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Indian Standard

METHODS FOR QUANTITATIVE DESCRIPTION OF DISCONTINUITIES IN ROCK MASSES

PART 1 ORIENTATION

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Indian Standard

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PART 1 ORIENTATION

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Indian Standard

METHODS FOR QUANTITATIVE DESCRIPTION OF DISCONTINUITIES IN ROCK MASSES

PART 1 ORIENTATION

0. FOREWORD

0.1 This Indian Standard (Part 1) was adopted by the Bureau of Indian Standards on 31 July 1987, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 In view of the advancement in the field of rock mechanics, a number of methods for assessing the strength characteristics of the rocks and rock masses are being formulated by Rock Slope Engineering and Foundation on Rock and Rock Mass Improvement Subcommittee. The majority of rock masses, in particular, those within a few hundred metres from the surface, behave as discontinuous, with the discontinuities largely determining the mechanical behaviour. It is, therefore, essential that structure of a rock mass and the nature of its discontinuities are carefully described and quantified to have a complete and unified descriptions of rock masses and discontinuities, and it may be possible to design engineering structures in rock with a minimum of expense *in-situ* testing. Careful field descriptions will enhance the value of *in-situ* tests that are performed since the interpretation and extrapolation of results will be made more reliable.

0.3 Discontinuity is the general term for any mechanical discontinuity in a rock mass, along which the rock mass has zero or low tensile strength. It is the collective term for most types of joints, weak bedding planes, weak schistocity planes, weakness zones, shear zones and faults. The ten parameters selected for rock mass survey to describe discontinuities are orientation, spacing, persistance, roughness, wall strength, aperture, filling, seepage, number, of sets, and block size. These parameters are also evaluated from study of drill cores to obtain information on the discontinuities.

0.4 It is essential that both the structures of a rock mass and the nature of its discontinuities are carefully described for determining the mechanical behaviour. This Indian Standard, covering various parameters to describe discontinuities in rock masses, is being formulated in various parts, each part covering one parameter. This part covers orientation. The other parts covering other parameters are also being formulated.

0.5 Orientation describes the attitude of discontinuity in space, and described by the dip direction (α azimuth and dip β) of the line of steepest declination in the plane of the discontinuity [Example: dip direction/dip (045°/30°)].

0.6 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard (Part 1) covers the method for the quantitative description of orientation of discontinuities in rock mass by compass and clinometer method, and photogrammetric method.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions of terms given in IS : 11358-1986† shall apply.

3. GENERAL

3.1 The orientation of discontinuities relative to an engineering structure largely controls the possibility of unstable conditions or excessive deformations/movements. The importance of orientation increases when other conditions for deformation are present, such as low shear strength and sufficient number of discontinuities or (joints) sets for slip to occur.

3.2 The mutual orientation of discontinuities will determine the shape of the individual blocks, beds or mosaics comprising the rock mass.

3.3 The orientation of the discontinuity is described by the dip direction (α) measured clockwise from true north and by the *dip* (β), of the line of the steepest declination measured from horizontal, for example, dip direction/dip.

*Rules for rounding off numerical values (*revised*).

†Glossary of terms and symbols relating to rock mechanics.

4. CAMPASS AND CLINOMETER METHOD

4.1 In campass and clinometer method, the compass is to be levelled by means of a spherical bubble before taking a dip direction reading measured clockwise from true north. The clinometer device built in the compass is used to measure the dip angle along the maximum declination direction.

NOTE 1 — Various types of clinometer compass are used in geological field surveys with spherical bubble and/or alidade device for orienting or sighting the clinometer parallel to the discontinuity plane before taking dip reading.

NOTE 2 — When estimating dip of the inaccessible discontinuity, it is convenient to use clinometer with an inclinable siting device in which reflected image of the horizontal bubble can also simultaneously be viewed.

NOTE 3 — When the rock is strongly magnetic, a clino-rule and measuring tape is used or direct reading azimuth protractor can be used.

4.2 The azimuth of the dip direction is measured in degrees counted clockwise from true north, and expressed as a 3 digit number, for example, 010°, 115°; (000° - 360°).

4.3 The maximum declination (dip) of the mean plane of the discontinuity is measured with the clinometer and should be expressed in degrees as a two digit number, for example, 05° or 45°; (00° - 90°).

4.4 The dip direction and dip should be recorded in that order, with the 3 digit and 2 digit numbers supported by a line, for example, 010°/25°. The pair of numbers represents the dip vector (Fig. 1).

NOTE 1 — Magnetic deflection caused by iron pipes or rails, steel structures or anamolies due to magnetic ore bodies will sometimes cause compass readings to be unreliable. In such cases a 50 metre long tape should be stretched parallel to the rock face or rock excavation surface and oriented by means of plane-table and/ or theodolite survey. The dip directions can then be measured relative to this tape using a theodolite or a clino-rule. A direct reading azimuth protractor can also be employed. The date should be corrected with reference to true north before analysis of the field measurement is undertaken.

