Classification on Shape of Granitoid Boulder Based on Size and Surface Roughness from Various Weathering Zones for Site Investigation Purposes

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Abstract. Boulder is often posed challenges to earthwork activities such as cut slope and foundation excavation especially in tropical weathered rock like Malaysia. In addition, the guidelines for hard material or rock excavation related to boulder provided by Department of Works Malaysia (JKR) are limited and there is a need to be revised. Therefore, this study aims to establish a classification chart of boulder's shape in different weathering zones for site investigation purposes. The parameters of size, volume and characteristics of surface roughness from moderately to completely weathered zone were measured and analysed statistically. Results of this study show that the increase of weathering zone from zone 3 to 5 significantly reducing the size and volume of boulder with reduction of 27% and 38.3%, respectively. Boulder in Zone 3 to Zone 5 can be classified into six typical sphericities: very flat, flat, sub-flat, sub-spherical, spherical and well-spherical. The results also revealed that the physical parameters of boulder can be classified into six classes based on Roundness Ratio (*Rr*) and Surface Roughness Index (*SRI*). Based on these results, a boulder shape classification chart was developed and useful as a guideline for engineering application especially in soil investigation purposes.

1. Introduction

Malaysia is known as one of the tropical humid countries that receive high intensity of rainfall along the year between 2000 mm to 3000 mm [1]. This phenomenon caused deep weathering up to 100m depth below ground surface [2]. The occurrences of deep weathering lead to the formation of homogenous and heterogeneous weathered zones, which is dominantly, consist of boulders with various shapes and sizes due to the spheroidal reaction such as spalling, fracturing and disintegration [3]. Boulder is also known as block in the matric or BIM rock [4], and talus with consist of centimeter to decimeter-sized angular block [5]. Boulder can be found as a large rounded mass of rock with size greater than 0.3 m which is lying on the surface of the ground or embedded in the sediment and soil [6].

As observed by Raj [7], boulders in heterogeneous zone in tropical region has no specific size and shape. Matula [8] indicated that boulder can be found more than 200 mm in diameter. A number of previous studies have attempted to classify the geometrical property of boulder in different weathering zones as summarized in Table 1.

Table 1. Geometry appearance of corestones in different weathering zones.

Author`	Boulder Size (m)		
	Completely Weathered Zone	Highly Weathered Zone	Moderately Weathered Zone
Alavi et al. [9]	1.0-6.5 m	1.0-4.0 m	-
Md Dan et al. [2]	>1.0 m	2.0-5.0 m	1.0-2.0 m
Alavi et al. [10]	1.0-17.0 m	1.5-13.5 m	-

The characteristics of granite boulders can be determined based on the shape, size and depth of deposited rock [3]. The shape of boulder can be classified a well-rounded shape and some of them are joint-bounded block which surrounded by deeply weathered rock [11]. Yang and Wu [12] proposed the Roundness Index (RI) using box-counting method to classify the core-stone shape in weathered columnar joint in various weathering grades of basalt based on Krumbein's chart and fractal dimension. The authors demonstrated that the core-stone with angular shape showed the higher RI than the rounded core-stone which shows the smaller RI value. Md Dan et al. [13], on the other hand, applied Croft's chart [14] to classify the shapes of boulders in tropical weathered granite (see Figure 1).

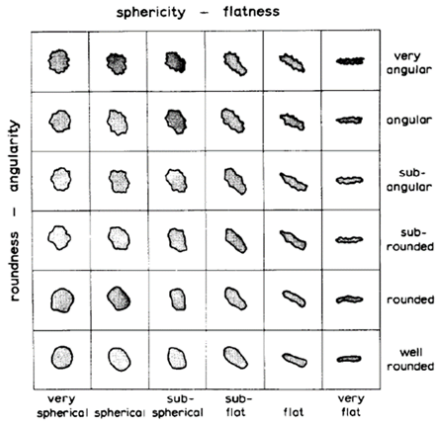


Figure 1. Croft's shape classification chart [14]

