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Influence of discontinuity sets on slope failures at Pos Selim Highway, Malaysia

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Abstract: The types of discontinuity of studied slopes are joints and foliations. The discontinuity sets in all the locations have maximum pole intensity of more than 8%. Several sets of discontinuities are recorded at each location. The stereographic plot of the discontinuities set revealed that most of the rock slopes have the potential to fail in the mode of wedge, planar and toppling, as well as the combination of more than one mode of failure. Potential wedge failure is found at seven locations, potential planar failure at five locations and potential toppling at four locations.

Abstrak: Jenis set-set ketakselanjaran di cerun yang dikaji adalah terdiri daripada kekar dan foliasi. Pada semua cerun didapati ketumpatan maksima kutub melebihi 8%. Terdapat beberapa set ketakselanjaran untuk setiap cerun. Pemplotan stereografi terhadap set–set ketakselanjaran mendapati cerun batuan mempunyai potensi kegagalan beragam baji, satah, terbalikan atau gabungan lebih daripada satu ragam kegagalan. Potensi kegagalan baji dicerap di 7 lokasi, potensi kegagalan satah di 5 lokasi dan potensi kegagalan terbalikan di 4 lokasi.

INTRODUCTION

This paper presents a case study of slope failure investigations. The study concentrates on discontinuity analysis with emphasis on their orientation. The orientation of the discontinuities and slopes direction is the basic data to perform a potential stability analysis. The objective of this paper is to determine the discontinuity sets which can potentially cause slope failure and the mode of slope failure. The study located along the Pos Selim Highway, part of the East West Highway project which is currently under construction. It stretches from Pos Selim in the Perak to Ladang Blue Valley at Cameron Highland, Pahang. The length of the highway is approximately 35 kilometers. The road transverses over the Titiwangsa Main Range bordering Pahang and Perak (Figure 1).

Discontinuities can be defined as any form of mechanical break or fracture within a rock mass which can cause the tensile strength across the fracture planes to approach zero or be lower than that of the rock material. Common examples of discontinuities include joints, fissures, faults, fault zones, bedding planes, cleavage and foliation. Discontinuities have many modes of origin, but two main types can be recognized i.e. those that occur in sets, for example bedding planes, joints and foliation, and the second type are unique forms for example faults, shear zones and planes of unconformity (Dearman, 1991). These features are often termed collectively as joints but this is an oversimplification, since the mechanical properties of these features will vary according to the process of their formation. Discontinuity generally is used to define the structural weakness plane where movement can take place. There are four basic mechanism of slope failure namely; circular failure, plane failure, wedge failure and toppling failure (Hoek and Bray, 1981).

SURFACE GEOLOGY

In the Pos Selim highway project, there are two main lithological units i.e. igneous and metamorphic rocks. The igneous rocks comprise mainly of granite and metamorphic rocks consist of closely foliated phylite and fine-grained schist. Granite covers about 63% the area, while metamorphic rock is about 37%. Due to the intrusion of the granite, schist is commonly situated at the higher elevation. The metamorphic rock is considered as a roof pendent on the granite (Figure 2).

DISCONTINUITY MAPPING

Discontinuity mapping is a process to identify the failure planes and to evaluate slope stability. The discontinuity mapping begins with the study of discontinuities present in the rock mass with particular attention given to their characteristics, geometry and spatial distribution. There are different methods of discontinuity mapping. It depends on the purposes of mapping and which stage we are at, whether pre-construction, construction and post-construction (Tajul, 2000). In this study, discontinuity mapping was carried out at the construction stage.

For this study, a Brunton Compass was used to measure dip and dip direction of the discontinuities. The most important rock slope analysis is a systematic data collection and a good presentation of geological data to be evaluated and incorporated into a stability analysis (Hoek and Bray, 1981). The stability assessment is based on pole concentration is subject to error because little recognition is given to specific major discontinuity, which can have a greater effect on stability than a large number of minor discontinuities over the slope face.

