Challenges to study the Anisotropic Rocks using index tests in the Himalaya Region: A review from the Nepal Himalaya

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Abstract. The Himalayas is one of the world's most tectonically active zones and its component rocks have faced multiple stages of the deformations like folding, faulting and fracturing due to the continent-continent collision and is still continuing. There are many challenges to study the anisotropic rocks like block sampling for coring of rocks, core sampling, core loss, inconsistent failure patterns and difficulties during the comparative analysis and assessment of geotechnical properties. From fieldwork to lab work and comparison analysis issues and problems are described in this paper. Two index tests i.e. uniaxial compressive strength test and point load index test were conducted. This study is an effort to give a factual presentation of the challenges while studying the anisotropic rocks in the Himalayan region although the rock samples are from the Nepal Himalaya only. However, the samples are chosen to cover all metamorphic regions of the Himalayas i.e. the Lesser and the Higher Himalayan region.

1. Introduction

The Himalayan region exhibits low to highly anisotropic rocks as it has faced many tectonic activities like the Gorkha Earthquake 2015 (Mw 7.8 by United States Geological Survey) occurred at 11:56 am local time (UTC + 05:45) on April 25. In the Himalayan region, rocks are strongly folded, fractured, brecciated, and even pulverized due to the temperature, fluids and high-stress rates. With multiple stages of folding, faulting and recrystallization, the Himalayan rocks are laminations and foliations forming the layering. The fabric elements present in such types of rocks are preferably oriented which is known as anisotropy [1–8]. Anisotropy implies different properties in regards to the orientation of the fabric elements e.g. presence of micaceous minerals along with the bedding, stratification, layering, fissuring or jointing etc. Layers of micaceous minerals with quartz and feldspar exist in Nepal Himalayan rocks such as gneisses, however, quartz and feldspar do not have preferred orientations in the fabric of rocks.

Due to the preferred orientation of micaceous minerals, there is a significant departure of physical properties of such rocks along and across the foliation that results anisotropy pronounced. The anisotropy is particularly manifested in geotechnical properties owing to such foliation and preferred orientations of minerals. The strength and deformation behaviour of anisotropic and fractured rock masses is a key issue for design and stability evaluations of rock engineering structures; hence the anisotropic nature of rocks is a highly concerned interest in many engineering applications [9,10].

This paper reviews the challenges or difficulties faced during the study of the Himalayan Anisotropic rocks. The selection of anisotropic rocks is chosen based on the geology, accessibility, and characteristics of the rocks by reviewing the various works in the geology of Nepal Himalaya.
The rocks investigated are augen gneiss, granitic gneiss, and greenschist from the Lesser and Higher Himalaya of Central Nepal (Figure 1).

This study gives a scenario of challenges faced to study geomechanical behaviour of the anisotropic rocks from field to lab study. Some crucial points regarding block sampling for coring of rocks, core sampling, core loss, inconsistent failure patterns and difficulties during the analysis of couple of physical properties like uniaxial compressive strength (UCS) and point load strength index (PLI) in anisotropic rocks study are presented in this paper.

2. Anisotropy of the rocks and index tests

The UCS test is a common laboratory testing method used to access the mechanical properties of the rock in which the stress applied is unidirectionally [15]. The testing methods for the UCS test are ISRM [15] and ASTM [16]. Similarly, the PLI test is an indirect tensile strength test where stress is applied by the point in the sample of rock [17]. The testing methods for the PLI test are ISRM [17] and ASTM [18].

In the case of the anisotropy, Ramamurthy [5] and ISRM [17] described that the strength anisotropy index is defined as the ratio of mean UCS or PLI values measured perpendicular and parallel to planes of weakness, i.e., the ratio of greatest to least UCS or PLI which can be visualized in Figure 2. In Figure 2, three types of curve namely ‘U-shaped’, ‘shoulder shaped’ and ‘wavy shaped’ is obtained during the study of strength and modulus responses of anisotropic rocks during the uniaxial compressive strength with respect to orientation angles. During the reviewing of the challenges or problems faced, the study of the anisotropic rocks is essential so that the study is done according to the Ramamurthy [5] for UCS test and ISRM [17] for PLI test.

For the UCS test, Ramamurthy [5] defined variation of strength in uniaxial loadings (Figure 2) and classified that the variation of strength in uniaxial conditions of intact rock regarding the loading conditions of intact rock concerning the loading angle, \( \theta \) (Table 1) is defined as the strength anisotropy, \( R_c \) as

\[
R_c = \frac{\sigma_{ci\,(90)}^{(\text{UCS})}}{\sigma_{ci\,(\text{min})}^{(\text{UCS})}}
\]

Where \( \sigma_{ci\,(90)} \) is the uniaxial compressive strength perpendicular to the planes of anisotropy, and \( \sigma_{ci\,(\text{min})} \) is the minimum value of \( \sigma_{ci\,(\text{min})} \) obtained from oriented under uniaxial angle variations compression, usually occurring at when the loading axis forms an angle to the foliation between \( \theta = 30^\circ \) and \( 45^\circ \).
Table 1. Standard anisotropic classification of UCS by Ramamurthy [5].

| Degree of compressive strength anisotropy, $R_c$ | Descriptive term          |
|------------------------------------------------|---------------------------|
| 1.0-1.1                                        | Isotropic                 |
| 1.1-2.0                                        | Fairly anisotropic        |
| 2.0-4.0                                        | Moderately anisotropic    |
| 4.0-6.0                                        | Highly anisotropic        |
| $>$6.0                                         | Very highly anisotropic   |

The classification of anisotropy (Table 2) for the PLI test is earlier than the UCS anisotropic classification by Ramamurthy [5]. Although Equation 1 is for the UCS test, it is the same in the case of PLI also that is suggested by ISRM (1985). Table 2 is followed in the study of anisotropic rocks for both axial and diametral index tests.

