present its information in a clear and complete manner. This guideline is intended to present considerations and methods for preparing uniform and usable geologic maps.

1.2 Limitations.

1.2.1 Data gathering. This guideline does not address methods for gathering geologic data in the field.

1.2.2 Interpretation. This guideline does not address interpretation of geologic data.

1.2.3 Geohydrology. This guideline does not apply directly to geo-hydrologic maps, although certain formatting principles may be applied.

2.0 Types of geologic maps

2.1 Areal geologic maps.

The purpose of an areal geologic map is to present the field data and basic interpretations concerning the surface distributions and orientations of rock and alluvial material within a given area.

2.2 Structural maps.

Structural maps present data and interpretations concerning the deformation and fracturing of the rock units. Particular emphasis is placed on faults and folds, with information about joint systems, structural contours, and other features included as appropriate.

2.3 Isopach maps.

Isopach maps present an interpretation of the thickness of individual rock formations as contour lines of equal thickness. The "depth-to" map is a variation of the isopach map, where the depth from the ground surface to the top of a particular formation is presented as a contour line of equal depth.

2.4 Special purpose and interpretive maps.

Special purpose maps present data and interpretations of value to particular phases of the project, and may include glacial deposit maps, seismic intensity maps, epicenter and focal mechanism maps, steepness-of-slope maps, distribution of individual outcrops, magnetic and gravitational anomaly maps and so on. Interpretive maps present interpretations of data, and include seismic risk maps, stress or deformation field maps, landslide risk maps, and so on.

3.0 Choice of map size and scale

3.1 Terms and definitions.

3.1.1 Large-scale maps - maps drawn so that small areas can be shown in fine detail and with great accuracy.

3.1.2 Small-scale maps - maps drawn so that large areas are covered showing only generalized detail.

3.1.3 Map size - the physical dimensions of the finished map sheet.

3.1.4 Base map - an existing map, generally topographic, but sometimes planimetric, upon which the geologic map is drawn.

3.2 Map purpose.

The purpose of the map determines the type and amount of information that must be displayed. For example, an isopach map of a single formation may be adequately presented on a small-scale map, while a combined geologic and structural map will require a much larger scale.

3.3 Data base.

The amount of data available for preparing the map should be reflected in the scale selected. For example, a detailed geologic survey conducted with 1 in.=500 ft (25.4 mm = 152.4 m) field maps cannot be shown adequately at a scale of 1 in.=1 mi (25.4 mm = 1.61 km) without considerable generalization. Conversely, choosing too large a scale may imply that more data were collected than the map shows.

3.4 Size of smallest details.

Both base and geologic maps should be comfortable to read at a normal distance from the user (approximately 16 to 24 in.; 40 cm to 60 cm). Details should be at least 0.1 in. (2.5 mm) in size.

3.5 Clarity of relationships.

If both general and detailed relationships are to be presented on the same map, the size and scale should be such that both types of relationships are clearly perceptible.

3.6 Use of insets.

Inset maps are maps of different scale and smaller size which are used to clarify another larger map printed on the same sheet. Insets allow different scale features or different types of maps to be presented together, for clarity and ease of use. They should be located in the margins rather than in the body of the main map. Insets are particularly useful for the following types of maps.

3.6.1 Location or index maps.

3.6.2 Detailed maps of specific areas or relationships.

3.6.3 Generalized maps. An example is an inset map of major tectonic structures.

3.6.4 Special purpose maps. Frequently, these may be adequately presented at a smaller scale than the main map.

3.7 Use of drafting capabilities.

3.7.1 Color. The use of color increases the contrast between various features and may allow smaller scale maps to be used.

3.7.2 Patterns. Black and white patterns are less easily distinguished than colors, but in certain cases may allow smaller scale maps to be used.

3.8 Compatibility with scale of base maps.

The scale of the geologic map should be compatible with the scale of the base map. This can be satisfied by recording the field data initially on a map of larger scale, then reducing the information gathered to the scale of the base map.

4.0 Base maps for preparation of geologic maps

4.1 Purpose of base map.

The base map controls the accurate plotting of geologic or other data. It should enhance the interpretation of that data.

4.2 Choice of base map.

4.2.1 Topographic maps.

4.2.1.1 A topographic map shows the relief of the ground surface by means of contour lines. It may also include some physical and cultural features such as vegetation, roads, etc.

4.2.1.2 Topographic maps are the preferred choice as base maps for areal and structural geology maps, because of the interdependence of structure, rock type and topography.

4.2.1.3 For most medium-and large-scale geologic maps, topographic quadrangle maps prepared by the U.S. Geological Survey (U.S.G.S.), Topographic Branch are recommended. These maps are updated periodically, prepared according to strict specifications and readily available for all of the USA at scales of 1:1,000,000 or 1:250,000, and most of the USA at scales of 1:100,000, 1:62,500 or 1:24,000. More detailed maps are available for many river systems. In many areas, topographic maps are available from state and local governmental agencies, generally at a scale suitable for large-scale geologic mapping, such as 1:1200, 1:2400, or 1:6000.

4.2.2 Planimetric maps.

4.2.2.1 Planimetric maps show only the horizontal positions of natural or cultural features; no vertical relief is presented.

4.2.2.2 Planimetric maps are most useful for showing site locations, geologic provinces, large tectonic features, and so on. Planimetric maps should be used as base maps for areal or structural geology only when details of topography would distract from, or obscure, relationships.

4.2.2.3 Planimetric maps are available in a variety of sizes and scales from state and federal agencies.

4.2.3 Orthophotographic maps.

4.2.3.1 An orthophotographic map is a composite areal photograph with corrections made for distortions due to relief and angle of perspective. It may also include printed contour lines to show elevation.

4.2.3.2 Orthophotographic maps are primarily useful for field mapping. In some instances, however, orthophotographic maps may be used as base maps for areal geology or structure where they clearly enhance the interpretation.

4.2.3.3 A limited number of orthophotographic maps are available from the USGS.

4.2.4 Special maps. Base maps must sometimes be specially surveyed; for example, for very large scale topographic maps or maps of the rock surfaces of underground structures. The accuracy requirements depend on the size, scale, and purpose of such maps, but in any case, standard and reliable methods of photogrammetry or surveying should be used to compile them.

4.3 Map base media.

4.3.1 Paper base. Paper base maps are most useful for field work and preparation of small-scale, generalized maps. Corrections are difficult on paper base maps, and printing from a paper base map can result in detail loss and scale distortion.

4.3.2 Mylar or acetate base. Mylar or acetate base maps allow corrections to be made and provide stability and accuracy during the printing process. These bases are recommended for areal geology and structural maps in particular.

4.4 Reducing line intensity.

The information on the base map should not obscure the information that will be placed on it. For this reason, it is necessary to reduce the intensity of the base map, so that it forms a background to data of interest, yet remains legible.

4.4.1 Screening. The base map may be printed through a fine screen to delete a certain percentage of all lines.

4.4.2 Color. The base map may be printed in a different or lighter shade than the geologic information.

4.4.3 Enlarging or reducing. Base maps should not be enlarged more than 2X, because line weights will be too heavy even with screening or color. They should not be reduced by more than 25% because of loss of detail. If scale changes greater than these are required, the base map should be redrawn at the desired scale.

5.0 Information required on geologic maps

5.1 Directly observed vs. inferred data.

Any geologic or geophysical data are gathered at a finite number of points, with the conditions between those points inferred. Geologic maps should clearly distinguish between actual data and inferred data, in order to allow the user to evaluate the validity of the map and suggest alternative interpretations.

5.1.1 Outcrop maps. Outcrop maps show rock outcrops that were actually examined when compiling the geologic data. This may be particularly important in areas of heavy soil or vegetation cover.

5.1.2 Surficial geologic maps. Surficial geologic maps show rock or soil directly observed at the ground surface.

5.1.3 Bedrock geologic maps. Bedrock maps show the geology of the rock surface either exposed or underlying unconsolidated surficial sediments. The latter is inferred and should be clearly presented as such by the use of dotted lines.

5.1.4 Tectonic or structural maps. Tectonic maps show structural features such as fold axes and fault traces. Features which are inferred should be clearly distinguished from features observed directly or through geophysical means by the use of dashed or dotted lines. This applies to cross sections as well as areal maps.

5.1.5 Isopach and "depth to" maps. Isopach maps show the varying thickness of a designated stratigraphic unit. These maps generally use core logs or geophysical exploration results as the basis for drawing subsurface contours. Boreholes should be designated, and depths along the seismic lines should be clearly distinguished from inferred depths.

5.2 Rock stratigraphic (lithostratigraphic) units.

Lithostratigraphic units should be used for areal geologic maps. These units are defined by observable physical features, such as uniform petrology or continuous lateral extent, rather than by inferred geologic history.

5.2.1 The American Commission on Stratigraphic Nomenclature's "Code of Stratigraphic Nomenclature" shall be the basis for defining and naming rock units.

5.2.2 Depending on the size and scale of map, individual rock units may be grouped into larger lithostratigraphic units for purposes of generalization.

5.2.3 If other units such as time-stratigraphic (rocks of a similar age forming a unit regardless of petrology), biostratigraphic (rocks containing similar ecological assemblages or fossils regardless of age or petrology), or magnetostratigraphic (rocks exhibiting similar magnetic properties) are used for an areal geologic map, they shall be clearly explained and presented.

5.3 Structural geologic data.

Significant faults and folds are generally presented on areal geologic maps. These should be clearly distinguished from other geologic features. Attitudes of beds, joints, foliation, etc. shall be shown at the locations of the measurement. The following data should be shown on all structural maps.

5.3.1 Orientation of structural data. The measured attitudes of strata and contacts should be clearly presented.

5.3.2 Location of faults. The location and orientation of observed faults, shear zones, etc. should be shown.

5.3.3 Evidence of motion. Geomorphologic features including offset of strata, attitude of slickensides, and other field evidence of the magnitude and sense of fault displacement, such as historical data, should be presented on the map.

5.3.4 Inferred structural data.

5.3.4.1 Fold axes and fault traces. Fold axes and inferred fault traces should be presented in such a way that they are distinct from directly observed features. Dashed lines for uncertain fault traces and dotted lines for traces beneath surficial deposits are standard.

5.3.4.2 Structural contours. Inferred structural contours should be clearly distinguished from observed features.

5.4 Cross sections.

Cross sections may often clarify areal geologic or structural maps and are presented in conjunction with them.

5.4.1 Scale. Exaggerated vertical scale should be avoided in geologic cross sections as far as possible, with the exception of well logs or detailed lithology.

5.4.2 Lines. All contacts and faults in cross sections should be shown on solid lines, which may be queried to indicate uncertainty. If a fault or contact is projected above the surface to show structure, it should be drawn as a dashed line.

5.5 Isopach and "depth to" maps.

5.5.1 Points of known thickness. Locations of actual thickness measurements should be clearly shown, along with the method of measurement, and the thickness itself.

5.5.2 Interpretation. Thickness contours should be clearly distinguishable from other types of contours.

6.0 Geologic map format

6.1 Legend.

6.1.1 Authorship and title. The title of the map and the names of those involved in compiling it shall be placed in the map margin, preferably the lower center.

6.1.2 Date. The date of the original compilation of the map, dates of revisions, and date of current printings shall be listed. The dates of the base maps used shall also be listed.

6.1.3 Credits and acknowledgments. The sources of information used in the map compilation shall be listed. For areal geology or structure, an inset map may be desirable.

6.1.4 Map scale. The scale shall be presented graphically in both English and metric units, and stated numerically, e.g. "Scale 1:250,000".

6.1.5 Explanation of symbols. Each symbol used on the map shall be fully defined.

6.1.6 Stratigraphic units. On areal geologic maps, the stratigraphic units shall be listed chronologically in the right-hand margin, with youngest units at the top. Rocks of different origins, such as sedimentation or intrusion, shall be placed in parallel columns. The pattern, color, and abbreviation for each unit used on the map shall be presented in a box. The name, age, or other description of the unit shall be listed to right of the box. Time units may be displayed graphically to the left of the column of boxes.

6.2 Margins.

6.2.1 Longitude and latitude. Geologic maps shall have the longitude and latitude marked at regular intervals on the border of the mapped area.

6.2.2 UTM coordinates. The Universal Transverse Mercator coordinates shall be marked at regular intervals on the border of the mapped area. If a local system of eastings and northings is used, it shall be referenced to the UTM system.

6.2.3 North. As a general rule, true north shall be at the top of the map. The directions of both true and magnetic north shall be shown by arrows in the margin.

6.2.4 Land survey boundaries. Section and township boundaries shall be shown and township and range numbers shall be marked at regular intervals on the border of the mapped area.

6.3 Line weights.

Unscreened lines shall be at least 0.01 in. (0.25 mm) wide, and screened lines shall be at least 0.02 in. (0.4 mm) wide.

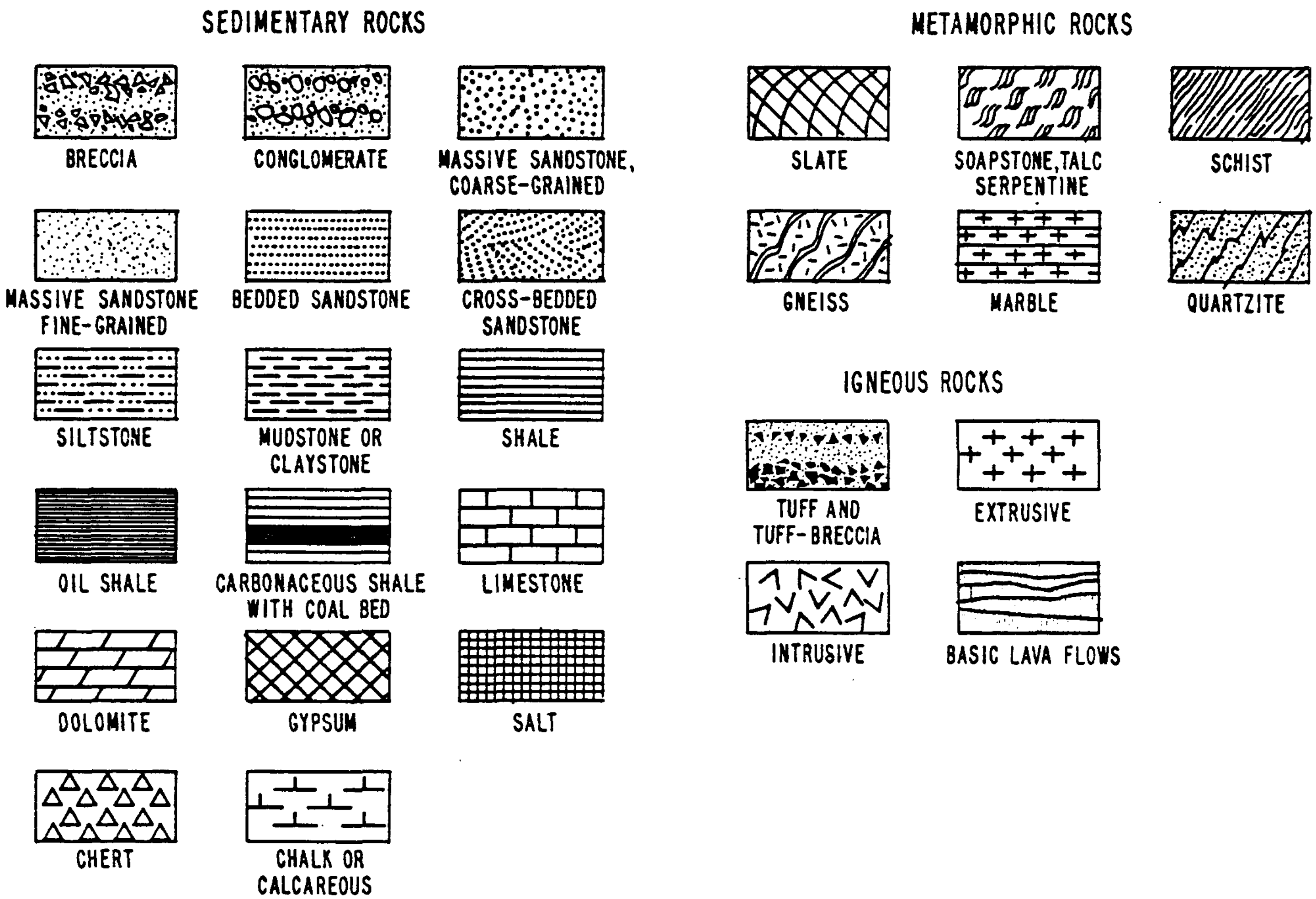
6.4 Symbols.

6.4.1 Structural. Standard structural symbols for use on maps are listed in Appendix GT-A.1-1.

6.4.2 Stratigraphic. Stratigraphic symbols are generally used on cross sections or lithic logs; they need not be used on areal geologic maps. A list of standard symbols is given in Table 6.1.

Table 6.1

Standard Lithic Symbols



6.5 Colors.

6.5.1 Lines and symbols. The color convention for lines and symbols is given in Table 6.2.

6.5.2 Rock units. While a standard color scheme for rock units has not yet been adopted, several conventions do exist. These have been incorporated into the suggested color scheme shown in Table 6.3. Whatever color scheme is used, it should provide enough contrast between adjacent rock units to make the geology clearly visible, yet not be so intense as to obliterate detail or base map information.

6.6 Abbreviations.

On areal geologic maps, the formation names are abbreviated. The first letter in the abbreviation is capitalized (with the exception of Precambrian units) and designates the rock system to which the formation belongs. Standard system symbols are given in Table 6.4. The next letters in the abbreviation are lower case and abbreviate the formation name or rock type. Rock unit abbreviations shall be at least two but no more than four letters long.

7.0 Quality Assurance

7.1 Consistency of map, legend.

Quality Assurance personnel shall review the map and legend to ensure that all symbols used on the map are explained and that the legend does not contain any superfluous symbols.

7.2 Accuracy of scale.

Quality Assurance personnel shall verify that the map scales are accurate, by comparing scaled distances with known distances measured from longitude and latitude, UTM, or other coordinate systems shown on the map.

7.3 Conformance and completeness.

Quality Assurance personnel shall review the map in a general way to ensure that it is complete and conforms with the guidelines established in this procedure.

8.0 References

8.1 Compton, R.R., 1962, Manual of Field Geology, John Wiley and Sons, Inc., New York.

8.2 Geological Society Engineering Group Working Party, 1972, "The Preparation of Maps and Plans in Terms of Engineering Geology", Q.J. Eng. Geol., 5.

8.3 Lahee, F.H., 1961, Field Geology, McGraw-Hill Book Co., Inc., New York.

8.4 U.S. Geological Survey, 1978, Suggestions to Authors of the Reports of the United States Geological Survey, Washington, D.C.

Table 6.2[1]

Standard Colors for Lines and Symbols

Feature	Color
Contour lines	Gray or Brown
Geologic contacts, symbols, and abbreviations	Black
Faults	Black or Red
Surface water	Blue
Geophysical or geochemical features	Orange
Mineral veins and ore bodies	Yellow
Works of man	Gray or Brown

[1] Geological Society Engineering Group Working Party, 1972, (see Ref. 8.2).

Table 6.3

Suggested Color Scheme for Rock Units

System or Era	Color
Quaternary	Yellows
Tertiary	Oranges, Reds
Mesozoic	Greens
Paleozoic	Blues
Precambrian	Grays, Browns

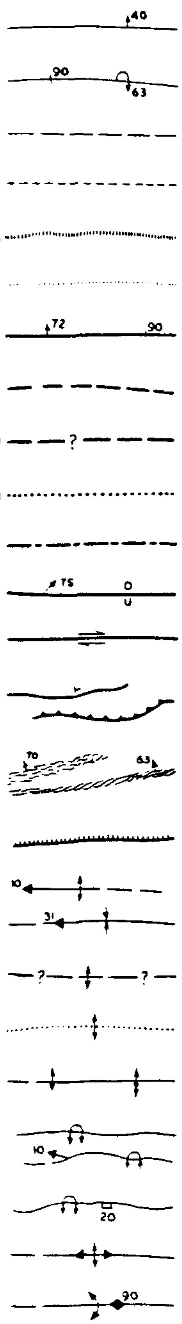
Table 6.4[1]

Standard Rock System Abbreviations

System	Abbreviation
Quaternary	Q
Tertiary	T
Cretaceous	K
Jurassic	J
Triassic	₮
Permian	P
Pennsylvanian	P
Mississippian	M
Devonian	D
Silurian	S
Ordovician	O
Cambrian	€
Precambrian	p€

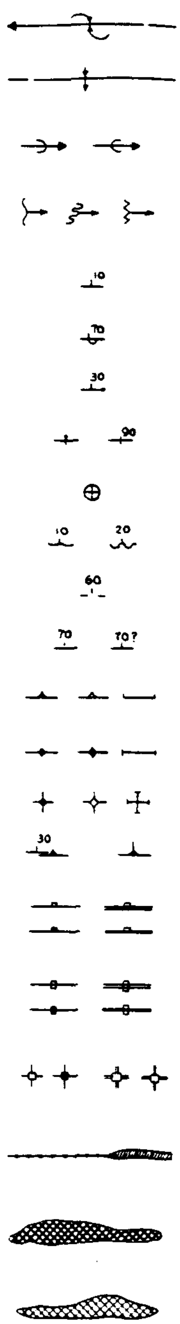
[1] U.S.G.S., 1978 (see Ref. 8.4)

Appendix GT-A.1-1
Standard Structural Symbols[1]



1	Contact, showing dip
2	Contact, vertical (left) and overturned
3	Contact, located approximately (give limits)
4	Contact, located very approximately
5	Gradational contact (a new symbol)
6	Contact, projected beneath mapped units
7	Fault, showing dips
8	Fault, located approximately (give limits)
9	Fault, existence uncertain
10	Fault, projected beneath mapped units
11	Possible fault (as located from aerial photographs)
12	Fault, showing trend and plunge of linear features (*D*, downthrown side; *U*, upthrown side)
13	Fault, showing relative horizontal movement
14	Thrust faults; *T* or sawteeth in upper plate
15	Fault zones, showing average dips
16	Normal fault; hachures on downthrown side
17	Anticline (top) and syncline, showing trace of axial plane and plunge of axis; dashed where located approximately
18	Anticline, existence uncertain
19	Anticline, projected beneath mapped units
20	Asymmetric anticline; steeper limb to south
21	Overturned anticline (top) and syncline, showing trend and plunge of axis
22	Overturned anticline, showing dip of axial plane
23	Doubly plunging anticline, showing culmination
24	Vertically plunging anticline

[1] Compton, R.R., 1962 (see Ref. 8.1)



25 Inverted (synformal) anticline

26 Monocline or flexure in homocline

27 Axial trend of small anticline (left) and syncline

28 Axial trend of folds that are too small to plot individually; patterns show general shapes of folds in profile

29 Strike and dip of bedding

30 Strike and dip of overturned bedding

31 Strike and dip of bedding where tops of beds are shown by primary features

32 Strike of vertical bedding; stratigraphic tops to north

33 Horizontal bedding

34 Undulatory or crumpled beds

35 Strike and dip of bedding, uncertain

36 Strike of bedding certain but dips uncertain

37 Strike and dip of foliations

38 Strike of vertical foliations

39 Horizontal foliations

40 Strike and dip where bedding parallels foliation

41 Strike and dip of joints (left) and veins or dikes

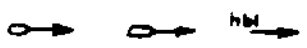
42 Strike of vertical joints (left) and veins or dikes

43 Horizontal joints (left) and veins or dikes

44 Trace (left) and mapped shape of ore vein

45 Body of high-grade ore, with stipples showing wall-rock alteration

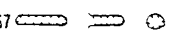
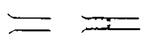
46 Body of low-grade ore

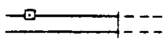
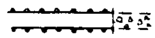
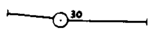
47		Trend and plunge of lineation
48		Vertical lineation
49		Trend of horizontal lineation
50		Trend of intersection of cleavage and bedding
51		Trends of intersections of two cleavages
52		Trends of pebble, mineral, etc., lineations
53		Trends of lineations lying in planes of foliations
54		Trends of horizontal lineations lying in planes of foliations
55		Vertical lineation and foliation

ACCESSORY SYMBOLS FOR SMALL-SCALE MAPS

56		Shafts, vertical (left) and inclined
57		Adits, open (left) and inaccessible
58		Trench (left) and prospect
59		Mine, quarry, or glory hole
60		Sand, gravel, or clay pit
61		Oil well (left) and gas well
62		Well drilled for oil or gas, dry
63		Wells with shows of oil (left) and gas
64		Oil or gas well, abandoned (left) and shut in
65		Water wells; flowing (left), nonflowing, and dry (right)

ACCESSORY SYMBOLS FOR LARGE-SCALE MAPS (plotted to scale)

66		Glory hole, open pit, or quarry
67		Trench (left), open cut, and pit (right)
68		Portal of tunnel or adit, that on right with open cut

69		Dump, showing track
70		Shafts at surface, vertical (left) and inclined
71		Shaft extending through a level (left), and bottom of shaft
72		Inclined shaft, with chevrons pointing down
73		Raise or winze, head (left) and foot
74		Raise or winze extending through a level
75		Level working, showing ore chute (left) and inaccessible area
76		Lagging or cribbing along working, with filled area to right
77		Drill holes, horizontal (left) and inclined at 30° (showing horizontal projection of end of hole)

Procedure GT-A.2

Guidelines for Rock Core Drilling

1.0 Background

1.1 Scope.

1.1.1 Objectives of rock core drilling.

1.1.1.1 Core recovery. The primary objective of core drilling is recovery of rock core samples. These samples provide information about the composition and structure of materials at depth, and are usually the raw material for the laboratory testing program. 100% core recovery is desirable.

1.1.1.2 Drilling characteristics. A secondary objective is to observe the drilling characteristics of the various rock formations. The drilling characteristics are related in part to the mechanical properties and structure of the rock, and are a particularly important source of information if complete core recovery cannot be achieved.

1.1.2 Objective of this guideline. This guideline establishes generalized requirements and procedures for fulfilling the objectives of rock core drilling. The procedure is written for drilling from the ground surface, but the same principles may be adapted to underground exploratory drilling.

1.1.3 Limitations of this guideline. This guideline does not cover drilling and sampling in soils or unconsolidated sediments.

1.2 General description of core drilling.

In rock core drilling, a bit with cutting surfaces made of industrial grade diamonds or carbide materials is rotated and simultaneously thrust against the rock. An annulus of material is abraded away. The remaining central portion forms a right circular cylinder, which moves into the hollow space behind the drill bit (the core barrel) as the bit is advanced. The core barrel is periodically brought to the surface and emptied to obtain the rock core. During drilling, water or drilling mud is continuously pumped over the bit to cool the bit and remove abraded material (cuttings).

1.3 References.

1.3.1 ASTM Test Designation D2113-70, 1981, "Standard Method for Diamond Core Drilling for Site Investigation," Annual Book of ASTM Standards, Part 19.

1.3.2 Hvorslov, M.J., 1949, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, ASCE Committee on Sampling and Testing, Soil Mechanics and Foundation Division, Waterways Experiment Station, Vicksburg, Mississippi.

1.3.3 ISRM Commission on Recommendations on Site Investigation Techniques, 1975, Recommendations on Site Investigation Techniques.

1.3.4 Winterkorn, H.F. and Fang, H.Y., 1975, Foundation Engineering Handbook, Van Nostrand Reinholdt Co., New York.

2.0 Prerequisites

2.1 Personnel prequalification.

The personnel in a core drilling program can be grouped into two major categories. The driller and his crew, often subcontracted, are responsible for primary selection of drilling equipment and techniques, and for performing the actual drilling. The Field Supervisor and Technicians are responsible for informing the driller of the borehole locations and orientations, receiving the recovered core, and inspecting and evaluating the drilling program on site. In practice, drilling decisions often draw upon the combined experience and technical knowledge of both groups.

2.1.1 Drilling personnel. Drilling personnel should be experienced in rock core drilling and should be familiar with the equipment required for the anticipated drilling conditions. Previous drilling experience in similar materials is desirable.

2.1.2 Field personnel. Field Supervisors and Technicians shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Exploration program established.

2.2.1 Borehole requirements. The number, locations, depths, and orientations of the exploratory boreholes should be determined as far as possible prior to the start of drilling. These factors depend on the objective of the program (e.g., general exploration or investigation of a specific feature), on previous drilling in the area, and on information available from other sources such as surface geologic mapping, geophysical exploration, or remote sensing. The drilling program should be sufficiently flexible to allow changes as the actual subsurface conditions are revealed.

2.2.2 Testing requirements.

2.2.2.1 The rock core will often be used for laboratory testing, and the lab testing diameter requirements will influence the drilling program.

2.2.2.2 Completed boreholes may be used for geophysical or hydrological testing at a later date. Borehole size should be compatible with anticipated equipment requirements.

2.3 Equipment condition and performance verified.

Drilling and sampling equipment shall be complete and in good working order. It shall be verified that measurement devices, such as pressure gages and RPM counters, are functioning in conformance with the manufacturer's specifications. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

3.0 Equipment

3.1 Drill.

A rotary drilling machine equipped with gages for measuring thrust and RPM shall be used. Hydraulic feed is recommended, but mechanical types are acceptable. The machine's capacity shall be sufficient for drilling smoothly and rapidly through the rock formations encountered, in order to produce even-diameter, high-quality rock core.

3.2 Drilling fluid system.

The drilling fluid system shall be designed to satisfactorily cool the drill bit and remove cuttings. If possible, clear water shall be used as a drilling fluid. In salt, a saturated brine solution shall be used. In weak materials, drilling mud may be required to keep the hole open. Long-term uses of the borehole shall be considered in selecting a drilling fluid. For example, permeability measurements are significantly affected by residual mud on the borehole wall, groundwater samples may be contaminated by the drilling fluid, and electric well logging can be affected by the electrical properties of the fluid. If drilling mud is used, an instrument for measuring viscosity, such as a Marsh funnel, shall be available.

3.3 Core barrels.

A double-tube, swivel-type, X-design core barrel shall be the basic sampling tool. In weaker materials, an M-design barrel (the inner tube extends into the core bit) or a triple tube barrel may be required. Single tube barrels shall not be used. Wireline equipment is acceptable.

3.4 Bits.

Drill bits with diamond cutting surfaces are generally used, although carbide bits may be satisfactory for soft formations. Surface-set or impregnated diamond bits are acceptable. The bit manufacturer generally designs the bit, the design depending on the other drilling equipment and the hardness and abrasiveness of the rock formations to be drilled.

3.5 Drill rods, casing, and other equipment.

Drill rods and connectors, casing, and other equipment shall be designed to maximize the effectiveness of the core barrel. Standard sizes as defined by the Diamond Core Drill Manufacturer's Association (DCDMA) are recommended.

4.0 Procedures

4.1 Overburden casing.

Any section of the borehole which penetrates the overburden shall be cased to prevent entrance of loose materials into the hole or loss of drill fluid. The casing shall extend at least 5 ft (1.5 mm) into the top of rock. Rock is defined here as material of sufficient strength that core drilling is required for sampling.

4.2 Normal operations.

Rock core shall be recovered continuously in the borehole. If recovery drops below 100%, drilling procedures shall be modified or different types of core barrels used until 100% recovery is achieved, or until no improvements can be made in the equipment. Mechanical breaks in the core shall be minimized in the same way.

4.3 Data requirements.

4.3.1 Drilling characteristics. The driller or technician shall periodically measure and record the drilling characteristics. It is particularly important to measure these data when a different rock formation or fractured zone is encountered; this is generally evidenced by an abrupt change in the penetration rate. Drilling characteristics include:

4.3.1.1 Thrust on bit.

4.3.1.2 Speed of rotation.

4.3.1.3 Penetration rate.

4.3.1.4 Viscosity of drilling mud (if used).

4.3.1.5 Color and texture of cuttings.

4.3.2 Depth and length. The driller shall be responsible for measuring the depth of the boring and the length of the core run to an accuracy of ±0.1 ft (±0.03 m).

4.4 Abnormal conditions.

4.4.1 Bit blockage. Bit blockage is caused by breaking and wedging of the core in the inner barrel and is indicated by an abrupt drop in the penetration rate to nearly zero. The driller shall cease drilling when blockage occurs and remove the core. Procedure or equipment changes may be necessary to correct the situation.

4.4.2 Rod whip and vibration. Drill rod whip or vibration can occur when drilling in excessively fractured rocks. The driller shall minimize or eliminate these motions, generally by changing the thrust or rate of rotation, in order to preserve the sample quality.

4.4.3 Drilling fluid loss or gain. Loss or gain of drilling fluid, when not associated with bit blockage, indicates penetration of a highly permeable feature. The rate of loss or gain and the total volume change (if the fluid volume stabilizes) shall be measured as closely as practical. If the volume of fluid increases, the viscosity shall be measured periodically. The depth at which loss or gain occurs shall be noted. Extreme losses may necessitate grouting of the zone.

5.0 Reporting

The core drilling report is presented with the core log report, as discussed in Procedure GT-A.3, "Techniques for Logging Rock Core." The borehole location, orientation, and elevation, the top and bottom depth of each core run, the percent recovery of each run, and the type of equipment used are presented on the core logs and need not be listed separately.

5.1 Equipment.

The model numbers and specifications of all equipment not included in the core log report shall be listed.

5.2 Drilling fluid.

The drilling fluid shall be described and the reasons for its use discussed.

5.3 Average drilling characteristics.

The average drilling characteristics, such as penetration rate vs. RPM or thrust, shall be presented for each rock formation.

5.4 Abnormal conditions.

Abnormal drilling conditions associated with composition of structures in the rock shall be described and discussed.

5.5 Loss or gain of fluid.

Loss or gain of drilling fluid shall be described, including depth of loss, rate of loss, change in viscosity of the fluid, etc. The probable reasons for loss or gain shall be discussed.

6.0 Quality Assurance

6.1 Personnel prequalification.

Prior to drilling, all personnel shall be prequalified as described in Section 2.1.

6.2 Drilling inspection.

Quality Assurance personnel shall inspect the drill equipment and review the test procedure and the equipment performance verification.

6.3 Documentation.

Quality Assurance shall maintain complete equipment calibration and performance verification records as appropriate.

Procedure GT-A.3

Guidelines for Logging Rock Core

1.0 Background

1.1 Scope.

1.1.1 Objective of core logging. A rock core log is a graphic and narrative description in symbolic form of the rock material recovered from a borehole. The objective of this guideline is to establish a standard method of core logging that will provide a complete description of the rock, and can be easily and quickly used by investigators who may have no other contact with the rock materials.

1.1.2 Limitations. This procedure assumes that the rock core has been recovered, cleaned, and placed in the core box with appropriate depth markings. Techniques for drilling, recovery, and storage of core are described in GT-A.2, "Guidelines for Rock Core Drilling" and GT-A.4, "Handling and Storage of Rock Core Samples."

1.2 General description of core logging.

The rock core log is a pre-printed standard form containing the following five basic categories of information.

1.2.1 Documentation: Project identification, location and orientation of the borehole, and other background information.

1.2.2 Drilling data: Type of drilling equipment, penetration rates, and other drilling information.

1.2.3 Description of the rock: Macroscopic description of the petrology of the rock.

1.2.4 Description of the structure: Identification of faults, joints, bedding planes, etc., and their orientations.

1.2.5 Other tests: Results of field classification tests such as relative hardness.

1.3 References.

1.3.1 ASCE Task Committee for Foundation Design Manual, 1972, "Subsurface Investigation for Design and Construction of Foundations of Buildings: Part II, "Proc. Am. Soc. Civ. Eng. J. Soil Mech. Fnds. Div., 98, SM6.

1.3.2 Dodds, R.K., 1971, "Effective Exploration Inspection," Foundation Sciences, Inc. Newsletter, 5, 1.

1.3.3 Geological Society of London Engineering Group, 1970. "The Logging of Rock Cores for Engineering Purposes,"Q.J. Eng. Geol., 3.

