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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock[1]

This standard is issued under the fixed designation D 4879; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Paragraph 1.9 was added editorially October 1998.

INTRODUCTION

This guide is intended for use in both civil and mining underground excavations, whether new or existing, which may be either regular or irregular in section, large enough to be accessible to a person, and for which a record of encountered conditions and features is desired. The details of the geotechnical mapping will be dependent upon the features being mapped, and the proposed use of the information. The information covered in this guide will be based upon observations and measurements at the surface of the excavation; geophysical measurements are not included. In general, sufficient information should be collected about features of interest to define uncertainty and facilitate consistent interpretation. Mapping in accordance with this guide is useful to provide a data base for design, for stability analyses, for confirmation of geotechnical predictions, for maintenance and monitoring, and as a permanent record of construction. This guide is not intended to provide, of itself, the methodology for rigorous collection of sufficient local, detailed, data for model development or verification, for in situ testing, or for ore search.

1. Scope

1.1 This guide recommends procedures for mapping large subsurface openings made for either civil or mining purposes.

1.2 The mapping provides characterization and documentation of the condition of the rock mass at the excavation surface.

1.3 The mapping may be accomplished during or after excavation; however, the mapping must be completed before construction activity modifies or obscures the surface condition.

1.4 The mapping level of detail shall be appropriate for its intended use. This mapping does not replace rigorous investigations to develop physical or mathematical models of behavior.

1.5 When soil or soil-like materials are encountered in the excavation, they should also be appropriately mapped and described in accordance with applicable ASTM standards.

1.6 Many of the procedures presented in this guide may be used, as well, to map surface excavations.

1.7 The mapping does not replace the surveying of excavation geometry.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *adit*—a horizontal or nearly horizontal passage driven

[1] This guide is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

from the surface for the working or unwatering of an underground excavation (based on Ref **(1)**).[3]

3.1.2 *alteration of rock*—any change in the mineralogic composition of a rock brought about by physical or chemical means, especially by the action of hydrothermal solutions; also, a secondary, that is, supergene, change in a rock or mineral **(2)**.

3.1.2.1 *Discussion*—Alteration is sometimes considered as a phase of metamorphism, but is usually distinguished from it because of being milder and more localized than metamorphism is generally thought to be **(2)**.

3.1.3 *aperture*—perpendicular distance between adjacent rock walls of a discontinuity in which the intervening space contains air, water, or uncemented infilling materials.

3.1.4 *back*—the roof or upper part in any underground cavity (based on Ref **(1)**).

3.1.5 *bedding surface*—the interface between two adjacent beds of sedimentary rock; bedding is the arrangement of sedimentary rock in layers of varying thickness, composition, texture, or color (based on Ref **(2)**).

3.1.6 *cleavage planes*—parallel or subparallel surfaces along which a rock or mineral separates. **D 653**

3.1.7 *crown*—the curved roof of a tunnel **(1)**.

3.1.8 *discontinuity—as used in this guide*, a surface of separation in the earth materials, which may be filled with other materials.

3.1.8.1 *Discussion*—Discontinuities include joints, cleavage, faults, induced fractures, and some bedding surfaces, some foliation surfaces and some contacts.

3.1.9 *drift*—a horizontal passage underground.

3.1.10 *face*—the surface exposed by excavation, at the end of the tunnel heading, or at the end of the full-size excavation (based on Ref **(1)**).

3.1.11 *fall of ground*—a mass of roof or side material which has fallen in any underground excavation resulting from any cause, natural or man-induced (based on Ref **(1)**).

3.1.12 *fault*—a natural break in the physical continuity of rock along which appreciable displacement has taken place parallel to the break's surface (based on Ref **(2)**).

3.1.12.1 *Discussion*—The term *shear* has been applied in geotechnical practice to small faults or faults with small displacement.

3.1.13 *floor*—that part of any underground opening upon which a person walks or upon which a roadway is laid (based on Ref **(3)**).

3.1.14 *flowing ground*—a mixture of earth materials and water flowing into the excavation like a viscous fluid.

3.1.15 *foliation*—the parallel arrangement of platy or prismatic minerals; also the parallel arrangement of streaks or irregular bands of minerals in metamorphic rocks; a generic term including schistosity and some rock cleavage.

3.1.16 *fracture—as used in this guide*, refers to an artificial break and is preceded by a modifier, for example, *blasting fracture*.

3.1.16.1 *Discussion*—This is the generic term of a natural break in the physical continuity of rock; includes joints and faults. **D 653**

3.1.17 *infilling*—material that separates the adjacent rock walls of a discontinuity and that may be weaker than the parent rock.

3.1.17.1 *Discussion*—Typical filling materials are sand, silt, clay, breccia, gouge, or mylonite. This term also includes thin mineral coatings and healed discontinuities, for example, quartz and calcite veins.

3.1.18 *invert*—the curved floor of a tunnel or other underground opening (based on Ref **(1)**).

3.1.19 *joint*—a natural break in the physical continuity of rock with little or no displacement parallel to the break's surface.

3.1.20 *overbreak*—the rock which is broken by blasting outside the intended excavation line (based on Ref **(1)**).

3.1.21 *parting*—a thin sedimentary layer within a bed, such as a shale parting in coal; also a surface along which a rock is readily separated, such as bedding surface parting (based on Ref **(2)**).

3.1.22 *planarity*—this refers to a wave length of asperities greater than 50 mm. It is described by the same asperity features as are used in roughness (see also *roughness*).

