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Description and classification of filled joint in granite — an approach

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Abstract: The weathering degree of joint blocks and its infilling affects the deformational behaviour of filled joint. To appreciate its behaviour and level of criticality to an engineering construction, filled joint should be described and classified according to its weathering degree. This paper proposes the procedures for classifying filled joint in the field. Based on weathering classification of weathered rock, the suggested method is suitable for filled joint resulting from differential weathering of joints in granite.

INTRODUCTION

When filled joints are reckoned to be critical to an engineering structure, their behaviour is often studied either using *in-situ* testing, full-scale modelling and computer simulation. This is because sampling of undisturbed filled joints for laboratory testing are almost impossible to undertake. The predicted behaviour based on field assessment is therefore important for planning these expensive and complex testing procedures. As far as field conditions are concerned, one feasible method to achieve this is through systematic classification. If properly implemented, such classification also facilitates determination of the relevant input parameters for testing and simulation. The input parameters, among others, are the characteristic components of filled joint as depicted in Figure 1.

Weathering classifications of rock mass, such as engineering and site-specific classification, are well documented in the literature. Therefore, they are widely used in the initial assessment of large engineering projects (Martin and Hencher, 1986). Classification of the *in situ* rock profile provides vital information on the expected constructional problems to be encountered in rock of different weathering grades. Like weathered rock mass filled joints pose a number of constructional problems (Sharp *et al.*, 1986; Carlsson *et al.*, 1989; Mohd Amin and Snee, 1994). The inhomogeneity of its weathered joint blocks and infilling make it extremely difficult to account for in design. However, their method of classification is still inadequate in providing informative data for engineering purposes.

In this paper, methods for classifying filled joint in the field are suggested which are based on the weathering classification of rock. The grading procedures for weathered *rock mass* and *rock material* are used as basis for classification. Infill characteristics and thickness are also highlighted mainly due to their significant effect in controlling joint behaviour. However, due to the variability of weathering mechanisms in different rock types, the proposed classification is confined to granite only and specifically, for filled joint resulting from differential weathering of joint blocks. It is hoped that the suggested approach will provide additional input in developing a more comprehensive classification system of filled joint.

FILLED JOINT IN GRANITE

Weathering of granite begins along major discontinuity surfaces. Discontinuities such as joint facilitates differential weathering zones, since it controls the rate and sequence of weathering. On joint surfaces, weathering starts off with stain of secondary minerals due to the breakdown of the least stable minerals like feldspars and micas. As this continues, discoloration starts to penetrate inwards from the discontinuity surfaces and eventually reach a depth of a few centimeters. Microfractures that are normally associated with the formation of joint (Baynes and Dearman, 1978) play a major role in the penetration of weathering actions into joint surfaces.

The increase in volume due to kaolinisation of feldspars and hydrolysis of micas may produce sufficient stress for the joint wall surface to spall off (Lamb, 1962) thus, offering a fresh surface for further weathering. Continuous and intense weathering of jointed granite eventually lead to the accumulation of weathered material in its joint aperture. Typical depth of occurrence and thickness of infill for filled joint in granite are listed in Table 1.

Being the weakest component, infilling contributes significantly to joint deformability and

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thus reducing joint strength and stiffness. In rough joint for instance, infill reduces interaction between the stronger joint walls. Thus, at a certain critical thickness, infill controls the behaviour of joint (De Toledo and De Freitas, 1993; Papaliangas *et al.*, 1993; Phien-wej *et al.*, 1992). In granite, infills may consist of weathered material of various grades, varying from loose cohesionless rock fragments to cohesive clayey material. It has noted that the weathering grade of the infill dictates its strength and behaviour. In general the higher the grade the weaker is the material (Murata *et al.*, 1990; Shimizu, 1990). The highly weathered granite infill is usually a well-graded sandy gravel with weak angular grains (Lee and Coop, 1995). Therefore, its material characteristics such as particle strength, shape, size and density affect the shear behaviour of the host joint (Mohd Amin and Kassim, 1999).

