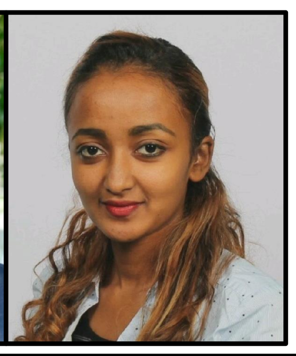

# Impact of Layering in Buckinghorse Shale on Strain Measurement Using Digital Image Correlation (DIC)

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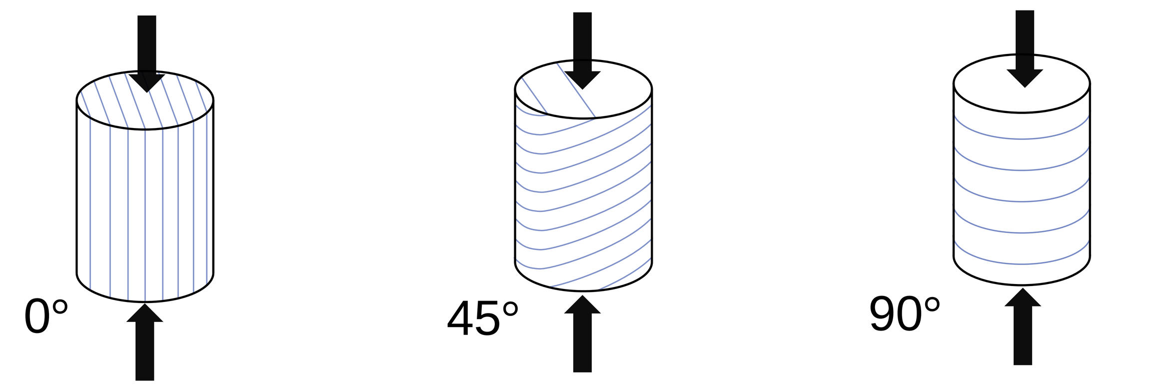
## BACKGROUND

The varying stiffness of pre-existing fractures and material layering can have significant effects on strain measurement of laboratory samples (Bandis et al., 1983; Homand et al., 1993). Strain measurement during laboratory testing requires careful placement and critical interpretation to ensure that the material deformation response is accurately characterized (Abdelaziz and Grasselli, 2021).

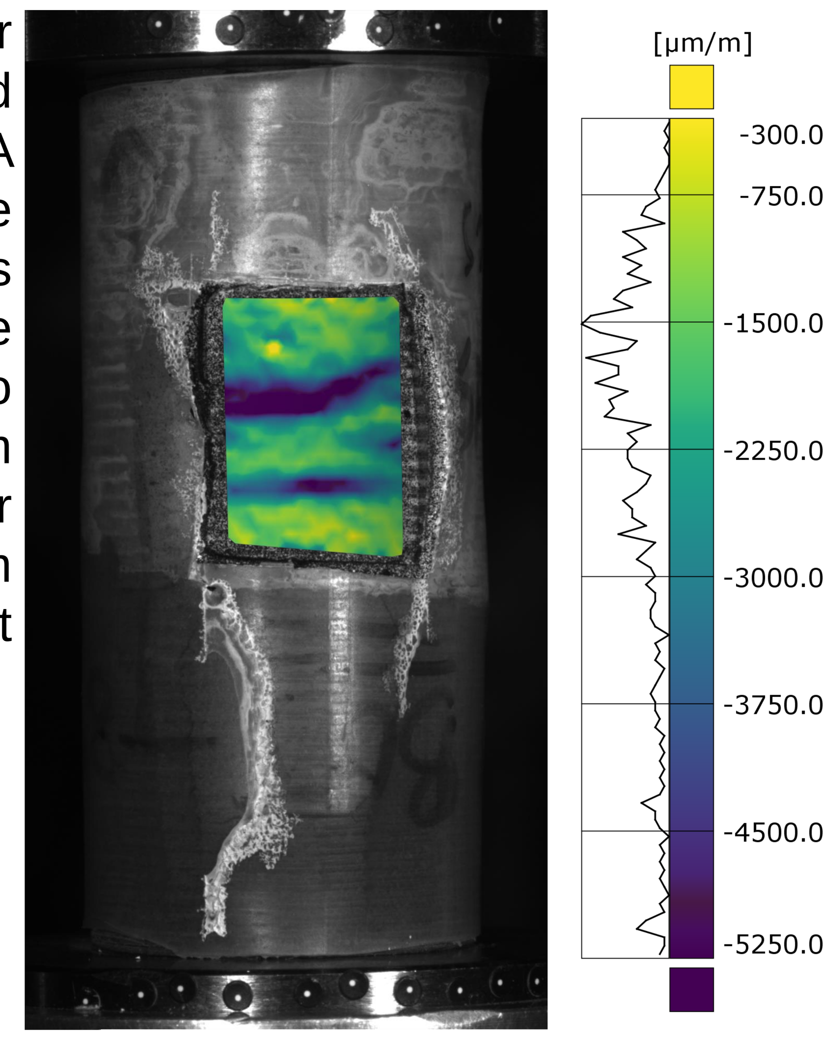
Despite careful planning and interpretation, the produced strain data may still be unexplainable without more detailed information about the sample deformation as strain measurement methods such as strain gauges and linear variable differential transformers (LVDTs) lack a comprehensive view of the sample's mechanical response. To track variation in deformation, digital image correlation (DIC) was used to measure the strain field of various unconfined compressive strength (UCS) tests on Buckinghorse shale. This method of strain measurement allows for continuous deformation tracking over an imaged sample area, providing the ability to see local strain developments that may appear and disappear with time.