1.3.4 Rankilor, P.R., 1974, "A Suggested Field System of Logging Rock Cores for Engineering Purposes," Bull. Assoc. Eng. Geol., 11, 3.

1.3.5 Winterkorn, H.F., and Fang, H.Y., 1975, Foundation Engineering Handbook, Van Nostrand Reinhold Co., New York.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in core logging, including the Technicians and Field Supervisor, shall be formally prequalified under Quality Assurance procedures established as part of the overall exploration program.

2.2 Exploration program defined.

The scope and goals of the exploration program should be established. Areas of special interest during core logging, such as weathered fractures, faults, weak formations, etc., should be defined.

3.0 Equipment

3.1 Log Forms.

Standard log forms (see Figure 3.1) shall be preprinted on NCR (no carbon required) paper which produces at least two copies of the original log.

3.2 Pens.

Fine or medium ballpoint pens with black permanent ink shall be used to complete the log forms.

3.3 Measuring rule or tape.

A wooden or metal rule or measuring tape graduated to at least 0.01 ft (0.1 cm) shall be used for measuring distances along the rock core.

3.4 Goniometer.

A goniometer graduated to at least 1° shall be used to measure the orientation of fractures and bedding planes in the core.

3.5 Hand lens.

A hand lens of at least 10X magnification shall be available for examining rock materials.

3.6 Color chart.

A Munsell or GSA Rock Color Chart shall be used to describe rock color.

ROCK CORE LOG

PROJECT	FEATURE	HOLE NO.
COORDINATES N.	E.	ELEVATION
HOLE ANGLE	BEARING	DEPTH
STARTED	FINISHED	NO. CORE BOXES
ELEV. WATER TABLE	ON (DATE)	LOGGED BY

ELEVATION	DEPTH	WEATHERING	LITHIC LOG	FRACTURE LOG	STRUCTURAL DESCRIPTION	CORE LOSS LOG	DRILL DATA	BOX NO AND TIME/DATE	LITHIC DESCRIPTION	BIT & SAMPLER	CASING	TESTS AND REMARKS

DATE	PAGE OF	SITE NO.	HOLE NO.

FIG. 3.1 STANDARD LOG FORM

3.7 Caliper.

A caliper graduated and accurate to at least 0.001 in. (0.025 mm) shall be used to measure core diameter.

3.8 Acid.

A 5% solution of hydrochloric acid shall be available for indicating the calcium carbonate content of rock cores.

3.9 Hammer and knife.

A standard geologist's hammer and 2- to 3-in.-long (51- to 76-mm-long) pocket knife shall be available to determine hardness.

3.10 Miscellaneous.

Other equipment including engineer's scale, straight edge, protractor, clipboards, etc. as required to complete the log form and perform the field characterization tests shall be available.

4.0 Procedure

Figure 4.1 is an example of a completed core log.

4.1 Documentation.

4.1.1 Project. The name of the project shall be recorded.

4.1.2 Feature. The name of the specific portion of the project where the boring is located shall be entered.

4.1.3 Hole number. The designation of the borehole shall be recorded on the top and bottom of the form.

4.1.4 Coordinates. The location of the top of the borehole in northings and eastings shall be recorded.

4.1.5 Orientation. The bearing, in degrees clockwise from north (e.g. due west is a bearing of 270°), and the inclination of the borehole in degrees from horizontal (e.g. a vertical hole has an inclination of 90°) shall be entered.

4.1.6 Elevation. The elevation of the ground surface above mean sea level at the top of the borehole shall be recorded.

4.1.7 Date started. The date on which borehole drilling was started, including any overburden drilling, shall be noted on all logs of a particular borehole.

4.1.8 Date finished. The date on which drilling of the borehole is finished shall be recorded on the last log for that borehole, and on earlier log forms if desired.

4.1.9 Depth. The maximum depth to which a borehole is logged on each log form shall be entered.

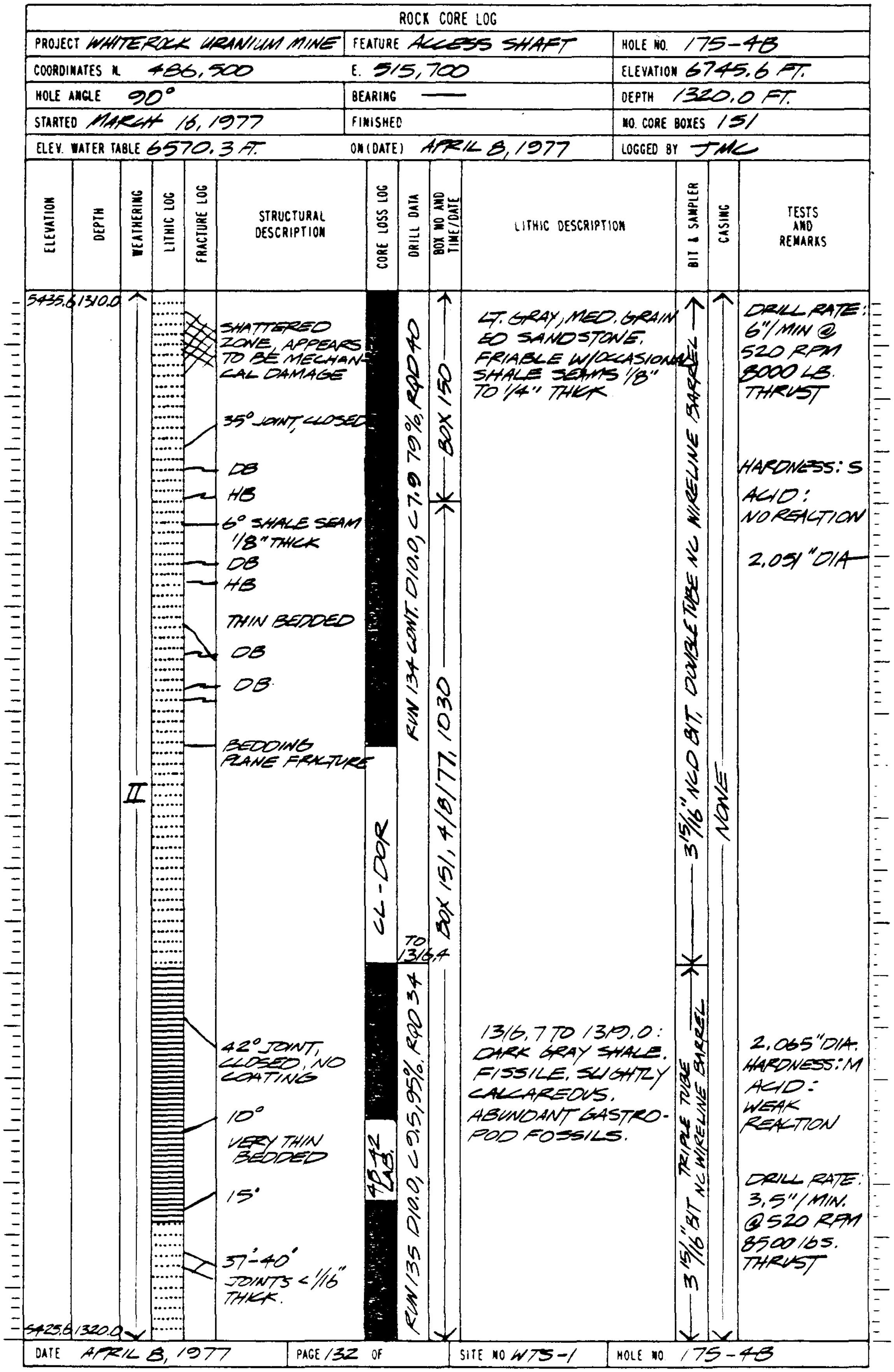


FIG. 4.1 EXAMPLE ROCK CORE LOG

4.1.10 Number of core boxes. The cumulative number of core boxes used for the borehole to date shall be entered on each log form, including new boxes begun on that form.

4.1.11 Water table. The elevation of the water table in the borehole above mean sea level and the date of the reading shall be recorded.

4.1.12 Logging personnel. The individual(s) logging the rock core shall record their initials in the appropriate location.

4.1.13 Date. The date the core is being logged shall be entered.

4.1.14 Page numbers. Each log form has enough space to record descriptive data for 10 ft (3.05 m) of core. Additional log forms are numbered successively as they are used. The total number of pages is entered after all core from the borehole is logged.

4.1.15 Site number. The site number may be an internal job number or a code for the project and feature.

4.2 Drilling data.

4.2.1 Elevation and depth. The elevation of the borehole above mean sea level and its depth below the ground surface shall be entered at the top and bottom of the appropriate columns, as a minimum on each log. This information shall also be recorded on the log where major formational changes or structural features are described.

4.2.2 Core loss. Sections of the borehole from which core was successfully recovered are indicated by a solid bar in the core loss column. Intervals of core loss, if known, are left open and labeled "CL". If the interval of core loss is unknown, it is assumed to be distributed over the length of the run. In this case, an interval of the appropriate length is left open at the end of the run and labeled "CL-DOR." Samples removed from the core boxes for laboratory testing shall likewise be indicated by an open interval in the core loss column, labeled with the sample number and "LAB".

4.2.3 Data from individual coring runs. At the top of each core run on the log form, the following information shall be recorded.

4.2.3.1 The run number. Runs are numbered in sequential order.

4.2.3.2 The length drilled during the run, indicated by "D" and the length to the nearest 0.1 ft (3 cm).

4.2.3.3 The length of core recovered from the run, indicated by "C" and the recovered length of core to the nearest 0.1 ft (3 cm).

4.2.3.4 The percent recovery.

4.2.3.5 The Rock Quality Designation (RQD) of the run. RQD is defined as the length of core recovered in 4-in. (10-cm) or longer segments divided by the total length of the run, expressed as a percentage. Handling- and drilling-induced breaks, where they can be positively identified, are not considered breaks when calculating RQD.

4.2.4 Box number and time or date. The number of the box in which the core is placed shall be entered between arrows indicating the interval of core contained in that box. The date and time that a new box is begun shall be indicated. Detailed boxing procedures may be found in GT-A.4, "Handling and Storage of Rock Core Samples."

4.2.5 Drill bit and sampling device. The type of drill bit and core barrel shall be recorded, with arrows extending over the entire zone where those pieces of equipment were used.

4.2.6 Casing. The type and diameter of casing, if any, shall be recorded in the appropriate column, with arrows extending over the entire interval where that casing was used.

4.3 Description of the rock.

4.3.1 Weathering. The degree of weathering of the rock shall be recorded in the appropriate column, using the designations listed in Table 4.1. The interval over which the designation applies shall be indicated by arrows.

4.3.2 Lithic log. The lithic log is a symbolic representation of the rock material. Standard symbols for various rock types are shown in Table 4.2. The type of rock material encountered shall be indicated using the standard symbols over the appropriate interval.

4.3.3 Lithic description. A standard macroscopic petrologic description of the rock shall be recorded for each rock type encountered. The description shall appear at least once on each log form, even where the same formation is logged over several forms. Variation of material within a formation shall be noted at the appropriate location. The description shall include the following information:

4.3.3.1 Color

4.3.3.2 Granularity

4.3.3.3 Name

4.3.3.4 Description of texture, voids, inclusions, etc.

4.4 Description of the structure.

4.4.1 Fracture log. Fractures shall be recorded graphically at the depths and orientations where they occur. Breaks which are clearly the result of drilling or handling shall be shown

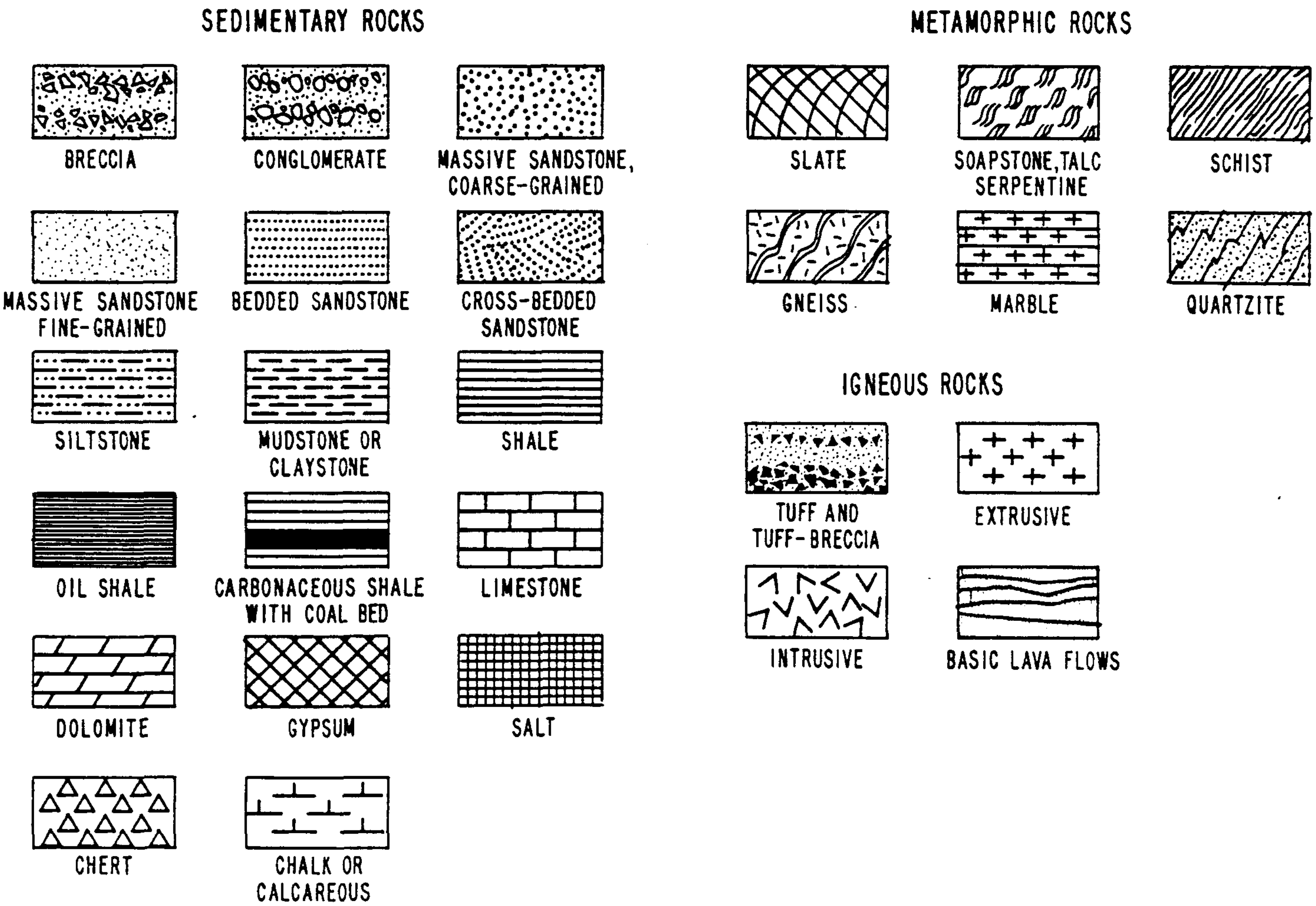
Table 4.1

Rock Weathering Descriptions

Designation	Description
I	Fresh: no visible sign of weathering
II	Faintly weathered: weathering limited to the surface of major discontinuities
III	Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material
IV	Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable
V	Highly weathered: weathering extends throughout rock mass and the rock material is partly friable
VI	Completely weathered: rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved
VII	Residual soil: a soil material with the original texture, structure and mineralogy of the rock completely destroyed

Table 4.2

Standard Lithic Symbols



with a jagged line and labeled "DB" and "HB", respectively.

4.4.2 Structural description. The jointing, bedding, foliation, shear or gouge zones, etc. shall be described. In general, the size of the feature, the geometry, the gradation, and any coatings or slickensides shall be noted as appropriate. Standards for describing feature spacing are listed in Table 4.3.

4.5 Other tests.

Results from field classification tests, drilling performance measurements, and any other remarks are recorded in the column labeled "Test and Remarks".

4.5.1 Hardness. The rock hardness shall be classified according to the system given in Table 4.4. Hardness tests shall be conducted on each different rock material or variation within the rock material encountered. The hardness designation shall be recorded on the log at the depth where the test was made.

4.5.2 Diameter. The diameter of the core shall be measured periodically to the nearest 0.001 in. (0.025 mm) and recorded at the appropriate depth.

4.5.3 Reaction with acid. Reaction with hydrochloric acid indicates the presence of calcium carbonate. Reactions shall be classified as none, weak, moderate, or strong, and recorded at the depth of the test.

4.5.4 Drilling performance measurements. Information about the drilling operation, such as penetration rate, thrust, and RPM, shall be recorded at the appropriate depths. The requirements for measuring these parameters may be found in procedure GT-A.2, "Guidelines for Rock Core Drilling."

5.0 Reporting

Core logs are generally incorporated into a more comprehensive geologic report about the site. The following are basic requirements that should be included in all reports.

5.1 Individual logs.

The individual core logs as prepared in the field shall be included, generally in an appendix. These logs may be redrafted for the sake of clarity and uniformity of presentation, but no information shall be added or deleted.

5.2 Summary logs.

Summary logs are designed to present the overall stratigraphic column in a concise way. Generally, summary logs include depth, lithic symbols, petrologic and structural descriptions, and histograms of core recovery and RQD. Figure 5.1 is an example of a summary log. The format may be expanded to include other information as necessary.

Table 4.3

Spacing of Rock Structures

(after ASCE, 1972)

Spacing	Joints	Bedding and Foliation
Less than 2 in. (<51 mm)	Very close	Very thin
2 in. to 1 ft (51 mm to 30 cm)	Close	Thin
1 ft to 3 ft (30 cm to 0.91 m)	Moderately close	Medium
3 ft to 10 ft (0.91 m to 3.1 m)	Wide	Thick
More than 10 ft (>3.1 m)	Very wide	Very thick

Table 4.4

Hardness Classification for Engineering Description of Rock (after ASCE, 1972)

Designation	Description
VH	Very Hard - Cannot be scratched with knife or sharp pick. Breaking of hand specimens requires several hard blows of geologist's pick.
H	Hard - Can be scratched with knife or pick only with difficulty. Hard blow of hammer required to detach hand specimen.
MH	Moderately Hard - Can be scratched with knife or pick. Gouges or grooves to 1/4 in. (6.4 mm) deep can be excavated by hard blow of point of geologist's pick. Hand specimens can be detached by moderate blow.
M	Medium - Can be grooved or gouged 1/16 in. (1.6 mm) deep by firm pressure on knife or pick point. Can be excavated in small chips to pieces about 1 in. (25 mm) maximum size by hard blows of the point of geologist's pick.
S	Soft - Can be gouged or grooved readily with knife or pick point. Can be excavated in chips to pieces several inches in size (50 to 75 mm) by moderate blows of pick point. Small, thin pieces can be broken by finger pressure.
VS	Very soft - Can be carved with knife. Can be excavated readily with point of pick. Pieces 1 in. (25 mm) or more in thickness can be broken by finger pressure. Can be scratched readily by fingernail.

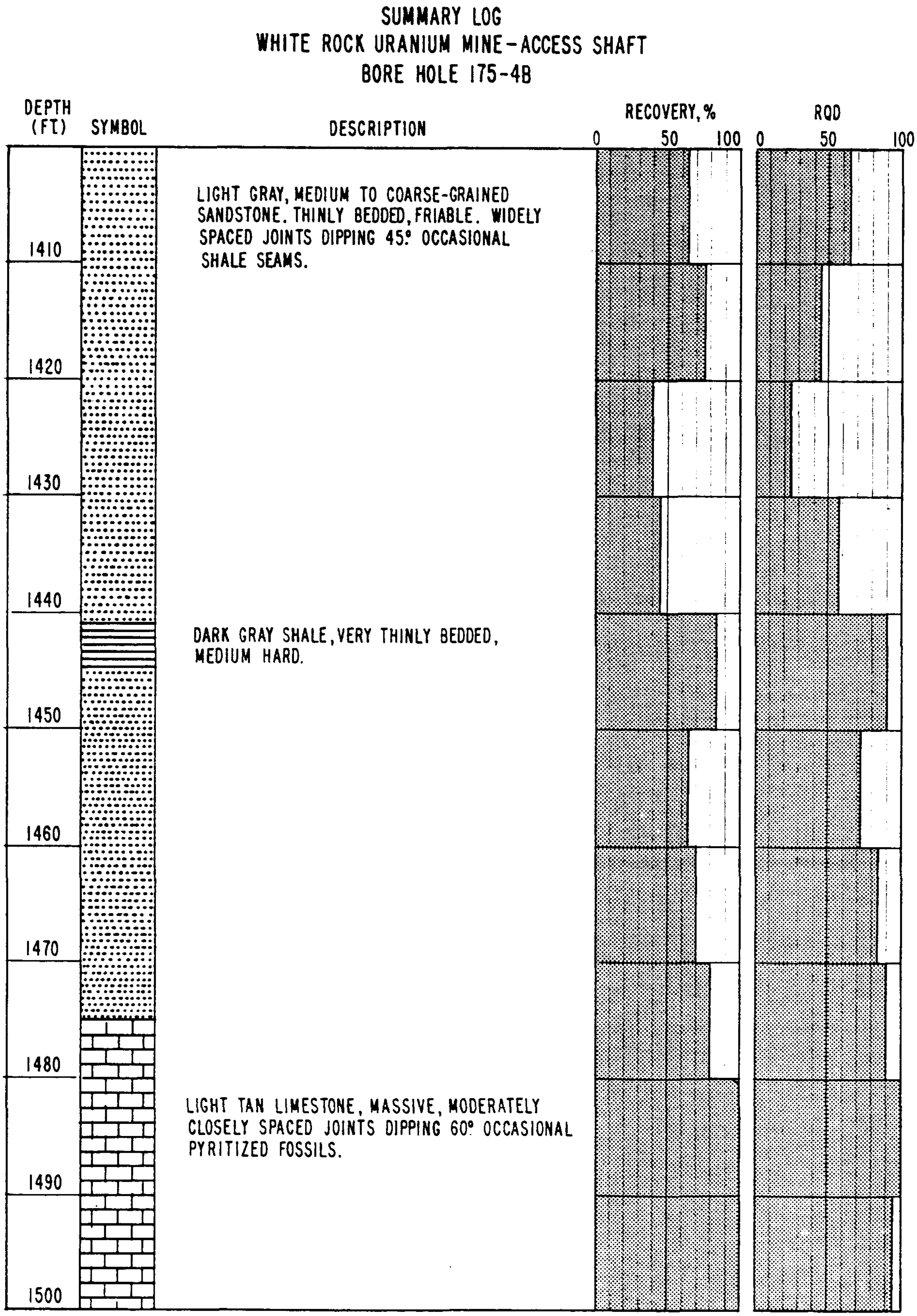


FIG. 5.1 EXAMPLE SUMMARY LOG

6.0 Quality Assurance

6.1 Personnel prequalification.

Prior to field operations, all personnel shall be prequalified as described in Section 2.1.

6.2 Field inspection.

Quality Assurance personnel shall review the logging procedure and completed logs during the field phase. Any materials not satisfactorily logged shall be relogged until they are in conformance with this procedure.

6.3 Required documentation.

Quality Assurance shall maintain completed copies of all field rock core logs.

Procedure GT-A.4

Handling and Storage of Rock Core Samples

1.0 Background

1.1 Scope.

1.1.1 Objective of this procedure. The objective of this procedure is to establish standard handling, labeling, and storage techniques that will preserve rock core samples in a usable and accessible manner. Special procedures for laboratory sample preservation are also established.

1.1.2 Limitations. This procedure discusses handling and storage of rock core from the time of recovery until its placement in permanent storage. Sampling and drilling techniques and logging procedures are discussed in procedures GT-A.2 "Guidelines for Rock Core Drilling" and GT-A.3 "Guidelines for Logging Rock Core".

1.2 General description of the procedure.

Rock core is removed from the core barrel, washed, and placed carefully in core boxes. The core is measured and labeled. Blocks are placed to indicate core loss. Samples for laboratory testing are sealed to preserve their moisture condition. Filled core boxes are placed in temporary storage, transported to permanent storage, and stored there in an accessible and organized manner.

1.3 References.

1.3.1 Geological Society of London Engineering Group, 1970, "The Logging of Rock Cores for Engineering Purposes", Q.J. Eng. Geol., 3.

1.3.2 Hvorslov, M.J., 1949, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, ASCE Committee on Sampling and Testing, Soil Mechanics and Foundation Division, Waterways Experiment Station, Vicksburg, Mississippi.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in handling the rock core, including the Technicians and Field Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Sampling program defined.

The number and types of laboratory samples required, and the criteria for their selection in the field, should be established prior to the start of the drilling program.

2.3 Shipping and storage.

Arrangements for shipping and storing the rock core should be made prior to the start of the drilling program. Shippers should be informed of the nature of rock core and the special requirements for its shipment.

3.0 Equipment

3.1 Core boxes.

Durably constructed wooden boxes with partitioned compartments and hinged lids shall be used for all recovered rock core.

3.1.1 Materials and dimensions. All boxes for a specific size core shall be stackable and of uniform size. An example core box is shown on Fig 3.1.

3.1.1.1 The core boxes shall be 3 to 5 ft (0.9 to 1.5 m) long. The storage capacity in length of core will vary depending in the core diameter; in no case, however, shall the boxes be too large to be easily handled by two persons when full. Each partitioned compartment shall be as wide and deep (with the box lid closed) as the core diameter plus 0.25 in. (6.4 mm).

3.1.1.2 The following are the minimum thicknesses for wood used in constructing the box:

top and bottom:	3/8 in. (9.5 mm)
sides:	3/4 in. (19 mm)
partitions:	1/4 in. (6.4 mm)

The wood shall be No. 2 grade or better, or exterior grade plywood. If glue is used in assembling the core box, it shall be waterproof.

3.1.1.3 The cover of the box shall be hinged, and two hook-and-eye fasteners shall be used to keep the cover closed during handling. Handles on the ends of the boxes are recommended.

3.1.2 Markings. Each box shall have the following information marked on the top cover:

Project Name

"HOLE NO. _____"

"SURFACE EL. _____"

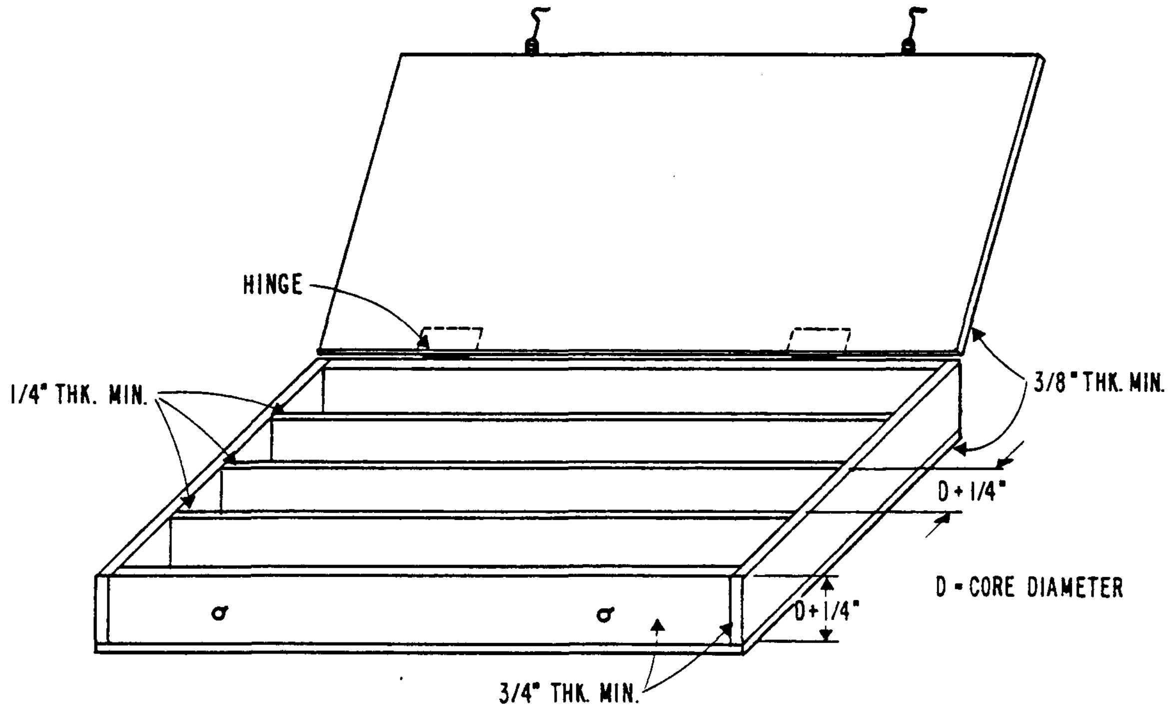
"BOX _____ OF _____"

"DEPTH: _____ TO _____"

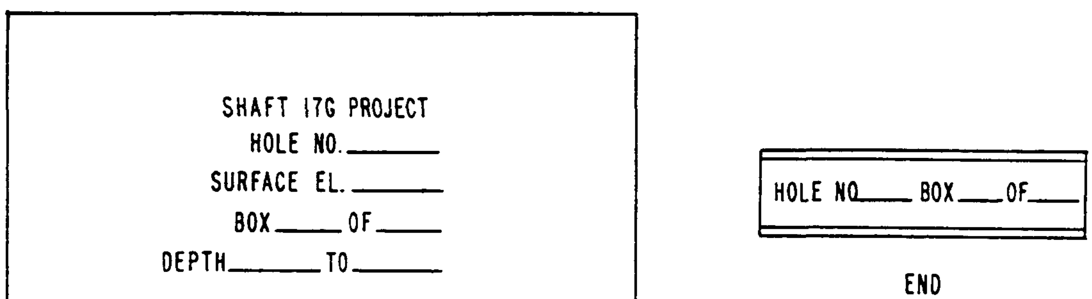
Both ends of the box shall be marked:

"HOLE NO. _____"

"BOX _____ OF _____"



A. CORE BOX CONSTRUCTION



COVER

B. CORE BOX MARKING EXAMPLE

FIG. 3.1 CORE BOX CONSTRUCTION AND MARKING

Capital letters shall be no less than 1 in. (25.4 mm) high. Black, waterproof paint shall be used. An example is shown on Figure 3.1.

3.2 Marking pens.

Pens for labeling samples and core boxes shall have a wide felt tip and dispense a heavy line of waterproof black ink.

3.3 Blocks.

Blocks are used for identifying the beginnings and ends of core runs, marking core loss, and indicating areas where samples have been removed. Blocks shall be made of wood, be at least as wide in both directions as the rock core diameter, and have at least one flat surface suitable for marking.

3.4 Laboratory preservation materials.

Samples for laboratory testing require special preservation.

3.4.1 Wrapping materials. Heavy-duty aluminum foil, heavy polyethylene plastic film, cheese cloth, nylon reinforced tape, or other similar materials may be used for wrapping.

3.4.2 Sealing materials. A microcrystalline wax shall be used to seal the samples against moisture loss. The wax shall be solid at normal temperatures but not brittle. A mixture of paraffin and at least 20% bee's wax has been found suitable.

3.4.3 Label materials. Masking tape, cardboard, heavy paper, or similar materials shall be available for labels.

3.5 Shipping containers.

Shipping containers for laboratory samples shall protect the samples from damage during transit. Lockable steel tool boxes or heavy-duty wooden crates are recommended. Suitable packing materials include styrofoam, plastic "bubble-wrap", foam rubber, excelsior, etc.

4.0 Procedure

4.1 Core box availability.

A sufficient number of boxes shall be available on the site to contain the rock core as it is recovered from the borehole.

4.2 Core recovery.

When brought to the surface, the core shall be removed from the core barrel carefully, to produce minimal additional disturbance. The core shall be placed in a temporary box or tray in correct sequence. Drilling personnel shall not perform this operation unless directly supervised by testing personnel.

4.3 Cleaning.

Drilling fluid, cuttings, and dirt shall be cleaned from the core by scrubbing with a medium stiff brush and rinsing in clean water.

A saturated brine solution shall be used for salt cores. For salt and shales that would be damaged by absorbing water, cleaning shall be done as rapidly as possible and the core surface dried immediately by wiping with a clean, dry cloth.

4.4 Boxing.

The core shall be placed in a clean core box so that the core closest to the borehole collar is in the upper left hand corner (next to the box cover) with the deeper core running left to right in sequential rows.

4.5 Labeling.

4.5.1 Run length. Blocks of wood labeled with the run number and depth accurate to within 0.1 ft (3 cm) shall be placed at the top and bottom of each run. The distance between the core blocks shall be equal to the length drilled and not the length recovered.

4.5.2 Mechanical breaks. Breaks in the core due to handling or mechanical damage during drilling shall be labeled by marking "HB" or "DB", respectively, directly on the two pieces of core adjacent to the break.

4.5.3 Loss of core. Core loss is the numerical difference between the length drilled and the length recovered in an individual core run. If the location of the core loss in the run is known, a wooden block shall be placed in that location marked with the letters "CL" and the upper and lower depths of the lost interval. If the location of the core loss is unknown, it is assumed to be distributed over the length of the run, and a block shall be placed at the end of the run (before the run length block) marked with the letters "CL-DOR" and the length of core loss.

Note: Core loss from one run is commonly recovered in the following run due to retrieval of a "stump" left in the borehole when the core barrel is pulled. For this reason, final labeling of core loss may only be completed when the following run is recovered.

4.6 Core logging.

Field logging of the core is generally done after the core is boxed and labeled. Detailed procedures are contained in GT-A.3 "Techniques for Logging Rock Core".

4.7 Photography.

It is recommended that high-quality color photographs be taken of each completed box of core. This shall be done after cleaning and labeling, but before any laboratory samples are removed. Only one box shall be photographed at a time in order to preserve as much detail as possible. Each photograph should include a standard color strip. Close-up photos of typical or unusual features are also recommended.

4.8 Laboratory samples.

The field personnel shall be familiar with the dimensional and material requirements of laboratory samples.

4.8.1 Time of preservation. Laboratory samples shall be preserved as soon as possible after their recovery. This is particularly important for rock susceptible to moisture changes.

4.8.2 Sample labeling. The following shall be legibly marked directly on the laboratory sample with a waterproof marker:

4.8.2.1 Borehole number.

4.8.2.2 Sample number.

4.8.2.3 Depth of upper and lower ends of sample. If the ends of the sample are not perpendicular to the long axis of the core, the exact location of the labeled depth shall be indicated by a line or arrow.

4.8.2.4 Orientation (if available).

4.8.3 Sealing. Laboratory samples shall be sealed to preserve their natural moisture content. Core shall first be wrapped in foil or plastic film, taking care to remove any air trapped between the core and its wrapping. The sample shall be dipped in wax, or the wax shall be painted on, until there is a complete and uniform coating at least 0.125 in. (3.18 mm) thick. The wax shall be at a temperature a few degrees above the congealing point. Cheese cloth or nylon tape may be incorporated between layers of wax to provide additional strength. If the wax is sufficiently transparent, a label containing the same information as in Section 4.8.2 shall be placed under the last few layers of wax; otherwise, this label shall be taped to the outside of the waxed sample.

4.8.4 Replacement. Laboratory samples shall be represented in the core box by a block of wood of equal length placed in the same location that the sample occupied. The elevation at the top and bottom of the sample, the sample number, and the date it was removed shall be printed legibly in indelible ink in large letters on a smooth surface of the block. If the sample is removed because it includes an unusual structural feature, such as a fault or filled joint, a short descriptive name of the feature shall be included on the block, such as "Fault Gouge" or "2-in.-thick Joint".

