Review Paper:

Application of Laubscher MRMR classification system in the design of open-pit chromite mines – A case study

Kumar Dinesh[1*], Avchar Akhil[2], Modak Kunal[3] and Kushwaha Abhishek Kumar[4]
1. Dept. of Geology, Patna Science College (PU), Patna, INDIA
2. Dept. of Mining Engineering, National Institute of Technology, Karnataka, Surathkal, INDIA
3. Borehole Geophysics Research Laboratory, Ministry of Earth Sciences, Karad, Maharashtra, INDIA
4. Geological & Geotechnical Dept., THDC India Limited, Uttarakhand, INDIA
*dineshkumar@pup.ac.in

Abstract

The study work was conducted at the Boula Chromite Mine site, focusing on geotechnical field observations in and around the area. The investigation aimed to comprehensively analyze surface and underground conditions, structural features, rock mass conditions and slope stability. The stereo net plot method was employed for slope stability analysis. Slope failures in rock masses were observed at the mine site at a few locations, prompting us to delve into understanding the events and proposing precise recommendations for safe and efficient mining practices. The analysis of results formed the core objective of this study. To achieve the stated goal, a rational and systematic study in the field was conducted. This encompassed examining the geological and structural setup of rock formations, conducting field investigations to asses various geotechnical parameters, identifying the most influential factors affecting rock mass behavior, categorizing rock masses into groups based on similar behavior (rock mass classes), gathering structural data on slopes, classifying rock mass conditions using Laubscher's rock mass classification and determining failure modes (planar, wedge, toppling and circular) in rock slopes through graphical analysis.

The comprehensive rock mass classification and failure analysis were compiled in this work. The findings are crucial for identifying and thoroughly analyzing potential risks. This knowledge can play a pivotal role in ensuring the safety and efficiency of mining operations in and around the Boula Chromite Mine site. Moreover, the knowledge acquired from the study can be instrumental in planning and opening pit projects with similar geotechnical and mining conditions. The study thus provides valuable information for the broader field and contributes to the overall advancement of safe and effective mining practices.

Keywords: Rock mass classification (RMR), mining rock mass rating (MRMR) classification system, stereo net, pit design.

Introduction

Chromite is one of the most important resources in Orissa. It is the only economically viable ore made of chromium. The deposits of chromite in Orissa are estimated to be around 183 million tons. The mining belts of Sukinda, Baula and Nuasahi are mostly found near Jajpur, Keonjhar and Dhenkanal districts. Orissa is home to 95% of the country's chromite deposits, 92% nickel deposits, 69% cobalt deposits, 55% bauxite deposits, 51% titanic magnetite deposits, 40% limestone deposits, 36% pyrophillite deposits, 33% hematite deposits, 26% sillimanite deposits, 25% fireclay deposits, garnet deposits, 24% coal deposits, zircon deposits and 20% vanadium resources as per Ministry of Mines 2010[17]. The strategic importance of the chromite reserves in Odisha's Sukinda valley in India is centered on their crucial role in advancing ferro-alloy industries[7].

Approximately 90% of India's chromite ore production comes from two vital chromite-rich areas: the Baula-Nuasahi belt and the Sukinda valley ultramafic complex deposit. At the Baula chromite mine, the host rocks and ore body are notably tough and dense, displaying structural imperfections like joints, faults and dykes[9,10]. Once surface mining extracts chromite ore to a profitable depth, underground mining is employed to access the remaining[6]. To address these challenges, it is imperative to carry out thorough geo-technical investigations in order to prevent any unforeseen complications that may arise during the development and operation of mines[4,18].

These examinations involve creating geotechnical maps of previously dug benches using scan line surveys, carrying out geo-technical drilling and logging cores to establish the Rock Quality Designation (RQD) and to detect structural breaks. Additionally, testing cores for material characteristics and then conducting assessments like Rock Mass Rating (RMR) and Mining Rock Mass Rating (MRMR) are done to decide on the most suitable steps forward[16.29]. The study discusses the findings of the geo-technical assessments and slope stability studies conducted to advise the planning and design of mine operations, based on geological and mining conditions.