Two parameters must be considered to classify the shape of boulder namely (1) roundness and (2) sphericity [6]. Roundness is the measurement of smoothness of the boulder's edges while sphericity can be briefly defined as how close a boulder to form spherical shape. In the context of civil engineering application, the occurrence of boulder beneath ground surface with various sizes and shapes posed issues in the underground and excavation works [15]. An initial planning during site investigation stage is normally required to solve this issue either treat it as common excavation or rock excavation. According to Jabatan Kerja Raya Malaysia [16], the excavation of boulder which is smaller than 0.5 m^3 is not considered as rock excavation but it is treated as common excavation without using blasting method, ripping or larger excavation equipment than for common excavation. Therefore, the information of the properties of boulder at the site is highly needed. Less information of this material will significantly increase the time of excavation, the total cost of the project through machineries used, and sometimes need to redesign the works method. This study aims to provide a systematic classification of boulders characteristics which take into account the size, volume and shape of boulder in different weathering zones to seek better understanding and excavation work purposes.

2. Research methodology

2.1. Study area and geological setting

The study areas were selected based on the availability of boulder in weathering granite zones. Five granitoid quarries were selected around Johor, located at Batu Pahat, Ulu Tiram, Pulai, Kulai and Kota Tinggi (see Figure 2). Each site was identified as granite based on the material production from the quarry and geological map of Peninsular Malaysia as reported by Tate et al. [17].

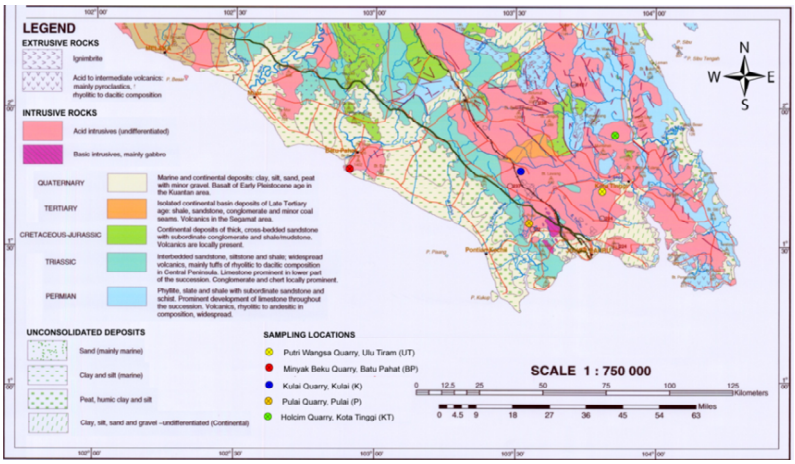


Figure 2. Distribution of granite intrusive in Johor, Malaysia and the sampling locations in the studied areas.

2.2. Weathering zone classification

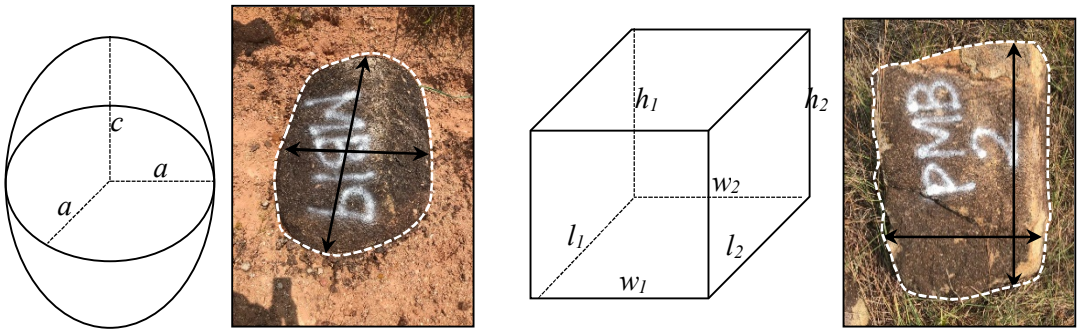
Weathering zone classification was qualitatively established based on the physical characteristics of the rock material and the distribution of boulder in weathering profile. The physical characteristics of each weathering zone include the degree of discolouration, friability of rock materials while the preservation of rock texture and/or the retention of the original rock fabric were qualitatively classified based on Weathering classification system for granitic rocks. The classification was adapted from [18] and [19] shown in Table 2.

