geoconvention
Calgary • Canada • May 15-19 2017

Geomechanical Characterization of a Montney Equivalent Outcrop

Scott H McKean, Mason MacKay, Dr. Jeffrey Priest
University of Calgary

Summary

A variety of geomechanical tests (point load strength, Brazilian, unconfined compressive strength (UCS), advanced triaxial, and pulse transmission) were applied to the Triassic Sulphur Mountain formation, a surface equivalent of the Montney formation. Each test is reviewed along with implications on strength, anisotropy, variability, and the Montney's response to hydraulic fracturing.

Introduction

A detailed understanding of both the static and dynamic geomechanical response throughout a sample's entire failure process is therefore required to properly interpret hydraulic fracturing and microseismic events. Index testing, including UCS, Brazilian, hardness, and mineralogy can cost effectively provide subsurface data; however triaxial testing remains the most important geomechanical test due to its ability to replicate reservoir confining stress (Fjaer et al. 2008). Dynamic testing (e.g. ultrasonic and acoustic emission testing) is essential for linking core to well logs and seismic surveys. The objective of this research is to consider anisotropy in both static and dynamic parameters through index testing, multiple failure state (MFS) triaxial testing, and ultrasonic pulse transmission (conducted while the sample fails in triaxial shear). This workflow has been applied to samples from outcrops located in Hood Creek, Kananaskis, Alberta, a surface equivalent of the Triassic Montney formation.

Point Load Strength Test

The point load strength test (ASTM D5731), popularized by Broch and Franklin (1972) and Bieniawski (1975), provides an index property often related to the UCS or tensile strength. Specimens were loaded using a manually operated hydraulic ram with applied stress recorded using a pressure gauge. 74 valid test results were obtained: 24 from the east (distal) outcrop (HCE), 20 from the middle (transition) outcrop (HCM), and 30 from the west (shelf) outcrop (HCW) (parallel to bedding denoted by "||" and perpendicular to bedding denoted by "P"). The results show a slightly increasing perpendicular strength trend (i.e. generally intact failure) from the basal depositional environment in the east to the shelf in the west, as well as a significant increase in bed parallel strength (i.e. discontinuity strength). This may indicate additional cementation and strength as the Hood Creek sequence moves from basally deposited siltstones to shelf-deposited sandstones. The anisotropy was highest for the basal outcrop and decreased considerably towards the shelf as strength increased.

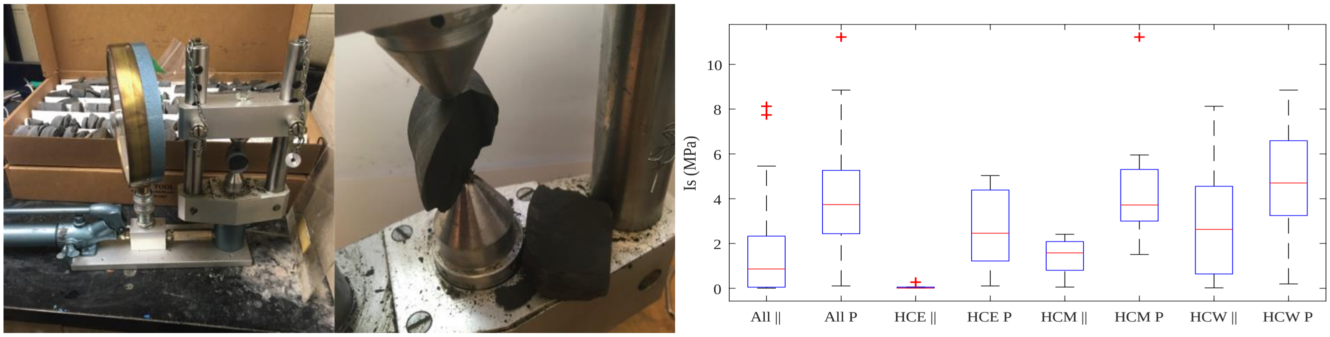

Figure 1: Photographs and Tukey box plot of the point load strength test results.

Outcrop	I_{S50} || (MPa)	I_{S50} P (MPa)	Anisotropy Index
All	1.27	3.84	3.0
HCE	0.02	2.64	106.2
HCM	1.49	3.94	2.65
HCW	2.88	4.74	1.65

Table 1: Point load strength anisotropy ratios.

