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No. 1110-2-300

31 October 1983

Engineering and Design
CHARACTERIZATION AND MEASUREMENT OF DISCONTINUITIES
IN ROCK SLOPES

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1. Purpose. This ETL provides guidance for characterizing and measuring rock discontinuities on natural slopes or slopes constructed in rock above reservoirs, dam abutments, or other types of constructed slopes. This ETL discusses and defines those rock discontinuities which influence rock slope stability, and the field methods for measuring them. Analytical procedures for determining slope stability, using the field data obtained by procedures outlined in this ETL, are identified by reference.

2. Applicability. This ETL is applicable to all field operating activities having responsibilities for civil works design and construction.

3. References.

a. Goodman, Richard E., Methods of Geologic Engineering in Discontinuous Rocks, West Publishing Co., P.O. Box 3526, St. Paul, Minnesota 55165, 1976.

b. International Society for Rock Mechanics, "Suggested Methods for the Quantitative Description of Rock Masses and Discontinuities", Committee on Field Tests Documents No. 2, Avenida da Brasil, Lisbon, 5, Portugal, 1977.

c. Hoek, E., and Bray, J. W., Rock Slope Engineering, The Institution of Mining and Metallurgy, 44 Portland Place, W1N4BR, London, England, 1974.

4. Characterization of Rock Slopes.

a. General. Rock slope investigations must recognize the inherent differences between the behavior of soil and rock. The soil mass is characteristically a continuous, relatively homogeneous medium of microscopic to macroscopic discrete particles, while a rock mass is a multiple phase, discontinuous medium of discrete, interlocked solid blocks separated by discontinuities. In soil, failure occurs through the soil mass, whereas in rock masses, the surface of failure tends to coincide with preexisting discontinuities with relatively little shearing through intact rock unless the rock is unusually soft. Soil masses can be characterized as virtually isotropic with respect to the direction of failure surfaces in comparison to the strength and deformation properties of rock masses which are highly anisotropic. The initial premise in the survey of rock slopes is that all phenomena related to the discontinuities in the rock mass are of major importance. The intact rock within the slope is subordinate to the nature of the discontinuities except where the lithology is nearly soil-like in continuity and strength (e.g., clay shales). In addition to purely rock mechanics considerations, the occurrence of water in a rock mass and the consequent affects of rapidly fluctuating pore pressures in the discontinuities are conditions which must be accounted for in determining the stability of slopes.

b. Discontinuities. Discontinuities in rock masses may be of various origins and prior deformational histories and may be described by the geologist as cross-bed joints, bedding separation joints, shear planes and zones, normal or reverse faults cutting across beds, or any surface upon which movement can take place. In addition, an important type of rock mass defect that must be recognized by the geologist and engineer is the failure surface of a preexisting slide mass. Quantitative descriptions of the system of discontinuities within a rock mass are required for analysis rather than qualitative listings of joint and fault occurrences. Quantitative parameters to describe discontinuties in rock mass are as follows (Reference 3 b):

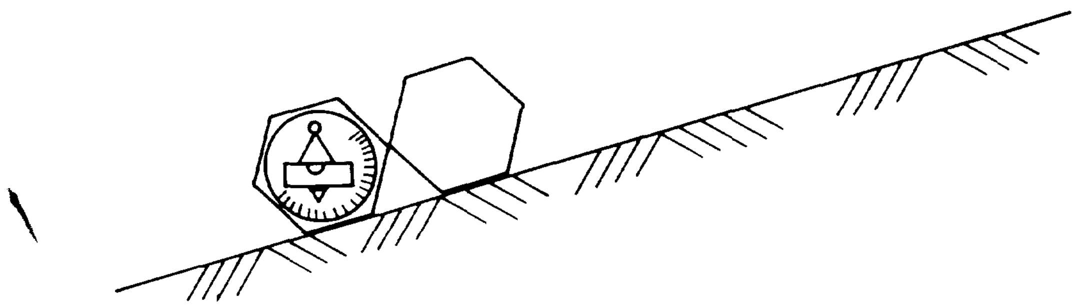
(1) Attitude	Orientation in space described by dip and strike (or dip direction vector).
(2) Spacing	Distance between adjacent, subparallel discontinuities.
(3) Persistence	A real extent or depth of penetration of the discontinuity. May sometimes be inferred from the generic origin, i.e., stress relief joints or regional tectonism.
(4) Roughness	Inherent departures of a discontinuity surface from its average plane. Both small-scale and large-scale roughness contribute to shear strength.
(5) Wall Strength	Equivalent strength of rock walls adjacent to a discontinuity normally is lower than intact rock strength. Discontinuity shear strength is increased if rock walls come in contact.
(6) Aperture	The distance between rock walls of a discontinuity.
(7) Filling	Material which fills an aperture of discontinuity including air and water. Frequently, but not always, it is weaker than wall rock. It may be granular, solid, or fluid in consistency.

