THE ASSESSMENT OF ROCK SLOPE STABILITY ANALYSIS

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RINGKASAN

Tulisan ini adalah merupakan suatu rangkaian dari perencanaan lereng/galian tebing jalan pada batuan, sehingga akan dapat membantu dalam hal perencanaannya. Untuk itu, dalam tulisan ini hanya dibahas perencanaan disain yang harus diperhatikan. Galian lereng / tebing jalan harus didisain aman sepanjang masa dari kemungkinan longsoran tebing batuan yang terjadi. Untuk maksud tersebut diperlukan evaluasi stabilitas pendahuluan untuk desain perencanaan galian tebing yang dapat dituangkan dalam petunjuk praktis lapangan. Penelaahan data dari faktor geologi berupa analisa diskontinuitas pada massa batuan dan material propertis tanah/batuan sangat penting untuk analisa stabilitas lereng/tebing batuan. Pengumpulan, pengukuran data di lapangan dapat dilakukan secara visual dengan mengamati perlapisan tanah/batuan di lapangan. Data yang diperoleh sangat berguna untuk analisa perencanaan lereng/tebing batuan. Teknik pengukuran diskontinuitas pada tanah/batuan yang telah didiskripsikan adalah merupakan tahapan penyelidaikan lapangan yang sangat penting. Aspek yang penting untuk diketahuai dalam analisa kemantapan lereng/tebing batuan adalah sistim pengadaan data dan cara mempresentasikan data yang diperoleh dan dapat dilakukan dengan "sherical projection methods". Dengan menggunakan "Great Circle Stereographic plot" pada kelompok joint set, seperti "fault" dapat diidentifikasikan potensial blok/bidang yang tidak stabil yang diperlihatkan dalam satu bentuk diagram keruntuhan

SUMMARY

This paper is the stages of rock slope stability design program for road cuttings, so that it is hopefully helping in the design procedures for road cuttings in rock which must be carefully done. In theoretically, highway cuts in rock should be designed to be absolutely safe at all time, because occasionally rock falls and slide movements happened. A practical guideline for preliminary stability evaluation of slopes in road cuttings is needed especially for rock excavation design. The geological factor information that could be used in rock stability analysis should be taken from the whole of rock mass and the properties of rock material. The stability of the rock mass may be determined from the analysis of discontinuities for rock engineering applications. Data collection,measurement and recording of discontinuities visible over or near the exposed rock face has the advantages of utilizing for the proposed excavation site. The measurement techniques of discontinuities on the soil and rock mass description are one of the most important features of site investigation. The important aspect of rock slope stability analysis is the systematic collection and presentation of geological data which it can be used spherical projections. Using a great circle stereographic plot of fracture sets, as well as showing important single fractures such as faults can be identified potentially unstable blocks which are represented on a single diagram in failures modes.

I. INTRODUCTION

1.1. General

Highway routes for transportation often require numerous high rock cuts in mountainous terrain. Occasionally rock falls and slide movements happen. Although theoretically, highway cuts should be designed to be absolutely safe at all times this is not always economic. Further, some cuts may require to be nearly vertical in order to preserve adjacent land, and this can represent a major stability problem.

The problems of the stability of highway cuts in mountainous areas are caused by many factors.

1. 2. Background and Objective

This paper is intended and to be developed as a practical guidelines to preliminary stability evaluation of slopes in road cutting especially for rock excavation design.
A list of project guidelines may be stated to be as follows:
(1) Collection of field data, based on the field informations.

(2) Collection of field data, based on the infrastructure networks including information on both stable and unstable slopes.

(3) Use of a flexible procedure methodology which can be adapted to variable project constraints in terms of time and man-power resources.

(4) Use of a flexible procedure methodology which can accommodate differing levels of information from a variety of resources with differing reliability.

(5) Inclusion of data terrain and the geology of bedrock's for future research purpose. The related maps at the location should be utilized to identify terrain types in conjungtion with field data

II. FAKTOR RELATING TO SLOPE STABILITY

The slope definition procedurs should be decided upon for each mayor types of site location and then the locatio themselves could be divided up as follows:

