Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Numerical Analysis on Stability Assessment of Left Bank Rock Slopes, Polavaram Irrigation Tunnel

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Abstract. With the increasing trend in the construction of tunnels in the last decade, especially in the mountainous areas and under unsymmetrical stress states in the slopes, these tunnels analysis needs particular attention. This area's rock slope is covered with loose soil and soft rock and is highly vulnerable to tunnel excavation forces. In the present study, slope stability analysis of the rock slope is carried in Finite element software Phase^2. The current research deals with the excavation of a tunnel that leads to a slope destabilization of the surrounding massif. The construction site selected for the study is Polavaram Left bank Irrigation Tunnel located on the Godavari River in the East Godavari District and Visakhapatnam Districts, Andhra Pradesh. Initially, the rock slope is considered devoid of any joints and is modeled as a continuum mass using equivalent Mohr-Coulomb shear strength criteria. In the second model, the tunnel excavation effect introduces in the finite element model. Design of support may be carried for stability of slopes.

Keywords: Rock slope stability; Numerical Modelling; Phase ^{2}; Tunnels

1 Introduction

The evaluation of the stability of slopes becomes essential at the site due to construction activities. When pre-existing geologic features govern the instability like fissures or joints, bedding planes, or faults in rock slopes, the failure will be different cases like plane sliding, wedge sliding, or toppling. A rock slope can fail mostly due to one or a combination of these three mechanisms.

[1] Bolla and Paronuzzi performed geomechanical survey study on a natural rock slope located in Italy. Their study considers the interaction between pre-existing discontinuities internal sub-blocks and evaluates the reason for the collapse of slopes. [2] Basahel and Mitri studied rock mass classification systems to rock slope stability. They use different empirical methods based on their failure mechanism and also their

limitations. [3]Seyed Abolhasan et al. studied the parameters like water level, cohesion, and distance of reinforcements numerically investigated on slope stability by using Plaxis 2D Software. [4]I.S. Buyuksagis studied the effect of Schmidt Hammer type on UCS prediction of rock. [5]Vinod K. Garga and Baolin Wang studied numerical models using block spring models for jointed rock mass. They analyse both end - anchored and fully grouted rock bolts for pre-tensioned or untensioned condition. [6]Latha and Garage studied the seismic slope stability analysis of a 350 m high slope using the equivalent continuum approach and the GHB failure criterion. [7]Pain et al. studied the rock slope's static stability analysis using the finite element method (FEM). [8][9]Griffiths and Lane use the finite element method (FEM) with the strength reduction technique (Matsui and San) to evaluate the factor of safety (FOS) of soil slope. From Literature survey, the design of support is a site specific for slope stability problems.

In this study, Stability of slopes of the Polavaram Left bank irrigation tunnel has analysed. It is a multipurpose project, predominantly a significant irrigation project involving the construction of a Rock Fill Dam, Gated Spillway, Powerhouse, Navigation Lock system, Canal, and Tunnel systems on either bank to provide irrigation for 23.20 lakh acres. The longitudinal section, along with the left bank approach and tunnel exit, is shown in Fig. 1. The site photos at left bank approach are shown in Fig.2. To design support system for stability of slopes.

2 Description of the Study Area

The study area is located on the Godavari River in the East Godavari District of Visakhapatnam Districts, Andhra Pradesh, India. Different field studies were carried out to find structural discontinuities, soil and weathering profile, topographical features and examination of drill cores and core logging. The rock samples were collected for assessing rock mass parameters. This region is covered with thick soil consists of silt, clay and laterite occurs for a depth of 8-20m and weathered zones of Kondalites varies from 3m to 20m. It is observed that a stretch of 600m from the entry portal is of Garnetiferous biotite gneiss (from Ch. 1960 to Ch. 2560) followed by 200m of charnokite (from Ch. 2560 to Ch. 2760) and 150m of Kondalites (from Ch. 2660 to Ch. 2825) across the proposed tunnel alignment. It can be seen that the proposed tunnel alignment falls in massive rock formations and the major rock type are biotite gneiss and Kondalites. The general strike of the above formations is NEE-SWW and dip at 40° to 60° towards NW or SE. Although strike joints, dip joints, oblique joints are common in this area, there are no folds and faults noticed in this area.

