

PROCEEDINGS
2019 AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIAN SYMPOSIUM

**Geotechnical characterisation –
managing design and construction risk**

Wednesday, 30 October 2019, 8:00am – 7:00pm
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER



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PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2019 Australian Geomechanics Society Victorian Symposium held on 30 October 2019.

In recent years Victoria has seen significant growth in the construction industry. Investment in both public infrastructure and commercial real estate is growing, and as our cities and infrastructure grow, so too does the need to develop parcels of land with challenging ground conditions. Economical and safe geotechnical design requires efficient and well thought through ground investigation and characterisation to identify and manage ground risks and opportunities.

The 2019 Australian Geomechanics Society Victorian Symposium presents an overview of current state-of-the-art practices, innovation, new research results and case studies relating to geotechnical characterisation with an emphasis on its implications for addressing and managing design and construction risk. The 2019 Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of ground characterisation.

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Keynote Address

'Value-adding' to routine rock testing for underground excavation projects.

W. E Bamford

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ABSTRACT

A geotechnical investigation will be enhanced by careful consideration, at its earliest stages, of the intended eventual construction methods and outcomes, and the expected time scales. This presentation will discuss the range of "routine" laboratory testing procedures for rocks that could be considered. Minor enhancements of standard testing and reporting procedures may yield valuable and subtle insights into potential rock mass behaviour and excavation efficiencies and contribute to beneficial improvements to eventual outcomes.

Keywords: rock strength, excavatability, abrasiveness, deformability, conductivity.

1 INTRODUCTION

When the investigation of a tunnelling or underground excavation project is being considered some fundamental and early planning assessments should include :

- What is the desired/expected time-scale for the construction process?
- What is the expected/possible difficulty of excavating the soil and rock spoil?
- What is the expected time-scale for the stability and durability of the completed engineered structures?

2 PURPOSE OF THE TESTING

- Constructability :
Excavatability & Abrasiveness?
- Stability – during construction?
- Stability – long-term?

2.1 Excavatability

How difficult will it be to remove the soils and rocks from beneath or around the constructed structures?

2.2 Abrasiveness

How much damage will their removal cause to excavating tools and machinery?

2.3 Stability

Will the materials remaining in place be strong enough to support the constructed infrastructure, or will they have to be artificially strengthened or supported?

2.4 Time-dependent behaviour

Will the designed and as-constructed properties of the rocks remain constant with time, or will they vary, and so change the stability and other environmental aspects?

3 STANDARDISED & NON-STANDARD LABORATORY TEST PROCEDURES

3.1 Physical properties (usually non-destructive)

Density
Hardness
Elastic Modulus, Bulk Modulus, Shear Modulus

Poisson's ratio
Compressional and Shear Wave Velocities
Porosity
Natural (as-received) Moisture Content

3.2 Mechanical properties (usually destructively measured)

Tensile Strength of Rock Substance T_o
Fracture Toughness
Splitting Tensile ("Brazilian") Strength
Flexural Strength
Modulus of Rupture
Point-Load Strength Index
Shear Strength of Rock Substance S_o
Punch Shear Strength
Block Punch Strength Index
Uniaxial Compressive Strength of Rock Substance (**UCS**)

Triaxial Compression Tests on Rock Substance
Deriving single points for H-B criterion
OR
Deriving Peak & Residual S_o and ϕ

Direct Shear Tests, on rock joints or defects
Deriving single points for H-B criterion
OR
Deriving Peak & Residual c and ϕ

3.3 Penetration resistance ("toughness")

Static Penetration of a Tool
Cone Indenter Index (*Steel conical pin*)
Button Indenter (Punch Penetration) Test (*Tungsten carbide hemispherical indenter*)
Stamp Test (*Steel cylindrical stamp*)

Penetration by Rotating Tungsten Carbide MicroBit
Goodrich Drillability Test
Sievers J-Value Test

Rotating Carborundum Wheel, eroding Rock Disc
Taber Abradability

3.4 Shatter strength ("brittleness" : comminution produced by kinetic energy)

Swedish Brittleness Number test

Protodyakonov's Rock Strength Coefficient
Coefficient of Rock Strength (CRS)
Rock Impact Hardness Number (RIHN)
Impact Strength Index (ISI)

3.5 Abrasiveness.

Solid Rock Substance :

CERCHAR Abrasivity Index (*steel pin*)
Goodrich Wear Number
(*Tungsten carbide microbit*)
Taber Abrasiveness (*Carborundum wheel*)

Granular Material : Crushed Rock <19mm, >9.5mm
Paddle Abrasiveness (*steel paddle*)

Granular Material : Crushed Rock <6.3mm, >4mm
LCPC (Abroy) Abrasimeter (*steel paddle*)

