EVALUATION OF STRENGTH AND DEFORMATION CHARACTERISTICS OF ANISOTROPIC AUGEN GNEISS ROCK

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ABSTRACT

Sirohi is a district in Rajasthan, India. The Aravalli hills are among the oldest mountain ranges on Earth believed to be around 2.5 billion years old. The region has undergone geological processes and there are metamorphic rocks like granite, gneiss, Phyllite and marble. Sirohi area is almost covered with augen gneiss phyllite rock. This rock are coarse-grained rocks with phyllite layer thus they are weak in nature. So due to its weak formation construction of tunnels or any other construction work would be problematic. In this research, the strength of rock samples is determined for various bedding angles (0°, 30°, 45°, 60° and 90°). Here engineering properties such as Dry Density, Water Content, Specific Gravity and Porosity have been determined. Shear parameters like Cohesion and angle of internal friction were obtained by triaxial test for different bedding angles and confining pressure while unconfined compressive strength was obtained by unconfined compressive strength (UCS) test. Additionally, point load test was done to establish a relation with unconfined compressive strength. The mohr-coulomb theory was applied to calculate cohesion and angle of internal friction. Failure mechanisms of rock samples were observed. These findings will be beneficial for slope stability and slope cutting in mining projects, tunnel construction and mitigating the risk of disasters.

KEYWORDS

Augen gneiss phyllite, triaxial, UCS, point load, bedding angle, Failure mechanisms, slope stability, mining projects, tunnel construction.

1. INTRODUCTION:

Understanding the physical and mechanical aspects such as quality, strength, deformation behaviour and failure mechanisms of intact rock masses is crucial for safety and economical engineering applications Rock anisotropy has a greatly impact on the stability of underground excavations, tunnelling, excavation and other civil and geotechnical projects. This anisotropic behaviour complicates the precise assessment of physical and mechanical properties of rock mass. (Rakesh Kumar, 2010) Although at material scale, mineralogy and geometric arrangement of particles, voids and microcracks are able to control the rock's mechanical behaviour. Microcracks are fundamentally important in this respect. (Xiaolong Guo, 2020) The most important aspect in tunnelling is stability of surrounding rock masses while conducting works with anisotropic rocks. The behaviours of anisotropic rocks differ according to the direction of their mineral grains, bedding planes and stresses put on them. (A. Basu, 2010; Tarun Singh, 2019)

Anisotropic rocks like schists, gneiss, phyllite and slate are strongly foliated and show strong anisotropy because of alignment of their minerals. Such flaky structures contribute to weak planes associated with anisotropy, which forms through deformation caused by shear and differential stresses along with recrystallization of minerals. (Rahmati Asghar, 2017; Ahmet Ozbek, 2017) The engineering behaviour of such rocks indicates importance of including anisotropic effects when using strength parameters in design processes. Research how the strength of foliated metamorphic rocks is greatly affected by alignment of the loading direction concerning weak planes. Examining strength anisotropy is critical for addressing engineering challenges, such as squeezing, pillar collapse and slope instability. (Xiaolong Guo, 2020; N.K. Samadhiya, 2003; Ramamurthy, 1993)

This study is on anisotropic mechanical behaviour of augen gneiss phyllite from a tunnel project in geologically diversified area of Rajasthan, Sirohi region. It was affected by changing bedding orientations and high-stress conditions during construction of tunnel. The purpose of this research is to evaluate variation in bedding about rock strength and deformation, and to establish correlations between test results and failure modes, which would be vital for the effective engineering design of the tunnels.

2. LITERATURE REVIEW:

Numerous researchers, such as Basu (2012), Sabatakakis et al. (2008), ISRM (1985), D'Andrea et al. (1964) have studied the effect of schistosity orientation of different anisotropic metamorphic rock on point load strength and Unconfined compressive strength (UCS) of the rock.