3.1.23 *ravelling ground*—chunks or flakes of material which begin to drop out of the arch or walls some time after the ground has been exposed.

3.1.23.1 *Discussion*—In fast ravelling ground the process starts within a few minutes after exposure; otherwise the ground is slow ravelling.

3.1.24 *roof*—the ceiling of any underground excavation **(3)**.

3.1.25 *roughness*—this describes the topography of a discontinuity surface (see also *planarity*).

3.1.25.1 *Discussion*—Degree of roughness refers to an asperity wave length of 50 mm or less (discernible in a 50-mm nominal diameter core). Degree of roughness is described by height and wave length of the asperities, as well as angularity and their true and apparent orientations.

3.1.26 *running ground*—granular materials without cohesion which are unstable at slopes greater than their angles of repose.

3.1.27 *schistosity*—foliation in coarse-grained metamorphic rocks. **D 653**

3.1.28 *set*—a group of parallel or subparallel joints or faults. **D 653**

3.1.29 *shaft*—an excavation of small area compared with its depth made for exploration or raising rock, soil or water, hoisting and lowering personnel and material, or ventilating underground excavations (based on Ref **(1)**).

3.1.30 *shear*—see *fault*.

3.1.31 *slaking*—the process of breaking up or sloughing where an indurated soil or a weak rock is alternately dried and immersed in water. **D 653**

3.1.32 *spring line*—the junction of the roof arch and the sides of a tunnel, drift, or adit (based on Ref. **(1)**).

3.1.33 *squeezing ground*—ground which extrudes plastically into the excavation without visible fracturing or loss of continuity.

3.1.34 *swelling ground*—ground which absorbs water, increases in volume, and expands slowly into the excavation.

[3] The boldface numbers in parentheses refer to References at the end of this standard.

3.1.35 *system*—two or more sets of joints or faults, or a group of joints or faults with a radiating, concentric or other characteristic, nonparallel pattern. **D 653**

3.1.36 *termination*—the end, or the form of the end, of the trace of a planar feature such as a joint.

3.1.37 *trace length*—the length of the line formed by the intersection between a planar feature such as a joint and an exposed surface of rock or soil in an excavation (based on Ref **(3)**).

3.1.38 *tunnel*—a horizontal or nearly horizontal underground passage that is open to the atmosphere at both ends; this term is often applied to an adit (based on Ref **(1)**).

3.1.39 *weathering*—the destructive process or group of processes constituting that part of erosion whereby earthy and rocky materials on exposure to atmospheric agents at or near the earth's surface are changed in character (color, texture, composition, firmness, or form), with little or no transport of the loosened or altered material; specifically the physical disintegration and chemical decomposition of rock that produce an in situ mantle of waste and prepare sediments for transportation **(2)**.

3.1.39.1 *Discussion*—Most weathering occurs at the surface, but it may take place at considerable depths, as in well jointed rocks that permit easy penetration of atmospheric oxygen and circulating surface waters **(2)**.

3.2 *Abbreviations:*

3.2.1 Some useful rock condition abbreviations are as follows:

3.2.1.1 blky—blocky.

3.2.1.2 br—breccia.

3.2.1.3 C—clay.

3.2.1.4 cr—crushed.

3.2.1.5 d.g.—decomposed granite (popular term in construction).

3.2.1.6 fr—fractured.

3.2.1.7 G—gravel.

3.2.1.8 g—gouge.

3.2.1.9 h—hard.

3.2.1.10 jt—joint.

3.2.1.11 M—silt (after Swedish word *mo*).

3.2.1.12 mas—massive.

3.2.1.13 mh—moderately hard.

3.2.1.14 ms—moderately soft.

3.2.1.15 rs—rust stains on joints.

3.2.1.16 S—sand.

3.2.1.17 s—soft.

3.2.1.18 sw—slightly weathered.

3.2.1.19 w—weathered or decomposed.

4. Significance and Use

4.1 The geotechnical map resulting from application of the procedures set forth in this guide is permanent documentation which may be used in the following ways:

4.1.1 Compilation of basic geotechnical information.

4.1.2 Design verification.

4.1.3 Evaluation of preconstruction assumptions.

4.1.4 Instrumentation location and data analyses.

4.1.5 Identification and location of problems and potential problems.

4.1.6 Provision of records for cost and claims adjustments.

4.1.7 Provision of information useful in future similar or nearby projects.

4.2 Construction or safety considerations may limit the ability to map to the full extent of the procedures of this guide.

4.3 There are significant benefits to mapping as close to the advancing face of the opening as is feasible, depending upon safety and logistical considerations.

4.4 Mapping emphasis should be placed on those geotechnical features which are anticipated or are found to affect overall performance of the excavation.

4.5 Dust, water, lack of light, limited exposures, or other physical factors may affect the quality of the mapping.

5. Apparatus

5.1 *Engineering Tape*, 100 ft or 25 m as appropriate.

5.2 *Waterproof Paper*, if tunnel wetness requires.

5.3 *Covered Clip Board*.

5.4 *Required Safety Equipment*, such as a hard hat.

5.5 *Protractor*, with movable arm.

5.6 *Engineer's Scale*.

5.7 *Pocket Transit* (Note 1).

NOTE 1—Readings may be affected by excavation steel supports, electrical and mechanical equipment, or natural sources.

5.8 *Supplemental Light Sources*.

5.9 *Pencils*.

5.10 *Sample Containers*.

5.11 *Optional Equipment*:

5.11.1 *Camera, Flash, and High-Speed Film*.