The assessment of instability of a rock slope is subtly

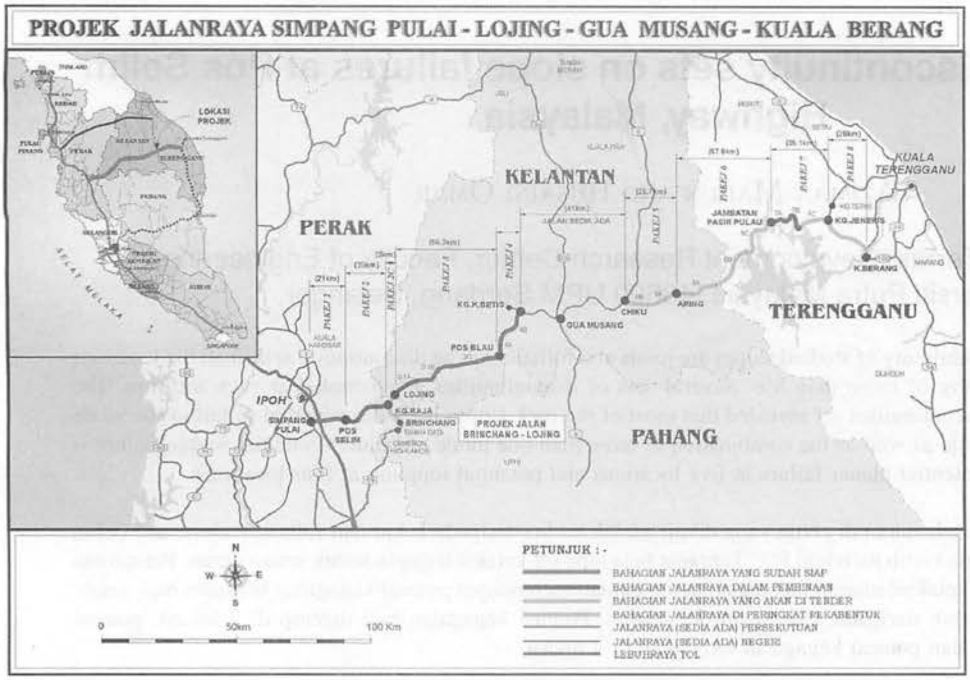

Figure 1: Location of the Pos Selim highway.

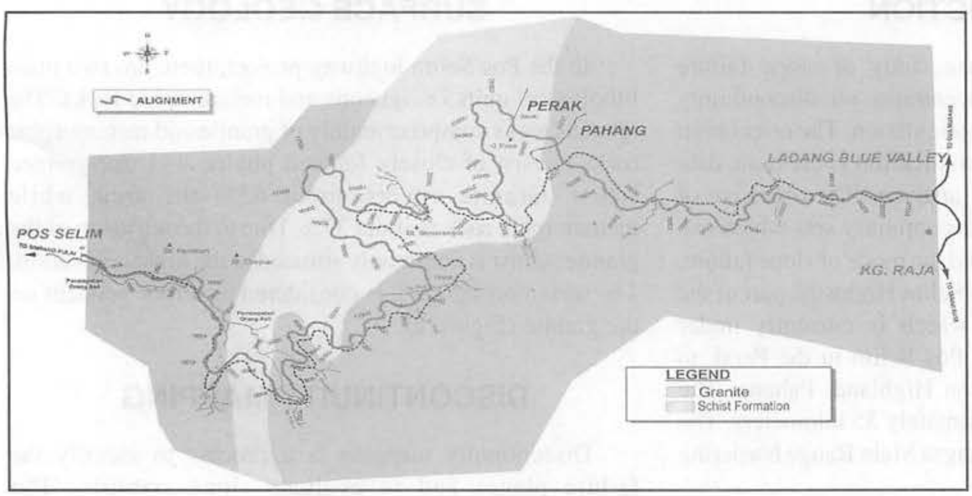

Figure 2: Geological map of the Pos Selim area.

different, depending on the scale of assessment. For overall stability of rock slopes it requires data collection, which involves the recognition, measurement and recording of discontinuities over the entire rock face. Generally, large numbers of discontinuity measurement are made for rock cutting. The scan line is 30 m to 50 m long and is dependent on the intensity of discontinuity and is located approximately at waist height. Every structural feature intersecting the scan line has its dip and dip direction recorded. At least 100 discontinuities should be collected for statistical study. There are additional information needed to be measured from the discontinuities including distance, types, orientation, persistence, aperture, natural infilling and hydraulic condition:

Distance – distance between discontinuities, which intersects the scan line.