(1) Natural slopes
(2) Eart work slopes
(3) Combinations of both

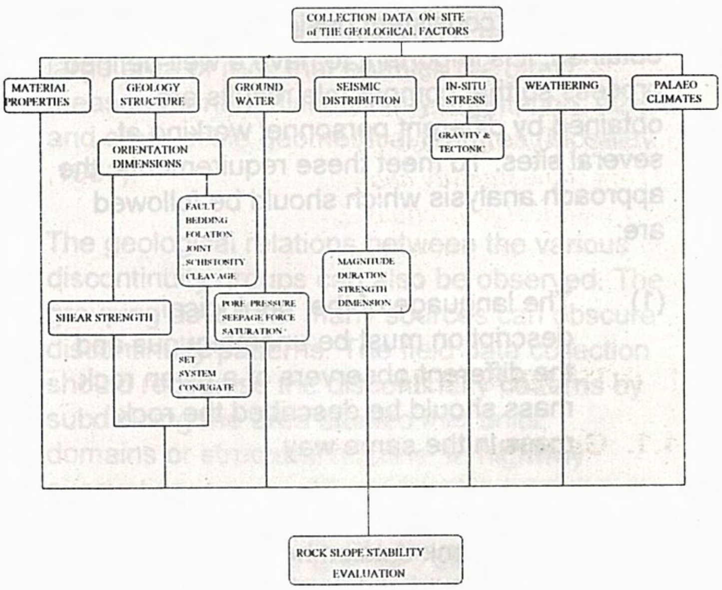
These may be sub divided on the basis of being stable or having failed. The work undertaken in this study proved to be an ideal trial area for these procedures. The key points to arise out of these trial areas can be listed as follows:

(1) The need to clearly identify the location of the site and typical slope cross sections within it.
(2) The need to identify typical failure types based on failure rock slope criteria.
(3) The importance of instability factors should be defined before detailed evaluation take place.
(4) The time scales involved in undertaking slope survey should be decided upon before the work is undertaken.

2.1. Data on Slope Stability

Slope stability data vary greatly. They may derive from varying origins and be very different in magnitude and quality. Technically it may refer to near surface disturbances of weathered zones all the way to deep seated displacements of large rock masses. Fig. 1 shows the procedure to collect the field data involving the geological factors that could be used in rock stability analysis.

Fig. 1.
GEOLOGICAL FACTORS FOR ROCK SLOPE STABILITY



2.2. Geology Factors

The geological factors involved in rock slope stability can be distinguished as The geological structure results in rock fabrics which is having a given orientation with respect to the force of gravity. Most of these phenomena are related to each other as cause and effects and its have been grouped by Blyth and de Freitas (1979) as follows :

(1) Material properties
(2) Geological structures
(3) Ground water
(4) Seismic disturbances
(5) In-situ stress
(6) Weathering
(7) Climates

These characteristics conclude that even a single structure may have a long and complex history of changing stress, temperature, strain rate, mineralisation and re-crystallisation, (Goodman ,1989).

Changes in these result in features which can be described as a discontinuity. Analysis of the stability of blocks of rock requires reliable information on the following two categories of characteristics, (Wyllie ,1992).

2.3. Recovery Data on Slope Types

In order that consistent design data can be obtained, it is important to have a well-defined process so that comparable results are obtained by different personnel working at several sites. To meet these requirements, the approach analysis which should be followed are:

(1) The language of the geological description must be unambiguous and the different observers of a given rock mass should be described the rock mass in the same way.

(2) To get the correct information, a simple measurement often helps and is better than a visual observation alone.

There are three categories of information should be used (Priest, 1993):

(1) Zoning the rock mass
(2) Description of the rock material
(3) Description of the rock mass

2.4. Zoning the rock mass

The rock mass should be divided into zones (geotechnical units whose characteristics may be considered uniform.

2.5. Description of the rock material

Deere and Miller (1966) indicated that the properties of the rock material depend upon the physical properties of the constituent minerals and their type of bonding one to another.

The method of the rock descriptions can be seen to be as follows:

(1) Index properties of rock materials, e.g. rock type, colour, grain size and texture/ fabrics.
(2) Index properties determined by classification tests, e.g. Hardness, Durability, Porosity, Density and Sonic Velocity.
(3) Index properties determined by complex testing, e. g. Modulus of Elasticity, Poison's ratio and Primary Permeability.

2.6. Description of the rock mass.

The rock mass may be a continuum, or the rock material may be divided into blocks or layers (vertically & horizontally) by planes of weakness. Plane of weakness can be called as a discontinuities, so that the parameters could be included in a description of the rock mass are as follows:

(a) Description of discontinuities, e.g. type, number of discontinuity sets, location, orientation (dip/dip-direction), spacing-separation of surface or dilatancy, infilling, persistence (continuous lengths), surface roughness/shape and comments

(b) Index properties determined by complex testing, e. g. Permeability, Seismic Velocity, Modus of Elasticity, and Shear Strength.