Table 2. Qualitative Weathering classification system for granitic rock. Adapted from [18] and [19]

Grade	Description	Discolouration	Colour(s)	Friability
I	Fresh	No visible signs of discolouration	Off-white gray	Requires many blows of geological hammer to fracture it.
II	Slightly Weathered	Discoloured along discontinuities	Gray with white-black spots	Requires many blows of geological hammer to fracture it.
III	Moderately Weathered	Completely discoloured	Brown-yellow	Can be fractured with more than one blow of hammer, cannot be scraped or peeled by penknife, pieces cannot be broken by hand.
IV	Highly Weathered	Completely Stained	Gray white, Gray Brown	Can be peeled with penknife, pieces can be broken by hand, does not slake readily in water
V	Completely Weathered	Completely Stained	Purplish red with gray-white, Gray yellow with gray white	Easily peeled by penknife, slake readily in water
VI	Residual Soil	Completely Stained	Purplish red	A soil formed by weathering in place but with original texture of rock completely destroyed

2.3. Determination volume of boulder

The volume of boulder were measured based on prolate spheroid (see Figure 3(a)) and cuboid shape (see Figure 3(b)). The volume of prolate spheroid and cuboid were measured based on equations (1) and (2), respectively.



(a) (b)

Figure 3.Volume of boulder, **a)** prolate spheroid, and **b)** cuboid

$$V_s = \frac{4}{3}\pi a^2 c \tag{1}$$

$$V_c = l_{avg} \times w_{avg} \times h_{avg} \tag{2}$$

where V_s is volume of prolate spheroid boulder, a is the equatorial semi axes, c is polar semi axis, V_c is volume of l_{avg} is the average length of boulder, w_{avg} is average width and h_{avg} is average high of boulder. The value of l_{avg}, w_{avg} and h_{avg} can be determined based on Equations (3) to (5).

$$l_{\text{avg}} = \frac{l_1 + l_2}{2} \tag{3}$$

$$w_{\text{avg}} = \frac{w_1 + w_2}{2} \tag{4}$$

$$h_{\text{avg}} = \frac{h_1 + h_2}{2} \tag{5}$$

2.4. Determination of surface roughness

In order to determine the surface roughness of boulder in moderately to completely weathered zone, the roughness profile as suggested by ISRM [20] was modified based on the angle edges and angularity of the boulder's surface. No grain size was considered in this method. Protractor was used to measure the surface's angle of boulder.

3. Results and discussions

3.1. Physical Parameters of Boulder in Various Weathering Zones

The physical parameters of boulder including size of shortest and longest, volume, roundness ratio, roundness-angularity and sphericity from moderately to completely weathering zones were statistical analyzed and tabulated in Table 3 and Table 4.

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Table 3. Size of boulder and volume in various weathering zones.

Weathering Zone	Shortest Axis, W (m)				Longest Axis, H (m)				Volume, V (m^3)			
	min	max	Mean	Std	min	max	Mean	Std	min	max	Mean	Std
Zone 3	0.35	1.51	0.82	0.29	0.78	2.23	1.37	0.38	0.05	1.37	0.60	0.55
Zone 4	0.32	1.51	0.75	0.27	0.53	1.90	1.20	0.36	0.03	1.96	0.45	0.43
Zone 5	0.31	1.28	0.64	0.25	0.46	1.71	1.00	0.34	0.03	0.34	0.37	0.33

Table 4. Roundness ratio, surface roundness index and edge angle of boulder in various weathering zones.