3 Material Properties

To perform the stability analysis, the material properties are evaluated from field data report from Polavaram Irrigation tunnel design report from Polavaram Irrigation Project

Head Works (PIPHW) and the lab tests results are used in the numerical simulation. In collection of field data, the joints are measured by using compass and Joint Roughness Coefficient (JRC) is measured based on roughness profiles developed by Barton. [10], [11]Hoek and Brown Failure criterion (1997 & 2002) is used for estimating the rock mass properties from intact uniaxial compressive strength test (σ_c), Geological Strength Index (GSI), Rock Quality Designation (RQD), Intact Modulus (E) and Disturbance factor (D). Samples were collected from the field for conducting Brazilian point load test of the available irregular samples of 50mm dia, and the equivalent sigma C values were calculated as per International Society for Rock Mechanics (ISRM) standards. From Roclab, Hoek- Brown Criterion parameters mb, s and a and Mohr – Coulomb parameters cohesion (c) and angle of internal friction (φ) are evaluated. The results are presented in Table 2 and Fig. 3.

Table 1. Rock Mass Properties

Unit Weight (γ) (kN/m^3)	Elastic Modulus (E) (GPa)	Poisson's ratio (ν)	Cohesion (c) (kPa)	Tension (kPa)	Angle of Internal Friction (φ)	GSI
26	0.11	0.3	1290	337	61	70

Table 2. Intact Rock Properties

Unit Weight (γ) (kN/m^3)	Elastic Modulus (GPa)	Poisson's ratio (ν)	mi	s	a
26	19.93	0.3	23	0.036	0.501

The equation is used in the analysis in FEM analysis is

$$\tau = c + \sigma_n \tan \Phi \tag{1}$$

where, τ is the shear strength of joint, φ is the friction angle, c is the Cohesion and σ_n is the Normal Stress.

The latest version of the Hoek-Brown failure criterion is expressed as the Eqs. (2) - (5)

$$\sigma_1{}' = \sigma_3{}' + \sigma_{ci}\left(m_b \frac{\sigma_3{}'}{\sigma_{ci}} + s\right)^a \tag{2}$$

Where

$$m_b = m_i\, exp\left(\frac{GSI-100}{28-14D}\right) \tag{3}$$

$$s = exp\left(\frac{GSI-100}{9-3D}\right) \tag{4}$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \tag{5}$$

