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Variability of mechanical and physical properties of Singapore Bukit Timah Granite Rocks and Residual Soils

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ABSTRACT

This paper presents the key mechanical and physical properties of Singapore BTG rocks and soils, based on the Factual Geotechnical Reports of Downtown Line stage II sites. The variations of parameters including the index properties, the hydraulics, the strength and stiffness, the compressibility for residual soils, the unconfined compressive strength, the point load strength index, the abrasivity, and slake durability index for rocks are derived from laboratory tests based on samples from different depths of different borelogs. Statistical information including the average mean values, the standard deviations and the coefficient of variations are provided for these parameters. It is hoped that these statistics will provide useful reference and insights for future projects involving in BTG Formation.

Keywords: variability; Bukit Timah Granite; strength; stiffness; unconfined compressive strength

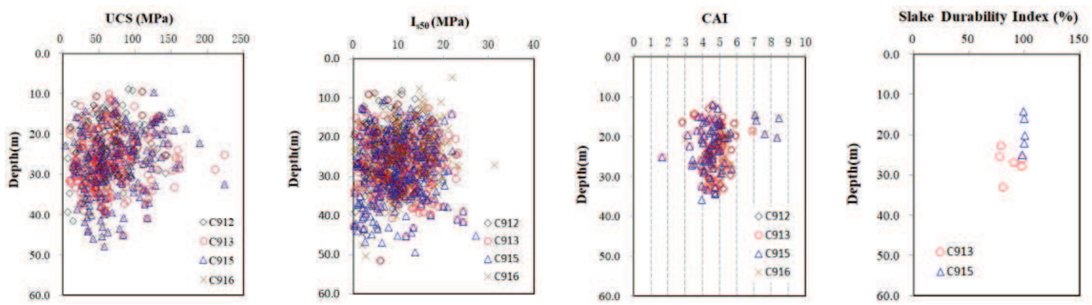
1 Introduction

The Bukit Timah Granite (BTG) Formation is widely distributed in the central and northern parts of Singapore Island. BTG is an acidic igneous rock formed in lower middle Triassic period. There is considerable hybridization of the rock within the formation and evidence of assimilation (Pitts, 1984). Therefore, there is also a great variation in the mechanical and physical properties of BTG rocks. Through field investigations and laboratory tests, Zhao et al. (1994) investigated the influences of the weathering grade and the weathering processes on the mechanical and physical properties of the weathered granitic rocks. Rahardjo et al. (2012) compiled the variation of index and engineering properties of BTG residual soils with depth. As the sixth line to be built, the Thomson-East Coast Line (TEL) involves lots of excavations in BTG Formation. Based on a large database from the Factual Geotechnical Reports on over 200 boreholes from the recent constructed Singapore Downtown Line stage II (DTL2), this study presents the key mechanical and physical properties of BTG Rocks and residual soil. The reported mechanical and physical properties, as well as the spatial variabilities may provide design guidance for TEL design and construction and alternatively update the statistical information with regard to the engineering properties of BTG formation.

2 Properties of BTG rock

2.1 *Unconfined compressive strength (UCS)*

According to Figure 1a, there are significant variations with regard to the UCS value, ranging from several MPa to over 200 MPa. Figure 2a plots influences of weathering grade on UCS. It is obvious that the UCS decreases considerably as the rock becomes more weathered, reducing from 79.27 MPa for GI to 61.97 MPa for GIII, which is consistent with reduction of 30-40% in strength parameters reported by Zhou (2001).

