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The paper was published in the proceedings of the 11th Australia New Zealand Conference on Geomechanics and was edited by Prof. Guillermo Narsilio, Prof. Arul Arulrajah and Prof. Jayantha Kodikara. The conference was held in Melbourne, Australia, 15-18 July 2012.

Rock Mass Classification of highly variable Lismore Basalts and its application to shallow cover tunnels

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ABSTRACT

As a result of the nature of basaltic lava flows they are subjected to a substantial degree of variability. There has often been a significant amount of time between individual flows which has allowed soil horizons to develop in variable locations. This creates significantly weaker horizons between each flow. The rubbly nature of basalt flow surfaces has also exacerbated the weathering between competent flow cores which makes determination of classification for the rockmass challenging. Therefore a classification system has been developed and engineering parameters of the Lismore Basalt formation derived based on the available field, sub surface investigations and tests results, supplemented with structural geological mapping and 3D geological modelling along a tunnel section including portals. The encountered strata have been classified into engineering rock mass units using an empirical classification system such as the Rock Mass Quality Index (Q-System) and typical active and passive support systems determined. This process has been assessed and the relative merits of each approach are commented on in this paper.

1 INTRODUCTION

In assessing any geological medium, there is always a degree of variability when categorising the medium into classes. Due to the flow emplacement mechanism of lava, it becomes particularly challenging with regards to the time, weathering conditions and mineralogy.

The project is part of the (RTA) Pacific Highway Upgrade Program. The section in question runs between Tintenbar to the north of Ballina and Ewingsdale to the west of Byron Bay in New South Wales.

The length of the proposed upgrade is approximately 17 km commencing from Ross Lane in Tintenbar and extending north to the existing Ewingsdale interchange. The design alignment is in close proximity to the existing highway corridor from Ross Lane to the existing Bangalow bypass. From Bangalow, the proposed upgrade diverges away from the existing Bangalow bypass to the northeast through Tinderbox Creek valley. To avoid steep grades at St Helena Hill, a tunnel is proposed to transverse beneath it.

2 GEOLOGY

2.1 Lismore Basalt

The Lismore basalts were extruded over a period of approximately 3 million years (20-23Ma) during the Tertiary, the most extensive eruptive phase of the Lamington Volcanics (Brodie R.S. and Green R 2002) and overlaid the previously exposed folded metasedimentary rocks of the Neranleigh- Fernvale group. They are laterally extensive (3000km²) due to their mafic nature (Transitional to Tholeiitic) and form the modern day Alstonville plateau.

The central source of the flows is represented today by the Mount Warning complex, which lies approximately 25km to the north-north west. The complex comprises a central vent system (modern day Mount Warning), which is ringed by numerous ring dykes. The lavas of the Lismore basalt are amongst the furthest to have travelled from this source and it is probable that they were erupted from a number of flank fissures or smaller vents.

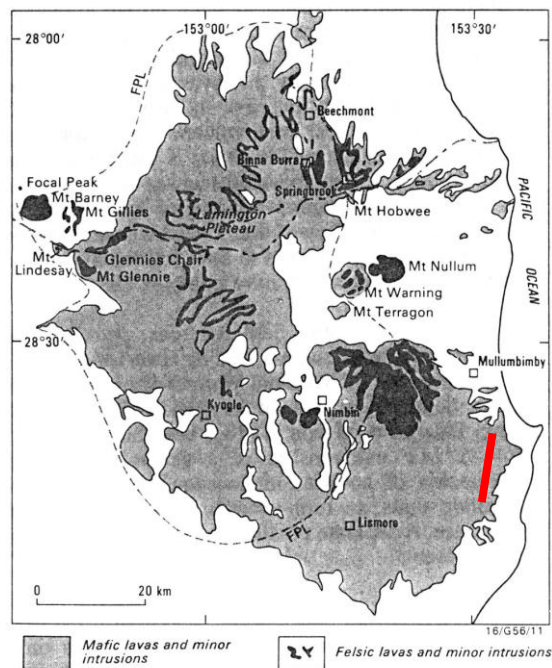


Figure 1. Extent of volcanic and intrusive rocks of the Focal Peak and Tweed provinces of southern Queensland and northern NSW (Johnson, 1989). The red line indicates approximate location of site.

