Site specific joint spacing distribution of roadcut slopes in a selected stretch of national highway in Indian Garhwal Himalayas

Lal Hruaikima
Indian Institute of Technology Roorkee, India

Mahendra Singh
Indian Institute of Technology Roorkee, India

Sarada Prasad Pradhan
Indian Institute of Technology Roorkee, India

Jaspreet Singh
Simon Fraser University, Burnaby, BC, Canada

ABSTRACT: Due to extensive road widening project in the Himalayas, the roads experience huge instability problems especially during monsoon season. For the present study, 50 rock slope sites were considered over a stretch of 35 km on a national highway. The various attributes of discontinuities governing the slope failure were observed and the joint spacing in the stretch of the national highway is studied in detail. Detailed scanline survey was carried out and a database comprising more than about 6000 datapoints was generated. It is observed that the joints are spaced between 1 cm to 60 cm for the stretch of road. Statistical analysis of the joint spacing shows that most of the joint sets follow Exponential distribution, Weibull distribution, and lognormal distribution. Slope stability analysis was performed using the joint spacing data for all the slopes. It was observed that 50% of the slopes were susceptible to failure.

Keywords: Discontinuities, Joint Spacing, Probability Distribution, Slope Stability.

1 INTRODUCTION

Engineering designs for rock slopes sometimes include discontinuities as a source of uncertainty and variable. The strength and geometric characteristics of the discontinuities are liable to change inside a rock slope, which is frequently observed in difficult and challenging terrains such as hilly regions (Basahel & Mitri, 2019). Spacing of discontinuities is one of the indispensable parameters of rock slopes which is used to determine the block size, the hydrogeological permeability, deformability, and strength of the rock masses (Wong et al., 2018).

Joint spacing in rocks have been studied by a number of researchers, and have reported to follow the Lognormal Distribution (Becker & Gross, 1996; Pascal et al., 1997; Wong et al., 2018), the Gamma Distributions (Castaing et al., 1996; Gross, 1993), the Negative Exponential Distribution (Hudson & Priest, 1983; Priest & Hudson, 1976, 1981), the Weibull Distribution (Wong et al., 2018) and the Normal Distribution (Ji & Saruwatari, 1998).

In the present study, 50 different rock slope sites were considered over a stretch of 35 km on a national highway. Detailed scanline survey was done to assess the spacing of the joints and a database which comprises of more than 6000 joints were generated.

2 STUDY AREA

The study area (Figure 1) covers a stretch of more than 35 km along a national highway in Garhwal Himalayas. The route is a backbone for the social and economic growth of the town and villages in the region. The route has witnessed an increase in the frequency of landslides especially during the monsoon season which become a source of concern and therefore requires urgent attention. Geologically, the study area comprises of various meta-sedimentary rocks of Proterozoic age (Jiang et al., 2003; Siddique et al., 2020; Tiwari et al., 2013) and lies roughly in the north-western flank of doubly plunging syncline, and the road section is also dissected by thrust faults (Kumar & Dhaundiyal, 1979). The area is highly vulnerable to landslides due to adverse geo-structural paradigm.

