

BEHAVIOUR OF FILLED JOINT UNDER SHEAR LOADING

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To my beloved family

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ABSTRACT

In tropical country like Malaysia, hot and wet weather encourages the formation of filled joint, which is one of the most critical discontinuities that affect the stability of rock mass. It is therefore essential to study the characteristics and behaviours of filled joint to understand their effect on rock mass. Filled joint resulting from *in situ* deposition of infilling in the joint aperture was the main focus of this study. Dominant components of this filled joint were identified and accordingly modeled in the laboratory tests. A large shear box apparatus (300mm square section) has been designed and fabricated specifically to simulate the loading configurations on the filled joint model. Cast concrete of different surface roughness (planar to rough) was used as joint block. Joint aperture was filled with actual infill material, with thickness between 5 to 15 mm (average density before shear of approximately 1800 kg/m³). The normal stress applied during shear was between 130 to 370 kPa, equivalent to typical slope height of 5 to 15 m. The study showed that the shear resistance of rough filled joint reduces with increasing infill thickness and eventually approaches the shear strength of the infill material. Infill thickness has no significant effect on the shear strength of filled joint with smooth surface texture as its shear strength is almost similar to that of the infill. Nevertheless, with very thin infill (approximately thickness of an infill particle) in smooth joint, the resultant shear resistance is much lower than that of the infill. This implies that the weakest shear plane of a filled joint might not lie within the infill, but at the interface between infill and joint surface. Crushing of infill particles has been noted to influence the shear and compressive behaviours of filled joint.

ABSTRAK

Di negara tropika seperti Malaysia, cuaca yang panas dan lembap sepanjang tahun mendorong pembentukan kekar berinti yang mana merupakan salah satu daripada ketakselajaran kritikal yang utama yang mempengaruhi kestabilan jasad batuan. Oleh itu, sifat dan kelakuan kekar berinti mesti dikaji untuk memahami pengaruhnya terhadap jasad batu. Satu kekar berinti yang terbentuk daripada pemendakan bahan inti ke dalam bukaan kekar dikaji dalam projek ini. Unsur-unsur utama sistem kekar berinti yang dimendapkan ke dalam bukaan kekar ini telah dikenalpasti dan disimulasikan dalam kajian makmal. Dalam projek ini, sebuah alat ricih besar (300 x 300mm) telah direkabentuk secara khusus untuk menyimulasikan kesan beban terhadap kekar berinti. Blok konkrit dengan pelbagai tekstur permukaan (dari rata ke kasar) dijadikan sebagai blok kekar. Bukaan kekar diisi dengan bahan inti sebenar dengan ketebalannya di antara 5 ke 15 mm (purata ketumpatan sebelum ricih dianggarkan sebagai 1800 kg/m^3). Tegasan normal yang dikenakan semasa ricihan adalah di antara 130 ke 370 kPa, iaitu menyerupai cerun batuan setinggi 5 hingga 15m. Hasil kajian menunjukkan bahawa, dalam kekar bermuka kasar, kekuatan ricih didapati berkurangan apabila ketebalan inti bertambah. Apabila ketebalan inti menjadi sangat tebal, kekuatannya menyerupai kekuatan bahan inti sahaja. Ketebalan inti didapati tidak mempengaruhi kekar bermuka rata, yang kekuatan ricihnya hampir sama dengan kekuatan bahan inti. Walau bagaimanapun, dengan wujudnya lapisan inti yang sangat nipis (setebal satu butiran) di antara permukaan rata, kekar akan menjadi lebih lemah daripada bahan inti. Ini membuktikan bahawa kegagalan ricih tidak semestinya berlaku dalam lapisan inti, tetapi mungkin pada sempadan di antara inti dan permukaan kekar. Retakan dan pecahan butiran inti telah dikenalpasti dapat mempengaruhi kelakuan ricihan dan mampatan kekar berinti.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xvi
	LIST OF APPENDICES	xiii
1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Background Problems	3
	1.3 Objectives of Study	4
	1.4 Significance of Study	4
	1.5 Scopes of Study	5
	1.6 Organisation of Thesis	5
2	LITERATURE REVIEW	
	2.1 Introduction	6
	2.2 Joint	7
	2.2.1 Filled Joints	9