NOTE 2 — The dip of discontinuities considered critical for stability should be measured using a down-dip base length *exceeding* the wavelength of surface undulations. The local inclination of non-planer features relative to *mean dip* will be an important component in the shear strength of the surface in question. The estimated direction of potential movement may not coincide with the down-dip direction.

NOTE 3 — It is desirable to measure a sufficient number of orientations to define the various joint sets of given domains. It is clear that the number to be recommended will vary with the area to be mapped, with the randomness of the orientations, and with the detail required in subsequent analysis. If orientations are consistent, careful sampling will reduce the amount of orientation data considerably.

NOTE 4 — The vertical circle of many clinometers is also expressed in quadrants of 100 divisions instead of 90. The particular system utilized should be clearly stated when orientation data is reported. It is most convenient to have dip mesurements measured in or converted to the older 0-90° system.

NOTE 5 — The accuracy of compass and clinometer orientation measurements will depend on several factors of which the probably most important are accessibility of the plane of interest, areal extent of the exposed plane, degree of planarity and smoothness, occassional magnetic anomalies, human errors. Human errors can be reduced by using a clinometer to locate the direction of maximum dip before taking the compass reading. It is sufficient to read dip direction to the nearest 5°, and *dip* to the nearest even number of degrees. However, if poles are to be plotted, it may in the end be more convenient to read to the nearest degree to reduce the occurrence of coincidental plotted points.

NOTE 6 — The mean orientation of major discontinuities can be obtained by the *three-point method.* The coordinates of three points lying in the plane of the discontinuity are all that is required. In the case of surface outcrops, the coordinates may be determined by accurate location on a contoured relief map. The orientation of major features may also be estimated from three boreholes that, intersect the plane. However, less persistent features may not be intersected by all the holes.

NOTE 7 — The orientation of minor discontinuities can be estimated from a single borehole, provided that the core can be oriented or that the borehole walls can be viewed. Core can sometimes be orientated using structural features such as bedding or foliation, if these natural markers have consistent orientation. Alternatively, the orientation of minor discontinuities can be estimated by down-the-hole viewing techniques, such as borehole television cameras, photographic cameras and borehole periscopes. Besides orientation, these methods also provide invaluable information concerning spacing, the thickness of the discontinuity fillings and the level of seepage paths.

NOTE 8 — A special core recovery method, known as the integral sampling method, is recommended for obtaining orientation data in heavily fractured rock masses. The method essentially consists of recovering a core sample which has previously been reinforced with a grouted bar whose azimuth is known from positioning rods. The reinforced bar is coaxially overcored with a larger diameter coring crown.

5. PHOTOGRAMMETRIC METHOD

5.1 Photogrammetric discontinuity mapping technique determines the coordinate of at least 4 points of each visible discontinuity plane, thereby defining the orientation of the given planes. Large planes can be mapped quite precisely, but the accuracy decreases as the area of the plane decreases. The method is usually only economic if the orientation of a large number of discontinuities is required. However, there are situations where photogrammetry is the only practical method of determining orientation, for example, if the rock is in the vicinity of the magnetic anomalies or if the rock is unstable and/or inaccessible.

5.2 The equipment required in photogrammetric method consist of reconnaissance survey equipment, phototheodolite and tripod, control survey equipment, and stereoscopic plotting instrument or stereocomparator with automatic recording equipment.

5.2.1 Reconnaissance survey equipment required will consist of optical square, Abney level, alidade and reconnaissance diagram mounted on a plane table.