The basalt flows flooded and filled the existing landscape, creating a wide range of textures, but thicknesses rarely exceed 10m. This geometry of individual flows is thus defined by the surface of the previous flow or other existing features. Thicker flows would have formed in topographic depressions and these thicker extents would have allowed slower cooling and the creation of columnar jointing that is often associated with basalt. Combined with this, the periods between eruptive activity allowed erosion and weathering, forming soils before the subsequent flow was emplaced, all of which adds complexity to the modelling of the geology.



Picture 1 – NMLC core sample retrieved from 28m to 40m (below the surface of St Helena Hill, Byron Shire, NSW) Note EL strength, highly weathered red zone from 31.9m to approximately 34m (below the surface of St Helena Hill)



Picture 2: Profile of columnar Lismore Basalt on Wyrallah Road cutting

Thick laterite soils (of up to 10m) have established across the region, largely due to the temperate coastal setting with plentiful rainfall allowing forests to establish.

Groundwater is controlled by the secondary porosity of the basalt material.

3 INVESTIGATIONS AND LABORATORY TESTS

In order to classify the strata, field investigations were undertaken in conjunction with laboratory tests.

3.1 Data collection

Data collection encompassed the following:

- Cored boreholes
- UCS and Point loads testing
- RAAX imaging
- Drillability assessments
- Direct shear testing
- Rock Mass Triaxial Testing
- Brazilian Testing
- Geophysical and Seismic profiling
- Packer Testing

3.2 Data interpretation

The application of any rock mass classification requires the core samples collected on site to be scrutinized and classified with regards to strength, fracture spacing and rock quality designation (RQD). This allows for stratigraphical classification which will then be used to derive rock mass types.

The stratigraphical units encountered along the tunnel alignment and relevant to the tunnel design are summarised in Table 1.

Table 1: Stratigraphical Units

Unit	Material	Origin	Approx. Thickness
C	Residual Soil/Extremely Weathered Basalt	Firm to hard clay to extremely weathered, extremely low strength basalt	0 - 20m
D1	Very Low to Low Strength	Highly to Moderately Weathered basalt	1 - 15m
D2	Medium Strength		
E1	High to Extremely High Strength	Fractured Slightly Weathered Basalt	1.5 - 25m
E2	High to Extremely High Strength	Competent Fresh Basalt	

The geological rock and soil units have been grouped into four Rock Mass Types; RMT I to RMT IV. These rock mass types are different to the geological units described above. The Rock Mass Types I-IV group the geological units according to the strength, fracture frequency and RQD. Consequently Rock Mass Types I-IV incorporate more than one geological unit within each individual type.

The results in Table 2 have been obtained from the field investigations. RMT II is characterised as being of medium to high strength. RMT III is of low to medium strength and RMT IV is again of medium to high strength. These strength characteristics will be further discussed in this paper. RMT I consists predominantly of residual soils and extremely weathered basalt and therefore behaves in a soil-like manner, such that rock mass classification systems are not applicable to this class. RMT I has been omitted in the application procedure of the classification system on this basis.

Table 2: IS50 and UCS ranges for rock mass types

	RMT I	RMT II	RMT III	RMT IV
Number of Tests	175	780	405	3283
Min. (MPa)	0.0	0.0	0.0	0.0
Max. (MPa)	10.9	11.5	9.7	14.0
Mean (MPa)	1.0	5.5	1.2	3.0
Median (MPa)	0.1	6.0	0.5	2.0
Interpreted UCS range	35	192	42	105

Rock Quality Designation (RQD) provides a quantitative estimate of the bed thickness from the borehole core logs, and is defined as the percentage of intact pieces longer than 100mm in the total length of core. RQD results for the various rock mass types are summarised in Table 3.

