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# The effect of scanline direction and extent of rock exposure on assessment of geometrical properties of discontinuities in rock mass

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# The effect of scanline direction and extent of rock exposure on assessment of geometrical properties of discontinuities in rock mass

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**Abstract.** In this study, the borehole coring method and discontinuity scanline survey method are used to characterize the rock mass for the engineering design of underground structures at a dam site. Scanline survey is conducted on rock exposures in an exploratory adit. Cores from a borehole drilled near to the exploratory adit are also examined. The purpose of this study is to highlight the merits and demerits and the capacity of each method to characterize the geometrical properties of discontinuities. It is observed in the study area that the discontinuity scanline survey being conducted on large exposures, provides good results in estimating the orientation, trace length, roughness and interconnectivity of discontinuities. However, the direction of scanline introduces bias in results, because discontinuities parallel to the scanline line are not considered. The borehole method provided a good reflection of the bed rock; however, it presents a very rough estimate of geometrical properties of discontinuities. Moreover, estimation of areal extent of discontinuity plane is not covered by both the methods. However, engineering judgement by experienced engineering geologists can help in taking an informed guess.

## 1. Introduction

In case of jointed rock mass, the geometrical properties of rock mass provide input for determining block size, which is an essential element in stability analysis of structures in rocks [1]. The dip of discontinuities can be easily determined from a rock core, however, for accurate measurement of dip direction, the borehole wall images obtained through borehole camera can provide satisfactory results [2]. However, the bias inherent in discontinuity attitude data must be considered and should be compensated in order to reach a reasonable estimate of discontinuity orientation and fracture network [3]. The stability of surface and underground excavations is directly affected by the anisotropy of rock mass [4-6]. Significant errors can occur during the execution of engineering design if anisotropy of rock mass is inappropriately determined during the investigation stage [7, 8].

Borehole sampling and outcrop mapping are commonly conducted to collect discontinuity data. Each of these methods have their own merits and demerits. For example, borehole method is effective for deep subsurface core sample collection for rock mechanics tests, indication of bedrock lithology, discontinuity orientation, rock quality designation (RQD), fracture frequency etc. However, the core is too small to measure all features of discontinuities accurately. On the other hand, the scanline survey involves sampling and measuring the trace length of the discontinuities intersected by the line set on the exposed surface of rock. Most of the rock engineering design tools consider the geometrical properties of discontinuities in a rock mass in order to predict the rock mass behavior during the construction stage. These geometrical properties include persistence, orientation, degree of interconnectivity and surface roughness (see figure 1). All these properties have a dominant effect on rock mass mechanical properties [9, 10]. However, the raw data obtained during coring and scan line mapping is proved to be biased due to some inherent limitation of these techniques. Park and West [11] observed significant differences in discontinuity orientation by comparing results from horizontal scanline sampling and vertical borehole method. Thus, sampling bias should be scrutinized and corrected before establishing representative orientation data for engineering design purposes. The use of outcrop data for predicting the subsurface discontinuity networks particularly in heterogeneous regions is not recommended, unless appropriate measures are taken to characterize the variations in fracture attributes [12]. Watkins, Bond, Healy and Butler [13] attempted to measure the trace length of discontinuities, using a finite window. They observed that the trace length of discontinuities whose both ends are observable can be measured easily, however, they failed to measure the trace length of discontinuities whose one or both ends were censored. They recommended probability and statistics to estimate a mean trace length.

Data from an exploratory adit and a borehole considered in this study is part of a mega geological investigation campaign, intended for characterization of rock mass for construction of hydropower caverns, such as diversion tunnels and headrace tunnels at Bunji hydropower project site, Pakistan. The rock mass characterization will provide input data for engineering design tools, such as empirical rock mass classification systems, analytical and numerical methods. For this purpose, discontinuity data from the exploratory adit and the borehole is collected and compared. The vertical borehole and horizontal adit intersect the same rock mass at a depth of about 54 m below the ground surface. From borehole log it is observed that the main rock type is foliated granitic gneiss with a foliation angle of nearly $45^0$ dipping towards North East. Most of the joints observed on the borehole core are oriented along the foliation direction. The discontinuities observed in the exploratory adit showed two main joint sets. Set 1 and Set 2 have a dip/dip direction of 40/055 and 37/294 respectively. Set 1 include most of the joints and its orientation is consistent with the foliation orientation observed from the borehole data. Set 2 is not observed during borehole data. The persistence, roughness and interconnectivity of joints is more evident from exploratory adit as compared to borehole data. It is recommended that the choice of method for investigating ground features should be purely based on the amount of accuracy needed for the intended structure.