Several laboratory experiments conducted through triaxial, point load test and unconfined compressive strength have given various results across various rock types, Gneiss (S. Kahraman, 2009; G. Tsiambaos, 2010; Rakesh Kumar, 2010; Lin Liu, 2015; Tarun Singh, 2019; D Acharya, 2021; Hongyuan Zhou, 2024), Phyllite (N.K. Samadhiya, 2003; Guowen Xu, 2018; Tarun Singh, 2019; Xiaolong Guo, 2020; Helin Fu, 2023), Schist (A. Basu, 2010; G. Tsiambaos, 2010; A. Basu, 2013; D Acharya, 2021)

Reference	Equation
D'Andrea et al. (1964)	$UCS = 15.3I_{s50} + 16.3$
ISRM (1985)	$UCS = 20\ldots25I_{s50}$
Sabatakakis et al. (2008):	
1) $I_s < 2$ MPa	$UCS = 13I_{s50}$
2) $I_s = 2–5$ MPa	$UCS = 24I_{s50}$
3) $I_s > 5$ MPa	$UCS = 28I_{s50}$
Basu (2012)	$UCS = 11.218I_{s50} + 4.008$

Table 1: Correlation between UCS and point load strength index

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3. THEORETICAL FRAMEWORK:

The strength of rocks is one of their most crucial engineering properties. This indicates the ability of rocks to withstand external forces without undergoing some deformation or failure. The strength is influenced by mineral composition, porosity and existence of micro cracks.

3.1 INDEX PROPERTIES

Index properties of rock specimens such as dry density, porosity, water absorption and specific gravity were performed as per IS: 13030:2021.

3.2 TRIAXIAL TESTING (IS:13047-2021)

The Triaxial test is used for obtaining values of strength and deformation behaviour of rock specimens under different confining pressure varying 1 MPa, 2 MPa and 3 MPa. Place the sample inside a triaxial cell. Apply confining pressure on the sample and axial load at a constant rate of strain 0.315 mm/min. The lateral confining pressure corresponds to the all-around pressure existing in the rock mass in the field. Three samples of rock are subjected to three different confining pressures and based on that Mohr's circle is drawn by which the shear strength parameters such as Cohesion (C) and angle of internal friction (Φ) of rock are obtained.

3.3 UNCONFINED COMPRESSIVE STRENGTH (UCS) TESTING (IS:9143-2021)

UCS tests were conducted on cylindrical samples to determine maximum axial stress the rock could withstand before failure without any lateral confinement. The UCS test is a simple and quick way to measure compressive strength of rock samples. Apply axial load at a constant rate of strain 1.25 mm/min. Record maximum load at failure and calculate UCS from the cross-sectional area and maximum load.

Fig. 1. Rock triaxial setup

Fig. 2. UCS setup

3.4 POINT LOAD TESTING (IS:8764-2019)

The point load strength test is a method used to determine point load strength index of rock and concrete specimens. It involves applying an axial load or diametrical load to a cylindrical specimen until failure occurs. The point load test is a simple and quick way to measure point load strength of rock specimen. Apply axial load and record the maximum load at failure and calculate the point load strength index $I_s(50)$. The UCS test is a simple and quick way to measure the compressive strength of rock samples.

$$I_s(50) = \frac{P}{D^{1.5}\sqrt{D_{50}}} \quad \text{.......... (1)}$$

Where, $I_s(50)$ = point load strength index in MPa,
P = failure load in N,
D = core diameter in mm,
D_{50} = standard core diameter (50mm)