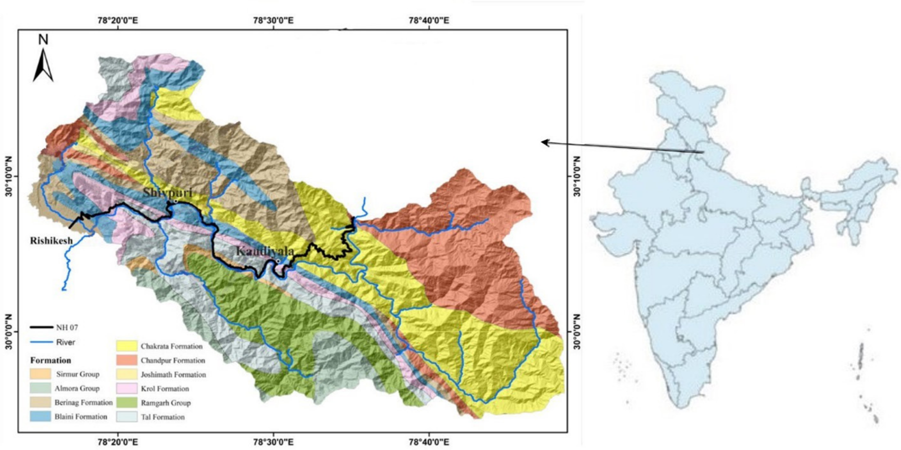


Figure 1. Geological map of the study area (modified after Valdiya, 1984).

3 METHODOLOGY

3.1 Field observations

Fifty rock slopes from different locations were selected along the highway and detailed observations were made. Scanline survey technique is adopted to gather the joint spacing data (Figure 2). The properties include the intersection distance, the orientation, semi-trace length, termination, roughness, and curvature were obtained from the scanline survey.

For the purpose of uniformity, a minimum spacing of 0.5 cm is taken in the study and the random joints which has an intersection distance of less than the set minimum is neglected. The width of the outcrop is selected based on the accessibility of the rock slopes. At least 15 m length of the scanline was selected for each rock slopes.

3.2 Analysis of joint spacing

From the scanline survey data, the normal spacing of the joints were calculated as per the methods described by Priest (1993). Statistical parameters of the spacing for each joint set are evaluated, and the probability distribution function for each discontinuity sets were determined, from approximately 100 joint set data from each site, which results in a database comprising of nearly 6000 joint spacing data.

From the result of the spacing analysis, Anderson-Darling test (Stephens, 1974) was done on the normal spacing for each joint sets to determine the statistical distribution of the joint spacing. p-value, which is an indicator of the hypothesis testing, are calculated to test different distribution. A level of significance of 0.05 is set for each p-value. When the p-value of the tested model is higher than the given level of significance, then the model can be statistically accepted.

Figure 2. Scanline survey done on Slope 1.

3.3 *Stability analysis of rock slopes*

The rock slopes were analysed as a combined continuum interface method. Two different approaches were adopted in the analysis. In the first approach, the joint spacing was considered to be deterministic, parallel to each other, and persistent. The materials are modelled using a Mohr-Coulomb failure criterion. The parameters used in the analysis are shown in Table 1.

Table 1. Parameter used for Slope Stability Analysis (Slope 1).

Parameters	Value	Parameters	Value
Rock type	Quartzite	Joint normal stiffness, J1 (GPa/m)	1.52
Unit weight (kN/m3)	27	Joint shear stiffness, J1 (GPa/m)	0.152
Elastic modulus (GPa)	3.85	Joint normal stiffness, J2 (GPa/m)	1.38
Poisson's ratio	0.3	Joint shear stiffness, J2 (GPa/m)	0.138
c_i (MPa)	5.8	Joint normal stiffness, J3 (GPa/m)	1.38
φ_i (Degree)	35	Joint shear stiffness, J3 (GPa/m)	0.138
Tensile strength	0		
Barton-Bandis shear strength parameters			
Joint cohesion J1 (kPa)	0	Joint Friction Angle J2 (Degree)	55.32
Joint Friction Angle J1 (Degree)	44.09	Joint Cohesion J3 (kPa)	0
Joint Cohesion J2 (kPa)	0	Joint Friction Angle J3 (Degree)	48.7

In the second approach, the influence of random variable on the stability of rock slopes were studied. In this method, the input parameters were subdivided into two groups based on their randomness: deterministic and probabilistic parameters. For the analysis, the orientation and height of the slopes as well as the shear strength parameters are deterministic. Based on the measured data in the field, tests results and physical properties of the materials, the probability density function and the statistical parameters for the analysis were chosen. The random parameters chosen for the analysis include the joint orientation and spacing of discontinuities.