CLASSIFICATION OF WEATHERED ROCK

Present classifications employ a six fold system and this is shown in Table 2 for granite. The classification description and grading are based on two scales (Dearman, 1986; Lee and De Freitas, 1989):

Small scale (material) weathering

Weathered rock material of similar weathering degree is given a *grade*. The weathered state comprises Grade I for *fresh rock* and Grade VI for *residual soils*. The intermediate grades, Grade II to V, are described by the terms *slightly weathered*, *moderately weathered*, *highly weathered* and *completely weathered*, respectively. To emphasize the dominant weathering type, the main grade

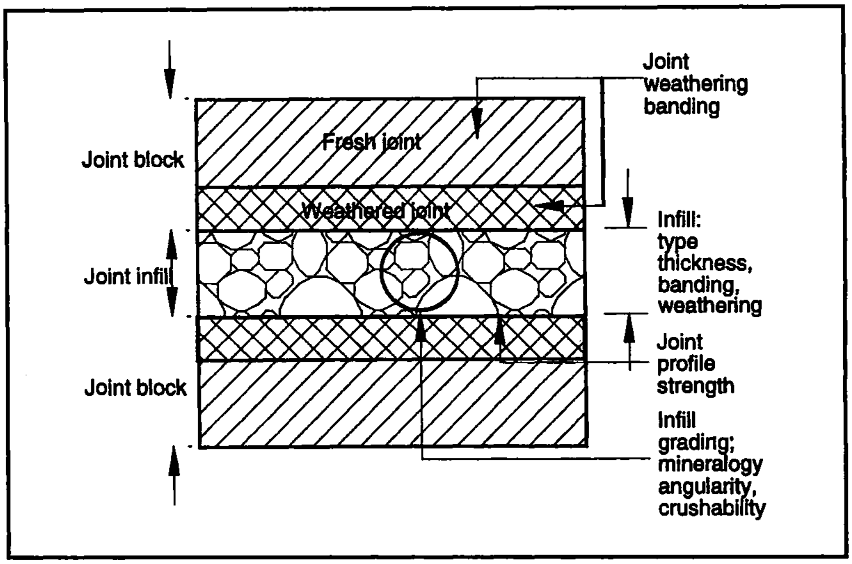


Figure 1. Characteristic components of filled joint. Properties some of these Components can be assessed geologically and mechanically, and graded accordingly.

Table 1. Occurrence of filled joint in granite.

Authors	Area, rock type and depth	Type of infill and thickness
Sharp *et al.* (1986)	Hong Kong granite, 60 m depth	Weathered joint 100 mm–1.0 m width with 20 mm completely decomposed material as centre core.
Ge Xiurun (1991)	China granite, 330–440 m depth	Altered granite, montmorillonite and quartzite-calcite, 200 mm thick.
Carlsson *et al.* (1989)	China granite, 200–300 m depth	Altered granite, 50–400 mm width and 10 mm quartzo-calcic core.

Table 2a. Typical classification of weathered rock mass and rock material.