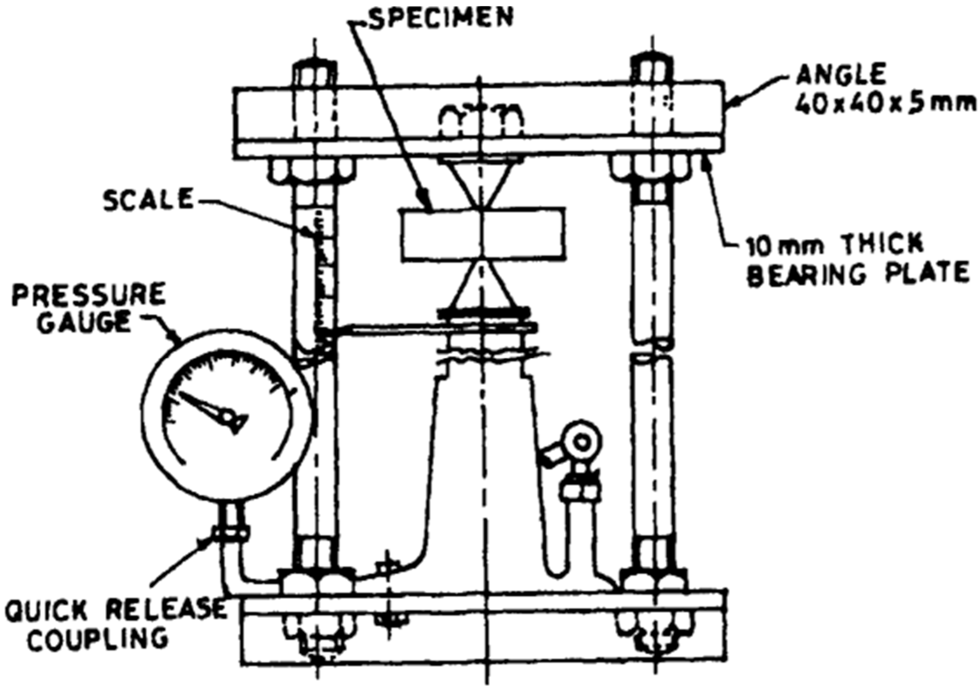

Fig. 3: Point load setup

4. RESULTS AND ANALYSIS:

The study focuses on the use of augen gneiss rock, which was collected as a chunk from the Sirohi region of Rajasthan. The selection and preparation of the rock samples were carried out in accordance with the guidelines in IS: 9179-2021, which provides detailed specifications for rock material preparation.

Procedure and sample preparation requirements according to IS:13047-2021 were used for triaxial tests, IS:9143-2021 were used for UCS tests and IS:8764-2019 were used for point load tests.

Core sample extraction of various orientations. Cylindrical specimens with diameter of 42mm and height of 84mm (L/D ratio of 2) for UCS tests and triaxial tests, and for point load tests size 42mm diameter and 42mm height (L/D ratio of 1). The orientation of core extraction is 0°, 30°, 45°, 60° and 90°.

4.1 INDEX PROPERTIES

The rock specimen from Sirohi was extracted in cylindrical form. Subsequently, tests were conducted to assess various index properties including dry density, porosity, water absorption and specific gravity.

Properties	**Value**
Dry Density (kN/m³)	26.4
Porosity (n%)	1.38
Water absorption (w%)	0.52
Specific Gravity (G)	2.65

Table 2: Index properties of rock

4.2 TRIAXIAL TEST

Bedding angle	**0°**	**30°**	**45°**	**60°**	**90°**
Cohesion (C) (MPa)	7.28	6.75	6.08	7.38	6.23
Angle of internal friction (Φ)	49.08	51.79	47.69	46.25	56.49

Table 3: Cohesion and angle of internal friction values for different bedding angles

From the test, the minimum value of cohesion (C) occurs at 45° and the maximum value is observed at 60°. Similarly, the minimum value of the angle of internal friction (Φ) is found at 60° and the maximum value of Φ is at 90°. As the bedding angle increases anisotropy decreases, making the rock behave more isotopically which gives higher strength of the rock.

Fig. 4(a)

Fig. 4(b)

Fig. 4(c)

Fig. 4(d)

Fig. 4(e)

Fig 4: Triaxial failure modes of (a) 0°, (b) 30°, (c) 45°, (d) 60°, (e) 90°.