4.8.5 Packing and shipping. Laboratory samples shall be packed with sufficient cushioning material to separate the samples and prevent damage during shipping. If the boxes are shipped via commercial carrier, they shall be labeled "Fragile". A laboratory transmittal form similar to Form GT-A.4-1 shall accompany the shipment.

4.9 Completed boxes.

Completed boxes shall be labeled on the outside with the required information using a waterproof black marker. Core from two boreholes shall not be stored in the same box. Cores of different sizes shall not be stored in the same box. The inside of a completed box is shown on Figure 4.1, as an example.

4.10 Temporary storage.

Core boxes shall not be left unsecured on the site. The core shall be protected from water and vandalism as required. Rock core samples shall not be allowed to freeze.

4.11 Shipping.

4.11.1 Inventory. An inventory control sheet shall be prepared for each box of core as shown on Form GT-A.4-2. This form shall be verified and signed by the Field Supervisor prior to shipment. Copies of the form shall accompany the shipment. The core boxes shall be examined upon arrival, and Form GT-A.4-2 shall be signed only if the pre- and postshipment inventories are in agreement.

4.11.2 Box closure. For long distance transport or shipping by commercial carriers, the core box covers shall be securely closed using nails, screws or banding.

4.12 Permanent storage.

Permanent storage of rock core shall satisfy the same requirements as temporary storage. In addition, the boxes shall be stored in an organized fashion so that they may be easily located upon request and be retrieved with a minimum of time and effort.

5.0 Quality Assurance

5.1 Personnel prequalification.

Prior to working in the field, all personnel shall be prequalified as described in Section 2.1.

5.2 Handling and labeling.

Quality Assurance personnel shall inspect and verify that the core is being handled and labeled in conformance with the requirements of the procedure.

5.3 Documentation.

Quality Assurance shall verify that inventory and shipping documents are correctly and completely filled out. Quality Assurance shall maintain copies of all forms GT-A.4-1, GT-A.4-2, and any other shipping and storage documents required for complete sample traceability.

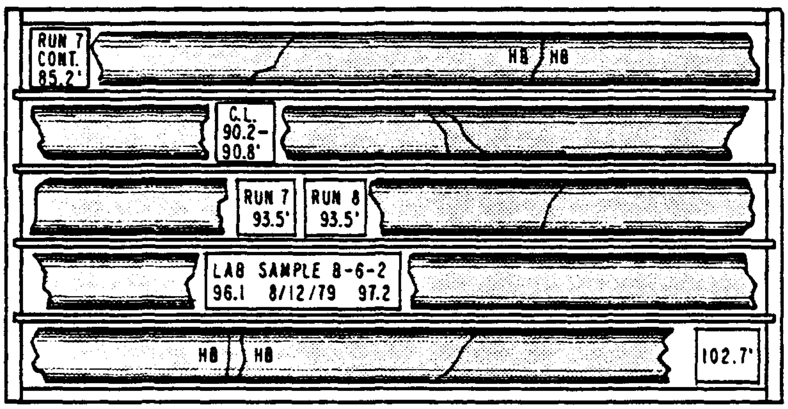


FIG. 4.1 EXAMPLE OF COMPLETED CORE BOX

Laboratory Sample Transmittal Sheet

Form GT-A.4-1

Project ____________________ Feature ____________________

Inventory:

Hole No.	Sample No.	Depth	Diameter

Inventoried by ____________________ Date ____________

Field Supervisor ____________________ Date ____________

Shipping: Shipper ____________________ Pick-up Point ________

Address ____________________ Destination ________

Phone ____________________

Invoice No. ________________

Received by ________________ Date ____________

Receiving: Received by ________________ Date ____________

Inventory verification ____________________

Date ____________

Core Box Inventory Control Sheet

Form GT-A.4-2

Project ______________________ Borehole No. ____________

Feature ______________________ Location ______________

Surface Elevation ________

Inventory:

Box No. ______________________ Total Number of Boxes _____

Depth ___________ to __________

Run Numbers ___________________

Core Loss Intervals ___________________________________

Laboratory Sample Numbers and Depths __________________________

____

Inventoried by ____________________ Date _____________

Field Supervisor ____________________ Date _____________

Shipping: Shipper ____________________ Pick-up Point ___________

Address ____________________ Destination ________

Phone ____________________

Invoice No. ________________

Received by ________________ Date _____________

Receiving: Received by ________________ Date _____________

Inventory Verification ______________ Date _____________

Procedure GT-B.1

Guidelines for Electric Logging of Boreholes

1.0 General

1.1 Scope.

1.1.1 Objective of this guideline. The objective of this guideline is to present an overview of various electric logging methods and to provide a degree of standardization of the method. Electric logging is generally performed by specialist organizations. Each organization may use slightly different techniques or equipment. Some types of probes and data reduction algorithms are proprietary. The adequacy of particular techniques used by the various specialist organizations will require review on a project-by-project basis.

1.1.2 Application of the method. Electric logging measures the electrical resistance of rock formations. While electric logs may be used in some cases to estimate the porosity of rock formations, the primary application for rock mechanics is as a correlation technique between boreholes to evaluate the structure at the site.

1.2 General description of electric logging.

A probe is lowered to the bottom of a borehole. It is raised at a uniform rate, and the resistance and spontaneous potential are recorded continously. A profile of electrical properties of the geologic section is obtained.

1.3 Theoretical background.

1.3.1 Spontaneous potential. Spontaneous potential is determined by measuring the voltage between the rock formation in the borehole and the ground surface. A schematic is shown in Figure 1.1. Alternatively, both electrodes may be downhole, a short distance apart. This second method, however, primarily detects the interfaces between formations, and generally provides less information than the first method.

The spontaneous electrical potential in a rock mass is caused by differences in electrical potential occurring opposite boundaries between different formations down the borehole. These potentials are of electrochemical origin.

The electrochemical potential, (spontaneous potential), E_c, is described in general terms by:

$$E_c = C \log_{10} \left(\frac{\rho df}{\rho w} \right) \quad (1)$$

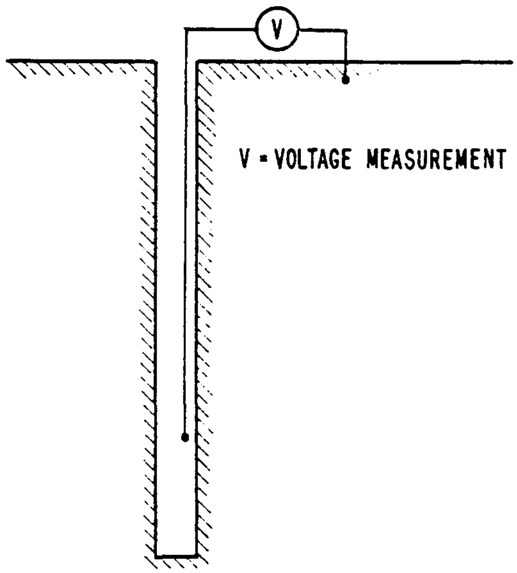


FIG. 1.1 SPONTANEOUS POTENTIAL SCHEMATIC

where:

C = a constant at a given temperature in a given geochemistry

ρdf = resistivity of drilling fluid that penetrates the formation

ρw = resistivity of water in the formation.

It may be seen from Equation 1 that spontaneous potential requires a contrast in resistivity between the fluid filling the borehole and the naturally occurring fluid in the formation.

In sedimentary formations, the SP curve usually shows two characteristics. It will be a more or less straight line opposite impermeable shales. It will show peaks to the left opposite permeable strata. The shapes and amplitudes of the peaks may be different according to the type of formation, as illustrated by Figure 1.2. However, there is no definite correlation between the amplitude of lines and the degree of permeability of the rocks.

In metamorphic igneous sequences, a consistent baseline value may not be established. The spontaneous potential characteristics of various formations must be determined by correlating the potential curve with the core log in at least one borehole (this is good practice in sedimentary sequences also). It may be difficult to separate the effects of change of rock formation from change of groundwater chemistry within a single formation.

1.3.2 Resistivity. The electrical resistivity of rock formations is governed by the presence and chemistry of interstitial water and by the size and continuity of the interstices, except in formations that contain electrically conductive minerals.

1.3.2.1 Unfocused resistivity. Single point resistivity measurements are made with the electrode configuration shown in Figure 1.3a. If the current is maintained at a constant value, the voltage is proportional to the resistance of the materials between the electrodes. The single point method does not give accurate values of formation resistivity, but does provide relative apparent resistivities.

A typical single point curve is shown in Figure 1.3b. The apparent thickness of the beds is considerably different than the actual thickness, because the single point method is strongly influenced by the electrical properties of the formations and drilling fluid in the vicinity of the downhole electrode. The zone of influence is about 10 times the electrode diameter.

The primary use of single point resistance is gross correlation of stratigraphic units.

The normal electrode configuration is shown on Figure 1.4a. The measured resistance, ρ_m, is approximated by:

$$\rho_m = \frac{4\pi \Delta V}{I} S \qquad (1)$$

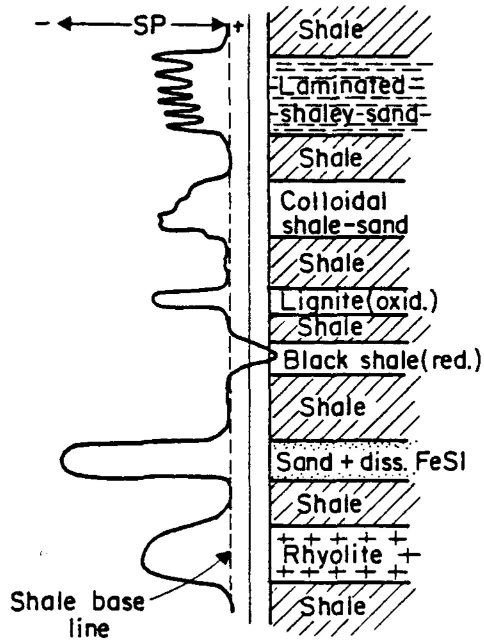


FIG. 1.2 SPONTANEOUS POTENTIAL LOG IN A SEDIMENTARY SEQUENCE (AFTER PIRSON, 1963)

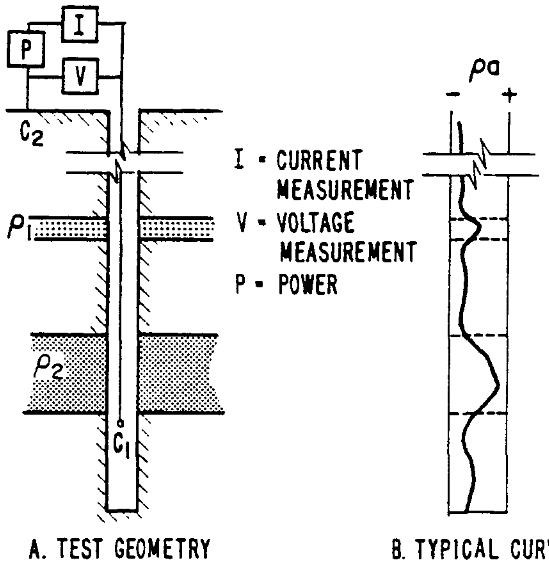


FIG. 1.3 SINGLE POINT METHOD FOR RESISTIVITY MEASUREMENTS (AFTER TELFORD, ET AL, 1976)

where:

ΔV = measured voltage

I = current

S = spacing between electrodes as shown on Figure 1.4a.

The measured resistivity is affected by the resistivity of the beds adjacent to electrodes C_1 and P_1, the resistivity of the drilling fluid, and the penetration of the drilling fluid into the rock. The depth of investigation of the resistivity measurement is approximately twice the electrode spacing; thus, shorter electrode spacings define thinner beds, but are more sensitive to effects of the drill hole, while longer spacing gives more accurate resistivity values. Two standard spacings are used: short-normal at 16 in. (41 cm) and long-normal at 64 in. (1.62 m). The definition and sharpness of both types of normal logs decreases with increasing borehole diameter and decreasing drill fluid resistivity.

A typical normal resistivity profile is shown on Figure 1.4b. The curve is symmetrical with the beds, and the interfaces are distinct, but not necessarily at their actual locations. High resistivity beds appear thinner and low resistivity beds appear thicker than they actually are.

The lateral electrode configuration is shown on Figure 1.5a. The measured resistance, ρ_m, is given by:

$$\rho_m = \frac{4\pi\Delta V}{I}\left[\frac{S_1 S_2}{(S_1 - S_2)}\right] \qquad (2)$$

where:

S_1 = the distance between P_1 and C_1

S_2 = the distance between P_2 and C_1

S_1 and S_2 are generally equal to 20 ft (6.1 m) and 17 ft 4 in. (5.29 m), respectively.

The curves produced by the lateral system are asymmetric, as shown on Figure 1.5b. The depth of investigation is approximately equal to the average of S_1 and S_2. This method is affected by the same factors as the normal method. Its primary importance is for accurately measuring the electrical resistivity of thick beds, and therefore its use in site characterization is limited.

<u>1.3.2.2 Focused resistivity</u>. These devices focus the electrical current into a narrow zone. The effects of drilling fluid and adjacent formations are significantly less than in normal or lateral logging. Focused resistivity allows delineation of the beds and can be used with low resistivity drilling fluids, such as brines.

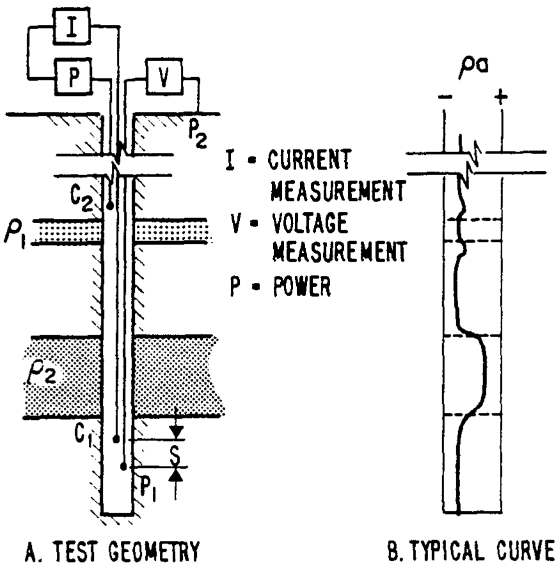


FIG. 1.4 NORMAL ELECTRODE CONFIGURATION FOR RESISTIVITY MEASUREMENTS (AFTER TELFORD, ET AL, 1976).

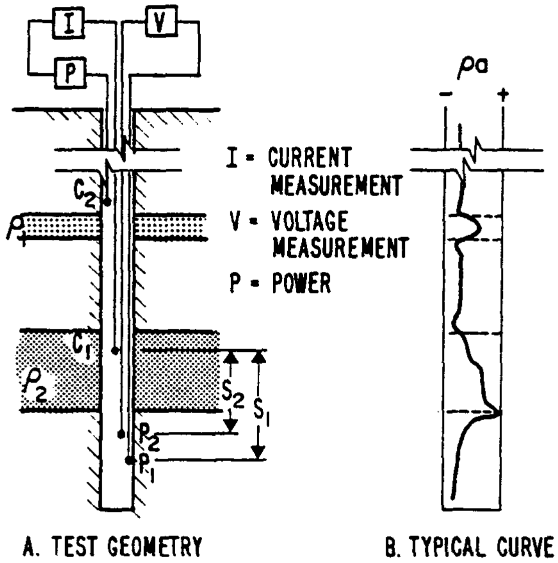


FIG. 1.5 LATERAL ELECTRODE CONFIGURATION FOR RESISTIVITY MEASUREMENTS (AFTER TELFORD, ET AL, 1976).

The Laterolog system is basically similar to the normal method, except guard electrodes above and below P_1 and C_1 are maintained at the same potential as P_1 by a current control system. This causes the current to flow laterally into the formation for a distance of about three times the length of the guard electrode.

Induction logging requires no electrodes or current flow from the probe to the rock formation. Instead, a transmitter coil is activated by a constant alternating current from an oscillator. The alternating magnetic field created by the transmitter coil on the probe induces eddy currents in the rock formations. These eddy currents have their own magnetic fields which induce a voltage in the receiver coil. Accordingly, the voltage induced in the receiver coil and recorded by a galvanometer on the surface is proportional to the conductivity (rather than the resistivity) of the surrounding rock.

The induction log has a penetration of about 1.5 times the spacing of the transmitter and receiver. It may be used in dry holes where other electrical methods are not suitable.

1.4 Data interpretation.

The interpretation of electrical borehole logs requires considerable experience and judgment. The interpretation generally will be more reliable when the results of logging with several different types of probes are considered together, and when redundant data have been obtained. The first step in the interpretation is to make any necessary corrections to the probe readings for borehole diameter and for drill fluid characteristics; this is done with correction charts that are specific to each type of probe. The various logs from several boreholes may then be compared and correlated.

1.5 References.

1.5.1 Dresser Atlas, 1971, Log Review 1: Review of Well Logging Principles, Dresser Atlas, Inc., Houston, Texas.

1.5.2 ISRM Commission in Standardization of Laboratory and Field Testing, 1981, "Suggested Methods for Geophysical Logging of Boreholes", Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 18, No. 1.

1.5.3 Moran, J.H. and Kunz, K.S., 1962, "Basic Theory of Induction Logging", Geophysics, 27.

1.5.4 Pirson, S.J., 1963, Handbook of Well Log Analysis for Oil and Gas Formation Evaluation, Prentice-Hall, Englewood Cliffs, N.J.

1.5.5 Schlumberger, 1972a, Log Interpretation, Vol. I. Principles, Schlumberger, Inc., New York.

1.5.6 Schlumberger, 1972b, Log Interpretation Charts, Schlumberger, Inc., New York.

1.5.7 Schlumberger, 1974, Log Interpretation, Vol. II, Applications, Schlumberger, Inc., New York.

1.5.8 Sheriff, R.E., 1970, "Glossary of Terms Used in Well Logging", Geophysics, 35.

1.5.9 Telford, W.M., Geldast, L.P., Sheriff, R.E., and Keys, D.A., 1976, Applied Geophysics, Cambridge University Press, Cambridge.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program. If the logging is done by a specialty organization, the organization shall be prequalified as determined by Quality Assurance procedures for evaluating subcontractors.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the manufacture's specifications shall be verified. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Test program established.

2.3.1. Number of boreholes. The number of boreholes will depend on the size of the project and complexity of the geology, if known. The program should be flexible enough to allow for additional holes in complex structures, as they are identified.

2.3.2 Types of logs. The type of logging device will depend on the composition and thickness of the formations, and the requirements of the investigation. Both resistivity and spontaneous potential logs should be run in each borehole to provide redundant data.

2.4 Boreholes.

2.4.1 Calibration hole. At least one borehole should be cored continuously and the rock core logged. This will allow correlation of rock formations and electrical properties. If one borehole cannot penetrate all the materials at the site, coring of several boreholes may be required.

2.4.2 Drilling methods. Boreholes other than calibration holes may be rotary drilled with non-coring bits, or percussion drilled.

2.4.3 Uncased boreholes. Electric logs require that the boreholes be uncased over the sections that will be tested.

2.4.4 Diameter. All boreholes in the program should be the same diameter so that the effects of diameter are consistent on all electric logs.

2.5 Drill fluid.

The resistance of the fluid in the boreholes may have to be "conditioned" for a particular type of probe. In general, water based drilling mud is sufficiently conductive for electric logging. The fluid should be circulated in the borehole immediately prior to testing to provide uniformity. The same fluid should be used in all boreholes.

2.6 Electrodes.

2.6.1 Surface. The surface electrode should be well grounded. This is generally accomplished by placing it in the mud pit or in a hole filled with drilling fluid.

2.6.2 Composition. All electrodes must be made of stable metals, such as oxidized lead, to avoid bimetallic corrosion.

3.0 Procedures

3.1 Logging

Logging should be conducted from the bottom of the hole toward the top. The rate of ascent should be constant, and is generally between 10 and 50 ft per minute (3 to 15.25 m per minute).

3.2 Repeat logging.

In order to verify the data, a 30- to 100-ft (9.2 to 30.5 m) section should be logged a second time, later in the program.

3.3 Documentation.

The data shown on Form GT-B.1-1 shall be recorded for each logging run.

4.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included. Since some well logging equipment and techniques are proprietary, complete documentation of these aspects may not be possible.

4.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the logging program.

4.1.1 Number and characteristics of boreholes. The borehole locations, lengths, diameters, inclinations, and directions shall be presented. The characteristics of the drilling fluid and location of any casing shall also be listed. A tabular presentation is recommended.

4.1.2 Rationale for selection of logging method. The reasons for selecting the types of logs used shall be discussed.

4.1.3 Limitations of the logging program. The areas of interest which are not covered by the logging program and the limitations of the data within the areas of application shall be discussed in general terms.

4.2 Logging method.

4.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for logging shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

4.2.2 Procedure. The procedure actually used for logging shall be listed in detailed steps.

4.2.3 Corrections. Any correction factors applied to the measured values shall be fully explained.

4.3 Results.

4.3.1 Correlation of rock types and electrical properties. The correlation logs obtained in the cored boreholes shall be presented, and the relationships between rock type and electrical properties shall be discussed.

4.3.2 Correlation between boreholes. The stratigraphy and structure between boreholes shall be presented in a graphic form. Alternate interpretations shall be discussed.

4.4 Appended data.

4.4.1 Logs. Copies of all electric logs shall be included in an appendix.

4.4.2 Data forms. Copies of data Form GT-B.1-1 for each log shall be included in an appendix.

5.0 Quality Assurance

The following items are the minimum requirements to ensure that the logging results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

5.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

5.2 Test Inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-B.1-1 shall be reviewed, and signed off only if correct.

5.3 Required documentation.

5.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

5.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-B.1-1.

5.3.3 Test sign-off. Quality Assurance shall maintain signed-off copies of Form GT-B.1-1.

5.3.4 Logs. Quality Assurance shall maintain copies of all electric logs.

Electric Logging of Boreholes

Documentation Sheet - Form GT-B.1-1

Project ______________________ Log No. ______________

Feature ______________________ Type of Log ______________

Borehole No. ______________________ Date ______________

Location ______________________ Logged by ______________

Orientation ______________________ Company ______________

Equipment Description	Serial No.	Date of Next Calibration

Depth of borehole ______________________ Test Fluid ______________

Diameter ______________________ Resistivity ______________

Interval Logged ______________________

Rate of Logging ______________________

Remarks:

Field Supervisor ______________________ Date ______________

Quality Assurance ______________________ Date ______________

Project Engineer ______________________ Date ______________

Procedure GT-B.2

Guidelines for Acoustic Logging of Boreholes

1.0 General

1.1 Scope.

1.1.1 Objective of this guideline. The objective of this guideline is to present an overview of the acoustic logging method and to provide a degree of standardization of the method. Acoustic logging is often performed by specialist organizations, each of which may use slightly different techniques or equipment. Some types of probes and data reduction algorithms are proprietary. The adequacy of particular techniques used by specialist organizations will require review on a project by project basis.

1.1.2 Application of the method. Acoustic logging measures the travel time of ultrasonic waves through the rock adjacent to the borehole. The primary application to rock mechanics is as a correlation technique between boreholes to evaluate the structure at the site. In hydrologic studies, acoustic logging is an important tool for measuring the in situ porosity of rock, because porosity is one of the primary factors determining wave velocity. If both compressional and shear wave velocities are measured, the dynamic elastic constants of the rock may be evaluated.

1.1.3 Limitations. Results from conventional acoustic logging are frequently unreliable in dry boreholes.

1.2 Description of the method.

A probe is lowered to the bottom of a borehole. It is raised at a uniform rate. Periodically, a sonic pulse is generated, and the travel time of the pulse through the formation is measured. A profile of the travel times through a geologic section is obtained; an example profile is shown in Figure 1.1.

1.3 Theoretical Background.

An acoustic wave which is generated by a transmitter in the probe travels to the borehole wall, where it is refracted into the rock formation, travels through the rock, and is refracted back into the receiver. The wave propagation is shown on Figure 1.2.

It may be seen that the travel time of an acoustic wave is influenced by material properties and geometry of the boreholes, fluid, and probe. Irregularities in the borehole diameter, variable centering of the probe in the hole, and mud build-up on the borehole wall are common problems. The effects of these factors are minimized by design of the probe. Two or more receivers are sometimes used to eliminate effects opposite the transmitters. This configuration is shown on Figure 1.3a. The travel time is the difference in arrival times at the two receivers. Receiver spacing is generally 1 to 3 ft (0.3 to 0.9 m) for rock mechanics

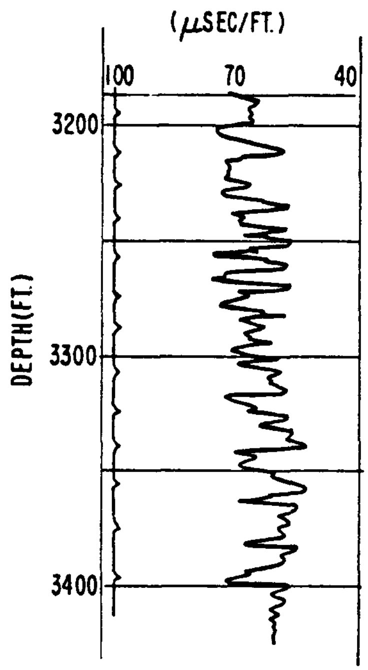


FIG. 1.1 EXAMPLE ACOUSTIC LOG
(AFTER TELFORD, ET AL, 1976)

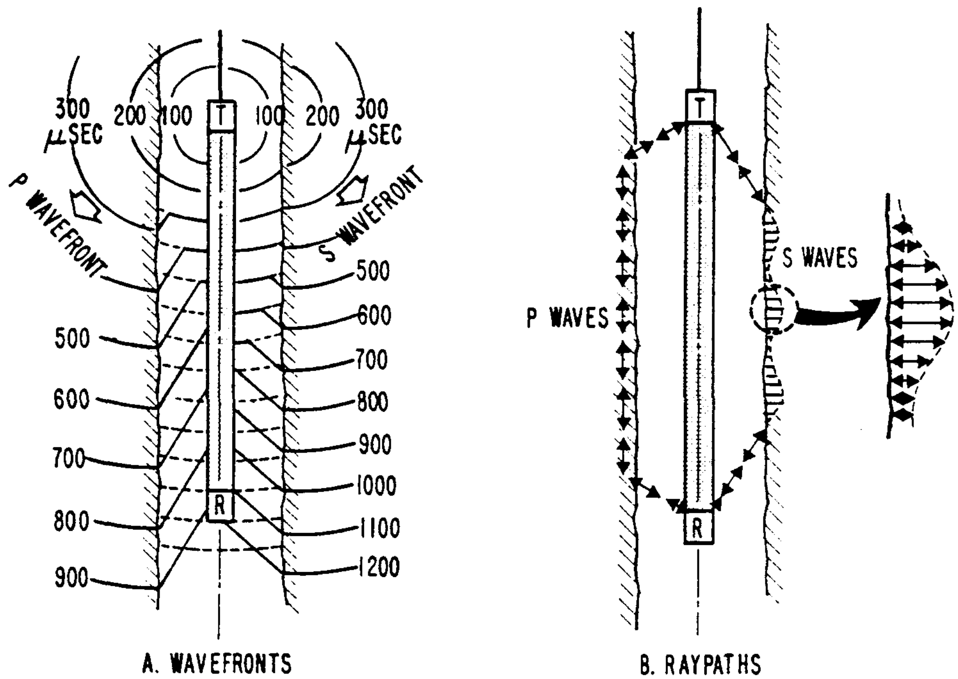
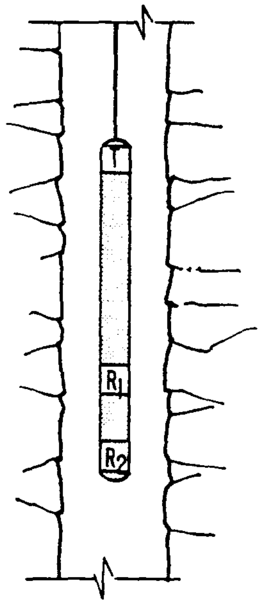
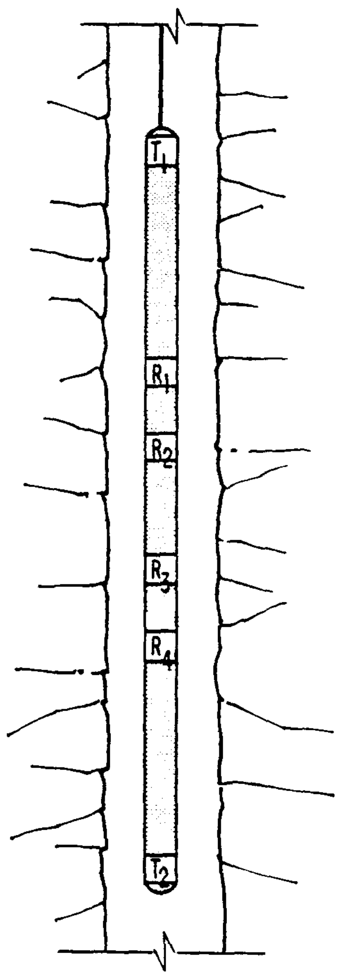


FIG. 1.2 WAVE PROPAGATION IN ACOUSTIC LOGGING
(AFTER GEYER AND MYUNG, 1971)



A. TWO RECEIVER CONFIGURATION



B. BOREHOLE COMPENSATED
SONIC PROBE

FIG. 1.3 SONIC PROBE CONFIGURATION

work. To eliminate effects opposite the receivers, the borehole compensated sonic log is used, as shown on Figure 1.3b. The transmitters are pulsed alternately, and the travel time of the wave generated by T_1 is measured by the difference in arrival times at R_2 and R_4, and the travel time of the wave generated by T_2 is measured by the difference in arrival times at R_3 and R_1. The velocity is calculated from the average travel time.

1.4 References.

1.4.1 Geyer, R.L. and Myung, J.I., 1971, "The 3-D Velocity Log: A Tool for In Situ Determination of the Elastic Moduli of Rocks", Proc. 12th Sym. Rock Mech., AIME, New York.

1.4.2 ISRM Commission on Standardization of Laboratory and Field Tests, 1981, "Suggested Methods for Geophysical Logging of Boreholes," Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 18, No. 1.

1.4.3 Schlumberger, 1972a, Log Interpretation: Vol. I, Principles, Schlumberger, Inc., New York.

1.4.4 Schlumberger, 1972b, Log Interpretation Charts, Schlumberger, Inc., New York.

1.4.5 Schlumberger, 1974, Log Interpretation: Vol. II, Applications, Schlumberger, Inc., New York.

1.4.6 Society of Professional Well Log Analysts, 1978, Acoustic Logging: SPWLA Reprint Volume, SPWLA, Houston, Texas.

1.4.7 Telford, W.M., Geldart, L.P. Sheriff, R.E., and Keys, D.A., 1976, Applied Geophysics, Cambridge University Press, Cambridge.

1.4.8 Tixier, M.P., Loveless, G.W., and Anderson, R.A., 1975, Estimation of Formation Strength from the Mechanical Properties Log", J.Pet. Tech., 27.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program. If the logging is done by a specialist organization, the organization shall be prequalified as determined by Quality Assurance procedures for evaluating subcontractors.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the manufacturer's specifications shall be verified. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to Standard Quality Assurance procedures.

2.3 Test program established.

The number of boreholes will depend on the size of the project and complexity of the geology, if known. Sufficient flexibility should be allowed for additional borings in complex structures as they are identified.

2.4 Boreholes.

2.4.1 Calibration hole. At least one borehole should be cored continuously and the rock core logged. This will allow correlation of rock formations and acoustic properties. If one borehole cannot penetrate all the materials at the site, coring of several boreholes may be required.

2.4.2 Drilling methods. Boreholes other than calibration holes may be percussion drilled or rotary drilled with non-coring bits.

2.4.3 Uncased boreholes. Acoustic logs require that the boreholes be uncased over the sections that will be tested.

2.4.4 Borehole diameter. All boreholes in the program should be the same diameter if possible, so that the effects of diameter are consistent on all acoustic logs.

2.5 Drill fluid.

The same drill fluid should be used in all boreholes if possible.

3.0 Procedures

3.1 Logging.

Logging should be conducted from the bottom of the hole toward the top. The rate of ascent should be constant, and is generally between 10 and 20 ft per minute (3 to 6.1 m per minute).

3.2 Documentation.

The data shown on Form GT-B.2-1 shall be recorded for each logging run.

4.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

Since some well logging equipment and techniques by specialist groups are proprietary, complete documentation of these aspects may not be possible.

4.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the logging program.

4.1.1 Number and characteristics of boreholes. The borehole locations, lengths, diameters, inclinations and direction, shall be presented. The characteristics of the drilling fluid and location of any casing shall also be listed. A tabular presentation is recommended.

4.1.2 Rationale for borehole locations. The reasons for selecting the borehole locations shall be discussed.

4.1.3 Limitations of the logging program. The areas of interest which are not covered by the logging program and the limitations of the data within the areas of application shall be discussed in general terms.

4.2 Logging method.

4.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for logging shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

4.2.2 Procedure. The procedure actually used for logging shall be listed in detailed steps.

4.2.3 Corrections. Any correction factors applied to the measured values shall be fully explained.

4.3 Results.

4.3.1 Correlation of rock types and acoustic properties. The correlation logs obtained in the cored boreholes shall be presented, and the relationships between rock type and acoustic velocities discussed.

4.3.2 Correlation between boreholes. The stratigraphy and structure between boreholes shall be presented in a graphic form. Alternate interpretations shall be discussed.

4.4 Appended data.

4.4.1 Logs. Copies of all acoustic logs shall be included in an appendix.

4.4.2 Data forms. Copies of data Form GT-B.2-1 for each log shall be included in an appendix.

5.0 Quality Assurance

The following items are the minimum requirements to ensure that the logging results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

5.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

5.2 Test Inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-B.2-1 shall be reviewed and signed off only if correct.

5.3 Required documentation.

5.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

5.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-B.2-1.

5.3.3 Test sign-off. Quality Assurance shall maintain signed-off copies of Form GT-B.2-1.

5.3.4 Logs. Quality Assurance shall maintain copies of all acoustic logs.

Acoustic Logging of Boreholes

Documentation Sheet - Form GT-B.2-1

Project ______________________ Log No. ______________

Feature ______________________ Date ______________

Borehole No. ______________________ Logged by ______________

Location ______________________ Company ______________

Orientation ______________________________________

Equipment Description	Serial No.	Date of Next Calibration

Depth of borehole ______________ Test Fluid ______________

Diameter ______________ Interval Logged ______________

Rate of Logging ______________

Remarks:

Field Supervisor ______________________ Date ______________

Quality Assurance ______________________ Date ______________

Project Engineer ______________________ Date ______________

Procedure GT-C.1

In Situ Stress Determination by Overcoring the USBM Borehole Deformation Gage

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The primary objective of this test is to determine the existing stresses in a rock mass. Either undisturbed stresses or the stresses as influenced by an excavation may be determined. This procedure is written assuming testing will be done from an underground adit; however, the same principles may be applied to testing in a rock outcrop at the surface.

1.1.2 Limitations.

1.1.2.1 This test is generally performed at depths within 50 ft (15.25 m) of the working face because of drilling difficulties at greater depths. Some deeper testing has been done, but should be considered developmental.

1.1.2.2. This test is difficult in rock with fracture spacings of less than 8 in. (20 cm). A large number of tests may be required in order to obtain adequate data.

1.2 General description of the test.

The overcore test measures the diametral deformation of a small-diameter borehole as it is removed from the surrounding stress field by coaxially coring a larger diameter hole. Deformation is measured across three diameters of the small hole, spaced 60° apart, using a deformation gage developed by the U.S. Bureau of Mines (USBM Gage). With knowledge of the rock deformation moduli, the measured borehole deformation can be related to the change in stress. This change in stress is assumed to be numerically equal, although opposite in sense, to the stresses existing in the parent rock mass. Deformation measurements from three non-parallel boreholes, together with rock deformation moduli, allow calculation of the complete three-dimensional state of stress in the rock mass.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deformation - change in dimension of the borehole due to change in stress.