III. STBAILITY ASSESMENT

3. 1. Discontinous of Strong Rock

3. 1. 1. Type of Discontinuities

Rock masses may contain discontinuities such features as bedding planes, faults, joints (shear and tension) include fissures and fractures, dykes cleavages and other planar structures, which formed from a wide range of geological processes. The stability of the rock mass may be determined from the analysis of discontinuities for rock engineering applications. Discontinuities or weakness planes are structural features that separate intact rock blocks within a rock mass.

According Priest (1993), the are two types of discontinuity that can be described as follows:

(1) Natural discontinuities-which are of geological origin

(2) Artificial discontinuities-which are created by such activities as drilling, blasting and excavation.

The discontinutity network or the rock structure is a complex three-dimensional structure of discontinuities in rock mass. Although discontinuities often have an irregular or curved geometry, there is usually a scale at which the whole surface is sufficiently planar to be represented by a single orientation value

3. 1. 2. Properties of Discontinuities

The properties of discontinuities that have the greatest influence at the design stage have been listed by Piteau (1970 and 1973), Priest (1993) as follows:

(1) Orientation,
(2) Size,
(3) Frequency,
(4) Surface geometry,
(5) Genetic type, and
(6) Infill material.

3.1.3. Particular Discontinuities

The type of discontinuities can be referred to the description of the mechanical properties that can be associated with a particular discontinuity (Hoek and Bray, 1981) such as follows:

(1) Major discontinuities : continuous planar structural features such as a fault.

(2) Discontinuity Sets : a system of discontinuities which have approximately the same inclination and orientation.

(3) Persistence or Continuous Length : a major structural feature such as faults or joints may run up to many meters or even kilometres.

(4) Gouge or Infilling : the material within two faces of structural discontinuities such as faults.

3.2. Field Data Collection

Data collection involves the recognition, measurement and recording of discontinuities visible over or near the proposed excavation site.

The measurement at the exposed rock face has the advantages of utilising a relatively large area of rock that enables the direct measurement of discontinuity orientation, size and other-scale geometrical features (Moseley ,1981).

The geological relations between the various discontinuity groups can also be observed. The grouping data from many sources can obscure discontinuity patterns. The field data collection should recognise the discontinuity patterns by subdividing the area studied into units, domains or structural regions. In highway excavation, geographic and rock type units are likely to be of most use.

Collection of data in domains allows individual or grouped assessments which are likely to be

... major importance to be identified, e.g. where alignment of rock types changes along the route.

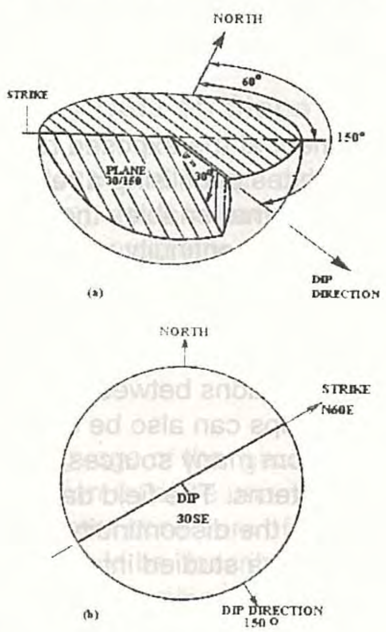
The standard discontinuity measurement approach can be seen in Fig. 2 and the definition of the geometrical terms can be explained as follows :

(1) Dip : the maximum inclination of a structural discontinuity plane to the horizontal, defined by the angle.

(2) Dip Direction or Dip Azimuth : the direction of the horizontal trace of the line of dip and measured clockwise from north.

(3) Strike : the trace of the intersection of an oblique inclined plane with a horizontal reference plane. Strike is at right angles to the dip and dips direction of the oblique plane.

Fig. 2.
TERMINOLOGY DEFINING FRACTURE ORIENTATION / DIP AND DIRECTION
(a) Isometric view (b) Plan view
(SourceWyllie D. C., 1992)



In the Table I can be seen the methods of measuring and recording discontinuity attitudes, Matheson (1983). The third method on these Table is to be recommended as a standard for discontinuity measurement.

Table I.
METHOD OF DISCONTINUITIES MEASUREMENT
(After Matheson,G.D. 1983)

Attitude DIP ORIENTATION		METHOD of MEASUREMENT	COMMENTS
45 TO SW	N 28 W	STRIKE COMPASS AND CLINOMETER OR GEOLOGY COMPASS	NAUTICAL TERMINOLOGY FOR ORIENTATION
45 TO W	332	STRIKE COMPASS AND CLINOMETER OR GEOLOGY COMPASS	GEOLOGICAL METHOD
45	242	AZIMUTH ENGINEERING GEOLOGI COMPASS	RECOMMENDED METHOD

IV. SOIL AND ROCK DESCRIPTIONS

4.1. Materials and Masses

The methods of discontinuities measurement depend on the measurement techniques of discontinuities and on the soil and rock mass description. Soil and rock mass description is one of the most important features of site investigation, and usually should be carried out only by suitable qualified and experienced persons It is important to recognise the differences between materials and masses which may consist of the following :

(1) Material descriptions applicable to small, essentially uniform samples.
(2) Mass descriptions applicable to larger samples or zones that may contain heterogeneous materials and structures.