Granular Material : Crushed Rock <1mm
Norwegian Abrasion Value NAV
(*tungsten carbide workpiece*)

Granular Material : Crushed Rock <1mm
Abrasion Value Steel AVS
(*disc cutter steel workpiece*)

Naturally Granular Material : Sand <4mm
Soil Abrasion Test Value SAT
(*steel workpiece*)

WET Naturally Granular Material : Sand <10mm
Soft Ground Abrasion Test SGAT
(*steel paddle*)

3.6 Time-dependent properties.

- Chemical
- Mechanical
- Hydraulic
- Thermal

3.6.1 Chemical

- Sodium Sulphate Soundness
- Magnesium Sulphate Soundness

3.6.2 Mechanical

DURABILITY

Slake Durability

SWELLING

Unconfined Swelling Strain
Swelling Strain Index, for radially-confined specimens
Swelling Pressure Index, under conditions of zero volume change

CREEP

Time-dependent (Non-Elastic) Deformation Under Constant Loading
Time-Dependent Decrease in Deformation Modulus Under Constant Load

3.6.3 Hydraulic

Rock Substance Permeability, measured by Falling-Head Permeameter

3.6.4 Thermal

- Thermal conductivity
- Specific heat capacity
- Thermal diffusivity

4. 'Value-adding' to routine rock testing

While the tests listed above, conducted under NATA certification, to AS or ASTM Standards, must contain only defined data and conclusions, it is open to a competent and technically sophisticated testing facility to offer knowledgeable and experienced clients more information and observations, in complementary non-NATA reports. These can enable planners, designers, and estimators to gain a more nuanced appreciation of the scope of potential problems and/or opportunities which could arise during construction and service.

They can also point to the approximate magnitudes of construction costs and timings which it is reasonable to expect could be achieved by contractors.

Some of these enhancements to "routine" test reporting and their potential benefits will be outlined in Table 1 below.

5. Different UCS & other strength values should be applicable for stability vs excavatability

If the amount of testing is adequate to fit a Probability Distribution Function to the results, then the strength value adopted for **Stability** should be the **Lower Quintile** value, and the strength value adopted to assess **Excavatability** should be the **Upper Quintile** value.

Table 1.

Test	Standard reported results	Available extra result	"Value-add" for?
Thermal rock properties	Thermal conductivity λ (W/mK), Thermal diffusivity κ (m ² /s), Specific heat capacity c_p (J/kgK)		The natural geothermal heat flux will transfer heat into tunnels and mine openings, which should be taken into account when designing ventilation systems, to accommodate this extra natural heating in addition to the requirements for machinery and people. The temperature rise in the tunnels can be calculated from the measured thermal properties plus the known regional heat flux.
Ultrasonic Velocities Measurement	P-Wave Velocity (m/sec) S-Wave Velocity (m/sec) E, G, K (GPa) ν	Ratio of laboratory velocities, in intact cores, to field velocities, measured through jointed rock mass.	Assessment of RQD, jointing intensity, joint spacings as inputs to RMR and Q classification systems. Seismic methods can penetrate the entire rock mass, and characterise weaker zones which may be missed by boreholes, which are inherently only able to investigate a minor volume of the rock mass. Correlations exist between lab/field velocity ratios and lab/field modulus ratios, as well as jointing intensities.
UCS	UCS (MPa) E (GPa) ν	Strain Energy at Failure (kJ/m ³)	Design of support systems to absorb energy likely to be released by rock upon failure.
		Specific Energy of Destruction (kJ/m ³)	Predict the power needed by excavating machines to break and remove rock.
UCS test with Cyclic Loading and Unloading		Unloading vs Loading E ratio	Classification of rock's internal structure, hysteresis and damage caused by repeated loadings.
UCS + STS	UCS (Mpa) STS (MPa) Density (t/m ³)	UCS/STS ratio Brittleness	Description of Drillability, and energy requirements in rock cutting.
Triaxial Compression Testing	σ_1 at failure (MPa) σ_3 at failure (MPa) E (GPa)	With controlled stage testing, producing 2 or 3 extra failures under incrementally higher confining pressures, peak and residual c and ϕ can be measured, and the "intact" C_0 can be estimated, unaffected by axial cleavage failure.	The rock cutting numerical models used for the design of tunnelling machines and roadheaders require c and ϕ as input data, rather than UCS alone.
Direct Shear Testing	Plot of Shear Stress vs Shear Displacement. Plot of Shear Stress vs Normal Stress Cohesion Phi	Plot of Normal Displacement vs Shear Displacement, to derive Normal Stiffness. Plot of Phi vs Normal Stress, showing the non-linear behaviour which is often characteristic of rough joints. Estimation of JRC Scanning to measure amplitudes and periods of asperities.	Design of slopes using more realistic non-linear, instead of linear ϕ values. Calculation of JRC for input to Barton-Bandis joint model. Development of fractal models to modify J_r and JRC extrapolating from lab scale to field scale.
Creep Tests	Plots of Strain vs Time, for each sustained load.	Deriving equations of apparent E vs time, for each applied stress level.	Calculating radial deformations and support pressures on tunnels increasing with time, consequent upon the apparent time-dependent decrease in the rock's deformation modulus.