1.3.1.2 In situ stress - the stress levels existing in the rock mass before excavation.

1.3.1.3 Stress - force per unit area.

1.3.2 Equations.

1.3.2.1 Secondary principal stresses. The secondary principal stresses are the two-dimensional principal stresses in the plane perpendicular to the axis of the overcoring borehole. Since the overcoring technique with the USBM Gage does not measure rock deformation along the axis of the borehole, an exact calculation of the secondary principal stresses is not possible unless some additional data is obtained regarding either axial deformation or axial stress. If the simplifying assumption that zero stress exists along the axis of the borehole is made, then the secondary stresses can be calculated using a plane stress solution. This solution, although not exact, results in an error of less than about 10%.

For three diametral deformations measured 60° apart in a borehole, the secondary stresses are calculated using the following equations for a 60° deformation rosette:

$$P = \frac{E}{6d}\left\{(U_1+U_2+U_3) + \frac{\sqrt{2}}{2}\left[(U_1-U_3)^2 + (U_3-U_2)^2 + (U_2-U_1)^2\right]^{1/2}\right\} \quad (1)$$

$$Q = \frac{E}{6d}\left\{(U_1+U_2+U_3) - \frac{\sqrt{2}}{2}\left[(U_1-U_3)^2 + (U_3-U_2)^2 + (U_2-U_1)^2\right]^{1/2}\right\} \quad (2)$$

$$\theta_p = \frac{1}{2}\tan^{-1}\frac{\sqrt{3}(U_3-U_2)}{2U_1-U_3-U_2} \quad (3)$$

where:

- P = major secondary principal stress
- Q = minor secondary principal stress perpendicular to P
- E = modulus of deformation of the rock
- d = borehole diameter
- U_i = diametral deformation across diameter 1, 2, or 3
- θ_p = orientation of major secondary principal stress, measured counterclockwise from U_1 to P. Also, if $U_2 + U_3 > 2U_1$, then $\theta_p = \theta_p + 90°$, and if $U_3 < U_2$ and $U_2 + U_3 < 2U_1$, then $\theta_p = \theta_p + 180°$.

Figure 1.1 illustrates the relationship between the orientations of the deformations, U_i, and the orientation of the major secondary stress, P. The minor secondary stress, Q, acts at 90° to P.

1.3.2.2 Three-dimensional principal stresses. At any point in the rock mass, the three-dimensional state of stress is fully defined by a total of six independent stress components (stress tensor). These are the three orthogonal components of normal stress, σ_x, σ_y, and σ_z, and the three components of shear stress, τ_{xy}, τ_{yz}, and τ_{zx}. If a local (1,2,3) coordinate system is defined at an overcore test location such that σ_2 acts along the axis of the borehole, then components τ_{12} and τ_{23} act parallel to the axis of the borehole and, thus, have negligible effect on the diametral

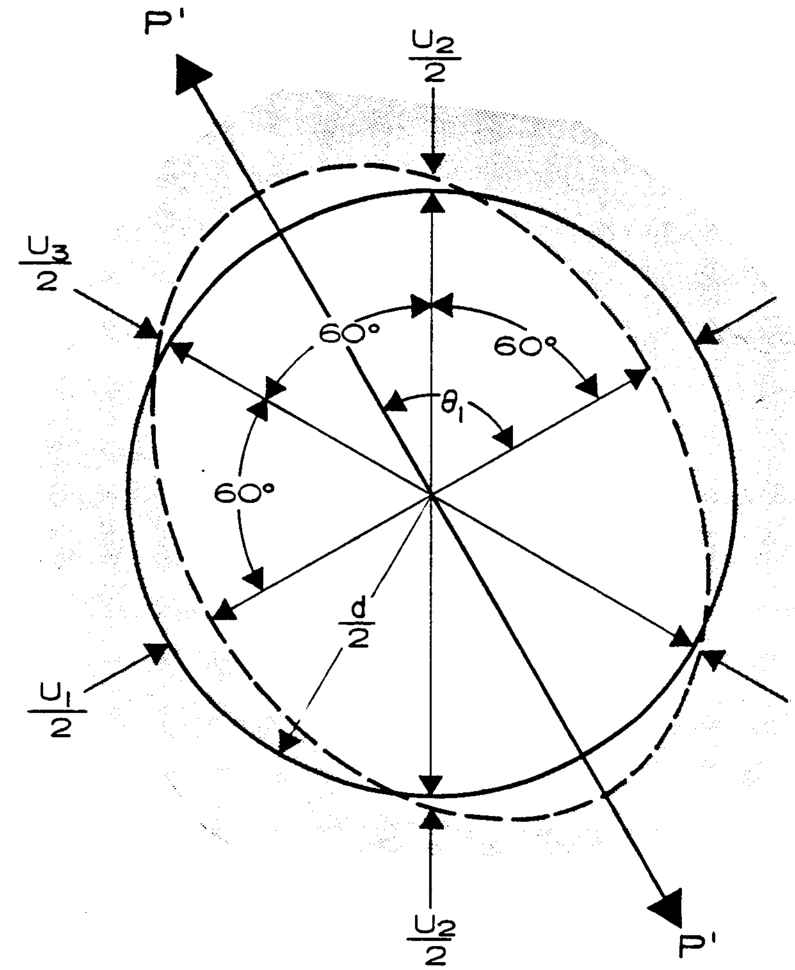


FIG. 1.1 ORIENTATIONS OF DEFORMATIONS AND SECONDARY PRINCIPAL STRESSES.

deformation of the borehole. The change in the diameter of the borehole is, therefore, a function of the three stress components σ_1, σ_3, and σ_{13} acting perpendicular to the borehole axis and the component σ_2 acting parallel to the borehole axis.

Using the plane strain condition of the theory of elasticity (i.e., $\varepsilon_2 = 0$), Panek (1966) solves for the borehole deformation caused by σ_1, σ_3 and τ_{13}. The effect of σ_2 on the diametral deformation is then superimposed on this solution. The total change in borehole diameter, U, may be expressed as:

$$U = \sigma_1 f_1 + \sigma_2 f_2 + \sigma_3 f_3 + \tau_{13} f_4 \quad (4)$$

where:

$$f_1 = d(1 + 2\cos 2\theta)(1 - \mu^2)/E + d\mu^2/E \quad (5a)$$

$$f_2 = -d\mu/E \quad (5b)$$

$$f_3 = d(1 - 2\cos 2\theta)(1 - \mu^2)/E + d\mu^2/E \quad (5c)$$

$$f_4 = d(4 \sin 2\theta)(1 - \mu^2)/E \quad (5d)$$

and where:

- d = diameter of borehole
- θ = angle of the diametral measurement axis from the horizontal of the local coordinate system
- μ = Poisson's ratio of the rock
- E = modulus of deformation of the rock.

Each overcore test measures the borehole deformation, across three different diameters 60° apart. However, no information is obtained about either σ_2 or ε_2 acting perpendicular to the axis of measurement. Thus, Equation 4 cannot be solved for the stress components unless additional information is obtained or assumed. Tests in differently oriented boreholes provide this information.

When determinations of U are made in more than one drill hole, all of the measurements must be related to a common coordinate system. Each stress component of the local coordinate system may be expressed as a function of the stress tensor of the common (x,y,z) system according to the standard rules of transforming stresses from one rectangular coordinate system to another. Doing this allows Equation 4 to be rewritten:

$$U = J_1\sigma_x + J_2\sigma_y + J_3\sigma_z + J_4\tau_{xy} + J_5\tau_{yz} + J_6\tau_{zx} \quad (6)$$

where J_i is a function of the f_i defined in Equations 5a-d and the direction cosines between the two coordinate systems.

With six independent measurements of U, the components of the stress tensor can be determined. Gray and Toews (1967) have shown that measurements in at least three non-parallel boreholes are required to fully define this tensor. In practice, the precision of the stress component determination is increased by applying statistical methods to the data. The method generally used is a least squares solution that combines all the deformation measurements from any number of boreholes regardless of their orientation.

Once the stress tensor is determined, the principal stresses in the rock mass are calculated using standard methods. The statistical approach to the data reduction allows confidence levels to be assigned to the results.

1.3.3 Assumptions.

1.3.3.1 The rock tested is homogeneous, isotropic and linearly elastic.

1.3.3.2 The rock surrounding the test adit is elastic, that is, it responds to stress changes instantaneously and the deformations are fully recoverable.

1.3.3.3 The physical conditions present in three separate drill holes describe the same point in space. This assumption is difficult to verify, as rock material properties and the local stress field can vary significantly over short distances. The key to satisfying this assumption is in careful test site selection.

1.4 References.

1.4.1 Gray, W. M. and Toews, N. A., 1967, "Analysis of Accuracy in the Determination of Ground-Stress Tensor by Means of Borehole Devices", Status of Practical Rock Mechanics, Proceeding of the Ninth Symposium on Rock Mechanics, Golden, Colorado.

1.4.2 Hooker, V.E., Aggson, J.R., and Bickel, D.L., 1974, Improvements in the Three-Component Borehole Deformation Gage and Overcoring Techniques, Report of Investigations 7894, U.S. Bureau of Mines, Washington, D.C.

1.4.3 Hooker, V.E. and Bickel, D.L., 1974, Overcoring Equipment and Techniques Used in Rock Stress Determination, Information Circular 8618, U.S. Bureau of Mines, Washington, D.C.

1.4.4 Panek, L.A., 1966, Calculation of the Average Ground Stress Components from Measurement of the Diametral Deformation of a Drill Hole, Report of Investigations 6732, U.S. Bureau of Mines, Washington, D.C.

2.0 Prerequisites

2.1 Personnel prequalification.

2.1.1 Test personnel. All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.1.2 Drilling personnel. Quality drilling is important to achievement of successful overcore tests. The drilling personnel shall be familiar with, and have had experience in, diamond core drilling underground.

2.2 Equipment performance verification and calibration.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally accomplished by calibration of the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Criteria for test site selection.

2.3.1 Number of boreholes. A minimum of three boreholes are required to determine the complete stress tensor. They should be oriented so that each forms an angle of about 60° to 70° with the other two. Boreholes inclined upward are generally easier to work in than holes inclined downward, particularly in fractured rock. Two boreholes inclined about 5° above horizontal and one inclined about 70° above horizontal have been found to be the most workable arrangement.

More than three boreholes are recommended at each test station to improve the accuracy of the stress determination. The orientation of additional boreholes should also be at 60° to 70° to the other boreholes.

2.3.2 Similar rock formations. Different rock formations have different mechanical properties and, hence, different abilities to transmit stress. Therefore, to satisfy the assumptions required by the data reduction, all boreholes at a single test station should be in the same formation. If the test adit penetrates two or more rock types, for example a dolomite and a sandstone, a group of at least three boreholes should be tested in each formation.

2.3.3 Influence of excavations. Openings in a rock mass concentrate the in situ stresses within a zone of two to three diameters away from the opening. The stress concentration depends on the shape of the opening as well as the relative and absolute magnitudes of the in situ stresses. Not all components of the in situ stress tensor will necessarily be concentrated to the same degree. Since most overcoring work is intended to measure undisturbed stress levels, the boreholes should be drilled from a portion of the test adit at least three diameters from any other opening or change in direction. The adit itself, of course, concentrates the stress around it; the depth of several of the tests should be sufficient to reach beyond the zone of concentration. The smallest adit that will accommodate the drilling equipment is recommended; adits from 8 to 12 ft (2.4 to 3.6 m) in diameter have been found satisfactory.

2.3.4 Influence of local geologic features. Local geologic features with mechanical properties different from those of the surrounding rock can significantly influence the local stress field (for example, a large quartz pod in a gneiss, or discontinuities, such as faults or shear zones. In general, these features should be avoided when selecting a test site location. However, it is often valuable to measure the stress level on each side of a large fault.

2.4 Deformational properties of the rock.

The modulus of deformation and Poisson's ratio of the rock are required for data reduction. The recommended method for determining modulus of deformation values involves biaxially testing the recovered overcores, as described in other procedures. If this is not possible, values may be obtained from laboratory testing of smaller cores. This approach, however, generally decreases the accuracy of the stress determination in all but the most homogeneous rock.

3.0 Equipment and apparatus

3.1 Drilling.

3.1.1 General. Holes of two sizes are drilled for the overcore test, an EX-size [1.5-in. (38-mm) diameter] hole for the deformation gage, and a large-diameter overcore hole, generally 5.625 to 6.000 in. (14.288 to 15.240 cm) in diameter. The two boreholes shall be coaxial to within 0.25 in. (6.35 mm). All drilling is done with diamond bits. The drilling equipment shall be in good working order, capable of performing as designed. Any pressure gages or other meters shall be functional and accurate to their original specifications.

3.1.2 EX hole. The EX hole shall be drilled using a double tube, swivel core barrel to obtain the highest quality core possible. Centering devices for the drill string shall be provided so the EX borehole may be restarted at the bottom of the large diameter hole at any time.

3.1.3 Overcore hole. It is desirable to obtain pieces of large-diameter core at least 10 to 12 in. (25.4 to 30.5 cm) long, in order to avoid damage to the deformation gage and for biaxial testing. In competent rock, a thin-wall barrel may be used. This barrel shall be capable of holding at least 3 ft (0.91 m) of core. In fractured rock, a double-tube, swivel barrel is recommended.

3.2 Borehole deformation gage.

The U.S. Bureau of Mines borehole deformation gage described in Reference 1.4.2 shall be used. In fractured rock, the reverse-case modification of the gage is recommended.

3.3 Readout equipment.

The borehole deformation gage contains three full-bridge strain gage circuits. Any excitation and readout system which allows the deformation to be measured to an accuracy of ± 5 x 10^{-6} in. (1.27 x 10^{-4} mm) with a resolution of 1 x 10^{-6} in. (2.54 X 10^{-6} mm) may be used. The excitation voltage shall be applied continuously to all three bridge circuits and shall be no greater than 2 V, to avoid the effects of self heating. A portable strain indicator with a switch and balance unit has been found satisfactory.

3.4 Thermometer.

A thermometer with an accuracy of at least ± 1.8°F (± 1°C) and a resolution of at least 0.36°F (0.2°C) shall be available to measure the temperature of the drill water.

4.0 Testing

4.1 Drill setup.

To obtain high quality data from the overcore test, it is important to minimize drilling vibrations during the test. To accomplish this, the drill shall be supported to prevent any motion while drilling. Rock bolts, roof jacks, timber posts and wedges, and other support systems have been used successfully.

4.2 Test intervals.

Tests should be conducted at intervals of no more than 5 ft (1.5 m) along the borehole. At least six tests per borehole are recommended, three of which shall be beyond the zone of influence of the excavation. In fractured rock, it may be necessary to test as often as possible to obtain a sufficient amount of usable data. In any case, the testing shall begin beyond the zone of damage caused by the excavation of the test adit, as determined from prior exploratory drilling or the initial coring of the overcore hole.

4.3 Coaxial requirements.

The EX and large-diameter boreholes shall be coaxial to within 0.25 in. (6.35 mm). When this tolerance is exceeded, the existing EX hole shall be overcored out and restarted.

4.4 Test location.

If possible, the plane of deformation measurement shall be located at least one diameter of the large borehole ahead of that hole at the start of overcoring. If this is not feasible, for instance because of fractures, the plane of measurement shall be located as far ahead of the large borehole as possible.

The accuracy of the test will be decreased, but the data may be corrected to some extent as discussed in Reference 1.4.2. The borehole deformation gage shall not be located so that the measuring buttons and support springs are located in different blocks of rock, which will experience differential movement when overcored. The exact test location may be determined from examination of the EX core. In highly fractured rock, examination of the EX borehole with a borescope is recommended.

4.5 Gage orientation.

The orientation of the borehole deformation gage in a particular position is not required; a variety of orientations are recommended to minimize systematic errors and uncertainties due to rock anisotropy. Each orientation, however, shall be accurately measured to within $\pm$ 5°. This may be accomplished by a measurement device on the end of the setting tools, by examining the gage in the borehole with a low-power telescope, or by other suitable means.

4.6 Thermal equilibrium.

While the circuits in the borehole deformation gage have been designed to minimize thermal drift, a total lack of thermal sensitivity is rarely achieved. After the gage has been placed at the test location and the drilling apparatus has been assembled for the overcore test, drill water shall be pumped as during the test. Deformation gage readings shall be taken at 2-minute intervals during this time. Drilling shall not begin until three consecutive readings of each channel differ by no more than 3×10^{-6} in. (7.6×10^{-5} mm). The temperature of the drilling water shall be measured at the beginning and end of the test, and at any other time when thermal drift is suspected.

4.7 Measurement intervals.

The deformation gage shall be read at each inch of bit penetration, or more frequently if appropriate. The three channels shall be read in the same sequence each time. The gage shall be overcored to at least one diameter of the large borehole beyond the plane of measurement or until three consecutive readings stabilize.

4.8 Time-dependent relaxation.

After the gage has been overcored to the desired depth, drilling shall be stopped. Each channel shall be read at 5-minute intervals for 1 hour to evaluate time-dependent (anelastic) deformation. During this period, drill water circulation shall be continued as during the test. The drilling equipment shall not be dismantled during this time.

4.9 Core handling.

Recovered overcore suitable for biaxial testing shall be marked with the following information:

4.9.1 Depth of each end of the core

4.9.2 Location of measurement plane

4.9.3 Orientation of the gage in the core

4.9.4 Orientation of the core itself.

The core shall then be wrapped and waxed according to procedure GT-A.4, "Handling and Storage of Rock Core Samples."

4.10 Data recording requirements.

The data as shown on Form GT-C.1-1 shall be recorded as a minimum for this test.

4.11 Gage calibration.

The USBM gage shall be calibrated prior to beginning the test program, and every 10 tests (successful or not) thereafter. The gage shall also be recalibrated if it has experienced severe vibration during testing, has sustained minor damage (especially to the signal cable), or if any other reasons exist to suspect that the gage performance has changed.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 The location and orientation of the overcore holes shall be presented. A graphic presentation is recommended.

5.1.1.2 The reasons for selecting the test locations shall be discussed.

5.1.1.3 The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock type shall be described macroscopically. Structural features affecting the overcore testing shall be discussed as appropriate.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test should be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a non-ideal situation shall be fully explained.

5.4 Results.

5.4.1 Deformation data. As a minimum, a summary table including the test number, borehole depth, probe orientation, and deformation of each channel shall be presented for each test.

5.4.2 Secondary principal stresses. The secondary principal stresses, including depth from the adit face, orientations, and magnitudes shall be presented for each test. A graphic presentation as well as a tabular summary is recommended.

5.4.3 Three-dimensional principal stresses. The orientations and magnitudes of the three-dimensional principal stresses shall be presented. A graphic presentation as well as a tabular summary is recommended.

5.4.4 Other. The following other types of data analyses and presentations may be included as appropriate.

5.4.4.1 The stress gradient away from the adit may be evaluated either by secondary principal stresses or, if sufficient tests have been run, by the complete stress tensor or principal stresses.

5.4.4.2 The stresses in different rock formations or in different relationships to geologic structures may be evaluated.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Stress error. The uncertainty associated with each component of the principal stresses is usually evaluated from the multiple regression analysis of the deformation data. This uncertainty contains random errors from the measurements and from the assumptions used in the data reduction. This uncertainty may only partially contain the effects of systematic differences in material properties or local stress fields between individual boreholes. These factors shall be discussed separately as quantitatively as possible.

5.6 Appended data.

5.6.1 Deformation vs. bit position. A deformation vs. drill bit penetration plot for each test shall be included in an appendix.

5.6.2 Deformation vs. time. A plot of deformation vs. time for each test shall be included in the appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and the equipment performance verification. After testing, the completed Form GT-C.1-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-C.1-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of GT-C.1-1.

In Situ Stress Determination by Overcoring the
USBM Borehole Deformation Gage

Test Data Sheet-Form GT-C.1-1

Project ____________________ Depth of EX Hole ____________________

Feature ____________________ Depth of Large Hole ____________________

Borehole ____________________ Depth of Measurement Plane ____________________

Orientation: Bearing ______ Gage Orientation ____________________

Inclination ______ Water Temperature: Start ____________

Date ____________________ Finish ____________

Tested by ____________________

Equipment Description	Serial No.	Date of Next Calibration

Sketch of bottom of large hole and probe orientation:

		Deformation Reading		
Time	Bit Penetration	Channel 1	Channel 2	Channel 3

Test Supervisor ______________________ Date ____________

Quality Assurance ______________________ Date ____________

Project Engineer ______________________ Date ____________

Procedure GT-C.2

In Situ Stress Determination Using the Hydraulic Fracturing Method

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to determine the magnitude and orientation of the principal stresses in a rock mass at depth. This method is the only nondevelopmental technique presently available for measuring stresses at depths greater than approximately 150 ft (45.75 m).

1.1.2 Limitations.

1.1.2.1 The hydraulic fracturing method requires that one of the principal stresses be closely aligned with the long axis of the borehole.

1.1.2.2 The hydraulic fracturing method is not suitable for extremely anisotropic rock.

1.2 General description of the test.

A section of a borehole is isolated with hydraulic packers. The pressure in the sealed-off interval is increased at a controlled rate by pumping fluid into it until a fracture occurs in the borehole wall. Pumping is stopped and the pressure in the interval is allowed to stabilize. The pressure is then reduced to the pore pressure of the rock formation, and the pressurization process is repeated. The magnitudes of the principal stresses are calculated from the various pressure readings. The orientation of the fracture is measured to determine the direction of the stresses. A typical pressure vs. time curve for a test interval is shown on Figure 1.1.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Pressure, stress - force per unit area.

1.3.1.2 Pore pressure - the pressure existing in the rock formation due to the hydrostatic pressure of the groundwater in the pores or fractures of the rock mass.

1.3.1.3 Critical (breakdown) pressure - the pressure at which a fracture in the test section occurs.

1.3.1.4 Shut-in pressure - the equilibrium pressure of the test section after the fracture has been formed.

1.3.1.5 Tensile strength - the tensile stress in the rock mass required to initiate a tensile fracture.

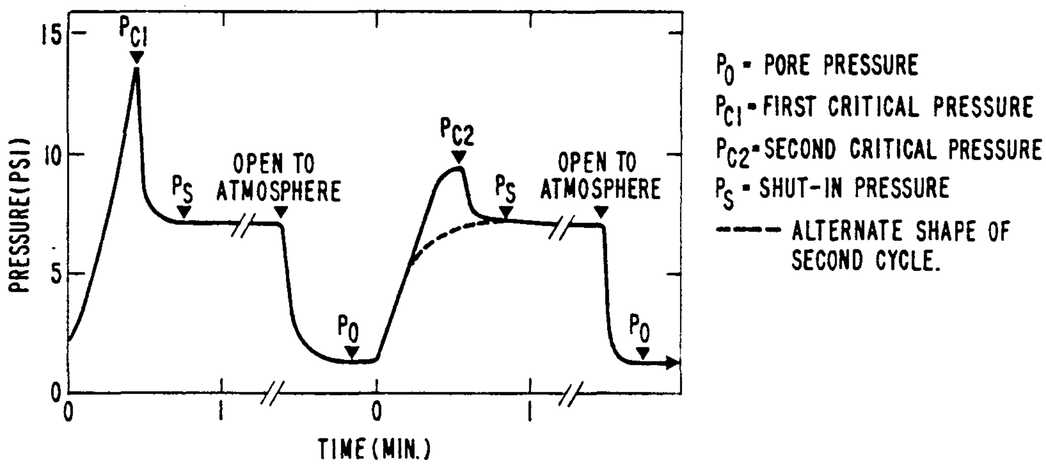


FIG. 1.1 EXAMPLE PRESSURE VS. TIME CURVE FOR HYDRAULIC FRACTURING TEST (AFTER HAIMSON, 1980).

1.3.2 Equations. The following equations assume the borehole is vertical. The theory is the same for boreholes in other orientations.

1.3.2.1 The pore pressure, P_o, is the static pressure measured in the test interval before any test fluid is introduced into the system.

1.3.2.2 The critical pressure, P_{c1}, is the pressure in the test section at the initiation of the tensile fracture. The second critical pressure P_{c2}, is the pressure in the test section required to reopen the tensile fracture. If the pressure is measured directly in the test interval, no corrections are necessary. If it is measured at the surface, corrections must be made, since the fluid is flowing into the test interval. The factors that cause pressure loss between the surface and test section include:

a. friction between test fluid and walls of the the pipe.

b. friction and turbulence caused by contraction or enlargements at pipe couplings.

c. friction due to bends in the pipe.

d. pressure loss as the fluid enters the test interval, which is a larger diameter than the pipe.

e. pressure loss at the gage, where the fluid is flowing past the opening to the measurement pipe at a finite velocity.

The pressure loss, P_{1e}, from Factor d may be calculated using:

$$P_{1e} = \frac{V_e^2 \gamma}{2g} \qquad (1)$$

where:

V_e = velocity at exit of pipe

γ = unit weight of fluid

g = acceleration of gravity.

The pressure loss, P_{1g}, from Factor e may be calculated using:

$$P_{1g} = \frac{V_g^2 \gamma}{2g} \qquad (2)$$

where:

V_g = velocity at pressure gage.

If the pipe is the same diameter at the pressure gage and where it enters the test interval, $V_e = V_g$, and the two effects cancel.

The effects of factors a through c may be evaluated either by calibrating the test system or using standard values from hydraulic handbooks. Therefore, the critical pressure, P_c, when the test pressure is measured at the surface is calculated using:

$$P_c = P_{cm} - P_f + P_h \tag{3}$$

where:

P_{cm} = measured critical pressure

P_f = pressure losses due to friction

P_h = pressure due to height of test fluid above test section.

1.3.2.3 If the shut-in pressure, P_s, shows a constant or uniformly decreasing value, the vertical stress, σ_v, cannot be directly measured. It may be calculated from the weight of the overburden:

$$\sigma_v = \gamma d \tag{4}$$

where:

γ = specific weight of overburden

d = depth of overburden.

1.3.2.4 The fracture will always be initiated in a vertical plane because of the loading geometry, but if the vertical stress is the minimum stress, horizontal fracture planes will begin to open as the vertical fracture propagates away from the borehole. If this is the case, the shut-in pressure, P_s, may show two distinct values, P_{s1} and P_{s2}. The vertical stress, σ_v, is equivalent to the second shut-in pressure:

$$\sigma_v = P_{s2} \tag{5}$$

1.3.2.5 The vertical fracture forms normal to the minimum horizontal stress, $\sigma_{H\,min}$. This stress is measured directly by:

$$\sigma_{H\,min} = P_s \tag{6a}$$

or

$$\sigma_{H\,min} = P_{s1} \tag{6b}$$

If the shut-in pressure does not remain constant, due to leakage into pores and joints in the rock mass or around the packers, continued pumping is required to maintain a constant pressure. If the pumping rate is low, and steady flow is achieved at two pressure levels, P_1 and P_2, the shut-in pressure may be calculated from the relationship:

$$\frac{P_1 - P_s}{P_2 - P_s} = \left(\frac{Q_1}{Q_2}\right)^{1/2} \qquad (7)$$

where:

Q_1, Q_2 = flow rates corresponding to P_1, P_2.

1.3.2.6 The maximum horizontal stress, $\sigma_{H\,max}$, is governed by the equation describing the critical pressure, P_{c1}, at fracture initiation:

$$P_{c1} - P_o = \frac{T + 3\sigma_{H\,min} - \sigma_{H\,max} - 2\,P_o}{K} \qquad (8)$$

where:

P_o = pore pressure in rock at tested depth

T = tensile strength of the rock

K = poro-elastic parameter as defined by Haimson (1978).

Haimson (1978) indicates that K is approximately equal to 1 at pressures less than 4000 psi. Therefore, for most testing, $\sigma_{H\,max}$ is calculated using:

$$\sigma_{H\,max} = T + 3P_s - P_{c1} - P_o \qquad (9)$$

If two pressurization cycles are performed, and a second critical pressure P_{c2} is observed, it corresponds to re-opening the fracture. The maximum horizontal stress may then be calculated:

$$\sigma_{H\,max} = 3P_s - P_{c2} - P_o \qquad (10)$$

This equation is preferred because it does not require a knowledge of the in situ tensile strength of the rock, which may be significantly lower than laboratory values.

1.3.2.7 If P_{c2} can be determined, the tensile strength of the rock mass in situ is calculated:

$$T = P_{c1} - P_{c2} \quad (11)$$

1.3.3 Assumptions and factors influencing the data.

1.3.3.1 The above equations assume that the rock is homogeneous, isotropic, brittle, linearly elastic, and that fluid flow through the pores and fractures obeys Darcy's law. Haimson (1980) found that isotropy of tensile strength and deformational properties within 10% was acceptable; however, this problem has not been studied in detail, and the acceptable level of anisotropy is not known with certainty.

1.3.3.2 The above equations assume that one of the principal stresses is parallel to the borehole. This is generally the case in deep vertical boreholes. Other situations, such as tests from an adit, require careful orientation and judgment.

1.4 References.

1.4.1 Haimson, B.C., 1978, "The Hydrofracturing Stress Measuring Method and Recent Field Results", Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 15, No. 4.

1.4.2 Haimson, B.C., 1980, "Near Surface and Deep Hydrofracturing Stress Measurements in the Waterloo Quartzite", Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 17, No. 2.

1.4.3 Zoback, M.D., Rummel, F., Jung, R., and Raleigh, C.B., 1977, "Laboratory Hydraulic Fracturing Experiments in Intact and Pre-fractured Rock", Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 14, No. 2.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Test program determined.

2.3.1 Number and orientation of boreholes. The requirements for determining the stress will depend on the objectives of the study and the geology at the site. Different formations can support different portions of the total load, depending on their material properties. In addition, major structural features such as faults can significantly change the regional stress field in their vicinity. For tests from underground excavations, several orientations are recommended, particularly if the direction of the principal stresses is unknown.

2.3.2 Various depths. Hydraulic fracturing tests should be conducted at several depths in each borehole to measure the stress gradient.

2.3.3 Various materials. All major formations should be tested.

2.3.4 Statistical requirements. Several tests should be conducted in each formation to give statistical validity to the results.

2.3.5 Intervals chosen. Test intervals should be between 3 and 10 ft (0.9 to 3.1 m) in length and contain as few fractures, bedding planes, or other discontinuities as possible. Test intervals are selected from rock core logs if available, well logs or direct observation via borehole cameras. Tests should be located so that the center of each test interval is at least 20 ft (6.1 m) from the center of any adjacent test interval.

2.4 Boreholes drilled.

2.4.1 Core logged. It is desirable to have continuous rock core from the borehole. The core should be logged as described in Procedure GT-A.3 "Guidelines for Logging Rock Core", boxed, and stored available for inspection as described in Procedure GT-A.4 "Handling and Storage of Rock Core."

2.4.2 Boreholes washed. The boreholes should be washed with clear water to remove all drilling mud and cuttings. These materials can interfere with breakdown pressure.

2.5 Laboratory testing.

The tensile strength of the rock must be determined in order to use Equation 9. The direct tensile test is recommended. For highly permeable rocks, or at high stress levels, measurement of the poro-elastic parameter may also be necessary. Haimson (1978) describes methods for measuring the poro-elastic parameter.

3.0 Equipment and apparatus

3.1 Pump and hydraulic system.

The pump must supply fluid at a pressure sufficient to overcome the friction losses and fracture the rock. The flow capacity depends on the permeability of the rock mass; higher flow is required in permeable rock to raise the borehole pressure while overcoming fluid loss. Pumps with a pressure rating of 10,000 psi (68.95 MPa) and a flow capacity of 100 gal. (378.5 l) per minute have been found adequate for most situations. The pump shall apply pressure in a smooth, continuously increasing manner, at a constant rate until the fracture is initiated.

3.2 Flowmeter.

In order to estimate the fracture size, the volume of fluid injected into the rock mass shall be measured using a flow meter. The flow meter shall have an accuracy of at least ± 1.0 gal. (± 3.79 l) and a resolution of at least 0.5 gal. (1.89 l).

3.3 Packers.

Pneumatic packers are recommended to seal the test interval; however, mechanical packers may be used if satisfactory performance can be verified. The packers shall be seated against the borehole wall during testing with a pressure at least 10% greater than the critical pressure, to avoid fluid leakage around them. The packers shall be at least 3 ft (0.91 m) long.

3.4 Pressure transducers.

Pressure may be measured using an electronic transducer at the surface, using an electronic transducer in the test interval and the readout device on the surface, or using a self-contained transducer/recorder package in the test interval. The second method is recommended because it is provides direct measurement of the test section pressure with output while the test is being performed. The transducer shall have an accuracy of at least ± 50 psi (0.34 MPa) including errors introduced by the readout system, and a resolution of at least 25 psi (0.17 MPa). A strip chart recorder having a variety of chart speeds shall be used to monitor transducer output. It is recommended that both a downhole and surface transducer be used to provide redundant data.

3.5 Test fluid.

A low viscosity fluid shall be used for the hydraulic fracturing test. Water is recommended, but brines may be used in salt, and dyes may be added if required for subsequent delineation of the fracture. Drilling muds shall not be used.

3.6 Fracture orientation devices.

Impression packers, borehole cameras, or other similar devices may be used to measure the orientation of the induced fracture. The orientation shall be measured to an accuracy of at least ± 5°. In deep boreholes where the twist in the pipe string may be significant, a downhole compass is recommended.

4.0 Testing

4.1 Packers.

The packers shall be maintained at a pressure at least 10% greater than the test section pressure throughout the test.

4.2 Pressurization rate.

Pressurization shall be rapid in order to minimize fluid penetration into the rocks. The critical pressure shall be attained in 1 to 2 minutes; this generally corresponds to pressurization rates of 1000 to 4000 psi (6.89 to 27.58 MPa) per minute.

4.3 Shut-in pressure.

Immediately after the critical pressure is achieved, pumping shall be stopped and the hydraulic circuit shall be closed. Shut-in pressure shall be monitored for at least 15 minutes.

4.4 Second cycle.

A second pressurization cycle similar to the first shall be performed. Between the cycles, the hydraulic circuit shall be opened to the atmosphere, and the test section pressure allowed to stabilize until it equals the head of fluid in the pipe (low permeability rock) or the initial pore pressure in the rock (high permeability rock).

4.5 Fracture orientation.

The fracture orientations may be determined after all fracturing tests in the borehole have been completed.

4.6 Data recording requirements.

The data will be recorded on the pressure time graph produced by the chart recorder. Other data shall be recorded as shown on Form GT-C.2-1.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In this case, an applications sections compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the nature of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 The location and orientation of the tested boreholes shall be presented. A graphic presentation is recommended.

5.1.1.2 The reasons for selecting the test locations and the basis for the test plan shall be discussed.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock type shall be described macroscopically. Structural features affecting hydraulic fracture propagation shall be discussed as appropriate.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Fracturing fluid. The hydraulic fluid shall be noted, and the rationale for selection of the fluid shall be presented.

5.2.3 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.4 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations and limitations in their applications shall be noted, and the effect on the results shall be discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary table. A table shall be presented which lists the rock formation, test depth, and magnitude and orientation of the principal stresses.

5.4.2 Individual results. A table shall be presented which lists each test number, the rock type, the test depth, the critical pressures, shut-in pressures, and pore pressures, and the magnitude and orientation of the principal stresses.

5.4.3 Other. The following other types of analyses and presentations may be included as appropriate.

5.4.3.1 Orientation of stress as a function of depth.

5.4.3.2 Magnitude of maximum and minimum principal stress as a function of depth.

5.4.3.3 Breakdown pressure as a function of pressurization rate.

5.4.3.4 Comparison of results to previous studies.

5.4.3.5 Comparison of laboratory and field tensile strengths.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers and readout devices.