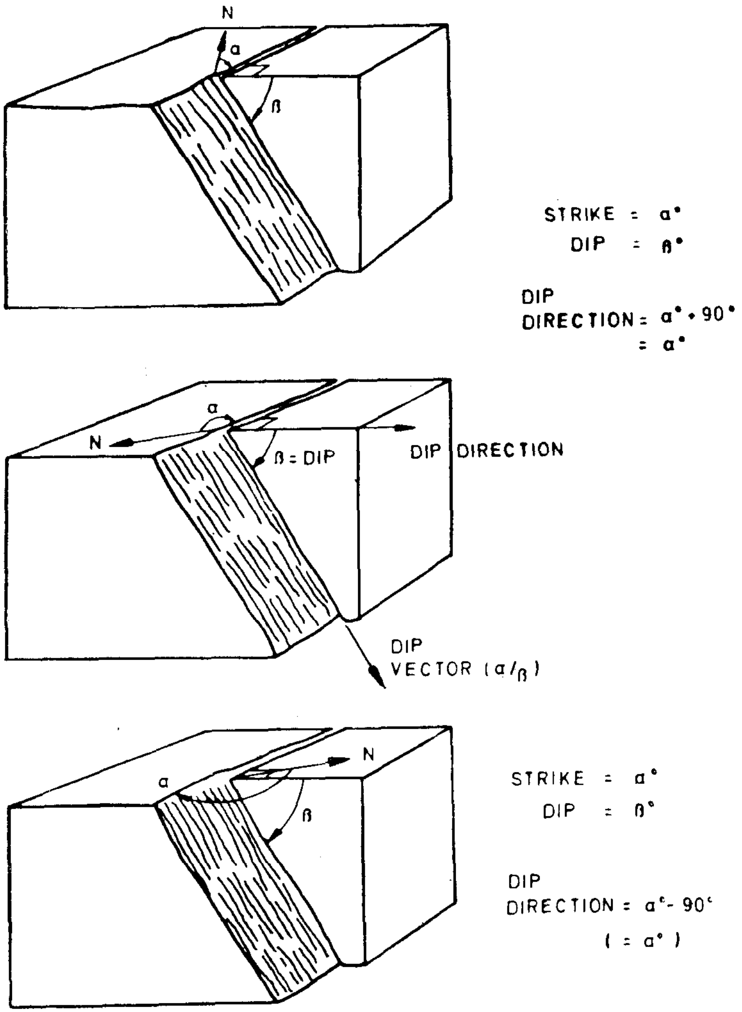


FIG. 1 DIAGRAM INDICATING THE STRIKE, DIP AND DIP DIRECTION OF THREE DIFFERENTLY ORIENTATED PLANES

5.2.2 Photogrammetry require a phototheodolite which consists of a theodolite with a survey camera located between upper and lower circles, The survey camera incorporates fiducial marks and has a lense of negligible distorsion characteristics. Six control targets are required for location of the rock face to be photographed. In order to be seen clearly in the stereoscopic model, their minimum dimension should be $\frac{1}{400}$ of the distance to the rock face. Their colour should be chosen for the maximum contrast with the rock when viewed in blue and black photography. Photographic films, photographic plates, photographic development facility (on site, if possible, to check for poor exposures) and light meter are also required for use.

5.2.3 Control survey equipment consists of tripod, tribrachs, tripod, targets, plumbing devices and subtence bar.

5.2.4 Stereoscopic plotting instrument or stereocomparator with automatic recording equipment are normally operated by a trained photogrammetrist and the users must consult a specialist for their use.

5.3 The procedure of determining orientation by photogrammetric method consist of reconnaissance survey, photography and control survey to obtain the survey information required for computations.

5.3.1 The purpose of reconnaissance survey is to determine suitable positions for both the camera stations over-looking the face and for controlled targets on the face (Fig. 2 and 3). The height of the face photographed, the accuracy required, the vertical and horizontal field angles of the camera and the available camera tilt must be considered prior to photography. In many cases, there will be physical limitations imposed by the site itself as illustrated in Fig. 4. Much better use of the overlap area is possible if camera axes can be approximately normal to the face.

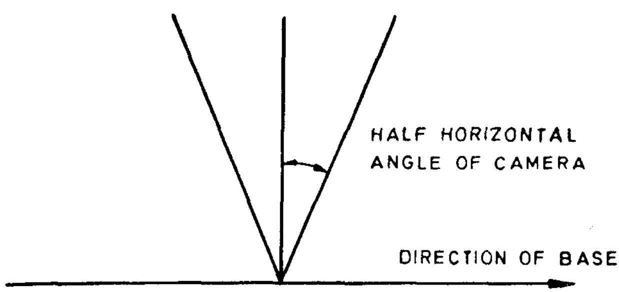


FIG. 2 RECONNAISSANCE DIAGRAM MOUNTED ON PLANE TABLE

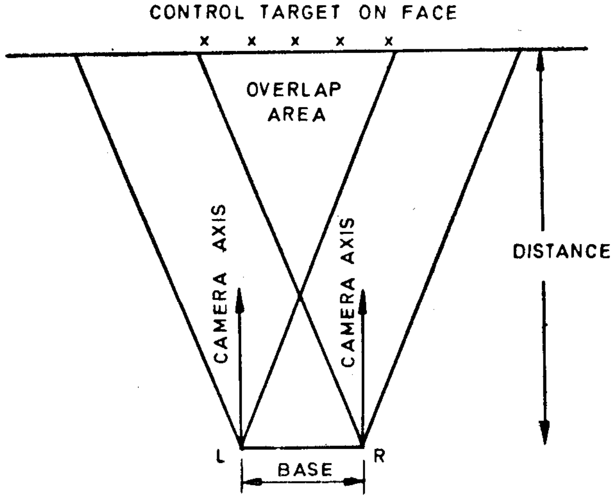


FIG. 3 FIELD SET-UP TO OBTAIN OVERLAPPING STEREO-PAIR

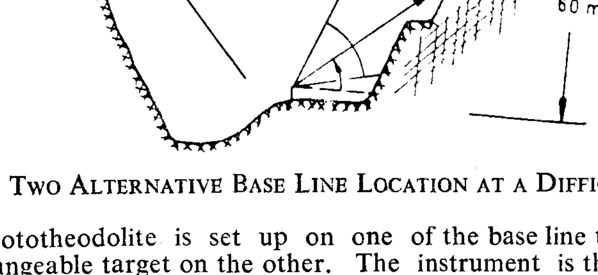


FIG. 4 TWO ALTERNATIVE BASE LINE LOCATION AT A DIFFICULT SITE

5.3.2 Phototheodolite is set up on one of the base line tripods, with an interchangeable target on the other. The instrument is then levelled, the camera tilted, exposure time and counter are set, and the photographic plate or film is loaded. The camera is orientated at right angle to the theodolite and the telescope is sighted on the other station. With the camera axis thus normal to the base, the photograph is taken. The theodolite and target are then interchanged at the base line stations and the procedure is repeated.