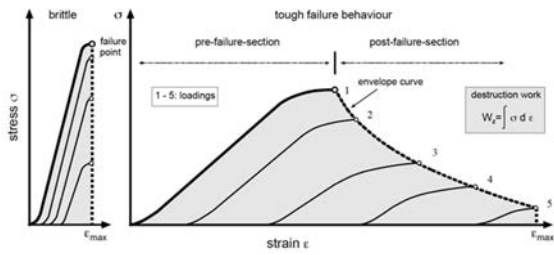


Figure 1. Explanation of Strain Energy at Failure (left) & Specific Energy of Destruction (right) (Thuro & Spaun 1996)

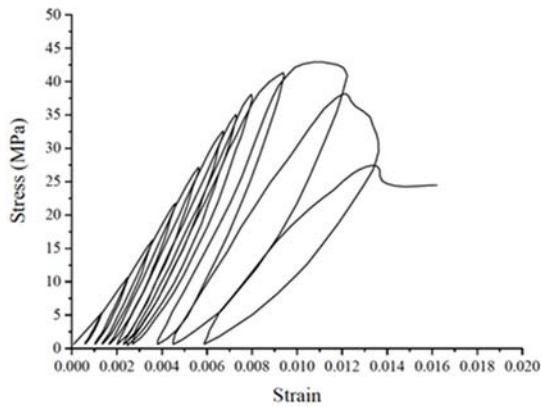


Figure 2. Curve of stress and strain of cyclic loading and unloading (Fu et. al. 2019).

Table 2. After Singh & Ghose (2006)

Ratio of Unloading Modulus to Loading Modulus	Classification
1	Strong Rock
2-5	Medium Strength Rock
5-10	Weak Rock

CREEP

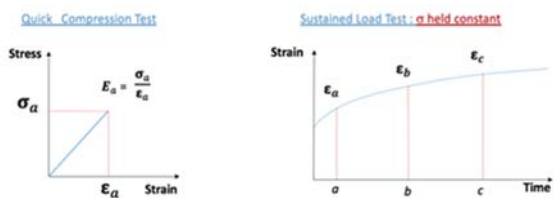


Figure 3. Elastic & Time-Dependent Strain

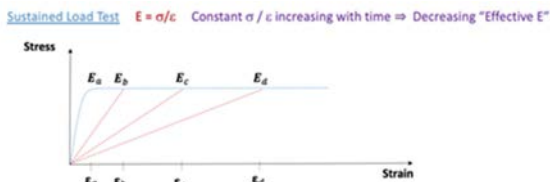


Figure 4. The slope of the stress/strain curve flattens with increasing time increments

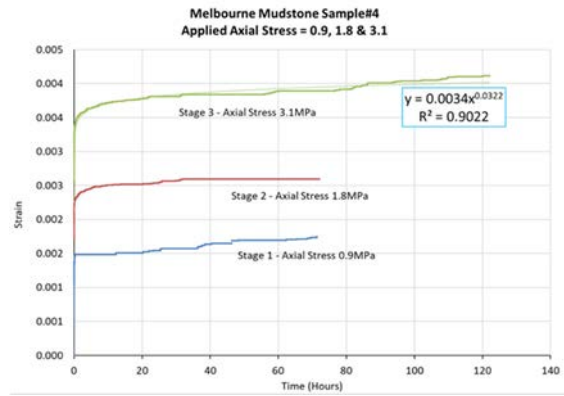


Figure 5. Examples of strain / time records, at different applied stress levels

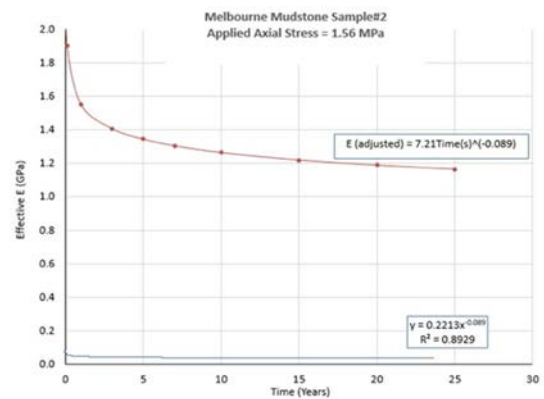


Figure 6. Deduced changes in effective E with increasing time at constant applied stress levels