The key to good description work is to be systematic, and a sample list of description items which can be made is given below. (Geotechnical Manual Slope, in Hong Kong, 1984)

4.4.1. Material Description may include:
(a) colour
(b) grain-size and other materials features
(c) composition
(d) degree of micro fracturing or disintegration

(e) strength
(f) soil rock name
(g) other characteristics such as slake durability

4. 4. 2. Mass description my include:

(a) size, angularity, percentage and distribution of harder fragments
(b) Spacing and nature of discontinuities
(c) Geological structure

4. 2. Joint Survey Records

The engineering properties of rock mass stability particularly in rock exposures are usually controlled by discontinuities sucuh as joints. At the site locations where there are surface exposures of the rock mass, a joint surveyy can be carried out.

This survey is important because the results obtained can be used to assess the risk of joint controlled instability. For accurate results, a join survey should be carried out by a suitable experienced geotechnical engineer or engineering geologist.

4. 3. Measurement Techniques for Discontinuities

The measurement techniques used at exposed rock face are "the scanline" and "the Window" sampling techniques.

4. 3. 1. Scanline Sampling

As a rough guide the sample zone should contain bertween 150 and 350 discontinuities data, of which about 50% should have at least one end visible. An approximately planar rock face is selected that is large relative to the size and spacing of the discontinuities exposed.
The scanline them selves are simply measuring tapes, between 2 and 30 meters long, pinned with masonry nails and wire to the rock face along its strike and line of maximum dip. Further scanline should be set up on a sechond rock face, approximately at the right angles to the first, to minimise the orientation sampling bias.

4. 3. 2. Window Sampling

The measurement technique is essentially the same as for scanline sampling except that all discontinuities that have portion of their trace lenght within a difined area of the rock face intersect the scanline

This method can be defined by setting up a rectangle of measuring tapes pinned to the rock face. The window should be as large as possible in order to minimise sampling bias effect, with each side of a length such that it intersects between 30 and 100 discontinuities.

V. DATA PROCESSING AND PRESENTATION

5. 1. Systematic Collection and Presentation

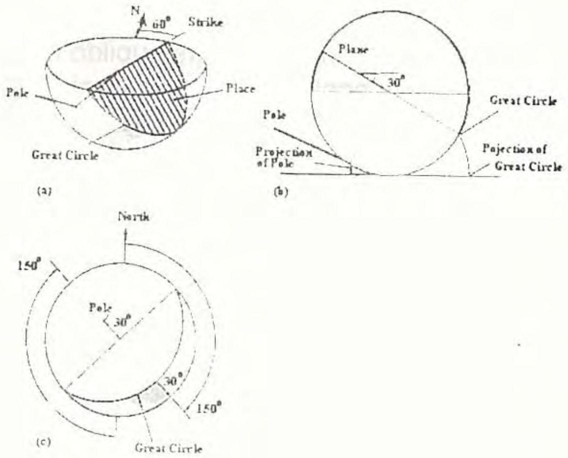
One of the important aspects of rock slope analysis is the systematic collection and presentation of geological data. It can than be properly evaluated and incoporated into stability analysis (Hoek and Bray, 1981). In recording dip and dip direction, the data can be written as dip/dip direction, example 45/060, (the dip of plane must lie between $0^{o}$and $90^{o}$and the angle of dip direction lies between $0^{o}$and 360^{o}). The presentation of data also can be provided in a convenient manner by using spherical projections.

5. 2. Stereographic Projection

Spherical projection is a graphical method whereby data on three-dimensional orientation of planar and linear features can be presented and analysed in two dimensions on sheet of paper, (Priest, 1985). This method is used in rock mechanics for analysing planar discontinuities, such as fracture, fasult, fissures and bedding planes that occur at various orientations within rock mass.

The advantages of the spherical projection is that it can be used for data collection and presentation and in the determination of the stability of rock blocks exposed at rock faces. Stereographic projection is a simplified graphical solution to solve the problems of the relative orientation of lines planes in space and for analysing the stability of rock blocks' exposures. The reference sphere is intersected by dip and dip direction to the North and its projection onto lower hemisphere can be seen in the Fig. 3.