## EXPERIMENT METHODOLOGY

UCS tests were performed on 25 mm diameter Buckinghorse shale samples. Samples were wrapped in shrink tube to retain their shape after failure. A window was cut in the shrink tube to expose the surface for DIC pattern application and acquire images during testing at 2 Hz. LVDTs were used to measure the axial change in sample length during testing. To account for the system compliance, an aluminum sample was used to determine the calibration factor that matched the LVDT strain to the strain of a 20 mm virtual extensometer from DIC analysis. Three different loading orientations relative to layering were tested.



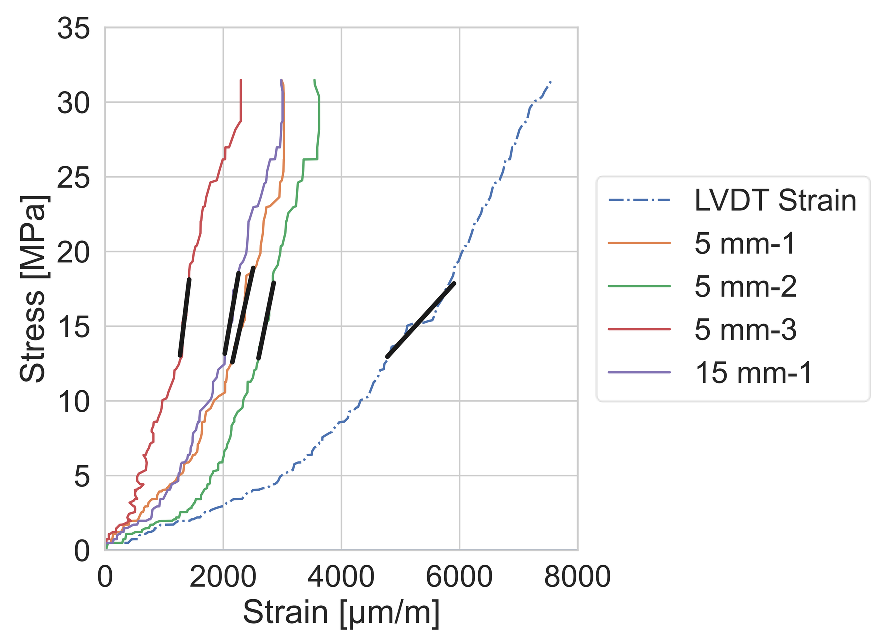

Sample layering orientations and loading directions



