Evaluation of natural foliation effect on deformation characteristic and shear strength parameters of Chamoli (Uttarakhand) rock using a Triaxial system.

Dinesh Jaganiya
Applied Mechanics Department, L.D. College of Engineering, Ahmedabad, India

Manish Shah
Applied Mechanics Department, L.D. College of Engineering, Ahmedabad, India

Usha Patel
Applied Mechanics Department, L.D. College of Engineering, Ahmedabad, India

ABSTRACT: In major part of the Chamoli, high degree of metamorphic rock are identified. The objective of this research paper is to examine the effect of natural foliation of Chamoli rock on shear characteristics and failure patterns through different anisotropic angles using an automated triaxial system. In present study, seven anisotropic angles (0°, 15°, 30°, 45°, 60°, 75°, and 90°) were simulated on a cylindrical specimen of diameter 50mm and length of 100mm based on the natural foliation of rock. From the experimental results and analysis based on Mohr-Coulomb and modified Hoek-Brown criteria, it is observed that the strength of rock decreased from 0° to 30° and the rock strength is continuously increased from 30° to 90°. Simulation of failure patterns in tested specimens are matched to anisotropy planes from 0° to 30°. As per above conclusion the natural foliation (anisotropic) behaviour is catastrophically affected on a strength and failure modes of Chamoli rock.

Keywords: Anisotropic rocks, Natural foliation, Chamoli rock, metamorphic rocks, Modulus anisotropy, Triaxial system.

1 INTRODUCTION

Himalaya, the juvenile and towering mountain ranges, forming the extra-peninsular and Indo-Gangetic part of the Indian subcontinent, has captivated people since times immemorial and has spiritual significance. The Chamoli, Uttarakhand area under scrutiny is one such part of the Lesser Himalaya which still confirms a number of natural landslide/rockslide records and had come in for many unsolved problems. Then some researchers worked on, (Oldham 1883, 1888; Middlemiss 1885, 1887) mapping of the Kumaun-Garhwal Lesser Himalaya and represent its geology. The rocks of the Kumaun and Garhwal Lesser Himalaya have been subjected to recapitulated stages of crustal movements (Auden 1937; Gairola 1975; Kumar and Agarwal 1975; Gairola and Srivastava 1982) which has derived in very complicated geology. The rocks type (D. H. Shugar et al. 2021) of the Chamoli region which is high to medium metamorphic rock (gneiss & schist) contains abundant of soft, platy, oriented minerals, and weathering will further weaken these rocks. In spite of many attempts made in the past to describe the engineering performance of transversely anisotropic rocks still their nature is not adequately understood. The oriented structures within the rock matrix such as schistosity, foliation, lamination and/or cleavage are responsible for anisotropic behaviour of rocks (Goodman 1989; Singh et al. 1989; Ramamurthy 1993; Nasseri et al. 2003; Esamaldeen et al. 2014).

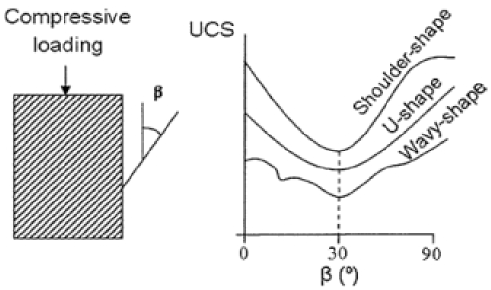


Figure 1. Curves of strength anisotropy according to Ramamurthy (1993).

The anisotropic strength behaviour of the rocks can be characterized according to the classification suggested by Ramamurthy (1993). He classified three different curves of strength anisotropy based on strength [MPa] and the anisotropy angle β^o, called “shoulder shaped”, “U-shaped” and “wavy shaped” anisotropy as illustrated in Figure 1.

2 MATERIAL AND METHOD

2.1 Sampling location and lithology

Keeping the objective in view large block samples of rock were collected from the recently rock sliding place of Chamoli, Uttarakhand (India) for laboratory investigation. Macroscopically, the rocks exhibit a distinct planar systematic-metamorphic fabric that is characterized by near-perfect metamorphic layering and mineral elongation (schistosity), and stretching lineation as shown in Figure 2. The foliation band varies in thickness ranging from 1 to 3 mm.