	ROCK MASS			ROCK MATERIAL	
Author(s) and rock material	**Zone characteristics**	**Weathering class/grade**	**Zone symbol**	**Material description**	**Grade symbol**
Zhao *et al.* (1992) Granite (Singapore) Objective — classification for underground excavation	Inner material is grade I; surface material is grade I or II.	Fresh rock	I	All mineral constituents are sound. Feldspars cannot be scratched with knife. Require many blows of geological hammer to fracture the rock. σ_c(dry) 130–180 MPa.	I
	Inner material is grade II; surface material is grade II or III.	Slightly weathered	II	Plagioclases are occasionally slightly decomposed. Biotites are slightly decomposed. Slightly weaker than fresh rock. σ_c(dry) 90–130 MPa.	II
	Inner material is grade III; surface material is grade III or IV, occassionally V.	Moderately weathered	III	Most plagioclases and some potash feldspars are moderately decomposed. Biotites are slightly decomposed (staining of surrounding minerals). Feldspar can be scratched with a knife. Considerably weaker than the fresh rock. σ_c(dry) 50–100 MPa.	III
	Inner material is grade IV; surface material is grade IV or V, occassionally VI.	Highly weathered	IV	All plagioclases are highly decomposed. Most potash feldspars are moderately decomposed. Biotites are highly decomposed staining most of the rock minerals. Feldspars can be peeled by knife with difficulty. Significantly weaker than fresh rock. σ_c(dry) 30–50 MPa.	IV
	Most material is grade V.	Completely weathered	V	All plagioclases and most of potash feldspars and biotites are completely weathered. Original texture present. Feldspars can be easily peeled by knife. Can be excavated by hand with some effort. Very low strength relative to fresh rock.	V
	Most material is grade VI.	Residual soils	VI	Feldspars and biotites are completely decomposed (clayey). Original textures are absent. Sample can be indented by thumb with moderate effort. Can be easily excavated by hand. Very low strength.	VI
Lee and de Freitas (1989) Granite (Korea) Objective — general classification of weathered granite	Inner material is grade I; outer material is grade I or II.	Fresh (rock)	I	All mineral constituents are sound no evident of microfracturing. Feldspars cannot be scratched with knife. Requires many blows of geological hammer to fracture sample. UCS(dry) 125–260 MPa.	I
	Inner material is grade II; outer material is grade II or III.	Slightly weathered (rock)	II	Plagioclases are occasionally slightly decomposed (gritty). Biotites are slightly decomposed beginning to stain some surrounding minerals. Slightly microfractured. Samples require more than one blow of geological hammer to fracture. UCS(dry) 100–170 MPa. Slightly weaker than fresh rock.	II
	Inner material is grade III; outer material is grade III or IV, occassionally V.	Moderately weathered (rock)	III	Most plagioclases and some potash feldspars are moderately decomposed (gritty). Biotites are slightly decomposed (staining of many surrounding minerals). Feldspar can be scratched with a knife. Sample can be fractured with single firm blow of geological hammer. Moderately microfractured, but fractures and grain boundaries are tight. UCS(dry) 60–120 MPa, medium strength.	III

Table 2b. Typical classification of weathered rock mass and rock material.

	ROCK MASS			ROCK MATERIAL	
Author(s) and rock material	**Zone characteristics**	**Weathering class/grade**	**Zone symbol**	**Material description**	**Grade symbol**
Lee and de Freitas (1989) Granite (Korea) Objective — general classification of weathered granite	Inner material is grade IV; outer material is grade IV or V, occassionally VI.	Highly weathered (rock/soil)	IV	All plagioclases and some potash feldspars are highly decomposed (gritty and clayey). Most potash feldspars are moderately decomposed. Biotites are highly decomposed staining most of the rock minerals. Feldspars can be peeled by knife with difficulty. Highly microfractured, grain boundaries tend to be slightly open. Significantly weaker than fresh rock. UCS(dry) 35–55 MPa.	IV
	Most material is grade V.	Completely weathered (soil)	v	All plagioclases and most of potash feldspars and biotites are completely decomposed (clayey). Some potash feldspars are highly decomposed (gritty and clayey). Original texture present. Feldspars can be easily peeled by knife. All microfractures and grain boundaries tend to be open. Can be excavated by hand with difficulty. Loses most of strength of fresh rock.	v
	Most material is grade VI	Residual soils (soil)	VI	Feldspars and biotites are completely decomposed (clayey). The existence of microfractures and grain boundaries are hardly distinguishable as original textures are absent. Sample can be indented by thumb with moderate effort. Can be easily excavated by hand. Very low strength.	VI
Hencher & Martin (1982) and Martin and Hencher (1986) Granite and volcanic rocks (Hong Kong) Objective — classification for slope stability in weathered granite	Excellent quality rock mass. 100% rock (grades I, II). No visible signs of rock weathering, slight discolouration along joints. Joints surface are strongly interlocking.	Fresh rock	1	No visible signs of weathering rarely encountered in surface exposures.	I
	Good quality rock mass: > 90% rock (grades I, II or III). Weathering along discontinuities.	Slightly decomposed	2	Schmidt rebound value (N) > 45; more than one blow of geological hammer to break sample; strength approaches that of fresh rock.	II
	Moderate quality rock mass: 50–90% rock (grades I, II or III). Severe weathering along discontinuities. Locked structure.	Moderately decomposed	3	N values 25–45. Considerably weathered but possessing strength such that 55 mm diameter pieces cannot be broken by hand; rock material not friable.	III
	Poor quality rock mass: 30–50% rock (grade I, II or III); corestones affect shear behaviour of rock mass.	Highly decomposed	4	N value 0–25; does not slake readily in water, hand penetrometer strength index > 250 kN/M^2; large pieces can be broken by hand; individual grains plucked from surface.	IV
	Soil with corestones: less than 30% rock (grade I, II, III); shearing can be affected through matrix; rock content significant for investigation and construction.	Completely decomposed	5	No rebound from Schmidt hammer; slakes readily in water. Rock is wholly decomposed but rock texture is preserved.	V
	Soil derived from *in situ* weathering: 100% soil (grade IV, V or VI); may or may not have lost rock mass features completely.	Residual soil	6	A soil mixture with the original texture of the rock completely destroyed.	VI