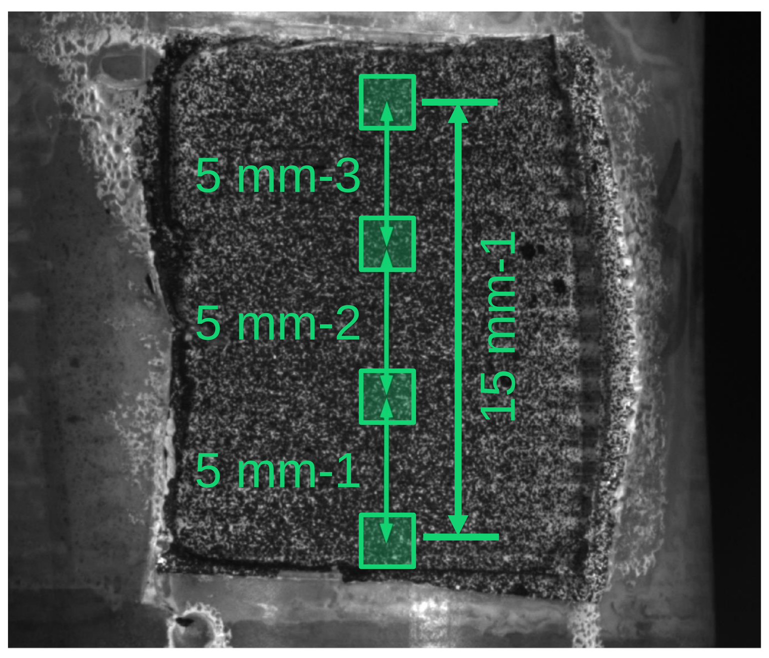

Minor strain DIC overlay on the 90° loaded UCS showing significant variation within the 10 mm x 15 mm window

## YOUNG'S MODULUS

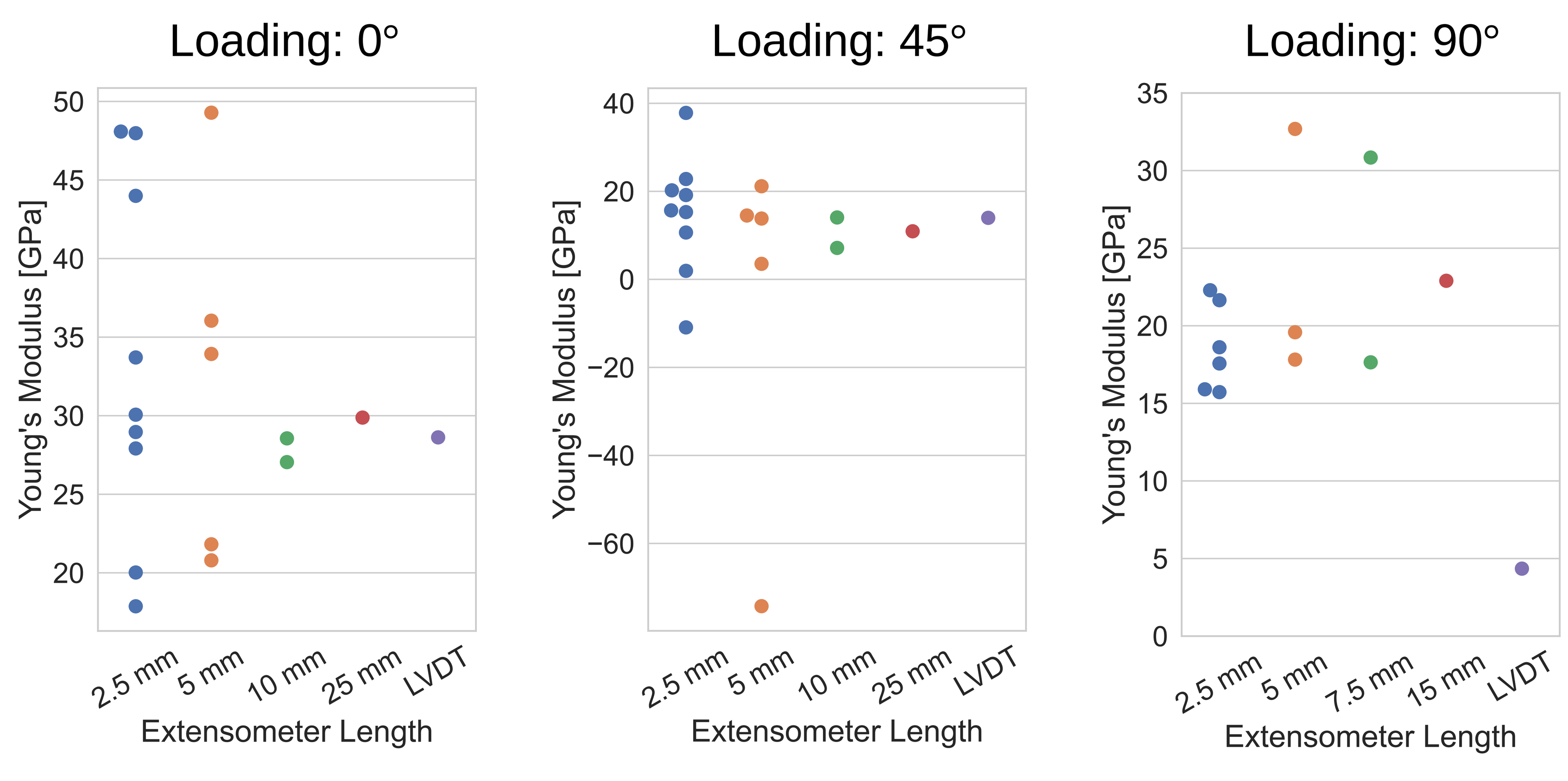
To evaluate the effect of layering, virtual extensometers of equal length were placed sequentially along the centre of the DIC window. Virtual extensometers of varying lengths were used to assess the effect of increasing measurement length. The Young's moduli were determined by linear best-fit using ±10% of the curve at 50% of the samples' strength (shown as solid black lines on the stress-strain plot). They were then compared between different loading orientations and extensometer lengths.




