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Relationships between chemical weathering indices and physical and mechanical properties of decomposed granite

C.F. Chiu [a,*], Charles W.W. Ng [a,b]

[a] Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, 1 Xikang Road, Nanjing 210098, China
[b] HKUST Fok Ying Tung Graduate School, Nansha IT Park, Nansha, Guangzhou, China

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ABSTRACT

Chemical weathering is one of the dominant mechanisms for weathering of granite in subtropical and tropical regions resulting in modifications of its chemical, physical and mechanical properties. Thus, the changes in chemical properties may provide insight about the changes in physical and mechanical properties of weathered granite. In this paper three quantitative chemical weathering indices are correlated to the dry density of decomposed granite. A linear relationship is found between each chemical weathering index and dry density for granitic saprolites. Mobiles index (I_{mob}) gives the highest coefficient of correlation among the three chemical weathering indices. Further investigations were conducted to establish the relationships between I_{mob} and other physical and mechanical properties of granitic saprolites. The test results showed that fines content increases with increasing I_{mob}, but peak strength increases with decreasing I_{mob}. The peak states of granitic saprolites are consistent with Rowe's stress–dilatancy relationship. Dilatancy increases with decreasing I_{mob} that contributes to a higher peak strength. Based on some test results presented in this study, it seems that I_{mob} could be a good indicator to quantify the effects of chemical weathering on physical and mechanical properties of granitic saprolites.

1. Introduction

Chemical weathering is one of the dominant processes for rock weathering in humid subtropical and tropical regions, like Hong Kong, Malaysia and Brazil. Weathered rock materials are quite widespread in these regions, on which it is not uncommon to construct engineering structures. To improve the analysis and design of these engineering structures, it is vital to develop a fundamental understanding of the effects of chemical weathering on the mechanical properties of rock materials.

For general descriptive purposes, the state of weathering of igneous rocks in Hong Kong is commonly classified into six decomposition grades (GEO, 2000b) as summarised in Table 1. Materials of grades I to III are considered as rocks. On the other hand, grades IV to VI are considered as soils. Grade IV (highly decomposed) and V (completely decomposed) soils are also termed saprolites which retain the structures of the parent rock. The behaviour of saprolites can differ considerably from that of sedimentary soils due to their special mineralogical and microstructural characteristics developed during weathering processes.

Saprolites are weakly bonded materials of varying strength and their void ratios vary widely. A significant number of studies have been conducted on the mechanical properties of saprolites in the laboratory and in the field (Lumb, 1962, 1965; Brand et al., 1983; Vaughan et al., 1988; Gan and Fredlund, 1996; Pun and Ho, 1996; Ng and Chiu, 2001, 2003; Wang and Yan, 2006; Ng and Leung, 2007). Pun and Ho (1996) reported the shear strength of granitic saprolites and provided a set of generalised shear strength parameters of completely decomposed granite. Gan and Fredlund (1996) investigated the shear strength of saturated and unsaturated completely decomposed granite using direct shear box and triaxial apparatus. The effects of matric suction on shear strength were quantified using an extended Mohr–Coulomb failure criterion. Based on recompacted samples of granitic and volcanic saprolites, Ng and Chiu (2001, 2003) found that apart from dry density and stress level, dilatancy is also influenced by soil suction.

Vaughan et al. (1988) summarised that the main mechanical features resulting from the geological origins of saprolites are (1) bonding, (2) varying mineralogy and grain strength and (3) widely varying void ratio or dry density. These mechanical features are influenced by the mineralogy and microtexture of the unweathered rock as well as the chemical weathering process. Hence, the chemical compositions of saprolites can influence their engineering properties to a certain extent.

Due to the variety and heterogeneity of saprolites, the simple "descriptive" type of rock classification scheme may not be sufficient to characterise the effect of chemical weathering on the engineering

* Corresponding author at: College of Civil and Transportation Engineering, Hohai University, 1 Xikang Road, Nanjing 210098, China. Tel.: +86 13770554507; fax: +86 25 83713073.
E-mail addresses: acf.chiu@gmail.com (C.F. Chiu), cecwwng@ust.hk (C.W.W. Ng).

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Table 1
Classification of rock material decomposition grades of Hong Kong (from GEO, 2000b).