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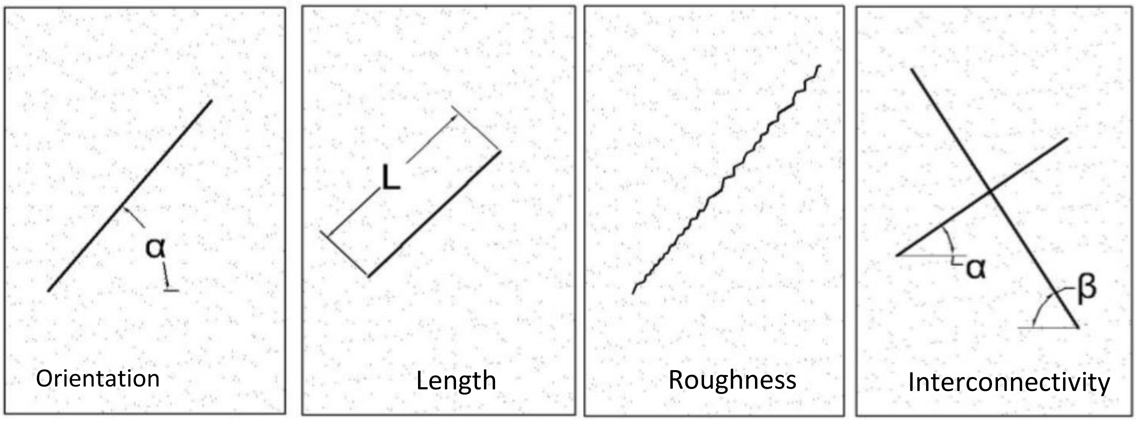


**Figure 1.** Major discontinuity geometrical properties. (reproduced from Piyal and Konietzky [9])

## 2. Materials and Method

Discontinuity data for this research was collected from an exploratory adit and a borehole. Scanlines were undertaken in general accordance with ISRM guidelines and the methods of Priest [14]. Scanlines were established using a measuring tape set as close to a suitable rock face as possible. Where the rock face changed orientation, the scanline was set up in linear sections, with the trend and plunge of the scanline section being recorded. For the given location, attempts were also made to establish scanlines at approximate right-angles and orthogonal to one another, to minimize sampling bias, however, this was not always possible due to access difficulties.

All discontinuities intersecting the scanline were recorded. The discontinuity orientation was determined by measuring the Dip/Dip direction of each discontinuity. Discontinuity analysis was performed by using Dips 7.0 (Rocscience) program in order to determine the dominant joint sets. Quantitative charts of discontinuity persistence, representing maximum, minimum, mean and standard deviation of each joint set was plotted (see Figure 4 and 5). Similarly, a quantitative chart showing the roughness of discontinuities is plotted (see Figure 6).

## 3. Sampling and experimental program

### *3.1. Lithological and mineralogical characterization*

The Granitic gneiss (Iskere gneiss) of the Indian plate are the oldest rock unit in the project area. These homogeneous quartzo-feldspathic gneisses are generally light grey to grey, porphyritic and mainly consist of quartz, feldspar and biotite. Biotite commonly occurs in the form of banding, with a typical thickness of 50 to 200 mm. The rock was found to be fine to medium grained and strongly foliated. The foliation is mainly tectonic. There are no microfractures, voids, open cleavage or crenulation. The petrographic study indicates that the rock contains between 36% and 42% quartz, and between 24% and 27% potassium feldspar and the percentage of biotite varies from 8% to 16% [15].

Most joints, including other tectonic joints have been re-cemented with minerals such as calcite and quartz. It has been found that there is no conformity in the orientation of the foliation and the joint sets in the Granite gneiss on the right and left banks of the Indus River at the dam site. The foliation is steeper on the left bank than on the right bank. One of the joint sets on the left bank strikes almost parallel to the river dipping at 55 degrees towards the river, but on the right bank it is not so pronounced. Within the right bank there is a slight variation in the orientation of the foliation and the joint sets.