5.11.2 *Containers*, or apparatus, to measure water flow quantities.

5.11.3 *Schmidt Rebound Hammer* **(4)**.

5.11.4 *Point Load Testing Device* **(5)**.

5.11.5 *Thermometer*.

6. Procedure

6.1 The mapping shall be performed by persons with training in geology and with experience in underground mapping. These persons shall become familiar with the regional and local geology prior to mapping. A geologically qualified professional shall supervise and be responsible for the mapping.

6.2 Provision for mapping operations and a description of any required constructor assistance in the mapping effort shall be included in the construction plan or specification.

6.3 The construction schedule shall provide time for geotechnical mapping.

6.4 A pre-mapping meeting shall be held among involved parties to determine required details of the mapping. Very careful consideration shall be given to the selection of those features to be mapped in detail and to the level of detail. The tendency to record every attribute of the rock mass and associated features can lead to the accumulation of extraneous details which could in some instances mask the relevant information.

7. Procedure

7.1 The objective of the mapping is to develop an appropriate visual and quantitative representation of the rock mass and associated features, such as excavation supports, in situ testing locations, and groundwater inflows. The details of this representation will vary with the rock type, the size of the opening, and the intended use of the data.

7.2 Time of mapping, relative to time of excavation, may be influenced by time-dependent rock behavior (for example, swelling, slaking, stress relaxation), but mapping is best performed as soon as exposures are made.

7.3 Map all excavated surfaces consistently. Also map the floor of the opening, when important to analysis or performance.

7.4 Of the currently available ways of displaying the results of such mapping, the full-periphery technique is generally recommended **(6)**, **(7)**. This representation shows all exposed features, including seepage, and is both simple to execute and to understand. See Appendix X1 for fuller explanation of the technique.

7.5 *Preparation*:

7.5.1 Surfaces of the excavation may need to be cleaned by water or air immediately prior to mapping. Give consideration to the potentially detrimental effects of cleaning on the natural materials.

7.5.2 Mark stationing or survey control points on the walls at appropriate intervals immediately prior to mapping.

7.5.3 If primary supports are needed for safety, place them prior to mapping. In addition, the area to be mapped must have adequate ventilation.

7.5.4 Those doing the underground geotechnical mapping must be equipped to be operationally independent and self sufficient during the mapping.

7.6 *Specific Mapping Procedures*:

7.6.1 Prepare base sheets which are numbered consecutively to an appropriate scale (Note 2). Tie base sheets to survey control.

NOTE 2—Experience has shown that a mapping scale of 1:120 (1 in. = 10 ft) is generally adequate for characterization and documentation.

7.6.2 Enter legend or key of general rock types on each base sheet prior to mapping.

7.6.3 Using mapping increments of approximately 10 ft (3 m) in length (Note 3), record and describe information itemized in Section 8. Use standard symbols in the mapping (see Fig. 1). Make appropriate notes about the geotechnical features which most strongly affect the performance of the opening.

NOTE 3—This is a convenient distance for a single view with minimal visual distortion.

7.6.4 Record location and features of areas of excessive overbreak and potential instability.

7.6.5 Record the types of ground support, and map their positions.

7.6.6 Map traces of discontinuities in freehand, as they appear at the excavation surface. See Fig. 2 for an illustration.

7.6.7 Transfer data from field sheets to master sheets in the office.

7.6.8 Review previous mapping, if any, for consistency of new with old documentation.

8. Details of Mapping

8.1 *Mapping*—All mapping shall include:

8.1.1 Dates of all observations,

8.1.2 Sample locations,

8.1.3 Photo locations, and

8.1.4 Locations of any special detailed mapping or sketching.

8.2 *Discontinuity Mapping*—Discontinuity (rock defect) mapping shall include the following for each set or system:

8.2.1 Type (joint, fault, bedding, cleavage, and the like),

8.2.2 Orientation (Note 4),

8.2.2.1 *Planar*—Strike or dip azimuth and dip angle,

8.2.2.2 *Linear*—Bearing and plunge,

NOTE 4—Variability of orientations requires multiple observations.

8.2.3 Roughness (small scale),

8.2.4 Planarity (large scale),

8.2.5 Aperture width (mode and range of values),

8.2.6 Spacing (minimum, mode, maximum),

8.2.7 Type of termination (see Fig. 3),

8.2.8 Trace length, and

8.2.9 Infilling (distribution, composition, texture (see Practice D 2488) degree of wetness).

8.3 *Rock Mass Response Mapping*—Rock mass response mapping and description shall include:

8.3.1 Overbreak or fall of ground (location, depth, quantity, cause; provide cross section(s) if significant to construction).

8.3.2 Stress-release features, including audible rock noise, slabbing, popping rock, and rock bursts (location, description, and time of occurrence (Note 5).

NOTE 5—For rock bursts, estimate the volume of rock detached.

8.3.3 Running ground, squeezing ground and swelling ground (location, description, and time of occurrence).

8.3.4 Unstable blocks or ravelling (location, description, and time of occurrence).

8.4 *Rock Descriptions*—Rock descriptions shall include:

8.4.1 Rock type; include definitive adjectives such as aplitic, porphyritic, cherty, silty; also formation name, if known.

8.4.2 Color and range.

8.4.3 Grain size and range.

8.4.4 Prominent minerals or percent rock clasts; type of cementation.

8.4.5 *Rock Defects*:

8.4.5.1 *Joints*—Open or closed, type of filling, cementation, attitudes, spacing, number, and orientation of prominent sets.