Geotechnical Challenges in India - An Overview: India possesses a vast and varied geological landscape that poses a multitude of obstacles for geotechnical engineering[2,28]. The subcontinent showcases a diverse range of geological characteristics, such as different soil compositions, rock

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formations, seismic activity and climatic conditions across its various regions[20]. The Himalayan mountain ranges, Deccan Plateau, coastal regions and river basins all exhibit distinct geological attributes, thereby presenting unique challenges for infrastructure and construction endeavors[26].

Significance of Rock Mass Assessment in Indian Projects: The assessment of rock masses holds great importance in India due to the notable geotechnical challenges[5,8,21]. It plays a crucial role in guaranteeing the triumph and security of various infrastructure projects, mining endeavors and tunneling activities[15]. Rock masses serve as the fundamental base for numerous civil engineering structures such as dams, bridges, highways and buildings[3,24,27]. The evaluation of rock mass is of utmost importance in dealing with the challenges encountered in Indian geotechnical engineering and mining practices due to their complexities. Approaches like Rock Mass Rating (RMR) and Mining Rock Mass Rating (MRMR) methodologies are essential in tackling these issues[19].

Geology of the mines: The Boula Chromite deposit is located within the Baula-Nuasahi Ultramafic complex. The formation containing chromite is present within the ultrabasic rocks, consisting of serpentine, talc serpents and talc tremolite schist, with occasional small asbestos veins. These formations are penetrated by various base intrusions like dolerite, gabbro, among others. Overall, the ultrabasic rock layers follow a northwest-southeast direction and have an inclination of 70° to 80° towards the northeast. The partially altered ultrabasic rocks exhibit varying degrees of mineralization in the chromite, which is primarily influenced by the lithologies and their structural alterations depicted in figure 1.