Indirect Tensile (Brazilian) Testing

Brazilian testing (ASTM D3967), after Carneiro (1943) and Akazawa (1943) was used to evaluate the indirect tensile rock strength in multiple orientations. A displacement of 0.5-1.0 mm/min was applied using flat loading platens until tensile failure occurred. Samples exceeded ASTM recommended thickness to increase the tensile strength; however Li (2013) shows that thickness is largely inconsequential to Brazilian testing. Complex failure mechanisms were observed for most samples, with several fractures forming during testing followed by another increase in strength. Only two samples displayed a monotonic stress-strain curve up to failure, and both were loaded perpendicular to bedding (indicating that progressive bedding plane failure may have occurred during parallel testing, transferring stress to adjacent bedding planes).

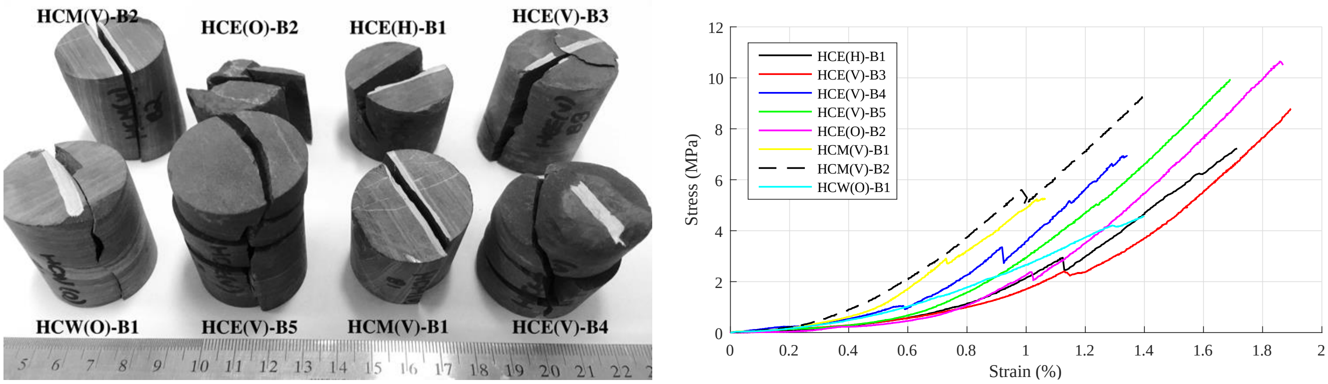

Figure 2: Photographs and graphical representation of Brazilian testing results.

Sample	Time (s)	Strength (MPa)	E (MPa)	Failure Mode
HCE(H)-B1	35	7.2	839	Compound w/ Vertical Oblique Bed Failure
HCE(O)-B2	77	10.6	1123	Intact w/ Horizontal Oblique Bed Failure
HCE(V)-B3	78	8.8	1039	Intact w/ Conjugate Bed Failure
HCE(V)-B4	55	6.9	1012	Intact w/ Conjugate Bed Failure(s)
HCE(V)-B5	69	9.9	1080	Intact w/ Conjugate Bed Failure(s)
HCM(V)-B1	44	5.3	779	Single Bedding Plane
HCM(V)-B2	57	9.2	867	Single Bedding Plane
HCW(O)-B1	57	4.6	532	Intact Failure

Table 2: Summary of Brazilian testing results.

Unconfined Compressive Strength Testing

Unconfined Compressive Strength tests (ASTM D7012) were completed by applying a displacement of 0.15 mm/min for 3 to 7 minutes until failure. Six specimens were tested, all of which failed by brittle and explosive axial splitting except for HCE(V)-U2 (which failed in bending due to poor dimensioning). The Young's modulus and Poisson's ratio values were calculated by fitting the assumed straight-line portion of each curve (generally from 0 to 50% of the peak axial stress) and assuming isotropic behaviour due to a lack of oriented cores.

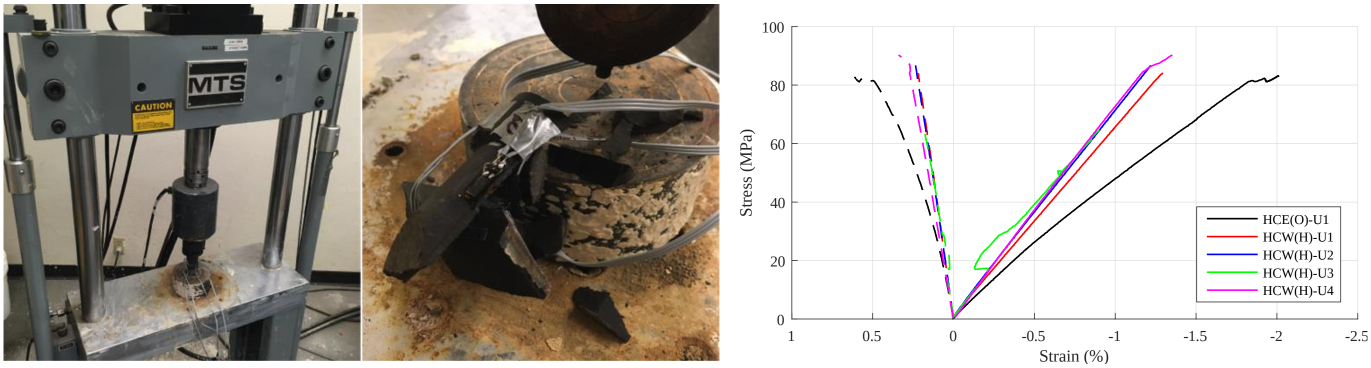

Figure 3: Photographs and graphical representation of unconfined compressive strength results.