5.5.2 Site variability. For each area or rock material tested, the mean stresses, range, standard deviation and 95% confidence limits for the mean shall be calculated, as a minimum. The uncertainty of the group shall be compared with the measurement uncertainty to determine whether measurement error or site variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Pressure vs. time curves. Pressure vs. time curves for each test shall be included in an appendix.

5.6.2 Test documentation. Completed data Form GT-C.2-1 for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-C.2-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-C.2-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-C.2-1.

In Situ Stress Determination Using
the Hydraulic Fracturing Method

Test Data Sheet - Form GT-C.2-1

Project ____________ Test No. ____________

Feature ____________ Borehole No. ____________

Test Location ____________ Orientation ____________

Date ____________ Depth of Test ____________

By ____________ Length of Section ____________

Rock Type ____________ Test Fluid ____________

Equipment Description	Serial No.	Date of Next Calibration

Chart Speed ____________ Scale Factor ____________

Flow Meter Reading: Initial ____________

Final ____________

Net ____________

Rate: ____________

Remarks:

Test Supervisor ____________ Date ____________

Quality Assurance ____________ Date ____________

Project Engineer ____________ Date ____________

Procedure GT-C.3

In Situ Stress and Modulus of Deformation Determination Using the Flatjack Method

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The flatjack test measures stress at a rock surface. The modulus of deformation and the long-term deformational properties (creep) may also be evaluated.

1.1.2 Limitations. The flatjack test measures stresses only at the surface of the test chamber. Undisturbed stress levels must be determined by theoretical interpretations of this data.

1.2 General description of the test.

The in situ stress in the rock mass is relieved by cutting a slot into the rock perpendicular to the surface of the test adit. The deformation caused by this stress relief is measured. A hydraulic flatjack is mortared into the slot and is pressurized until the rock returns to its original position. This reapplied stress is approximately equal to the stress in the rock mass at the test location in a direction perpendicular to the plane of the jack. The deformational characteristics of the rock mass are evaluated by incrementally loading the flatjack and measuring the deformation. Long-term deformational properties are evaluated by maintaining a constant pressure in the flatjack and periodically measuring the deformation.

1.3 Data Reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deformation - the change in dimension of a rock mass.

1.3.1.2 Stress - force per unit area.

1.3.1.3 Skin stress - the tangential stress at the surface of an opening.

1.3.1.4 Undisturbed stress - the stress field existing in a rock mass prior to excavation of an opening.

1.3.1.5 Cancellation pressure - the pressure in the flatjack required to return the rock to its initial position.

1.3.2 Equations. The calculation of stress and modulus of deformation from flatjack data is influenced by the complex loading geometry of the test. In addition, the load applied by the flatjack is not the same as the load originally acting on the rock. The jack expands in one direction only, so lateral and shear components are not restored. This is particularly significant when the jack is not aligned with a principal stress. Several elastic models and assumptions have been used to compensate for these factors, leading to varied and sometimes contradictory methods of data reduction. The equations presented here are among the more widely accepted and have been found to produce results comparable with those of other in situ methods. The analysis of data, however, is dependent on site-specific factors such as geology and the existing stress field. In the future, individualized analysis of each test by numerical techniques such as finite element methods may prove to be the most effective approach.

1.3.2.1 The cancellation pressure is not necessarily equal to the skin stress because of the factors discussed above. Skin stress calculations fall into two major categories: one in which deformations are measured on one side of the flatjack slot, and one in which deformations are measured across the slot.

When deformation is measured between points on one side of the flatjack slot, the skin stress is calculated using elastic theory and strain. Tincelin (1952) found that the strain caused by cutting the slot was similar to the strain produced by a long elliptical opening in an elastic plate, and the strain produced by the flatjack was similar to that caused by uniformly loading the edge of a semi-infinite plate. The ratio of actual stress to cancellation pressure is shown in Table 1.1 for cancellations measured at various distances from the slot, and for several Poisson's ratios. These factors were derived by Tincelin for a 1-meter-square (1.09 yd) flatjack, but are not substantially different for jacks nearly this size. Field experience indicates that this table cannot be used to correct cancellation pressures directly, but only as an indication of where to locate the cancellation measuring points to minimize error. In practice, skin stress measurements are made close enough to the slot that they may be assumed to equal the cancellation pressure within an acceptable error.

When deformation is measured between points on opposite sides of the flatjack slot, elastic theory and deformation are used to calculate skin stress. Alexander (1960) assumed that the deformations due to cutting the slot were similar to the deformations caused by a finite elliptical opening in a uniformly loaded elastic plate, and the deformations caused by the jack were similar to those caused by an infinitely thin elliptical opening the length of the jack. The deformation on one side of the jack, due to cutting the slot, W, is given by the following equations:

$$W_o = \frac{SC}{E}\left\{(1-\mu)\ [(1 + \frac{Y^2}{C^2})^{1/2} - \frac{Y}{C}] + (1+\mu)/(1 + \frac{Y^2}{C^2})^{1/2}\right\} \quad (1)$$

$$W_1 = \frac{SY_o}{E}\left\{(-2\mu)\ [(1 + \frac{Y^2}{C^2})^{1/2} - \frac{Y}{C}] + (1+\mu)/(1 + \frac{Y^2}{C^2})^{1/2}\right\} \quad (2)$$

$$W_2 = -W_1 \frac{Q}{S} \quad (3)$$

$$W = W_o + W_1 + W_2 \quad (4)$$

where:

- W_o = displacement on one side of the slot during cutting of an infinitely thin slot
- W_1 = displacement on one side of the slot due to finite slot width
- W_2 = displacement on one side of the slot due to biaxial stress
- S = rock stress normal to the jack
- Q = rock stress parallel to the jack
- C = half-length of the slot
- Y = distance of measuring point from center line of jack
- Y_o = half-width of slot
- E = modulus of deformation of the rock mass
- μ = Poisson's ratio of the rock mass.

The deformation caused by pressurizing the jack, W_j, is given by:

$$W_j = \frac{PC_o}{E}\left\{(1-\mu)\ [(1 + \frac{Y^2}{C_o^2})^{1/2} - \frac{Y}{C_o}] + (1+\mu)/(1 + \frac{Y^2}{C_o^2})^{1/2}\right\} \quad (5)$$

where:

- P = jack pressure
- C_o = half-length of jack.

At cancellation pressure,

$$W = W_j \quad (6)$$

Table 1.1

Ratio of Skin Stress to Cancellation Pressure

for 1-Meter-Square (1.09-yd-square) Flatjack

(after Tincelin, 1952)

Distance from slot	Poisson's Ratio of Rock 0.10	0.20	0.33	0.50
0	0.99	0.99	0.98	0.92
0.1 L	0.98	0.98	0.94	0.89
0.2 L	1.00	0.98	0.93	0.88
0.3 L	1.04	1.01	0.98	0.93
0.4 L	1.10	1.08	1.02	1.01
0.5 L	1.20	1.17	1.11	1.08
0.6 L	1.31	1.27	1.24	1.18
0.7 L	1.44	1.39	1.37	1.30
0.8 L	1.58	1.52	1.48	1.38
0.9 L	1.71	1.69	1.61	1.46
1.0 L	1.87	1.83	1.73	1.53

L = width of flatjack.

Solving for the skin stress, S, yields the following generalized equation:

$$S = aP + bQ \tag{7}$$

where:

a,b = coefficients depending on rock properties and test geometry.

It should be noted that these equations assume that the jack is aligned with the principal skin stresses.

1.3.2.2 Undisturbed stress level. An underground opening will produce stress concentrations in the rock surrounding the opening. These stress concentrations, which are the skin stresses, are related to the size and shape of the opening, the relative magnitudes of the undisturbed stresses, and the material properties of the rock adjacent to the opening. While undisturbed stress levels are not measured directly, they may be estimated by use of elastic theory, such as solutions for holes in plates.

1.3.2.3 The modulus of deformation calculations again fall into two categories. When deformation is measured on one side of the slot, the modulus, E, is calculated using (Dodds, 1969):

$$E = \frac{PLR}{2\pi\Delta Y} \tag{8}$$

where:

P = pressure in flatjack

L = distance between measuring points

R = stress distribution factor

ΔY = deformation between measuring points.

The stress distribution factor, R, is calculated:

$$R = A_q + \sin A_q - \mu(A_q - \sin A_q) + A_z + \sin A_z - \mu(A_z - \sin A_z) \tag{9}$$

where:

μ = Poisson's ratio of the rock

A_q, A_z = angles between the measuring points and the edges of the flatjack, as shown on Figure 1.1.

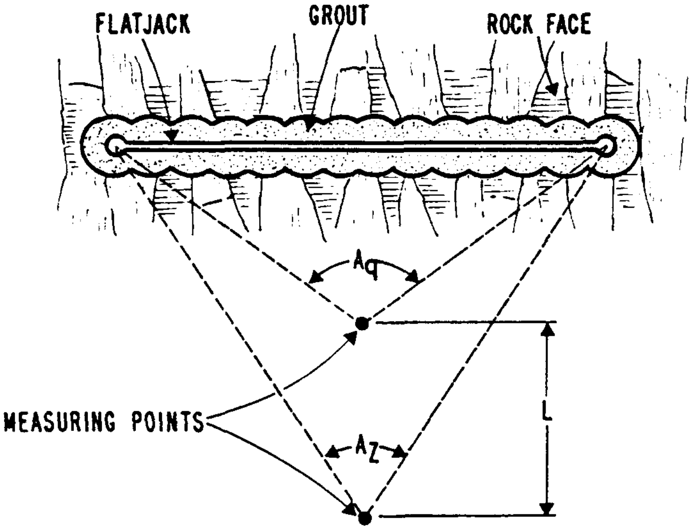


FIG. 1.1 DEFINITION OF GEOMETRIC TERMS FOR MODULUS DETERMINATION.

When deformation measurements are taken across the slot, Equation 5 above is rearranged to solve for the modulus, E:

$$E = K \frac{P}{\Delta Y} \qquad (10)$$

where:

P = pressure in flatjack

ΔY = deformation between measuring points

K = coefficient dependent on test geometry.

1.3.3 Assumptions and factors influencing the data.

1.3.3.1 The stress relief is assumed to be an elastic, reversible process. In non-homogeneous or highly fractured materials, this may not be completely true.

1.3.3.2 The equations assume that the rock mass is isotropic and homogeneous. Anisotropic effects may be estimated by testing in different orientations.

1.3.3.3 The flatjack is assumed to be 100% efficient. The design and size requirements of Section 3.1 were determined to satisfy this requirement to within a few percent.

1.3.3.4 The jack is assumed to be aligned with the principal stresses on the surface of the opening. The opening itself tends to align the stresses with the axes of symmetry to some extent. In addition, the required test orientations prevent the misalignment from being excessive for at least one of the tests.

1.4 References.

1.4.1 Alexander, L.G., 1960, "Field and Laboratory Tests in Rock Mechanics", Third Australia - New Zealand Conference on Soil Mechanics and Foundation Engineering, Sydney, Australia.

1.4.2 Dodds, D.J., 1969, Flatjack Tests, Foundation Sciences, Inc., Report to the Army Corps of Engineers, Missouri River District Laboratory, Portland, Oregon.

1.4.3 Panek, L. A. and Stock, J. A., 1964, Development of a Rock Stress Monitoring Station Based on the Flat Slot Method of Measuring Existing Rock Stress, Bureau of Mines Report of Investigation 6537, Dept. of the Interior, Washington, D.C.

1.4.4 Tincelin, M.E., Mesure des pressions de terrains dans les mines de fer de l'Est: Annales de l'Institut Technique de Batiment et des Travaux Publics, serie: Sols et Foundations, No. 58, pp. 972-990. Trans. by Britt, S.H., 1953, U.S. Geol. Survey open file report No. 28927, Washington, D.C.

2.0 Prerequisites

2.1 Personnel prequalification.

2.1.1 Test personnel. All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.1.2 Drilling personnel. Quality drilling is important to achievement of successful flatjack tests. The drilling personnel shall be familiar with, and have had experience in, drilling underground.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Criteria for test site selection.

2.3.1 Tests in orthogonal directions. The flatjack most accurately determines the stress parallel to the long axis of the adit, because this stress is the least concentrated. (The other tangential stress is highly concentrated). In addition, if the adit is in a stress field where one of the stresses is significantly larger than the others (3 or 4 times), certain locations in the adit may be in very low compressive or tensile stress. Flatjack tests in these locations can give anomalous and misleading results. Because of these factors, the test adit should have at least two, and preferably three, long (at least 4 to 5 times the diameter), straight sections at about 90° to each other. Testing should be distributed evenly in all three sections to provide redundant data and, if results in one section are anomalous due to the stress field, to allow the program to produce sufficient usable data.

2.3.2 Groups at each test station. At least one group of jacks should be tested in each adit section. Each group should have three flatjacks installed at 0°, 45°, and 90° to the long axis of the adit. The jacks in each group should all be placed in one part of the adit, i.e., all in the rib or all in the crown. The three jacks should be within 20 ft (6.1 m) of each other along the length of the adit.

2.3.3 Tests in different material. Different rock types can transmit different amounts of stress and have different deformational properties. Each rock type that will be encountered during construction should be tested.

2.3.4 Local geologic features. Local features, particularly faults, shear zones, etc., can influence the local stress field. Large inclusions in the rock can affect both the stress and deformational properties. Test locations should be carefully selected so that the effects of such features are minimized or, if they are the features of interest, accounted for fully.

2.3.5 Influence of excavations. Other excavations intersecting the test adit will cause complex stress concentration effects by superposition. Flatjack tests should be located at least three diameters of the intersecting feature away from that feature.

3.0 Equipment

3.1 Flatjacks.

Flatjacks shall be designed to operate at pressures of several thousand psi when properly installed. The jacks shall be constructed so that the two main plates move apart in a parallel manner over the range of the jack. The range shall be at least 0.25 in. (6.35 mm). The jacks shall be square and no less than 2 ft (0.61 m) wide.

3.2 Transducers.

3.2.1 Pressure. Electronic transducers or hydraulic gages may be used to monitor flatjack pressure. The pressure transducer shall have an accuracy of at least ± 20 psi (0.14 MPa), including errors introduced by the readout system, and a resolution of at least 10 psi (0.069 MPa).

3.2.2 Deformation. Deformation transducers include dial gages, Whittemore-type strain gages, and electronic transducers such as LVDTs or linear potentiometers. The transducer shall have an accuracy of at least ± 0.0001 in. (0.0025 mm) and a resolution of at least 0.00005 in. (0.0013 mm).

3.2.2.1 For stress determinations, "point" measuring devices such as strain gages or borehole deformation gages may be used to obtain cancellation values.

3.2.2.2 For modulus determinations, the transducer shall measure deformation across at least 10 in. (25.40 cm) of rock, or over a longer length if necessary to encompass a representative mass of the rock.

3.3 Mortar.

Mortar shall be used to cement the flatjack into the slot. A high-early strength, non-shrink material shall be used, such as Embeco or Five Star grout. The mortar may include up to 50% clean sand by weight, with grain size between 20- and 60-mesh. Clean, potable water shall be used for the mortar.

3.4 Drilling equipment.

Equipment for drilling the slot may be either rotary (core or plug) or percussive. Rotary drilling shall be used in weak or fractured rocks where percussive drilling would damage the adjacent rock. Drilling for deformation transducers depends on the type of transducer chosen; percussion is generally acceptable, but rotary may be required for borehole devices.

4.0 Testing

4.1 Surface preparation.

4.1.1 Dimensions. The prepared surface shall extend at least 1 ft (0.31 m) past either end of the flatjack slot and at least 1 ft (0.31 m) past the furthest measuring points. The transducers or flatjack shall not be within 1 ft (0.31 m) of unprepared surface at any point. The prepared surface dimensions are shown on Figure 4.1.

4.1.2 Method. Percussion drilling to a uniform depth is recommended to prepare the rock face. Residual rock between the drill holes may be removed by moving the bit back and forth until a smooth surface is achieved. Alternatively, in hard, competent rock, controlled blasting with very small charges may be used to remove the residual rock. In softer material, coarse grinding or cutting devices may be required.

4.1.3 Rock quality. The flatjack and deformation transducers shall be installed in sound rock. Loose and broken rock from the excavation process shall be removed. Deeper breaks may be detected by a dull, hollow sound when struck with a hammer; such material shall also be removed.

4.1.4 Smoothness. Ideally, the prepared surface shall be a plane. The difference between the highest and lowest points on the prepared surface shall be not greater than 2 in. (51 mm).

4.2 Transducer installation.

Transducers shall be installed on the center line normal to the flatjack, either at the surface or at depth. A recommended measuring setup is shown on Figure 4.1.

4.2.1 Stress determination. Transducers for stress determination shall be installed within L/2 of the flatjack slot, where L is the width of the flatjack. If surface measuring points are used, the entire deformation interval shall be within L/2. For cancellation measurements on the same side of the slot, it is recommended that the transducer remain installed for the duration of the test, rather than being removed during the slot-cutting operation. If surface measuring points are installed in the rock face, the mortar shall set for at least 24 hours prior to initial reading.

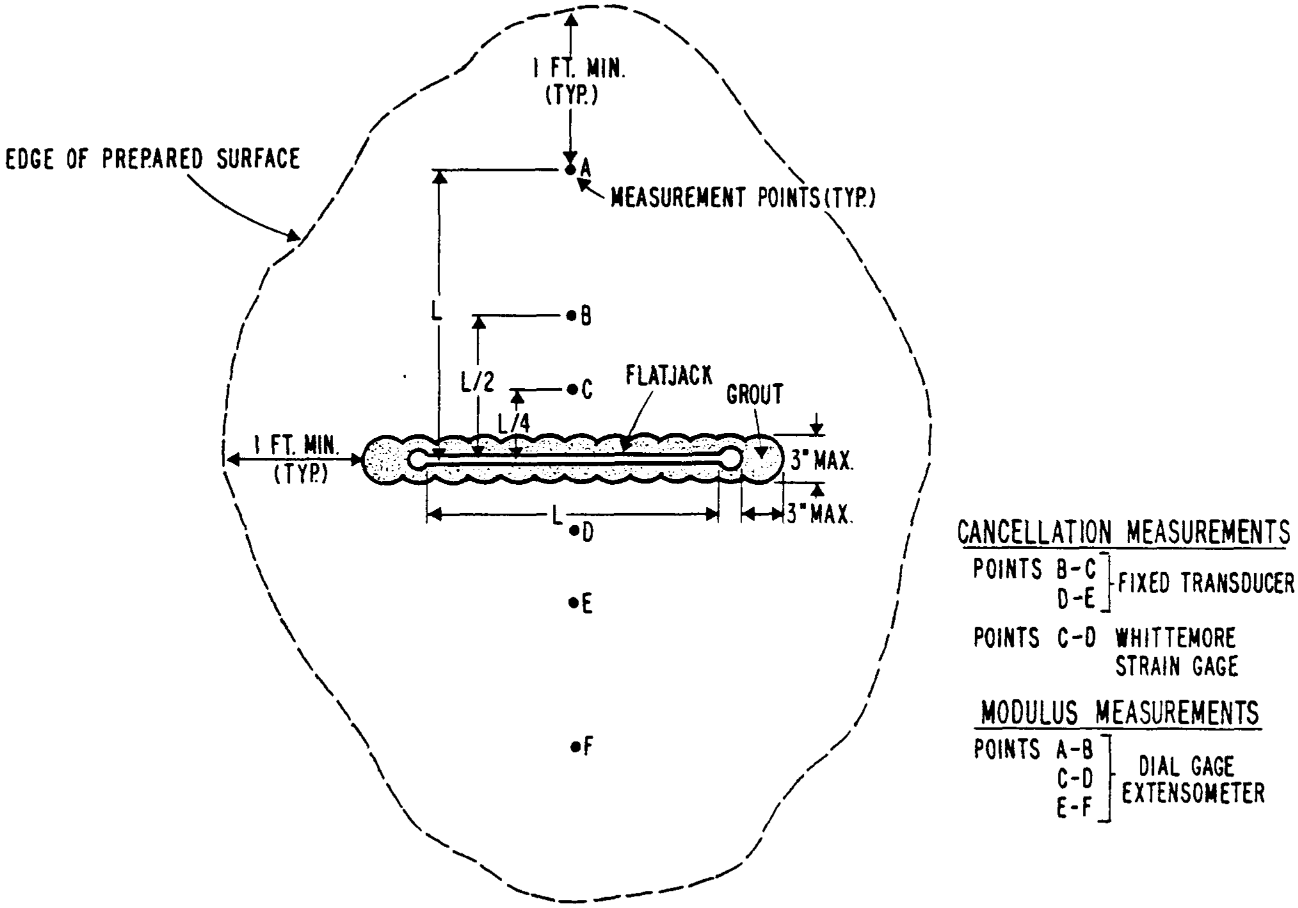


FIG. 4.1 RECOMMENDED FLATJACK MEASUREMENT ARRAY,
SURFACE MEASUREMENTS

4.2.2 Modulus determination. The transducer gage length for modulus measurements shall be at least 10 in. (25.40 cm). Surface measuring points with provision for across-the-slot measurements are recommended. These transducers may be installed after the slot is cut; if mortar is used, it shall set at least 24 hours before readings are taken.

4.3 Initial measurements.

Initial measurements shall be taken prior to cutting the slot. If a Whittemore-type strain gage is used, it shall be zeroed against an Invar standard, and at least 12 readings shall be taken across each set of measuring points. If electronic transducers are used, readings shall be taken at 1 minute intervals until three consecutive readings are stable within the limitations of the equipment.

4.4 Slot cutting.

The slot is generally formed by drilling overlapping holes with a suitable guide. The slot shall be no more than 3 in. (76 mm) wide, and extend no more than 3 in. (76 mm) past the edges of the flatjack. It shall be deep enough that the flatjack may be inserted 3 in. (76 mm) beyond the lowest point on the rock face adjacent to the slot. Care shall be taken that the holes are parallel, to keep the slot from becoming unacceptably large at depth. The slot shall be washed clean of all dirt and drill cuttings, using clean water.

4.5 Relaxation measurements.

Deformation shall be measured immediately upon completion of slot cutting, and again immediately prior to testing. If the rock undergoes strain under constant load over a period of time, several intermediate readings shall be taken to evaluate this effect.

4.6 Flatjack installation.

Flatjacks shall be centered in the slot and recessed 2 in. (51 mm) from the face of the excavation to minimize the possibility of rupture during pressurization. The mortar surrounding the jack shall be free from voids. The jack shall be installed at least 24 hours prior to testing.

4.7 Flatjack testing.

4.7.1 Cancellation and modulus. The flatjack pressure shall be raised in 100 psi (0.69 MPa) increments until cancellation of all measuring points has been achieved. Deformation shall be read after each pressure increment. The peak cancellation pressure shall be maintained for 15 minutes to check for time-dependent deformation; deformation readings shall be taken every 5 minutes. The pressure shall be reduced in 100 psi (0.69 MPa) decrements to zero, with deformation read after every decrement. Zero pressure shall be maintained for 15 minutes to check for time-dependent deformation; deformation readings shall be taken every 5 minutes. The cycle shall be repeated, except that 10 equal pressure increments and decrements shall be used. Jack pressure shall never exceed cancellation pressure.

4.7.2 Creep. Time-dependent deformation may be measured by maintaining a fixed pressure in the flatjack and measuring deformation periodically. The pressure level shall be not greater than the cancellation pressure.

4.8 Data recording requirements.

The data shown on Form GT-C.3-1 shall be recorded as a minimum.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the materials tested.

5.1.1 Scope of testing program.

5.1.1.1 Location and orientation. The location and orientation of each flatjack shall be presented. A graphic presentation is recommended.

5.1.1.2 Rationale for test location selection. The reasons for selecting individual test locations shall be discussed.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The geology of each test location shall be described including the rock type, fractures, alterations, inclusions, etc. A simple geologic map of the test adit at the flatjack location, showing the jack and measuring points, is recommended.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations and any limitations in their applications shall be noted, and their effects on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary of results. A table including rock types, orientations, average cancellation pressures and skin stress values, average modulus of deformation values, ranges, and uncertainties shall be presented.

5.4.2 Individual results. A table including test numbers, rock types, orientations, relaxation deformation, cancellation pressure, skin stress, and modulus of deformation values shall be presented.

5.4.3 Graphics. Typical pressure vs. deformation curves for each rock type shall be presented.

5.4.4 Creep. Deformation vs. time curves for all creep tests shall be presented.

5.4.5 Other. The following other types of data analyses and presentations may be included, as appropriate.

5.4.5.1 Histogram of results.

5.4.5.2 Comparison of results to results from other types of in situ tests.

5.4.5.3 Estimate of undisturbed stress levels.

5.4.5.4 Comparison of results to other studies.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all pressure and deformation measurements.

5.5.2 Rock mass variability. For each suite of similar tests, the mean modulus of deformation, the range, standard deviation and 95% confidence limits for the mean shall be calculated, as a minimum. The uncertainty of the group shall be compared with the measurement uncertainty to determine whether measurement error or sample variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed differences between groups are significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Pressure vs. deformation curves. A pressure vs. deformation curve for each test shall be included in an appendix.

5.6.2 Data sheets. A completed Form GT-C.3-1 for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test where Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, the test procedure, and the performance verification of the equipment. After testing, the completed Form GT-C.3-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-C.3-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-C.3-1.

In Situ Stress and Modulus of Deformation Determination
Using the Flatjack Method

Test Data Sheet - Form GT-C.3-1

Project ______________________ Test No. ______________________

Feature ______________________ Test Location ______________________

Rock Type ______________________ Orientation ______________________

Equipment Description	Serial No.	Date of Next Calibration

Sketch of flatjack, geology, and measurement geometry:

					Deformation		
Date	Time	By	Pressure	No. 1	No. 2	No. 3	Remarks

Test Supervisor ______________________ Date ____________________

Quality Assurance ____________________ Date ____________________

Project Engineer _____________________ Date ____________________

Procedure GT-D.1

In Situ Modulus of Deformation Determination Using the NX Borehole Jack

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to measure the in situ modulus of deformation at various depths and orientations in a rock mass. Information on time-dependent deformation may also be obtained.

1.1.2 Limitations. The volume of rock tested is only about 1 ft^3 (0.028 m^3), which may not include enough discontinuities for the test results to be representative of a larger section of the rock mass.

1.2 General description of the test.

The borehole jack exerts pressure on two opposing sides of an NX (3-in. (76 mm)-diameter) borehole over a length of approximately 8 in. (20 cm), by forcing two curved rigid plates into the borehole wall. Deformation between the plates is measured by linear variable differential transformers (LVDTs). Pressure is measured with a standard hydraulic transducer. During the test, the pressure is cycled incrementally and deformation is read at each increment. The modulus is then calculated. To determine time-dependent behavior, the pressure is held constant and deformation is observed over time.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deformation - the change in the diameter of the borehole.
1.3.1.2 Stress - force per unit area.

1.3.2 Equations and corrections.

1.3.2.1 The modulus of deformation, E, is calculated using (Goodman et al., 1968):

$$E = 0.86K(\mu,\beta)\frac{\Delta Q}{\Delta U/d} \qquad (1)$$

where:

$K(\mu,\beta)$ = a function of Poisson's ratio, μ, and the half contact angle, β

ΔQ = change in pressure on borehole wall

ΔU = change in borehole diameter

d = borehole diameter.

The values of K for various Poisson's ratios and a half contact angle of 45° (full platen/borehole contact), are given in Table 1.1.

Table 1.1
Values of K (μ, 45°)
(after Goodman, 1968)

Poisson's Ratio	K (μ, 45°)
0	1.282
0.05	1.288
0.10	1.288
0.15	1.282
0.20	1.271
0.25	1.254
0.30	1.232
0.35	1.204
0.40	1.170
0.45	1.131
0.50	1.087

A tangent modulus may be calculated if the ratio of pressure change to diameter change in Equation 1 is evaluated instantaneously:

$$\frac{\Delta Q}{\Delta U} = \frac{\partial Q}{\partial U} \qquad (2)$$

It may be seen that $\frac{\partial Q}{\partial U}$ is the slope at any point of the pressure vs. deformation curve shown on Figure 1.1.

A secant modulus may be calculated if the pressure and diameter change are related to the initial values using:

$$\frac{\Delta Q}{\Delta U} = \frac{Q(i)-Q(1)}{U(i)-U(1)} \qquad (3)$$

where:

$Q(i)$ = pressure on borehole wall at pressure level i

$Q(1)$ = initial pressure level on borehole wall

$U(i)$ = borehole diameter at pressure level i

$U(1)$ = initial borehole diameter.

The secant modulus is shown on Figure 1.2.

Modulus values may also be calculated over any finite segment of the pressure-deformation curve as required.

1.3.2.2 The pressure on the borehole wall, Q, is related to the pressure in the hydraulic system, S, as follows:

$$Q = kS \qquad (4)$$

where:

k = a constant inherent to the model of borehole jack being used.

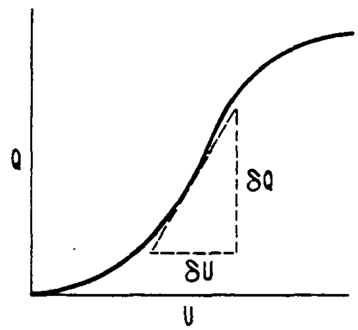


FIG. 1.1 PRESSURE AND DEFORMATION USED IN CALCULATION OF TANGENT MODULUS.

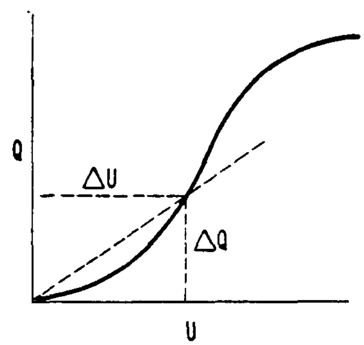


FIG. 1.2 PRESSURE AND DEFORMATION USED IN CALCULATION OF SECANT MODULUS.

1.3.2.3 The modulus values obtained with the borehole jack are generally low (Meyer and McVey, 1974). Several correction methods exist.

a) Heuze and Salem (1976) have attributed low modulus values to longitudinal flexure of the loading platens. They derived a correction curve from a finite element analysis. The polynomial form of the curve is:

$$E_c = -0.2259+1.989E-2.383E^2+2.4467E^3-1.0258E^4+0.19376E^5-0.012017E^6 \quad (5)$$

where:

E_c = corrected modulus value divided by 10^6

E = uncorrected modulus value divided by 10^6.

The uncorrected modulus value, E, is calculated as in Section 1.3.2.1. Equation 5 is valid for uncorrected modulus values of 1.0 to 4.0 x 10^6 psi (0.007 to 0.028 MPa), corresponding to corrected modulus values of 1.0 to 12.8 x 10^6 psi (0.007 to 0.088 MPa). Modulus values below 1.0 x 10^6 psi (0.007 MPa) are not corrected by this method, as longitudinal flexure is a negligible factor in softer materials.

b) Hustrulid (1976) attributes low modulus values to incomplete contact between the loading platens and borehole wall due to differences in radii. Using the data from Meyer and McVey (1974), he suggests that the modulus, E, may be calculated:

$$E = T^* \frac{\Delta Q}{\Delta U/d} \quad (6)$$

where:

T^* = a constant depending on Poisson's ratio, μ, of the rock and the half constant angle, β.

The values of T^* are given in Table 1.2.

c) Shuri (1981) studied the problem of borehole/platen radii mismatch from a different point of view than Hustrulid (1976). He developed a series of equations describing the mechanical interaction of the platen and borehole, which may be used to simulate borehole jack tests. He found that results of individual field tests did not correlate with theoretical predictions and were not totally corrected using Heuze and Salem's method.

TABLE 1.2

Values of T* For Various Half Contact Angles as a Function of Poisson's Ratio

β (Degrees)	Pressure Range (psi)	POISSON'S RATIO										
		0.0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
3.5	1000-2000	5.201	5.165	5.101	5.009	4.888	4.740	4.563	4.358	4.124	3.863	3.573
4.4	2000-3000	4.641	4.613	4.560	4.482	4.379	4.252	4.100	3.923	3.721	3.494	3.243
5.2	3000-4000	4.288	4.265	4.218	4.149	4.057	3.943	3.806	3.646	3.463	3.258	3.030
5.7	4000-5000	4.111	4.090	4.046	3.982	3.895	3.787	3.657	3.506	3.333	3.138	2.922
6.3	5000-6000	3.931	3.911	3.871	3.810	3.729	3.627	3.505	3.362	3.198	3.014	2.809
6.9	6000-7000	3.776	3.759	3.721	3.664	3.587	3.490	3.374	3.238	3.082	2.907	2.713
7.4	7000-8000	3.663	3.647	3.611	3.557	3.483	3.390	3.278	3.147	2.998	2.829	2.641
7.8	8000-9000	3.582	3.566	3.532	3.479	3.407	3.317	3.209	3.081	2.936	2.771	2.589
8.3	9000-10000	3.488	3.473	3.441	3.390	3.321	3.234	3.129	3.006	2.865	2.705	2.528

[1] after Hustrulid, 1976 (see Ref. 1.4.4)

If a sufficient number of tests are performed in a single rock type, however, the distribution of results with borehole diameter may be used to estimate the rock mass modulus.

1.3.3 Assumptions. In these analyses, the rock is assumed to be homogeneous and isotropic. The effect of anisotropy is evaluated by selectively orienting the tests; however, the data reduction equations discussed above are still used. The error which this introduces has not been evaluated.

1.4 References.

1.4.1 de la Cruz, R.U., 1978, "Modified Borehole Jack Method for Elastic Property Determination in Rocks", Rock Mechanics, 10.

1.4.2 Goodman, R.E., Tran, K.V., and Heuze, F.E., 1968, "Measurement of Rock Deformability in Boreholes", Proceedings of the 10th Symposium on Rock Mechanics, University of Texas at Austin, Austin, Texas.

1.4.3 Heuze, F.E. and Salem, A. 1976, "Plate Bearing and Borehole Jack Tests in Rock - A Finite Element Analysis", Proceedings of the 17th Symposium on Rock Mechanics, Snowbird, Utah.

1.4.4 Hustrulid, W.A., 1976, "An Analysis of the Goodman Jack", Proceedings of the 17th Symposium on Rock Mechanics, Snowbird, Utah.

1.4.5 Meyer, T.O. and McVey, J.R., 1974, NX Borehole Jack Modulus Determinations in Homogeneous, Isotropic, Elastic Materials, Report of Investigations 7855, U.S. Bureau of Mines, Washington, D.C.

1.4.6 Shuri, F.S., 1981, "Borehole Diameter as a Factor in Borehole Jack Results", Proceedings of the 22nd Symposium on Rock Mechanics, Cambridge, Massachusetts.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to Standard Quality Assurance procedures.

2.3 NX boreholes drilled.

2.3.1 Number and orientation of boreholes. The number and orientation of the boreholes depends on the geometry of the project and the geology of the site.

2.3.1.1 Each type of rock should be tested. In addition, areas of low modulus of deformation within a rock mass, such as fracture or alteration zones, are of particular interest and should be tested.

2.3.1.2 Tests should be conducted at orientations to sample the anisotropy of the rock mass, for example, parallel and perpendicular to the bedding in a sedimentary sequence, or parallel and perpendicular to the long axes of the columns in a basalt flow. Boreholes should generally be orthogonal to each other and either parallel or perpendicular to the structure of the rock formation.

2.3.1.3 A sufficient number of tests should be conducted to allow the statistical methods described above to be utilized. At least 30 tests in each rock material are recommended.