NOTE — It is helpful if the photographic plates or films are developed in nearby dark room so that, if the same are not up to the quality required for photogrammetric analysis, the photographs may be retaken before the camera station tripods and control target are removed. It is desirable to complete all the photography as soon as possible in order to avoid differences caused by shadow on corresponding photographs of a stereo-pair.

5.3.3 After completion of the photography, a control survey has to be carried out in order to determine the coordinates of at least four targets within the overlap area. The theodolite is used for necessary angle measurements from each end of the base line and two rounds of horizontal and vertical angle are made to the control targets and at least three other stations whose coordinates are known. From these observations, the coordinates are determined by resection.

5.3.4 The base line is measured by setting an interchangeable subtense bar on one station trybrach, and observing it from the other. The distance is calculated from the mean subtended angle. This procedure is performed from both ends of the base line as a check.

NOTE — A minimum of one day should normally be allowed for the work associated with each stereo-pair. The base line may subsequently be extended to a series of consecutive camera stations if the overlap area obtained with one stereo-pair is insufficient to cover the whole rock face.

5.3.5 The exact format of the survey information required depends on the programme being used to analyze the results. Generally, if the theodolite observations have been made from the same trybrach position as used for the photography, the survey information required consists of the theodolite coordinates in the ground system, and vertical and horizontal theodolite observations to the targets, reduced and meaned as appropriate.

5.4 It is convenient to provide detailed instructions for the photogrammetrist to enable to work in a manner that the information can be analyzed by a computer. The work is best specified by making detailed notes and by making an enlarged photograph of the overlap area. The information requested may consist of : (a) joint areas indicated on the enlarged photograph from which a specified number of orientations are required for statistical analysis like plotting on an equal area net; (b) particular discontinuity planes individually identified on an enlarged photograph for which the location, orientation and extent are required more precisely, like for use in stability analysis. Generally up to ten points per plane are sufficient for defining these features.

5.5 Usually the negative plates are observed directly but, if preferred by the operator, diapositives can be made. An operator unaccustomed with the technique of observing discontinuities requires a few hours observing practice. The coordinates of at least four points are required for each visible plane. The coordinates of at least four points are noted in an identical format and shall consist of an identifier followed by X, Y and Z coordinates of the point. All points referring to a particular discontinuity should have the same identifier. The operator thus proceeds from point to point, discontinuity to discontinuity and area to area. It is important that the operator makes a number of independent checks on the accuracy of his observations at field scale. This will give all concerned a feel of likely errors.

5.6 The basic information required in photogrammetric method consist of control survey data (*c*) and the photogrammetric data (*f*), and the computer calculations comprise transformation of the target coordinates to the ground system and setting up the transformation matrix. The planes are fitted to the sets of points by the method of least square, and direction cosines are determined from a symmetrical coefficient matrix and subsequently transformed by the transformation matrix. The planes may then be described in terms of *dip-direction* and *dip*. The last part of the computational phase involves the calculations of proper errors.

NOTE 1 — The summary of equipment and procedure described provide introduction to the technique and it is desirable to obtain the services of a trained photogrammetrist for determination of orientation of the discontinuity planes by photogrammetric method.

NOTE 2 — In any photogrammetric system, the sources of errors have to be considered relating to film, camera, plotting instrument, recording method, control survey, earth curvature, atmospheric refraction and instrument operator errors. Compared to the other sources of errors, the operating errors caused by the instrument operator are very significant. These are mainly due to the limitation in the operators stereoscopic perception and due to misinterpretation. The operator must make arbitrary decisions as to the positioning of the floating marks in the instrument if discontinuity images are poorly defined. These operating errors can usually be kept to tolerable errors by using large base/distance ratios.

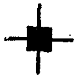
NOTE 3 — In highly altered or weathered rock, it may be difficult to distinguish the geological features in photographs and discontinuities may be noted as rough surfaces. In such a case, the error may be significant.

NOTE 4 — Considerable amount of useful information is obtained from the photogrammetric mapping techniques in addition to orientation of discontinuity planes, for example, *roughness* profiles of individual discontinuity, overall distribution of discontinuity spacing, discontinuity persistance and general condition of rock surface. In addition, stereo-pairs exposed at different stages during the life of a project (an open pit), provide a permanent visual record, which can be specially useful, when extrapolating major features.

6. PRESENTATION OF RESULTS

6.1 Strike and Dip Symbols — The simplest methods of data presentation are the strike and dip symbols drawn in the correct location on the geological map of the area. For example :

45° represents a discontinuity (joint) with a dip of 45° and strike as shown by the orientation of the line. The dip direction is indicated by the down-dip symbol.

 represents a horizontal discontinuity (joint).

 represents a vertical discontinuity (joint) with a strike as shown by the orientation of the line.