Facies	Strength (MPa)	*E* (MPa)	ν (-)
HCE(O)-U1	83.1	512	0.20
HCW(H)-U1	84.1	676	0.17
HCW(H)-U2	86.8	742	0.19
HCW(H)-U3	64.7	804	0.20
HCW(H)-U4	90.3	748	0.24

Table 3: Summary of unconfined compressive strength testing results.

Triaxial & Pulse Transmission Testing

Multiple failure state (MFS) triaxial testing, after Kovari (1983) and Holt and Fjaer (1991), was conducted using a stiff servo-controlled loading frame to determine the strength and static elastic parameters of two vertical HCE specimens and a set of oriented (horizontal, vertical, and 45°) HCW cores. Testing was conducted on air-dried samples in order to replicate drained conditions (due to the excessive time required to achieve equilibration, difficulty in ensuring saturation, limited ability to accurately record pore pressure changes in saturated samples). Samples were hydrostatically pre-consolidated to 10 MPa above the confining pressure of each test stage (10, 20, 30, and 40 MPa) prior to shearing. Pulse Transmission Testing (ASTM D2845), after Birch (1960), was used to measure compression (P) and shear (S) wave velocities throughout the triaxial testing. The pulse-transmission equipment consisted of a circular P-wave piezocrystal surrounded by four S-wave piezocrystals with a resonant frequency of 200 kHz. Received pulses were filtered using a 20th order 150 kHz low pass finite impulse response (FIR).

Triaxial testing results currently underway, will be updated when complete in February.

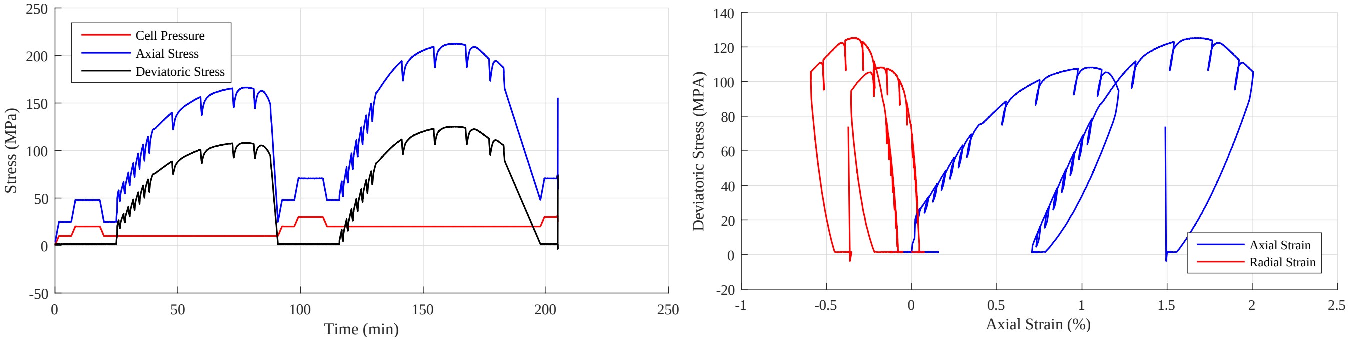

Figure 4: Stress vs. time (left) and deviatoric stress (q) vs. axial strain (p) curves from HCE(V)-T1.

The shelf deposits (HCW) generally displayed higher P-velocities than the basal deposits (HCE). The P-velocities parallel to bedding were 16\% higher then those perpendicular to bedding, yet the shear wave velocities indicated the opposite trend which resulted in markedly increased Vp/Vs ratios and dynamic Poisson's ratios (despite a similar dynamic stiffness). It is also worthwhile to note that the increased perpendicular dynamic stiffness for HCW(H)-T1 corresponds well with the point load anisotropy results.