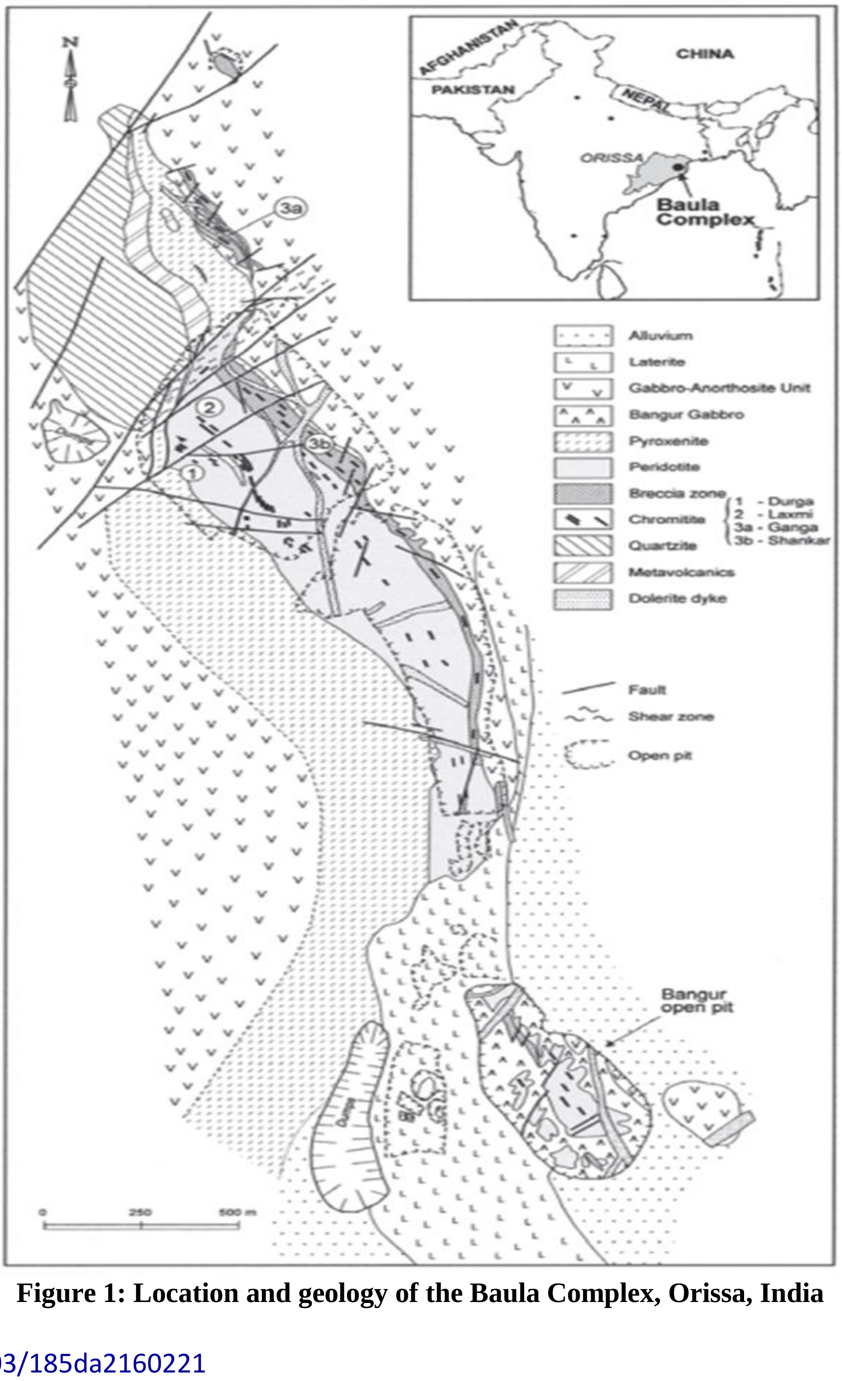

Figure 1: Location and geology of the Baula Complex, Orissa, India

Rock mass classification system for mining

Rock Mass Rating System of Bieniawski: In 1976, the geomechanics classification, or RMR, was published. As more case records were studied, the RMR classification was refined over the years[13]. It is important to note that the 1976 and 1989 versions of the RMR classification contain significant modifications in the ratings attributed to various parameters. Both 1976 and 1989 RMR classify rock masses by estimating their strength[1].

This categorization method partitions the rock mass into distinct structural zones, each assessed separately. Usually, these zones are demarcated by significant structural elements like faults or shifts in rock composition. At times, considerable gaps in discontinuity or alterations in rock type might necessitate further division of the rock mass into smaller structural segments[12]. The Rock Mass Rating (RMR) system evaluates and assigns a rating to six parameters within each of these regions. These individual ratings are then totaled to derive the RMR[25,31].

Mining Rock Mass Rating Classification of Laubscher: Originally, the RMR classification was based on case histories from the field of civil engineering. As a result, the classification was seen as somewhat conservative by the mining industry. Several changes have been made to the RMR classification to make it more applicable to mining applications.

Laubscher along with Laubscher and Taylor have explained a Modified Rock Mass Rating (MRMR) system specifically designed for mining purposes. This MRMR system incorporates the fundamental RMR value and modifies it to consider factors such as *in situ* and induced stresses, stress variations and the impacts of blasting and weathering[11]. Additionally, a set of support recommendations is associated with the resultant MRMR value[22].

Geotechnical Inspection

Geotechnical surveys play a pivotal role in strategically planning and advancing both surface and underground mining endeavors. Insufficient geometric data in the initial phases of mining can lead to unforeseen challenges. Therefore, it is crucial to collect precise geometric information right from the project's start to its completion. These geotechnical site investigations involve various activities including drilling, assessing rock quality through core samples or field inspections, testing core samples for properties like compressive strength, shear strength, tensile strength, Young's modulus, Poisson's ratio, as well as measuring permeability and porosity.

Furthermore, these investigations entail detailed geotechnical mapping of discontinuities using scan line surveys, analyzing structural data via stereonets and characterizing the rock mass using diverse geomechanics classification systems. Determining the stress conditions in the region is crucial for deep mining projects. Assessing *in situ* stresses, their strength and direction provide vital insights into the stress patterns where underground mining is planned. Although conducting *in situ* stress experiments can be expensive, they offer valuable input for numerical stress analysis. Hydrogeology plays a massive role in underground mining projects, influencing their development significantly. Understanding surface and groundwater conditions in the area is imperative. Table 1 summarizes the datasets collected for the geotechnical assessment.