8.4.5.2 *Faults*—Type (dip-slip, normal, reverse, thrust, strike-slip), attitude, displacement, filling (mylonite, gouge, breccia), thickness of zone.

8.4.5.3 *Weathering and Decomposition*—Degree of mechanical or chemical weathering, hydrothermal alteration, oxidation.

8.4.6 *Rock Structures*:

8.4.6.1 *Sedimentary*—Stratified, massive, lensed, attitudes, degree of cementation, cross-bedding, inferred current directions, clast shapes. Describe fossils.

8.4.6.2 *Metamorphic*—Migmatitic, cataclastic, schistose, gneissic, foliated. Identify grade of metamorphism.

8.4.6.3 *Igneous*—Aphanitic, porphyritic, zoned, dike, intrusive extrusive, flow banding.

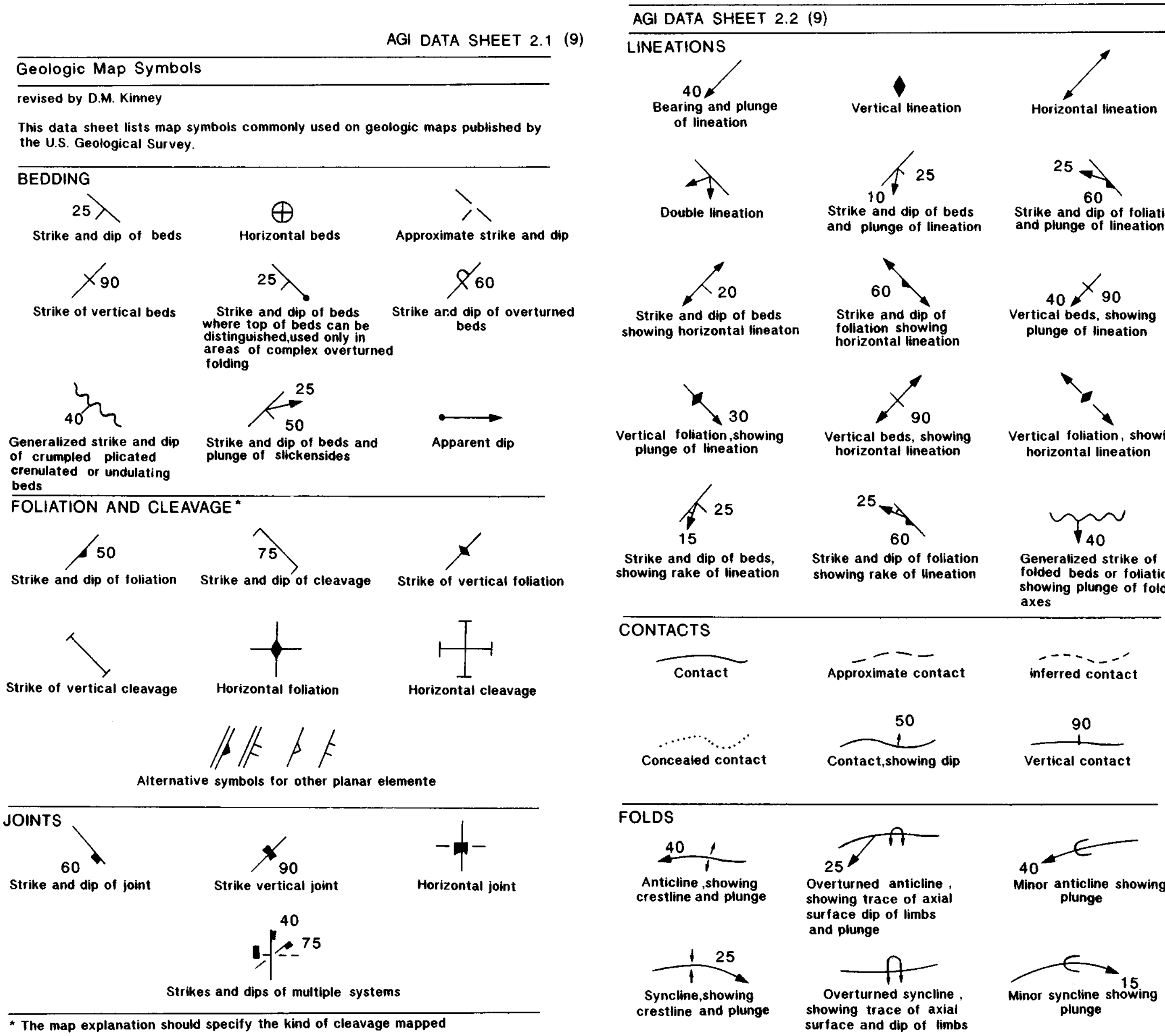


FIG. 1 Data Sheets of Mapping Symbols (9)

8.4.7 *Rock Condition*—Soundness, consistency, behavior; soft or hard (see section 8.4.7.1). Fresh cut stands well (no sloughing), stands moderately well, or stands poorly (considerable sloughing and raveling). See 3.2 for some useful rock condition abbreviations.

NOTE 6—These terms apply to tunnel rock regardless of actual rib spacings or amount of supports used by contractor.

Rock Hardness Scale (see also Table 1)

(*a*) *Hard*—Very abrasive, dense rock that rings when struck with a hammer. May be broken with repeated heavy hammer blows. Grossly equivalent to Mohs hardness> 5.

(*b*) *Moderately Hard*—Rock has dull ring and hammer produces minor indentation. May be broken with one sharp blow of hammer. Grossly equivalent to Mohs hardness 3–5.