### *3.2. Discontinuity survey*

Planer structures induce anisotropy in rock. Discontinuities are planer structures in rock and their orientation can affect the strength characteristics and rock mass behavior [16, 17]. Hoek and Brown [18] classified the foliated metamorphic rocks as anisotropic. The discontinuity survey is conducted using scanline method and borehole coring method (for details see sections 3.2.1 and 3.3).

*3.2.1. Discontinuity orientation from exploratory adit*

According to Park, West and Woo [19], the identification of the preferred orientation of joint sets in rock mass is the principal need for characterization purposes. In this study discontinuity scanline survey is conducted along 14 m length of an exploratory adit. A total of 80 discontinuities are intersected, showing two major joint sets, Set 1 and Set 2, see Figure 2 and Table 1. Several random joints are also observed. Figure 3 shows a rosette plot showing that most of the joints are striking along North-West and South-East.

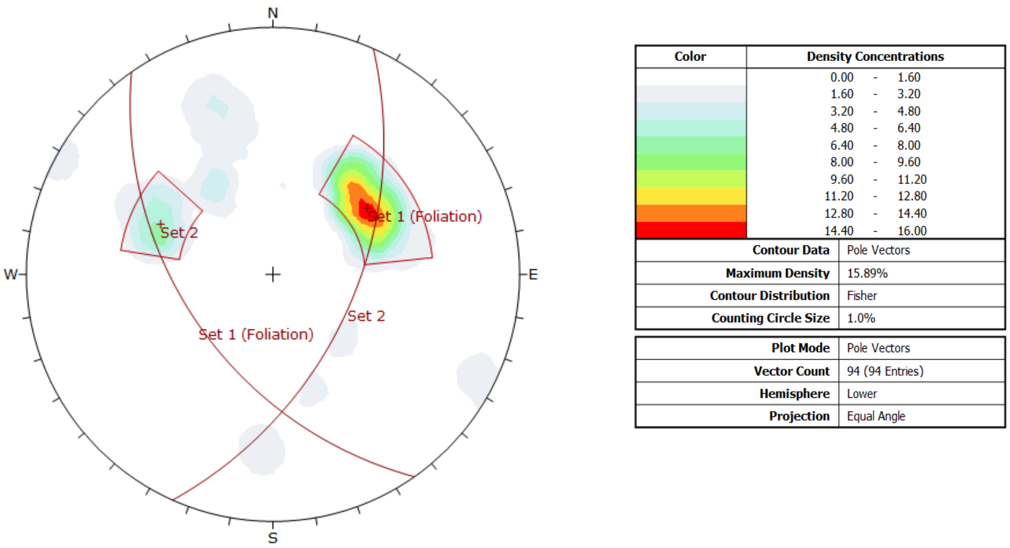


**Figure 2.** Contoured pole plots of scanline data.

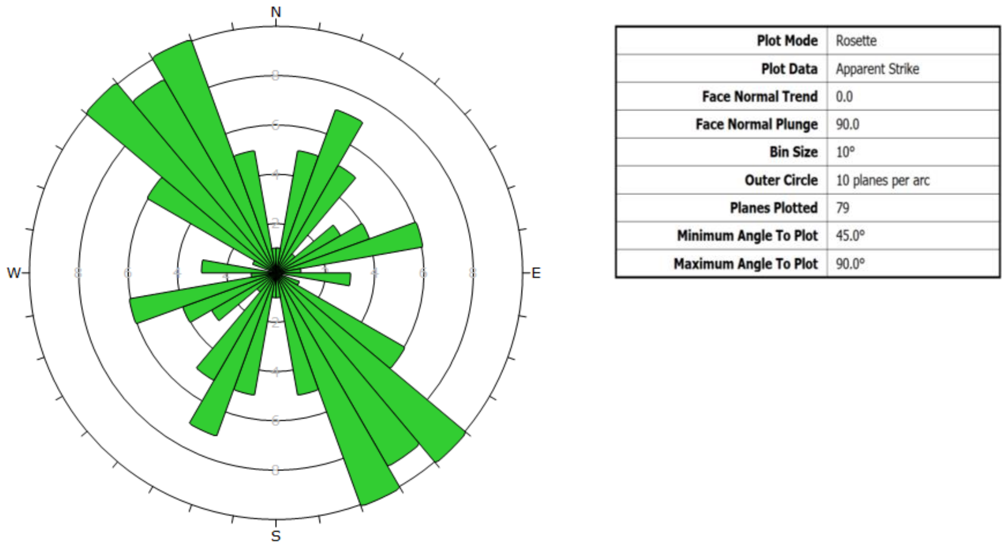