2.2 Petrographic Description of Rocks

The mineral composition verities of subtype samples of collected rock were determined by the X-ray diffraction method (XRD) as shown in Figure 3. The XRD analysis of selected rock samples was performed based on the microscopic textural variation of Chamoli rocks. The predominant mineralogical composition is almost calcite, quartz, and $Si_{14}O_{28}$. The main microstructure of these rocks is well-developed alternative layers of calcite and quartz characterized by a higher degree of texture anisotropy.

Figure 2. Large block samples of rock.

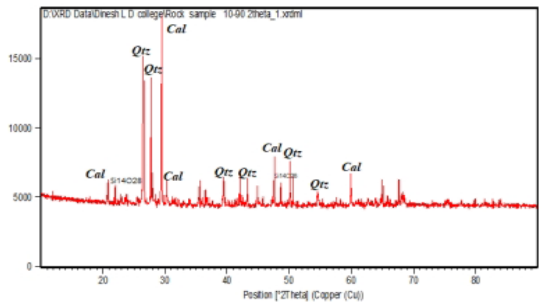


Figure 3. XRD analysis of rock.

2.3 Specimen Preparation and Triaxial Test

The rock sample were prepared to confirm IS 9179:1979.The rock chunk were collected from one location to minimize the material variation. Core sample with aspect ratio 2.0 were obtained using heavy-duty diamond drill assembly, equipped with 50 mm internal diameter core bits and a water feeding system. Using cutter machine rock specimens were prepared as per the schematic of coring direction in relation to the weakness plane is shown in Figure 4 and Figure 5.

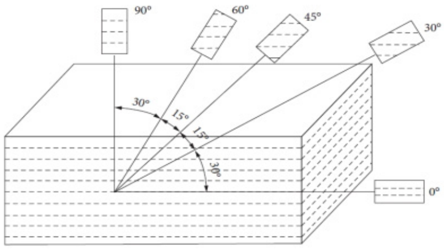


Figure 4. Rock sample preparation diagram.

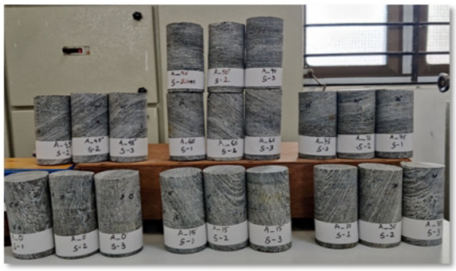


Figure 5. Specimens at anisotropic angles (β°).

The Triaxial tests were conducted on different orientation specimens of rock angle at confining pressures (σ_3) of 1, 2, and 3MPa as per the IS 13047:2010 testing outlined. The first was subjected to hydraulic stress to be applied then the axial stress was increased until the specimen failed. Stress-strain measurement were recorded and young's modulus E [MPa] was estimated.

3 EXPERIMENTAL RESULT AND ANALYSIS

Physical properties are determined/identification of the rock as per conformed IS 13030:1991. Physical properties like density, water content, and porosity are given in Table 1. As per the standard range of physical properties tested rock fall in metamorphic type rock.

Table 1. Physical and mechanical properties of the rock.

PROPERTIES	GROUP 0°	GROUP 15°	GROUP 30°	GROUP 45°	GROUP 60°	GROUP 75°	GROUP 90°
γ[Kg/m^3]	2883.41	2853.28	2837.58	2835.19	2803.04	2941.92	2824.04
n[%]	0.54	0.32	0.34	0.24	0.44	0.43	0.29
V_P[m/s]	5365.67	5254.00	4976.00	4809.00	4005.33	3656.33	4856.33
Vs[m/s]	2958.14	2844.16	2775.69	2446.18	2303.09	2795.09	2958.14
UCS[MPa]	39.74	41.78	38.78	35.16	40.76	43.82	46.88
E_{stat} [GPa]	29.29	28.20	23.36	24.97	24.56	28.29	30.38

3.1 Velocity Anisotropy

The velocities of ultrasonic waves (compression waves) were measured along the core axes for each core sample with reference to the foliation angle. P-waves were determined as per the IS 13311-1:1992 standard. Table 1 summarizes the ultrasonic wave's velocity measurements on the core samples where an average of 3 sample results. The velocities parallel to foliation range from 5217-5517 m/s with a mean of 5365.67 m/s, while 4724-5000 m/s with a mean value of 4856.33 m/s was recorded in a perpendicular direction.