(*c*) *Moderately Soft*—Rock is considerably deformed when struck by hammer. May be broken in the hands, but does not crumble readily. Grossly equivalent to Mohs hardness 1–3.

(*d*) *Soft*—Material can be dug out and crumbled with fingers. Mohs hardness <1.

8.5 *Fluid Descriptions*—Mapping and description of fluids (liquids and gases) shall include:

8.5.1 Nature and location of fluid; detectors for identification and classification of gases in accordance with applicable regulations may be needed.

8.5.2 Rate of inflow (as shown below). Estimate volumetric rate of flow and variations, if any, of flow with time:

8.5.2.1 *Dry*—No water visible on rock surface; dry to touch.

8.5.2.2 *Damp*—Water present on rock surface but not flowing; moist to touch.

8.5.2.3 *Wet*—Rock surface coated with water.

8.5.2.4 *Dripping*—Water drips very common and continual.

8.5.2.5 *Rainy*—Water falling as if raining.

8.5.3 Effluent or pumping rate from local construction

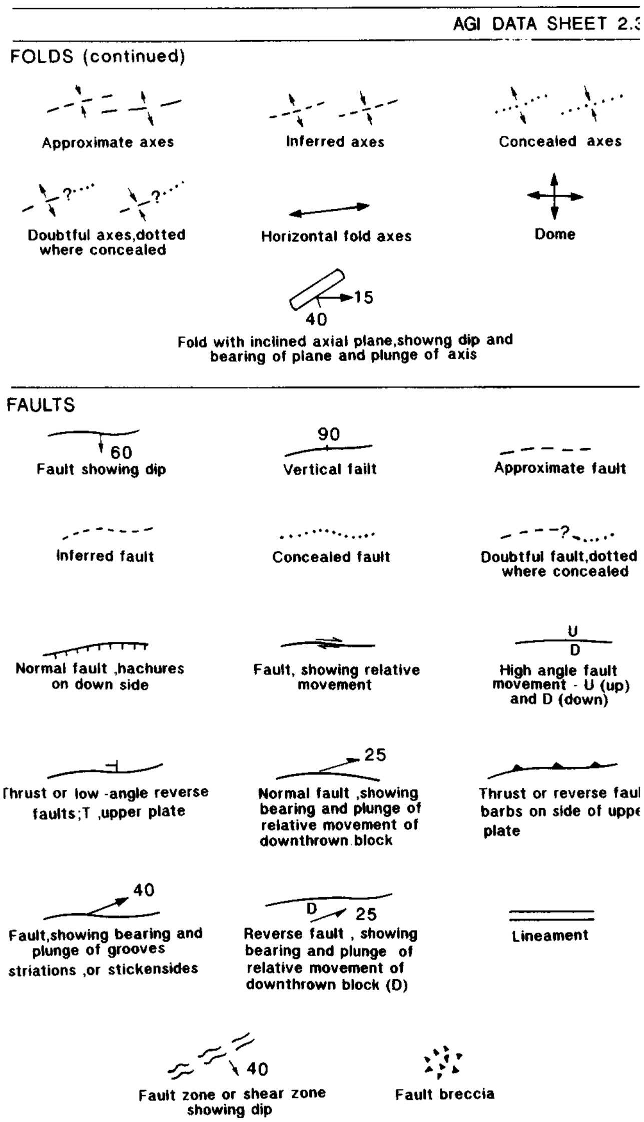
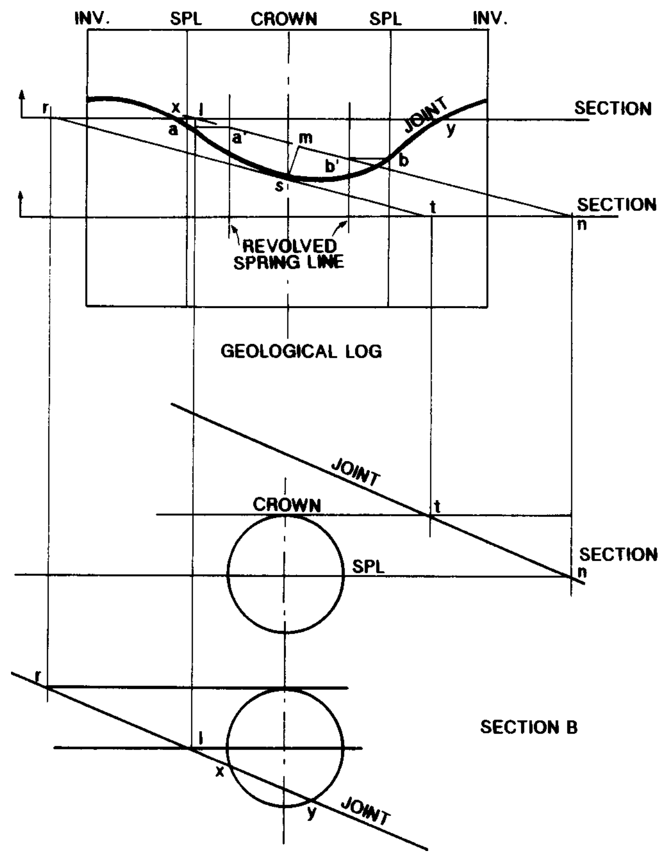


FIG. 1 *(continued)*



NOTE 1—Method of projecting geological data from geological log of tunnel to draw cross sections: (1) The strike in relation to the tunnel can be found by three different methods—(*a*) revolved springline in Fig. 1 to tunnel diameter and measure strike *a*′*b*′; (*b*) measure tangent to curve at the crown; (*c*) use measured strike in the field. (2) Project the intersection of the strike at the crown *s* to sections desired. For example, joint is at crown level at *t* and *r* respectively in sections A and B. (3) Project the strike of the joint at springline level to the sections desired; in the example, joint is at springline elevation at points *n* and *a* respectively in sections A and B. (4) Line *tn* is the trace of the plane on section A. Line *rl* is the trace of the plane on section B. (Points *x* and *y* show where the joint plane intersects the tunnel boundary in section B. It does not intersect the boundary in section A.) (5) Find dip δ from distance *sm*. $\delta = \tan^{-1}$(tunnel radius/*sm*), or use dip measured in the field.