**Figure 3.** Rosette plot showing the prevailing strike direction.

**Table 1.** Major joint sets.

| Joint Set | Orientation (Degree) Dip | Dip Direction | Total number of joints | Average Persistence (m) | Roughness |
|---|---|---|---|---|---|
| Set 1 | 40 | 055 | 25 | 2.7 | Rough Planer |
| Set 2 | 37 | 294 | 11 | 3.3 | Rough Undulating |

Figure 4 depicts plan view of a section of the horseshoe shaped exploratory adit. The dark and green lines in figure 4 represent the scanline orientation along the adit. The number of discontinuities intersected by each scanline varies considerably due to the change in location and orientation of the scanline. Also, an accurate measure of the trace length is difficult for those discontinuities which are extended beyond the rock exposure limit, a drawback of scanline measurement previously noted by Priest and Hudson [20]. From a practical engineering perspective, the trace length of discontinuities embedded in the rock is more important for selecting appropriate reinforcement during construction.

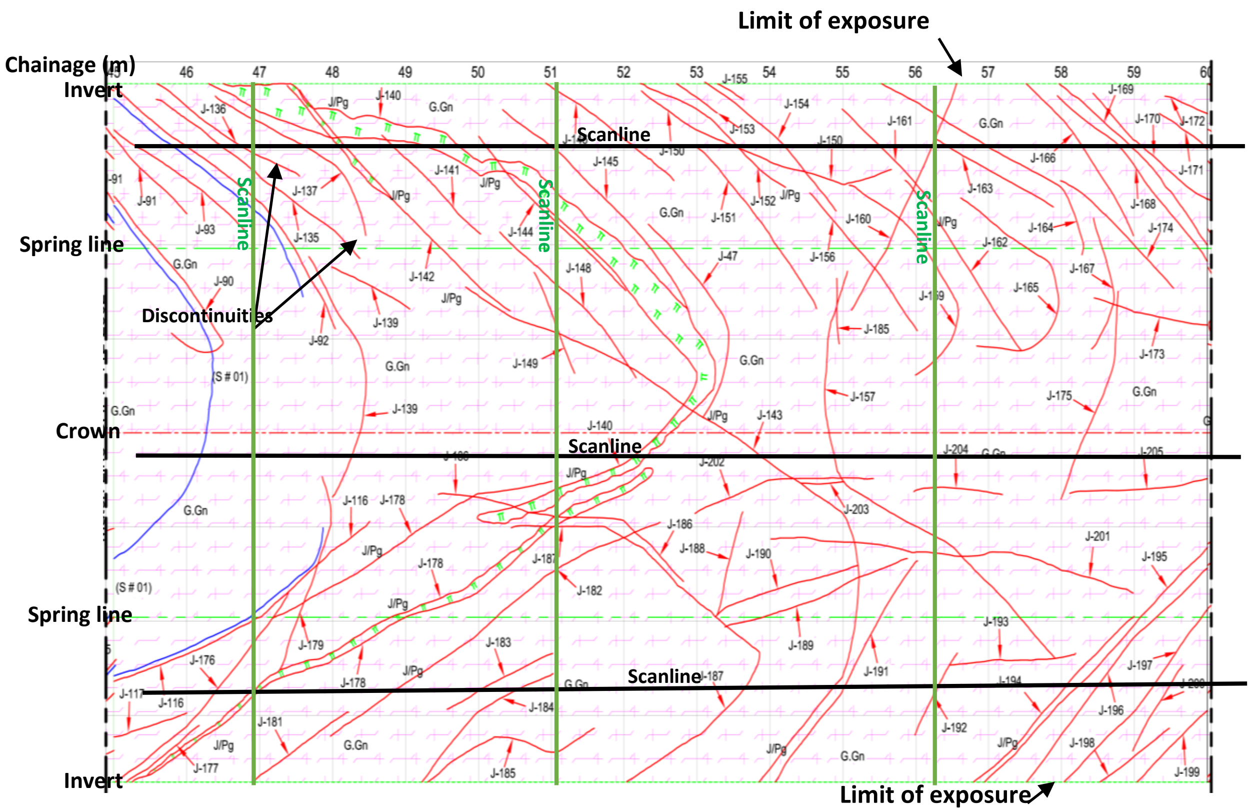


**Figure 4**. Plan view of horseshoe shaped adit presenting the influence of scanline orientation and location on geometrical properties of discontinuities.