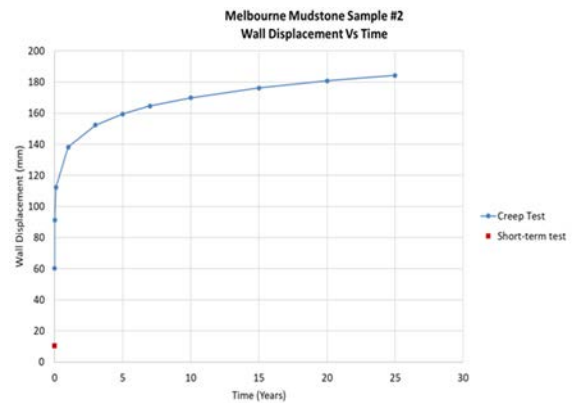


Figure 7. An example of calculated tunnel wall convergence with time

Table 3.

Excavation type	Method	Predictable performances?	Applicable rock tests
Surface Excavation	Surface Miner	Excavatability Index Production Rate (m ³ /hr)	Point-Load Strength Index (MPa) UCS (MPa) RQD (%) CERCHAR Abrasivity Index
	Ripping	Production Rate (m ³ /hr)	P-Wave Velocity (m/sec) UCS (MPa) Average Discontinuity Spacing (m) Schmidt Rebound Hammer Hardness
	Blasting	Blastability Classification Powder Factor (kg/tonne)	UCS (MPa) STS (MPa) Density (t/m ³) E (GPa), Poisson's ratio P-Wave Velocity (m/sec) Fracture Toughness (MPa.√m) Mean Block Size (m) c & φ of discontinuity planes
Tunnels	Roadheader	Production Rate (m ³ /hr) Pick Consumption Rate (cutters/bank cubic metre)	UCS (MPa) STS (MPa) Cone Indenter Hardness CERCHAR Abrasivity Index Rock Block Sizes & Orientations Joint Surface Conditions
	TBM - Rock	Net Penetration Rate (m/hr) Disc Cutter Wear Rate (m ³ /disc replaced)	UCS (MPa), STS (MPa) CERCHAR Abrasivity Index Punch Penetration Test Sievers J-Number Drillability Swedish Brittleness Number Abrasion Value Steel AVS Joints spacing & orientations
	TBM – Soft Ground	EPB or Slurry Shield Tool Life (m ³ /cutter)	Soil Abrasion Test SAT Soft Ground Abrasion Test SGAT
	MicroTBM	Penetration/revolution (mm) Torque Demand, for given applied thrust (kNm)	UCS (MPa) STS (MPa) c & φ of rock substance Punch Penetration Test Angle of friction between cutter material and rock substance ψ
Raises & Shafts	Raise Borer	Penetration Rate (m/hr)	UCS (MPa), STS (MPa) CERCHAR Abrasivity Index Punch Penetration Test

6. EBR? c.f. GBR?

The Geotechnical Baseline Report (GBR) has become well accepted in excavation and tunnelling projects. Is there scope for developing Excavatability Baseline Reports (**EBR**), also?

A suggested concept could be to have an independent consultant prepare best estimates, using the methods outlined in Table 3 and the geotechnical properties assembled in the GBR, of predicted performances of "industry-standard" excavating machinery, to be available to both designers, estimators, and tenderers. This could make for more realistic cost and progress rate estimates, and all tenderers would be competing on the basis of the competence of their equipment and management, not on their ability to "guess the ground conditions". Performance exceeding the EBR estimates could be rewarded by bonus payment rates, above the tender values.

7. CONCLUSIONS

Rocks are innately significantly more variable and anisotropic than soils. Most engineering soils have been derived from the weathering and decomposition of rocks, with much of the variability of the parent material being smoothed out in the process, aided by later transport and deposition.

Investigation and design procedures which have been found to be appropriate for soils may not be extensive or rigorous enough for rocks, which are likely to be both more variable and stronger, and so require more sophisticated and more robust testing procedures and equipment.

Because the Coefficients of Variation of rock properties are likely to be many times as large as those of concrete and several times as large as those of soils, the quantities of testing regarded as statistically adequate to

characterise concrete or soils are likely to be grossly inadequate for the much more variable rocks.

While stability of excavations can be assessed using the results of a range of standard rock tests, the assessment of excavatability requires a combination of standard rock mechanics tests and an array of empirical testing procedures which mimic aspects of rock breaking and cutting processes.

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