3.2 *Strength Anisotropy*

After conducting a series of Triaxial compressive strength tests on Chamoli rock as per the mentioned seven anisotropic angle (β^o) under confining pressure (σ_3),it was invariably noted the failure pattern and young's modulus measurement were compared with various rock sample angle. The shear strength parameters viz. cohesion (C) and the angle of internal friction (Φ^o), were determined using a conventional Mohr-Coulomb failure envelope. Experimental results are compared using Mohr-Coulomb and modified Hoek-Brown (2016) criterion. The maximum principal stress (σ_1) and axial Strain of specimens were recorded during the test of each specimen. The variations of σ_1 with β^o for tested rock are plotted in Figure 6. In the studied rock, with an increasing σ_3, the value of σ_1 is increased. Variation rates of σ_1 at $\beta = 90^o$ are greatest in all anisotropy angles. These results are comparable to the results presented by Saroglou et al. (2004) Akai et al. (1970), Goshtasbi et al. (2006), Ramamurthy et al. (1993), and Nasseri et al. (2003).

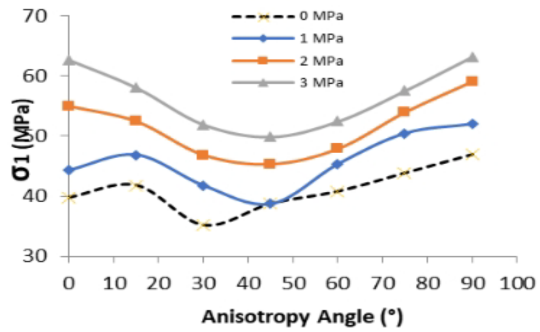


Figure 6. Variation of σ_1 and σ_3 with angle (β^o).

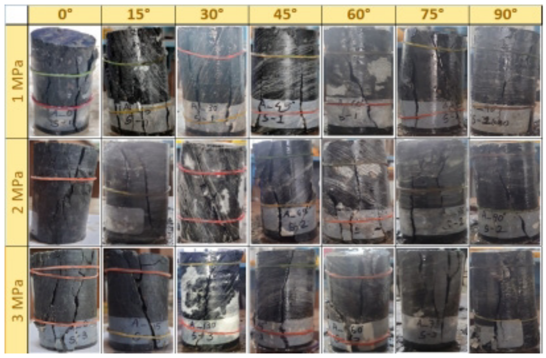


Figure 7. Failure at various anisotropic angle (β^o).

Figure 7 shows the failure patterns of the sample of studied rock after performing the triaxial compressive strength tests at different σ_3 and β^o as a representative sample. After performing the tests, failure planes in specimens are matched to anisotropy planes at $\beta = 0^o$, 15^o and 30^o. At $\beta =$ propagate parallel to anisotropy planes. This failure pattern led to a crashed rock specimen. Thus, at the anisotropy angles of less than 30, the shear failure pattern of tested rock specimens is affected by anisotropy planes, whereas at the anisotropy angles of more than 45, the failure pattern of tested rock specimens is usually controlled by the shear failure mechanism in intact rock.

Correlation curves between shear strength parameters (C and Φ^o) and anisotropy angles (β^o) are presented in Figure 8 and Figure 9. For tested rocks, the maximum values of cohesion and friction angles were obtained at $\beta = 75^o$ and $\beta = 0^o$, respectively, whereas the minimum values of cohesion and friction angle were obtained at $\beta = 0^o$ and $\beta = 60^o$, respectively.

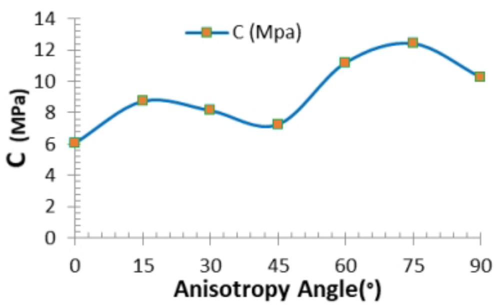


Figure 8. Variation of cohesion with angle β^o.