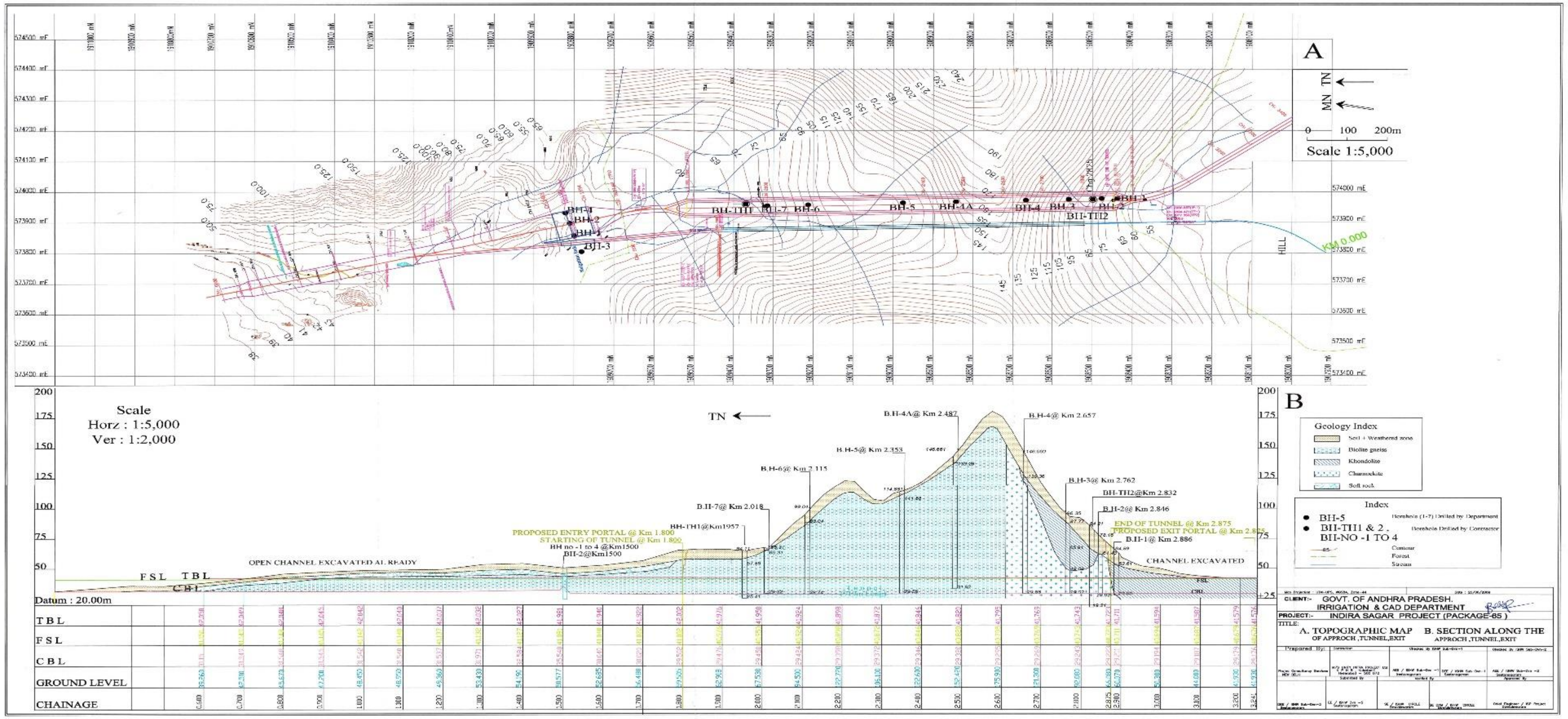

Fig. 1. Longitudinal Section along the approach, tunnel exit

Fig. 2. Site Photos at Approach of left Irrigation tunnel of Polavaram

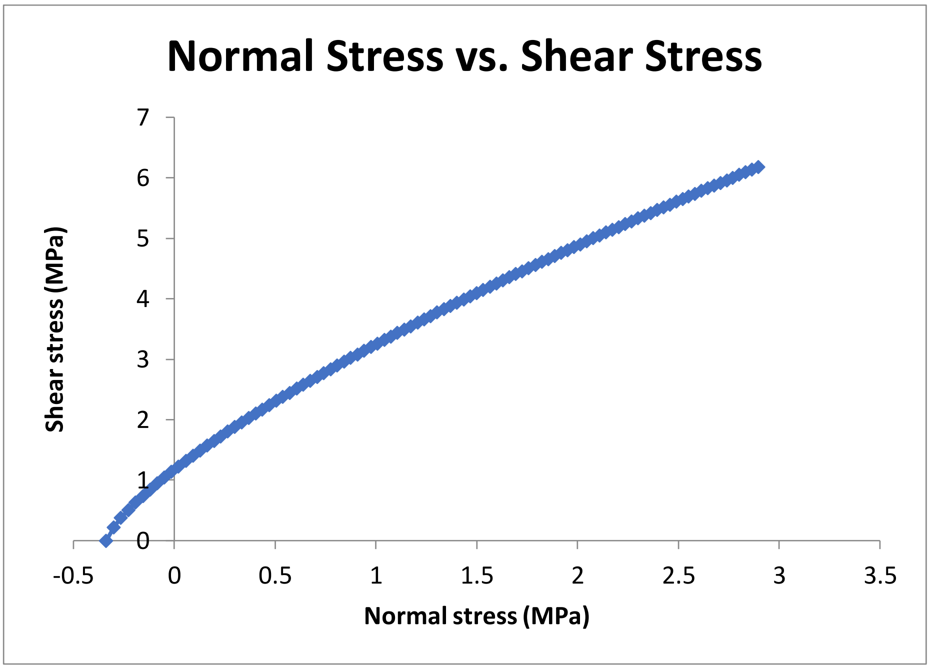

Fig. 3. Normal Stress Vs Shear Stress for rockmass

4 Stability Analysis

The FE model discretized into six-nodded triangular element mesh in $Phase^2$ software. In $Phase^2$ factor of safety is calculated using shear strength reduction method for finding the critical strength reduction factor. The strength of material is reduced by some factor and FE solution is evaluated to obtain the critical SRF. The probabilistic analysis carried using Slide2 and the plot for the factor of safety variation with cohesion and the Angle of Internal friction shown in Figs. 4 and 5.