Table 3. Diagnostic characters used to define various grade of granite. The length of line drawn above the name of each character describes the range of grades over which it may be effectively used (after Lee and De Freitas, 1989).

Weathering grade/zone		F	SW	MW	HW	CW	RS
Rock Material	Visual recognition	Presence of original texture					
		Degree of discolouration of rock material					
		Degree of chemical decomposition of biotite and feldspar					
		Presence of humus and roots					
	Mechanical recognition	Degree of physical disintegration					
		Disintegration of material in water (slakability)					
		Relative rock material strength					
		Breakability of NX core in the hand					
		Friability					
		Relative hardness by hammer blow					
		Schmidt hammer value					
		Method of hand excavation					
		Degree of plucking of individual grains					
		Degree of penetration of geological pick or knife					
		Hand penetrometer value					
Rock Mass	Visual recognition	Degree of discolouration along joint plane					
		Presence of original structure					
		Rock to soil ratio					
		Degree of weathering along joint plane					
		Angularity of corestone					
		Opening of joint					
	Engineering recognition	NX core recovery					
		Relative rock mass permeability					
		RQD					

terms are written as either *decomposed* (chemically weathered) or *disintegrated* (mechanically weathered).

Large scale (mass) weathering

Weathered rock mass of broadly similar weathering grade is grouped into *zone*. The stratigraphical sequence comprises Zone I at depth passing up into Zone VI at the surface. Similar grade terms and numeral ratings are used for the grading of zones.

Generally, the assessment and description of a rock mass and rock material at various weathering stages are based on three methods: visual identification of certain geological characteristics, assessment of relevant mechanical characters and appraisement of a mixture of geological and mechanical factors. Quantitative assessment methods are normally preferred for engineering purposes (Hencher and Martin, 1982; Lee and De Freitas, 1988). For rock material, these quantitative methods consist of simple index tests like the point-load test, Schmidt hammer test and slake durability test. In the case of the rock mass, these include RQD assessment and relative permeability test. Table 3 summarises the diagnostic features and characterisation tests for classification of weathered rock.

WEATHERING CLASSIFICATION OF ROCK MATERIAL

Sequence of physical changes in crystalline rock due to weathering has been divided into four stages and these form the basis for classifying weathered rock into either *rock* or *soil* (Irfan and Dearman, 1978). Due to the significant changes in physical properties of weathered rock at the *discoloured stage*, it is subdivided into 2; *slightly* and *highly*. Thus, the classification can be presented as:

Rock — *fresh, slightly and highly discoloured*
Soil — *decomposed* and/or *disintegrated*

The followings are suggested as general guidelines in determining the grading and the condition terms for classification of weathered rock material:

- From the durability point of view, Grade I to Grade III materials may be considered as *rock* and, Grade V to Grade VI as *soil*. The Grade IV is a transition between *rock* and *soil*.