4 RESULTS

4.1 *Joint Spacing Analysis*

From the analysis of joint spacing, it was observed that the joints have a spacing ranging from 1 cm to 60 cm with the mean spacing for each joint sets ranging between 3.07 cm to 44.25 cm.

Statistical analysis of the joint spacing for each joint set reveal that more than half of the joint spacings are following the Exponential Distribution, followed by the Weibull distribution and a few of the joint spacings are following the Lognormal Distribution. Figure 3 shows the summary of the statistical analysis. Figure 4 shows the statistical distribution of the joint spacing for Slope 1.

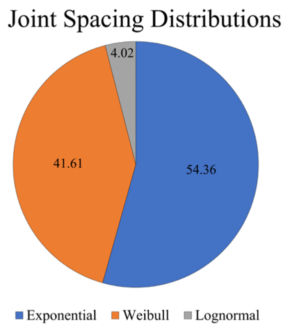


Figure 3. Pie chart showing the Joint Spacing Distribution observed from analysis.

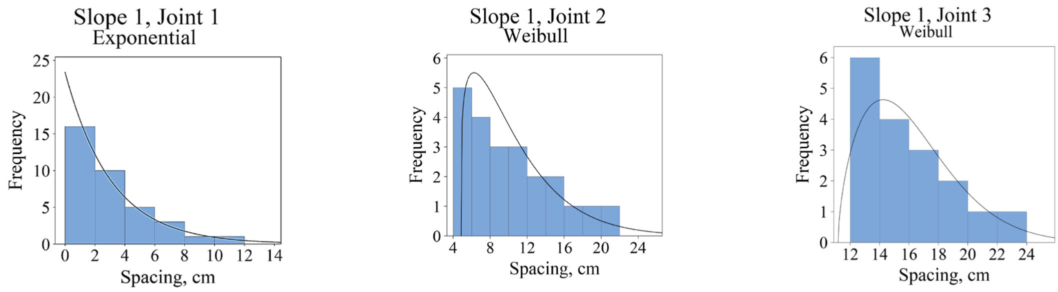


Figure 4. Histogram showing the Joint Spacing Distribution for each joint set (Slope 1).

4.2 *Analysis of Orientation Data and Kinematic Analysis*

The orientation data obtained from scanline survey are plotted on a stereonet and a clustering is done to determine the number of joints sets in the field. The plotting is done using Dips software and the representative dip and dip direction for each slope are determined from the stereographic projection.

Kinematic instability in rock slopes is highly influenced by the orientation of the joint. In the present study, kinematic analysis is done using stereographic projection to determine the possibility of structurally controlled instability in the rock slopes. The result of Kinematic analysis for Slope 1 is given in Figure 5. It was observed that from the 50 slopes analyzed, 32 slopes are susceptible to planar failure, 35 slopes are susceptible to wedge failure and 24 slopes are susceptible to toppling failure.

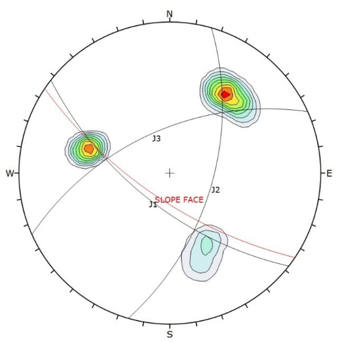
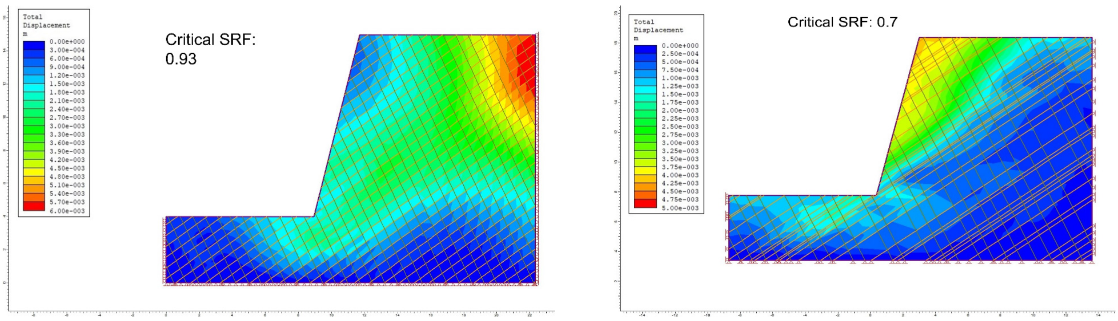


Figure 5. Stereographic projection for Slope 1.

