Study on Poisson's Ratio Anisotropy of Foliated Metamorphic Rocks of Central Nepal

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Abstract: Poisson's ratio, defined as the negative ratio of transverse to axial strain under uniaxial stress, quantifies the lateral deformation behavior of materials and is crucial for analytical and numerical modeling in engineering. In metamorphic rocks, Poisson's ratio exhibits strong anisotropy due to foliation orientation related to applied axial stress. This study experimentally investigates the Poisson's ratios of fine-grained slate, medium-grained metasandstone, and coarse-grained Higher Himalayan banded gneiss from the Lesser Himalaya, Central Nepal. A total of 157 specimens, cored at varying angles to foliation planes, were tested under uniaxial compression. Results reveal orientation-dependent maxima and minima in Poisson's ratio, controlled by foliation, grain size, and mineral composition.

Keywords: ***Poisson's ratio, Anisotropy, Foliated rock.***

Introduction

Poisson's ratio (ν) is a fundamental material property defined as the negative of the ratio of transverse strain (ε_{trans}) to axial strain (ε_{axial}) when an isotropic material is subjected to uniaxial stress (Christensen, 1996; Gercek, 2007; Poisson, 1829; Timoshenko and Goodier, 1970; Wang and Ji, 2009):

$$\nu = -\frac{\varepsilon_{axial}}{\varepsilon_{trans}}$$

It characterizes how a material laterally deforms when subjected to axial loading and is indispensable in structural, geotechnical, and rock mechanics engineering. In isotropic materials, Poisson's ratio is uniform in all directions. However, metamorphic rocks often exhibit foliation and layering, introducing mechanical anisotropy that significantly affects elastic and inelastic deformation behaviors. Accurate characterization of Poisson's ratio in foliated rocks is therefore essential for predicting deformation, stability, and failure in engineering structures, tunnels, slopes, and underground excavations.

Previous studies on anisotropic Poisson's ratio using unconfined compressive tests in metamorphic rocks such as slate (Saeidi et al., 2014), gneisses, schists, and slates (Cho et al., 2012; Kim et al., 2012), schists (Zhang et al., 2011), gneiss, and phyllite (Wu et al., 2020) have highlighted the effect of foliation orientation, mineral composition, and grain size on the mechanical properties of metamorphic rocks. Despite its importance, detailed experimental investigations of Poisson's ratio in fine-grained slate, medium-grained metasandstone, and banded gneiss in the Lesser Himalaya remain virgin. This study aims to fill this gap by conducting systematic uniaxial compression tests on specimens cored at various anisotropic angles to foliation planes.

Geological and Material Background

The Lesser Himalaya, Central Nepal, comprises a diverse assemblage of metamorphic rocks, ranging from low-grade slate to medium-grade metasandstone and high-grade banded gneiss.

- Fine-grained slate exhibits pronounced foliation due to alignment slaty cleavage layering in planes oriented to the direction of metamorphic compression, indicating the strong anisotropy.
- Medium-grained metasandstone contains quartz-rich grains cemented with mica and feldspar, showing intermediate anisotropy.
- Higher Himalayan banded gneiss features course grained foliated metamorphic rock, derived from platy phyllite, as a product of the high grade metamorphism and formed alternating light and dark mineral bands with coarse grain size, representing high-grade metamorphism and complex foliation.

Experimental Methodology

A total of 157 cylindrical specimens were cored from intact rock blocks, maintaining a height-to-diameter ratio of 2–2.5. The specimens were oriented at different angles (β = 0° to 90° at 10° intervals) relative to the foliation plane, capturing the full range of anisotropic behavior. Care was taken to ensure flat, parallel ends and minimal surface irregularities to reduce experimental artifacts. Uniaxial compression tests were conducted according to ASTM D7012-14ε1 (2015) standards for measuring mechanical properties of rock specimens. Axial load was applied using a calibrated automatic hydraulic testing frame, and both axial and lateral strains were recorded using strain gauges mounted orthogonally. Three forms of Poisson's ratio were calculated for each specimen: Secant, Tangent and Average Poisson's ratio.

Results

The experimental results indicate a clear dependency of Poisson's ratio on foliation orientation:

- Fine-grained slate: Maximum Poisson's ratio observed at 60° relative to foliation; minimum at 30°.
- Medium-grained metasandstone: Maximum at 40°, minimum at 30°.
- Banded gneiss: Maximum at 50°–70°, minimum at 30°.

Lateral deformation peaks at intermediate angles to foliation and is minimized when loading is parallel or perpendicular. Slate shows the strongest Poisson's ratio anisotropy; metasandstone moderate; banded gneiss intermediate. Secant and average Poisson's ratios align well in the elastic range for design use. Tangent Poisson's ratio reflects early-load anisotropic response and microcrack initiation.

Discussion

Anisotropic Poisson's ratio significantly affects numerical modeling of rock masses, slope stability, and underground excavation design. Overestimating or underestimating lateral strain can result in inaccurate predictions of stress distribution, crack propagation, and deformation patterns.

- Tunnels and underground structures: Foliation orientation should guide tunnel axis and support design.
- Slope stability: Accurate Poisson's ratios inform stress-strain calculations in rock slopes.
- Finite element and boundary element modeling: Incorporating anisotropic Poisson's ratio improves simulations of rock mass response to uniaxial and triaxial loading.

The observed maxima around 50°–70° and minima around 30° reflect a combination of foliation, mineral alignment, and grain size effects. Fine-grained, highly foliated rocks show more pronounced variation, highlighting the importance of material-specific characterization in engineering design.

Conclusion

Poisson's ratio in Lesser Himalayan metamorphic rocks shows strong anisotropy controlled by the angle between loading and foliation, with maximum lateral deformation at intermediate angles (50°–70°) and minimal strain when loading is near parallel or perpendicular. Secant, tangent, and average Poisson's ratios each capture different aspects of this behavior, aiding accurate modeling. Mechanical response is further influenced by grain size, mineralogy, and foliation geometry, highlighting the need for site-specific testing. These findings support improved structural design, slope stability evaluation, and excavation planning in foliated terrains.

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