2.3.2 Boreholes cored. The boreholes shall be drilled using diamond core techniques. Continuous core should be obtained.

2.3.3 Core logged. The recovered core should be completely logged, with emphasis on fractures and other mechanical non-homogeneities, as described in procedure GT-A.3 "Techniques for Logging Rock Core."

2.4 Test locations selected.

Within each borehole, locations for each test should be selected based on the core logs. In some cases, observation of the borehole with a borescope may be useful.

2.4.1 Testing all materials. All different rock materials in a borehole should be tested.

2.4.2 Testing discontinuities. Tests should be located both in intact zones and fractured zones to evaluate the effects of the discontinuities.

3.0 Equipment

3.1 NX borehole jack.

The borehole jack for which the equations and corrections of Section 1.3 were derived is currently manufactured under patent. The following specifications are given:

range of travel: 0.50 in., from closed at 2.75 in. to fully open at 3.25 in. (12.70 mm, from closed at 69.85 mm to fully open at 82.55 mm)

maximum pressure on borehole wall: 9300 psi (hard rock model) (64.12 MPa)
5544 psi (soft rock model) (38.23 MPa)

deformation resolution: 0.001 in. (0.025 mm)

The maximum pressure is achieved with a hydraulic system pressure of 10,000 psi (68.95 MPa). The deformation is measured by LVDTs at each end of the loading platens, which are referred to as the near and far LVDTs.

3.2 Pressure transducer.

A hydraulic gage or electronic transducer may be used to measure the hydraulic system pressure. The transducer shall have an accuracy of at least ± 20 psi (0.14 MPa), including errors introduced by the readout equipment, and a resolution of at least 10 psi (0.07 MPa).

3.3 Casing alignment system.

The borehole jack is attached to BX drill casing and lowered into position in the borehole. To determine the orientation of the jack, an orientation mark is transferred to successive sections of casing as they are added. To avoid introducing a systematic and progressive error into the orientation, an alignment device shall be used to transfer the mark from one casing section to another. In vertical boreholes, a plumb line may be sufficient. In inclined or horizontal boreholes, a marking guide such as the one shown on Figure 3.1 has been found satisfactory.

4.0 Testing

4.1 Boreholes.

Boreholes shall be totally free from dirt and drill cuttings. The borehole shall be washed with clean water if necessary.

4.2 Initial seating pressure.

When the jack is at the test location and in the desired orientation, the hydraulic pressure shall be raised to 50 psi (0.34 MPa) to seat the platens against the borehole wall. This pressure shall be used as the "zero" pressure throughout the remainder of the test.

4.3 Pressure level.

The rock shall be tested to the maximum capacity of the jack or until failure occurs under the loading platens. Failure may be recognized by increasing deformation without a corresponding increase in pressure. Failure should occur only in the weakest rock types.

4.4 Pressure cycles.

In at least 25% of the tests in each rock material, multiple-pressure cycling to progressively higher loads shall be conducted to evaluate permanent deformation and the effects of cycling on modulus. The peak pressures shall be approximately 30, 60 and 100% of the maximum. During each cycle, the pressure shall be increased in 10 equal increments and decreased in 10 equal decrements. At the end of each cycle, the pressure shall be returned to the initial

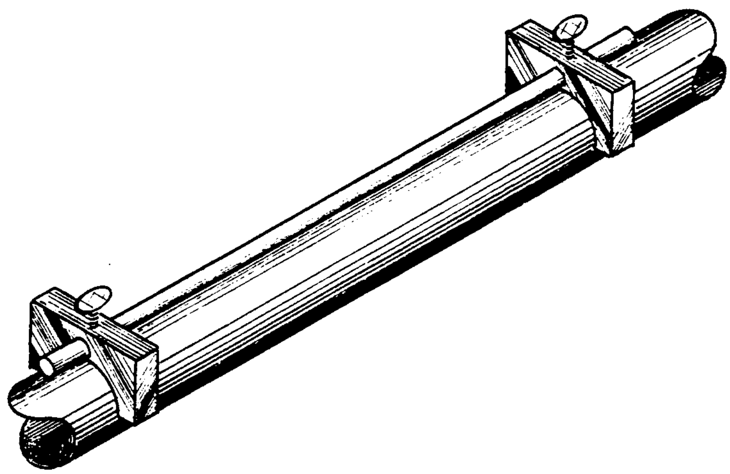


FIG. 3.1 MARKING GUIDE ON SECTION OF BX CASING

seating pressure. If cycling is not performed for a particular test, the pressure shall be raised to the maximum in 10 equal increments and lowered to the seating pressure in 10 equal decrements.

4.5 Orthogonal Tests.

At each test depth in the borehole, two tests shall be conducted with the directions of applied load at 90° to each other.

4.6 Time-dependent effects.

Time-dependent deformation shall be evaluated during the test by maintaining the maximum test pressure for 15 minutes and recording deformation at 5 minute intervals. When the pressure is reduced to the initial seating pressure, deformation readings shall again be taken at 5 minute intervals for 15 minutes. If at least three such determinations are made in a given rock material, and the deformation indicated by either LVDT does not change by more than 0.001 in. (0.025 mm) over the 15-minute interval in any of the tests, it may be assumed that the material does not exhibit time-dependent behavior at these stress levels, and this portion of the pressure cycle may be deleted for the remainder of the tests in this rock material.

4.7 Calibration.

The borehole jack shall be calibrated prior to, and at the completion of, the test program according to manufacturer's directions and following standard Quality Assurance procedures. In addition, the jack shall be calibrated during the test program if the deformation readings become suspect. This is particularly likely if the difference in the readings of the near and far LVDTs exceeds the manufacturer's recommendation of 0.020 in. (0.51 mm), indicating excessive misalignment of the platens.

4.8 Data recording requirements.

The data shown on Form GT-D.1-1 shall be recorded as a minimum for the test.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 The location and orientation of the test boreholes shall be presented. A graphic presentation is recommended.

5.1.1.2 The reasons for selecting the test locations shall be discussed.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock type shall be described macroscopically. Structural features affecting the borehole jack testing shall be discussed as appropriate.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure has varied from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary table. A summary table shall be presented including the rock materials, the pressure range over which the modulus values were calculated, the average modulus values, ranges, and uncertainties.

5.4.2 Table of individual results. A table listing test number, rock material/structure, and average modulus values for each location shall be presented.

5.4.3 Graphic presentations. A typical pressure vs. deformation curve for each rock material shall be presented.

5.4.4 Other. The following other types of analyses and presentations may be included as appropriate.

5.4.4.1 Relationship between modulus and applied stress.

5.4.4.2 Discussions of modulus dependence on geology.

5.4.4.3 Histograms of results.

5.4.4.4 Comparison with laboratory modulus values or the results of other in situ modulus tests.

5.4.4.5 Comparison of results to other rock types or previous studies.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Sample variability. For each rock material or structure, the mean modulus of deformation, range, standard deviation and 95% confidence limits for the mean shall be calculated as a minimum. The uncertainty of the group shall be compared with the measurement uncertainty to determine whether measurement error or rock variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Pressure vs. deformation curves. A pressure vs. deformation curve from each test shall be included in an appendix.

5.6.2 Test form. A completed test data Form GT-D.1-1 for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-D.1-1 shall be reviewed and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-D.1-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of GT-D.1-1.

In Situ Modulus of Deformation
Using the NX Borehole Jack

Test Data Sheet - Form GT-D.1-1

Project ____________________ Test No. ________________

Feature ____________________ Depth ________________

Borehole ____________________ Orientation ________________

Orientation: Bearing __________ Rock Type ________________

Inclination __________

Date __________

Tested By __________

Equipment Description	Serial No.	Date of Next Calibration

Time	Pressure Reading	Near LVDT	Far LVDT

Time	Pressure Reading	Near LVDT	Far LVDT

Remarks:

Test Supervisor ______________________ Date ________________

Quality Assurance ____________________ Date ________________

Project Engineer _____________________ Date ________________

Procedure GT-D.2

In Situ Modulus of Deformation Determination
Using the Rigid Plate Loading Method

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to measure the modulus of deformation of a rock mass in situ. Time-dependent behavior may also be investigated. This test is designed to be conducted in an adit or small underground chamber; however, with suitable modification it could be conducted at the surface.

1.2 General description of the test. Areas on two opposing faces of a test adit are flattened and smoothed. A mortar pad and rigid metal plate are installed against each face and a hydraulic loading system is placed between the rigid plates. The plates are loaded incrementally and the average deflection of each plate is measured at each pressure increment. The modulus of deformation is then calculated.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deflection - the movement of the rigid plate in response to the applied load.

1.3.1.2 Load - the total force acting on the rigid plate or rock face.

1.3.1.3 Stress - force or load per unit area.

1.3.2 Equation. This equation is based on the elastic solution for a rigid circular die (constant deflection) pressed into the surface of a semi-infinite elastic medium. The modulus, of deformation, E, is calculated using:

$$E = \frac{(1-\mu^2)P}{2W_a r} \qquad (1)$$

where:

μ = Poisson's ratio of the rock

P = total load on the rigid plate

W_a = average deflection of the rigid plate

r = radius of the rigid plate.

1.3.3 Assumptions and factors influencing the results.

1.3.3.1 In practice, the plate used to load the rock face is not perfectly rigid. Dodds (1974) estimates that the error introduced is 8% at most. To minimize this error, the plate is constructed to be as rigid as possible, the rock face is smoothed, the thickness of the mortar bearing pad is minimized and a high modulus material is used for the pad.

1.3.3.2 The rock under the plate is not homogeneous as assumed in theory. The rigid plate test produces an average modulus value for the material tested. For this reason, measurement of deformation at discrete points within the rock under the plate is not an allowable technique with this test.

1.4 References

1.4.1 Coates, D.F. and Gyenge, M., 1966, "Plate Load Testing on Rock for Deformation and Strength Properties", Testing Techniques for Rock Mechanics, ASTM Special Technical Publication 402, Philadelphia, Pennsylvania.

1.4.2 Dodds, D.J., 1973, "Interpretation of Plate Loading Test Results", Field Testing and Instrumentation of Rock, ASTM Special Technical Publication 554, Philadelphia, Pennsylvania.

1.4.3 Dodds, D.J. 1974, A Manual for Plate Loading Tests Performed on Rock, Master's Thesis, Oregon State University, Corvallis, Oregon.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to Standard Quality Assurance procedures.

2.3 Testing program established.

2.3.1 Tests in all pertinent rock types. Each rock type that will be subject to significant loading by the project should be tested.

2.3.2 Anisotropy. The effects of anisotropy should be investigated by appropriately oriented tests, for example, parallel and perpendicular to the bedding of a sedimentary sequence, or parallel and perpendicular to the long axes of columns in a basalt flow.

2.3.3 Depth of investigation. The zone of rock that contributes to the measured deflection during the plate loading test depends on the diameter of the plate and the applied load. Larger plates and higher loads measure the response of rock further away from the test adit. Thus, if the rock around the adit is damaged by the excavation process, values may be obtained which do not represent the "true" in situ modulus unless large enough plates and loads are used to affect rock beyond the damaged zone. If the deformational properties of the damaged zone are the primary objective of the test program, small-diameter plate tests on typically excavated surfaces are adequate. If the undisturbed in situ modulus is desired, larger diameter plates and higher loads may be used, although practical considerations often limit the size of the equipment. Alternatively, careful excavation procedures, such as pre-splitting or other types of smooth-wall blasting, may be employed in the test area to limit damage to the rock.

2.3.4 Local geologic features. Any geologic features having different deformational characteristics than the primary rock mass, such as faults, fracture zones, cavities, inclusions, etc., should be tested to evaluate their effects. The testing program should be designed so that the effects of local geology can be clearly distinguished.

2.4 Poisson's ratio known.

Poisson's ratio for the rock mass must be known to use Equation 1. This may be obtained from laboratory testing or other types of in situ tests.

3.0 Equipment and apparatus

3.1 Loading equipment.

The loading equipment includes the device for applying the load, and the reaction members which transmit the load to each bearing plate. Load is generally applied hydraulically using hydraulic rams or flatjacks. If flatjacks are used, they shall have sufficient range to allow for the deflection of the rock and shall be constructed so that the two main plates move apart in a parallel manner over the usable portion of the range. The reaction members are generally thick-walled aluminum or steel pipes. A spherical bearing of suitable capacity shall be incorporated against one of the bearing plates.

3.2 Transducers.

3.2.1 Load. An electronic load cell is recommended to measure the load on the bearing plate. The cell shall have an accuracy of at least ± 1000 lb (453.6 kg) including the errors introduced by the readout system, and a resolution of at least 500 lb (226.8 kg). Alternatively, a pressure gage or electronic transducer may be used to monitor hydraulic pressure for calculation of load, provided the device can measure the load to the same specifications as the load cell. If a hydraulic ram is used, the effects of ram friction shall be determined. If flatjacks are used, care shall be taken that the jacks do not operate at the end of their range, where a significant fraction of the load may not be transferred to the rock because of jack stiffness.

3.2.2 Displacement. Displacement transducers are used to measure the deflection of the rigid plate as it is loaded. The transducers shall have an accuracy of at least ± 0.0001 in. (0.0025 mm), including the error introduced by the readout equipment, and a resolution of at least 0.00005 in. (0.0013 mm). Standard dial gages or linear variable differential transformers (LVDTs) are recommended.

3.3 Bearing pads.

The bearing pad material shall have a modulus of deformation of at least 4.0 X 10^6 psi (0.03 MPa). It shall be capable of conforming to the rock surface and bearing plate. High-early strength grout or molten sulfur bearing pads are recommended.

3.4 Bearing plates.

The bearing plates shall be designed to approximate a rigid die as closely as practical. Bearing plates shall not have a differential deflection between any two points against the bearing surface of more than 0.0005 in. (0.01 mm).

4.0 Testing.

A schematic of the test setup is shown on Figure 4.1.

4.1 Location.

The test shall be conducted across a "diameter" of the adit (a line containing the main axis of the adit) to minimize the resistance of the adjacent walls during loading.

4.2 Surface preparation.

4.2.1 Method. The surface shall be prepared by a method which causes the minimum damage to the finished rock face. Percussion drilling to a common depth is recommended for most rock types. Residual rock between the drill holes may be removed by moving the bit back and forth until a smooth face is achieved. Alternatively, in hard, competent rock, controlled blasting with very small charges may be used to remove the residual materials. In softer materials, coarse grinding or cutting devices may be used.

4.2.2 Size. The prepared rock surface shall extend at least one half the diameter of the bearing plate beyond the edge of the plate during the test.

4.2.3 Rock quality. The bearing surface shall be prepared in sound rock. Loose and broken rock from excavating shall be removed. Deeper breaks may be detected by a dull hollow sound when struck with a hammer; such material shall also be removed.

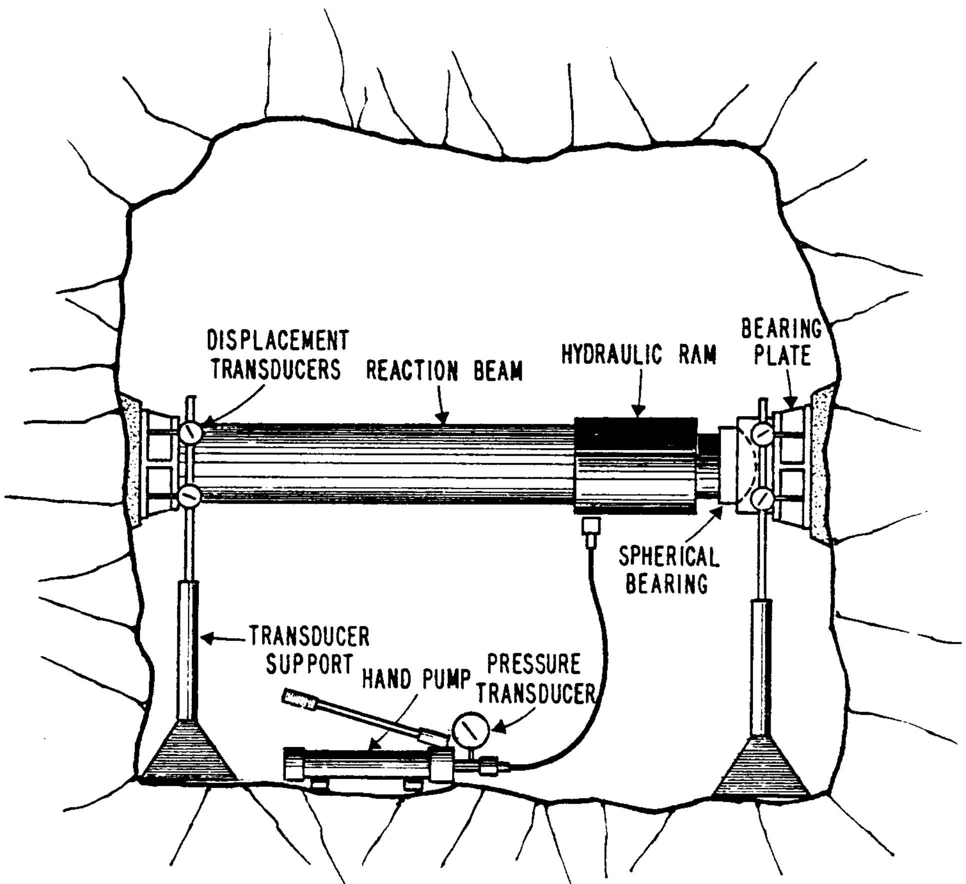


FIG. 4.1 TYPICAL RIGID PLATE BEARING TEST SETUP SCHEMATIC

4.2.4 Smoothness. The prepared rock face shall be as smooth as practical. In no case shall the deviation from a plane between the highest and lowest points exceed 1 in. (25.4 mm).

4.2.5 Cleaning. After the surface has been prepared, it shall be scrubbed and rinsed with clean water to remove any loose particles or dirt caused by the smoothing operation.

4.3 Bearing pad construction.

The bearing pad shall be constructed with the bearing plate in position, by pouring the pad material between the rock surface and plate. The pad material shall be contained by suitable form work around the edges of the plate. The only exception to this method is for near vertical tests where cement pads are used. In this case the lower bearing plate may be placed directly upon the pad prior to curing. In all cases, care shall be exercised to avoid air pockets or other cavities within the pad. The pad shall be no more than 1.5 in. (38.1 mm) thick at any point. The dimensional requirements of the rock face and bearing pad are shown on Figure 4.2.

4.4 Measuring points.

4.4.1 Location. The deflection of the bearing plate shall be measured in at least three equally spaced locations around the plate.

4.4.2 Support requirements. The displacement transducers shall be supported so that only the deflection of the bearing plate itself is measured. Generally, this means mounting the transducers on supports located outside the zone of influence of the test. In no case shall the transducers be mounted on the loading apparatus.

4.5 Pressurization cycles.

Four pressure cycles to peak pressures of 25, 50, 75 and 100% of the maximum load shall be conducted. Each cycle shall consist of 10 equal loading increments and 10 equal unloading decrements. Deflection readings shall be taken after each load increment and decrement. The peak and zero pressures for each cycle shall be maintained for 10 minutes, with deflection readings taken at 5-minute intervals.

4.6 Time-dependent behavior.

Transient, or primary, creep may be evaluated by maintaining a given load over a period of time and reading the deflection at various time intervals. The load shall be maintained to within $\pm$ 1% of the nominal value. The duration of the test depends on the type of rock, but is usually between 3 and 30 days. The reading interval depends on the transient creep rate, and ranges from every 2 to 3 hours during the early phases of the test to daily for its duration.

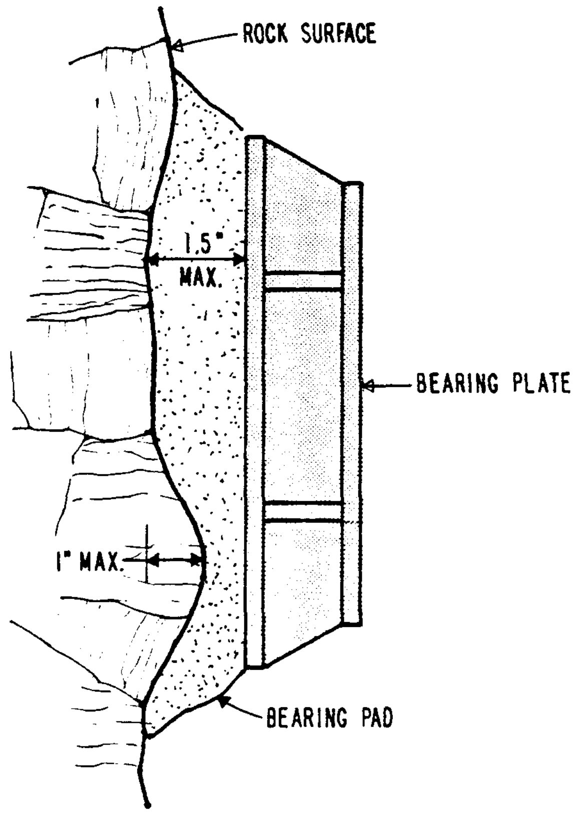


FIG. 4.2 ALLOWABLE DIMENSIONS FOR ROCK SURFACE AND BEARING PAD, RIGID PLATE LOADING TEST.

4.7 Data recording requirements.

The data shown on Form GT-D.2-1 shall be recorded as a minimum for this test.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 Test locations. The location and orientation of the plate loading tests shall be presented. A graphic presentation is recommended.

5.1.1.2 Test rationale. The reasons for selecting the test locations shall be discussed.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program, and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock types shall be described macroscopically. Structural features affecting the plate loading test shall be described. A diagram of the geology of each test area is recommended.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test should be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary Table. A summary table shall be presented including the rock materials, the pressure range over which the modulus values were calculated, the average modulus values, ranges, and uncertainties.

5.4.2 Table of individual results. A table listing test number, rock material/structure, and average modulus values for each test location shall be presented.

5.4.3 Graphic presentations. A typical average deflection curve for each rock material shall be presented.

5.4.4 Time-dependent properties.

5.4.4.1 A comparison of deflection at various time intervals for the rock types of interest shall be presented.

5.4.4.3 Typical transient creep curves for each rock type shall be presented.

5.4.5 Other. The following other types of analyses and presentations may be included as appropriate.

5.4.5.1 Relationship between modulus and applied stress.

5.4.5.2 Discussion of modulus dependence on geology.

5.4.5.3 Histograms of results.

5.4.5.4 Comparison with laboratory modulus values or the results of other in situ modulus tests.

5.4.5.5 Comparison of results to other rock types or previous studies.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Sample variability. For each rock material or structure the mean modulus value, range, standard deviation and 95% confidence limits for the mean shall be calculated, as a minimum. The uncertainty of the group shall be compared with the measurement uncertainty to determine whether measurement error or rock variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Average deflection curves. A pressure vs. average deflection curve from each test shall be included in an appendix.

5.6.2 Test form. A completed test data Form GT-D.2-1 for each test shall be included in an appendix.

5.6.3 Creep curves. If appropriate, a transient creep curve for each creep test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure and equipment performance verification. After testing, the completed Form GT-D.2-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-D.2-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of GT-D.2-1.

In Situ Modulus of Deformation Using the Rigid Plate Loading Method
Test Data Sheet - Form GT-D.2-1

Project ____________________ Test No. ____________________

Feature ____________________ Rock Type ____________________

Test Location ____________________ Plate Diameter ____________________

Orientation ____________________ Tested by ____________________

Date ____________________

Equipment Description	Serial No.	Date of Next Calibration

Time	Load Reading	Displacement Reading No. 1	No. 2	No. 3

Time	Load Reading	Displacement Reading No. 1	No. 2	No. 3

Remarks:

Test Supervisor ____________________ Date ________________

Quality Assurance __________________ Date ________________

Project Engineer ___________________ Date ________________

Procedure GT-D.3

In Situ Modulus of Deformation Determination Using the Flexible Plate Loading Method

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to measure the modulus of deformation of a rock mass in situ. Time-dependent behavior may also be investigated. This test is designed to be conducted in an adit or small underground chamber; however with suitable modifications it could be conducted at the surface.

1.2 General description of the test.

Areas on two opposing faces of a test adit are flattened and smoothed. If deflection is to be measured within the rock mass, instruments are installed in the rock. A mortar pad is placed on each face. A hydraulic loading system consisting of flatjacks, reaction members, and associated hardware is constructed between the faces. The two faces are loaded incrementally and the deformation of the rock mass either within the rock or at the surface is measured after each increment. The modulus of deformation is then calculated.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deflection - the movement of the rigid plate in response to the applied load.

1.3.1.2 Load - the total force acting on the rigid plate or rock face.

1.3.1.3 Stress - force or load per unit area.

1.3.2 Equations. The equations are based on the elastic solution for uniformly distributed load (constant stress) over a circular area acting on a semi-infinite elastic medium. The deflection is always defined as the movement in the same direction as the applied load.

1.3.2.1 The modulus, E, calculated from the deflection at the center of a circularly loaded area at the rock surface is:

$$E = \frac{2(1-\mu^2)qr}{w_c} \qquad (1)$$

where:

μ = Poisson's ratio of the rock

q = pressure on loaded area

r = radius of loaded area

w_c = deflection at center of loaded area.

1.3.2.2 The modulus, E, calculated from the deflection at the edge of a circularly loaded area at the rock surface is:

$$E = \frac{4(1-\mu^2)qr}{\pi\ w_e} \tag{2}$$

where:

$\pi\, w_e$ = deflection at the edge of the loaded area.

1.3.2.3 The modulus, E, calculated from the deflection at a point within the rock mass beneath the center of a circularly loaded area is:

$$E = \frac{2q(1-\mu^2)}{w_z}\left((r^2+z^2)^{1/2}-z\right) - \frac{qz(1+\mu)}{w_z}\left(z(r^2+z^2)^{-1/2}-1\right) \tag{3}$$

where:

z = depth beneath center of loaded area
w_z = deflection at depth z.

1.3.2.4 The modulus, E, calculated from the deflection at the center of an annularly loaded area at the rock surface is:

$$E = \frac{2q(1-\mu^2)(r_2-r_1)}{w_c} \tag{4}$$

where:

r_2 = outside radius of annulus
r_1 = inside radius of annulus.

1.3.2.5 The modulus, E, calculated from the deflection at the the edge of an annularly loaded area at the rock surface is:

$$E = \frac{4q(1-\mu^2)(r_2-r_1)}{\pi\ w_e} \tag{5}$$

1.3.2.6 The modulus, E, calculated from the deflection at a point within the rock mass beneath the center of an annularly loaded area is:

$$E = \frac{2q(1-\mu^2)}{w_z}\left((r_2{}^2+z^2)^{1/2}-(r_1{}^2+z^2)^{1/2}\right)+\frac{z^2q(1+\mu)}{w_z}\left((r_1{}^2+z^2)^{-1/2}-(r_2{}^2+z^2)^{-1/2}\right) \tag{6}$$

1.3.2.7 The deflection, w_z, along the centerline beneath the loaded area may be expressed in a general form from Equation 3 or 6:

$$w_z = \frac{q}{E} K_z \tag{7}$$

From this, it follows that the modulus, E, may be calculated from the relative deflection between two positions below the center of the loaded area:

$$E = q \frac{K_{z1}-K_{z2}}{w_{z1}-w_{z2}} \tag{8}$$

where:

K_{z1}, K_{z2} = geometric coefficients for depths z1 and z2, respectively

w_{z1}, w_{z2} = deflection at depths z1 and z2, respectively.

1.3.3 Assumptions and factors influencing the results. The rock under the loaded area is generally not homogeneous as assumed in theory. It will respond to the load according to its local deformational characteristics. Therefore, deflection measurements at discrete points on the rock surface tend to be heavily influenced by the deformational characteristics of the rock mass at that location, and may give results that are unrepresentative of the rock mass. Redundant measurements and statistical examination of the data are used to mitigate this problem.

Measurement of the deflection within the rock mass can utilize a finite gage length to reflect the average rock mass deformational properties between the measuring points. This approach contains two drawbacks, however. First, the dissipation of pressure beneath the loaded area is quite rapid and the rock mass is tested at very low stress levels unless the measurement points are very close to the rock surface. In that case the same problems as with surface measurements occur. Tests at low stress levels may give unrealistically low modulus values as microfractures, joints, and other discontinuities in the rock close. Measurement point spacing has been specified to minimize the problem. Secondly, the disturbance caused by implanting the deflection transducer in the rock mass is difficult to evaluate. The techniques in this procedure are designed to produce minimal disturbance.

1.4 References.

1.4.1 Dodds, D.J., 1973, "Interpretation of Plate Loading Test Results", Field Testing and Instrumentation of Rock, ASTM Special Technical Publication 554, Philadelphia, Pennsylvania.

1.4.2 Dodds, D.J., 1974, A Manual for Plate Loading Tests Performed on Rock, Master's Thesis, Oregon State University, Corvallis, Oregon.

1.4.3 ISRM Commission on Standardization of Laboratory and Field Tests, 1979, "Suggested Methods for Determining In Situ Deformability of Rock", Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 16, No. 2.

1.4.4 Misterek, D.L., Sleber, E.J., and Montgomery, J.S., 1974, "Bureau of Reclamation Procedures for Conducting Uniaxial Jacking Tests", Field Testing and Instrumentation of Rock, ASTM Special Technical Publication 554, Philadelphia, Pennsylvania.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to Standard Quality Assurance procedures.

2.3 Testing program established.

2.3.1 Sampling various rock types. Each rock type that will be subject to loading by the project should be tested. The effects of anisotropy should also be investigated by appropriately oriented tests, for example parallel and perpendicular to the bedding of a sedimentary sequence, or parallel and perpendicular to the long axes of columns in a basalt flow.

2.3.2 Depth of investigation. The zone of rock that contributes to the measured deflection during the plate loading test depends on the diameter of the flexible plate and the load. Larger plates and higher loads measure the response of rock further away from the test adit. Thus, rock around the adit which is damaged by the excavation process may contribute to values which do not represent the "true" in situ modulus if the plates and loads used for testing are too small. If the deformational properties of this damaged zone are the primary objective of the test program, small-diameter plate tests on typically excavated surfaces are adequate. If the undisturbed in situ modulus is desired, a larger-diameter plate and higher loads may be used, although practical considerations often limit the size of the equipment. Alternatively, careful excavation procedures to minimize damage to the rock, such as pre-splitting or other types of smooth-wall blasting, may be employed in the test area.

2.3.3 Local geologic features. Any geologic features that have different deformational characteristics than the main rock mass, such as faults, fracture zones, cavities, inclusions, etc., should be tested to evaluate their effects. The testing program should be designed so that the effect of local geology can be clearly distinguished.

2.4 Poisson's ratio known.

Poisson's ratio for the rock mass must be known to apply Equation 1. This value may be obtained from laboratory testing or other types of in situ tests.

3.0 Equipment and apparatus

A typical flexible plate loading test setup is shown on Figure 3.1.

3.1 Loading equipment.

The loading equipment includes the device for applying the load and the reaction members to transmit the load to each rock face. Flatjacks at each rock face shall be used to apply the load. They shall have sufficient range to allow for the deflection of the rock and shall be constructed so that the two main plates move apart in a parallel fashion over the usable part of their range. The reaction members are generally thick-walled aluminum or steel pipes. A spherical bearing of suitable capacity shall be incorporated in the reaction members.

3.2 Transducers.

3.2.1 Pressure. A pressure gage or electronic transducer shall be used to measure the pressure in the flatjacks. The transducer shall have an accuracy of at least ±25 psi (0.17 MPa) including errors introduced by readout equipment, and a resolution of at least 10 psi (0.069 MPa).

3.2.2 Deflection. Various types of deflection transducers may be used depending in part on the location of the measurements. For surface measurements, dial gages or linear variable differential transformers (LVDTs) are generally used. For measurements within the rock mass, multiple position borehole extensometers with LVDT sensors, vibrating wire strain meters, joint meters, and other types of devices may be used. The deflection shall be measured to an accuracy of at least 0.0001 in. (0.0025 mm), including errors caused by readout equipment, and a resolution of at least 0.00005 in. (0.0013 mm).

3.3 Bearing pads.

The bearing pad material shall have a modulus no greater than the modulus of the rock being tested as determined from an intact sample. Generally, a neat cement grout is satisfactory if the curing time does not exceed several days. Fly ash or other suitable materials may be added to reduce the stiffness if necessary.

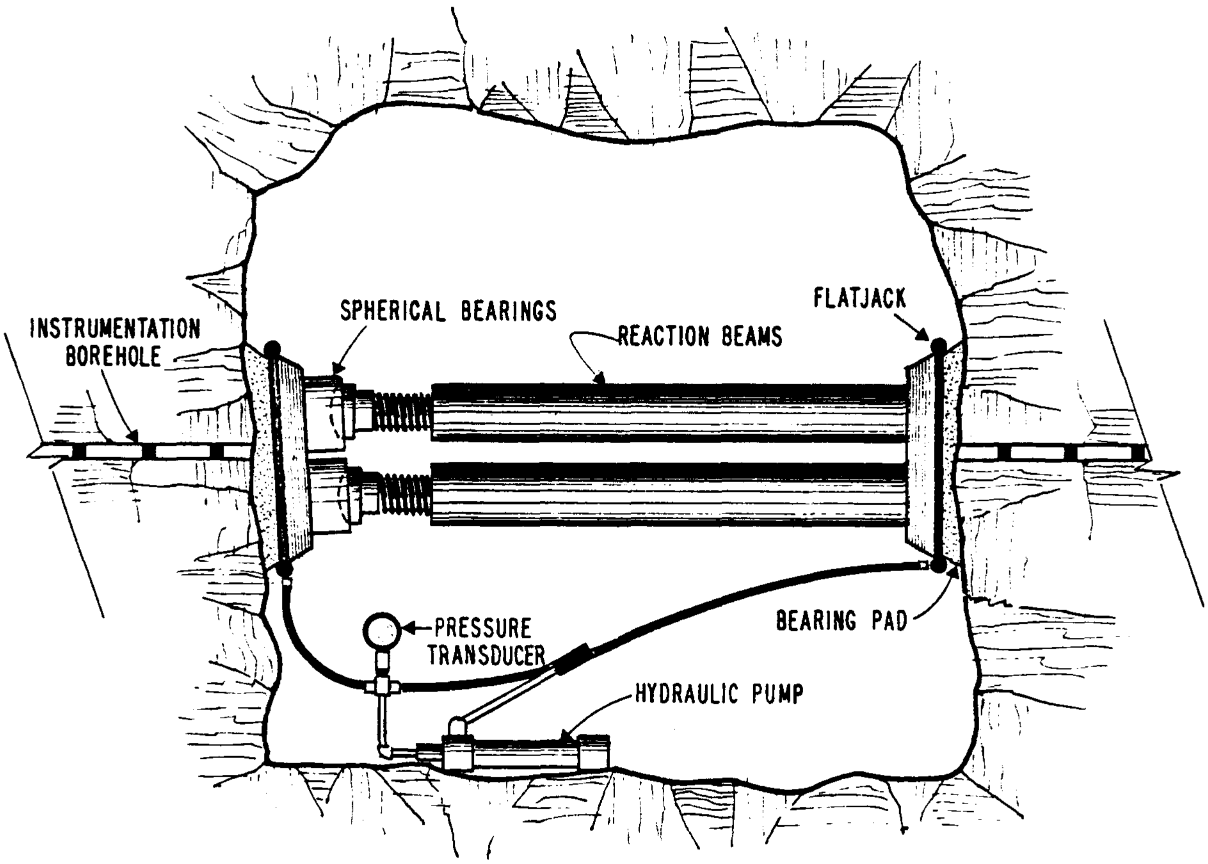


FIG. 3.1 TYPICAL FLEXIBLE PLATE LOADING TEST SETUP SCHEMATIC
(DEFLECTION MEASURED IN ROCK MASS)

4.0 Testing

4.1 Location.

The test shall be conducted across a diameter of the adit (a line containing the main axis of the adit) to minimize the resistance of the adjacent walls during loading.