Strata Conditions Review: During the geotechnical inspection phase, development is progressing on two different elevations: '0' mRL and +30 mRL. The drives and crosscuts vary in height and width, spanning from 2 m to 3 m. These levels are being constructed in the NW-SE direction, aligning with the general strike of the chromite bands. Examination reveals that the roof and sidewalls of the levels are structurally robust, showing only minor imperfections. Some discontinuities exhibit weathering and alteration with infill gouge material. In areas where the strata are weak, immediate roof sections are being supported during development using rock bolts with timber lagging.

Rock Mass Classifications: The primary aim of gathering discontinuity data is to construct detailed geological maps that capture the present underground conditions before commencing stoping activities. This information facilitates comparisons between the current ground state and identifies potential areas requiring support during stoping. Moreover, the resulting geotechnical data will be employed to evaluate support needs through quantitative analysis, comparing them against established empirical systems.

Table1
Assessment of Rock mass properties

Rock type	RMR	MRMR	Rock Mass Strength (MPa)
Chromite ore	48	38.3	16.3
Serpentinite	36	29	15.3
Disseminated ore	46	36.7	17.7
Dolerite	43	34	34.1
Gabbro	52	41	74.8
Pyroxenite	50	39.9	45.1

Thorough scan line surveys were conducted across open pit benches and crosscuts, specifically in areas earmarked for a "trial stope" development. The purpose of the geotechnical mapping was to grasp a detailed understanding of the present and expected rock mass conditions at 0mRL and 30mRL. Every noteworthy discontinuity observed in the roof and sidewalls was meticulously mapped using a scale of 1 cm = 2 m. The Rock Quality Designation (RQD) values for each surveyed scan line were evaluated based on visual assessments during these surveys. The determination of Rock Mass Rating (RMR) values relied on input data encompassing intact rock strength, discontinuity spacing, roughness and alteration, Rock Quality Designation (RQD) and groundwater conditions.

Calculations were conducted for each rock type to categorize them according to standard geomechanics classifications. The computed RMR values for the open pit mine fall within the "Fair" and "Good" categories, while the Mining Rock Mass Rating (MRMR) values correspond to "Stable" and "Support effective" respectively. Physico-mechanical properties of representative drill core samples were evaluated and the resulting values have been summarized in table 2.

Geomechanical Characteristics: Certainly, the laboratory analysis of various core samples aimed to ascertain the geo-mechanical characteristics of the chromite ore zone, alongside the footwall and hanging wall formations. In this area, four rock types exist: gabbro, serpentine, marketable ore and subgrade ore. However, in modeling scenarios without a post pillar, the modulus of elasticity for each rock mass is presumed to be 40% and 20% of the tested value for RMR of 70 and 50 respectively. These assumptions align with criteria set by Hoek and Brown.

In Boula Chromite mines, there are three lodges Shanker, Lakshmi and Durga. These are stratiform deposits, dipping steeply 65° to 75° and fragmented by numerous strike and dip faults. The chromite is associated with serpentinite mainly. The average strike length of the ore body is 1 310 m NW/SE and the dip of the ore body varies from 65° to 75° towards the NE. The width varies from 1.5 m to 4.0 m. The ore body has been proven to a depth of 250 m. Opencast mining has been carried out to a depth of 90 m and underground mining to a depth of 200 m.

Stereographic projection

A graphical stereonet analysis method is utilized to evaluate the relative stability and potential for future rock falls. This method enables the analysis of the orientations of joints, bedding planes and fractures at multiple locations, helping to identify which discontinuities are more likely to serve as failure surfaces for future rock falls[14].