Types – whether joint, fault, foliation or any geological features cause tensile strength approaching zero.

Orientation – dip direction and dip measured by geological compass.

Persistence – length of discontinuity from its inception to its termination in solid rock or against another discontinuity.

Aperture – distance between adjacent walls of discontinuity.

Natural infilling – aperture filled by minerals such as calcite, clay, etc.

Hydraulic condition – whether dry, wet or with water flow.

Highly to completely weathered rocks are weak and readily slake in water. The rock texture and discontinuity are still preserved. In this condition, random mapping should be carried out when scan line method cannot be practiced (Tajul, 2000). The technique is to walk along the cut slope and record any relict discontinuity and measure the dip and dip direction. Other information that can be detected should be noted.

METHOD OF DISCONTINUITY ANALYSIS

The orientation data, either obtained from the scan line method or collected randomly from cut slopes, is plotted into the lower hemisphere for presentation of data. Instead of the great circle, the pole of a plane can also define the inclination and orientation of that plane. The pole is a point at which the surface of sphere is pierced by the radial line that is normal to the plane. In plotting a large number of dips and dip directions of discontinuities, it is convenient to work with poles rather than great circles. In order to communicate the information given by the great circle and the position of pole of lower hemisphere, a two-dimensional representation is obtained by projecting this information onto the equatorial reference plane. The method of analysis is by using equal area projection or the Schmidt net (Hoek and Bray, 1981).

In order to determine significant pole concentrations, contours of the pole densities are prepared. Several methods of contouring the pole plots have been suggested. According to Braun (1969) the circle cells is divided into 100 squares with 1% each. The plot of poles on a tracing paper is positioned onto the counting cells. The total number of poles falling in this circle cells are marked at the center of the circle cells. For contouring the poles, the following procedures are recommended:

Count the number of pole falling in each counting cell.

Sum total number of poles plotted on the circle cell and established the number of poles per 1% area, which corresponds, to the different contour percentage values.

Draw the contours starting with low value contours inwards to the maximum pole concentrations.

Find the high percentage of poles and determine the center of the pole concentration, which may be two or more points. Mark as a doted point and reverse the procedure on construction of poles. The great circle plane for the discontinuity set can thus be determined.

Potential instability analyses were carried out using the technique proposed by Markland (1972) in Hoek and Bray (1981). The analysis technique enables the determination of kinematics sliding of rock blocks or saprolitic soil blocks along discontinuity planes and also along the lines of intersections of discontinuity planes. The information required for kinematics stability analyses are friction angle of the discontinuity planes, slope angle and slope direction. Friction angle of the discontinuity planes is controlled by roughness, grades of weathered, natural infill material, presence of water and surface of discontinuity planes (Tajul, 1991). Approximate friction angle values in fresh fine granite rock is 29° to 35°, while for slate rock is 25° to 30° (Hoek and Bray, 1981). In tropical residual soil, discontinuity are mostly infilled by clay and eventually make the material weaker, as a result shear strength should be lower compared to the hard rock material. The angle of friction of 25° is assumed for all discontinuity surfaces that are observed to be smooth and cohesive with material infill in this slope stability analysis.

Geometric factors that are used for kinematics stability analyses are slope angle and slope direction. Normally, the cut slope angles between berms are between 45° to 73°. The bottom of hills is usually designed to be steeper than the top of hills. Generally the residual soil slope is designed with an angle of 45°, the highly to completely weathered slope at 56° to 63°, and the slightly weathered to fresh rock slope at 73°.

RESULTS AND DISCUSSION

Eight cut slopes in granite and schist have been surveyed. They are at chainage 4+940 and 9+100 for granite, and chainage 9+700, 15+500, 16+300, 18+800, 20+750 and 21+400 for schist. All the discontinuity data have been plotted as equal area projection of poles to obtain the pole concentration. Then major discontinuity sets are defined. The discontinuities set are then plotted for potential instability analysis together with slope geometry and friction angle. The results will give the critical sets of discontinuity and their likely mode of failure (Figure 3).