- The boundary between Grade III and IV is estimated using the 50:50 *rock:soil* ratio.
- *Friability* of material indicates if the material is effectively a *soil* or *rock*. *Partly friable* means the presence of both materials.
- In *non-friable* material (Grade I to III) weathering effect is recognised by *discoloration*. In Grade II and III normally more than half of rock exhibits iron-staining, a stage before the rock breaks down from its massive state.
- Presence of *original texture* is the diagnostic feature used to distinguish completely weathered granite (Grade V) from residual soil (Grade VI).

WEATHERING CLASSIFICATION OF ROCK MASS

The assessments and description for rock material can also be applied to rock mass but with additional consideration of the *spatial distribution* of weathering. Thus, the weathering profile in a rock mass can be described on the basis of the distribution of the weathered rock materials and the effect of weathering on rock discontinuities.

An ideal weathering profile of a rock mass consists of three basic zones (Fig. 2); *rock*, *rock-and-soil* and *soil*. As boundaries between zones are usually gradational and irregular, each zone is subdivided into two justifiable zones, thus giving a six-zonal classification (see Table 2). Boundaries between subdivision of each zone can be identified by *discoloration* of the rock zone, *rock:soil* ratio and *original texture* of the soil zone. The following guidelines are recommended for zonal grading of a weathered rock mass (Martin and Hencher, 1986):

- In Zone I the rock mass will be either *fresh* or *slightly weathered*. Grading of each zone are distinguished by the degree of *discoloration* in Zones I and II, and the loss of *mass structure* for Zones V and VI. If the original structure is absent, the rock mass is graded as Zone VI.
- Two methods for separating Zones III, IV and V. Firstly, using *50% rock:soil ratio* as cut-off point for Zones III and IV. Secondly, using cut-off points; 50–90% for Zone III, 30–50% for Zone IV and < 30% for Zone V.

WEATHERING GRADES AND MATERIAL PROPERTIES

Weathering significantly effect rock material properties such as strength and permeability. In granite this can be attributed to changes in material characteristic and micro-fabric:

- Feldspars, which makes up about 50 to 60% of granite by volume, is a mineral of low crushing strength when weathered (Feda, 1971).
- Material crushability increases with weathering grade. This is due to increasing particle angularity as a resulting of increasing number of micro-cracks in minerals, surface pitting of quartz and decomposition of highly cleaved feldspar (Baynes and Dearman, 1978).
- Void spaces, which contributes to compressibility, also increases with weathering grade (Shimizu, 1990).

The mechanism of particle crushing (Hagerty *et al.*, 1993) implies that crushability and compressibility of weathered granite material increases with weathering grade. Hence, for joint in granite, the reduction in strength is inevitable if its aperture is filled with a highly weathered granite.

CONCEPTUAL WEATHERING STAGES OF A JOINT

Based on an ideal weathering profile and the weathering zone around a single core stone (Dearman, 1986), the weathering stages of a joint in granite are conceptually presented in Figure 3. The weathering action starts on the joint walls and spreads laterally into the joint blocks. Assuming a similar rate of weathering acting on both joint walls then, this creates a mirror image on either side of the joint centre line. If the weathering sequence, stage 1 through 5, commences with staining or discoloration of the joint surfaces, each weathering stage produces layers or bands of weathered material. The bands comprise the least weathered material within the joint blocks and the most