FIG. 2 Method of Projecting Geological Data

area(s) and final discharge point(s).

8.5.4 Temperature.

8.5.5 Immediate source and probable origin, if known.

8.5.6 Odor, bubbles, color, clarity.

8.5.7 Ice accumulations.

8.5.8 Efflorescence, stains, precipitates, and other deposits.

8.6 *Engineering and Construction Features*—Requirements for description of engineering and construction features shall include the following:

8.6.1 Type, location, and orientation of reinforcement and supports.

8.6.2 Locations of excavation methods used.

8.6.3 Features of rock surface resulting from excavation method (remaining blast hole traces, blast-induced fracturing, and occurrence of unusual cutter marks from the mechanical excavator).

8.6.4 Location and description of turnouts and niches as excavated.

8.6.5 Location and condition of exploratory bore holes and shafts.

8.6.6 Geotechnical instrumentation type, location, and orientation.

9. Report

9.1 The geotechnical mapping and summary may include letter of transmittal, executive summary, and supplementary appended materials.

9.2 Suggested report outline is as follows:

9.2.1 *Introduction*:

9.2.1.1 Purpose of mapping.

9.2.1.2 Description of project.

9.2.1.3 Name(s) of supervisor(s), mapper(s), and their affiliation(s).

9.2.2 Mapping procedures and limitations.

9.2.3 *Geologic Setting*:

9.2.3.1 Regional.

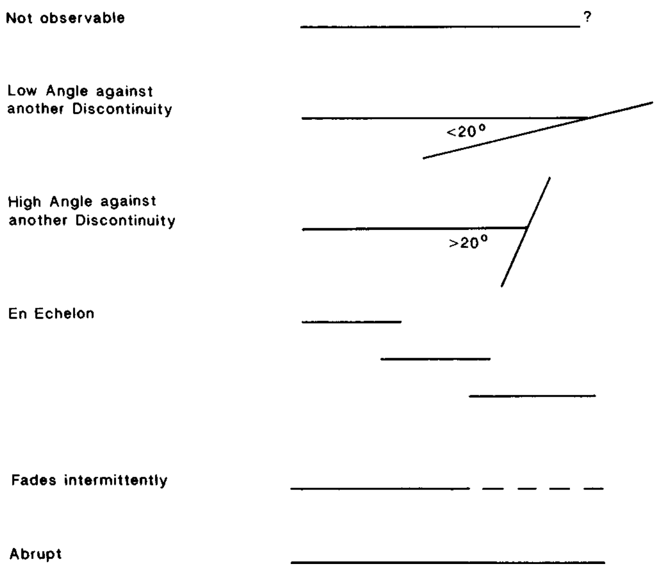


FIG. 3 Discontinuity Termination Types

9.2.3.2 Site (local), including formation names.
9.2.4 Excavation geology.
9.2.5 Excavation methods and progress.
9.2.6 Geologic material properties (including in situ and laboratory test results).
9.2.7 Technical discussion of geotechnical map.
9.2.8 Descriptions and discussion of problem areas and potential problem areas relative to:
9.2.8.1 Design.
9.2.8.2 Construction.
9.2.8.3 Operation.
9.2.9 *Terminology*— Terminology in underground excavations can be confusing and local. Terms used in the application of this guide must be in accordance with generally accepted usage as defined in standard glossaries, and inclusion of definitions of special terms used is required.
9.2.10 References.
9.3 Suggested illustrations for report are as follows:
9.3.1 Required full periphery or other map record. See Appendix X1.
9.3.2 Cross sections.
9.3.3 Block diagrams.
9.3.4 Discontinuity orientations plotted on hemispherical projections or polar diagrams.
9.3.5 Other diagrams.
9.3.6 Photographic record.

10. Keywords

10.1 cavern design; civil underground excavations; cleavage planes; discontinuities; excavation site; face; fault zones; geotechnical mapping; mapping; mines; rock; rock mass response mapping; subsurface openings; surface analysis; underground environments; underground excavations (civil/mining)

TABLE 1 Terzaghi's Guide for Distinguishing Rock, Weathered Rock, and Soil (8)

In Original State	After Repeated Drying, Immersing, and Shaking, or upon Prolonged Exposure to the Atmosphere	Volume Change Produced by Saturating Dried Fragments with Water	Group
Solid with ringing sound when struck with a hammer	unchanged	imperceptible	(*a*) solid rock
	breaks up into small hard pieces with clean surfaces		(*b*) finely fissured or crushed unaltered rock
	breaks up into small fragments with "greasy" surfaces owing to the presence of fine-grained weathering products		(*c*) slightly decomposed fissured rock
	breaks up into individual sand or silt particles		(*d*) sandstone or mudstone with unstable cement
	breaks up into small angular fragments without any indication of chemical alteration	measurable	(*e*) intermediate between rock and clay, rock characteristics dominant
Solid with dull sound when struck with a hammer	gradually transformed into a suspension of soil particles		(*f*) intermediate between rock and clay, clay characteristics dominant
	gradually transformed into a suspension of clay particles and a sediment consisting of angular rock fragments		(*g*) thoroughly decomposed rock
	completely transformed into a suspension and/or a loose sediment	imperceptible to important	(*h*) clay, silt, and very fine sand in dry or a very compacted condition