In the granite area at CH 4900 a random discontinuity survey was carried out. Four sets of discontinuity are observed. The major discontinuity sets are joints with intensity of more than 8% at 302°/46°. Intensity of other joints sets are between 4 and 6% at 30°/70°, 142°/62° and 100°/72° (Figure 3, Table 1). The plane of discontinuity sets is plotted together with the slope face to analyze the potential instability. The four discontinuity planes are plotted together with the slope dip angle of 75°, and an assumed friction angle of 25° is also plotted to define the critical zone with the slope face. The intersection between J1 (302°/46°) and J2 (30°/70°) is marked as I_{12} is one intersection point of discontinuity planes which falls within the critical zone defined by the slope face and the angle of friction, indicating the possibility of wedge failure along the line of intersection of with a orientation of 321°/44°. The possibility of planar failure exists, as plane J1 is daylighting. The possibility of toppling failure exists due to the intersections of two sets of cross-cutting discontinuities dipping into the slope by discontinuities sets J2 with J3 (142°/62°) and J3 with J4 (100°/72°).

At the cut slope at CH 9100 a random discontinuity survey was carried out. There are four sets of discontinuities. The major discontinuity sets are joints with intensity of more than 8% at 340°/78°. Other joint sets have intensities of between 4 and 6% at 225°/75°, 238°/54° and 330°/50°. The four discontinuity sets are plotted together with the slope angle of 63° and a friction angle of 25°. Two intersection points of discontinuity planes fall within the critical zone defined by the slope face and the angle of friction, indicating the possibility of wedge failure. These are intersection of J1 (340°/78°) and J3 (238°/54°) marked as I_{13} with sliding along 266°/50° and the intersection of J3 and J4 (330°/50°) marked as I_{34} with sliding along of 289°/41°. The possibility of planar failure exists, as plane J3 is daylighting. Plane J2 (225°/75°) is steeper than the slope,