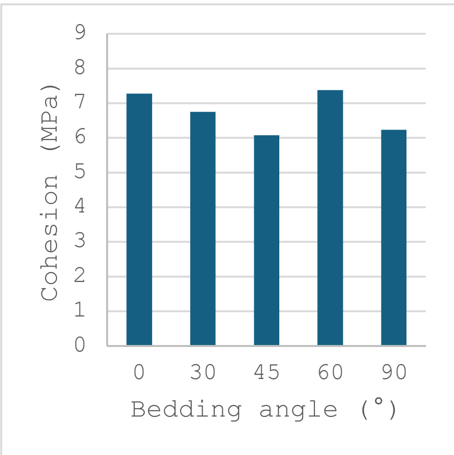

Fig. 5: Cohesion value of different bedding angle

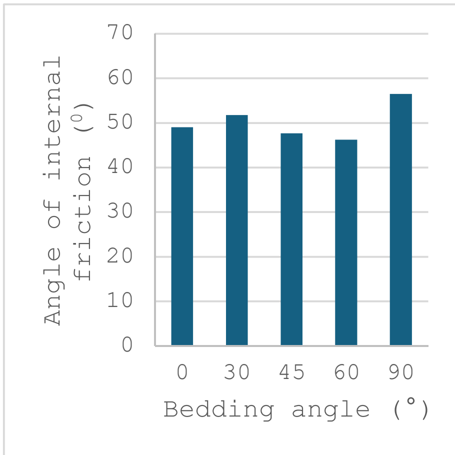

Fig. 6: Angle of internal friction value of different

Angle (°)	Shear strength (MPa) at various confining pressures			Avg. shear strength (MPa)
	1 MPa	2 MPa	3 MPa	
0	59.26	69.28	75.75	68.09
30	65.28	77.12	86.69	76.37
45	48.27	54.15	62.85	55.09
60	52.29	56.82	63.65	57.59
90	84.34	98.62	117.92	100.29

Table 4: Shear strength at different confining pressures and different bedding angles

The Mohr-Coulomb theory was applied to determine shear strength of intact rock specimens with findings summarized in the table. It is observed that shear strength of the rock rises with higher confining pressures.

These values were compared to the shear strength at 90° for each corresponding confining pressure. The greatest reduction in shear strength of Sirohi rock was noted at 45° foliation angle across all three confining pressures.

Bedding angle	Confining pressure (MPa)	Deviator stress (σ_d) (MPa)	Failure modes
0°	1	44.05	Along foliation
	2	51.73	Along foliation
	3	56.34	Axial splitting
30°	1	45.07	Along foliation
	2	53.39	Shearing along one plane
	3	59.92	Double shear
45°	1	37.38	Along foliation
	2	41.74	Shearing along one plane
	3	48.65	Double shear
60°	1	41.99	Axial splitting
	2	45.32	Double shear
	3	50.86	Multiple fracturing
90°	1	50.7	Shearing along one plane
	2	59.15	Y-shaped failure
	3	70.93	Axial splitting

Table 5: Failure modes at different confining pressures and different bedding angles

4.3 UNCONFINED COMPRESSIVE STRENGTH (UCS) TEST

Bedding angle	0°	30°	45°	60°	90°
Avg. unconfined compressive strength (MPa)	51.65	28.17	35.11	37.96	54.03

Table 6: unconfined compressive strength of different bedding angles

From the test, the minimum value of unconfined compressive strength occurs at 30° and maximum value is observed at 90°. As the bedding plane and loading direction is aligned UCS value will be lower for rock samples.

Fig. 7(a)

Fig. 7(b)

Fig. 7(c)

Fig. 7(d)

Fig. 7(e)

Fig 7: UCS failure modes of (a) 0°, (b) 30°, (c) 45°, (d) 60°, (e) 90°.

Bedding angle	Sample	UCS Strength (MPa)	Failure modes
0°	1	48.65	Shearing along one plane
	2	52.24	Axial splitting
	3	54.06	Along foliation
30°	1	26.26	Along foliation
	2	27.03	Shearing along one plane
	3	31.24	Along foliation
45°	1	32.78	Y-shaped failure
	2	34.68	Double shear
	3	37.89	Shearing along one plane
60°	1	35.19	Shearing along one plane
	2	39.78	Multiple fracturing
	3	38.92	Axial splitting
90°	1	52.75	Double shear
	2	53.82	Axial splitting

	3	55.82	Multiple fracturing

Table 7: Failure modes at different bedding angles

4.4 POINT LOAD TEST

Bedding angle	0°	30°	45°	60°	90°
Avg. point load strength (MPa)	2.77	1.62	2.4	2.6	3.36

Table 8: Point load strength of different bedding angles

From the test, the minimum value of point load strength occurs at 30° and maximum value is observed at 90°. As the bedding plane and loading direction is aligned UCS value will be lower for rock samples.