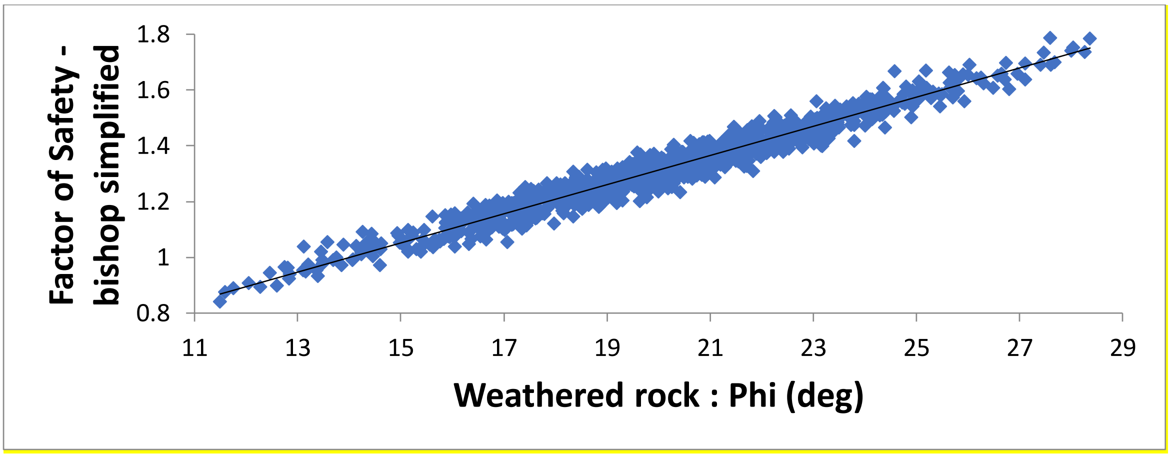

Fig. 4. Factor of safety Vs Phi for weathered rock

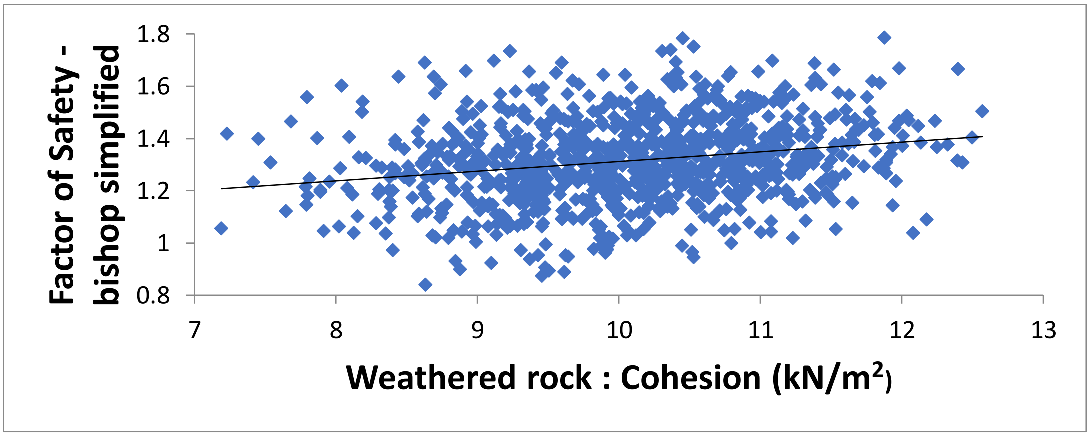

Fig. 5. Factor of safety Vs Cohesion for weathered rock

4.1 Static Stability Analysis

Two- Dimensional plane strain approach used for the stability of rock slope. In this model, the rock slope as a continuum model. The effect of discontinuities considered reducing the properties and strength of intact rock to those of the rock mass. FOS calculated using the Shear Strength Reduction (SSR) method (Matsui and San, 1992).

4.2 Results of Finite Element Analysis

The results from numerical simulation of the rock slopes using a continuum model with and without tunnel effect.

4.2.1 Results of Continuum Analysis

The rock slope is evaluated under gravity using the input parameters. Figure 6 shows the discretized Finite Element (FE) model of the rock slope. The FE model has discretized into a deformable 6 noded triangular plane strain finite element. The stresses vary linearly with depth, and the ratio of the horizontal to vertical stress in the rock mass was equal to 1.0. For a particular mesh resolution, we perform several trials. The most common method for improving the solution convergence is by successively increasing mesh resolution, i.e., increasing the number of elements. The total displacement contour of the continuum FE model in Fig. 7. The factor of safety to be 1.29 in continuum analysis. The total displacement contour of continuum FE model with tunnel interface in Fig. 9. The factor of safety in continuum analysis with tunnel interface is 0.8 due to excavation of tunnel. The total displacement contour of continuum FE model with tunnel interface in Fig. 11. The factor of safety to be 1.64 in continuum analysis with support.