(8) Seepage	The presence, rate of flow, and pressure of water in a discontinuity. It may be variable with season and climate. Potential for freezing may contribute to pressure variations.
(9) Number of Sets	Number of groups of discontinuities, geometrically similar to each other, which are distinguishable from other groups. It is most frequently applied to joints.
(10) Block Size	Dimensions of rock blocks that are defined by intersecting sets and individual discontinuities. Qualitative description of shapes is useful.

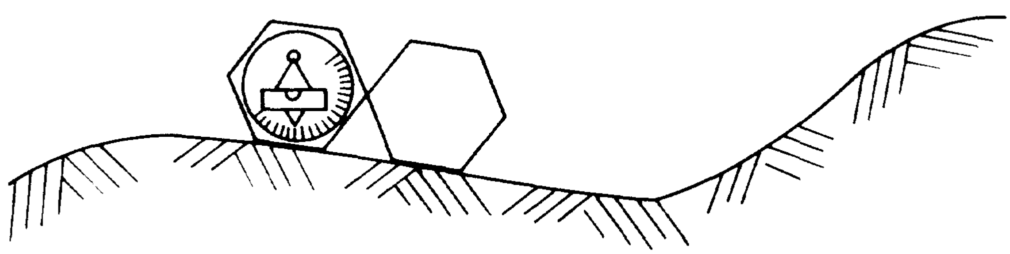
5. Preliminary Investigations. In the case of an operational project for which safety must be established, or at the site of a new project, historical and geologic evidence of prior slope failure must be investigated. Geomorphically, the evidence can be in two forms. The displaced slide mass may be recognized topographically as an irregular, hummocky surface often with disrupted drainageways and closed depressions. In addition to subaerial topographic evidence, the investigator should consider subaqueous bathymetric maps, subbottom profiles, and side-scan sonar surveys as potential sources of land slide information. The second primary topographic expression of past rock slope failures is the scar left by the failed mass. Repetitive rectilinear corrugations of the natural slope are expressions of multiple-plane, wedge-type failures resulting from well-developed systems of unfavorably oriented discontinuities. Planar surfaces or facets on natural slopes can be expressions of single-plane slides, particularly if there are a number of facets along slopes which are subparallel. Pronounced convexities of the slopes (overhanging masses being an extreme example) should be examined carefully even in the absence of other diagnostic features.

6. Field Investigations. Any available outcrop of the rock mass in the slope must be examined in detail to ascertain the characteristics of the discontinuity systems. Attention must be paid to the extent and variability of discontinuity parameters in three dimensions. Traces of discontinuities exposed by outcrops will provide data on attitude, wall strength, aperture filling, and seepage. Outcrops will provide two-dimensional data on spacing, persistence, roughness, number of sets, and block size. During construction, more of the rock mass will be exposed and the mapping and quantitative descriptions of the discontinuities can be updated and compared with the initial assumptions used during the design phase. Measurements can be made using clinometer/compass and line mapping techniques; boreholes should be utilized where available.

a. Clinometer/Compass Techniques. The attitude of discontinuities can be obtained by standard geologic clinometer/compass techniques. A sufficient number of direct measurements is necessary to define all exposed sets of discontinuities without exaggerating any one set. When roughness measurements are made directly on rock surfaces, care must be exercised to insure that the base length of the instrument exceeds the wavelength of the natural roughness of the surface (Figure 1c).

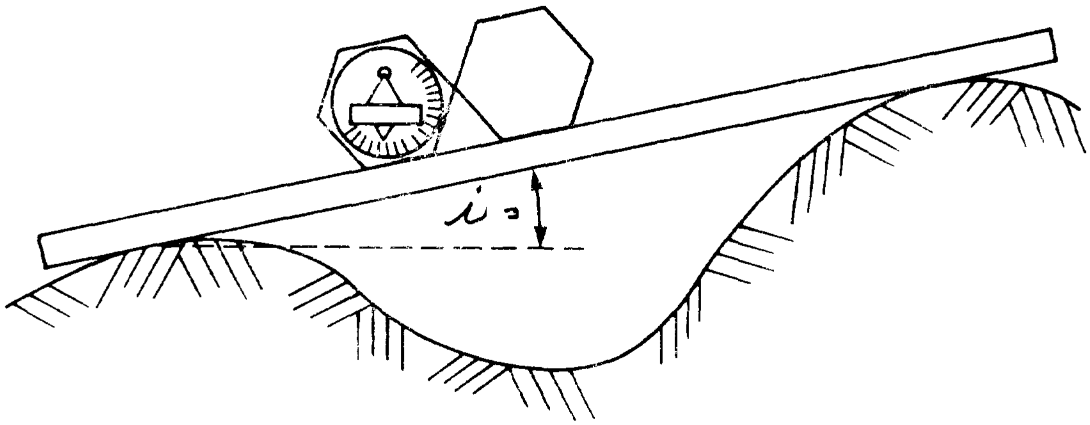


a. Compass/Clinometer on Smooth Surface.



b. Method for asperity measurement.