Fig. 3.
THE PROJECTION OF DIP/DIP DIRECTION ON THE SPHERE
(SourceWyllie D. C., 1992)



5.3. Scaling Data

Scaling data is used because the technique of assessing stability both from individual pole plots or pole concentration are open to error. These errors can be caused by the following :

(1) The relative importance of each discontinuity is not assessed yet some may have more effect on the stability of the rock face than others.
(2) The technique fails to distinguish between a set of prominent and pervasive discontinuities and a group of discontinuous fractures of lesser importance.

The scaling data method is suggested so that the importance of each discontinuity can be measured in addition to the orientation, the persistence and the nature of any filling in the dilatancy. The measure of importance can be obtained by scaling of the resultant values. The formulae suggested for scaling the measure of importance is as follows, Matheson (1983).

$$\text{Importance} = \text{Persistence}\ x\ \text{factorA}\ x\ \text{factorB}$$

where is :

1. Persistence or continuous length in metres
2. Factor A is a Dilatancy or Discontinuity/joint spacing-separation of surfaces
3. Factor B is an Infill within dilatancy
4. The valu of factor A and B can be seen in Table II.

Table II.
FACTOR A and B
(After Matheson G.D., 1983)

Discontinuity Dilatation (MM)	Factor A	Infilling	Factor B
up to 10 MM	1.0 + Dilatation / 10	Soft Clay or Highly Weathered	2.0
over 10 MM	2.0	Other or No Infilling	1.0

VI. STABILITY ASSESSMENT

6.1. Determination of Rock Failures

Hard or soft rock is usually so intensically quite strong that failure under gravity alone is possible only if discontinuities permit easy movement of discrete blocks.
Geological structure, such as bedding or foliation, when cut by joints will provide many possibilities for block movement along planes of weakness (Hoek and Bray, 1981).
Different geological structures can be related to different types of rock slope failures. Thus in order to recognise the potential for instability in a rock slope, the structural pattern present in

the rock should be recognised and measured. in an actual rock slope, a combination of present. This could give rise to additional types of failures.
Also in the case of rock cuttings, choosing the safe angel for the rock slopes requires identification of the controlling discontinuities surfaces

6. 2. Assesment of Rock Stability

by using a great circle stereographic plot of fracture sets, as well as showing important single fractures such as faults, potentially unstable blocks can be identified (wyllie, 1992). such as analysis is carried out by plotting great circles for each of fracture set face of the slope rock cutting.
The importance of using the great circle for each orientation is that the surfaces which have an influenceon stability are represented on a single diagram. The failure or sliding plane can occur a long the line intersection and hence the plunge of the line of intersection must be less than the Dip of the slope face

These method have limitation on the number of great circles that can be used, because if the number of great circles on the plot is more than six, it is difficult to identify all the intersections of the circles.

The method of using the Great circles is hown in Figures 4 and 5. There are two methods which acn be used to define the direction of sliding and the line of intersection.

Fig. 4.
THE GREAT CIRCLE FOR DEFINING THE DIRECTION OF SLIDING
(Source Hoek and Bray, 1981)

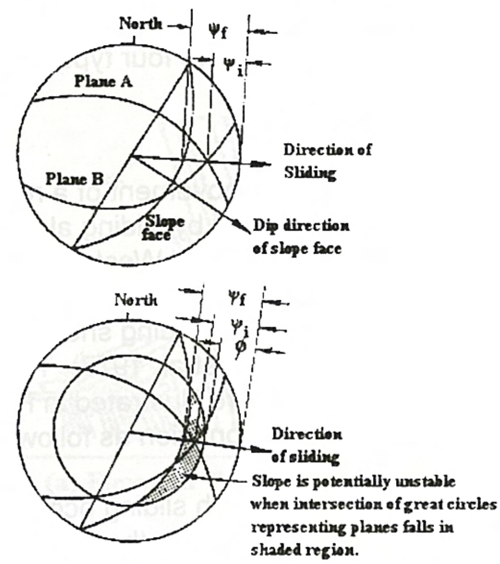
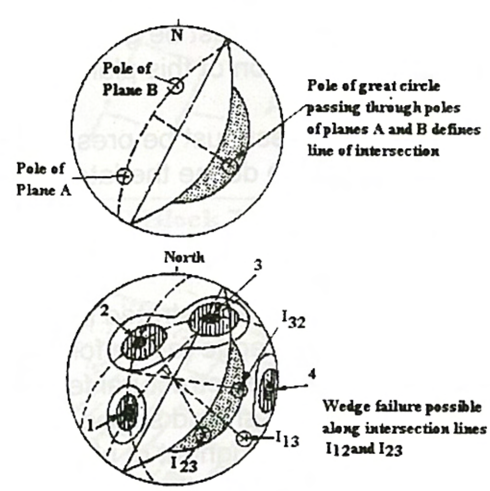