Fig. 8(a)

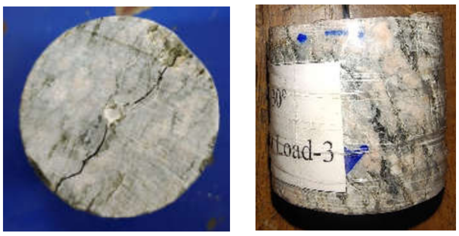

Fig. 8(b)

Fig. 8(c)

Fig. 8(d)

Fig. 8(e)

Fig 8: UCS failure modes of (a) 0°, (b) 30°, (c) 45°, (d) 60°, (e) 90°.

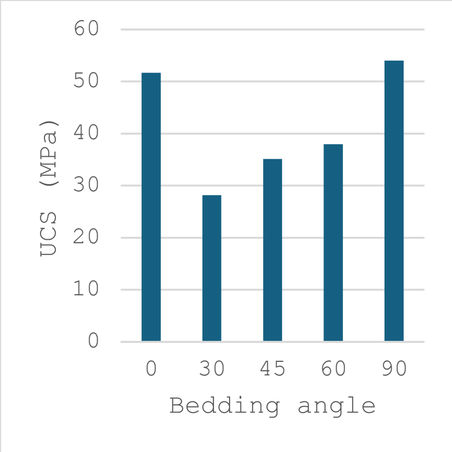

Fig. 9: UCS value of different bedding angle

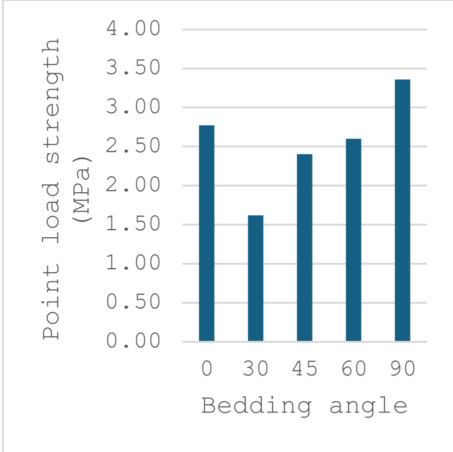

Fig. 10: Point load strength value of different bedding

4.4 RELATION BETWEEN UCS AND POINT LOAD

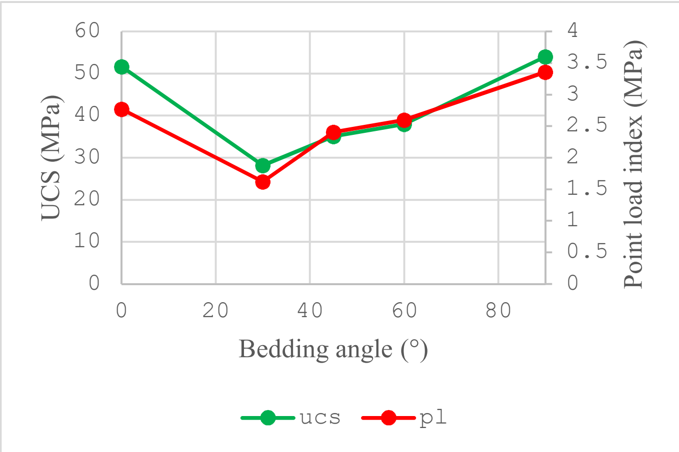

Fig. 11: UCS and point load values of different bedding

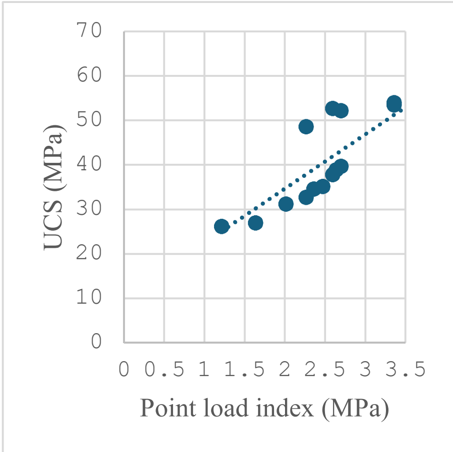

Fig. 12: UCS vs Point load graph

The values of UCS and PLI obtained from 30 tests on augen gneiss specimens are plotted in Fig. 9 and Fig. 10. Figure 11 and Figure 12 represent the test data of UCS and Point load axial test. In the UCS test, minimum strength is obtained in the 30° and maximum on the 90° loading angle concerning foliation. Similarly, observed in the point load axial test in which minimum strength is obtained at 30° and maximum on the 90° loading angles concerning foliation.

The relation between UCS and point load obtained from the test is as follows,

$UCS = 12.213 * I_s(50) + 10.24$ ……. (2)

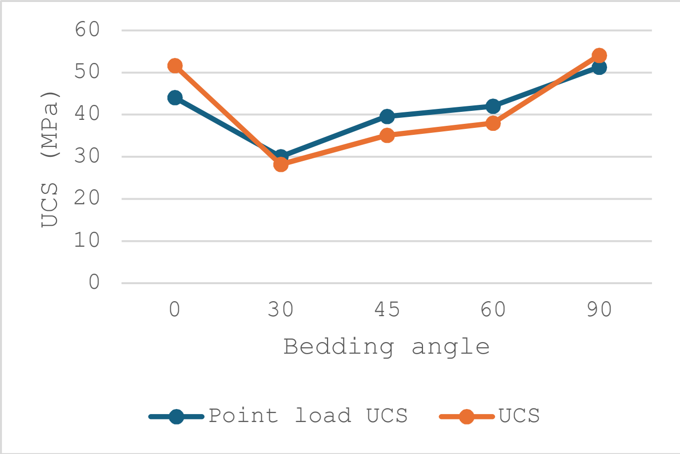

Fig. 13: UCS test vs UCS value from Point load test

Referring to figure 13 shows comparison of UCS value derived using equation 2 and its experimental value.

5. CONCLUSION:

- The findings show a percentage decrement in cohesion relative to 0° (7.28 MPa) for 30°, 45° and 90° is 7.28%, 16.48% and 14.42%. Respectively for the 60° natural foliation angle increase in cohesion (C) was observed concerning the 0° angle showing a percentage increment of 1.37%. Also, a percentage decrease in angle of internal friction relative to 90° (56.49°) for 0°, 30°, 45° and 60°, which are 5.52%, 2.81%, 5.57%, and 15.09% respectively.