Table 2
Average value of different tests results

Rock type	UCS (MPa)	Tensile Strength (MPa)	Young's modulus (GPa)
Chromite	45.3	3.16	78.90
Serpentinite	64.1	4.82	79.45
Disseminated Ore	52.1	3.96	86.16
Dolerite	110	7.90	111.98
Gabbro	187.1	12.66	108.24
Pyroxenite	118.8	9.44	84.83

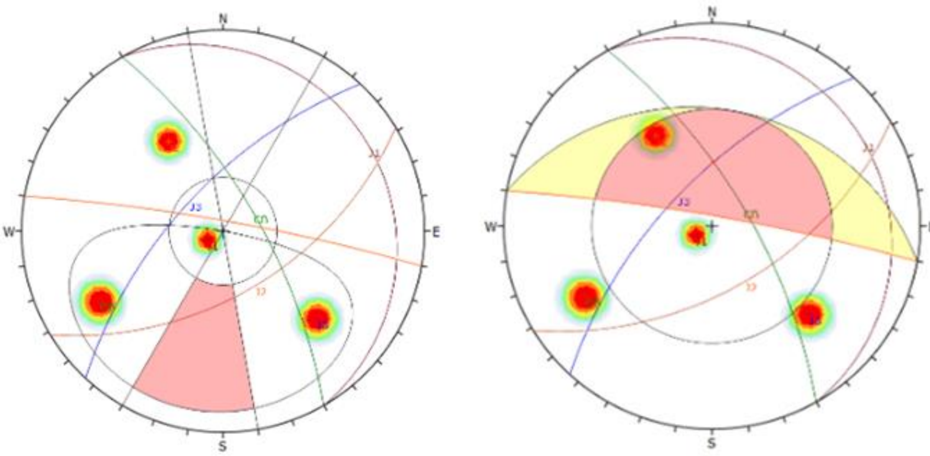

Figure 2: Stereographic view of joints and bedding plane with friction angle, Shankar open pit mine

By comparing the slope's orientation with that of rock discontinuities and considering the internal angle of friction of the rock, this method determines which fractures, joints, or bedding planes render the rock mass theoretically unstable[30]. The DIPs software package is utilized to conduct a rock-slope stability analysis. This software enables the assessment of the potential for plane or wedge failure on a rock slope. By plotting a friction circle, the rock slope face and discontinuities on a stereonet, the critical zone is determined. Discontinuities falling within this zone represent kinematically feasible failure surfaces[23].

Strata failure Analysis

All discontinuity orientations were processed for kinematic analysis based on equal-angle lower hemisphere stereographic projection. The dominant joint sets present on the pyroxenite rock slope of the Shankar lode site are identified. Mostly wedge failures are observed in this area based on stereographic failure analysis and the direction of failure is the northern side.

Conclusion

Geotechnical investigations play a pivotal role in designing and planning underground excavations. Understanding the stress conditions in the area is crucial for accurately configuring numerical models, providing vital insight into *in situ* stress, both in magnitude and direction. Moreover, employing ground instrumentation is vital for monitoring stress, strain and rock mass deformation, facilitating precise forecasts of strata behavior during mining operations. Geological mapping conducted at open pit benches and levels '0' mRL and +30 mRL revealed that the rock mass conditions within the underground excavations are classified as FAIR, with an RMR value of 50 and an MRMR value ranging from 35 to 41. The footwall, ore body and hanging wall demonstrate relatively hard and compact physico-mechanical properties.

The Gabbro has a UCS value 187 MPa and the talc-serpentinite 64 MPa. As for Dolerite, the value is 110 MPa. In slope, mainly wedge failure has been observed during analysis. Based on literature, the factor of safety is 1.2. In light of the rock mass characteristics, outcomes from geotechnical analysis and the presence of a substantial ore deposit, the sublevel stopping technique proves to be economically feasible. This is further supported by the favorable dip and stability of the surrounding wall rocks. Additionally, it is worth noting that the stope height can be maintained at a maximum of 30 m without posing any significant risks of instability. Further, for accurate mine planning and design, numerical modeling tools can be used.