Fig. 5.
THE GREAT CIRCLE FOR DEFINING THE LINE OF INTERSECTION
(Source Hoek and Bray, 1981)



6.3. Possible Failure Modes

In rock slope stability there are three basic mechanisms by which the majority of the rock slope failures are caused. Failures in rock slope involving movement of rock blocks on discontinuities could be combined with one or more of the three basic modes of plane, wedge and toppling, although in some cases they may have a circular failure mode.

All of the likely patterns/modes of slope failure should be known for rock slope stability analyses. Figure 6. shows four types of rock slope failure.

6.3.1. Plane Failure

A plane failure is the movement of a rock block or mass occurring by sliding along a basal slip plane, (Evan and West, 1981). The following geometrical condition must be satisfied to produce that sliding should occur in single plane, (Fairhurst et al, 1977). The typical plane failures are illustrated in Fig. 6.(a) with the geometrical condition as follows:

(1). The plane on which sliding occurs must strike parallel , where the azimuth or dip direction of the slope plane must lie $\pm 20^0$ to the slope azimuth.

(2). The failure plane must " Daylight " or "Outcrop" in the slope face, usually the dip direction must be smaller than the dip of the slope face.

(3). The dip of failure must be greater than the angle of friction of this plane.

(4). Release surfaces must be present in the rock mass to define the lateral boundaries.

6.3.2. Wedge Failure

Typical wedge failures are illustrated in Fig. 6.(b) which shows the wedge failure formed by joint sets of closely spaced structural features. The analytical treatment should still be based upon the assumption throughout of planar features, although in the field the definition of the dips and dip directions at each location of these planes may present difficulties.

The assumption of the water pressure distribution for the wedge failure analysis is based upon the hypothesis that the wedge itself is impermeable and that water enters the top of the wedge along lines, (Fairhurst et al, 1977). Two basic conditions that occurred in the wedge failure and it must be recognised which are discussed by Evan and West (1981).

(1). The line of intersection must daylight or can be seen on the slope.

(2). The dip of the line of intersection must exceed the friction angles of the planes.

6.3.3. Toppling Failure

Modes of Toppling failure consist of rotation and block movement about some fixed base by which sliding or erosion of the toe of the slope allows the toppling process to start. A number of different types of toppling failure that may be encountered in the field have been discussed by Hoek and Bray(1981) also Goodman (1989). Each of these types of toppling failure can be described as follows. Typical toppling failures are illustrated in Fig. 6.(C).

Topping failure in rock masses can occur if the discontinuities have been oriented so the block of masses is not in the original position. The are two conditions to recognise the toppling failure occurred by Evan and West (1981).

6.3.3.1. Flexural Toppling.

Flexural toppling-is continuous column of rock, which is separated out by steeply dipping discontinuities. An example of flexural toppling failure is illustrated on Figure 7.(a). Toppling failure is difficult to recognise in the field, because the blocks have been disoriented and disordered, mainly at the bottom of the slope. In the field, these failure types can be recognised by the cracks in the top of surfaces.

6.3.3.2. Block Toppling

Block toppling can occur if the individual columns of rock blocks are divided by orthogonal joints. Figure 7.(b) shows an example of typical from block toppling.

6.3.3.3. Block-Flexure toppling

Block - flexural toppling combines of two characteristic toppling failures, so that this toppling failure can be characterised by pseudo-continuous flexure along columns which are divided by numerous cross joints. Figure 7.(c) shows an example of block-flexural toppling failure.

(1). Two sets of cross cutting discontinuities should be present and the Intersection of them should as dip into the slope. When the dip angles, in excess of (90^0 - friction angle) so the condition of toppling become favourable.

(2) Basal planes dipping out the slope at angles less than the friction angle should be present.

6.3.4. Rock Fracture Failures

This type of failures can be said look likes and similar such as soil failures. The failure happened, that is caused by randomly oriented fractures, so the pole plotted of stereo graphical projection can not be drawn. Typical of rock fracture failures can be ilustrated in Fig. 6 (d), such as sircular failure modes.