Descriptive term	Grade symbol	General characteristics for granite and volcanic rocks and other rocks of equivalent strength in the fresh state	Additional typical characteristics for granite
Residual soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains	Reddish brown, Feldspars completely destroyed Quartz is only remaining primary mineral Usually dull, etched or pitted and reduced in size compared with fresh condition
Completely decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily indented by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock	Yellowish brown to reddish brown Feldspars powdery to soft Hand penetrometer shear strength index <250 kPa Zero rebound from N Schmidt hammer
Highly decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock	Yellowish brown to yellowish orange/brown Feldspars powdery Hand penetrometer shear strength index >250 kPa Positive N Schmidt rebound value < 25
Moderately decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout	Yellowish brown Feldspars gritty Biotite not shiny N Schmidt rebound value 25–45
Slightly decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces	Feldspars hard to slightly gritty Orthoclase feldspars often pink Biotite slightly stained and dull around edges N Schmidt rebound value > 45
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)	Overall rock colour grey/white Feldspars hard and shiny Biotite shiny, not stained Quartz colourless or grey, glassy

properties. A considerable amount of work (Reiche, 1943; Moignien, 1966; Ruxton, 1968; Rocha Filho et al., 1985; Suoeka et al., 1985; Harnois and Moore, 1988; Irfan, 1996; Guan et al., 2001; Ng et al., 2001; Kim and Park, 2003; Moon and Jayawardane, 2004; Lee et al., 2008; Heidari et al., 2011; Khanlari et al., 2012) has been done to quantify the degree of weathering by some chemical indices. Guan et al. (2001) and Ng et al. (2001) studied the weathering mechanism based on some chemical weathering indices. They reported that among various quantitative chemical indices reported in the literature, weathering potential index (*WPI*) and mobiles index (I_{mob}) can provide some indication of the extent of weathering for rock materials. In addition to these chemical indices, Suoeka et al. (1985) has postulated that the degree of weathering of rock materials may be characterised by the loss on ignition (*LOI*). Past studies have proposed some correlations (Irfan, 1996; Kim and Park, 2003; Moon and Jayawardane, 2004) between chemical indices and engineering indices, like dry density, standard penetration test (SPT) *N* value, Schmidt hammer value, uniaxial compressive strength and vane shear strength. However, limited attempt has been made to correlate these chemical indices to some fundamental mechanical properties of saprolites, like shear strength and dilatancy.

This paper first presents the results of chemical analysis, mineralogical analysis, physical index and triaxial tests conducted on decomposed granite. Some indices such as *WPI*, *LOI* and I_{mob} are then correlated with dry density. Their suitability to quantify the degree of chemical weathering is discussed. Furthermore, the relationships between I_{mob} and shear strength and dilatancy are investigated for granitic saprolites.

2. Testing program and procedures

2.1. Tested material

The rock and soil samples were taken from five different boreholes in Hong Kong. Table 2 summarises the borehole information. All samples are derived from the same geological formation—a medium to coarse grained granite of the Kowloon Pluton (Strange, 1990). The testing program is presented in Table 3. Tests conducted in this study include chemical analysis, mineralogical analysis, physical index and triaxial tests. Conventional wet chemistry analysis and X-ray fluorescence spectrometry (*XRF*) were used to analyse the chemical compositions of bulk rock. X-ray diffraction analysis (*XRD*) was conducted for mineral identification. The particle size distribution and dry density were determined in accordance with the procedures given in BS1377: 1990 (BSI, 1990). As decomposed granite has a wide range of particle size, both wet sieving and hydrometer tests were conducted to capture a complete particle size distribution curve from gravel size to clay size. Consolidated drained (*CD*) triaxial tests were conducted on intact samples of granitic saprolites (i.e. grades IV and V decomposed granite) obtained by rotary sampling using Mazier triple-tube core-barrel (GEO, 2000a).

2.2. XRF

XRF was conducted using a Philips PW 1400 spectrometer. Specimens were prepared first by grounding into a fine powder. After that

Table 2
Borehole information.

Borehole identity	Depth of hole (m)	No. of specimens	Texture	Structure
DH1	15.34	43	Medium to coarse grain	Very closely to closely spaced, rough planar and undulating joints, dipping at 10° and 20°
DH2(95)	27.84	56	Medium to coarse grain	Widely, occasional closely spaced, rough planar joints, dipping at 0 to 10°, 35 to 40°
BH1	40.00	25	Medium grain	Very closely spaced, rough planar round undulating joints, dipping 10–15° and 20°
BH2	20.37	26	Medium to coarse grain	Closely and widely spaced rough undulating joints, dipping at 10°
BH3	40.00	84	Coarse grain	Closely spaced rough undulating to stepped clean joints