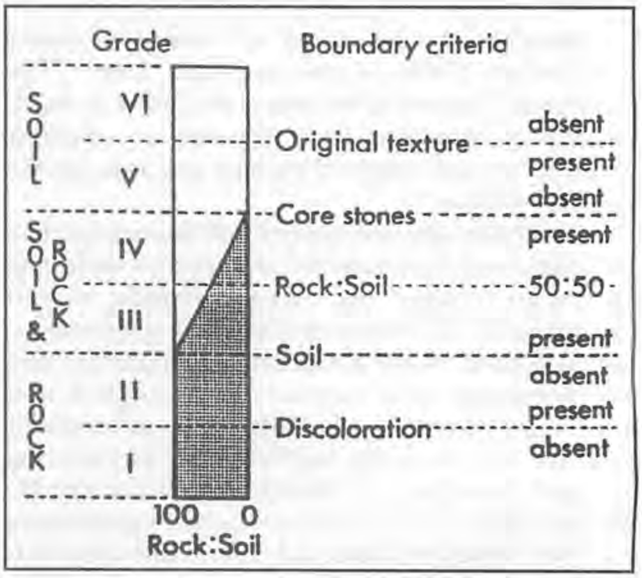


Figure 2. Gradings and boundary criteria for an idealised weathering profile (after Dearman, 1986).

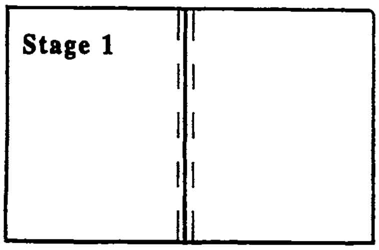
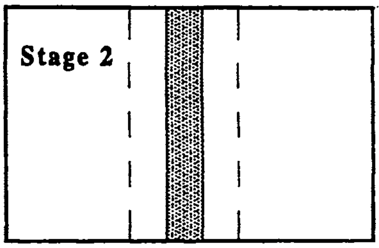
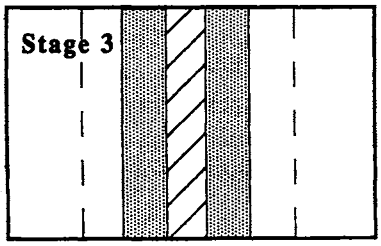
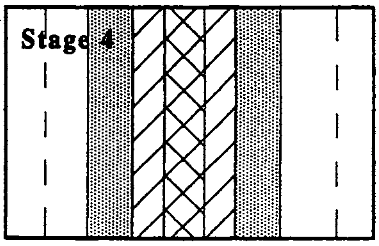
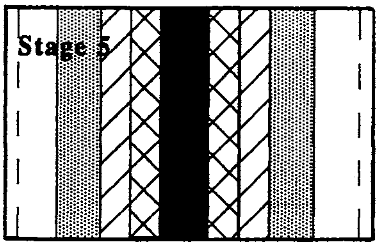
Weathering stages	Material — description and grade	Rock mass — zone and weathering class
	Block: stain margin in joint blocks indicates weathering starts to penetrate into the joint wall, but rock material is still intact and sound. **Grade I** Joint: discoloration on joint surfaces. **Grade II**	**Zone I**: SW with discoloration on joint surfaces
	Block: material closer to the joint is highly discoloured. Grain boundaries start to open but material is not friable. Stain margin penetrates deeper. **Grade I** (if volume % of fresh blocks > discoloured volume). Joint: surfaces completely discolored, joint beginning to open-up with slight scaling of joint wall material. **Grade III**	**Zone I**: SW with highly discolored joint surfaces and in material closer to the joint.
	Block: Grade II and III layers occurs deeper in the block but less than 50% of the block volume. **Grade I** (approching Grade II). Joint: Previously Grade III layer and joint walls begin to disintegrate to friable material, transition from completely discoloured rock to soil. Increase in 'effective' joint width due to presence of infill material scaling of joint wall. **Grade III** or **IV** (depend on vol. %).	Between **Zone I** and approaching **Zone II**, with moderately & highly decomposed/disintegrated friable material in the joint aperture (specify volume of infill as % of intact joint block).
	Block: Layer of Grade II and III cover more than 50% of block volume Compare vol.% of Grade II and III. **Grade II** (slightly weathered material is dominant). Joint: Filled with highly and completely decomposed/disintegrated material Grade IV & V (previously Grade III and V, respectively). Original texture still intact. **Grade V** (if completely weathered material is dominant)	**Zone II** (if vol. % of dominant infill material < than the slightly weathered block), joint is filled with highly and completely decomposed/disintegrated material (specify volume of infill as % of slightly weathered block).
	Block: Volume of **Grade II** and **III** cover more than 50% of block. Probably at this stage Grade III material is more dominant than Grade II. Blocks almost completely affected by weathering **Grade II I.** Joint: joint aperture is filled with three different grades of material; highly and completely decomposed/disintegrated materials and residual soil (with original texture destoyed). **Grade V** or **VI** (whichever is dominant)	**Zone II** but approaching **Zone III**. Joint is filled with completely decomposed/disintegrated materials and residual soil (specify total volume of infill as % of blocks). Note: if volume of infill is greater than block then, the most dominant infill grade material dictates the zone grade.