Figure 1. Use of Compass/Clinometer on Rock Surfaces



c. Method for average plane; i = roughness angle.

Figure 1, Cont. Use of Compass/Clinometer on Rock Surfaces.

b. Line Mapping. Line mapping is a technique whereby a taut measuring line is affixed to the outcrop face. The line's exact position and orientation are recorded. Beginning at one end, the features on the exposed rock mass along the line are measured and recorded referenced to the distance along the line. Spacings of discontinuities along the line are directly available. A line of reference is provided for locating index or in situ strength tests for wall and filling parameters for respective sets of discontinuities. The taut line may be used directly on exposed discontinuity faces or along traces to measure profiles of the roughness and aperture offset from the taut line. If an outcrop is not physically accessible, a photographic transparency may be made of the exposure. Projecting the transparency will enlarge its image and a straight-edge may be substituted for the taut string on the image. Stereographic photographs (references 3a and 3c) can be made of inaccessible rock exposures. Extreme care is necessary in providing appropriate length scales in the original photographs. High contrast photos are desirable and special features on the outcrop may be highlighted with high contrast paint marks. The camera orientation should be as nearly normal to the rock face as possible. If a very large portion of a critical natural discontinuity is exposed, the use of photogrammetric methods to develop a contour map of the surface may be justifiable. Sufficient roughness profiles may then be made on the map to enhance the statistical validity of interpreted roughness values. The latter is a cumbersome survey method and is best justified if the particular discontinuity is one of a set of similar features or has great persistence into the rock mass. Individual roughness measurements can be made on wavy rock surfaces by use of a measuring stick laid from peak to peak of adjoining asperities. The wavelength is measured along the stick and the greatest distance to the rock perpendicular to the stick is the roughness amplitude (Figure 1c).

c. Borehole Analysis. Boreholes essentially provide a line map oriented into the rock mass. Perceived in that manner, geophysical logging data and the recovered core provide a third-dimension of the rock mass. Attitudes are available only from oriented core or special geophysical tools. Borehole equipment useful in discontinuity surveys include television cameras, photographic cameras, and acoustic imagery tools (televiewer or seisviewer). The latter are well adapted to boreholes filled with mud or turbid water. Discontinuity spacings are directly available from the core. Persistence can be determined only by correlating from boring to boring. Only small-scale roughness measurements can be made. Wall rock and filling samples are provided by the core for field or laboratory testing. Conservatism should be exercised in making discontinuity aperture measurements from core because they can be rendered unreliable by the drilling operation. Hydrologic conditions inside the rock mass can be determined by using the borings for observation wells. Multiple borings, together with all outcrop data, are required to sufficiently define all the sets of discontinuities in the rock mass.

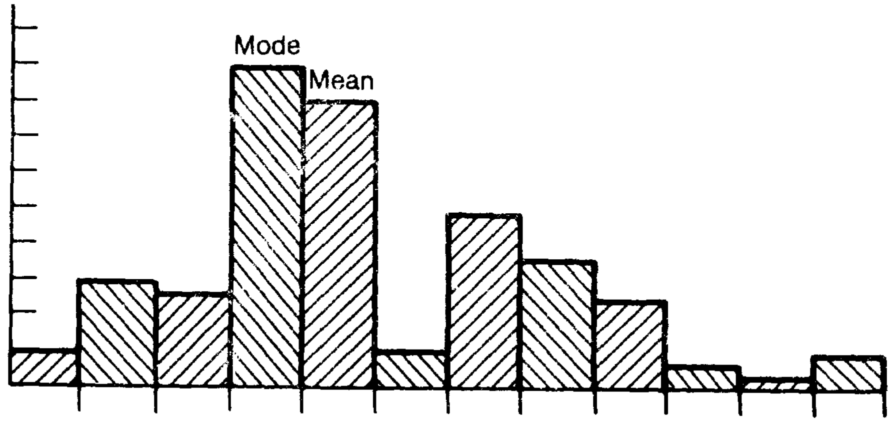
(4) Categorization of Discontinuities. The different sets and individual discontinuities should be categorized initially on the basis of average attitudes and relative frequencies. Suggested notation is illustrated below:

Set A: 2 per meter, dip 75 deg S, strike N90E;
Set B: 1 per meter, dip 60 deg E, strike N-S;
Set C: 1 per 2 meters, dip 10 deg N, strike N45W;
Individual D: Dip 60 deg W, strike N-S, exposed at sta DS+914, C_L + 500.