2.3	Filled Joint Elements	11
2.3.1	Material of Infilling	12
2.3.2	Particle Shape of Infill Material	15
2.3.3	Thickness of Infilling	16
2.3.4	Particle Size Distribution	20
2.3.5	Density of Infill	21
2.3.6	Surface Roughness	22
2.4	Granite and Decomposed Granite	30
2.5	Scale Effect	31
3	RESEARCH METHODOLOGY	
3.1	Introduction	35
3.2	Field Study	36
3.3	Sample Preparation	40
3.3.1	Infill	40
3.3.2	Artificial Joint Block	41
3.4	Preliminary Tests	42
3.4.1	Static Compression Test	43
3.4.2	Uniaxial Compression Test	44
3.4.3	Direct Shear Test on Infill Material	46
3.4.4	Direct Shear Test on Joint-Infill Boundary	47
3.5	Main Test Programme	48
3.5.1	Experimental Setup	50
3.6	Field and Laboratory Test Equipment	54
3.6.1	Uniaxial Compression Machine	54
3.6.2	Data Logger	55
3.6.3	Design and Fabrication of Large Shear Box Apparatus	56
4	RESULT AND ANALYSIS	
4.1	Introduction	64
4.2	Field Investigation	64

4.2.1	Schmidt Hammer Test	66
4.2.2	Joint Roughness Coefficient	67
4.3	Preliminary Tests	68
4.3.1	Particle Size Distribution and Specific Gravity	68
4.3.2	Static Compression Test	71
4.3.3	Uniaxial Compression Test	73
4.3.4	Direct Shear Test on Infill Material	81
4.3.5	Direct Shear Test on Joint-Infill Boundary	87
4.4	Main Test Programme	91
4.4.1	Direct Shear Test on Infill Material	91
4.4.2	Direct Shear Test on Smooth Unfilled Joint	95
4.4.3	Direct Shear Test on Smooth Filled Joint	98
4.4.4	Direct Shear Test on Filled Joint with Thin Infill	105
4.4.5	Direct Shear Test on Rough Unfilled Joint	107
4.4.6	Direct Shear Test on Rough Filled Joint	110
4.4.7	Degradation of Surface Irregularities and Crushing of Infill Particles	116
4.4.8	Comparison and Summary	120
5	CONCLUSIONS AND RECOMMENDATIONS	
5.1	Introduction	124
5.2	Conclusions	125
5.3	Recommendations	127
	REFERENCES	128
	APPENDICES A-S	136- 207

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Mechanical weathering processes	8
2.2	Classification of joint filler by origin	10
4.1	JCS at different parts of joint system	66
4.2	Particle size and content of infill sample	69
4.3	Density of infill before and after static compression test	72
4.4	UCS and E Values of rock specimens	79
4.5	Settlement of infill sample at different stages	86
4.6	Shear characteristics of infill with and without preloading	86
4.7	Shear stress and normal displacement of infill material taken at 25 mm shear displacement	94
4.8	Comparison between results obtained by using large and small shear box	95
4.9	Result of direct shear test on smooth unfilled joint	98
4.10	Average maximum shear stress and maximum vertical displacement of smooth filled joint	104
4.11	Average maximum shear stress and maximum vertical displacement of rough unfilled joint	109
4.12	Average maximum shear stress and maximum vertical displacement of rough filled joint.	115