Weathering Zone	Roundness Ratio, Rr (W/H)				Surface Roundness Index (SRI)				Edge Angle (°)			
	min	max	Mean	Std	min	max	Mean	Std	min	max	Mean	Std
Zone 3	0.25	0.98	0.61	0.18	4.00	6.00	5.30	0.64	67.00	130.00	89.43	14.15
Zone 4	0.34	0.93	0.64	0.17	2.00	5.00	3.44	0.66	92.00	157.00	129.62	14.64
Zone 5	0.26	0.96	0.65	0.17	1.00	3.00	1.57	0.59	143.00	181.00	166.82	10.12

Data for roundness-angularity and sphericity of boulder from moderately to completely weathered zones are tabulated in Table 5 and Table 6, respectively. Table 5 presents boulder with roundness-angularity of very angular, angular and sub-angular are found abundantly in zone 3 with percentage occurrence of 20%, 52.5% and 27.5, respectively. In weathering zone 4, boulder with roundness-angularity of sub-spherical, sub-rounded and rounded are mostly found with percentage occurrence of 15.4%, 28.8% and 55.8%, respectively. Well-rounded is the major roundness-angularity found in Zone 5 with percentage occurrence of 50%, followed by rounded and sub-rounded with percentage presence of 33.9% and 16.1%, respectively.

Table 5. Roundness-Angularity of boulder in various weathering zones.

Weathering Zone	Roundness-Angularity						
	VA	A	SA	SR	R	WR	Total
Zone 3	8	21	11	0	0	0	40
Zone 4	0	8	15	29	0	0	52
Zone 5	0	0	0	9	19	28	56
Total	8	29	26	38	19	28	148

VA=Very Angular, A=Angular, SA=Sub-Angular, SR=Sub-Rounded, R=Rounded, WR=Well-Rounded

Table 6. Sphericity of boulder in various weathering zones.

Weathering Zone	Sphericity						
	VF	F	SF	SS	S	VS	Total
Zone 3	6	8	4	8	7	7	40
Zone 4	5	9	6	12	11	9	52
Zone 5	6	6	9	12	12	11	56
Total	17	23	19	32	30	27	148

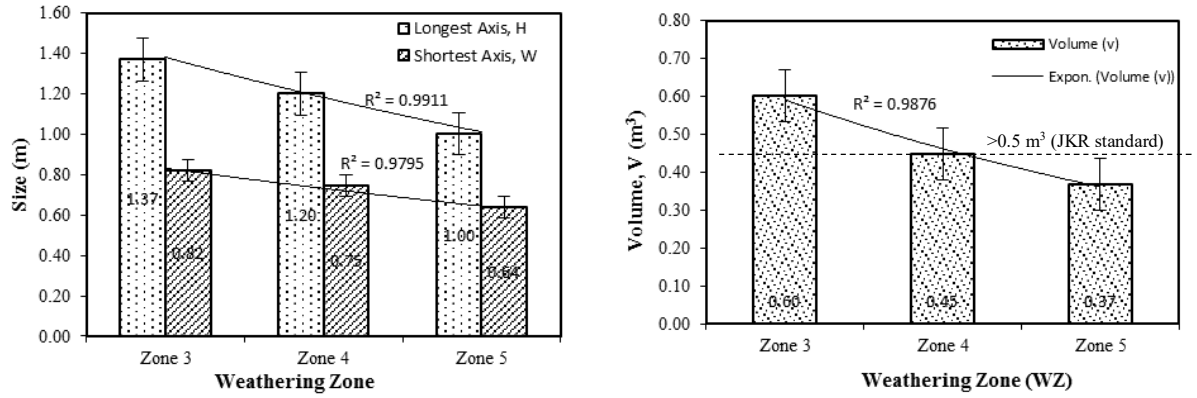
VF=Very Flat, F=Flat, SF=Sub-Flat, SS=Sub-Spherical, S=Spherical, VS=Very Spherical

3.2. Analysis on boulder parameters in various weathering zones

Based on the statistical analysis in Figure 4(a), the increment of weathering zone from zone 3 to zone 5 is significantly reducing the longest and shortest size of boulder with percentage reduction of 27.0% and 22.0%, respectively. The increment of weathering zone 3 to zone 5 is also reduced 38.3% of the volume of boulder (Figure 4(b)).