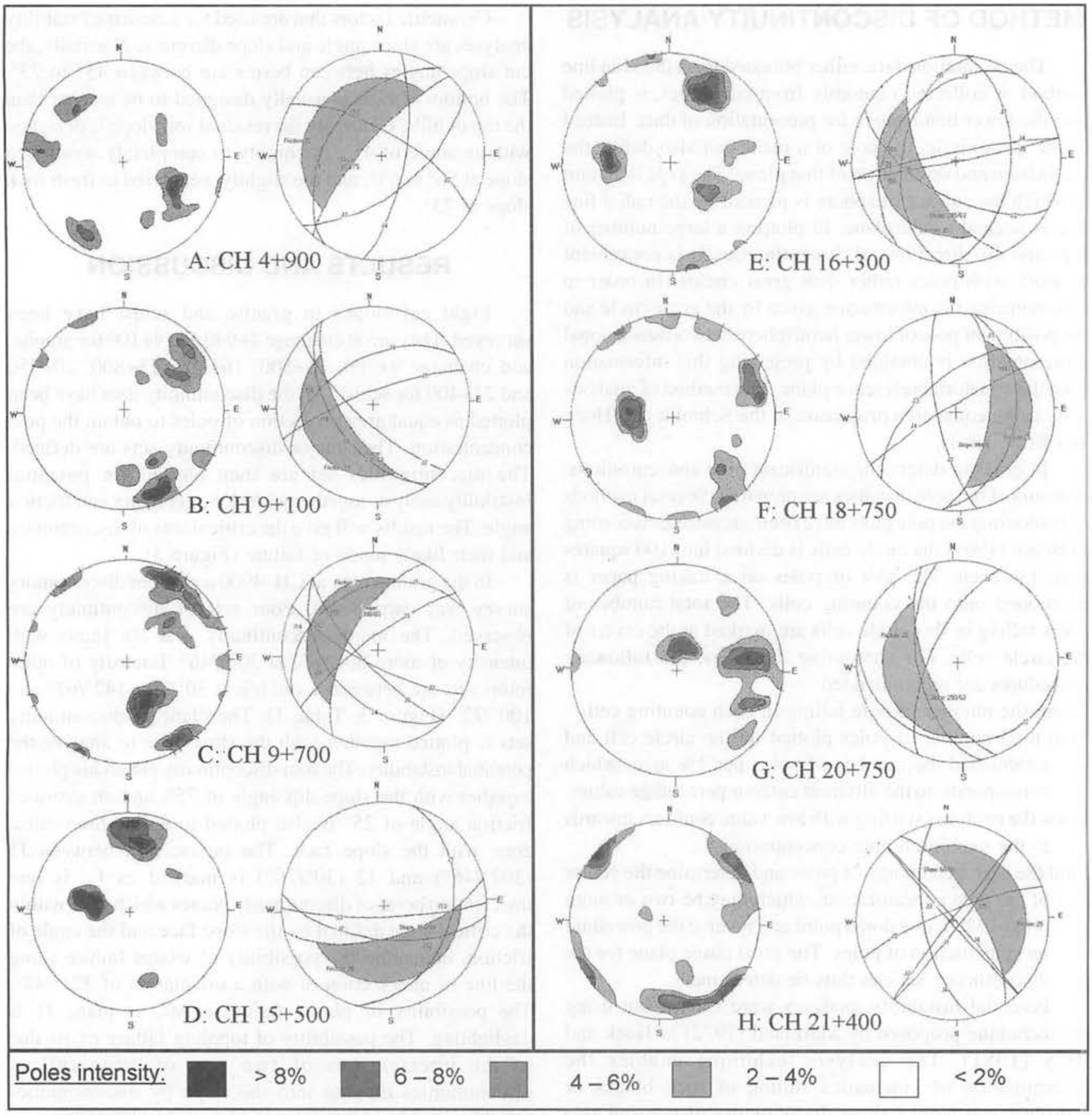

Figure 3: Discontinuity analysis.

therefore the problem of daylighting does not arise. A possibility of toppling failure also does not exist.

Within the schist area, a scan line discontinuity survey was carried out on the cut slope at CH 9700. There are five sets of discontinuities. The discontinuity sets are designated J1 to J5, based on their equal area intensities. A major discontinuity is foliation, where dip direction and dip is 336°/34° and the equal area intensity is more than 8%. Another major discontinuity with intensity of more than 8% is represented by joints at 210°/76°. Other joint sets which have intensity from 4 to 8% were recorded at 325°/78°, 230°/45° and 230°/75°. The five discontinuity planes are plotted together with the slope dip angle of 63° and an assumed friction angle of 25° is also plotted. A total of four intersection points of discontinuity planes fall within the critical zone, indicating the possibility of wedge failures. These are the intersection of J1 (336°/34°) and J2 (210°/76°) marked as I_{12} and sliding along 293°/26°, the intersection of J1 and J4 (230°/45°) marked as I_{14} and sliding along 291°/25°, the intersection of J1 and J5 (230°/75°) marked as I_{15} and sliding along 310°/31°, and the intersection of J3 (325°/78°) and J4 marked as I_{34} with sliding along 230°/45°. The possibility of planar and toppling failure does not exist.

At cut slope CH15500 a scan line discontinuity survey was carried out. There are three sets of discontinuities. The discontinuity sets have been designated J1 to J3. The major discontinuity sets with intensity of more than 8% are foliations at 110°/35° and a joint set at 192°/62°. The intensity of the other joint set is between 6 to 8% at 182°/80°. These three discontinuity planes are plotted together with the slope angle of 63°. A total of two intersection points of discontinuity planes fall within the critical zone defined by the slope face and the friction angle of 25°, indicating the possibility of wedge failure. These are the intersection of J1 (110°/35°) and J2 (192°/62°) marked as I_{12} with sliding along 122°/34° and intersection of J1 and J3 (182°/80°) marked as I_{13} with sliding along 100°/34°. However the possibility of planar and toppling failures does not exist.

