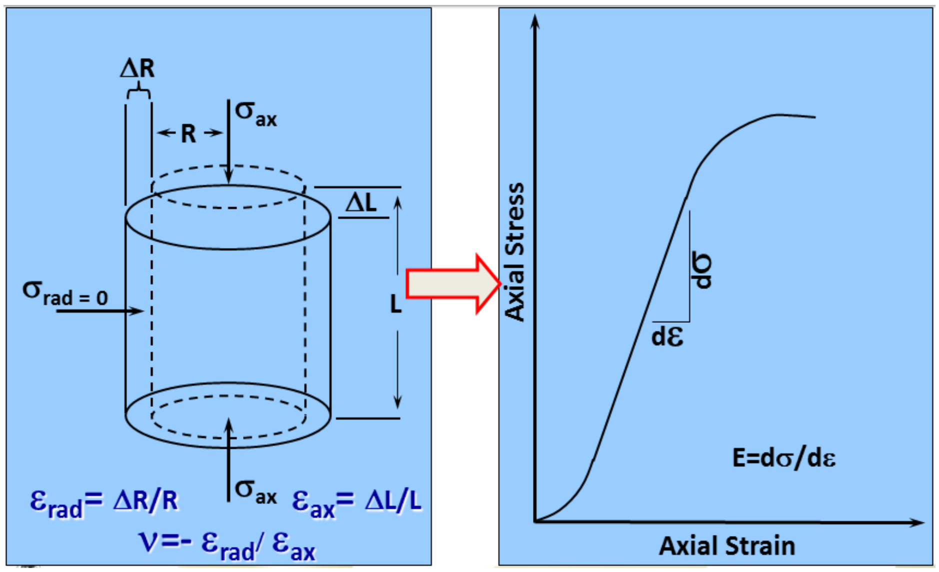
On Proper….And Not So Proper…Rock Mechanics Laboratory Testing for Young's Modulus and Poisson's Ratio in Oil & Gas Operations



When I first started working on geomechanics issues in the oil & gas in the 1980s, well before geomechanics was even widely known in oil & gas operations (and when there were still heated arguments about calling it 'geomechanics' versus 'rock mechanics'), I had the pleasure of learning the business while working on compaction and subsidence issues for Phillips' Ekofisk Field, which was the first of the great North Sea oilfields. At the time, it was very common to evaluate reservoir rock compressibility (i.e., its compactability) using a hydrostatic test in which a cubic rock sample was subjected to hydrostatic pressure (and all three principal stresses on the sample were equal). However, this did not replicate actual reservoir stress conditions and resulted, often, in significant errors in the estimation of reservoir compaction. As a result, we began using Uniaxial Compaction Tests in which a cylindrical rock sample was prevented from laterally deforming (i.e., no radial strain) as an axial load was applied. This configuration was thought to more accurately represent the stress conditions in the reservoir.

I mention this because a Uniaxial Compaction Test often employs a triaxial test cell (as used commonly today) wherein the confining pressure was constantly adjusted (mostly increased) to ensure zero lateral strain as the axial stress was ramped up. Due to the Poisson's ratio effect, as a cylindrical sample is axially stressed, it will tend to expand laterally; however, if the lateral stress (the confining pressure in a triaxial cell) is increased in the proper increments, the lateral expansion can be prevented. In fact, this concept is really the foundation for the estimation of frac gradient that I discussed in a previous post (that is, the means to evaluate frac gradient, like Eaton's approach, are based on the concept that the minimum horizontal stress, Shmin, is due to the earth acting like a Uniaxial Compaction Test where Shmin is equivalent to the confining pressure).

Amongst many other important learnings, my laboratory work on Ekofisk taught me two very key concepts related to evaluating and designing a laboratory rock mechanics test program. First, the axial stiffness in a Uniaxial Compaction Test is greater than Young's modulus. The slope of the axial stress versus axial strain curve (the definition of modulus or stiffness) for a Uniaxial Compaction Test is a 'confined' modulus, which, again, is greater in magnitude than Young's modulus. In fact, Young's modulus is only correctly determined from a uniaxial, unconfined test. The second key concept my experience revealed was that confining pressure will tend to reduce the lateral strain of a sample and, in the extreme case, sufficient confining pressure will reduce the lateral strain to zero (as intended for a Uniaxial Compaction Test). And, like Young's modulus, Poisson's ratio is only correctly determined from a uniaxial, unconfined test.

Fast forwarding to the present-day, we recently worked on a tight gas field for a client in which they had very limited rock mechanics laboratory testing data (as an aside, the increased use of physical rock mechanical testing within the oil & gas industry has been a critical, and important, trend tied to the development of Unconventional Plays). Ignoring the impact of the very limited testing for a moment, we found that the client was attempting to compare their field to common Unconventional Plays in the United States through a comparison of rock mechanics laboratory-reported Young's modulus and Poisson's ratio values (likely a consequence of the too often misunderstood and miss-applied 'brittleness' concept). While our client's data reflected very low modulus, the reported Poisson's ratio values were right in the correct range for all the big Unconventional Plays in the US. Again, while the number of samples were very limited, the tests to determine Young's modulus and Poisson's ratio followed common industry practice today wherein a triaxial test cell was used and a confining pressure (700 psi in this case) was applied.