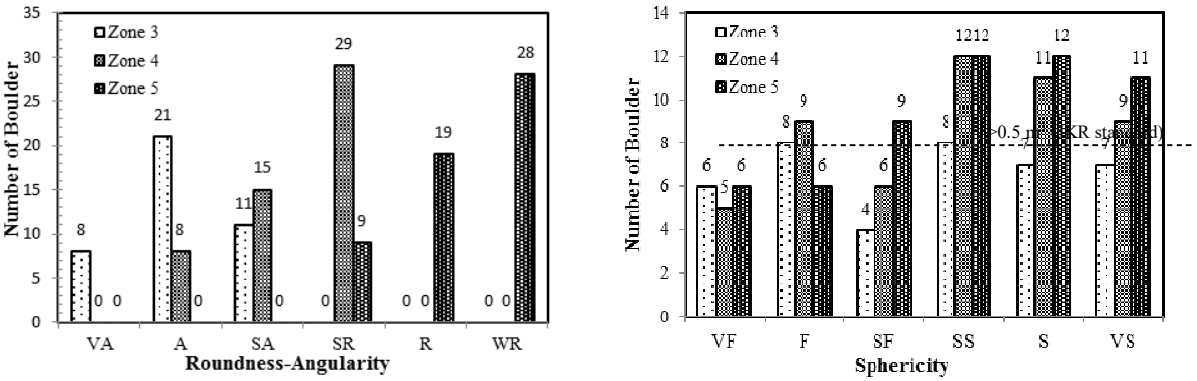
Figure 4(b) shows that boulder in Zone 3 with average volume of 0.6 m^3 can be classified as rock excavation based on Jabatan Kerja Raya Malaysia [16] due to the volume that larger than 0.5 m^3. Meanwhile, boulder in Zone 4 and Zone 5 averagely possess volume of 0.45 m^3 and 0.37 m^3, respectively which is lesser than 0.5 m^3. Therefore, boulder in Zone 4 and 5 can be classified as common excavation. Distribution of roundness-angularity and sphericity of boulder in moderately to completely weathered zone can be seen in Figure 5(a) and Figure 5(b), respectively. Analysis on

Figure 5(a) shows that the dominant roundness-angularity of boulder in Zone 3, Zone 4 and Zone 5 is Angular, Sub-Sounded and Well-Rounded with percentage occurrence of 52.5%, 55.8% and 50.0%, respectively. Figure 5(a) also shows that very angular boulder can be found only in Zone 3. For Rounded and Well-Rounded boulder is only can be found in Zone 5 or completely weathering zone.



(a) (b)

Figure 4. Correlation between boulder size and volume to different weathering zones.



(a) (b)

Figure 5. Physical characteristics of boulder in various weathering zones, (a) roundness-angularity, and (b) sphericity

Analysis on the sphericity of boulder (Figure 5(b)) shows that the boulder in Zone 3 to Zone 5 consist of six major types of sphericity namely very-flat, flat, sub-flat, sub-spherical, spherical and very spherical. Dominant sphericity in Zone 3 is flat and sub-spherical with percentage occurrence of 20%. Sub-spherical is dominant in Zone 4 with 23.1% occurrence. In Zone 5, the dominant sphericity of boulder are sub-spherical and spherical shape with percentage occurrence is 21.4%, respectively.

3.3. Boulder shape classification based on surface roughness index and roundness index

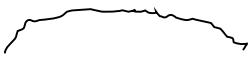
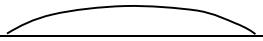
Surface roughness index (*SRI*) was proposed based on the field investigation and analysis on 146 boulders with various shapes and sizes from moderately to completely weathered as classified in Table 7. *SRI* consists of six indexes which were classified based on roundness and angularity, surface characteristics and angle edges. Roundness and angularity were classified based on Croft [14] which is consist of very angular, angular, sub-angular, sub-rounded, rounded and well rounded edges. The characteristics of boulder's surface were measured according to the surface textures and angle edges of the boulder.

Boulder Shape Classification (*BSC*) is proposed to classify the shapes of boulder in various weathering zones (see Figure 6). This classification chart was systematically classified the shapes of

boulder from moderately to completely weathering zones based on roundness-angularity, sphericity, the roundness ratio (*Rr*) and surface roughness index (*SRI*).