Table 2. Classification of anisotropy according to point load strength index, (ISRM, [17]).

| Degree of point load strength anisotropy, $I_{a(50)}$ | Descriptive term          |
|-----------------------------------------------------|---------------------------|
| 1                                                   | Quasi-isotropic           |
| 1.0-2.0                                             | Fairly moderately anisotropic |
| 2.0-4.0                                             | Highly anisotropic        |
| $>$4.0                                              | Very highly anisotropic   |

3. Methodology

This study is focused on the challenges faced during the geotechnical characterisation of anisotropic rocks. The difficulties from fieldwork to all lab works are pointed out. In order to review the field to lab-scale work and experiments that have become essential for the characterization of challenges, two index tests i.e. UCS and PLI tests are selected for the study. The UCS test was conducted as suggested by ISRM [15] in which the diameter is 51mm and the height is 102±10mm. Similarly, the PLI test was done as suggested by ISRM [17]. The diameter is the same as in the UCS test with the $H/D$ ratio is 2-2.5 and the $H/D$ ratio for the axial PLI test of 0.35 to 0.7 and for the diametral PLI test of 1.0 to 1.3.

Difficulties from characterizing and screening of block samples to core samples from the field to lab and lab testing are reviewed and presented here. Here, laboratory-scale experiments are essential to conclude the study so that samples are collected in the form of the rock blocks in the site areas. The rock blocks are fitted to the base of the laboratory drilling machine to facilitate coring at different angles (Figure 3). Here, data gathered from field to lab work and testing is examined by avoiding errors in order to present an accurate scenario for the study of the Himalayan anisotropic rocks.
4. Challenges in the study of the Himalayan Anisotropic Rocks
The challenges faced during the study of the anisotropic Rocks using index tests in the Himalaya Region regarding the Nepal Himalaya are described in the following sub-headings.

4.1. Challenge encountered for cutting the blocks from the rock mass
It is one of the toughest physical challenges for anisotropic rocks. Before coring, the rocks in the lab, the blocks should be extracted from the in-situ conditions. The study of Figure 3 is the representation of the coring of blocks from in situ conditions for perfect coring was made. An attempt to extract the blocks in the perfect cube size however there is uneven fracturing of the block due to the foliated and laminated nature of the rocks, during cutting of the blocks. The block samples could not cut in the perfect cube that affects the required sample sizes of the cores. In addition, many block samples are needed for meeting the selected target samples numbers for the study of the anisotropic rocks that gives too much physical work stress during the coring of the samples. It is very time consuming and the biggest issue that we faced during the study samples in the lab for the index tests.

![Figure 3. Coring of the block samples for lab testing for the selected index tests.](image)

4.2. Recovery of the cores during the study
The recovery of the cores is another major issue during such study especially, for phyllites and schist type of rocks than gneiss. Gneisses have high recovery than other rocks types, if not weathered. The Nepal Himalaya is one of the belts where fractured, weathered, jointed, faulted, sheared, crushed and folded rocks are encountered. This places constraints on the extraction of cores as can be seen from Figure 4.

![Figure 4. Nature of the cores extracted in anisotropic rocks in the Nepal Himalaya during exploratory drilling.](image)

The rock in Figure 4 is the sericite- chlorotic green to grey, fine to medium-grained schist. It is medium to strongly laminated, jointed and highly fractured with an excessive amount of quartz veins which make less recovery of the core and very less rock quality designation (RQD). According to the
suggested diameter ≥ of 51mm by ISRM [15] for the UCS test, the height of the sample should be ≥102 mm to meet the ratio of $H/D = 2.0-2.5$ that is directly related to the $RQD$ of the core samples. This means the higher $RQD$ class of the rocks gives the number of samples that are more than 10 cm. From Figure 4, recovery of the core box is

\[
\text{Recovery} = \frac{\text{Total length of core recovered}}{\text{Total length of core run}} \times 100
\]

\[
Recovery = \frac{319.75}{550} \times 100 = 58.14\%
\]

And, the $RQD$ of Figure 4 according to Deere & Deere (1989),

\[
RQD = \frac{\sum \text{Length of core pieces} > 10 \text{ cm length}}{\text{Total length of core run}} \times 100
\]

\[
RQD = \frac{12.4 + 10.02 + 10.16 + 11.09 + 13.86 + 24.67 + 28.1 + 13.46 + 19.93}{550} \times 100 = 26.13\%
\]

The obtained value is very less $RQD$ which is in the poor class according to the Bineawaski [19]. If there will be less $RQD$, the obtained core samples do not meet the standards of the index testing methods, especially for the UCS test. In Equation (4), there are 9 samples which are ≥102 mm. Among them, the samples having the length of 10.02 cm and 10.16 should be reduced because the size will be decreased during the cutting and smoothing of the edges so that only 7 samples (123.51 cm) can be used for the UCS tests. In general, 550 cm of the total core run only 123.51 cm is usable and are without the microfractures, pores, partitions and defects, present in the core samples. This situation presents another core studying the anisotropic rocks.