*3.2.2. Discontinuity persistence*

In this study the borehole data is insufficient to measure the persistence of discontinuities. A relatively good measure of persistence is made by using scanline data along the exploratory adit, see Figure 5. The joints in Set 1 are more persistent with a maximum persistence of 15 m. These joints are of the same orientation as the foliation. The foliation has provided a weakness plane along the walls of the exploratory adit and hence resulted in more persistent joints. The joints in set 2 are less persistent and only observed in adit as shown in Figure 6.

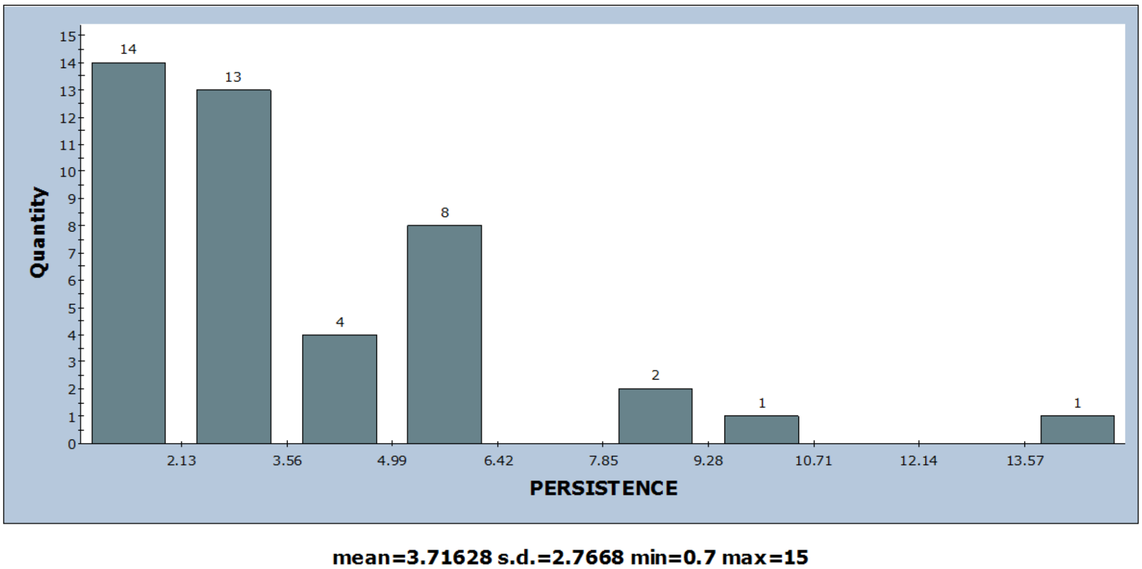


**Figure 5.** Quantitative chart of persistence for Joint Set 1.

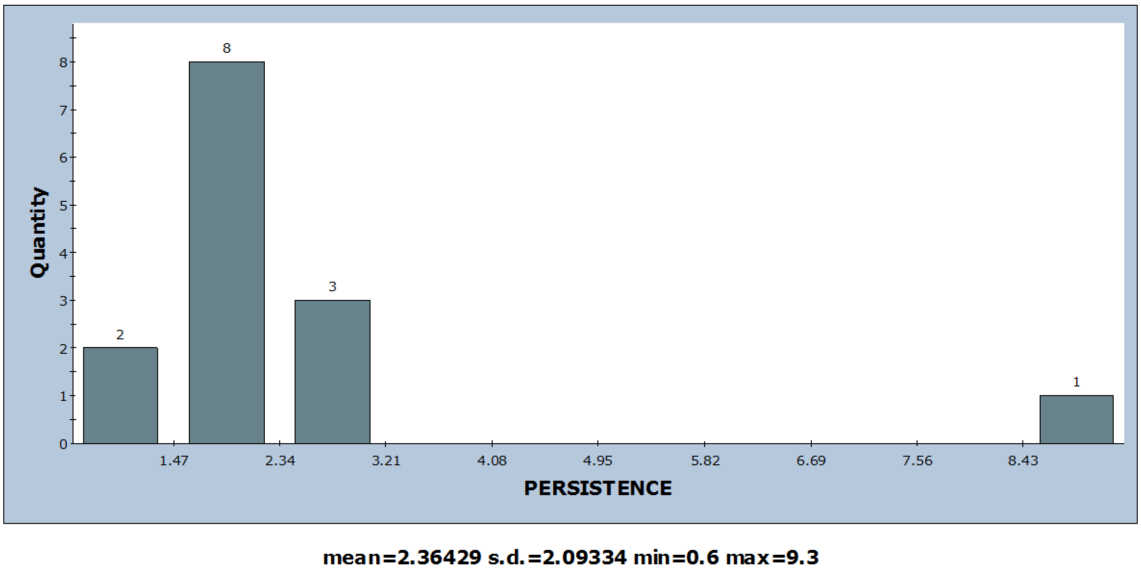


**Figure 6.** Quantitative chart of Persistence for Joint Set 2.

*3.2.3 Joint Roughness*

Joint roughness is a measure of the shear strength of discontinuities and plays an important role in stability analysis of structures in blocky rock mass. A very limited portion of the discontinuity plane is visible in the borehole core. An underestimation or overestimation of roughness can drastically affect the safety and support