Fig. 6.
MAIN TYPE OF SLOPE FAILURE AND STEREO PLOTS OF STRUCTURAL CONDITIONS LIKELY TO GIVE RISE TO THESE FAILURE (Source Hoek and Bray, 1981)

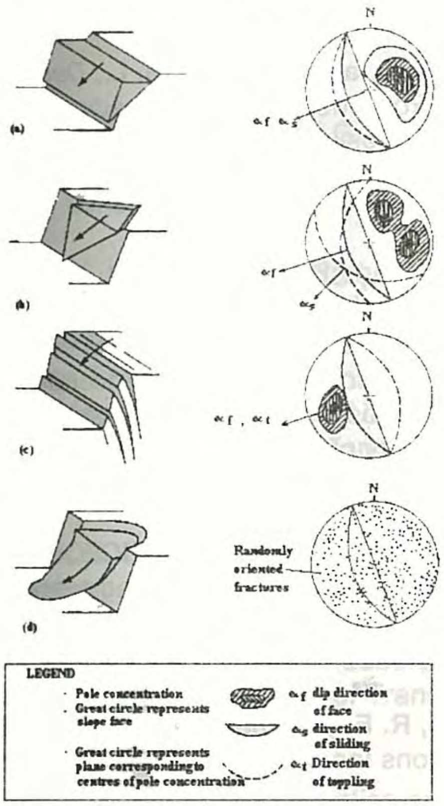
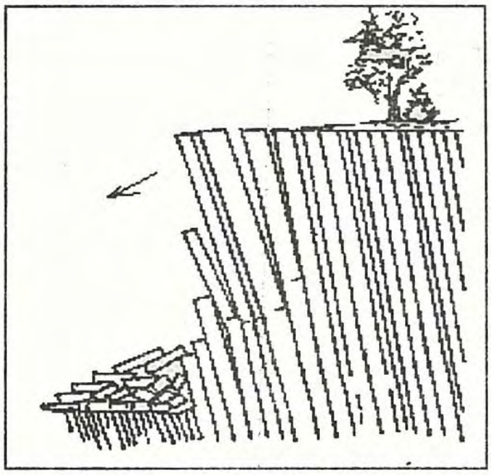
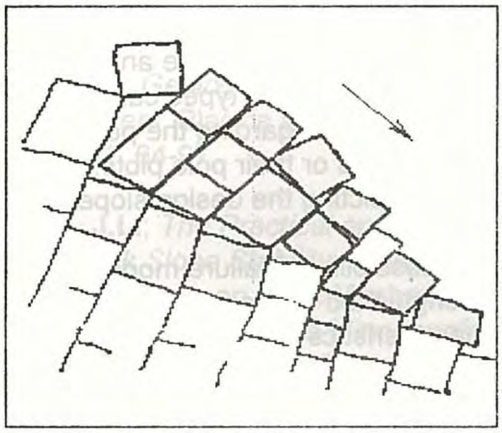


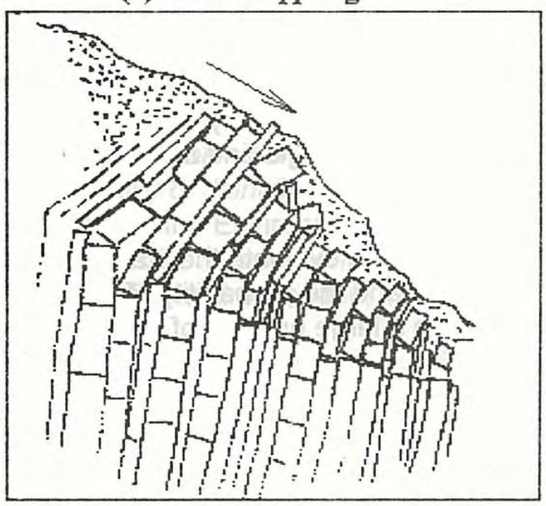
Fig. 7.
TYPICAL OF TOPPLING FAILURES (Source Hoek and Bray, 1981)



(a) Flexural Toppling



(b) Block Toppling



(c) Block Flexural Toppling

VII. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

(1). In highway excavation, the field data collection such as geological structure and rock type units can be recognised from the patterns of the discontinuities by subdividing the area study into units and structural regions.

(2). There are two types of discontinuity measurement consist of Scanline sampling and Window sampling.

(3). The assessment of the rock slope stability can be analysed and evaluated by their discontinuity pattern in terms of great circles or a pole plots on stereonet projection.

(4). The stability of rock slope and the possibility of failure types can be evaluated by regarding the position of the great circles or their pole plots, to a great circle depicting the design slope.

(5). The possibility of failure modes can be distinguished by discontinuity characteristics which depend on the relative orientation of the slope faces and the fractures.