6.1.1 Further detail can be obtained by using different symbols to represent the various types of discontinuities. For example,

joints (), bedding (), foliation ().

6.1.2 The outcrop of major discontinuities should be drawn directly on geological maps. For example, thick continuous lines (—) can be used for major, persistent discontinuities that are visible, and thick broken lines (- - - -) for major discontinuities whose persistence is implied, but which are locally covered.

6.2 Block Diagrams — At an early stage in the assessment and communication of raw field data, it is helpful to present orientation measurements qualitatively using some visual technique. Perspective drawings such as that shown in Fig. 5 A help to give an overall view of the relationship between the engineering structure and the rock mass structure. (If available, a stress ellipsoid giving the measured principal stress vectors might also be presented on such a diagram, to aid in the evaluation of the optimum orientation of the structure.)

6.2.1 On a more detailed scale block *diagrams* can be used, such as that illustrated in Fig. 5 B. Many types of structures can be represented in this idealized manner, for example, tunnel portals, cross-sections through tunnels or large rock caverns, rock slopes, dam abutments, etc. (Depending upon the scale, the discontinuity spacing and persistence may be represented in addition to the orientation.)

6.2.2 Block diagrams showing 'excavated' corners as in Fig. 5 C give a visual impression of the rock structure. They are also a useful substitute for photographs where foliage or soil cover partly obscure the exposure.

6.2.3 In the examples shown in Fig. 5, it is helpful to number the joint sets, show the orientation relative to true N, and list the dip direction and dip at the site of the diagram. (This is also helpful when presenting photographs of rock mass structures.)

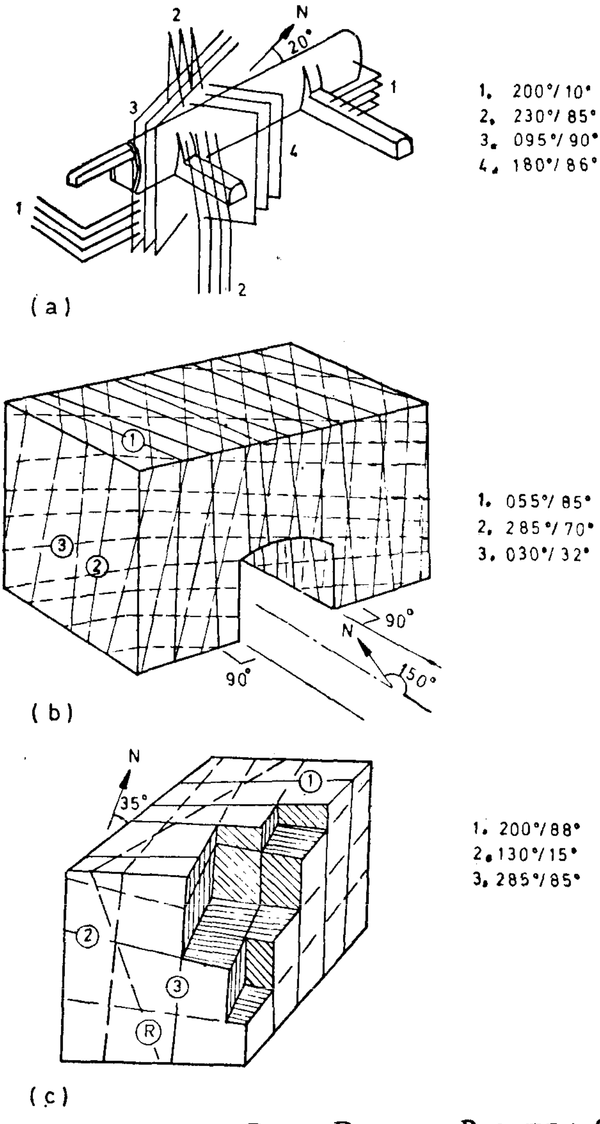


FIG. 5 PERSPECTIVE VIEWS AND BLOCK DIAGRAMS PROVIDE A QUALITATIVE PICTURE OF JOINTING AND ITS RELATIONSHIP TO ENGINEERING STRUCTURES

6.3 Joints Rosettes — A common method of plotting and presenting a large number of orientation measurements in a more quantitative manner than the above is by means of joint rosettes.

6.3.1 In this instance, measurements are represented on a simplified compass rose, marked from 0 - 360° (or 0 - 400^g) with radial lines at 10° intervals. Observations are grouped in the nearest 10° sectors. The number of observations are represented along the radial axes, using numbered concentric circles representing 5, 10 and 15 observations or as convenient. The resulting strike 'petals' have mirror images about the centre of the rosette. The range of dip observations for each discontinuity set cannot be represented within the rosette and shall, therefore, be shown outside the circumferance.

NOTE — Measurements of strike or dip direction of sub-horziontal discontinuities are inherently unreliable. Therefore, in general, such features cannot be represented satisfactorily using joint rosettes. It should be noted that, although the joint rosette is a widely used polar diagram, it misrepresents the data to some extent. Large concentrations are exaggerated and small concentrations are suppressed. This bias results from the fact that areas in each angle sector vary with the square of the radial coordinate, whereas in a true histogram, the area of each bar or sector should vary with the frequency, not with the square of the frequency.