Based on Figure 6, six sphericity shapes is classified as very flat, flat, sub-flat, sub-spherical, spherical and very spherical possess roundness ration (*Rr*) range of 0.30 to 0.40, 0.41 to 0.50, 0.51 to 0.60, 0.61 to 0.70, 0.71 to 0.80 and 0.81 to 1.00, respectively. All these sphericity can be found in moderately to completely weathering zones (Zone 3 to Zone 5). Boulder with very angular and angular shapes can be found in moderately weathered zone (zone 3). Sub-rounded and sub-angular boulder are identified in highly weathered zone (Zone 4). Boulders in completely weathered zone (Zone 5) are classified as rounded and well-rounded roundness-angularity. Surface roughness index (*SRI*) are different based on weathering zones where the boulder is found.

Table 7. Proposed surface roundness index based on roundness characteristics and edges surface of of boulder.

Roundness and Angularity	Typical Roughness Profile	Description of Surface Characteristics	Angle Edges (°)	Surface Roundness Index, *SRI*
Very Angular (VA)		Very coarse surface texture. Very pointed and very angular edges.	< 90°	6
Angular (A)		Coarse surface texture. Pointed and/or angular edges.	90° - 100°	5
Sub - Angular (SA)		Coarse to fine surface texture. Concave edges.	100° - 130°	4
Sub - Rounded (SR)		Fine to coarse surface texture. Concave to smooth edges.	130° - 150°	3
Rounded (R)		Fine surface texture. Smooth edges surface.	150° - 170°	2
Well Rounded (WR)		Very fine surface texture. No edges in pointed surface.	170° - 180°	1

Boulder in Zone 3 comprises coarse to very coarse surface texture and angular to very angular edges which are indexed from 5 to 6. Boulder in Zone 4 commonly possess coarse to fine surface texture and concave to smooth edges which are indexed as 3 to 4. Boulder in Zone 5 are classified as index 1 or 2 based on fine or very fine surface texture and smoothness edges of boulder.

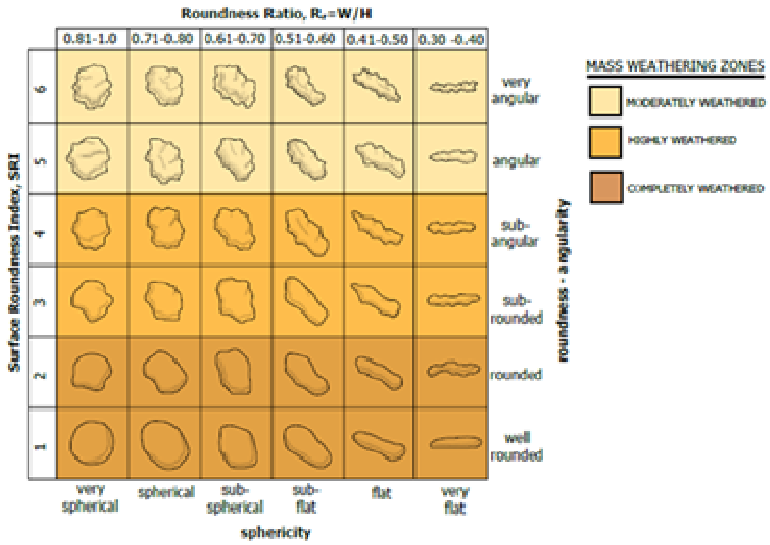


Figure 6. The proposed boulder shape classification (*BSC*) based on surface roughness index (*SRI*) and roundness ratio (*Rr*).

4. Conclusions

It can be concluded that the boulder in different weathering zones comprises different shapes and characteristics that can be classified based on roughness index (SRI), roundness ratio (Rr), roundness-angularity and sphericity. The main parameters of the classification are the longest and shortest size of boulder and the roughness characteristics. This proposed classification is comprehensive to be applied by both competent and incompetent engineers to classify the shape of boulder in weathered granitoid mass during site investigation works.

5. References

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