- The percentage decrease in shear strength was observed to vary across different foliation inclination angles (0°, 30°, 45° and 60°) relative to the 90° samples is 32.1%, 23.85%, 45.06% and 42.57% respectively.
- Unconfined compressive strength (UCS) test shows a percentage decrease in unconfined compressive strength relative to 90° (54.03 MPa) for 0°, 30°, 45° and 60°, which are 4.4%, 47.84%, 35%, and 29.73% respectively.
- Also, point load test shows a percentage decrease in point load strength relative to 90° (2.75 MPa) for 0°, 30°, 45° and 60°, which are 17.52%, 51.85%, 28.45%, and 22.62% respectively.
- The results of UCS test and UCS value from point load strength show a percentage difference for 0°, 30°, 45°, 60° and 90°, which are 14.65%, 6.44%, 12.75%, 10.6% and 5.1% respectively.
- The triaxial test results show large differences in shear strength. Across anisotropic orientations as the shear strength greatly increases. Notably, the 45° sample exhibits a reduction in shear strength that is relatively greater. This observation implies that foliation angle of 45° may face an increased susceptibility and risk.
- Unconfined compressive strength test and point load test results show large differences in strength. Across anisotropic orientations as the strength greatly increases. Notably, the 30° sample exhibits a reduction in strength that is relatively greater.