6.3.2 Figure 6 shows two methods of representing orientation data on a joint rosette. The observations grouped in the nearest 10° sectors can be represented either as solid radial sectors (left hand side) or their strike values averaged resulting in sharp 'petals' (right hand side). The latter method reduces the bias referred to above, but may not be satisfactory if there is little dispersion of the data. (The radius of the polar diagram can be used to good effect in plotting other parameters than the frequency of observation. A particularly useful parameter is the total observed length of discontinuities of given orientation.)

6.4 Spherical Projection — Several projection methods are used to represent the orientation of geological planes. The geological text books give comprehensive discussions of the various techniques available. In this standard, only one projection is being mentioned, the *equal area projection* (In this method, the spatial distribution of data is accurately represented on a Schmidt or Lambert net. In the case of *equal angle projection*, the angular relationships between features are accurately represented by plotting data on a Wulff net.)

6.4.1 A discontinuity plane (α/β) can be uniquely represented as a great circle or as a pole on a reference hemisphere, when the centre of the sphere lies in the plane of the discontinuity (Fig. 7 A). For engineering purposes, the lower reference hemisphere is used. A two-dimensional representation is obtained by projecting this information onto an equal area net.

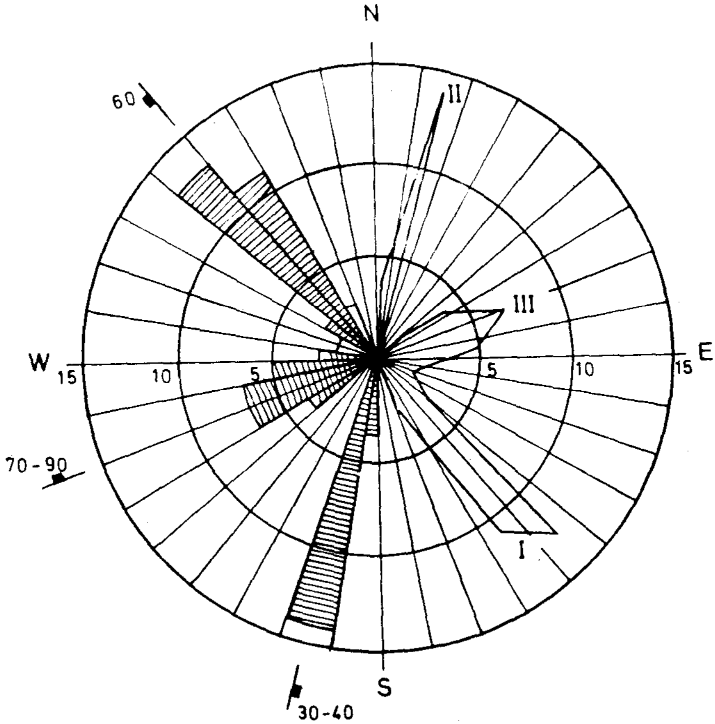


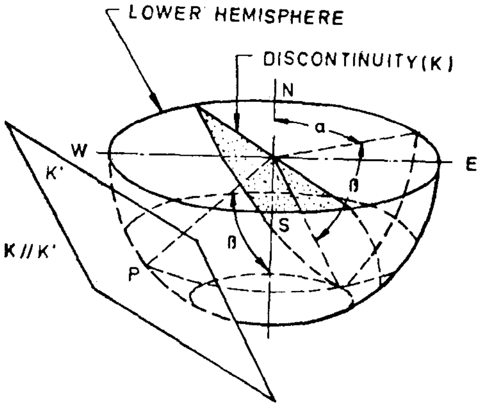
FIG. 6 TWO METHODS OF REPRESENTING ORIENTATION DATA ON A JOINT ROSETTE

6.4.2 In Fig. 7 A, the pole *P* of the discontinuity *K* is the point of intersection of the normal to the plane with the lower hemisphere. To plot the pole on a polar equal area net (Fig. 7 B), the dip is counted from the centre of the net at right angles to the strike towards the periphery.

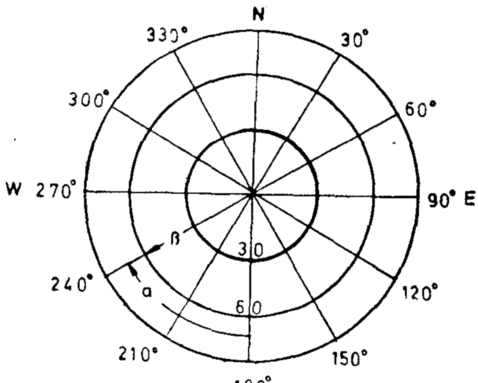
6.4.3 To plot the plane as a great circle on an equatorial equal area net (Fig. 7C), the strike (+ 90°) is counted from north clockwise on the periphery using a rotatable tracing or plastic overlay on which N has been marked. The dip is plotted at right angles to the strike, measured from the periphery towards the centre. The pole *P* can also be represented on the equatorial equal area net, both nets yielding the same geometrical distribution of poles.