requirements during construction of tunnels. A good estimate of joint roughness is strongly dependent on persistence measurement or in other words the extent of rock exposure. In this study the joints observed along the borehole core are mostly planer rough. On the other hand, most of the joints in exploratory adit are found to be rough undulating, see Figure 7.

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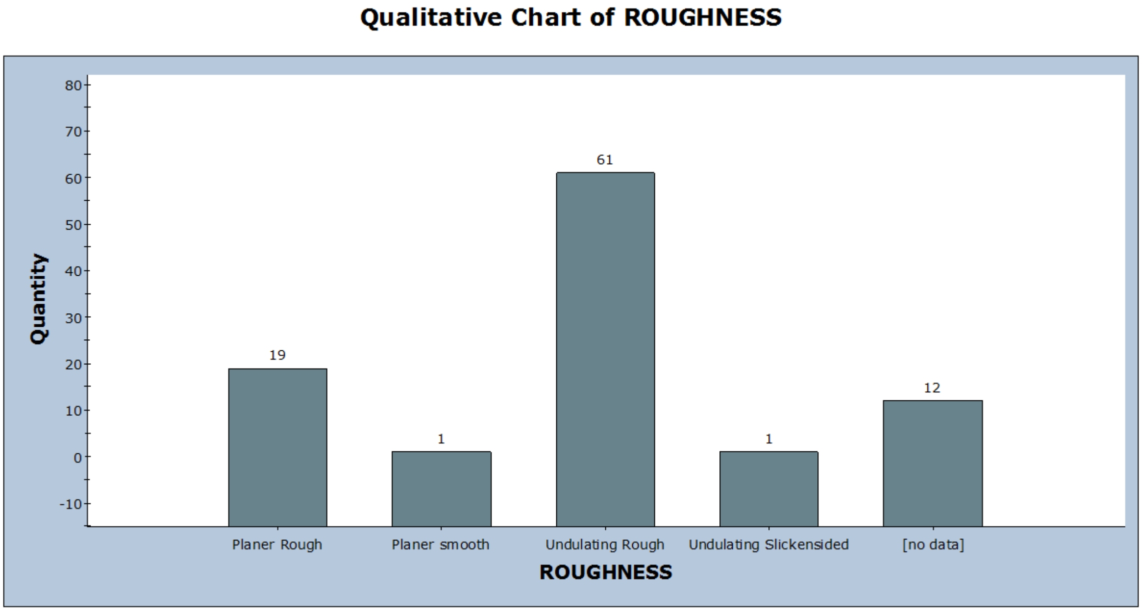


**Figure 7.** Quantitative chart of joint roughness.

*3.3. Borehole core data*

The core shown in figure 8 is retrieved from a borehole located 5 m away from the axis of the exploratory adit towards east. A 28 m long section of the core is examined to determine the lithology of bedrock and the orientation of discontinuities. The dominant rock type observed from the core is foliated granitic gneiss with pegmatite veins of varying thickness. The foliation is dipping approximately $45^0$ towards North-East (NE). Most of the observed joints are along the foliation plane. A few random joints are also observed. Very fractured rock is observed at five locations along the core with a length ranging from 0.2 – 0.3 m.