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Mode of failure for joint filled with clayey materials	14
2.2	Layers and movement of grains of infill	17
2.3	Four categories of discontinuity filling thickness	18
2.4	Grain arrangement in	
	(a) coarse-grained sample	21
	(b) fine-Grained sample	21
2.5	Rough joint	
	(a) before shearing	24
	(b) during shearing processes	24
2.6	Roughness profiles and corresponding range of JRC values associated with each one	25
2.7	Typical roughness profiles and suggested nomenclature	26
2.8	Condition at joint wall-infill interface for granular infill at	
	(a) rough joint surface, and (b) smooth joint surface	28
2.9	Normal stress versus deformation relations of intact and fractured cylindrical specimen of granodiorite	29
2.10	Normal stress versus discontinuities closure for <i>unweathered</i> discontinuities in range of rock types for three loading cycles	29
2.11	An example of a discontinuity illustrating first- and second-order irregularities	32
2.12	Influence of scale on the three components of discontinuity shear strength	33

2.13	Relation between peak shear strength and equivalent joint length	33
3.1	Site location map	37
3.2	Highly jointed granite outcrop selected for the field study	38
3.3	Filled-joint system, infill sandwiched between two joint blocks	38
3.4	Measuring of Joint Surface Roughness	39
3.5	Concrete block with flat and planar surface	41
3.6	(a) Concrete block with saw-toothed surface	42
	(b) Schematic diagram of saw-toothed surface	42
3.7	Schematic diagram of static compression test	44
3.8	Model of specimen tested In uniaxial compression test, (a) Intact Rock, (b) Matched Joint, (c) Mis-matched Joint, (d) Filled Joint (t = 10mm) and (e) Filled Joint (t = 20mm)	45
3.9	UCT test specimens	45
3.10	Direct shear test for the investigation of shear strength of joint-infill boundary for (a) Smooth joint	48
	(b) Rough joint	48
3.11	Direct shear test programme	50
3.12	Experimental setup for direct shear test on filled joint model	51
3.13	Preparation of infill material for preloading, according to the designed thickness	52
3.14	Infill material leaks out of the upper block area	53
3.15	Experimental setup for direct shear test on infill alone	53
3.16	MaTest 500 compression machine used in UCT	55
3.17	Data Logger	56
3.18	Large shear box apparatus	57
3.19	300 x 300 x 200mm steel shear box	58
3.20	Steel arm to hold upper box in position	59
3.21	Linear guide-roller bearing between lower section and base plate	59

3.22	OTIS-LG AC servomotor	60
3.23	LG Pack (serial no.: FDA-5000) controller	61
3.24	Basic principle of closed-loop servo-mechanism	62
3.25	Separated unit of control box	63
3.26	Control panel of the shear box	63
4.1	Filled joint system with no banding of weathering grade across the infill and joint blocks	65
4.2	Joint surface profiles (a) JRC = 14.1 and (b) JRC = 4.7	67
4.3	PSD curve of infill material	69
4.4	Infill sample divided according to the grain size	70
4.5	Compressibility vs. infill thickness graph	71
4.6	Compressibility vs. normal stress graph	72
4.7	Stress-strain relationship of intact rocks	74
4.8	Stress-strain relationship of matched-joints	74
4.9	Stress-strain relationship of mismatched-joints	75
4.10	Stress-strain relationship of filled joint (10mm infill)	77
4.11	Stress-strain relationship of filled joint (20mm infill)	78
4.12	Stress-strain relationship of different rock specimens	78
4.13	Particle size distribution of infill material after UCT	80
4.14	Shear stress versus displacement, for infill with preloading, under normal stress of	
	(a) 133 kPa	81
	(b) 264 kPa	82
4.15	Shear stress versus displacement, for infill without preloading, under normal stress of	
	(a) 133 kPa	83
	(b) 264 kPa	83
4.16	Shear stress versus displacement, for infill samples with and without preloading	84
4.17	Normal versus shear displacement, for infill sample with and without preloading	85
4.18	Shear stress versus displacement, for smooth soil-rock contact	87

