Stochastic Fracture Characterization for a Tunnel site in Southern California

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1. Introduction

The San Bernardino Mountains Segment consists of two tunnels with a combined length of 15.7 km through the San Bernardino Mountains, California. This tunnel will be excavated through a variety of ground conditions ranging from completely weathered rock near the portals to hard and strong igneous and metamorphic rocks in the mountains. Rock types include metamorphic rocks (gneiss with lesser amounts of schist and marble), granitic rocks (quartz monzonite and quartz diorite) and conglomeratic sandstone. The fracture network of the rock mass around the tunnel plays a very important role related to the tunnel excavation and construction. This paper focuses on the fracture characterization performed for the gneissic rock mass of the tunnel site. The fracture data for the gneissic rock mass were collected from scanlines placed on inclined surface outcrops. A total of 16 scanlines (LS7 – LS22), from the gneissic rock mass were used to conduct the fracture mapping for the gneissic rock mass of the tunnel site. A total of 859 fractures were mapped from these scanlines. The fracture data were analyzed: (a) to determine the number of fracture sets and their orientation distributions; (b) to study the effect of orientation sampling bias on the orientation distribution of fracture sets; (c) to estimate the spacing distribution along the mean normal vector direction of each of the fracture sets; (d) to predict the one-dimensional fracture frequency along the tunnel axis direction; and (f) to estimate the three dimensional fracture frequency parameters such as the block size, number of blocks per unit volume and number of fractures per unit volume. The obtained results are given in this paper including appropriate discussions and conclusions.

2. Analyses, Results and Conclusions

The fracture data were analyzed according to the clustering algorithm of Shanley and Mahtab (1976) and Mahtab and Yegulalp (1984) to find the dense points and the resulting fracture sets. Even though this methodology suggests a procedure for finding the optimum number of fracture sets using three objective functions, for the analyzed data, it was not possible to find a unique number for the optimum number of fracture sets only from the results of this procedure. Four fracture sets (3 sub-vertical joint sets and one flat lying foliation set) were found to exist in the gneissic rock mass. All fracture set distributions exhibit high variability. Table 1 shows the summary of fracture delineation results obtained

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for the gneissic rock mass based on the scanline data. Both the hemispherical normal and Bingham distributions were found to be unsuitable to represent the statistical distribution of orientation for most of the fracture sets. This means that if one wants to generate orientation data accurately for any of the fracture sets, then it is necessary to use the empirical distribution obtained for the orientation based on the corrected relative frequencies.

Table 1. Summary of fracture set delineation results for the gneissic rock mass.

Fracture set number	Number of fractures	Mean orientation	
		Dip direction (deg.)	Dip angle (deg.)
1	89	294	82
2	411	225	85
3	218	160	81
4	141	327	14

Goodness-of-fit tests were performed to find the suitable probability distributions as well as the best probability distribution to represent the statistical distribution of spacing for each fracture set obtained from each line survey. The probability distributions, gamma, exponential and lognormal were found to be highly suitable to represent the distribution of spacing of fracture sets. From the fracture set delineation analysis, the mean normal vector direction is known, for each fracture set. This information was used to calculate the mean 1-D frequency along the mean vector direction for each fracture set. The one-dimensional (1-D) fracture frequency of the rock mass in all directions in 3-D was calculated and is presented in terms of a stereographic plot (Fig. 1). The 1-D fracture frequency along the tunnel alignment direction (trend = 340° and plunge = 0°) was predicted to be about 6.5 fractures/m. This prediction was found to be accurate compared to the observed value obtained about one year later during the tunnel construction.