4.2 Surface preparation.

4.2.1 Size. The prepared rock surface shall extend at least one-half the diameter of the flatjack beyond the edge of the flatjack.

4.2.2 Method. The surface shall be prepared by the method which causes the minimum damage to the finished rock face. Percussion drilling to a common depth is recommended for most rock types. Residual rock between the drill holes may be removed by moving the bit back and forth until a smooth face is achieved. Alternatively, in hard, competent rock, controlled blasting with very small charges may be used to remove the residual rock. In softer materials, coarse grinding or cutting devices may be used.

4.2.3 Rock quality. The bearing surface shall be constructed in sound rock. Loose and broken rock from excavating shall be removed. Deeper breaks may be detected by a dull, hollow sound when struck with a hammer; such material shall also be removed.

4.2.4 Smoothness. The rock face shall be made as smooth as practical. In no case shall the deviation from a plane between the highest and lowest points exceed 1 in. per ft (25.4 mm per 0.305 m) of flatjack diameter.

4.2.5 Cleaning. After the surface has been prepared, it shall be scrubbed and rinsed with clean water to remove any loose particles and dirt caused by the smoothing operation.

4.3 Bearing pad construction.

The bearing pad shall be constructed with a smooth surface against which the flatjack can be placed directly. The flatjack itself may be used as part of the formwork. Care shall be exercised to avoid any air pockets or other cavities within the pad. The thickness of the pad shall be no greater than 1.5 in. per ft (38.1 mm per 0.305 m) of flatjack diameter at any point. The dimensional requirements of the rock face and bearing pads are shown in Figure 4.1.

4.4 Measuring points.

4.4.1 Surface measurements. Measurements at the edge of the bearing pad shall be taken at a minimum of six equally spaced intervals around the edge of the pad. If measurements are made at the center of the loaded area using an annular flatjack they shall be taken at a minimum of three equally spaced positions

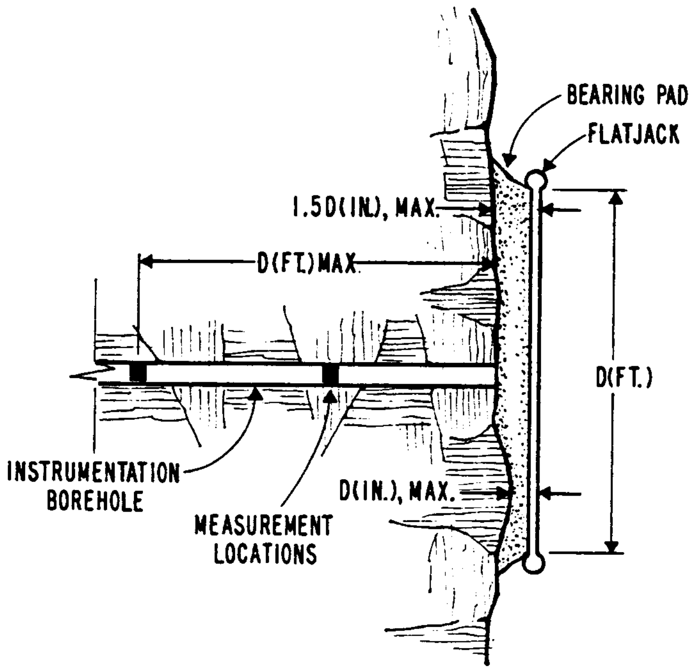


FIG. 4.1 ALLOWABLE DIMENSIONS FOR ROCK SURFACE AND BEARING PAD, FLEXIBLE PLATE LOADING TEST

around the edge of the opening of the annulus. The displacement transducers shall be supported so that only the deflection of the rock itself is measured. Generally this means mounting the transducers from supports located outside the zone of influence of the test. In no case shall the transducers be mounted on the loading apparatus.

4.4.2 Measurements within the rock mass.

4.4.2.1 Deflection measurements in the rock mass itself shall be taken along a line parallel to the direction of loading within 5° and located at the center of the loaded area to within 10% of the width of the loaded area.

4.4.2.2 The holes for instruments shall be as small as possible yet accommodate the instrument. Holes shall be diamond rotary drilled and continuously cored.

4.4.2.3 The location of each measurement point shall be selected by examining the rock core and inspecting the borehole with a borescope or other suitable device. Measuring points shall be placed on either side of joints, thin beds, seams, etc. At least two measuring points shall be placed within one flatjack diameter of the rock surface. The deepest measuring point shall be located six flatjack diameters from the bearing surface.

4.5 Pressurization cycles.

Four pressure cycles shall be conducted to peak pressures of 25, 50, 75 and 100% of the maximum load, respectively. Each cycle shall consist of 10 equal loading increments and 10 equal unloading decrements. Deflection readings shall be taken after each load increment and decrement. The peak and zero pressures for each cycle shall be maintained for 10 minutes, with deflection readings taken at 5-minute intervals.

4.6 Time-dependent behavior.

Transient, or primary, creep may be evaluated by maintaining a given load over a period of time and reading the deflection at various time intervals. The load shall be maintained within ±1% of nominal value. The duration of the test depends on the rock type, but is generally between 3 and 30 days. The reading interval depends on the transient creep rate, and ranges from several hours during the early phases of the test to daily for its duration.

4.7 Data recording requirements.

The data shown on Form GT-D.3-1 shall be recorded for each test as a minimum.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 The location and orientation of the plate loading tests shall be presented. A graphic presentation is recommended.

5.1.1.2 The reasons for selecting the test locations shall be discussed.

5.1.1.3 The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock types shall be described macroscopically. Structural features affecting the plate loading test shall be described. A diagram of the geology of each test area is recommended.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test should be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary table. A summary table shall be presented including the rock materials, the pressure range over which the modulus values were calculated, the average modulus values, ranges, and uncertainties.

5.4.2 Table of individual results. A table listing test number, rock material/structure, and average modulus values for each test location shall be presented.

5.4.3 Graphic presentations. A typical deflection curve for each rock material shall be presented.

5.4.4 Time-dependent properties

5.4.4.1 A comparison of strain deflection at various times for the rock types of interest shall be presented.

5.4.4.2 Typical transient creep curves for each rock type shall be presented.

5.4.5 Other. The following other types of analyses and presentations may be included as appropriate.

5.4.5.1 Relationship between modulus and applied stress.

5.4.5.2 Discussion of modulus dependence on geology.

5.4.5.3 Histograms of results

5.4.5.4 Comparison with laboratory modulus values or the results of other in situ modulus tests.

5.4.5.5 Comparison of results to other rock types or previous studies.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Sample variability. For each rock material or structure the mean modulus value, range, standard deviation and 95% confidence limits for the mean shall be calculated, as a minimum. The uncertainty of the group shall be compared with the measurement uncertainty to determine whether measurement error or rock variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Pressure deflection curves. A pressure vs. deflection curve for each test shall be included in an appendix.

5.6.2 Test form. A completed test data Form GT-D.3-1 for each test shall be included in an appendix.

5.6.3 Creep curves. If appropriate, a transient creep curve for each creep test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, the procedure, and the equipment performance verification. After testing, the completed Form GT-D.3-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-D.3-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-D.3-1.

In Situ Modulus of Deformation Using the
Flexible Plate Loading Method
Test Data Sheet - Form GT-D.3-1

Project ____________ Test No. ____________
Feature ____________ Rock Type ____________
Test Location ____________ Plate Diameter ____________
Orientation ____________ Tested By ____________
Date ____________

Measurement Depths No. 1 _____ No. 4 _____
No. 2 _____ No. 5 _____
No. 3 _____ No. 6 _____

Equipment Description	Serial No.	Date of Next Calibration

		Deflection Readings					
Time	Load Reading	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6

		Deflection Readings					
Time	Load Reading	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6

Remarks:

Test Supervisor ______________________ Date ____________

Quality Assurance ______________________ Date ____________

Project Engineer ______________________ Date ____________

Procedure GT-F.1

In Situ Permeability Measurement of Rock Using Borehole Packers

1.0 Background

1.1 Scope.

1.1.1 Objective of the test. The objective of this test is to measure the ability of a rock mass in situ to transmit water.

1.1.2 Limitations. Permeability values determined from borehole packer tests represent the combined effects of many features of the rock which may have widely varying individual permeabilities. However, the measured permeability can give a good approximation of the capacity of the given stratum to transmit water, providing the test section includes rocks and fractures which are typical of the entire formation.

1.2 General description of the test.

A borehole is drilled into a rock mass. A section of the borehole is sealed off with pneumatic or mechanical packers. Water is pumped into the test section under pressure and out into the rock mass until a constant flow rate is achieved at a constant pressure. The test is repeated at several pressure levels. Permeability is then calculated.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Corrected average pressure - the net pressure at the center of the test interval.

1.3.1.2 Permeability - the capacity of a porous or fractured medium for transmitting water.

1.3.1.3 Equivalent permeability - the permeability of the rock mass, assuming that the rock is uniform and porous over the entire test section.

1.3.1.4 Darcy - a unit of permeability. A porous medium has a permeability of 1 darcy when a fluid of 1 centipoise viscosity [water has 1 centipoise viscosity at 68°F (20°C)] flows through it at a rate of 0.06 in.^{3} (1 cm^3) per second per 0.16 in.^{2} (1 cm^2) of cross-sectional area and 0.39 in. (1 cm) of length at a pressure differential of 1 atmosphere [407 in. (1034 cm) of water at the same temperature].

1.3.2 Equations. The equations used in this procedure are based on U.S. Army Corps of Engineers (1980) and Dodds (1969).

1.3.2.1 The corrected average pressure, P_c, is calculated by two different methods depending on where the test pressure is measured.

If the test pressure is measured at the center of the test section, P_c is calculated using:

$$P_c = P_t - P_i \qquad (1)$$

where:

P_t = total measured pressure during the test

P_i = initial measured pressure prior to the start of the test.

The initial pressure is due to the static pressure existing in the formation.

If the test pressure is measured at the surface, it must be corrected for the effects of the piping between the pressure gage and the test interval, which cause pressure to be lost. These effects include:

a. friction between the water and walls of the pipe,
b. friction and turbulence caused by contraction or enlargements at pipe couplings,
c. friction due to bends in the pipe,
d. pressure loss as the water enters the test interval, which is of larger diameter than the pipe.
e. pressure loss at the gage where the water is flowing past the opening to the measurement pipe at a finite velocity;

The pressure loss from Factor d, P_{le}, may be calculated using:

$$P_{le} = \frac{V_e^2 \gamma_w}{2g} \qquad (2)$$

where:

V_e = velocity at downhole end of pipe

γ_w = unit weight of water

g = acceleration of gravity.

The pressure loss from Factor e, P_{lg}, may be calculated using:

$$P_{lg} = \frac{V_g^2 \gamma_w}{2g} \qquad (3)$$

where:

V_g = velocity at pressure gage.

If the pipe is the same diameter at the pressure gage and at the downhole end, then $V_e = V_g$, and the two effects cancel.

The effects of Factors a through c, the friction losses, may be evaluated by calibrating the test system or by using standard values from hydraulic handbooks.

The corrected average pressure when the test pressure is measured at the surface is calculated using:

$$P_c = P_t - P_f + P_h \qquad (4)$$

where:

P_t = measured test pressure

P_f = pressure losses due to friction

P_h = pressure difference between induced hydrostatic head (due to test setup) and static formation pressure.

1.3.2.2 The flow in the rock mass may be either laminar or turbulent. The nature of the flow is determined by plotting the flow rate as a function of average corrected pressure. A linear relationship indicates laminar flow, as shown on Figure 1.3a. A concave downward curve, as shown on Figure 1.3b, indicates turbulent flow. A concave upward curve, as shown on Figure 1.3c, indicates that the permeability is increasing with pressure. This generally occurs in fractured rocks, where the fractures are forced apart or fracture fillings are washed out by the water. In such cases, it cannot be definitely stated whether the flow is laminar or turbulent.

1.3.2.3 The equivalent permeability, k, in darcies, is calculated for laminar flow using:

$$k = \frac{Q\,\mu \times 10^2}{2\,\pi L P_c} \ln\left(\frac{R}{r}\right) \qquad (5)$$

where:

Q = flow rate (cc/sec)

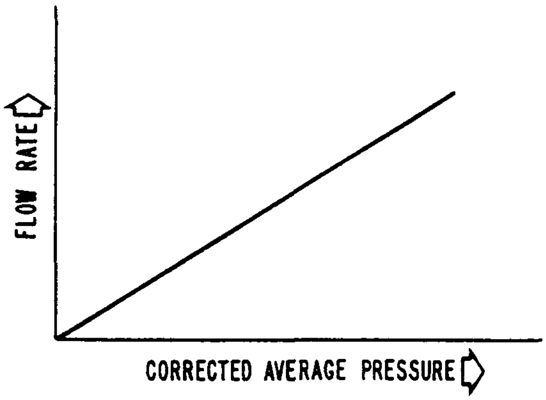
μ = absolute viscosity of water (poises, from Table 1.1)

L = length of test section (cm)

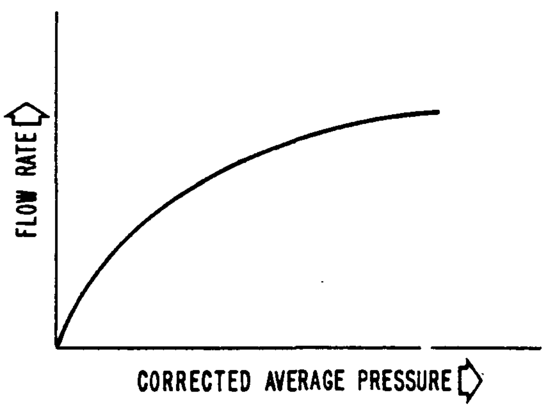
P_c = corrected average pressure (atm)

R = radius of influence (cm)

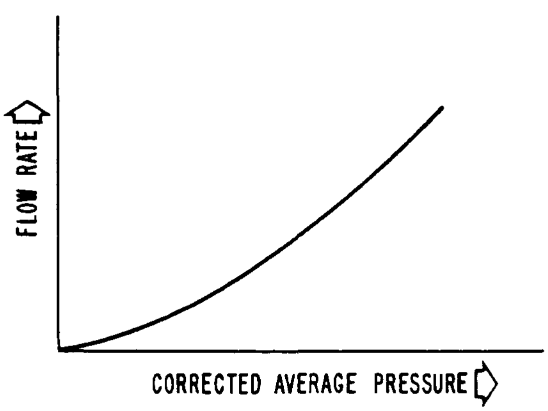
r = radius of borehole (cm).



A. LAMINAR FLOW



B. TURBULENT FLOW



C. FRACTURE WIDENING OR CLEANING

FIG. 1.3 IDEALIZED FLOW CURVES

Table 1.1

Viscosity of Water

Temp. °C	Absolute Viscosity poise or Kinematic Viscosity, cm^2/sec
0	0.0179
2	0.0167
4	0.0157
6	0.0147
8	0.0139
10	0.0131
12	0.0124
14	0.0117
16	0.0111
18	0.0106
20	0.0100
22	0.0096
24	0.0091
26	0.0087
28	0.0084
30	0.0080
32	0.0077
34	0.0074
36	0.0071
38	0.0068
40	0.0066

The radius of influence is the radial distance from the test section over which the test pressure dissipates. It is dependent on many of the same factors as permeability, and is not directly evaluated in this type of test. For most rock, it is estimated to be betwen 0.5L and 1.0L.

1.3.2.4 The equivalent permeability, k, is calculated for turbulent flow using:

$$k = \frac{\mu x \ 10^2}{P_c} \left(\frac{Q}{2\ L}\right)^m \frac{(R^{1-m} - r^{1-m})}{(1-m)} \qquad (6)$$

where:

m = degree of nonlinearity.

The degree of nonlinearity is calculated from the straight line approximation of the plot of log P_c vs. log Q. The value should be between 1 and 2.

1.3.2.5 Permeability of individual fractures assumes that the flow is laminar between two parallel plates and that the rock between the fractures is impermeable. The equivalent parallel plate aperture, e, is calculated using:

$$e = \left[\frac{Q\ln(R/r)\ 12\,\mu}{2\ \pi n P_c}\right]^{1/3} \qquad (7)$$

where:

n = number of fractures

μ = absolute viscosity of water (poises, from Table 1.1.)

P_c = corrected average pressure (dynes/cm^2, equivalent to atmospheres x 1.0132 x 10^6)

The zone of influence, R, is dependent on the geometry and roughness of the joint. The factor ln (R/r) varies between 2.3 and 3.9 when the zone of influence is assumed to be 10 and 50 times the borehole radius, respectively. For most joints, it is reasonable to assume that friction effects will cause the pressure to dissipate within this zone, so a value of 3 may be assigned to the factor ln(R/r) without changing the equivalent parallel plate aperture by more than 10%. Equation 7, then, may be rewritten:

$$e = \left[\frac{18Q\,\mu}{\pi n P_c}\right]^{1/3} \qquad (8)$$

1.3.2.6 For laminar flow, the permeability in darcies of a single fracture, k, is calculated using:

$$k = 1034\ \frac{ge^2}{12\nu} \qquad (9)$$

where:

g = accelepation of gravity (cm/sec^2)

ν = kinematic viscosity of water (cm^2/sec).

1.3.2.7 For turbulent flow, the equivalent parallel plate aperture, e, is determined from the linear portion of the flow vs. average corrected pressure curve. The permeability, k, is calculated using:

$$k = \frac{Q^m \mu \times 10^2 \ (R^{1-m} - r^{1-m})}{(2\ \pi n e)^m \ P_c (1-m)} \qquad (10)$$

1.3.3 Assumptions. The equations presented above were derived for a homogeneous isotropic medium. Rock in situ is rarely so, but the size and orientation of the test interval can be adjusted to conform as far as possible to these assumptions.

The equations for permeability of individual fractures assume that the borehole is perpendicular to the fracture plane. Again, this assumption is satisfied by proper orientation of the borehole

1.4 References.

1.4.1 Daugherty, R.L. and Franzini, J.B., 1965, Fluid Mechanics: with Engineering Applications, McGraw-Hill, Inc., New York.

1.4.2 Davis, S.N. and DeWiest, R.J., 1966, Hydrogeology, John Wiley and Sons, Inc., New York.

1.4.3 Dodds, R.K., 1969, "Effective Exploration Inspection - Water Pressure Tests in Borings", Newsletter, 2, No. 3., Foundation Sciences, Inc., Portland, Oregon.

1.4.4 Louis, C. and Maini, Y.N., 1970, "Determination of In Situ Hydraulic Parameters in Jointed Rock", Proceedings of the Second Congress of the ISRM, Belgrade, Yugoslavia, 1.

1.4.5 U.S. Army Corps of Engineers, 1980, Standard RTH 381-80, "Suggested Method for In Situ Determination of Rock Mass Permeability Using Water Pressure Tests", Rock Testing Handbook, Geotechnical Laboratory, Waterways Experiment Station, Vicksburg, Mississippi.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified.

If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Boreholes drilled.

2.3.1 Number and orientation. The number of boreholes should be sufficient to sample each major rock formation to the detail required by the scope of the project. The boreholes should be oriented to intersect major fracture sets at right angles.

2.3.2 Boreholes cored. The boreholes should be continuously core-drilled using diamond bits. This will provide a relatively smooth borehole wall for packer seating, as well as core for determining the test locations.

2.3.3 Core logged. The rock core from the boreholes should be logged, with particular emphasis on basic materials and natural fractures, as described in procedure GT-A.3 "Techniques for Logging Rock Core."

2.3.4 Boreholes washed. The boreholes must not contain any material that could be washed into the permeable zones during testing, changing the permeability. The boreholes should be flushed with clean water until the return is free from cuttings or dirt.

2.4 Test locations and intervals selected.

Test locations and intervals are determined from the core logs, inspection of the core, and, if necessary, visual inspection of the borehole with a borescope or TV camera.

2.4.1 All materials sampled. Each major ruck type that can be isolated with the packers should be tested.

2.4.2 Discontinuities sampled. Discontinuities are often the major permeable features in hard rock. Jointed zones, fault zones, bedding planes, etc. should be tested both by isolating individual features and evaluating the combined effects of several similar features.

2.4.3 Redundant tests. Several tests should be conducted in the same rock type or should encompass similar features, in order to evaluate variability within the rock mass.

3.0 Equipment and apparatus

A schematic of the test setup is shown on Figure 3.1.

3.1 Pump.

The pump shall deliver water to the test interval at a uniform flow and constant pressure. A turbine pump has been found satisfactory. The pump shall deliver water at a maximum pressure of at

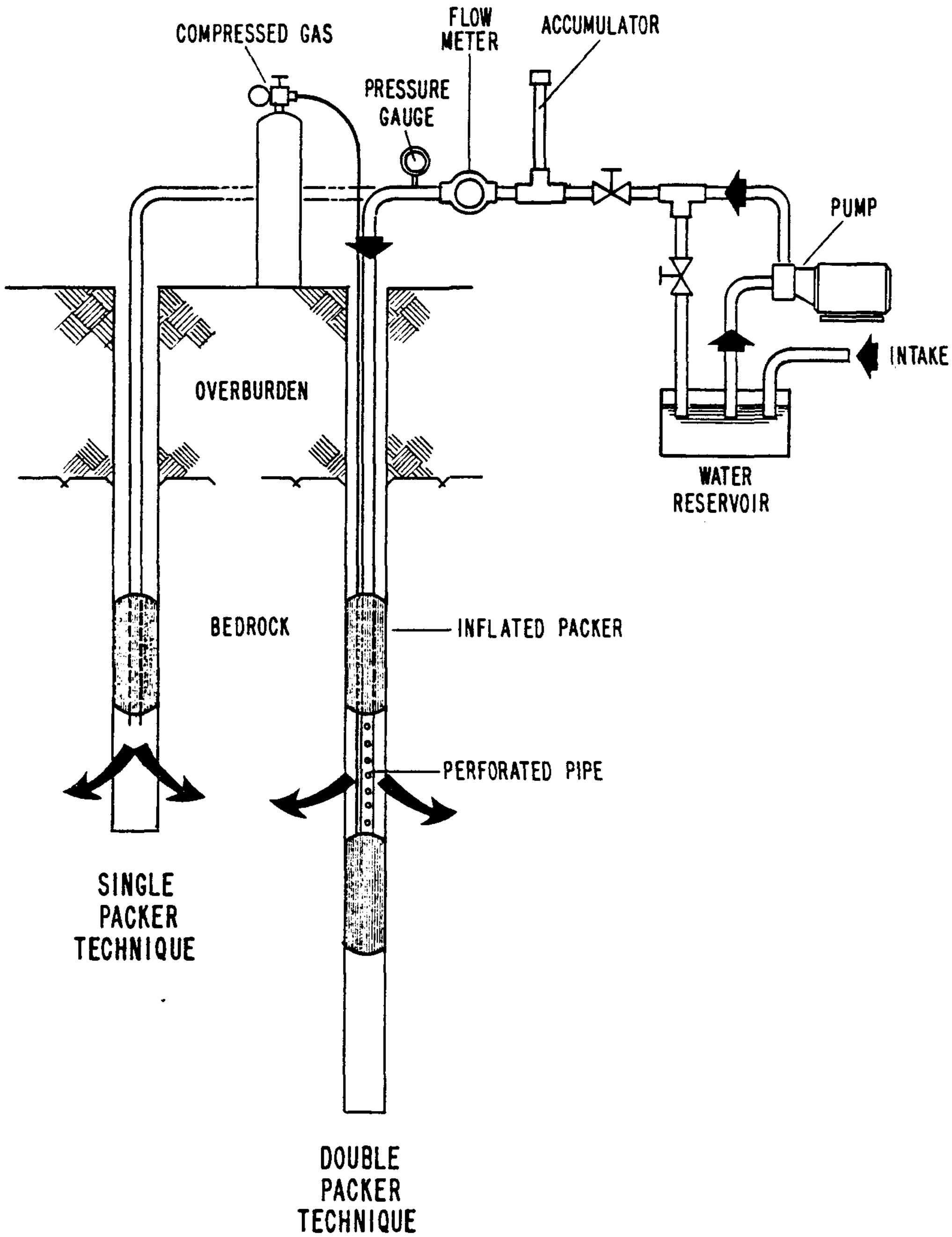


FIG. 3.1 TYPICAL PERMEABILITY TEST SETUP

least 150 psi (1.034 MPa). The volume capacity depends on the length of the test interval and the expected permeability of the rock, but the pump shall have a capacity of at least 20 gal. (75.7 l) per minute.

3.2 Packers.

Pneumatic packers are recommended because they produce a positive seal on the borehole wall; however, mechanical packers may be used. Each packer shall seal a portion of the borehole wall at least 18 in. (0.46 m) in length with an applied pressure at least 100 psi (0.69 MPa) greater than the maximum water pressure to be applied to the interval.

3.3 Pressure transducers.

It is recommended that the test pressure be measured directly in the test interval with an electronic pressure transducer. Alternatively, pressure may be measured at the surface with an electronic transducer or pressure gage. In any case, the transducer shall have an accuracy of at least ±1 psi (0.0069 MPa), including errors introduced by the readout equipment, and a resolution of at least 0.5 psi (0.0034 MPa).

3.4 Flow meter.

A flow meter that records total volume shall be used. It shall have an accuracy of at least ±0.1 gal. (0.38 l) and a resolution of at least 0.05 gal. (0.19 l). Very low permeability materials may require a more sensitive flowmeter.

3.5 Stop watch.

A stop watch capable of measuring accurately to within 0.1 second shall be available.

3.6 Hydraulic manifold, pipe, and hoses.

A hydraulic manifold with a bypass shall be used to control system pressure. An accumulator shall be incorporated to dampen any pressure surges in the system. The use of valves is recommended. The pressure transducer (if surface mounted) and flow meter shall be mounted between the valves and the downhole portion of the test apparatus. The pipe diameter should be as large as possible, to minimize friction losses. The pipe diameter shall be equal where it enters the test interval and at the surface pressure transducer (if used). If the zone packer method with a perforated pipe between the packers is used, the total area of the holes in the pipe shall be at least three times the cross-sectional area of the pipe.

4.0 Testing

4.1 Test water.

4.1.1 Quality. Water used for permeability tests shall be clear and fresh. The presence of even small amounts of silt or clay in the injection water could plug the rock around the test interval and give permeability results that are too low.

4.1.2 Temperature. The temperature of the test water shall be no more than 9°F (5°C) cooler than the rock mass to be tested. Cold water injected into a warm rock mass causes air to come out of solution, and the resulting bubbles may greatly reduce water acceptance by the rock.

4.2 Borehole washing.

Sufficient time shall be allowed after washing the borehole for any induced formation pressures to dissipate. This is particularly important for single packer tests, which are generally done as part of the drilling operation.

4.3 Pressure levels.

The permeability test shall be conducted at no fewer than three pressure levels to obtain flow vs. pressure data. Pressure levels of approximately 25%, 50%, and 100% of the maximum test pressure shall be used. The maximum test pressure is generally 120 to 150 psi (0.83 to 1.03 MPa); however, in no case shall the effective stress be exceeded. If the flow-pressure relationship is notably nonlinear, an increased number of intermediate pressure levels is recommended.

4.4 Constant flow.

Water shall be pumped into the test section continuously at the specified pressure during the test. Periodically, the time required for a known volume of water to be pumped into the rock mass shall be measured. The volume of water shall be 5, 10, or 20, etc. gal. (18.9, 37.9 or 75.7 l) as required for a measurement interval of at least 60 seconds. A constant flow rate is achieved when the time of two consecutive measurements of the same volume of water differ by less than 1%.

4.5 Data recording.

The data shown on Form GT-F.1-1 shall be recorded as a minimum.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

5.1.1 Scope of testing program.

5.1.1.1 Location and orientation of the boreholes. The location and orientation of boreholes and test intervals shall be presented. For tests in many boreholes or a variety of rock types, the test matrix should be presented in tabular form.

5.1.1.2 Rationale for test location selection. The reasons for the number, location, and size of test intervals shall be clearly stated.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test intervals. Rock type, structure, fabric, grain size, discontinuities, voids, and weathering of the rock mass in the test intervals shall be described, as a minimum. Further detail depends on the application of the results, but in general is not required. In variable material or for several rock types, many intervals may be described, and a tabular presentation is recommended for clarity.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications shall be listed for each major piece.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations and any limitations in their applications shall be noted, and their effects on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual laboratory test conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Summary table. A table of results including the rock or discontinuity types, the average values of the permeabilities, the ranges, and the uncertainties shall be presented.

5.4.2 Individual results. A table of individual results including test number, interval length, rock type, permeability, and total volume of water injected shall be presented.

5.4.3 Graphic data. Typical flow vs. pressure curves for each rock or discontinuity type shall be presented. The type of flow indicated by each curve shall be discussed.

5.4.4 Other. The following other types of analyses or presentations may be included as appropriate.

5.4.4.1 Discussion of the nature of the permeable structures.

5.4.4.2 Histograms of results.

5.4.4.3 Comparison of results to other studies or previous work.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all pressure and flow rate determinations.

5.5.2 Sample variability. For each rock or discontinuity type, the mean permeability, range, standard deviation and 95% confidence limits for the mean shall be calculated, as a minimum. The uncertainty for each rock type shall be compared with the measurement uncertainty to determine whether measurement error or sample variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Data curves. A flow vs. corrected average pressure curve for each test shall be included in an appendix.

5.6.2 Data forms. A completed data Form GT-F.1-1 for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-F.1-1 shall be reviewed and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-F.1-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-F.1-1.

In Situ Permeability Measurement of Rock
Using Borehole Packers

Test Data Sheet - Form GT-F.1-1

Project ______________________ Test No. ______________________

Feature ______________________ Borehole No. ______________________

Test Location ______________________ Orientation ______________________

Rock Type ______________________ Depth of Test ______________________

Date ______________________ Length of Interval ______________________

Testing by ______________________ Rock Temperature ______________________

Equipment Description	Serial No.	Date of Next Calibration

Borehole Diameter ______________________ Packer Pressure ______________________

Length of Pipe Above Packer ______________________ Pipe I.D. ______________________

Length of Hose Between Pipe and Pressure Gage ______________________ Hose I.D. ______________________

Time	Water Temp., °C	Water Pressure, psi	Meter Reading, gal.	Elapsed Time, minutes	Flow Rate, gal. per minute
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		

Time	Water Temp., °C	Water Pressure, psi	Meter Reading, gal.	Elapsed Time, minutes	Flow Rate, gal. per minute
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		
			Initial		
			Final		
			Δ		

Test Supervisor ______________ Date ______________

Quality Assurance ______________ Date ______________

Project Engineer ______________ Date ______________

Procedure GT-H.1

Rock Bolt Anchor Pull Test

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to measure the working and ultimate capacities of a rock bolt anchor, in order to determine the best anchor system for a particular rock type.

1.1.2 Applicability. This procedure is applicable to mechanical, cement grout, or epoxy resin anchor systems.

1.2 General description of the test.

A rock bolt is installed in the same manner and in the same material as its intended construction use. The bolt is pulled hydraulically and the deflection of the bolt head is measured concurrently. The bolt is pulled until the anchor system or rock fails. The ultimate and working capacities of the bolt are calculated from the plot of load vs. deflection.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Deflection - the movement of the rock bolt head.

1.3.1.2 Failure - the inability of the anchor system or rock to sustain increased load without rapidly increasing deformation. In some instances, the peak load itself cannot be sustained.

1.3.1.3 Load - the total axial force on the rock bolt.

1.3.1.4 Pressure, stress - the force per unit area.

1.3.1.5 Ultimate capacity - the maximum load sustained by the anchor system.

1.3.1.6 Working capacity - the load on the anchor system at which significantly increasing deflection begins.

1.3.2 Equations.

1.3.2.1 The stress in the bolt, σb, is calculated using:

$$\sigma b = \frac{P}{A} \qquad (1)$$

where:

P = load on the bolt

A = cross-sectional area of the bolt

1.3.2.2 The elastic deformation of the bolt, U, is calculated as:

$$U = \frac{\sigma b}{E} L \qquad (2)$$

where:

L = ungrouted or unanchored length of bolt above the anchored zone

E = elastic modulus of the steel in the bolt.

1.3.2.3 The working and ultimate capacities of the anchor system are determined from the plot of load vs. deflection. A typical curve is shown on Figure 1.1. Interpretation of the curve often requires some engineering judgment.

1.3.3 Factors influencing the results. Ideally, the rock bolt anchor should fail by shear at the anchor/rock interface or bond. Therefore, the local characteristics of the rock, such as roughness and induced fractures, are significant factors in the anchor strength. To obtain realistic strength values, the test holes should be drilled using the same methods as the construction rock bolt holes.

It should also be noted that rocks with significant time-dependent behavior, such as rock salt or shale, may respond to the anchor system itself and change the anchor strength. In these cases, consideration should be given to testing bolts over a period of time.

The objective of the test is to measure anchor performance and not the performance of the rock bolt itself. Thus, to ensure that the bolt response during the test is minimal and predictable, large diameter, short lennth bolts have been specified.

1.4 References.

1.4.1 ISRM Commission on Standardization of Laboratory and Field Tests, 1974, "Suggested Method for Determining the Strength of a Rock Bolt Anchor (Pull Test)", in Suggested Methods for Rock Bolt Testing.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Techniciansand Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the

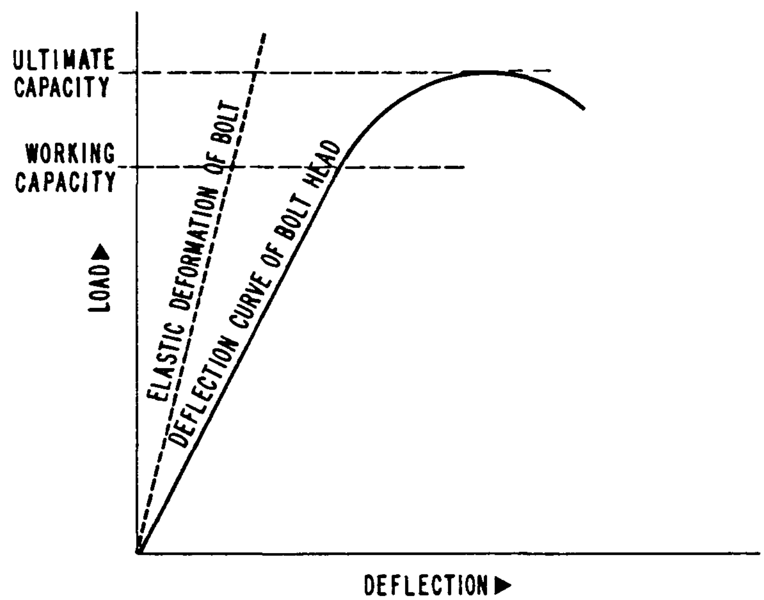


FIG. 1.1 TYPICAL LOAD VS DEFLECTION CURVE FOR ROCK BOLT PULL TEST.

required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to the standard Quality Assurance procedures.

2.3 Testing program established.

2.3.1 Tests in different rock types. Anchor pull tests should be conducted in all rock types in which construction bolts will be installed. If the rock is anisotropic, e.g., bedded or schistose, the tests should be conducted in various orientations relative to the anisotropy, including those at which the construction bolts may be installed.

2.3.2 Tests of different anchor systems. Different anchor systems may be tested in the same rock type and orientation to determine the relative capacities. Several types of mechanical shell anchors, for example, may be tested to determine the most appropriate design. Several lengths of epoxy grouting may be tested to determine required length for a specified load. The relative strength of mechanical and grouted anchors may be evaluated.