At the cut slope at CH16300 a scan line discontinuity survey was carried out. The major discontinuity set is foliation with intensity of more than 8% at 96°/48°. Another major joint set is 210°/60°. The intensity of the other joints set are between 2 to 6% at 305°/35°, 350°/85°, 170°/88° and 260°/46°. The six discontinuity planes are plotted together with the slope angle of 63°. A total of four intersection points of discontinuity planes fall within the critical zone defined by the slope face and the friction angle of 25°, indicating the possibility of wedge failures. These are the intersection of J2 (210°/60°) and J3 (305°/35°) marked as I_{23} with sliding along 305°/35°. Intersection of J2 and J4 (350°/85°) marked as I_{24} with sliding along 266°/46°. Intersection of J2 and J6 (260°/46°) marked as I_{26} with sliding along 266°/46°. Intersection of J5 (170°/88°) and J6 marked as I_{56} with sliding along 258°/46°. Furthermore there exists the possibility of planar failure, as there are discontinuity planes parallel and subparallel to this slope. As the plane J2 is daylighting planar failure is possible. The possibility of toppling failure are due to the intersections of two sets of cross-cutting discontinuities dipping into the slope these are the discontinuities sets J1 (96°/48°) with J2, J1 with J3 (305°/35°) and J1 with J5.

A scan line discontinuity survey was carried out at cut slope CH18750. There are four sets of discontinuities. The major discontinuity set is foliation with more than 8% intensity is marked as 102°/40°. Other joint sets have intensities of between 4 to 8% at 260°/46°, 320°/60° and 330°/85°. The four discontinuity planes are plotted together with the slope dip angle of 63° and a friction angle of 25°. Only one intersection between J1 (102°/40°) and J4 (330°/85°) marked as I_{14} with sliding along 57°/31° falls within the critical zone, indicating the possibility of wedge failure. The possibility of planar failure also exists, as the plane J1 is daylighting. The possibility of toppling failure exists due to the intersections of two sets of cross-cutting discontinuities dipping into the slope. These are the discontinuity sets J2 (260°/46°) with J3 (320°/60°) and J2 with J4.

At the cut slope CH20750 a random discontinuity survey was carried out. There are three sets of discontinuities. The discontinuity sets have been designated as J1 to J3. The major discontinuity set is joints with more than 8% intensity, marked as 260°/56°. Other sets are foliation with between 6 and 8% intensity at 190°/20°, and joints at 295°/66° with intensity of 4 to 6%. The three discontinuity planes are plotted together with the slope dip angle of 63° and a friction angle 25°. The possibility of wedge failure does not arise as there is no intersection of discontinuities and therefore the slope is stable with respect to such failure. But the possibility of planar failure exists, as the plane J1 (260°/56°) is daylighting. The possibility of toppling failure does not exist.

A scan line discontinuity survey was carried out at CH 21400. There are 6 sets of discontinuities, and 2 sets have intensities of more than 8% at 130°/85° and 310°/88°. The others have intensities of between 6 and 8% at 230°/88°, 50°/88°, 340°/80° and 260°/65°. All the discontinuity sets are joints. The six discontinuity planes are plotted together with the slope dip angle of 68° and a friction angle of 25°. Only one intersection point fall within the critical zone. This is the discontinuity set J1 (130°/85°) and J5 (340°/80°) marked as I_{15} with sliding along 52°/62°, indicating the possibility of wedge failure. The possibility of planar

Table 1: Pole intensity and discontinuity set of each studies location.

Location of slope	Pole intensity	Discontinuity set	Marked	Types of discontinuity set	Geology
CH 4900	>8%	302°/46°	J1	joint	Granite
	4-6%	30°/70°	J2	joint	
	4-6%	142°/62°	J3	joint	
	4-6%	100°/72°	J4	joint	
CH 9100	>8%	340°/78°	J1	joint	Granite
	4-6%	225°/75°	J2	joint	
	4-6%	238°/54°	J3	joint	
	4-6%	330°/50°	J4	joint	
CH 9700	>8%	336°/34°	J1	foliation	Schist
	>8%	210°/76°	J2	joint	
	6-8%	325°/45°	J3	joint	
	6-8%	230°/45°	J4	joint	
	4-6%	230°/75°	J5	joint	
CH 15500	>8%	110°/35°	J1	foliation	Schist
	>8%	190°/62°	J2	joint	
	6-8%	182°/80°	J3	joint	
CH 16300	>8%	96°/48°	J1	foliation	Schist
	>8%	210°/60°	J2	joint	
	4-6%	305°/35°	J3	joint	
	4-6%	350°/85°	J4	joint	
	4-6%	170°/88°	J5	joint	
	2-4%	260°/46°	J6	joint	
CH 18750	>8%	102°/40°	J1	foliation	Schist
	>8%	260°/74°	J2	joint	
	4-6%	320°/60°	J3	joint	
	4-6%	330°/85°	J4	joint	
CH 20750	>8%	260°/56°	J1	joint	Schist
	6-8%	190°/20°	J2	foliation	
	4-6%	295°/66°	J3	joint	
CH 21400	>8%	130°/85°	J1	joint	Schist
	>8%	310°/88°	J2	joint	
	6-8%	230°/88°	J3	joint	
	6-8%	50°/88°	J4	joint	
	6-8%	340°/80°	J5	joint	
	6-8%	260°/65°	J6	Joint	