4.3. Inconsistent failure patterns
Mostly, the fracturing of the Himalayan anisotropic rocks is triggered along planes of weakness plane present in it on the application of load during testing. However, many failure patterns of a very indistinct nature are particularly seen in PLI tests. Some examples of such failure patterns are shown in Figure 5. Since, in the case of PLI tests, the load is concentrated over a point. This leads to breakage of the sample along the anisotropic or other inconsistent planes which may not conform to the conspicuous nature of the samples as shown in Figure 5.

![Figure 5](image-url)

Figure 5. Inconsistent failure modes of the samples by PLI test.

The strength nature along the planes of weakness results in a completely different strength nature than the planes of weakness is normal to them that has a significant impact on PLI failure modes.
4.4. Comparison of the results between the index tests

The influence of loading angles on the foliation (anisotropy) plane on the rock strength has been extensively analysed. The challenges experienced during the comparison of results between the index test regarding this study in the anisotropic rocks will be discussed here.

Figures Figure 6, Figure 7 and Figure 8 represents the test data of UCS, PLI axial and diametral test of selected samples according to the individual rock types. In the UCS test, minimum strength is obtained in the 30˚-40˚ and maximum on the 90˚ loading angle with respect to foliation. Similarly, this phenomenon is observed in the point load axial test in which minimum strength is obtained in the 45˚ and maximum on the 90˚ loading angles with respect to foliation. But in the case of the diametral test, minimum strength is obtained in the 90˚ and the maximum at 0˚ loading angles with respect to foliation. This type of different characteristics is affecting anisotropic index and anisotropic classification in the same rock types from the same location in different index tests which are noticed in Table 3.

Table 3. Anisotropic index determination and anisotropic classification for data of the Himalayan anisotropic rocks according to the Ramamurthy [5] for UCS and ISRM [17] respectively.

| Test               | UCS | PLI Axial | PLI Diametral |
|--------------------|-----|-----------|---------------|
| Rock type          | Rc  | $I_{a(50)}$ | $I_{u(50)}$   |
|                    |     | Anisotropic classification | Anisotropic classification | Anisotropic classification |
| Augen gneiss       | 2.34| 2.45       | 28.00         |
|                    |     | Moderately anisotropic      | Highly anisotropic         | Very highly anisotropic    |
| Granitic gneiss    | 2.47| 2.44       | 5.74          |
|                    |     | Highly anisotropic          | 12.67                      |
| Green schist       | 2.40| 2.93       |               |

Table 3 is the overall comparison of the anisotropic index tests obtained from Figure 6, Figure 7 and Figure 8. It shows that the anisotropic index value and classification have a very wide variation in
tested samples although the same rock types at the same locations are tested. The variances in the anisotropic index and anisotropic classification by the UCS and PLI tests of the same samples from the same location are large enough to suggest that there are variations between the results of the anisotropic rocks regarding index tests that are shown by the comparison results from Table 3. This places a serious constraint on test up, interpretation and application of such values in engineering design if used blindly.

5. Conclusions
The Himalayan region precoats rocks with a low to highly anisotropic nature. The mountains have undergone many tectonic activities i.e. several folding, faulting and recrystallisation cycles. The Nepal Himalaya is the one belt of the Himalaya region where rocks are mainly sheared, jointed, folded, and faulted. As a result, studying metamorphic (anisotropic) rocks in the Himalayas is difficult and fraught with difficulties. The issues are highlighted in this study of Nepal Himalayan anisotropic rocks from the same location with the same rock types that are characterized in terms of UCS and PLI.

Although the anisotropic behaviour of the rocks has many complications, the major challenges faced are cutting the blocks from the rock mass, recovery of the cores from field exploratory drilling and blocks, inconsistent failure patterns and significant variability of results of the index tests. The issue encountered for cutting the blocks from the rock mass is too much physical work stress due to uneven fracturing during the cutting of block due to foliated and laminated properties of the rocks. During the coring of the samples, recovery and RQD are less due to folding, fracturing, jointing etc. In such rocks meeting the standards of the index test testing methods thus becomes difficult. Another issue is the plane of weakness present in the anisotropic rocks gives inconsistent failure modes on the point load index tests. Lastly, a comparison of the results between the index tests has a very wide variation in the anisotropic index classification.

This indicates that application of limited tests of UCS/PLI without considering these effects may severely impact the bearing capacity calculated for modelling rock response in underground excavations. This study emphasises the need to revisit up the testing standards and specifying their use and correlations in case of the Himalayan anisotropic rocks.

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