53.21m

57.58m

57.58m

62.77m

62.77m

67.37m

**Figure 8.** Core boxes showing the core recovered from the borehole in the study area.

## 4. Results and Discussion

Rock mass is often composed of complex network of discontinuities and it is very difficult to characterize every discontinuity. To make this process easy, joints with parallel or nearly parallel orientation are counted as a single joint set [21]. However, the joints in a single set are not exactly parallel [22, 23]. Thus, a careful estimation of joint orientation is necessary to characterize a jointed rock mass for engineering design. The rock mass strength varies with the orientation of discontinuities intersecting the mass and the level of confinement. When the confinement direction is normal to the discontinuity plan, it is considered a favorable condition particularly during excavation. A number of previous studies have been conducted, showing the variation of rock mass strength against discontinuity orientation, among these Jaeger [10], [24] presented models for sliding plane of weakness. It has been observed that the influence of discontinuity orientation on rock mass strength decreases with the increase in confining pressure [25]. However, the strength of intact rock, joint persistence, roughness, interconnectivity and nature of infilling material (which is the focus of this study) play an equal role in rock mass strength variation apart from confining stress.

The two approaches used in this study i.e., scanline survey of rock exposures and borehole method, presents an opportunity to select appropriate method for appraisal of geometrical properties of discontinuities, keeping in view the objective of the investigation program. The scanline survey in this study is carried out inside an exploratory adit, that is why it presents reasonably good results as compared to borehole method. If the scanline is carried out on rock exposures at the ground surface, then the uncertainty level will be high as compared to borehole method.

The persistence of discontinuities plays the leading role and all the rest of geometrical properties are dependent on it. If the persistence of discontinuities is not measured accurately all the other properties will be questionable. Most of the models that simulate fractured rock masses assume fully persistent discontinuities, simplifying the fact that, in nature, fractured rock masses are made of non-continuous sets of joints [1]. Accurate measurement of discontinuity persistence is subject to extent of rock exposure. A rock bridge which is often ignored during persistence measurement can give an effective cohesion to the fracture and a block of rock cannot fall or slide until all the rock bridges fail [1].

Discontinuity persistence can affect the stability of structures i.e., it defines the dimensions and areal extent of a discontinuity. It is a crude measure of the penetration length of a fracture in rock mass [26]. It cannot be measured by using borehole data, unless the boreholes are very closely spaced. However, scanline or outcrop mapping method is good to analyze relatively large volume of rock mass and discontinuity characteristics can be directly measured. In this method 2-dimentional characteristics of discontinuities can be observed unless the rock face is not damaged. However, the rock exposures in the exploratory adit are damaged mainly due to blasting. Many induced fractures observed in the adit are oriented parallel to the foliation direction. It gives the idea of expected pattern of joints during construction.

## 5. Conclusions

From the analysis of the discontinuity data obtained from borehole method and scanline survey of rock exposures in an adit, the following conclusions are drawn:

- The number of discontinuities intersected by a scanline or borehole is directly affected by their orientation. Joints parallel to the scanline or borehole axis are not recorded which is a drawback of both methods.
- The persistence of discontinuities is highly dependent on the extent of rock exposure. Persistence measurement from borehole method is a poor representation of real case.
- The borehole data can provide a reasonable estimate of the orientation of discontinuities in cases where the rock mass is bedded or foliated, or the boreholes are closely spaced.
- From a practical engineering perspective, joints generated during the excavation operation are considered in stability analysis and support design. On the other hand, these new joints cannot be forecasted when borehole data is used for estimating the rock mass behavior and support requirements. In such a situation a test adit can reveal more information regarding the behavior of rock mass.
- The borehole coring method is good for a general estimate of rock type, locating geological structures and sample collection for laboratory testing. However, for stability analysis and estimating support requirements for tunnels, this method must be assisted by other exploratory technique.