4.19	Shear stress versus displacement, for rough soil-rock contact	88
4.20	Shear stress (at 10 mm shear displacement) versus normal shear stress, for smooth and rough joint-infill contact	89
4.21	Normal versus shear displacement, for shearing of different joint-infill boundaries	90
4.22	Shear stress versus displacement, for infill material under normal stress of 133, 264 and 396 kPa	92
4.23	Peak shear strength-normal stress relationship of infill material	93
4.24	Normal versus shear displacement, for infill material, under normal stress of 133, 264 and 396 kPa	94
4.25	Shear stress-displacement relationship of smooth unfilled joint, at normal stress of 133, 264 and 396 kPa	96
4.26	Normal-shear displacement relationship of smooth unfilled joint, at normal stress of 133, 264 and 396 kPa	96
4.27	Shear stress-displacement relationship of smooth filled joint under normal stress of	
	(a) 133 kPa	99
	(b) 264 kPa	99
	(c) 396 kPa	100
4.28	Normal-shear displacement relationship of smooth filled joint under normal stress of	
	(a) 133 kPa	101
	(b) 264 kPa	101
	(c) 396 kPa	102
4.29	Normal-shear displacement relationship of smooth filled joint with 15 mm thick infill	103
4.30	Maximum vertical displacement vs. infill thickness for smooth filled joint	104
4.31	(a) Shear stress-displacement relationship,	105
	(b) Normal-shear displacement relationship, of smooth joint with thin infill	106

4.32	(a) Shear stress-displacement relationship,	107
	(b) Normal-shear displacement relationship, of rough unfilled joint	108
4.33	(a) Shear stress-displacement relationship,	110
	(b) Normal-shear displacement relationship, of rough filled joint, under normal stress of 132 kPa	111
4.34	(a) Shear stress-displacement relationship,	113
	(b) Normal-shear displacement relationship, of rough filled joint, under normal stress of 264 kPa	113
4.35	(a) Shear stress-displacement relationship,	114
	(b) Normal-shear displacement relationship, of rough filled joint, under normal stress of 396 kPa	114
4.36	Peak shear stress vs. infill thickness, for rough filled joint	115
4.37	Maximum vertical displacement vs. infill thickness, for rough filled joint	116
4.38	Smooth concrete block (after being sheared)	117
4.39	Rough concrete block (after being sheared)	118
4.40	PSD curves of infill material in smooth filled joint, tested under normal stress of 396 kPa	118
4.41	PSD curves of infill material in rough filled joint, tested under normal stress of 396 kPa	119
4.42	Shear stress-displacement relationship of smooth joint specimen, under normal stress of 396 kPa	121
4.43	Shear stress-displacement relationship of rough joint specimen, under normal stress of 396 kPa	121
4.44	Peak shear strength envelope of joint	123

LIST OF SYMBOLS

Δ_x	-	Shear displacement
Δ_y	-	Vertical displacement
σ_p	-	Shear stress
σ_n	-	Normal stress
σ_c	-	Unconfined compression strength
ϕ	-	Basic friction angle
τ	-	Peak shear strength
γ	-	Dry density of rock
c	-	Coefficient of cohesion
IA	-	Infill material alone, with normal stress of 133 kPa
IB	-	Infill material alone, with normal stress of 264 kPa
IC	-	Infill material alone, with normal stress of 396 kPa
JRC	-	Joint roughness coefficient
PSD	-	Particle size distribution
R	-	Rebound number
RUA	-	Rough unfilled joint, with normal stress of 133 kPa
RUB	-	Rough unfilled joint, with normal stress of 264 kPa
RUC	-	Rough unfilled joint, with normal stress of 396 kPa
RFA	-	Rough filled joint, with normal stress of 133 kPa
RFB	-	Rough filled joint, with normal stress of 264 kPa
RFC	-	Rough filled joint, with normal stress of 396 kPa
SFA	-	Smooth filled joint, with normal stress of 133 kPa
SFB	-	Smooth filled joint, with normal stress of 264 kPa
SFC	-	Smooth filled joint, with normal stress of 396 kPa
SUA	-	Smooth unfilled joint, with normal stress of 133 kPa

