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/m^3). 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 ketakselanjaran 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 diisikan 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 rich 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.

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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

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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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