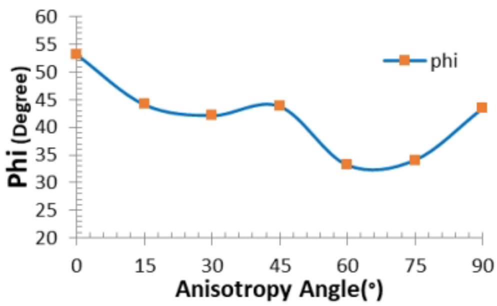
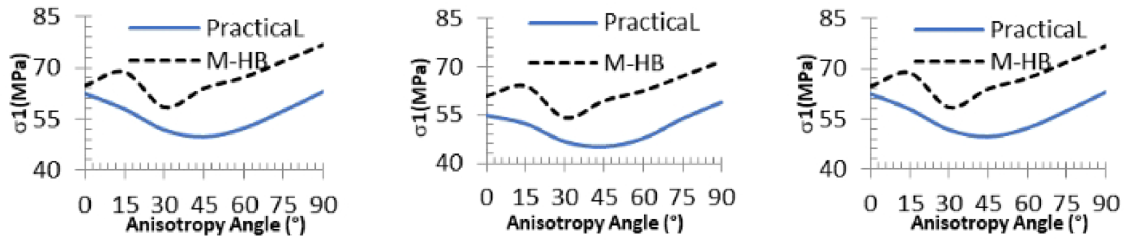


Figure 9. Variation of friction angle with angle β^o.

3.3 Analysis Using Theoretical Background

In present investigation, Experimental results were compared with the both Mohr-Coulomb and modified Hoek-Brown (2016) criterion. The effect of anisotropic behavior is considered in Modified Hoek-Brown criterion. The variation of experimental and theoretical major principal stress is shown in Figure 10.



(a) (b) (c)

Figure 10. Comparison of experimental and theoretical major principal (σ_1) a) 1MPa b) 2MPa c) 3MPa.

4 CONCLUSIONS

The research study was set out to identify the strength anisotropic and deformation responses of Chamoli (Uttarakhand) rock, and the following inferences were drawn:

- For Chamoli rock, when natural foliation plane is increased from 0° to 90° the percentage increment in cohesion(C) with respect to 0°(6.05 MPa) is 44.31%, 34.56%, 19.63%, 85.16%, 105.65% and 70.02% while the percentage decrement in angle of internal friction(Φ^0) with respect to 0°(53.22°) is 17.03%, 20.79%, 17.62%, 37.59%, 35.95% and 18.39%.
- The Ultrasonic pulse velocity test data indicate the P-wave and S-wave getting high velocity for wave propagating parallel to foliation and significantly lower velocities 75° to it.
- Triaxial test data reveals, the value of Young modulus (E) for confining pressure of 1 MPa varies from 20.26 – 27.34 GPa, for 2 MPa varies from 23.58 – 30.43 GPa, and for 3 MPa it varies from 25.39 – 33.86 GPa for different anisotropic angle.
- The percentage error in experimental and theoretical (MHB) value of major principle stress at 1 MPa varies from 8.08 – 22.50%, at 2 MPa varies from 9.67 – 23.68% and at 3 MPa varies from 3.18 – 21.92%. The percentage error shows that the theoretical value of major principle stress which is calculated by the Modified Hoek-Brown theory is overestimated.
- Failure patterns in tested specimens under confined conditions are matched to anisotropy planes at all anisotropy angles from 0°to 30°. At anisotropy angles from 45° to 90°, failure planes are not matched to the anisotropy planes.

This present study confirm that the Chamoli rock shows anisotropic behaviour on shear strength parameters and failure mode. The above anisotropic behaviour of Chamoli rock are consider during the slope stability (slope cutting and slope nailing) design. This study not only revolve experimental work using a triaxial set-up its validity and comparison are closely well with known modified Hoek-Brown criteria further suggesting that consider the mineral effect for better study of strength parameters and failure path. Which are helpful for conservative, safe and economical design of Chamoli region.

ACKNOWLEDGEMENTS

With gratitude, I would like to thank thankful to Prof. Dr. R. K. Gajjar, Principal, L. D. College of Engineering, Ahmedabad and Dr. C S Sanghvi, Head of Applied Mechanics Department, L.D. College of Engineering for providing all necessary testing facilities for the fulfillment of this research work.

REFERENCES

Allirote D, Boehler JP (1970) Evaluation of mechanical properties of a stratified rock under confining pressure. Proceedings of the fourth congress on. I.S.R.M., Montreux, vol. 1, pp. 15–22.

Auden, J.B., 1937. Structure of the Himalaya in Garhwal, Rec. Geol. Surv. India., 71, vol. 4, pp. 407-433.

Barla G (1974) Rock Anisotropy, Theory and laboratory Testing.In: Muller L (ed) Rock mechanics. Springer, New York, pp 131–169.

Basu A, Mishra DA, Roy Chowdhury K (2013) Rock failure modes under uniaxial compression, Brazilian and point load tests. Bull Eng Geol Environ 72:457–475.