6.4.4 The polar equal area net is the most convenient for plotting poles as no rotation of overlay is necessary. The first step in obtaining mean orientation data for the different discontinuity sets requires that clusters of poles can be visually recognised. The Schmidt contouring method is used to determine the pole densities, an example of which is shown in Fig. 8.

6.4.5 The contouring involves superimposing a square grid on the equal area net. A circle, shown in Fig. 8, which represents 1 percent of the total area of the equal area net, is placed with its centre at the grid intersections.



(a)



(b)

Fig. 7 Method of Representing a Discontinuity *K* as a Pole *P* and as a Great Circle on (a) Polar Equal-Area net (b) and on an Equatorial Equal-Area net (c) Using the Lower Reference Hemisphere. A Rotatable Transparent Overlay is Used with the Equatorial Equal-Area Net — *Continued*

The number of poles within the circle is counted and noted on each grid interesection. Pole densities can then be contoured, using up to six contour intervals.

6.4.6 The central value of the highest concentration of poles can be taken as representing the mean orientation of the given set of discontinuities. However, since there are variations from the mean, orientation is strictly a random variable with a certain dispersion associated with each mean value. Probability techniques are recommended for a more precise analysis (It should be noted that density contours obtained by the Schmidt method violate probability theory since poles are counted more than once).

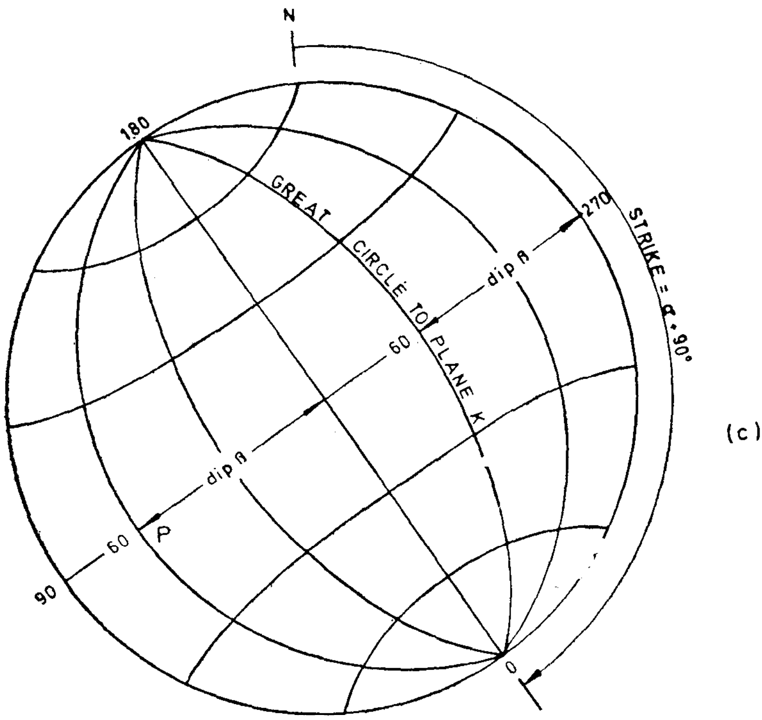


FIG. 7 METHOD OF REPRESENTING A DISCONTINUITY *K* AS A POLE *P* AND AS A GREAT CIRCLE ON (a) POLAR EQUAL-AREA NET (b) AND ON AN EQUATORIAL EQUAL-AREA NET (c) USING THE LOWER REFERENCE HEMISPHERE. A ROTATABLE TRANSPARENT OVERLAY IS USED WITH THE EQUATORIAL EQUAL-AREA NET