Example stress-strain plot for a 90° bedding sample with LVDT strain compared against 5 mm and 15 mm virtual extensometer strain; Young's modulus fitting shown by solid black lines




5 mm virtual extensometers showing tracking squares. The 15 mm virtual extensometer occupies the same tracking squares.

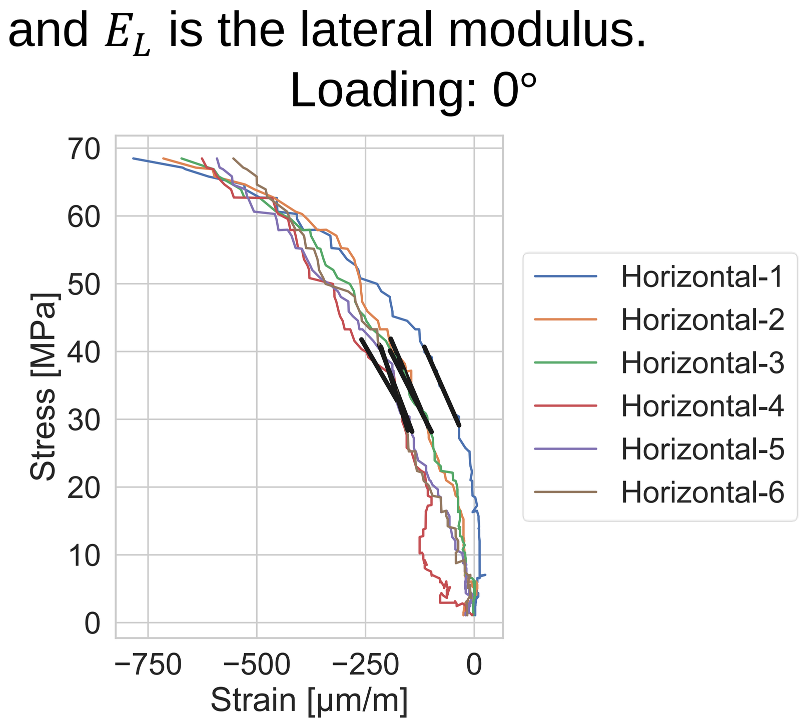


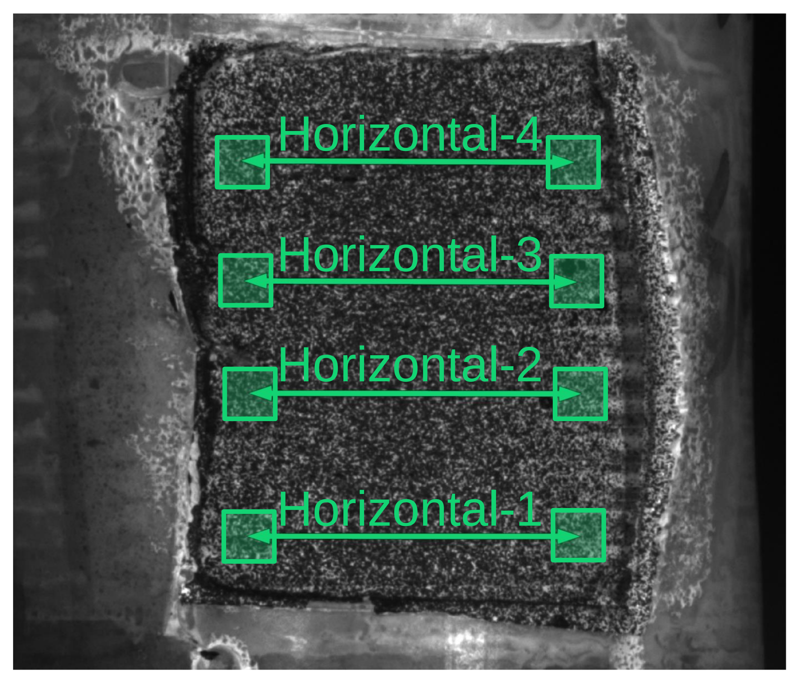

Young's modulus comparison with varying extensometer length, LVDT measurement, and loading orientation

Layering may have a significant effect on the Young's modulus based on the location of sampling and the length of measurement. The Young's modulus may have a significant spread even when measuring across large portions of the sample. Dilation may also occur locally as demonstrated by the 45° sample. As the extensometer length increases, localized effects diminish and approach the LVDT strain. The Young's modulus calculated using a whole-sample measurement method, such as the LVDT, tends to be similar to the DIC calculated one, despite the fac that the LVDT may capture deformation outside of the observed DIC window (e.g., Loading: 90°).