Table 3: Rock Quality Designation (RQD)

	RMT I	RMT II	RMT III	RMT IV
No. of Sampled Intervals	16	151	140	1015
Min. (%)	0	0	0	0
Max. (%)	82	100	100	100
Median (%)	51	93	57	87

Direct shear tests were undertaken along the tunnel alignment to determine the strength parameters of the defects and these are summarised in Table 4 according to rock mass type.

Table 4: Summarised Defect Shear Strength Parameters

RMT	Cohesion (kPa)		Friction Angle (Degrees)	
	Peak	Residual	Peak	Residual
II	101	32	40	39
III	39	23	23	19
IV	77	21	49	17

Once the relevant strength parameters, RQD and fracture spacing have been determined, empirical classification systems can be used to gain an understanding of the expected behaviour of each rock mass type. These empirical systems have been derived from numerous previous case studies, with project data relating to the various rock mass types and applied support systems.

4 APPLICATION OF EMPIRICAL CLASSIFICATION SYSTEMS

The most commonly used is the Q-system proposed by Barton *et al* (1974). The Q-System is popular for its practical use and the ability to convert geological data into engineering parameters despite of some limitations which will be touched on briefly in this paper.

4.1 Tunnel Quality Index (Q-System) by Barton *et al*.

Barton proposed the Tunnel Quality Index based on a large number of case studies of underground excavations. This system is widely used in the industry to determine rock mass parameters and tunnel support requirements. In determining the Tunnel Quality Index (Q-Value) for rock mass types, the classification system incorporates the following parameters:

1. Rock Quality Designation (RQD),
2. Joint set number (J_n),
3. Joint roughness (J_r),
4. Joint alteration (J_a),
5. Joint water reducing factor (J_w) and
6. Stress reduction factor (SRF).

These parameters are used to determine three quotients, which are crude measures of:

- Block Size (RQD/J_n);
- Inter-block shear strength (J_r/J_a);
- Active Stress (J_w/SFR).

These quotients are multiplied as, $(RQD/J_n) \times (J_r/J_a) \times (J_w/SRF)$, to produce the Q-value.

When applying the Q-system to Rock Mass Types II, III and IV, the following Rock Quality Indices were calculated:

Table 5: Q-System Rock Mass Classification Results

RMT	RQD	J _n	J _r	J _a	J _w	SRF	Q-Value	Description
II	79	9	1.5	2	1	1	6.58	Fair
III	56	12	1.5	8	1	1	0.88	Very Poor
IV	73	9	1.5	4	0.66	1	2.01	Poor

Barton and Grimstad (1993) developed the Q-Chart after analysing previous case records and suggested using an ESR (Excavation Support Ratio) of 1.5 for temporary support regimes. The Q-chart provides an initial estimate pertaining to the support regime that could be adopted and should only be used as a guide. Engineering experience, detailed analysis and modelling should be applied to develop the support systems, as part of the detailed design development.

Figure 2 illustrates the region in which the Q – Chart is considered to be most effective. Rock units that fall within the Extremely to Exceptionally poor classes will require passive support systems, comprising steel sets or lattice girders encased in sprayed concrete arch linings.