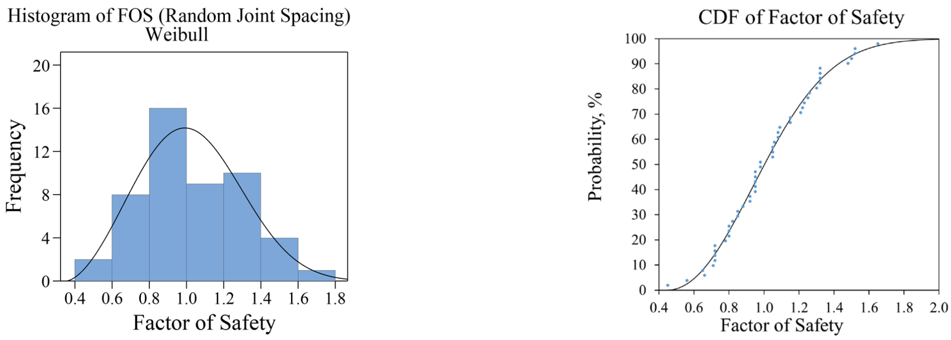
4.3 Stability Analysis of Slope

The rock slopes were modelled as a combined continuum interface method. The model was discretized using a 3-noded triangular element and Shear strength reduction analysis was performed using RS2 for each section to determine the critical SRF. The slopes were first analysed by using a deterministic value of joint spacing. In the second analysis, the joint spacing were randomized using the data obtained from the statistical analysis of the joint spacing to study the effect of random joint spacing on the stability of the slopes. The results of the analysis for slope no 1 is shown in Figure 6.



(a) Deterministic Joint Spacing (b) Random Joint Spacing

Figure 6. Result of Slope Stability Analysis (Slope 1).



(a) (b)

Figure 7. Statistical Analysis showing (a) Probability Density Distribution and (b) Cumulative Distribution of FOS (Random Joint Spacing).

The SRF obtained from the slope stability analysis were statistically analyzed and it was observed that the critical SRF of the slopes are following the Weibull Distribution (Figure 7). From the CDF of the critical SRF, it can be observed that 50% of the slopes are in critical condition, which agrees with the conditions of slopes observed in the field.

5 CONCLUSION

Fifty rock slopes along a national highway in Garhwal Himalayas were surveyed and the spacing of the joints were analysed. Statistical analysis of the joint spacing data shows that the joints are following either the Exponential Distribution, the Weibull Distribution or the Lognormal Distribution. These results were in accordance with those given in the literature. The result of the stability analysis shows a decrease in the Factor of Safety of the slope when the random distribution of the joint spacing are considered. Statistical analysis suggest that the Factor of Safety follows the Weibull Distribution. Cumulative Distribution Curve drawn from the result of the statistical analysis shows that nearly 50% of the slopes are susceptible to failure. This observation is in accordance with the observation made on the slope in during the survey.

REFERENCES

Basahel, H., & Mitri, H. (2019). Probabilistic assessment of rock slopes stability using the response surface approach – A case study. *International Journal of Mining Science and Technology*, *29*(3), 357–370. https://doi.org/10.1016/j.ijmst.2018.11.002

Becker, A., & Gross, M. R. (1996). Mechanism for joint saturation in mechanically layered rocks: an example from southern Israel. In *Tectonophysics* (Vol. 257).