At this point, you might wonder what my Ekofisk experience from nearly 30 year ago has to do with a client tight gas project circa 2015. As the late (and truly great) Paul Harvey would say…'here's the rest of the story'.

In the laboratory setting, static Young's modulus and Poisson's ratio (I add 'static' here since acoustic-based mechanical properties are also now commonly evaluated in the laboratory) are derived from the evaluation of the slopes of the axial stress versus axial strain curve and the slope of the axial stress versus radial strain curve. Importantly, both the International Society of Rock Mechanics (ISRM) and the American Society for Testing and Materials (ASTM) have long-established standards for proper testing procedures to ensure reliable results for Young's modulus and Poisson's ratio. The ISRM standard was most recently established in 1978 (SM, Deformability of Rock Materials), while the ASTM standard was most recently established in 2014 (ASTM D7012-14). Unfortunately, while the standards provide clear guidance on test procedures and sample preparation, they do not address the fundamental concept that Young's modulus and Poisson's ratio are defined only for uniaxial, unconfined tests and cannot be directly evaluated from triaxial, confined tests. This oversight fundamentally means that vast amounts of reported oil & gas "Young's modulus" and "Poisson's ratio" data, generated from triaxial, confined tests, are, well….bad.

Coming back to our client's data, "Young's modulus" was reported to be about 300,000 psi, "Poisson's ratio" was about 0.22, the unconfined strength, UCS, was about 2500 psi and the confining pressure was 700 psi. The Poisson's ratio value is oddly low – particularly given the very low stiffness.

Notwithstanding that the sample was not likely acting elastically, what could cause the low Poisson's ratio values? The answer is in the confining pressure. Confining pressure, just as in the Uniaxial Compaction Test, affects the amount of radial strain (where, again, the confining pressure is used to maintain a zero radial strain in the Uniaxial Compaction Test). As Poisson's ratio is defined as the amount of radial strain to axial strain, as the radial strain is reduced, Poisson's ratio is reduced (and, as in the Uniaxial Compaction Test, if the confining pressure is great enough and the radial strain is zero – the reported Poisson's ratio would be….zero!).

This brings us to two important questions: 1) Does it really matter?; and 2) Why would the labs run the tests this way?

I can emphatically say that the issue of obtaining "Young's modulus" and "Poisson's ratio" values from triaxial tests is important. In my own experience, where we have companion or near-companion Young's modulus and Poisson's ratio results from uniaxial, unconfined tests and triaxial, confined tests, the confined "Young's modulus" values were as much as 30-40% greater than the correct Young's modulus values. Poisson's ratio results were not as consistent, but a significant number of samples suggested that confined "Poisson's ratio" values could be as much as a factor of two smaller than actual values (a 0.2 reported, confined value versus a 0.4 reported, unconfined value). Interesting, the ASTM standard contains example values for Young's modulus and Poisson's ratio for several rock types under unconfined and confined conditions. This data also shows a 30-40% increase in Young's modulus with confinement, while showing inconsistent behavior for Poisson's ratio (one rock showed a decrease with confinement while two suggested no effect). Furthermore, it is critical to keep in mind the application of the laboratory rock mechanical parameters. If these parameters are to be used in numerical simulations for example, where linear elasticity is often assumed, the code expects the correct value of the elastic parameters – not values determined at some arbitrary confining pressure.

Why would the labs run the tests this way? First, the better labs work with their clients to understand what the clients' needs are and from these design a test program to meet these needs. When this is done, the types of issues I raise in this post can largely be avoided. Second, particularly for weak core samples, confining pressure is often required to obtain any test results (and the labs largely only get paid when they get results); however, in these cases the confining pressure is kept as low as possible <u>and</u> the better labs note that the reported elastic parameters are estimates only (due to the effect of confining pressure). Finally, the labs have responded to the requests of the clients who ask for elastic parameters 'under downhole stress conditions' while not understanding both the testing and simulation implications of obtaining results in this manner.

As a final comment, when I first starting seeing the common practice of reporting "Young's modulus" and "Poisson's ratio" values from triaxial, confined tests, my first thought was that I just being dense and missed something. I looked in all my geomechanics text books and no one addressed this issue…until I went back to my very first rock mechanics text book by Obert and Duvall from my first geomechanics course taught by the late Professor Charles Haas at the University of Missouri (then UMR, now MS&T). Obert and Duvall not only discussed the effect of confining pressure on the evaluation of stiffness but also provided a correction that I still use today (and I later derived the correction for Poisson's ratio). As a result, I routinely correct triaxial, confined "Young's modulus" and "Poisson's ratio" values, teach the importance of the issue in all our training courses, and work with our clients to collect enough uniaxial, unconfined data to have some hard data to correct the triaxial, confined data.