SUB	-	Smooth unfilled joint, with normal stress of 264 kPa
SUC	-	Smooth unfilled joint, with normal stress of 396 kPa
TFA	-	Smooth joint filled with very thin infill, with normal stress of 133 kPa
TFB	-	Smooth joint filled with very thin infill, with normal stress of 264 kPa
TFC	-	Smooth joint filled with very thin infill, with normal stress of 396 kPa
UCT	-	Uniaxial compression test
XIA	-	Non-preloaded infill material alone, with normal stress of 133 kPa
XIB	-	Non-preloaded infill material alone, with normal stress of 264 kPa

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Probable weathering stages of filled joint in granite	136
B	Comparison of uniaxial compressive and uniaxial tensile strengths of rocks	138
C	Corrections for reducing measured Schmidt hammer rebound (R) when the hammer is not used vertically downwards	139
D	Weathering grade and rock properties	140
E	Strength classification based on point load index; Unconfined compressive strength of the main rock types; Categorization and description of rock based on its uniaxial compressive strength	141
F	Data of Rebound hammer test	143
G	Calculation of surface roughness	144
H	Specific gravity of infill particles	149
I	Result of Static Compression Test	151
J	Data of preliminary test (direct shear test on preloaded infill material alone)	153
K	Data of preliminary test (direct shear test on non-preloaded infill material alone)	157
L	Data of preliminary test (direct shear test on smooth joint-infill boundary)	160
M	Data of preliminary test (direct shear test on rough joint-infill boundary)	162

N	Data of direct shear test on infill material	164
O	Data of direct shear test on smooth unfilled joint	169
P	Data of direct shear test on smooth filled joint	172
Q	Data of direct shear test on smooth filled joint with thin infill	186
R	Data of direct shear test on rough unfilled joint	191
S	Data of direct shear test on rough filled joint	194

CHAPTER 1

INTRODUCTION

1.1 Introduction

Geological processes and environment such as tectonic movements and cooling of magma tend to create various geological structures and discontinuities in rock masses such as fold, fault and joint. Due to the presence of these discontinuities, rock masses are often weak, anisotropic and inhomogeneous. Consequently, excavation work in rock can be subjected to various problems, particularly in terms of stability. Among these discontinuities, joints are the most common weakness planes found in rock outcrops in Malaysia, particularly in igneous rock.

In tropical countries, high temperature and high rate of rainfall help to induce a desirable environment for continuous and intensive weathering to take place in rock. Weathering affects surface of rock mass. However, through the joint (secondary permeability), water and other weathering agents can penetrate deeper into the rock masses. This allows greater weathering effect on the internal portion of the rock. Upon weathering, the material of the joint surface is being disintegrated and decomposed to form a completely weathered material which is very much

weaker than the host rock. This leads to the accumulation of weak infill material in the joint aperture, in other words, a completely weathered material is “sandwiched” in between the joint blocks. *In-situ* deposition, on the other hand, involves the in-wash of surface materials into the originally open joint (infill material not resulted by gradual weathering of host rock). Both weathering of the joint surface and the *in-situ* deposition in the joint aperture are the processes that lead to the formation of the most critical type of joint in rock, namely filled joint.

The presence of weathered material in joint aperture, which is normally much weaker than the joint blocks, induces a high degree of inhomogeneity into this weakness plane. Inhomogeneity leads to the unique behaviours of filled joint. Normally, materials that fill the joint apertures are highly weathered rock of grade V (completely weathered rock) and grade VI (residual soils). The infilling material is often more compressible and crushable than the intact rock. The different particle size, shape and mineral composition induce a significant variation in the properties of the granular infill material. Together with the weathered joint surface, the nature of contact between the interfacing joint surfaces and the nature of the infill create a very complex deformational behaviour of filled joints as compared to unfilled (clean) joint.