REFERENCES:

[1] Lin Liu, Weiya Xu, **"Experimental Researches on Long-Term Strength of Granite Gneiss"**, *Advances in Materials Science and Engineering (2015), DOI:10.1155/2015/187616.*

[2] D Acharya, A K Raina, S Panthee, **"Challenges to study the Anisotropic Rocks using index tests in the Himalaya Region: A review from the Nepal Himalaya"**, *IOP Conf. Series: Earth and Environmental Science 861 (2021), DOI:10.1088/1755-1315/861/2/022050.*

[3] Riya Dutta, Harsh Bhu, Ritesh Purohit and Kamal Kant Sharma, **"Geology of granitoids of pindwara–abu road belt from mesoproterozoic delhi supergroup: tectonic implications"**, *Journal of earth system science (2021), DOI:10.1007/s12040-021-01607-0.*

[4] Yi Liu, Feng Dai, **"A review of experimental and theoretical research on the deformation and failure behavior of rocks subjected to cyclic loading"**, *Journal of Rock Mechanics and Geotechnical Engineering (2021), DOI:10.1016/j.jrmge.2021.03.012.*

[5] R. Mohantya, S. Mohantyb, M.K. Roy, **"Structural geometry of uraniferous rocks in the Umra area, Aravalli Supergroup, India"**, *Journal of Asian Earth Sciences 25 (2005), DOI:10.1016/j.jseaes.2004.01.011.*

[6] A. Basu , M. Kamran, ***"Point load test on schistose rocks and its applicability in predicting uniaxial compressive strength"***, *International Journal of Rock Mechanics & Mining Sciences (2010), DOI:10.1016/j.ijrmms.2010.04.006.*

[7] Guowen Xu, Chuan He, Ang Su, Ziquan Chen, **"Experimental investigation of the anisotropic mechanical behavior of phyllite under triaxial compression"**, *International journal of rock mechanics and mining sciences (Elsevier) (2018).*

[8] Xiaolong Guo, Zhongsheng Tan, Xiao Wang, **"Effect of bedding angle and mineral composition on mechanical properties and fracture behavior of phyllite under unloading confining pressures"**, *Geotechnical and geological engineering (Springer) (2020).*

[9] *D Acharya, S Panthee, A K Raina, "Analysis of failure behaviour of the anisotropic rocks in the point load index test", IOP Conf. Series: Earth and Environmental Science 833 (2021), DOI:10.1088/1755-1315/833/1/012193*

[10] Rakesh Kumar, K.G. Sharma, A. Varadarajan, "**Post-peak response of some metamorphic rocks of India under high confining pressures"**, *International Journal of Rock Mechanics & Mining Sciences (2010), DOI:10.1016/j.ijrmms.2010.08.016.*

[11] Andrea Bercakova, Rostislav Melichar, **"Mechanical Properties and Failure Patterns of Migmatized Gneiss with Metamorphic Foliation Under UCS Test"**, *Rock Mechanics and Rock Engineering (2019), DOI:10.1007/s00603-019-02012-2.*

[12] Hongyuan Zhou, Zaobao Liu, Fengjiao Liu, **"Anisotropic strength, deformation and failure of gneiss granite under high stress and temperature coupled true triaxial compression"**, *Journal of Rock Mechanics and Geotechnical Engineering (Elsevier) (2024).*

[13] Matthew A. Perras, Mark S. Diederichs, **"A Review of the Tensile Strength of Rock: Concepts and Testin"**, *Geotech Geol Eng. (2014), DOI:10.1007/s10706-014-9732-0.*

[14] Umer Waqas, Mohsin Usman Qureshi, Shahab Saqib, **"Evaluation of Strength Anisotropy in Foliated Metamorphic Rocks: A Review Focused on Microscopic**

Mechanisms", *Geosciences (2024), DOI:10.3390/geosciences14100253.*

[15] Tarun Singh, Ashwani Jain, K. S. Rao, **"Rock failure modes under uniaxial compression, brazilian, and point load tests"**, *Geotechnical applications (Springer) (2019).*

[16] S. Kahraman, **"The determination of uniaxial compressive strength from point load strength for pyroclastic rocks"**, *Engineering Geology (2014), DOI:10.1016/j.enggeo.2013.12.009*