Castaing, C., Halawani, M. A., Gervais, F., Chilès, J. P., Genter, A., Bourgine, B., Ouillon, G., Brosse, J. M., Martin, P., Genna, A., & Janjou, D. (1996). Scaling relationships in intraplate fracture systems related to Red Sea rifting. *Tectonophysics*, *261*(4), 291–314. https://doi.org/10.1016/0040-1951(95)00177-8

Gross, M. R. (1993). The origin and spacing of cross joints: examples from the Monterey Formation, Santa Barbara Coastline, California. *Journal of Structural Geology*, *15*(6), 737–751. https://doi.org/10.1016/0191-8141(93)90059-J

Hudson, J. A., & Priest, S. D. (1983). Discontinuity frequency in rock masses. *International Journal of Rock Mechanics and Mining Sciences And*, *20*(2), 73–89. https://doi.org/10.1016/0148-9062(83)90329-7

Ji, S., & Saruwatari, K. (1998). A revised model for the relationship between joint spacing and layer thickness. *Journal of Structural Geology*, *20*(11), 1495–1508. https://doi.org/10.1016/S0191-8141(98)00042-X

Jiang, G., Christie-Blick, N., Kaufman, A. J., Banerjee, D. M., & Rai, V. (2003). Carbonate platform growth and cyclicity at a terminal Proterozoic passive margin, Infra Krol Formation and Krol Group, Lesser Himalaya, India. *Sedimentology*, *50*(5), 921–952. https://doi.org/10.1046/j.1365-3091.2003.00589.x

Kumar, G., & Dhaundiyal, J. N. (1979). Stratigraphy and structure of Garhwal Synform, Garhwal and Tehri Garhwal districts, Uttar Pradesh; a reappraisal. *Himalayan Geology*, *9*(1), 18–41. https://eurekamag.com/research/018/309/018309129.php

Pascal, C., Angelier, J., & Hancock, P. L. (1997). Distribution of joints: probabilistic modelling and case study near Cardiff (Wales, U.K.). In *Journal of Structural Geology* (Vol. 19, Issue 10).

Priest, S. D. (1993). Discontinuity Analysis for Rock Engineering. In *Discontinuity Analysis for Rock Engineering*. Springer Netherlands. https://doi.org/10.1007/978-94-011-1498-1

Priest, S. D., & Hudson, J. A. (1976). Discontinuity spacings in rock. *International Journal of Rock Mechanics and Mining Sciences And*. https://doi.org/10.1016/0148-9062(76)90818-4

Priest, S. D., & Hudson, J. A. (1981). Estimation of discontinuity spacing and trace length using scanline surveys. *International Journal of Rock Mechanics and Mining Sciences And*, *18*(3), 183–197. https://doi.org/10.1016/0148-9062(81)90973-6

Siddique, T., Pradhan, S. P., Vishal, V., & Singh, T. N. (2020). Applicability of Q-slope Method in the Himalayan Road Cut Rock Slopes and Its Comparison with CSMR. *Rock Mechanics and Rock Engineering*, *53*(10), 4509–4522. https://doi.org/10.1007/s00603-020-02176-2

Stephens, M. A. (1974). EDF Statistics for Goodness of Fit and Some Comparisons. *Journal of the American Statistical Association*, *69*(347), 730. https://doi.org/10.2307/2286009

Tiwari, M., Parcha, S. K., Shukla, R., & Joshi, H. (2013). Ichnology of the Early Cambrian Tal Group, Mussoorie Syncline, Lesser Himalaya, India. *Journal of Earth System Science*, *122*, 1467–1475.

Valdiya, K. S. (1984). Evolution of the Himalaya. *Tectonophysics*, *105*(1–4), 229–248. https://doi.org/10.1016/0040-1951(84)90205-1

Wong, L. N. Y., Lai, V. S. K., & Tam, T. P. Y. (2018). Joint spacing distribution of granites in Hong Kong. *Engineering Geology*, *245*(April), 120–129. https://doi.org/10.1016/j.enggeo.2018.08.009