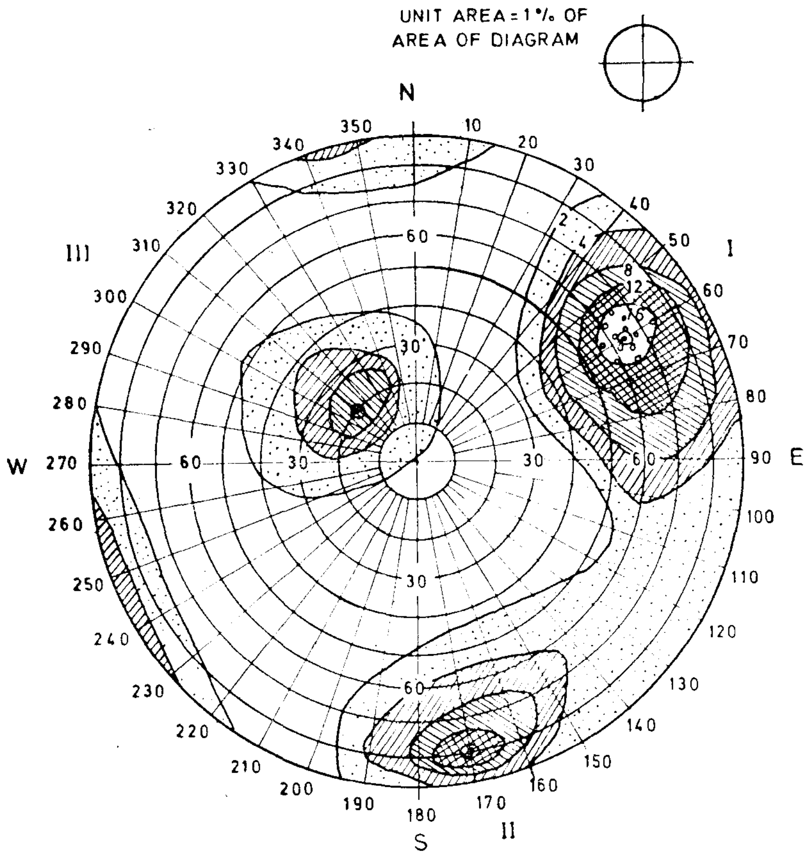


FIG. 8 SCHMIDT CONTOUR DIAGRAM REPRESENTING THE ORIENTATION OF THE THREE SETS OF JOINTS PLOTTED ON A POLAR EQUAL-AREA NET. THE MAIN SET I AND II ARE APPROXIMATELY NORMAL TO EACH OTHER AND THE MINOR SET III IS NEARLY HORIZONTAL

6.4.7 Figure 9 illustrates the use of equatorial equal area nets for plotting both poles and great circles to represent typical rock mechanics problems, such as slope stability. Spherical projection methods of greatest value where stability depends on the relative three-dimensional orientation of discontinuities and free surfaces.

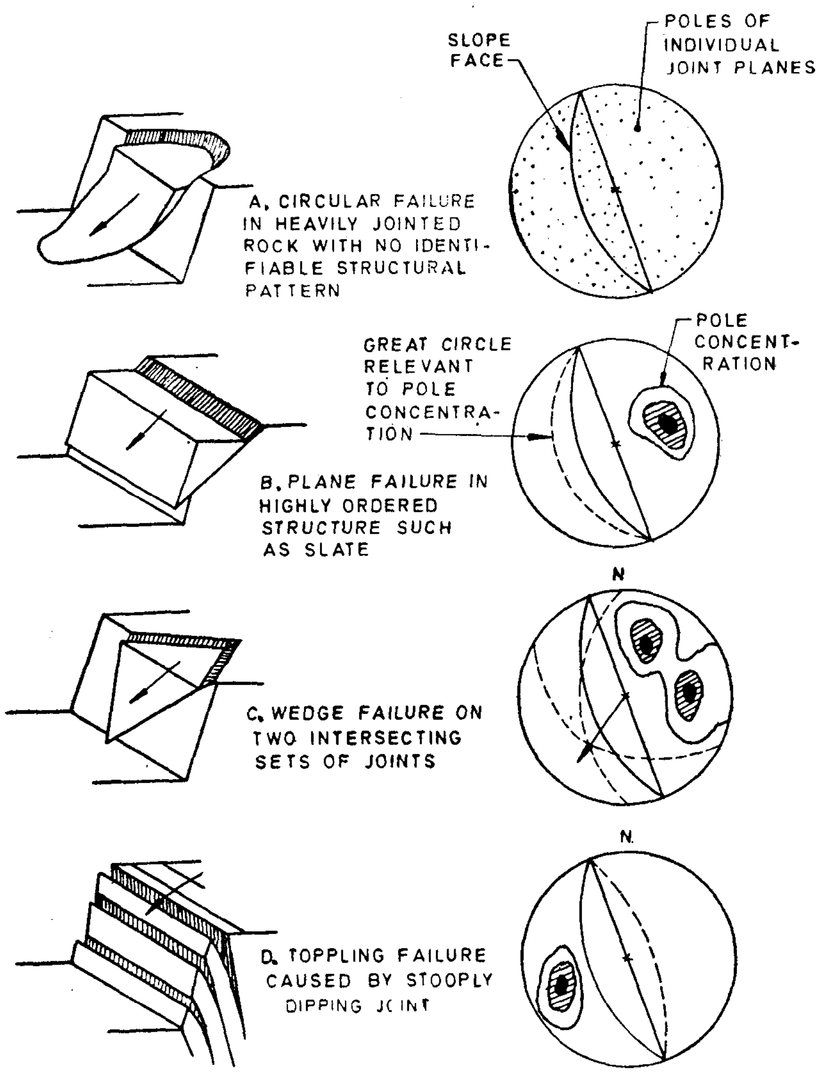


FIG. 9 REPRESENTATION OF STRUCTURAL DATA CONCERNING FOUR POSSIBLE SLOPE FAILURE MODES, PLOTTED ON EQUATORIAL EQUAL-AREA NETS AS POLES AND GREAT CIRCLES

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

QUANTITY	UNIT	SYMBOL
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

QUANTITY	UNIT	SYMBOL
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

QUANTITY	UNIT	SYMBOL	DEFINITION
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2