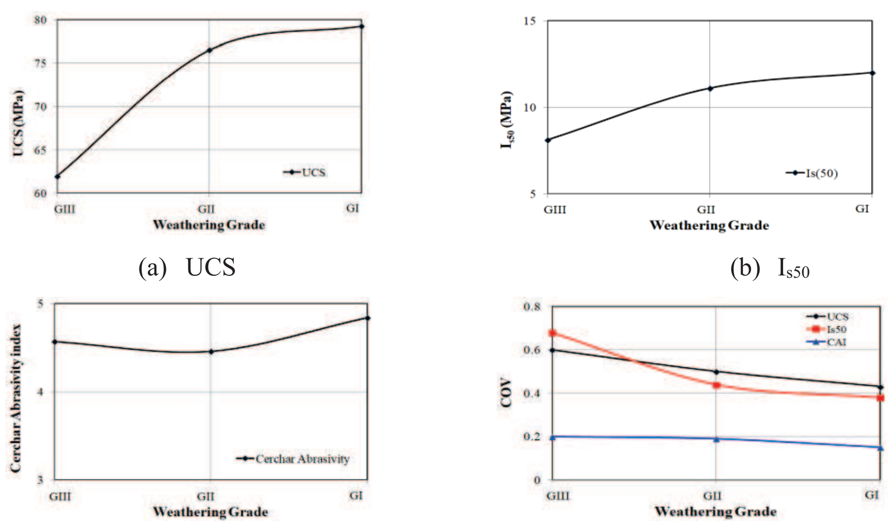


(a) UCS (b) I_{s50} (c) CAI (d) SDI

Figure 1. Variation of mechanical and physical properties of BTG Rocks with depth

2.3 *Point load strength index (I_{s50})*

Based on the plot of Figure 1b, the I_{s50} value ranges from several MPa to over 30 MPa. Figure 2b shows that the I_{s50} increases significantly as the rock becomes less weathered, increasing from 8.14 MPa for GIII to 11.13 MPa for GII, also consistent with the reported percentage of 30-40% by Zhou (2001).



(a) UCS (b) I_{s50}

(c) CAI (d) COV

Figure 2. Influences of weathering on: (a) UCS, (b) I_{s50}, (c) CAI, and (d) COV

However, the difference of I_{s50} between GII and GI is marginal, with the average 11.13 MPa for GII and

12.03 MPa for GI. In addition, Figure 2d indicates that as the rock becomes less weathered, the coefficient of variations (COV, as defined in Eq. (1)) of I_{s50} value decreases, changing from 0.68 for GIII to 0.38 for GI rock.

$$COV = SD/\mu \tag{1}$$

where SD is the standard deviation, μ is the average value.

2.4 *Cerchar Abrasivity Index (CAI)*

According to Figure 1c, CAI of BTG rocks is less varying, compared with UCS and I_{s50}. Also based on Figure 1c, most of the CAI value ranges from 4.0 to over 5.0, indicating the BTG rocks are very highly and extremely highly abrasive. Figure 2c shows that the difference of CAI between GIII and GII is marginal while the CAI of GI rock is obviously higher than that of GIII and GII rocks. In addition, Figure 2d indicates that as the rock becomes less weathered, the variation of CAI value decreases, changing from 0.20 for GIII to 0.15 for GI rock.

2.5 *Slake Durability*

The slake durability index (Id2 – second cycle) was calculated as the percentage ratio of final to initial dry sample weight (Table 1) (Franklin and Chandra, 1972). Figure 1d plots the distribution of slake durability index along depth in C913 and C915 sites. It is of the category ranging from high durability to extremely high durability, with average value of 91.33.

Table 1. Classification and characterization of durability (after Franklin and Chandra 1972)

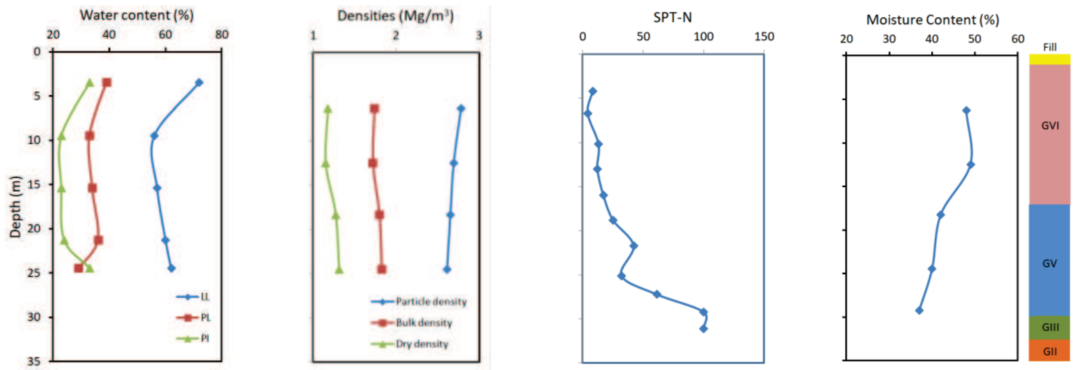
BTG formation	Soil			Rock		
Classification of durability	Very low	Low	Medium	High	Very high	Extremely high
Slake durability index Id2 (%)	0-25	25-50	50-75	75-90	90-95	95-100