Table 2: Kinematics stability analysis to find potential unstable slopes.

Location of slope	Slope bench dip direction/ slope angle	Friction angle	Potential wedge failure Intersection of discontinuity set and sliding plane				Potential planar failure discontinuity set and sliding plane	Potential toppling failure
CH 4900	310°/75°	25°	J1 and J2 (I12) Sliding plane: 321°/44°	—	—	—	J1 302°/46°	J2 & J3 J3 & J4
CH 9100	240°/63°	25°	J1 and J3 (I13) Sliding plane: 266°/50°	J3 and J4 (I34) Sliding plane: 289°/41°	—	—	J3 238°/54°	Possibility of toppling does not arise
CH 9700	300°/63°	25°	J1 and J2 (I12) Sliding plane: 293°/26°	J1 and J4 (I14) Sliding plane: 291°/25°	J1 and J5 (I15) Sliding plane: 310°/31°	J3 and J4 (I34) Sliding plane: 230°/45°	Possibility of planar failure not form	Possibility of toppling does not arise
CH 15500	168°/63°	25°	J1 and J2 (I12) Sliding plane: 122°/34°	J1 and J3 (I13) Sliding plane: 100°/34°	—	—	Possibility of planar failure not form	Possibility of toppling does not arise
CH 16300	245°/63°	25°	J2 and J4 (I24) Sliding plane: 266°/46°	J2 and J6 (I26) Sliding plane: 266°/46°	J5 and J6 (I56) Sliding plane: 258°/46°	J2 and J3 (I34) Sliding plane: 305°/35°	J6 260°/46°	J1 & J5 J1 & J2 J1 & J3
CH 18750	98°/63°	25°	J1 and J4 (I14) Sliding plane: 57°/31°	—	—	—	J1 102°/40°	J2 & J4 J2 & J3
CH 20750	250°/63°	25°	Possibility of wedge failure does not arise				J1 260°/56°	Possibility of toppling does not arise
CH 21400	60°/68°	25°	J1 and J5 (I15) Sliding plane: 52°/62°	—	—	—	Possibility of planar failure does not arise	J1 & J3 J1 & J6 J3 & J5 J5 & J6

failure does not exist. There were four possibilities of toppling failures due to the intersections of two sets of crosscutting discontinuities dipping into the slope. There are J1 with J3 (230°/88°), J1 with J6 (260°/65°), J3 with J5 (340°/80°) and J5 with J6.

The equal area intensities and discontinuity sets of the study area are tabulated in Table 1 and potential instability analyses results tabulated in Table 2. Potential wedge failure is observed at seven locations and potential planar failure at 5 locations while potential toppling at 4 locations. The slope failures occur as single failure or a combination of several failure modes.

CONCLUSION

Based on the discontinuity studies, joints were considered as major sets with more than 8% of pole intensity at all the investigated slopes. From potential instability analysis, most of the joint sets are intersecting and fall in the critical zone define by the slope face and a friction angle at 25°. Slopes at CH 9700 and CH 16300 showed the highest number of the intersection planes. These are located on schist, which is moderately to highly weathered and highly fractured. At these locations, 5 discontinuity sets have the potential to cause planar modes of failure. At CH 21400, two sets of crosscutting discontinuities dipping into the slope face has the potential to induced toppling failure. The stereographic plots of discontinuities revealed that most of the rock slopes have the potential to fail in wedge, plane and toppling modes, as well as a combination of more than one modes of failure.

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