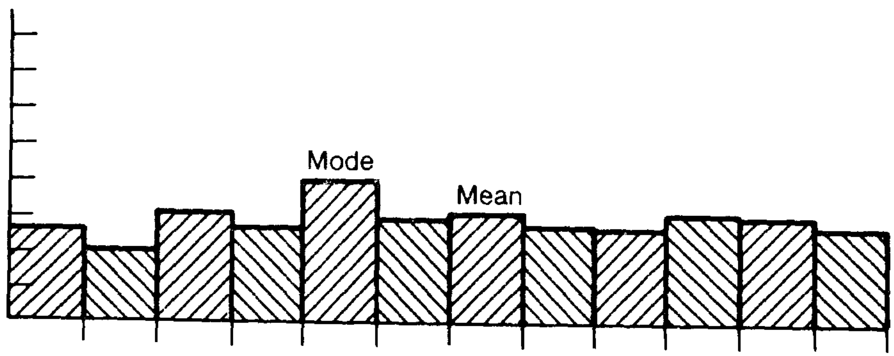
An equivalent tabulation using dip vector notation for vectorial analysis purposes is as follows:

Set A: 2 per meter dipping 75 deg to azimuth 180 deg:
Set B: 1 per meter dipping 60 deg to azimuth 90 deg;
Set C: 1 per 2 meters dipping 10 deg to azimuth 135 deg;
Individual D: Dipping 60 deg to azimuth 270 deg and exposed at sta DS+914, C_L + 500.

Each set and each individual discontinuity is then characterized in terms of its descriptive parameters as determined by the survey. As shown in Figure 2, the variations should be plotted as histograms of frequency of occurance of numerical intervals. The characterization value should be chosen as the mode of the distribution of variation, e.g., the most frequently measured value interval. If the distribution of variation is uniform or shows equal frequencies or if the modal value interval is anomalously isolated from the main body of data then the arithmetic mean of the distribution of variation should be chosen as the characteristic value.

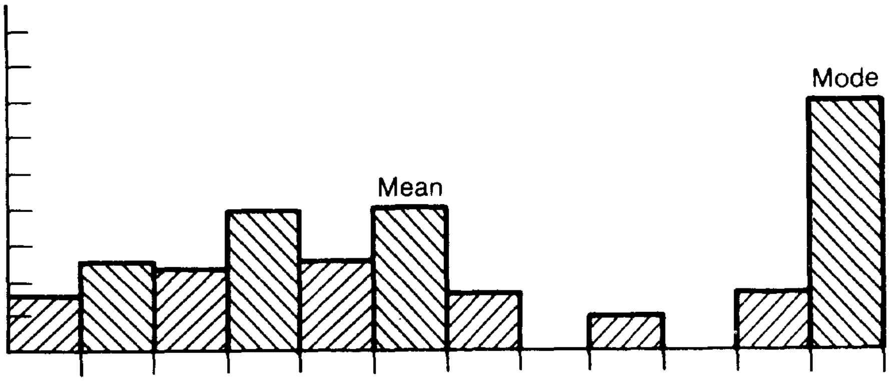


a. Typical Distribution:
Use Mode Value



b. Uniform Distribution:
Use Mean Value

Figure 2. Frequency Histograms of Discontinuity Parameters.



c. Isolated Anomalous Mode Distribution:
Use Mean Value

$$\text{Frequency of Occurrence (\%)} = \frac{\text{No. of Occurrences}}{\text{Total No. of Measurement}} \times 100$$

Figure 2. Con't. Frequency Histograms of Discontinuity Parameters.

As more detailed surveys are made, including those made during construction, the discontinuity parameter variation histograms can be kept current and deviations from the initial characterizations should be communicated to the design engineer. Most frequently, changes of this nature will arise from discovery of previously undetected, individual major discontinuities. Long term changes can occur in the form of increases or decreases in seepage or alteration of filling and wall rock material properties.

6. Summary. The primary purpose for collecting and analyzing the data characterizing rock discontinuities is to determine the stability of rock slopes, natural and constructed. In the first case, safety is the primary concern. In the latter case, the constructed slope is a result of combining required safety factors with a least-cost which will satisfy project needs. Graphical and analytic procedures for designing slopes are beyond the scope of this ETL, but are suitably outlined in Reference 3a and 3c.

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