3 Properties of BTG residual soils

3.1 *Physical properties of BTG residual soils*

3.1.1 *Index properties*

According to Figure 3a, the plasticity index (PI) decreases rapidly with increasing depth, while the plastic limit (PL) and liquid limit (LL) do not indicate conclusive trend. Figure 3b shows the variation of the particle density, the bulk density, and the dry density with depth. The plot indicates a decrease of the particle density and an increase of the dry density and bulk density with increasing depth. However, these increase or decrease of the density with depth is not so significant. The standard penetration test (SPT) in Figure 3c showed that the penetration resistivity increases with the depth. The soil varied from soft at the ground surface to hard near the weathered rock. Figure 3d indicates a clear decrease of the moisture content with increasing depth.

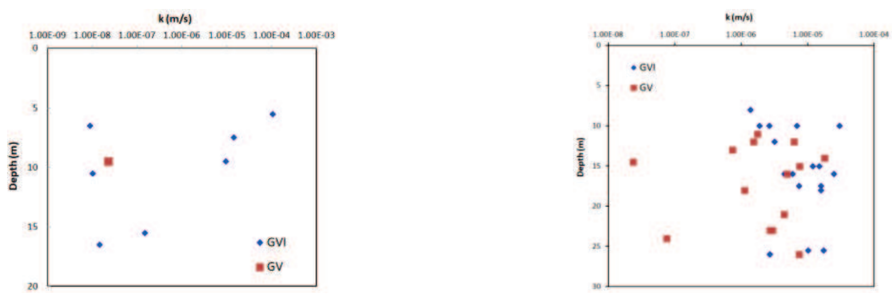


(a) WC (b) Densities (c) SPT-N (d) MC

Figure 3. Variation of index properties with depth for BTG residual soil (based on DT2439 of C913)

3.1.2 *Hydraulic properties*

Figure 4a shows the laboratory test results for GVI and GV at different depth. Figure 4b plots the field test results for GVI and GV. There are great scatters with regard to the coefficient of permeability for both the GVI and GV soils with depth. Generally, the GVI soil is more permeable than GV soil.



(a) Laboratory test results (b) Field test results

Figure 4. Variation of coefficient of permeability with depth for BTG residual soil

3.2 *Mechanical properties of BTG residual soils*

3.2.1 *Strength*

Table 2 presents the categorical average and the standard deviation of the cohesion and friction angle, respectively, based on the SPT-N values. With increase of N, the increase of the cohesion value is significant while for the friction angle, it is less significant. In addition, the standard deviation cohesion becomes greater as N increases, while the standard deviation friction angle becomes smaller.

Table 2. Strength of BTG GVI and GV soils based on CU and CD tests

Test type	SPT-N	Average μ_c and the standard deviation σ_c cohesion / kPa	Average μ_ϕ and the standard deviation σ_ϕ friction angle / °
CU tests	N≤10	μ_c=8.8, σ_c=10.1	μ_ϕ=28.6, σ_ϕ=8.2
	10<N≤30	μ_c=13.8, σ_c=21.5	μ_ϕ=29.8, σ_ϕ=7.0
	N>30	μ_c=18.4, σ_c=24.9	μ_ϕ=30.5, σ_ϕ=6.6