APPENDIX

(Nonmandatory Information)

X1. FULL PERIPHERY GEOLOGIC MAPPING OF UNDERGROUND OPENINGS

X1.1 Introduction

X1.1.1 The peripheral method of logging all geologic features exposed in an underground excavation was developed by geologists of the Omaha District of the United States Army Corps of Engineers. The method was first described by H. A. Jack **(7)** and was later presented in Engineering Technical Letter No. 1110-1-37 **(6)**. This appendix presents a synopsis of the method as described in these two earlier articles.

X1.1.2 A base map for the full peripheral geologic mapping method is constructed by "unrolling the circumference'' of the entire wall surface of the underground opening into a plan view. Thus, the geologic features exposed on the surface of the underground opening can be mapped in their "real'' positions. Using the peripheral mapping method minimizes possible errors and visual perspective problems that can be associated with other methods of projecting the geologic data to plan views or cross sections representing planes through or tangent to the underground opening such as at the springline, waste level, or the crown of the opening.

X1.1.3 The peripheral geologic mapping method is simple, easy to use, and is applicable to large- and small-diameter tunnels, shafts, and adits with either circular, horseshoe, or irregular shapes.

X1.2 Procedure

X1.2.1 The first task in implementing the full-periphery geologic mapping techniques is to develop the base map. The excavation line of the underground opening, as presented on the design and construction documents and plans, should be used to construct these base maps. Appropriate modifications can be made to accommodate as-built changes in the opening shape. The scale of the base map should be consistent with the level of detail required by the purpose and use of the geologic data collected during the mapping. Generally, a scale of 1 in. = 10 ft is most useful. In areas of complex geology with closely spaced discontinuities, larger scales, such as 1 in. = 5 ft, may be more appropriate. Figs. X1.1-X1.3 and Fig. 2 are examples of developed layouts prepared for base maps for use in peripheral mapping in a variety of underground structures with varying shapes. For example, in a circular tunnel, as shown in Fig. X1.1, the crown of the tunnel is represented in the center of the developed layout and the invert is represented both on left and right edges of the plan. The right and left spring line are midway between the crown line and the right and left lines representing the invert. A grid system is laid out perpendicular (for a straight tunnel) to the developed layout which corresponds to the tunnel stationing. In actual mapping exercises, intermediate control points can be added to further improve the accuracy of the mapping. These intermediate control points might be individual steel sets or rock bolts that have been installed in the underground opening.

X1.2.2 The geology, including the rock type, any contacts between rock types and the rock mass discontinuities can be plotted on the developed layout at their respective locations as seen on the perimeter of the underground opening. During mapping, the view on the map is usually from the inside out. The alternative view, that is, looking at the rock mass surrounding the opening from outside the opening, can be achieved by transferring the mapped data to transparent map bases, and wrapping the map around a dimensionally correct model of the underground opening.

X1.2.3 The full peripheral method of mapping provides an advantage over planar or section maps in that the three-dimensional perspective allows assessments of strike and dips of rock mass features without the use of pocket transit compasses which are often affected by the metal and electrical

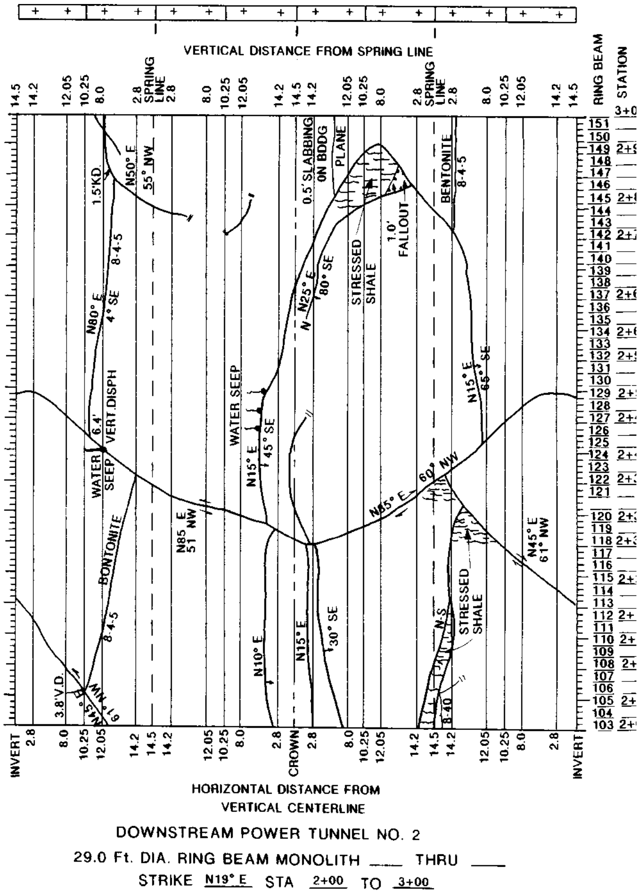


FIG. X1.1 Oahe Dam, Tunnel Number 2 (7)

systems installed in the underground opening.