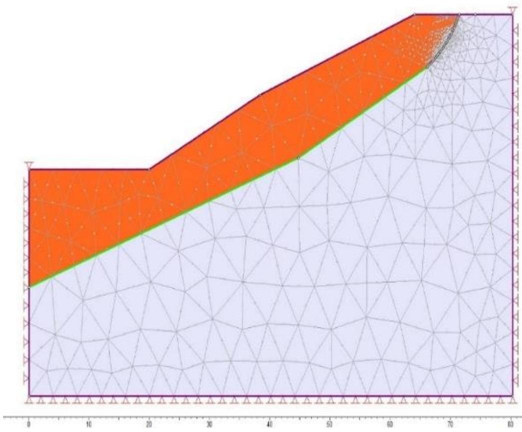

Fig. 6. Discretised FE mesh for Continuum Analysis

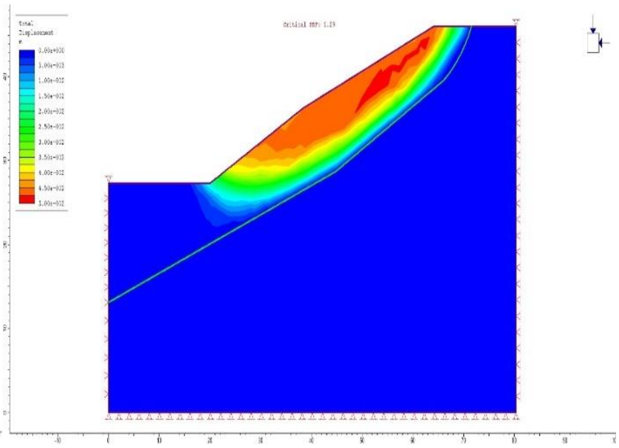

Fig.7. Total displacement contour

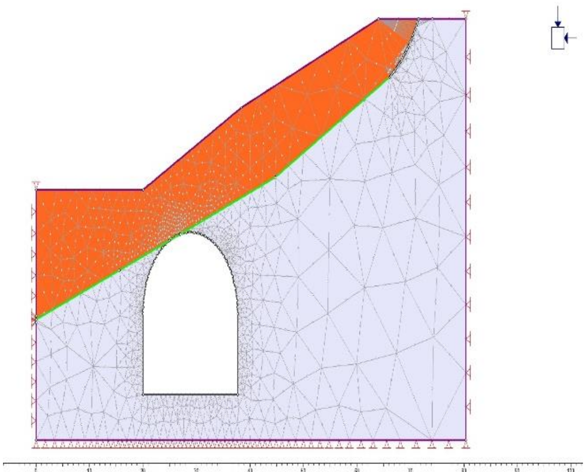

Fig. 8. Rock Slope with tunnel portal

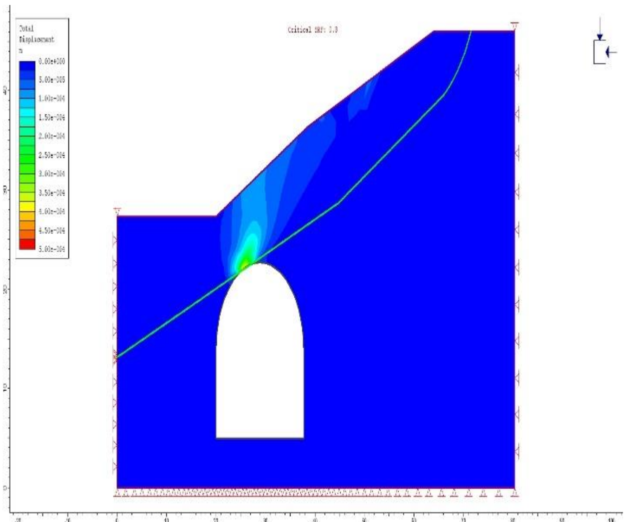

Fig. 9. Displacement Contours

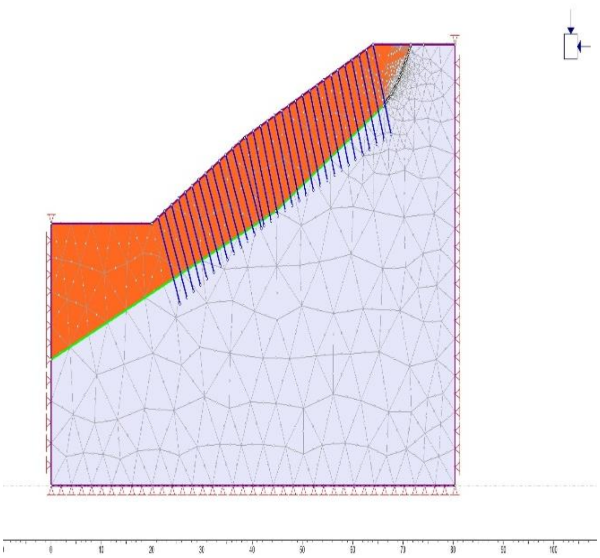