## 6. References

[1] Kim B, Kaiser P and Grasselli G 2007 Influence of persistence on behaviour of fractured rock masses *Geological Society, London, Special Publications* **284** 161-73
[2] Barnes R, Dee S, Sanderson D and Bowden R 1998 Interpretation of structural domains in discontinuity data from Nirex deep boreholes at Sellafield *Proceedings of the Yorkshire Geological Society* **52** 177-87
[3] Gillespie M, Barnes R and Milodowski A 2011 *British Geological Survey scheme for classifying discontinuities and fillings*: British Geological Survey)
[4] Hoek E 1964 Fracture of anisotropic rock *Journal of the South African Institute of Mining and Metallurgy* **64** 501-23
[5] Ulusay R and Gokceoglu C 1997 The modified block punch index test *Canadian Geotechnical Journal* **34** 991-1001
[6] Özbek A and Gül M 2015 The geotechnical evaluation of sandstone–claystone alternations based on geological strength index *Arabian Journal of Geosciences* **8** 5257-68

[7] Cho J-W, Kim H, Jeon S and Min K-B 2012 Deformation and strength anisotropy of Asan gneiss, Boryeong shale, and Yeoncheon schist *International Journal of Rock Mechanics and Mining Sciences* 158-69
[8] Kim H, Cho J-W, Song I and Min K-B 2012 Anisotropy of elastic moduli, P-wave velocities, and thermal conductivities of Asan Gneiss, Boryeong Shale, and Yeoncheon Schist in Korea *Engineering Geology* **147** 68-77
[9] Piyal W P L and Konietzky H 2016 Geometrical properties of rock joints and their effects on rock mechanical behaviour. Retrieved)
[10] Jaeger J 1959 The frictional properties of joints in rock *Geofisica pura e applicata* **43** 148-58
[11] Park H and West T 2002 Sampling bias of discontinuity orientation caused by linear sampling technique *Engineering Geology* **66** 99-110
[12] Zhang Q, Wang Q, Chen J, Li Y and Ruan Y 2016 Estimation of mean trace length by setting scanlines in rectangular sampling window *International Journal of Rock Mechanics and Mining Sciences* 74-9
[13] Watkins H, Bond C E, Healy D and Butler R W 2015 Appraisal of fracture sampling methods and a new workflow to characterise heterogeneous fracture networks at outcrop *Journal of Structural Geology* **72** 67-82
[14] Priest S D 1993 *Rock Testing and Site Characterization*: Elsevier) pp 167-92
[15] WAPDA 2012 Geological and geotechnical assessment.
[16] Ramamurthy T, Rao G V and Singh J 1993 Engineering behaviour of phyllites *Engineering Geology* **33** 209-25
[17] Saeidi O, Vaneghi R G, Rasouli V and Gholami R 2013 A modified empirical criterion for strength of transversely anisotropic rocks with metamorphic origin *Bulletin of Engineering Geology and the Environment* **72** 257-69
[18] Hoek E and Brown E T 1997 Practical estimates of rock mass strength *International journal of rock mechanics and mining sciences* **34** 1165-86
[19] Park H-J, West T R and Woo I 2005 Probabilistic analysis of rock slope stability and random properties of discontinuity parameters, Interstate Highway 40, Western North Carolina, USA *Engineering Geology* **79** 230-50
[20] Priest S and Hudson J 1981 Estimation of discontinuity spacing and trace length using scanline surveys. In: *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*: Elsevier) pp 183-97
[21] Hodgson R A 1961 Classification of structures on joint surfaces *American journal of science* **259** 493-502
[22] Dyer R 1988 Using joint interactions to estimate paleostress ratios *Journal of Structural Geology* **10** 685-99
[23] Rives T, Razack M, Petit J-P and Rawnsley K 1992 Joint spacing: analogue and numerical simulations *Journal of Structural Geology* **14** 925-37
[24] Jaeger J, Cook N and Zimmerman R 2007 Fundamentals of Rock Mechanics, 4th edn., volume ISBN: 9780632057597, ISBN10: 0632057599. Blackwell Publishing)
[25] Ramamurthy T and Arora V 1994 Strength predictions for jointed rocks in confined and unconfined states
[26] Singhal B and Gupta R 2010 *Applied Hydrogeology of Fractured Rocks*: Springer) pp 13-33