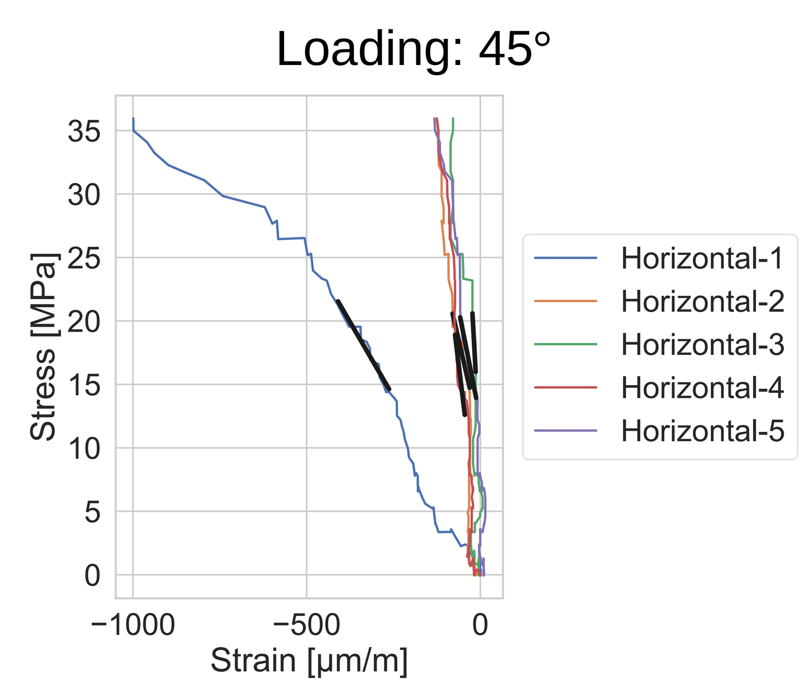
## POISSON'S RATIO

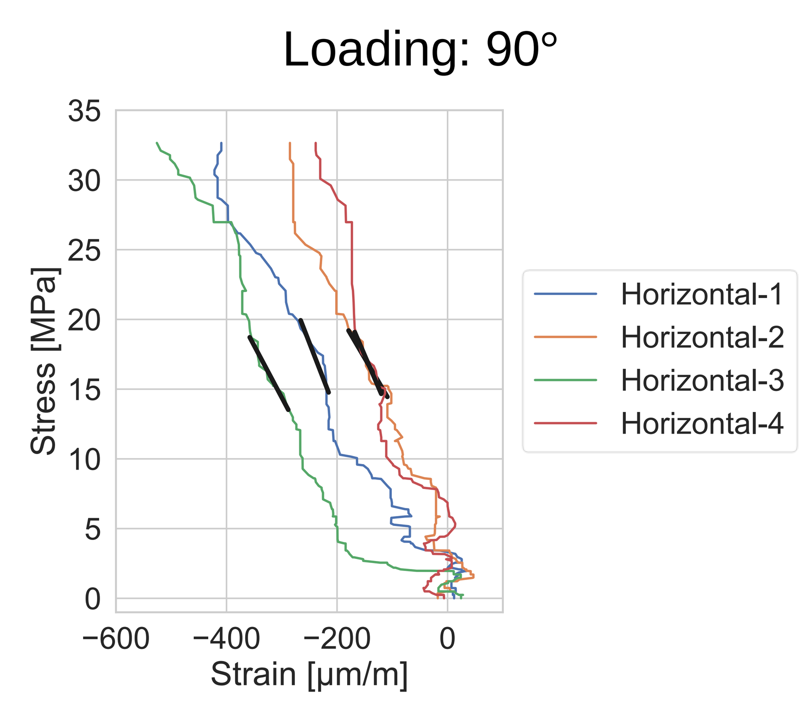
The effect of layering on the Poisson's ratio was analyzed by using horizontal virtual extensometers placed sequentially along the DIC window. Similar to the Young's moduli, the lateral moduli were determined by linear best-fit using using ±10% of the curve at 50% of the samples' strength. The average Young's moduli measured from the axial virtual extensometers were used for the Poisson's ratio calculation as $\nu = E_Y/E_L$ where $E_Y$ is the Young's modulus and $E_L$ is the lateral modulus.



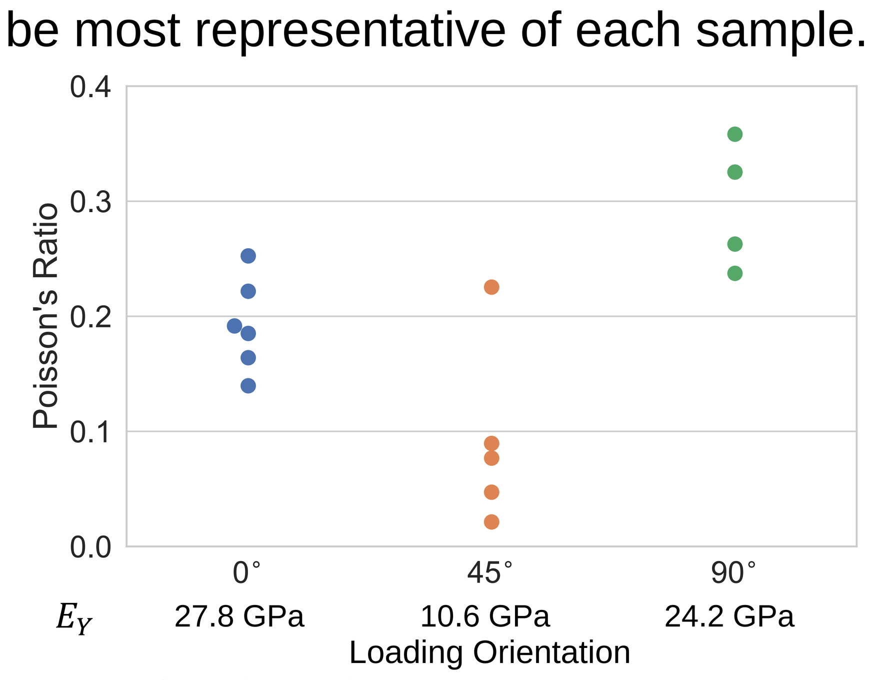

Horizontal extensometers for 90° loading with tracking squares




Horizontal extensometer stress-strain plots showing consistent deformation for 0° loading and varying deformation for 90° loading

While the spreads in the calculated Poisson's ratio appear consistent with different loading orientations, the horizontal extensometer stress-strain plots better demonstrates the deformation response history with the 0° loading path being more consistent and the 45° and 90° loading paths being less consistent. The average Young's moduli from the 10 mm and 7.5 mm axial extensometers were used for each load configuration's Poisson's ratio calculation since this length scale appeared to be most representative of each sample.




Calculated Poisson's ratio with the $E_Y$ for each loading orientation

**DIC analysis performed on layered anisotropic rocks shows that significant local variability in stiffness caused by layering may strongly influence the Young's modulus and Poisson's ratio which, consequently, affects their mechanical characterization.**

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- Bandis, S. C., Lumsden, A. C., & Barton, N. R. (1983). Fundamentals of Rock Joint Deformation. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 20(60), 249–268.
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