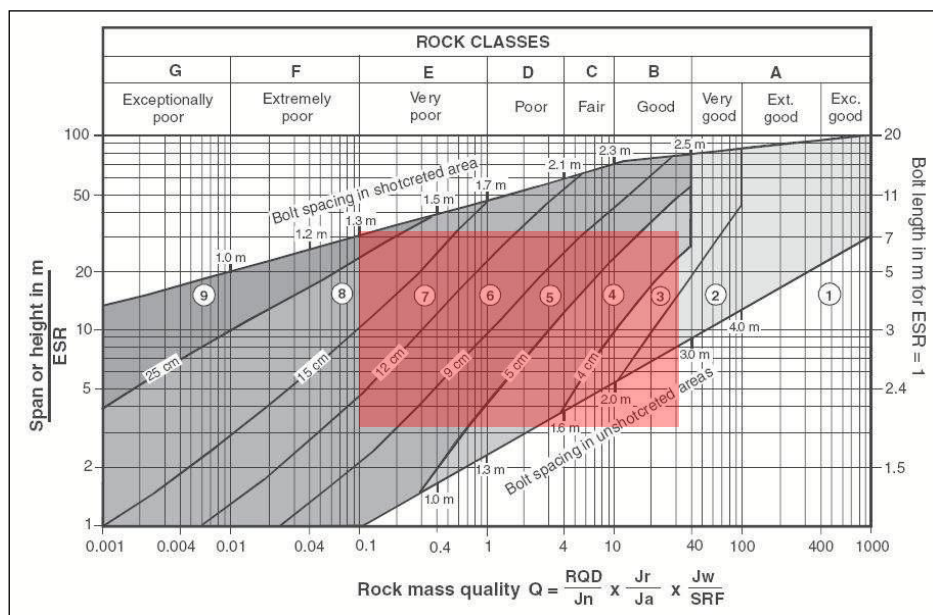


Figure 2: Region where Q-System Chart is Considered Most Effective

Based on this limitation, the support systems obtained using the Q-system have been divided into two support regimes, namely semi-active and active.

Semi-active support is a combination of both active support systems, such as rock bolts, and passive support systems, such as steel sets and forward rock reinforcement; it is applied in regions where the rock is expected to behave in a soil-like manner, due to its fractured nature. Active support systems consist of rock bolts and thin sprayed concrete linings that effectively reinforce the rock mass, thereby activating a reinforced rock arch that becomes the main support element for the tunnel structure.

Support types relevant to the derived Q values are summarised in Table 6.

Table 6: Indicative Tunnel Support using the Q-System

Support Type	Q	Rock bolt length (m)	Bolt cc spacing (m)	Sprayed concrete (mm)
ST1	> 3.0	5.0 to 6.5	2.0 to 2.5	50
ST2	0.5 to 3.0	5.0 to 6.5	1.6 to 2.0	50 to 100
ST3	0.1 to 0.5	5.0 to 6.5	1.3 to 1.6	100 to 150
ST4	< 0.1	5.0 to 6.5	0.9-1.2	150 to 250 *

*Note: ST4 Includes steel set/lattice girders at 0.75m-1.2m cts

4.2 Determination of the Modulus of Elasticity of the Rock Mass (E_{mass})

Barton proposed an empirical relationship using the Q-value of a rock mass to determine the Modulus of Elasticity for the rock mass, (E_{mass}).

$$E_{\text{mass}} = 10 \cdot Q_c^{1/3}$$

where Q_c is the modified Q value determined from the uniaxial compressive strength component of the rock mass.

Due to the shallow cover of less than 25m and the rubbly nature of the basalt, it may be assumed that the contributing uniaxial compressive strength component is negligible and Q_c is therefore equal to Q for this case.

The results from laboratory tests undertaken to determine the modulus of elasticity for each sample (E_{sample}) have been compared to the derived E_{mass} and the outcomes are summarised in Table 7.

Table 7: *Moduli of Elasticity*

Rockmass	Q Value	E_{mass} (GPa)	E_{sample} (GPa)
II	6.58	18.7	18.1 to 23.9
III	0.88	9.6	2.57 to 9.64
IV	2.01	12.6	2.68 to 22.16

The E_{mass} determined using Barton's relationship falls within the range of E_{sample} and provides some verification of assumptions and estimates made at the start of the investigation and design process.

5 CONCLUSIONS

The field data and laboratory results confirm the initial assumption of the highly variable, rubbly nature of the basalt. The different flow emplacements make it challenging to apply an empirical classification system across widely differing rock mass types.

By applying empirical classification systems, specifically the Q-System, it was possible to convert geological field data into engineering parameters for a high variable, fractured medium. This system relies highly on the accuracy of the initial mapping and field investigations undertaken for this tunnel.

Empirical systems provide an initial estimation or "best guess" of the engineering behaviour of the expected strata for the tunnel. As with all investigation and design processes, it is the failure mechanisms and structural dynamics which govern the design.

Numerical analysis and modelling needs to be undertaken, to provide additional checks and scrutinize such issues as loading scenarios and potential failure mechanisms.

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