The spacing distributions obtained along the mean normal vector directions for regional fracture sets were used along with the orientation distributions of the fracture sets in generating rock blocks in 3-D using the Monte-Carlo simulation procedure. Orientations for the fracture sets were generated according to the obtained empirical orientation distributions. When spacing values are generated from a certain distribution, irrespective of the distribution, a certain proportion of small values are produced. Because the block volume is proportional to the third power of spacing, even moderate spacing values can produce extremely small block volume values. These extremely small block volumes can produce extremely large values for the parameter number of blocks per unit volume because this parameter is inversely proportional to the block volume. These extremely high values can totally distort the mean and standard deviation estimations obtained for the parameter number of blocks per unit volume. By the same token, extremely high spacing values generated through probability distributions, can give rise to large block volumes and small values for the parameter number of blocks per unit volume. These extreme values can also distort the estimations obtained for the mean and standard deviation. Therefore, it is reasonable to calculate the mean and standard deviation by removing these low and high extreme values from the distributions. Such estimations are termed as trimmed values. Trimming can be done at different percentage levels. The following values are suggested as most likely values for the 3-D fracture frequency parameters: (a) mean volume of equivalent matrix block = 0.03 – 0.06 m^3, (b) mean number of matrix blocks per unit volume = 16.7 – 28.6 blocks/m^3, (c) number of fracture centers per unit volume = 11.8 /m^3

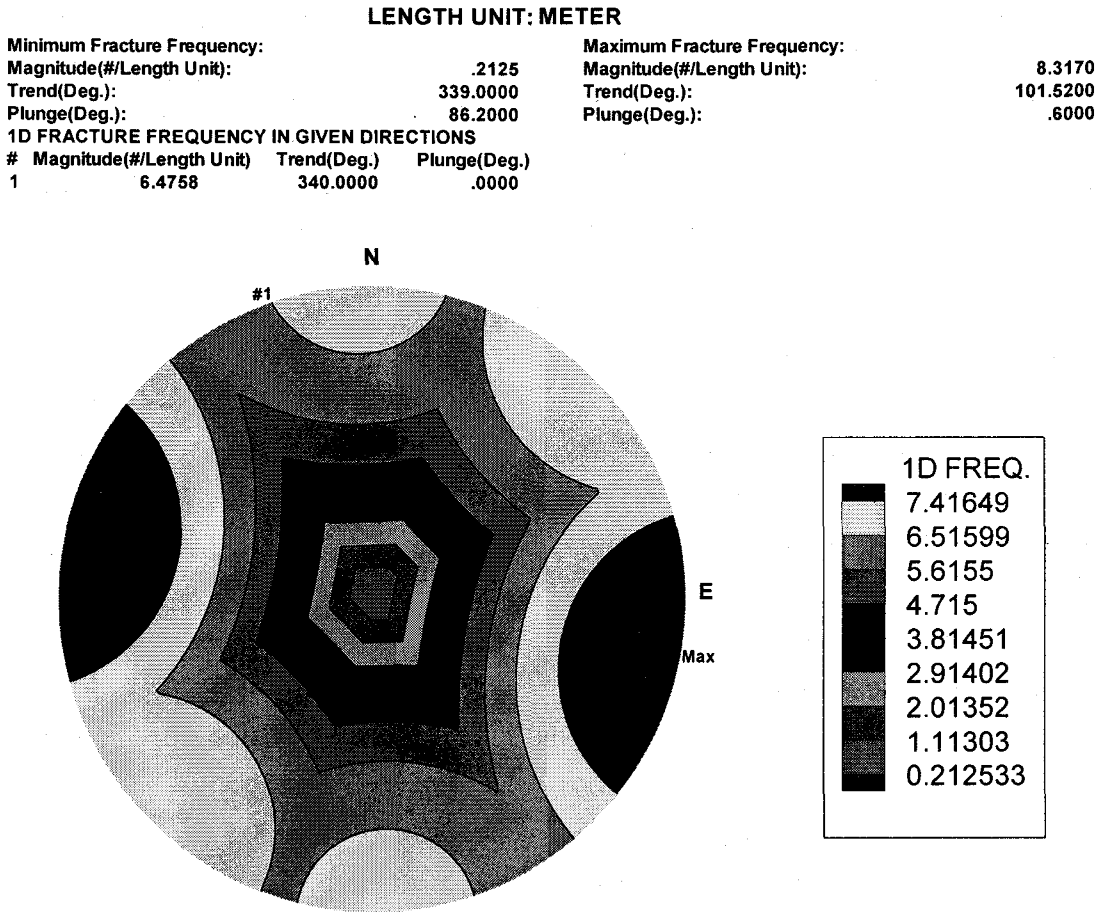

Fig. 1. 1-D fracture frequency distribution in 3-D space for the gneissic rock mass on an upper hemispherical equal angle equatorial projection using the fracture data of LS-22 scanline.

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