Fig. 10. Rock Slope with Support

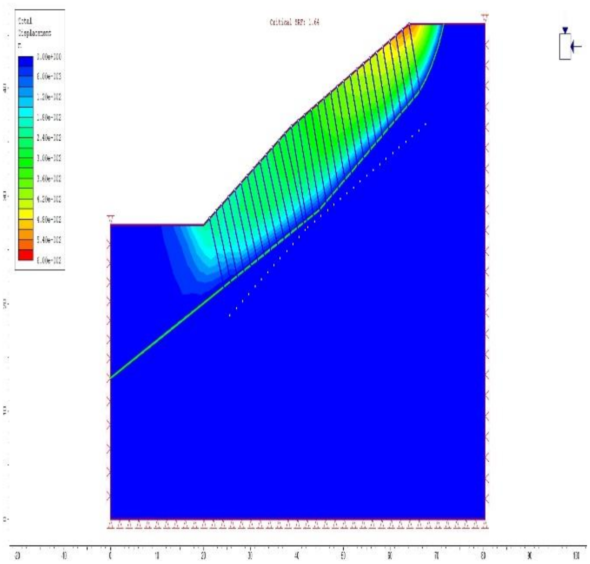

Fig. 11. Displacement Contours

5 Conclusions

A continuum model performed the stability analysis of the rock slope with and without a tunnel using Phase^2. The rock mass in these slopes is blocky or very blocky. From the FE analysis, the following significant conclusions drawn.