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References

1. Aksoy C.O., Review of rock mass rating classification: Historical developments, applications and restrictions, *J. Min. Sci.*, **44(1)**, 51–63, doi: 10.1007/s10913-008-0005-2 **(2008)**

2. Avchar A., Choudhary B.S., Budi G. and Sawaiker U., Applicability of Size-strength Rippability Classification System for Laterite Excavation in Iron Ore Mines of Goa, *Model. Meas. Control C*, **78(3)**, 378–391, doi: 10.18280/mmc_c.780309 **(2017)**

3. Avchar A., Choudhary B., Budi G. and Sawaiker U., Effect of rock properties on rippability of laterite in Iron Ore mines of Goa, *Math. Model. Eng. Probl.*, **5(2)**, 108–115, doi: 10.18280/mmep.050208 **(2018)**

4. Avchar A. and Choudhary B.S., Ripper production prediction for laterite excavation in iron ore mines, *J. Min. Sci.*, **57(1)**, 66–75, doi: 10.1134/S1062739121010087 **(2021)**

5. Avchar A., Pal S.K., Tripathi A.K. and Kumar G., Subsidence Analysis for Old Abandoned Board and Pillar Coal Mines Using ANSYS and Monte Carlo Simulation, *J. Min. Sci.*, **59(6)**, 938–948, doi: 10.1134/S1062739123060078 **(2023)**

6. Behera S.K., Singh P., Mishra K., Mandal P.K., Mandal S.K. and Kumar R., Underground Mine Backfilling Transition in Sukinda, Odisha: present and future, In Asian Mining Congress, Cham: Springer Nature, Switzerland, 276–291, doi: 10.1007/978-3-031-46966-4_22 **(2023)**

7. Chakraborty K.L. and Chakraborty T.L., Geological features and origin of the chromite deposits of sukinda valley, Orissa, India, *Miner. Depos.*, **19(4)**, doi: 10.1007/BF00204378 **(1984)**

8. Choubey V.D. and Chaudhari S., Geotechnical appraisal of the foundation rock mass behaviour of Narmada Sagar Dam project, central India: a case study, *Can. Geotech. J.*, **28(1)**, 148–159, doi: 10.1139/t91-016 **(1991)**

9. Dhakate R., Singh V.S. and Hodlur G.K., Impact assessment of chromite mining on groundwater through simulation modeling study in Sukinda chromite mining area, Orissa, India, *J. Hazard Mater.*, **160(2–3)**, 535–547, doi: 10.1016/j.jhazmat.2008.03.053 **(2008)**

10. Das S. et al, A study on soil physico-chemical, microbial and metal content in Sukinda chromite mine of Odisha, India, *Environ. Earth Sci.*, **69(8)**, 2487–2497, doi: 10.1007/s12665-012-2074-4 **(2013)**

11. Esmaeili A., Hamidi J.K. and Mousavi A., Determination of sublevel stoping layout using a network flow algorithm and the MRMR classification system, *Resour. Policy*, **80**, 103265, doi: 10.1016/j.resourpol.2022.103265 **(2023)**

12. Ferrari F., Apuani T. and Giani G.P., Rock Mass Rating spatial estimation by geostatistical analysis, *Int. J. Rock Mech. Min. Sci.*, **70**, 162–176, doi: 10.1016/j.ijrmms.2014.04.016 **(2014)**

13. Khademi Hamidi J., Shahriar K., Rezai B. and Rostami J., Performance prediction of hard rock TBM using Rock Mass Rating (RMR) system, *Tunn. Undergr. Sp. Technol.*, **25(4)**, 333–345, doi: 10.1016/j.tust.2010.01.008 **(2010)**

14. Kıncal C., Application of two new stereographic projection techniques to slope stability problems, *Int. J. Rock Mech. Min. Sci.*, **66**, 136–150, doi: 10.1016/j.ijrmms.2014.01.006 **(2014)**

15. Kumar S. and Pandey H.K., Slope Stability Analysis Based on Rock Mass Rating, Geological Strength Index and Kinematic Analysis in Vindhyan Rock Formation, *J. Geol. Soc. India*, **97(2)**, 145–150, doi: 10.1007/s12594-021-1645-y **(2021)**

16. Milne D., Hadjigeorgiou J. and Pakalnis R., Rock mass characterization for underground hard rock mines, *Tunn. Undergr. Sp. Technol.*, **13(4)**, 383–391, doi: 10.1016/S0886-7798(98)00081-9 **(1998)**