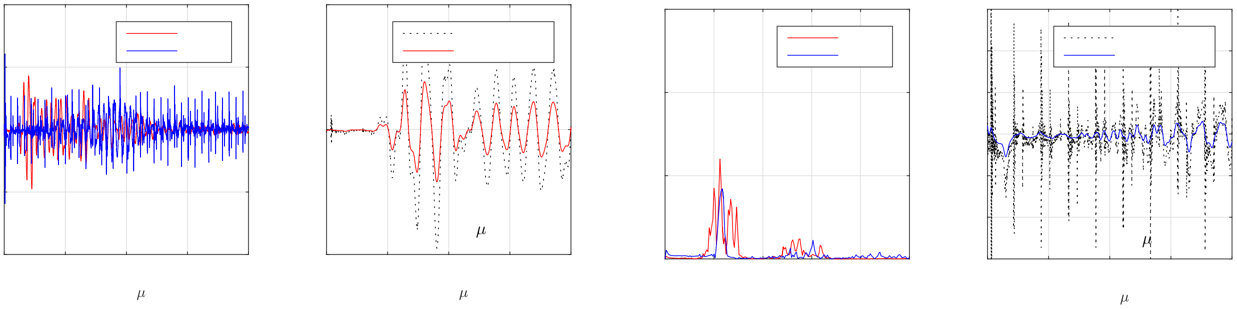

Figure 5: Pulse transmission results from HCW(H)-T1 (parallel to bedding).

Sample	Vp1	Vp2	Vp3	Vs1	Vs2	Vs3	Vp/Vs	ν_d	E_d
-	(km/ s)	(km/ s)	(km/ s)	(km/ s)	(km/ s)	(km/ s)	(-)	(-)	(GPa)
HCE(V)-T1	4.19	4.19	4.16	2.15	2.17	2.14	1.94	0.32	32.9
HCE(V)-T2	3.60	3.85	4.89	2.04	2.07	2.42	1.89	0.31	33.3
HCW(V)-T1	4.99	5.12	3.92	2.59	2.54	2.22	1.91	0.31	42.2
HCW(H)-T1	5.66	5.35	5.27	2.09	2.11	2.12	2.58	0.41	33.6
HCW(O)-T1	5.61	5.61	5.53	1.73	2.23	2.22	2.71	0.42	32.1

Table 4: Summary of unconfined compressive strength testing results.

Conclusions

To be completed after triaxial testing results complete (February/March); subject to decision of latest submission date by review committee and editorial review.

Acknowledgements

This work was supported by a Collaborative Research and Development Grant from the Natural Sciences and Engineering Council of Canada. This study and accompanying future work would not have been possible without the support of Dr. Ron Wong and Dr. Per Pedersen and the help of Dr. Chris Clarkson and Dr. Amin Ghanizadeh from the Tight Oil Consortium.

References

Akazawa, T., 1943. New test method for evaluating internal stress due to compression of concrete (the splitting tension test)(part 1). *J Jpn Soc Civ Eng*, 29, pp.777–787.

ASTM, 2005. ASTM D2845-00: Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock. *Astm*, pp.5–11.

ASTM, 2008. ASTM D3967-08: Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens 1. *ASTM International, West Conshohocken, PA,*, pp.20–23.

ASTM, 2014. *ASTM D7012-14: Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures*,

ASTM, 1985. ASTM D5731-08: Standard Test Method for Determination of the Point Load Strength Index of Rock 1. *Rock Mechanics*, 22(2), pp.1–9.

Bieniawski, Z.T., 1975. The point-load test in geotechnical practice. *Engineering Geology*, 9(1), pp.1–11.

Birch, F., 1960. The velocity of compressional waves in rocks to 10 kilobars: 1. *Journal of Geophysical Research*, 65(4), pp.1083–1102.

Broch, E. & Franklin, J.A., 1972. The point-load strength test. *International Journal of Rock Mechanics and Mining Sciences and*, 9(6), pp.669–676.

Carneiro, F., 1943. A new method to determine the tensile strength of concrete. In *Proceedings of the 5th meeting of the Brazilian Association for Technical Rules*. pp. 126–129.

Fjaer, E. et al., 2008. *Petroleum Related Rock Mechanics* 2nd ed., Amsterdam, The Netherlands: Elsevier.

Holt, R.M. & Fjaer, E., 1991. Validity of Multiple Failure State triaxial tests in sandstones. In *7th ISRM Congress*. International Society for Rock Mechanics, pp. 509–511.

Kovari, K. et al., 1983. Suggested methods for determining the strength of rock materials in triaxial compression: Revised version. *International Journal of Rock Mechanics and Mining Sciences and*, 20(6), pp.285–290.

Kramer, S.L., 1996. *Geotechnical earthquake engineering*, Pearson Education.

Li, D. & Wong, L.N.Y., 2013. The brazilian disc test for rock mechanics applications: Review and new insights. *Rock Mechanics and Rock Engineering*, 46(2), pp.269–287.