2.3.3 Number of tests. In each rock type, at each orientation, and for each anchor system, a sufficient number of tests should be conducted to determine the average and minimum bolt capacities within a fixed uncertainty at the 95% confidence level. The allowable uncertainty band depends on the project and involves such factors as the rock quality, expected project lifetime, and importance of the areas to be bolted. Its determination will require considerable engineering judgment. As a rough guideline, at least 10 to 12 pull tests for a single set of variables have been found necessary to satisfy the statistical requirements.

3.0 Equipment and apparatus

3.1 Loading system.

A system for pulling the rock bolts shall consist of a hollow center hydraulic ram and mounting/reaction frame. The hydraulic ram shall be of sufficient capacity to fail the anchor and shall have a travel range of at least 2 in. (51 mm). The mounting/reaction frame shall be usable against uneven rock surfaces. The loading system shall apply a force that deviates by no more than 5° from the long axis of the bolt during the test.

3.2 Transducers.

3.2.1 Load. An electronic load cell may be used to measure the load on the rock bolt. The cell shall have an accuracy of at least ±200 lb (91 kg), including errors introduced by the excitation and readout system, and a resolution of at least 100 lb (45 kg). Alternatively, a pressure gage or electronic transducer may be used to measure the pressure applied to the ram, provided that the load measurement requirements above are satisfied, including the effects of friction in the hydraulic ram, etc.

3.2.2 Displacement. A dial gage is recommended to measure the displacement of the rock bolt head. It shall have an accuracy of at least ±0.001 in. (0.025 mm), a resolution of at least 0.0005 in. (0.013 mm), and a range of at least 2 in. (51 mm). It shall be mounted along the axis of the rock bolt, and shall be supported from a point no closer than 3 ft (0.92 m) from the reaction frame on the rock face. The end of the rock bolt, or pulling rod if used, shall be smooth with a counter-sink area approximately 0.25 in. (6.35 mm) in diameter to accommodate the measuring tip of the dial gage. Other types of displacement transducers may be used provided they satisfy the requirements of this system.

3.3 Anchor systems.

The anchors used for testing shall be from the manufacturer's standard production stock. Mechanical anchors shall be inspected to ensure that no defective anchors are tested. Grout or epoxy resin shall be fresh (within the shelf life) and obtained from unopened containers.

3.4 Rock bolt and accessories.

The rock bolt shall be of sufficient diameter and strength that its elastic range is not exceeded during testing. Standard bearing plates, washers, etc. may be used as required.

3.5 Drilling equipment.

The same type of drilling equipment and drill bits that will be used for installing rock bolts during the construction phase of the project shall be used as far as possible to drill the test holes.

3.6 Torque wrench.

If expandable shell mechanical anchors are used, a torque wrench shall be used to set them. The wrench shall have a capacity at least 80% greater than the manufacturer's recommended anchor setting torque. It shall have an accuracy of at least ± 2% of the full-scale reading, and a resolution of at least 1% of the full-scale reading.

3.7 Borehole diameter measuring gage.

A gage shall be used to measure the diameter of the borehole at the anchor location. It shall have an accuracy of at least ±0.01 in. (0.25 mm) and a resolution of at least 0.005 in. (0.13 mm).

4.0 Procedure

4.1 Drilling the test hole.

The test hole shall be drilled using the same procedure that will be used during construction. The borehole shall be washed clean of all cuttings.

4.1.1 Depth. The hole need not be as deep as the proposed length of the rock bolts. It shall, however, be deep enough to set the anchor past the zone of disturbance caused by the excavation and the zone of stress concentration caused by the reaction of the pulling frame. For mechanical shell anchors, the hole shall be drilled 1 ft (0.305 m) past the end of the anchor. A hole approximately 6 ft (1.83 m) in length has generally been found to be adequate.

4.1.2 Straightness. The test hole shall be visually inspected using a flashlight. If more than one half of the bottom of the hole cannot be seen, the hole is not sufficiently straight for a pull test and shall not be used.

4.1.3 Diameter measurement. The test hole diameter shall be measured in two perpendicular directions at the top and bottom of the anchor location for a total of four measurements.

4.2 Preparation of anchors.

Expansion shell-type anchors, or the portion of the grouted rock bolt to be embedded in the anchoring medium, shall be brushed free of dirt and rust. Grease or oil shall be removed with an appropriate solvent if necessary.

4.3 Setting the anchor.

4.3.1 Mechanical anchors. The downhole end of the rock bolt shall be lightly lubricated and the anchor shall be screwed on. When in position, the bolt shall be torqued to the manufacturer's recommended level to set the anchor. If this torque cannot be achieved because of anchor slippage due to shear failure in the rock, the maximum torque reading shall be noted and subsequent anchors installed to 80% of this value. Anchors which slip shall not be tested. In all cases, any slipping or other anomalous behavior shall be recorded on Form GT-H.1-1.

4.3.2 Cement grout or epoxy resin anchors. Cement grout or epoxy resin anchors shall be installed according to manufacturer's recommendations.

4.4 Testing.

A typical rock bolt anchor pull test schematic is shown on Figure 4.1.

4.4.1 Load cycling. On at least half of the tests, three loading and unloading cycles shall be performed to check for prefailure anchor movements. The load shall be applied in cycles to 1/4, 1/2, and 3/4 of the estimated failure load. The bolt shall be loaded in 10 equal increments and unloaded in 10 equal decrements.

4.4.2 Rate. The load shall be applied smoothly and rapidly.

4.4.3 Failure. After the third cycle, the bolt shall be pulled to failure in the same increments as during the last cycle or in 500 lb (226.8 kg) increments, whichever is less.

4.4.4 Noncycled bolts. Bolts which are not cycled shall be tested to failure in 20 equal load increments or increments of 500 lb (226.8 kg), whichever is less.

4.4.5 Deflection readings. Deflection shall be read and recorded after each pressure increment or decrement, as soon as the readings are stable.

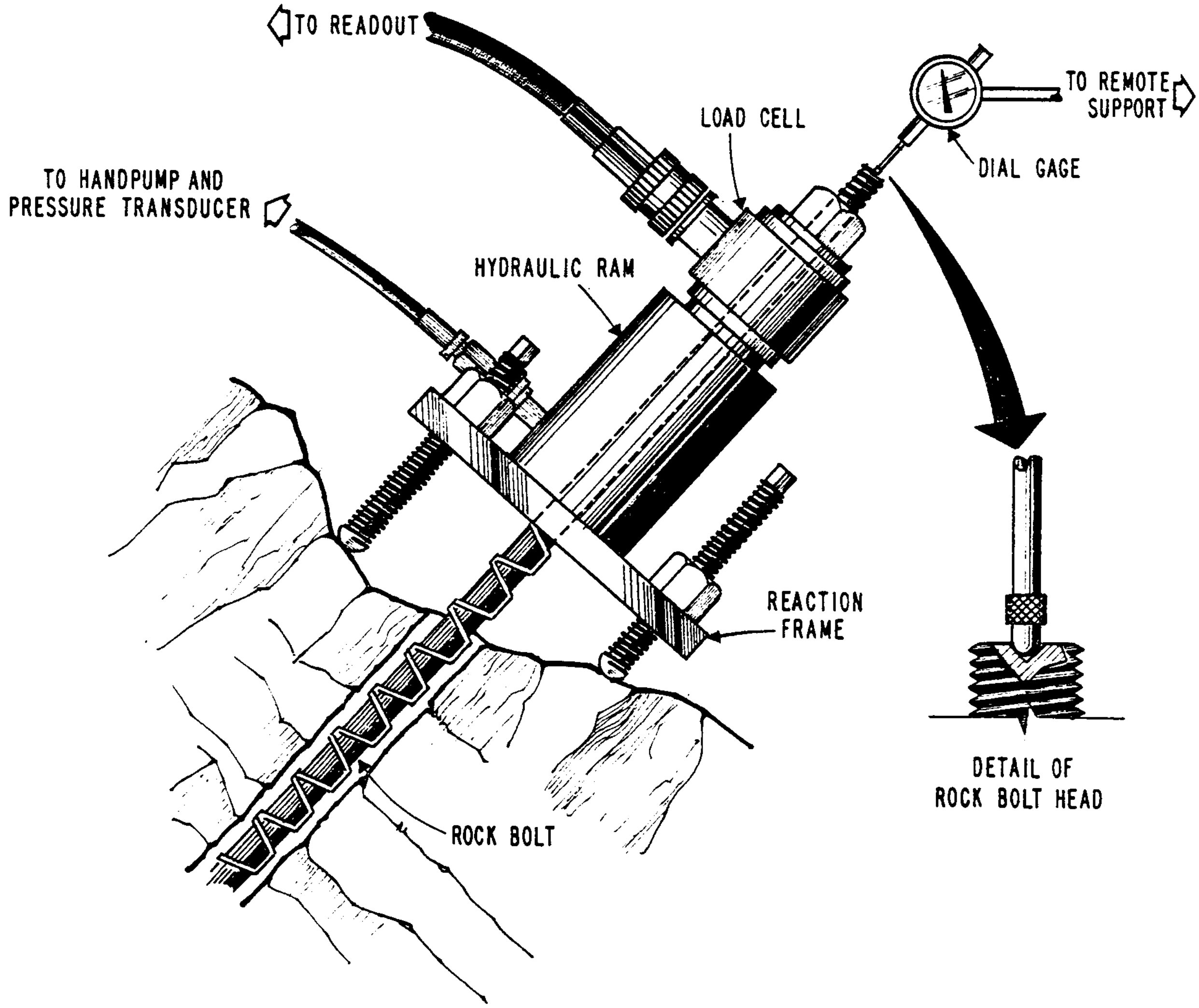


FIG. 4.1 TYPICAL ROCK BOLT ANCHOR PULL TEST SCHEMATIC

4.4.6 Failure. Failure shall be the peak load sustained by the bolt, as shown on Figure 1.1, or a total deflection of 0.5 in. (12.7 mm).

4.4.7 Postfailure loading. The bolt shall be pulled 0.5 in. (12.7 mm) beyond the failure deflection, with load recorded every 0.05 in. (1.3 mm).

4.5 Data recording.

The data shown on Form GT-H.1-1 shall be recorded as a minimum for the test.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the materials tested.

5.1.1 Scope of testing program.

5.1.1.1 Number of anchors and rock types tested. In a large report covering the results of tests in several rock types with several anchor types, the test matrix is best presented in a tabular form.

5.1.1.2 Rationale for test selection. The reasons for the number, locations and types of anchors tested shall be clearly stated.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test locations. The rock type, major structures, weathering, and any other factors which influence the anchor capacity shall be described and discussed.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual in situ conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Anchor capacities.

5.4.1.1 A summary table listing the performance of each anchor type in different rock types shall be presented. The table shall include, as a minimum, rock type, average value of the working capacity, range, and uncertainty of the mean.

5.4.1.2 A summary table listing the performance of all anchor types in each rock type shall be presented. The table shall include, as a minimum, anchor type, average value of the working capacity, range, and uncertainty of the mean.

5.4.1.3 A summary table of individual results for each test including, as a minimum, test number, anchor type, rock type, working capacity, and ultimate capacity shall be presented.

5.4.2 Postfailure behavior. Summary tables of postfailure capacities similar to those of Section 5.4.1 shall be presented.

5.4.3 Graphic presentations. Typical load-deflection curves shall be presented as examples for each rock and anchor type.

5.4.4 Other. The following other types of analysis or presentation may be included as appropriate.

5.4.4.1 Histograms of results.

5.4.4.2 Comparison of results to other rock suites, anchor types, or previous studies.

5.5 Error estimate.

The results shall be analyzed using standard statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Sample variability. For each suite of rock types and anchor types, the mean working capacity, range, standard deviation and 95% confidence limits for the mean shall be calculated as a minimum. The uncertainty of the suite shall be compared with the measurement uncertainty to determine whether measurement error or suite variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Data forms. Each completed test Form GT-H.1-1 shall be included in an appendix.

5.6.2 Data curves. The load vs. deflection curve for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-H.1-1 shall be reviewed and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-H.1-1.

6.3.3 Test sign offs. Quality Assurance shall maintain signed-off copies of Form GT-H.1-1.

Rock Bolt Anchor Pull Test
Test Data Sheet - Form GT-H.1-1

Project ______________________ Rock Type ______________________

Feature ______________________ Test No. ______________________

Test Location ______________________ Orientation ______________________

Date ______________________ Anchor Type ______________________

By ______________________ Test Depth ______________________

Setting Torque ______________________

Equipment Description	Serial No.	Date of Next Calibration

Borehole Diameter ________ ________ ________ ________

Average ________

Time	Pressure/ Load Reading	Deflection Reading	Net Deflection

Time	Pressure/ Load Reading	Deflection Reading	Net Deflection

Remarks:

Test Supervisor ____________________ Date ____________________

Quality Assurance ____________________ Date ____________________

Project Engineer ____________________ Date ____________________

Procedure GT-H.2

Rock Bolt Long-Term Load Retention Test

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to determine the time over which rock bolt tension decreases from the installed value to a designated minimum value. This time period is the interval during which the bolt must be encapsulated during construction. The load on the bolt at installation can decrease over time due to deterioration of the borehole wall, creep, and other factors.

1.1.2 Applicability. This procedure is applicable to any anchor system which is not fully encapsulated immediately upon installation, including mechanical, cement grout, or epoxy resin systems.

1.2 General description of the test.

A rock bolt is installed in the same manner and in the same material as its intended construction use. The load on the bolt is monitored over a period of time, generally several weeks.

1.3 Data reduction.

1.3.1 Terms and definitions.

1.3.1.1 Load - the total axial force on the rock bolt.

1.3.1.2 Design load - the load specified for the rock bolt during the life of the project.

1.3.1.3 Installation load - the load on the bolt immediately after installation.

1.3.1.4 Stand time - the time required for the bolt load to decrease from the installation load to the design load.

1.3.2 Evaluation. The data is plotted as load vs. time. The stand time is determined graphically, as shown on Figure 1.1.

1.3.3 Factors influencing the results. The local characteristics of the rock, such as roughness of the borehole and induced fractures, are significant factors in the load loss characteristics of the bolt. To obtain realistic values, the test holes should be drilled using the same methods as those used for the construction boreholes.

1.4 References.

1.4.1 ISRM Commission on Standardization of Laboratory and Field Tests, 1974, "Suggested Method for Monitoring Rock Bolt Tension Using Load Cells", in Suggested Methods for Rock Bolt Testing.

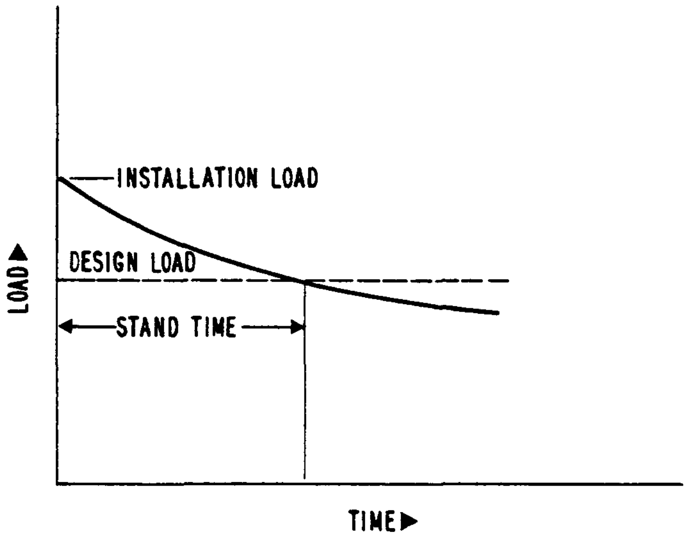


FIG. 1.1 EXAMPLE LOAD VS TIME CURVE FOR A ROCK BOLT

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with the performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

2.3 Testing program established.

2.3.1 Tests in different rock types. Load retention tests should be conducted in all rock types where construction bolts will be installed. If the rock is anisotropic, for example, bedded or schistose, the tests should be conducted in the same orientations relative to the anisotropy as the construction bolts will be installed.

2.3.2 Tests of different anchor systems. Different anchor systems may be tested in the same rock type to determine the relative long-term capacities. Several types of mechanical shell anchors, for example, may be tested to determine the most appropriate design. Several lengths of epoxy grouting may be tested to determine required length for a specified load. The relative performance of mechanical and grouted anchors may be evaluated.

2.3.3 Number of tests. In each rock type, at each orientation, and for each anchor system, a sufficient number of tests should be conducted to determine the average and minimum long-term capacities within a fixed uncertainty band at the 95% confidence level. The allowable uncertainty band depends on the project and involves such factors as rock quality, expected project lifetime, and importance of the areas to be bolted. Its determination will require considerable engineering judgment. As a rough guideline, at least six long-term tests for a single set of variables have been found necessary to satisfy the statistical requirements.

2.3.4 Loads determined. The design load and installation load of the rock bolt system should be determined. The installation load is less than the anchor capacity (see procedure GT-H.1, "Rock Bolt Anchor Pull Test"). The design load is less than the installation load; the amount depends on rock properties and the minimum time required to encapsulate the bolts. Alternatively, this test can be run for a specified time interval based on construction requirements, and a realistic design load can be determined from the data.

3.0 Equipment and apparatus

3.1 Load cell.

A load cell shall be used to measure the tension in the rock bolt. The cell may be of the mechanical, photoelastic, hydraulic, rubber compression pad, or electronic type; however, the latter is recommended. The cell shall have an accuracy of at least ±200 lb (91 kg), including errors introduced by the excitation readout system, and a resolution of at least 100 lb (45 kg).

3.2 Anchor systems.

The anchors used for testing shall be from the manufacturer's standard production stock. Mechanical anchors shall be inspected to ensure that no defective anchors are tested. Grout or epoxy resin shall be fresh (within the shelf life) and obtained from unopened containers.

3.3 Rock bolt and accessories.

The rock bolt shall be of sufficient diameter and strength that its elastic range is not exceeded during the tests. Standard bearing plates, washers, etc. may be used as required to align the load cell. A spherical bearing is desirable on very uneven surfaces.

3.4 Drilling equipment.

As far as possible, the same type of drilling equipment and drill bits that will be used for installing rock bolts during the construction phase of the project shall be used to drill the test holes.

3.5 Torque wrench.

If expandable shell mechanical anchors are used, a torque wrench shall be used to set them. The torque wrench may also be used to load the bolts. It shall have a capacity at least 80% greater than the manufacturer's recommended anchor setting torque. It shall have an accuracy of at least ±2% of the full-scale reading and a resolution of at least 1% of the full-scale reading.

3.6 Hydraulic pulling system.

A hydraulic ram and reaction frame may be used to tension the bolts.

3.7 Borehole diameter measuring gage.

A gage shall be used to measure the diameter of the borehole at the anchor location. It shall have an accuracy of at least ±0.01 in. (0.25 mm) and a resolution of at least 0.005 in. (0.13 mm).

4.0 Testing

4.1 Drilling the test hole.

The test hole shall be drilled using the same procedure that will be used during construction. The borehole shall be washed clean of all cuttings.

4.1.1 Depth. The hole need not be as deep as the proposed length of the construction rock bolts. It shall, however, be deep enough to set the anchor past the zone of disturbance caused by the excavation. For mechanical shell anchors, the hole shall be drilled 1 ft (0.305 m) past the end of the anchor. A hole approximately 6 ft (1.83 m) in length has generally been found to be adequate.

4.1.2 Straightness. The test hole shall be visually inspected using a flashlight. If more than one-half of the bottom of the hole cannot be seen, the hole is not sufficiently straight for the test and shall not be used.

4.1.3 Diameter measurement. The test hole diameter shall be measured in two perpendicular directions at the top and bottom of the anchor location for a total of four measurements.

4.1.4 Location. The test area shall not be located in a zone that will be affected by future excavations, as rock response to stress changes can produce load changes in the bolt.

4.2 Preparation of anchors.

Expansion shell-type anchors or the portion of the grouted rock bolt to be embedded in the anchoring medium shall be brushed free of dirt and rust. Grease or oil shall be removed with an appropriate solvent if necessary.

4.3 Setting the anchor.

4.3.1 Mechanical anchors. The downhole end of the rock bolt shall be lightly lubricated and the anchor screwed on. When in position, the bolt shall be torqued to the manufacturer's recommended level to set the anchor. If this torque cannot be achieved because of anchor slippage due to shear failure in the rock, the maximum torque reading shall be noted and subsequent anchors installed to 80% of this value. Anchors which slip shall not be tested. In all cases, any slipping or other anomalous behavior shall be recorded on Form GT-H.2-1.

4.3.2 Grout or epoxy resin anchors. Grout or epoxy anchors shall be installed according to manufacturer's recommendations.

4.4 Loading the bolt.

4.4.1 Method. The torque wrench is recommended for tensioning the bolt. Alternatively, the hydraulic pulling system may be used to apply load.

4.4.2 Load level. The bolt shall be tensioned until the load cell indicates that the installation load has been achieved.

4.5 Reading intervals.

The load on the bolt shall be monitored at least twice daily for a period of 2 weeks after installation, and once daily thereafter. Bolts in rapidly yielding material may require more frequent readings.

4.6 Data recording.

The data shown on Form GT-H.2-1 shall be recorded as a minimum for the test.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the materials tested.

5.1.1 Scope of testing program.

5.1.1.1 Number of anchors and rock types tested. In a large report covering the results of tests in several rock types with several anchor types, the test matrix is best presented in a tabular form.

5.1.1.2 Rationale for test selection. The reasons for the number, locations, and types of anchors tested shall be clearly stated.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test locations. The rock type, major structures, weathering, and any other factors which influence the anchor capacity shall be described and discussed.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations or limitations in their applications shall be noted, and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual in situ conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Long-term anchor capacities.

5.4.1.1 A summary table listing the performance of each anchor type in different rock types shall be presented. The table shall include, as a minimum, rock type, average value of the stand time, range, and uncertainty of the mean.

5.4.1.2 A summary table listing the performance of all anchor types in each rock type shall be presented. The table shall include, as a minimum, anchor type, average value of the stand time, range, and uncertainty of the mean.

5.4.1.3 A summary table of individual results for each test shall be presented, including, as a minimum, test number, anchor type, rock type, and stand time.

5.4.2 Graphic presentations. Typical load vs. time curves shall be presented as examples for each rock and anchor type.

5.4.3 Other. The following other types of analysis or presentation may be included as appropriate.

5.4.3.1 Histograms of results.

5.4.3.2 Comparison of results to other rock suites, anchor types, or previous studies.

5.5 Error estimate.

The results shall be analyzed using standardized statistical methods. All uncertainties shall be calculated using a 95% confidence interval.

5.5.1 Measurement error. The error associated with a single test shall be evaluated. This includes the combined effects of all transducers, power supplies, readout devices, etc.

5.5.2 Sample variability. For each suite of rock types and anchor types, the mean stand time, range, standard deviation and 95% confidence limits for the mean shall be calculated as a minimum. The uncertainty of the suite shall be compared with the measurement uncertainty to determine whether measurement error or suite variability is the dominant factor in the results.

5.5.3 Group correlation. When appropriate, the means of groups shall be compared to determine whether the observed difference between groups is significant at the 95% confidence level.

5.6 Appended data.

5.6.1 Data forms. Each completed test Form GT-H.2-1 shall be included in an appendix.

5.6.2 Data curves. The load vs. time curve for each test shall be included in an appendix.

6.0 Quality Assurance

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test at which Quality Assurance action ir required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, procedure, and equipment performance verification. After testing, the completed Form GT-H.2-1 shall be reviewed, and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-H.2-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-H.2-1.

Rock Bolt Long-Term Load Retention Test
Test Data Sheet - Form GT-H.2-1

Project ______________________ Rock Type ______________________

Feature ______________________ Orientation ______________________

Test Location ______________________ Anchor Type ______________________

Test Number ______________________ Test Depth ______________________

Equipment Description	Serial No.	Date of Next Calibration

Borehole diameter __________ __________ __________ __________

Average __________

Date	Time	By	Reading	Load

Date	Time	By	Reading	Load

Remarks:

Test Supervisor ____________________ Date ____________________

Quality Assurance ____________________ Date ____________________

Project Engineer ____________________ Date ____________________

Procedure GT-H.3

Prop Load Cell Tests

1.0 Background

1.1 Scope.

1.1.1 Objective of this test. The objective of this test is to monitor the load on steel arch or similar types of supports for an underground structure over time, using load cells installed in the supports.

1.2 General description of the test.

Load cells are installed in several adjacent underground supports so that the load on these supports may be accurately determined. Load is monitored as the working face is advanced beyond the immediate zone of the supports.

1.3 Data reduction.

1.3.1 Terms and definitions

1.3.1.1 Load - the total force acting on the part of the support being monitored.

1.3.2 Interpretation. Data is generally plotted as load vs. time. A typical curve is shown on Figure 1.1. The position of the working face is also shown. The relationship of these curves provides information about the behavior of the rock and the effectiveness of the support system.

1.4 References.

1.4.1 U.S. Army Corps of Engineers, 1980, Test Standard RTH 305-80, "Load Cells", Rock Testing Handbook, Geotechnical Laboratory, Waterways Experiment Station, Vicksburg, Mississippi.

2.0 Prerequisites

2.1 Personnel prequalification.

All personnel involved in performing the test, including the Technicians and Test Supervisor, shall be formally prequalified under the Quality Assurance procedures established as part of the overall testing program.

2.2 Equipment performance verification.

The compliance of all equipment and apparatus with performance specifications in Section 3.0 of this procedure shall be verified. If no requirements are stated in Section 3.0, the manufacturer's specifications for the equipment shall be the required level of performance. Performance verification is generally done by calibrating the equipment and measurement systems. Calibration and documentation shall be accomplished according to standard Quality Assurance procedures.

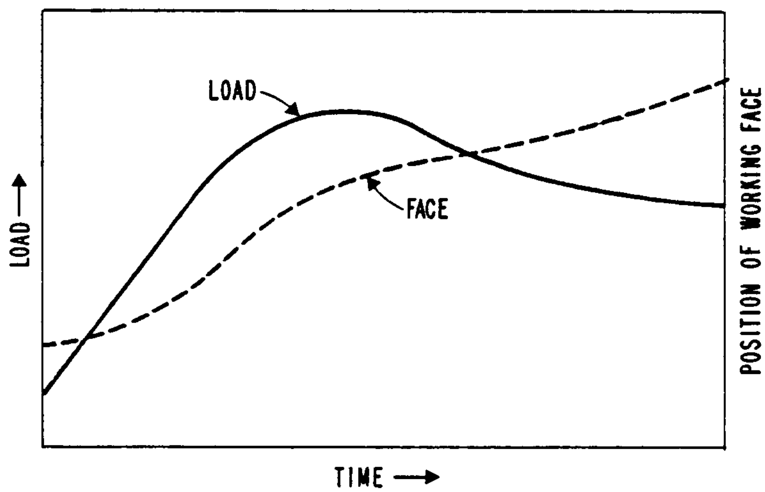


FIG. 1.1 IDEALIZED CURVES FOR PROP LOAD CELL TESTS

2.3 Testing program established.

2.3.1 Test sections in different rock types. A test section of several adjacent supports should be installed in each rock type where that support is proposed for use.

2.3.2 Type of support. Each proposed type of support should be tested to evaluate its performance.

3.0 Equipment and apparatus

3.1 Load cells.

The load cells may be of any type, including mechanical, hydraulic, photoelastic, or electronic, with either bonded resistance strain gages or vibrating wire transducers. Electronic load cells are recommended because of their sensitivity and stability. The resolution of the load cell depends on the expected load, but shall be at least 0.5% of the working capacity of that section of the support where the cell will be used. Likewise, the accuracy shall be at least $\pm 1\%$ of the working capacity. The cells shall be free from noncharacterizable long-term drift of more than 1% of the working capacity of that section of the support where they are installed. The cells shall be of sufficient capacity to remain in the linear portion of their range to at least 110% of the ultimate capacity of that section of the support where they will be used. If blasting is used for excavation, the cells shall be sturdy enough to withstand the shock.

3.2 Readout equipment.

The type of readout equipment depends on the kind of load cell used. The effects of the readout equipment shall be included in the performance requirements of Section 3.1.

4.0 Testing

4.1 Location

The instrumented test section shall consist of at least five supports. In order to monitor the entire load history of the supports, these shall be located as close to the working face as possible and shall be installed as soon after excavation as possible. In each support, load cells shall be installed at locations that will monitor the load in a known and complete way. For example, in steel arch supports, load cells are recommended under each leg and in the crown. For ring supports, load cells are recommended at 90° intervals around the periphery. These locations are shown on Figure 4.1.

4.2 Installation.

4.2.1 Surface preparation. The surfaces of the load cells and the supports shall be free from dirt, rust, grease and other foreign materials where they will be in contact. The surface of the support shall conform to the shape of the load cell.

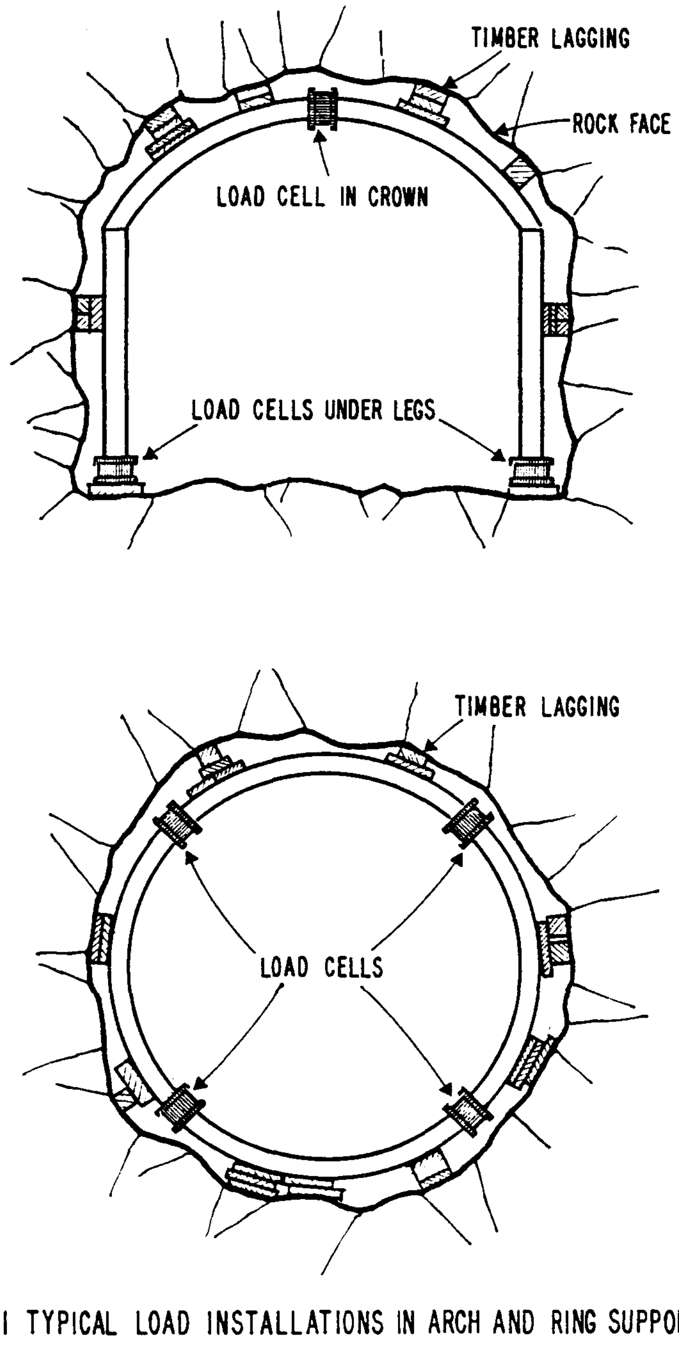


FIG. 4.1 TYPICAL LOAD INSTALLATIONS IN ARCH AND RING SUPPORTS

4.2.2 Alignment. The load cells shall be carefully installed so that the center of the cell is aligned with the axis of thrust in the support member. Cells may be bolted or welded in place if necessary, providing such attachment does not reduce the load transmitted through the cell.

4.3 Protection.

If blasting is used for excavation, the load cells and readout cables (if any) shall be protected from flying rock. Steel plates, protective conduits, wooden barriers, etc. are acceptable.

4.4 Monitoring.

4.4.1 Reading frequency. The frequency of load cell readings depends on how rapidly the load is transferred to the support after excavation. Initially, readings should be taken at least twice each working shift. Readings may be taken less frequently as the rate of load change diminishes.

4.4.2 Duration. Readings shall be taken until the load becomes constant within the limitations of the cell and readout system over a period of at least 7 days.

4.5 Data recording requirments.

The data as shown on Form GT-H.3-1 shall be recorded as a minimum.

5.0 Reporting

The purpose of this section is to establish the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. The analysis of load cell data is beyond the scope of the procedure, but if an analysis is included, it should be complete and consistent with the other sections of this procedure.

5.1 Introductory section of the report.

The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the materials tested.

5.1.1 Scope of testing program.

5.1.1.1 Location, rock type, and support type. The location of the test sections, the type of rock, and the type of support shall be presented. In a larger report covering the results of several types of supports or rock, the test matrix is best presented in a tabular form.

5.1.1.2 Rationale for test selection. The reasons for the number and locations of the test sections shall be clearly stated.

5.1.1.3 Limitations of the testing program. The areas of interest which are not covered by the testing program and the limitations of the data within the areas of application shall be discussed in general terms.

5.1.2 Brief description of the test site geology. The rock type shall be described macroscopically. Structural features affecting the load cell testing shall be discussed as appropriate.

5.2 Test method.

5.2.1 Equipment and apparatus. A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

5.2.2 Procedure. The procedure actually used for the test shall be listed in detailed steps.

5.2.3 Variations. If the actual equipment or procedure varies from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

5.3 Theoretical background.

5.3.1 Data reduction equations. All equations used to reduce the data shall be clearly presented and fully defined. Any assumptions inherent in the equations and limitations in their applications shall be noted and the effect on the results discussed.

5.3.2 Site-specific influences.

5.3.2.1 Assumptions. The degree to which the actual site conditions conform to the assumptions contained in the data reduction equations shall be discussed.

5.3.2.2 Correction factors. Any factors or methods applied to the data to correct for a nonideal situation shall be fully explained.

5.4 Results.

5.4.1 Graphic presentation. A load vs. time curve similar to Figure 1.1 shall be presented for each load cell.

5.4.2 Data. A complete listing of load and time data shall be included in the report. This may be attached as an appendix.

5.5 Measurement error.

The error associated with a single test shall be evaluated at the 95% confidence level. This includes the combined effects of all transducers, power supplies, readout devices, etc.

6.0 Quality Assurance.

The following items are the minimum requirements to ensure that the test results are defendable and traceable. It is not the intent of this section to establish Quality Assurance procedures, but to identify those points during the test where Quality Assurance action is required.

6.1 Personnel prequalification.

Prior to testing, all personnel shall be prequalified as described in Section 2.1.

6.2 Test inspection.

Quality Assurance personnel shall review the test setup, the procedure, and the equipment performance verification. After testing, the completed Form GT-H.3-1 shall be reviewed and signed off only if correct.

6.3 Required documentation.

6.3.1 Equipment performance verification. Quality Assurance shall maintain complete calibration records and certificates.

6.3.2 Equipment serial numbers. Quality Assurance shall verify that serial numbers of all equipment used in the test are recorded on Form GT-H.3-1.

6.3.3 Test sign-offs. Quality Assurance shall maintain signed-off copies of Form GT-H.3-1.

Prop Load Cell Tests

Test Data Sheet - Form GT-H.3-1

Project ______________________ Support No. ______________________

Feature ______________________ Support Type ______________________

Test Location ______________________ Cell Orientation ______________________

Rock Type ______________________

Equipment Description	Serial No.	Date of Next Calibration

Date	Time	By	Reading

Date	Time	By	Reading

Remarks:

Test Supervisor ______________________ Date ____________

[illegible]ance ______________________ Date ____________

[illegible]eer ______________________ Date ____________