In summary, filled joint is one of the most critical discontinuities in rock mass. It often exhibits high deformability and low shear strength when subjected to loading. These characteristics appear to be unfavourable for any civil engineering constructions particularly when it involves excavation of rock mass. They may induce instability to excavated surfaces such as rock slopes and tunnel walls. Therefore, the properties and behaviours of filled joints must be understood and appropriately interpreted to ensure adequate information is available for the design and construction of structure in rock mass that consists of filled joint.

1.2 Background Problems

Being the most critical discontinuity in rock masses, filled joint poses several engineering problems. Specifically, its deformability, compressibility and shear strength behaviours are thought to be detrimental to the stability of any excavation in rock. In addition, each constitutive component of filled joint, such as joint surface, infill material and joint blocks, displays its own discrete characteristics. Each characteristic of the constitutive component contributes to the behaviours of filled joint interactively. Therefore, sufficient knowledge on the characteristics of each relevant component is essential in order to understand the overall behaviours of filled joint.

Behaviours and properties of filled joint are reckoned to be critical to excavation in rock mass. Due to its uniqueness and complexity, extensive and detailed study must be carried out on this critical discontinuity. *In-situ* testing, full-scale laboratory modeling and computer simulation are often used to study the behaviours of filled joint comprehensively. However, these methods are relatively expensive and complex to be undertaken. Moreover, sampling of undisturbed filled joint for laboratory testing is almost impossible to be conducted. Therefore, an appropriate method in interpreting the behaviour and criticality of filled joint is essential. This method should be suitable to characterise filled joint, specifically its characteristics that are relevant to construction. These characteristics must be those properties that can be easily measured and evaluated using relatively simple laboratory and field tests.

1.3 Objectives of Study

This study is undertaken in order to achieve the following objectives:

1. To select and to verify the physical properties of filled joint that are relevant to the behaviour of filled joints.
2. To establish the characteristics of the selected components (in the field and laboratory) and subsequently to verify the effect of these components on the behaviour of filled joint.
3. To establish the typical behaviours of filled joint under shear loading and the interacting effect of its constitutive components, using a specially fabricated large shear box

1.4 Significance of Study

The behaviour of filled joint specifically under shear load is significantly affected by its constitutive components, which include type of infill, surface of joint blocks and thickness of infill. By verifying the interacting effect between these components, a general behaviour of filled joint can be established. The general behaviour of filled joint, particularly with respect to shear loading, is an important information to be considered in designing a structure associated with excavation in rock mass. The established behaviour may serve as guidelines in evaluating the level of criticality of filled joint on any excavated surface in rock.

1.5 Scopes of Study

The scopes of this study, among others, cover the following aspects:

1. A filled joint resulting from *in-situ* deposition and with granular, granite residual soils as infilling.
2. Characteristics of filled joint components selected for study are thickness of the infill, type of infill and roughness of joint surface.
3. Laboratory tests were carried out on model of filled joint consisting of cast concrete as joint block (flat surface and saw-toothed surface) and granular granite residual soil as infill material (dry, average density of 1842 kg/m^3).
4. Deformational behaviours of filled joint under shear loading at various normal load (130 to 390 kPa), infill thickness and roughness of joint surface were types of test set-up being investigated.

1.6 Organisation of Thesis

This thesis consists of five chapters. Introduction, background problems, objectives and scopes of study and its significance are mentioned in Chapter 1. Chapter 2 comprises of some important theories and past researches about filled joint. Chapter 3 is all about the methodology of this research, which includes site investigations, laboratory assessments, and the fabrication of the equipment. The results, analysis, and interpretation from the experiments are discussed in Chapter 4. And, lastly, Chapter 5 summarizes the research findings and also some recommendations for further researches.

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