CD tests	N≤15	μ_c=39.4, σ_c=27.9	μ_ϕ=32.5, σ_ϕ=6.0
	N>15	μ_c=43.8, σ_c=37.0	μ_ϕ=35.6, σ_ϕ=3.1

3.2.2 *Stiffness*

Figure 5 shows the secant modulus of a particular pressuremeter curve (Ep) plotted against its corresponding radial strains, based on Borehole DT2207 of C912 (εr =R/Ro). There is a decrease in the pressuremeter modulus, even within the range where a best-fit line is used to estimate the unload-reload modulus in soil investigation reports, which reflects the strain-dependent behavior of soil within the elastic region.

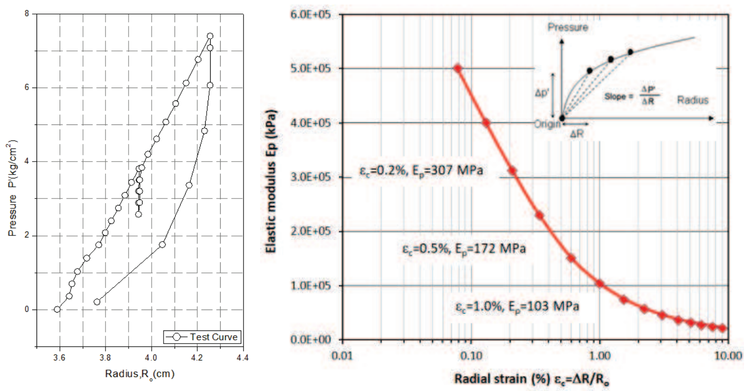


Figure 5. Strain dependent behavior of pressuremeter modulus

By repeating this for all the 71 pressuremeter test data sets, it would be possible to characterize the strain-dependent behavior of pressuremeter modulus, as in Eq. (2).

$$E_p/N = 0.111 * (\Delta R/R_o)^{-0.669} \quad (2)$$

3.2.3 *Compressibility*

Based on the pre-bored pressuremeter tests, using the Oyo-type pressuremeter Elasmeter 200, Table 3 gives the statistical information of the compression index C_c for the 4 sites. It is obvious that the average compression index is about 0.303 and the coefficient of variation COV is 0.462, well above the commonly adopted value of 0.25 as considerable uncertainty.

Table 3. Statistical information of the compression index C_c

Site	Average	SD	COV
C912	0.294	0.154	0.524
C913	0.329	0.150	0.456
C915	0.299	0.130	0.435
C916	0.289	0.138	0.478
Overall	0.303	0.140	0.462

4 Conclusions

For BTG rocks, its mechanical and physical properties, i.e., the UCS, I_{s50}, and CAI, vary greatly with the weathering grade. For the BTG soil, it becomes more sandy as weathering decreases with depth from the top of the formation. Apart from some conclusions with regard to the variability of mechanical and physical properties of Singapore BTG rocks and residual soils and the influence of weathering grade on these properties, arrived at in the text, some main findings are summarized and shown in Table 4.

Table 4. Some engineering properties of Bukit Timah Granite rocks and soils

	GI	GII	GIII	GV, GVI (N<15)	GV, GVI (N>15)
Average UCS of intact rock (MPa)	79.27	76.52	61.97		
Average I_{s50} of intact rock (MPa)	12.03	11.13	8.14		
Average CAI	4.84	4.46	4.57		
Coefficient of permeability k (m/s)				GVI: $1.0\times10^{-6} \sim 5.0\times10^{-5}$ (field) GV: $2.0\times10^{-8} \sim 2.0\times10^{-5}$ (field)	
Effective shear strength parameters c′-φ′				c′=39.4 kPa φ′=32.5º	c′=43.8 kPa φ'=35.6º
Elastic modulus derived from Eq. (2)				E_p=11.3N (0.1% radial strain) E_p=7.1N (0.2% radial strain) E_p=3.8N (0.5% radial strain) E_p=2.4N (1.0% radial strain)	

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