Colak K, Unlu T (2004) Effect of transverse anisotropy on the Hoek–Brown strength parameter 'mi' for intact rocks. Int J Rock Mech Min Sci 41:1045–1052.

Cvetkovic SM (1993) Static and dynamic properties of gneiss as a function of foliation. In: Anagnos-topoulos et al. (eds) Geotechnical engineering of hard soils–soft rocks, vol. 1, pp. 63–67.

Esamaldeen A, Wu G, Zhao Z, Jiang W (2014) Assessments of strength anisotropy and deformation behaviour of banded amphibolies rocks. Geotech Geol Eng 32:429–438.

Gairola, V.K., 1975. On the petrology and structure of the Central Crystallines of the Garhwal Hima-laya. Him. Geol., vol. 5, pp.455-468.

Gairola, V.K., and Srivastava, H.B., 1982. Structure and deformation history of a part of Dudhatoli Syn-form around Srinagar, District Pauri Garhwal, U.P. Mitt. Geol. Ist. ETH Zurich, Neue Folge, 239a, pp. 106-108.

Ghazvinian A, Geranmayeh Vaneghi R, Hadei MR (2012) Behavior and failure mechanism of angoran schists under uniaxial compression loading. In: Rock Engineering and technology for sustainable underground construction. EUROCK 2012—ISRM International Symposium.

Goshtasbi K, Ahmadi M, Seydi J (2006) Anisotropic strength behavior of slates in the Sirjan-Sanandaj Zone. J S Afr Inst Min Metall 106(1):71–76.

Karakul H, Ulusay R, Isik NS (2010) Empirical models and numerical analysis for assessing strength anisotropy based on block punch index and uniaxial compression tests. Int J Rock Mech Min Sci 47(4):657–665.

Kumar, G., and Agarwal, N.C., 1975. Geology of the Srinagar- Rudraprayag area (Alaknanda Valley), Chamoli, Garhwal and Tehri-Garhwal District, Kumaun Himalaya, U.P., Him. Geol., vol. 5, pp. 29-59.

Middlemess, C.S., 1885. A fossili ferous series in the Lower Himalaya in Garhwal. Rec. Geol. Surv. In-dia. vol. 18, pp. 73-77.

Middlemess, C.S., 1887. Crystallines and metamorphic rocks of the Lower Himalaya, Garhwal and Kumaun., Rec. Geol. Surv. Indian, vol. 20(3), pp. 134-143.

Nasseri MHB, Rao KS, Ramamurthy T (2003) Anisotropic strength and deformational behaviour of Himalayan schists. Int J Rock Mech Min Sci 40:3–23.

Oldham, R.D., 1883. Note on geology of Jaunsar and the Lower Himalaya. Rec. Geol. Surv. India, vol. 16(4), pp. 193-198.

Oldham, R.D., 1888. Some notes on the geology of northwest Himalayas. Rec. G.S.I., vol. 12, pp. 149-167.

Omid S, Rashid GV, Vamegh R, Raoof G (2013) A modified empirical criterion for strength of transversely anisotropic rocks with metamorphic origin. Bull Eng Geol Environ.

Plinninger RJ, Alber M (2015) Assessment of intact rock strength in anisotropic rock—Theory, experiences, and implications on-site investigations. In: Schubert W (ed) Proceedings of the ISRM.

Ramamurthy T (1993) Strength modulus response of anisotropic rocks. In: Hudson JA (ed) Compressive rock engineering 1. Pergamon, Oxford, pp. 313–329.

Singh M, Samadhiya NK, Kumar A, Kumar V, Singh B (2015) A nonlinear criterion for triaxial strength of inherently anisotropic rocks. Rock Mech Rock Eng 48:1387–1405.

Singh J, Ramamurthy T, Venkatappa RG (1989) Strength anisotropies in rocks. Ind Geotech J 19:147–166.

Srivastava, H.B., Thomas, T., and Tripathi, R.N., 2003. A petrographically approach to strain estimation in deformed rocks; example from granitic gneisses of a part of Almora Synform Garhwal Lesser Himalaya. Mem. Geol. Soc. India, vol. 52, pp. 427-446.

Usol'tseva O, Tsoi P, Semenov V (2017) The influence of anisotropy angle on the strength and deformation properties of artificial geo-materials and rocks. Procedia Eng 191:512–519.

Yin P-F, Yang S-Q (2018) Experimental investigation of the strength and failure behaviour of layered sandstone under uniaxial compression and Brazilian testing. Acta Geophysics 66:585–605.