17. Ministry of Mines New Delhi, Annual Reports 2010-2020, Ministry of Mines, https://www.india.gov.in/annual-reports-ministry-mines, Available: https://www.india.gov.in/annual-reports-ministry-mines **(2024)**

18. Mukherjee S., Introduction to Tectonics and Structural Geology: Indian Context, 1–5, doi: 10.1007/978-3-319-99341-6_1 **(2019)**

19. Naithani A.K., Singh L.G. and Jain P., Rock Mass Characterization and Support Design for Underground Additional Surge Pool Cavern—A Case Study, India, *Geomaterials*, **07(02)**, 64–82, doi: 10.4236/gm.2017.72006 **(2017)**

20. Pal Samir Kumar, Avchar Akhil and Tripathi Anup Kumar, Comparison of model study with field implementation of gravity blind backfilling method to control subsidence induced disaster in abandoned underground coal mines, *Disaster Advances*, **16(5)**, 10–18 **(2023)**

21. Pal S.K., Avchar A., Vyas A. and Tripathi A.K., Prediction of the specific energy requirement of hydraulic rock breaker based on laboratory impact hammer - a case study, *Int. J. Min. Miner. Eng.*, **15(2)**, 237–259, doi: 10.1504/IJMME.2024.140075 **(2024)**

22. Panzhin A.A., Kharisov T.F. and Kharisova O.D., Substantiation of Stable Pitwall Parameters Based on the Mining Rock Mass Rating, *J. Min. Sci.*, **55(4)**, 522–530, doi: 10.1134/S1062739119045867 **(2019)**

23. Park H.J., Lee J.H., Kim K.M. and Um J.G., Assessment of rock slope stability using GIS-based probabilistic kinematic analysis, *Eng. Geol.*, **203**, 56–69, doi: 10.1016/ j.enggeo.2015.08.021 **(2016)**

24. Sarkar S., Kanungo D.P. and Kumar S., Rock Mass Classification and Slope Stability Assessment of Road Cut Slopes in Garhwal Himalaya, India, *Geotech. Geol. Eng.*, **30(4)**, 827–840, doi: 10.1007/s10706-012-9501-x **(2012)**

25. Şen Z. and Sadagah B.H., Modified rock mass classification system by continuous rating, *Eng. Geol.*, **67(3–4)**, 269–280, doi: 10.1016/S0013-7952(02)00185-0 **(2003)**

26. Sundaram R., Gupta S. and Gupta S., Advances in the State-of-Practice of Geotechnical Investigation in India, *Indian Geotech. J.*, doi: 10.1007/s40098-023-00750-3 **(2023)**

27. Verma R., Jaiswal A. and Avchar A., A Numerical Method Approach for Analyzing the Effects of Joint Orientation on Stability of Open-stope in Metalliferous Mines, *Ann. Chim. - Sci. des Matériaux*, **43(2)**, 129–134, doi: 10.18280/acsm.430211 **(2019)**

28. Viladkar M.N., Geomechanical Challenges: Practices and Innovations, *Indian Geotech. J.*, **48(1)**, 1–51, doi: 10.1007/s40098-017-0285-z **(2018)**

29. Warren S.N., Kallu R.R. and Barnard C.K., Correlation of the Rock Mass Rating (RMR) System with the Unified Soil Classification System (USCS): Introduction of the Weak Rock Mass Rating System (W-RMR), *Rock Mech. Rock Eng.*, **49(11)**, 4507–4518, doi: 10.1007/s00603-016-1090-1 **(2016)**

30. Zheng J., Lü Q., Deng J., Yang X., Fan X. and Ding Z., A modified stereographic projection approach and a free software tool for kinematic analysis of rock slope toppling failures, *Bull. Eng. Geol. Environ.*, **78(7)**, 4757–4769, doi: 10.1007/s10064-018-1426-z **(2019)**

31. Zhang Q., Huang X., Zhu H. and Li J., Quantitative assessments of the correlations between rock mass rating (RMR) and geological strength index (GSI), *Tunn. Undergr. Sp. Technol.*, **83(73–81)**, doi: 10.1016/j.tust.2018.09.015 **(2019)**.

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