[17] Ziquan Chen, Chuan He, Guowen Xu, **"A Case Study on the Asymmetric Deformation Characteristics and Mechanical Behavior of Deep-Buried Tunnel in Phyllite"**, *Rock Mechanics and Rock Engineering (2019), DOI:10.1007/s00603-019-01836-2.*

[18] Ritesh Purohit, Dominic Papineau, Kamal K. Sharma, **"Carbon isotope geochemistry and geochronological constraints of the Neoproterozoic Sirohi Group from northwest India"**, *Precambrian Research, DOI:10.1016/j.precamres.2012.07.012.*

[19] E. Broch, J. A. Franklin, **"THE POINT-LOAD STRENGTH TEST"**, *International Journal of Rock Mechanics and Mining Sciences*, *Vol. 9, pp. 669-697, Pergamon Press (1972).*

[20] M K Pandit, H De Wall, H Daxberger, **"Mafic rocks from Erinpura gneiss terrane in the Sirohi region: Possible ocean-floor remnants in the foreland of the Delhi Fold Belt, NW India"**, *J. Earth Syst. Sci. 120, No. 4, August 2011, pp. 627–641.*

[21] N.K. Samadhiya, P.K. Jain, **"Strength behaviour of phyllites under triaxial stress condition"**, *Indian institute of technology Roorkee (2003).*

[22] M K Pandit, H De Wall, H Daxberger, M Bestmann and K K Sharma Mafic, **"Rocks from Erinpura gneiss terrane in the Sirohi region: Possible ocean-f loor remnants in the foreland of the Delhi Fold Belt, NW India"**, *Journal of Earth System Science (2011).*

[23] S. H. Rasul**, "The chemical composition and original nature of the dharwar phyllites of the shivrajpur-bamankua area, district panch mahals, Gujarat state"**, *department of geology, aligarh muslim university, aligarh (1963).*

[24] Tarun Singh, Ashwani Jain and K. S. Rao, **"Rock Failure Pattern Under Uniaxial, Triaxial Compression and Brazilian Loading Conditions"**, *Springer Nature Singapore (2019), DOI:10.1007/978-981-13-0368-5_26.*

[25] Amalesh Jana, Mithresh Pushpan, Arindam Dey, S. Sreedeep and A. Murali Krishna, **"Static and Dynamic Slope Stability Assessment of a Himalayan Rock Slope"**, *S pringer Nature Singapore (2019), DOI:10.1007/978-981-13-0368-5_25.*

[26] Mahtab Alitalesh, Mostafa Mollaali and Mahmoud Yazdan, **"Correlation between uniaxial strength and point load index of rocks"**, *Japanese Geotechnical Society Special Publication (2016), DOI: 10.3208/jgssp.IRN-08***.**

[27] A. Basu, D. A. Mishra, K. Roychowdhury, **"Rock failure modes under uniaxial compression, Brazilian, and point load tests"**, *Bulletin of Engineering Geology and the Environment (2013), DOI 10.1007/s10064-013-0505-4.*

[28] Wawersik Wr, Fairhurst C, **"A study of brittle rock fracture in laboratory compression experiments"**, *Int J rock mech min sci. (1970).*

[29] ATTEWELL PB, SANDFORD MR. INTRINSIC, **"Shear strength of a brittle, anisotropic rock-I: experimental and mechanical interpretation"**, *Int J rock mech min sci geomech abstr. (1974).*

[30] S. Kahraman, O. Gunaydin, **"The effect of rock classes on the relation between uniaxial compressive strength and point load index"**, *Bull Eng Geol Environ (2009) 68:345–353 DOI: 10.1007/s10064-009-0195-0*

[31] Yin, X., Zhang, A., Zhang X., **"A review of the influence of microscopic characteristics on the progressively brittle failure of foliated rocks subjected to compression loading"**, *Geotech. Geol. Eng. 2021*

[32] S. Kahraman**, "The determination of uniaxial compressive strength from point load strength for pyroclastic rocks"**, *Engineering Geology, vol. 122, Oct. 2019, DOI: 10.1016/j.enggeo.2013.12.009.*