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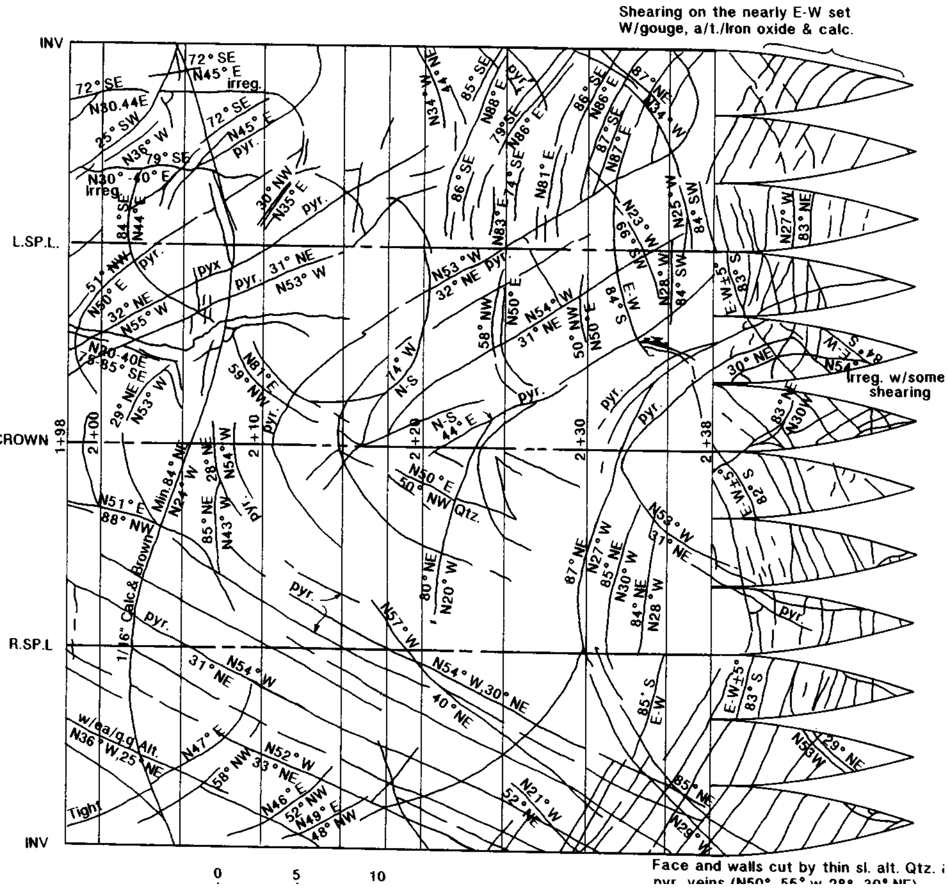

FIG. X1.2 Log of a Circular Tunnel (7)

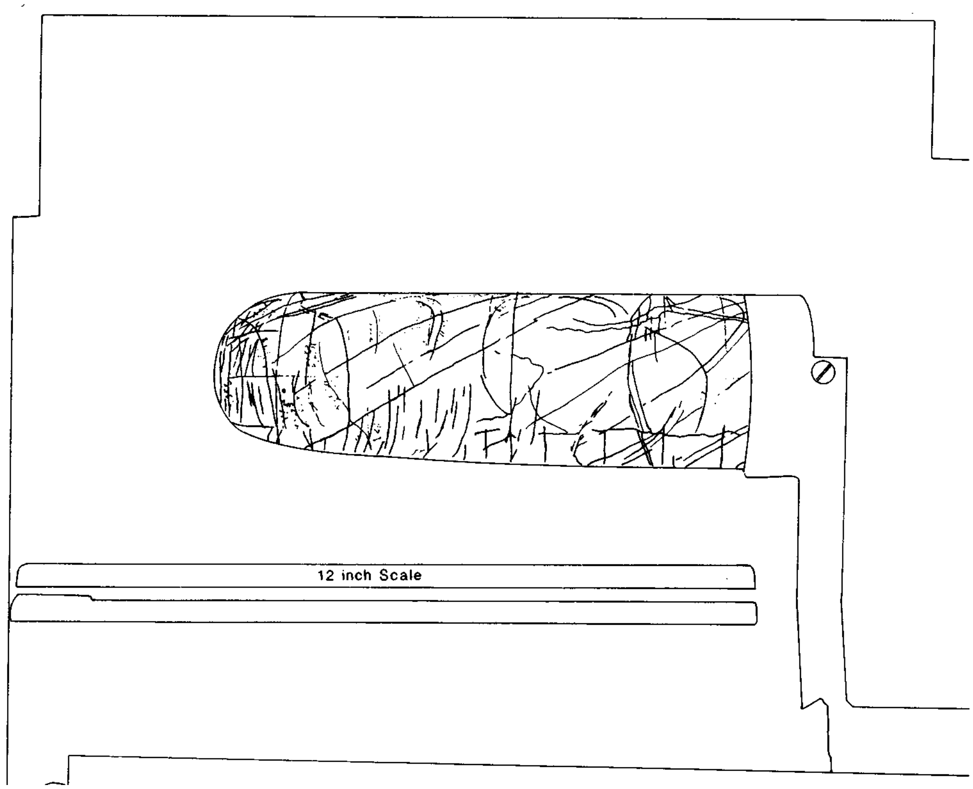

FIG. X1.3 Model of Tunnel Wall (7)

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