Figure 3. Probable weathering stages of filled joint in granite — proposed description and classification.

weathered as core of the infill. Similar banding of weathered granite around a single joint has been observed by Ge Xiurun (1991).

The banding pattern in the infill and joint blocks at the highest weathering stage (i.e. stage 5) can be presented as Figure 4. The banding may not be as distinctive but will probably be a gradual change from stained margin in the joint block, to residual soil (RS) in the centre. However, the interface between Grade III and IV layer is easily distinguishable as Grade III exhibits distinctive rock characteristics. The distance between these interfaces (Fig. 4) is considered as the 'effective' joint width or aperture. Several important points can be deduced from Figures 3 and 4:

1. The thickness of each successive layer will vary and each layer displays an increasing thickness with each weathering stage. It is thought that the most weathered will be thicker than the less weathered one.
2. An increase in the 'effective' aperture and depth of discoloration of the joint block after each weathering stage.
3. Joint block material undergoes at least four stages of weathering (stage 2 through 5) before the aperture of the previously closed joint could be filled with RS.
4. Failure is more likely to commence in the centre layer i.e. the most weathered.

WEATHERING DESCRIPTION AND CLASSIFICATION OF FILLED JOINT

The concept for weathering classification of rock mass and rock material can be used to classify filled joint according to its respective weathering grade. When the rate of penetration of weathering effects into the joint wall is considered, the size of the original joint block is essential before the grade at various weathering stages could be defined. This however, entails scale effect (Dearman, 1986) and can be overcome by considering the distribution of weathered materials in a rock mass in terms of percentage volume (Lee and De Freitas, 1989). The following simplifications are made to assist in the grading and subsequent classification of filled joint:

- The 'effective' joint aperture defines the infill thickness therefore, infillings imply those friable materials of either grade IV, V or VI (Fig. 4).
- If the infill remains in joint aperture, the amount of joint block that has been weathered is approximately equals to the infill volume.
- Weathering of the other exposed surfaces of the joint block may be ignored. This applies when joint bounded by two blocks is a major joint and those enclosing the blocks are minor joints.

The proposed procedures for classifying the *infill*, *joint blocks* and *joint-block system* are as follows:

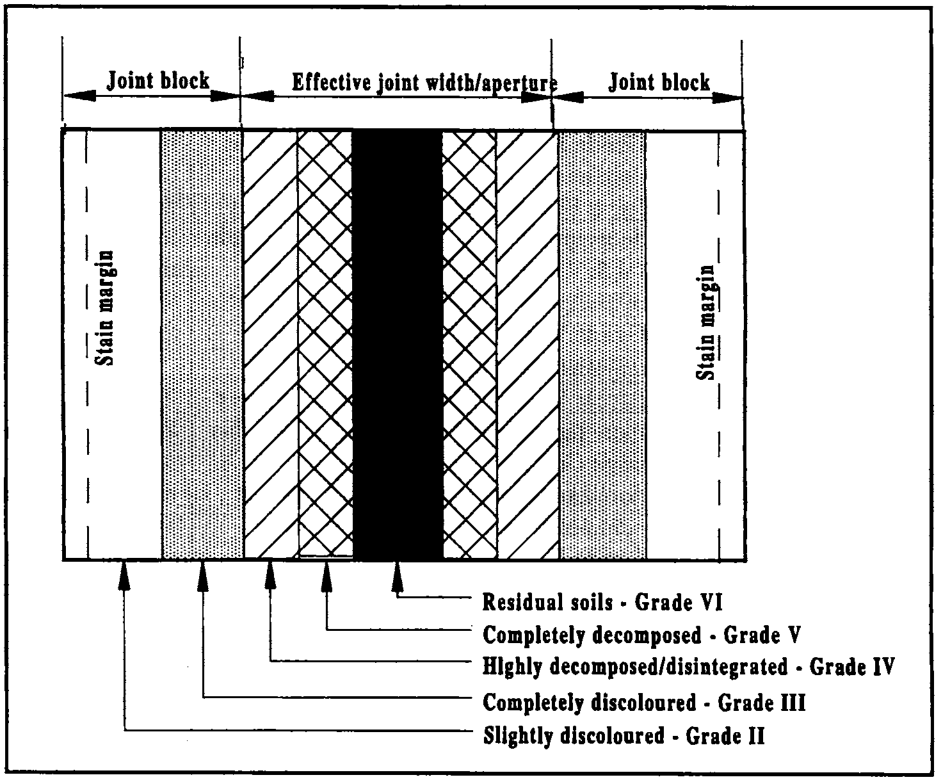


Figure 4. Probable banding pattern of infill and joint blocks resulting from differential weathering along a joint.

1. **Infill** (material classification):
   (a) Joint opening may indicate disintegration of joint walls, so identify any friable material within the joint aperture. If banding of materials occurs identify the major layer.
   (b) Estimate the volume of the most dominant material (as % volume of infill), the grade of this material represents the weathering grade of the infill.
2. **Joint block** (material classification):
   (a) In the case of closed joint, note the discoloration and its depth of penetration into the joint blocks, estimate the volume of discoloration (as % of joint block), this percentage determines the weathering grade of the block.
   (b) If infill is present, its volume represents the volume of joint block that has been weathered. The % volume of the infill, expressed in terms of the original block size, determines the weathering grade of the block.
3. **Joint-blocks system** (rock mass classification):
   (a) Compare the volume of the most dominant material within the joint-blocks system, the greatest volume of material of a specified weathering grade classifies the zone grade.
   (b) If the % volume of the infill is more than 50% then, the grade of the infill dictates the zone grade of the joint-block system, if less than 50% then, the grade of the joint block gives the zone grade.

The typical description and proposed classification of filled joints at the various weathering stages is shown in column 2 and 3 of Figure 3. It may be noted that the percentage volume of infill may categorise a joint-block system as slightly weathered (SW) zone. For example, a 20 mm thick infill bounded by 2 blocks of 2 m edge length would gives 1% disintegration of the joint block material. Since the effect of infilling on joint behaviour is significant therefore, it is important to acknowledge its presence even if the joint-block system is classified as SW.

CONCLUSIONS

A systematic field classification scheme is a practical method for obtaining initial data pertaining to geological materials and structures which are difficult to sample.

Like weathered rock masses, filled joints are formed by weathering process. Therefore, one feasible method to classify them in the field is through weathering classification of their major components namely, joint blocks and infilling.

The weathering classification of rock material and rock mass can be used to classify filled joint into various weathering grades. The joint-block system undergoes at least four weathering stages before joint aperture could be filled with residual soils. When infill consists of layers of material, the most weathered layer controls the joint behaviour. Therefore, it is essential to acknowledge its presence irrespective of the weathering grade of the joint-block system.

The geological and mechanical characteristics of certain components of filled joint can be assessed in the field and laboratory. These include crushability, particle grading and weathering grade of the infill, and strength of the joint surfaces. If the assessed characteristics can be numerically graded according to their degree of significance in controlling joint behaviour, they may be used as basis for a comprehensive classification. A research is now being undertaken (RMC/UTM Vot 71319) to study this possibility.

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