1. The critical Strength Reduction Factor (SRF) obtained is 1.29 in model with continuum analysis, and it is decreased further 0.8 in continuum analysis with a tunnel at slope face.
2. The critical SRF is increased from 0.8 to 1.64 with addition of rock bolts of length 10m End anchored and 1.5m spacing and placing normal to the slope face.

Acknowledgement

The Authors are grateful to Superintending Engineer, Deputy Executive Engineer, Assistant Executive Engineer and Junior Engineer of PIPHW Circle, Dowlaiswaram and M/s Max Infra Manager for his kind permission to do work and provide the field data to publish this work.

References

[1] A. Bolla and P. Paronuzzi, "Geomechanical Field Survey to Identify an Unstable Rock Slope: The Passo della Morte Case History (NE Italy)," *Rock Mech. Rock Eng.*, vol. 53, no. 4, 2020, doi: 10.1007/s00603-019-01963-w.

[2] H. Basahel and H. Mitri, "Journal of Rock Mechanics and Geotechnical Engineering Application of rock mass classi fi cation systems to rock slope stability assessment : A case study," *J. Rock Mech. Geotech. Eng.*, vol. 9, no. 6, pp. 993–1009, 2017, doi: 10.1016/j.jrmge.2017.07.007.

[3] S. A. Naeini, N. Gholampoor, and R. R. Kashki, "The Effect of Reinforcement on Stability of Slopes," vol. 3, no. 1, pp. 35–38, 2015.

[4] I. S. Buyuksagis and R. M. Goktan, "The effect of Schmidt hammer type on uniaxial compressive strength prediction of rock," *Int. J. Rock Mech. Min. Sci.*, vol. 44, no. 2, pp. 299–307, 2007, doi: 10.1016/j.ijrmms.2006.07.008.

[5] Baolin Wang and V. K. Garga, "A numerical method for modelling large displacements of jointed rocks. I. Fundamentals," *Can. Geotech. J.*, vol. 30, no. 1, pp. 96–108, 1993, doi: 10.1139/t93-009.

[6] G. M. Latha and A. Garaga, "Seismic stability analysis of a himalayan rock slope," *Rock Mech. Rock Eng.*, vol. 43, no. 6, pp. 831–843, 2010, doi: 10.1007/s00603-010-0088-3.

[7] A. Pain, D. P. Kanungo, and S. Sarkar, "Rock slope stability assessment using finite element based modelling - examples from the Indian Himalayas," *Geomechanics and Geoengineering*, vol. 9, no. 3. pp. 215–230, 2014, doi: 10.1080/17486025.2014.883465.

[8] D. V. GRIFFITHS and P.A.LANE, "Slope stability analysis by ® nite elements," *GeÂotechnique*, vol. 49, no. 3, pp. 387–403, 2013.

[9] T. Oikawa, "NII-Electronic Library Service," *Chem. Pharm. Bull.*, no. 43, p. 2091, 2002, [Online]. Available:http://www.mendeley.com/research/geology-volcanic-history-eruptive-style-yakedake-volcano-group-central-japan/.

[10] E. Hoek and E. T. Brown, "Practical estimates of rock mass strength," *Int. J. Rock Mech. Min. Sci.*, vol. 34, no. 8, pp. 1165–1186, 1997, doi: 10.1016/S1365-1609(97)80069-X.

[11] E. Eberhardt, "The Hoek-Brown failure criterion," *Rock Mech. Rock Eng.*, vol. 45, no. 6, pp. 981–988, 2012, doi: 10.1007/s00603-012-0276-4.

[12] E. Hoek and J.W. Bray: Rock Slope Engineering. Third Edition, Taylor & Francis, London (1981).

[13] PHASE^2: A 2D finite element program for calculating stresses and estimating support around the underground excavations. Geomechanics Software and Research. Toronto, ON: Rocscience Inc (2012).