7.2. Recommendations

(1). The discontinuities can be measured by the standard discontinuity measurement such as the dip angle and the dip-direction or the strike.

(2). It is possible to evaluate the stability of rock slope and the probability of failure types with a large number of discontinuity data.

(3). Failures in rock slope involving movement of rock blocks on discontinuities patterns could be combined with one or more of three basic modes of failure, plane, wedge and toppling. The rock fills or closely fractured rocks usually occurred in the circular failure mode.

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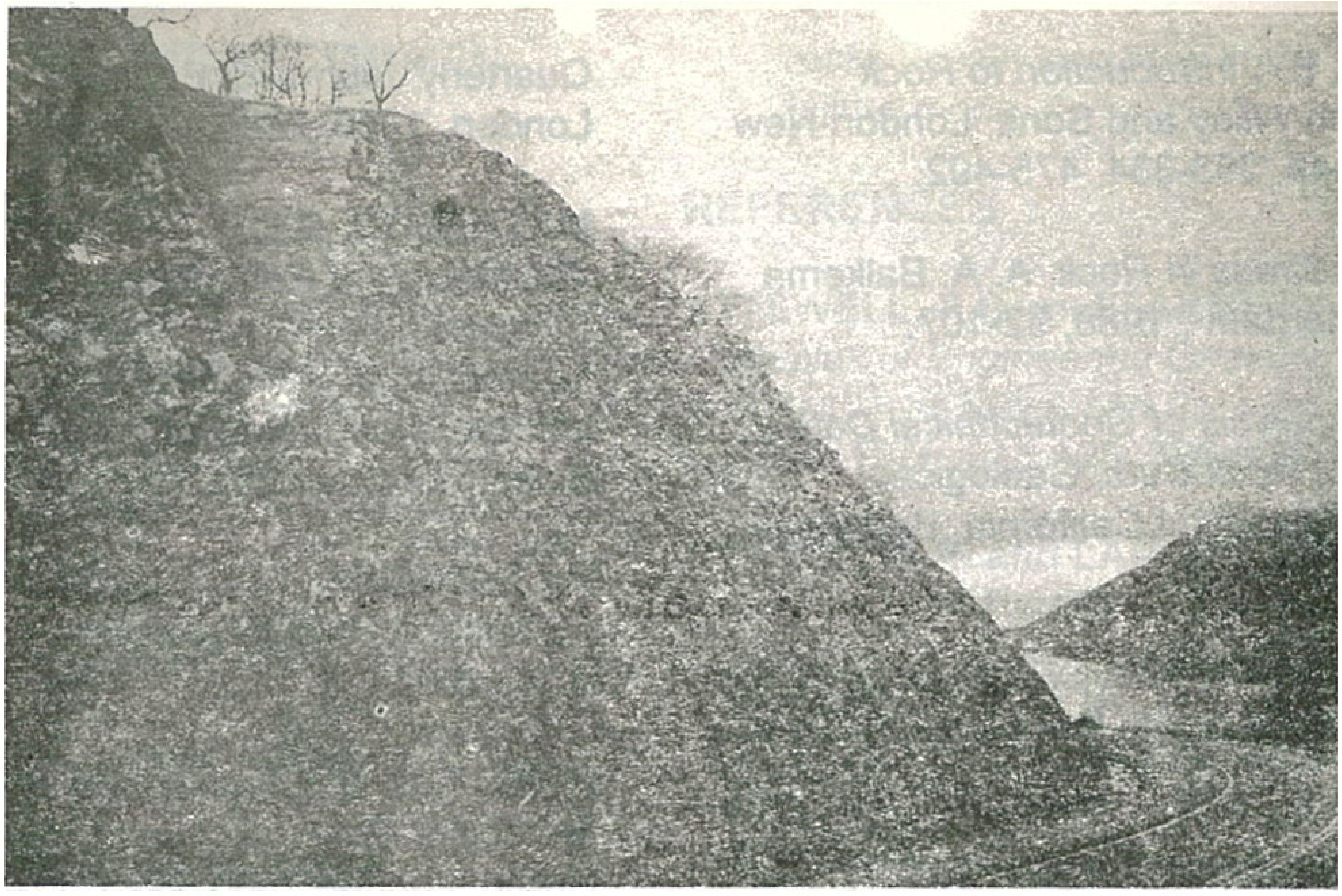

Photo 1. Rock Cutting in Road side of Loch Lomond,
The Rock Cutting 70 meters high with the slope cutting 45^0 and 70^0
On the top of face cutting can be seen the Wedge Failure type.

Photo 2. The Faces of Slope cutting have done by split blasting method.
In this photos can be seen the type of plane failure and rock fall.