COMPRESSIBILTY AND YOUNG'S MODULUS OF FILLED JOINT

ZAIHASRA BINTI ABU TALIB

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Faculty of Civil Engineering
Universiti Teknologi Malaysia

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DEDICATION

To my beloved mum,
Puan Hajah Salmah binti Sardan
And
All my Family.....

Especially for,
Mohd Khaire bin Hj Mohd Nor

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Alhmadulilah, Praise to Almighty Allah for the blessing and permission of-Nya, I am able to complete my master project.

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ABSTRACT

A number of the engineering structures such as tunnels, powerhouse cavern and mining shaft are constructed in the rock mass. The stability of these structures are greatly influenced by the engineering behaviour of the rock mass. For intact rock, its low deformability behaviour indicates that it is a stronger material. However, the condition changes with the presences of joint as discontinuity features in the rocks. The presence of this joint influence the strength and deformability of rock to a great extend. The situations become worst when intensive weathering of jointed rock mass under tropical climate leads the formation of the filled joint. Being the weakest component of a filled joint, filling materials contributes significantly to joint deformability and thus reducing joint strength and stiffness. In construction work that involving excavation in rock masses, filled joint poses a number of design and constructional problem that may influence the stability and factor of safety to the structure. Due to the above problems, a series of laboratory testing of physical models, which comprised of filled and unfilled joint, was carried-out. Comparing the stress-strain curves and Young's Modulus value has done analyses of the experimental result. The result suggested that the filled joint exhibits high deformation behaviour due to a lowest value of Young's Modulus. This behaviour contributed by the deformation and compressibility of the infilling material and as well as the deformation of joint blocks.

ABSTRAK

Terdapat beberapa pembinaaan struktur seperti terowong, penjanakuasa gegua dan perlombongan dibina di atas atau di dalam massa batuan. Kestabilan struktur-struktur ini banyak dipengaruhi dengan sifat-sifat kejuruteraan massa batun. Di dalam batuan yang utuh, mempunyai kekuatan yang lebih tinggi seperti yang digambarkan oleh sifat kebolehcanggannya yang kecil. Walaubagaimanapun, keadaan berubah dengan kehadiran kekar sebagai ketakselarasan dalam batuan. Kehadiran kekear ini memberi kesan yang besar terhadap kekuatan dan kebolehcanggan batuan tersebut. Keadaan bertambah buruk apabila berlaku perluluhawaan secara intensif terhadap kekar dalam massa batuan di bawah iklim tropika yang menjurus kepada pembentukan kekar berinti. Sebagai komponen yang paling lemah, bahan-bahan inti memberi kesan kepada kekar dan kebolehcanggaan, dengan yang demikian mengurangkan kekuatan dan kekerasan kekar. Dalam kerja pembinaan yang melibatkan pengorekan pada massa batuan, kekar berinti menyebabkan beberapa masalah kepada rekabentuk dan pembinaan, dimana ia mempengaruhi kestabilan dan factor keselamatan kepada struktur-struktur tersebut. Berdasarkan masalah di atas satu siri ujikaji makmal telah dijalankan terhadap model fizikal yang terdiri daripada kekar dan kekar berinti. Analisis dari keputusan ujikaji telah dibuat dengan membandingkan lengkung-lengkung tegasan-terikan dan nilai-nilai Young's Modulus yang didapati. Keputusan yang diperolehi mencadangkan bahawa kekar berinti mempamerkan kebolehcanggaan yang tinggi berdasarkan modulus yang terendah. Sifat ini dihasilkan dari canggaan bahan-bahan inti dan canggaan blok-blok kekar.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Rock is an excellent material upon which to bear a building foundation. A number of engineering structures such as tunnels, powerhouse cavern and mining are also constructed in rock mass. It is because rock is a very stable material exhibits practically no compression under load. The stability of these structures are greatly influenced by the engineering behaviour of the rock mass. The behaviour of the rock mass is controlled by many factors, such as, joint spacing, joint behaviour, joint orientation and the condition of the joint. The latter include joint roughness, joint wall weathering and infilling material. Therefore, understanding of the mechanical properties of jointed rock mass is important for analyzing, designing and stability performance of structure built in or on rock mass.

Normally, intact rock displays a higher strength is becoming. However, the condition may change by the existence of joints in rocks. It comes worst when joints are filled with infilling materials. The tropical climate facilitates an intensive in-situ weathering of the rock joint, which contribute to the formation of the infilling in the joint aperture. Infilling material normally comprises highly weathered material; therefore, it exhibits compressible and crushable characteristics that lead to high deformation behaviour. The high deformation of the filled joint caused problems to the structures built in or on the rock mass. These problems are normally associated with block displacement and settlement. Due to a higher degree deformability of filled joint, a study has been carried out to verify the effect of infilling on the behaviour of joint.

1.2 Project Background

The presence of joint in the rock mass will increase its deformability. However, the deformability of the rock mass may increase further when the aperture of the prevailing joints is filled with weak infillings. These types of joints are termed as filled joints and commonly found in tropical countries where intensive and continuous weathering of rock mass is inevitable. The main effect of filled joint is that they weaken the rock mass in terms deformability under both normal and shear loading. Consequently, this critical discontinuity may impose a detrimental effect on the stability of a structure associated with excavation in rock mass.

1.3 Significance of the Study

Filled joint may be subjected to both normal and shear loading due to stress redistribution following any excavation in a rock mass. Study on the deformation behaviour of filled joint under normal loading is therefore form an essential part in understanding this critical geological discontinuity. This knowledge is important in designing a structure, such as slopes and openings, in rock mass that contain filled joints.

1.4 Objective

The main objectives of this study consists of the following:

a) To review the effect of infilling material on joint deformability
b) To study the behaviour of filled joint by under normal loading through series of laboratory tests on model filled joint
c) To verify the effect of infilling on compressibility and elastic modulus.

1.5 Methodology

Methodologies been used to achieve our objectives of study are:

a) Literature review
b) The laboratory testing

1.6 Scope of the Study

The study will focus on the following:

a) A physical model representing a filled joint forms by in-situ deposition of weathered materials in joint aperture.
b) Infill material that consists of granular, granite residual soils.
c) Deformation of filled joint due to uniaxial loading only.
d) Behaviour of filled joint in terms of compressibility and modulus of elasticity.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

There are three types of rocks, which are igneous, sedimentary and metamorphic rock. Rock can be classified by its origin or its texture. In the rock mass, rock is inhomogeneous and anisotropic material. The weathering process will change physical properties and chemical composition of the rock. The presence of discontinuities influences the strength and deformability of rock to a great extend. The deformation of rock joints represents a significant part of the total deformation of the rock mass encountered in rock engineering practices. The main cause of instabilities and failure of man-made structure in rock is associated with joints and joint infilling. Consequently, the characterization of discontinuities is a relevant step in rock engineering design of underground excavations, slopes and foundation.

In describing rock joints, emphasis has to be laid on the strength properties of the joint and its infill (if presence). For filled joint the compressibility and deformational behaviour of the infill impose significance effect on joint. Many investigations on strength of filled and unfilled joint have been carried out by many authors example Barton (1974,1978), Barton and Chopubey (1977), Barton et. al

(1985) and Baria et. al. (1985,1987). Howing and Kutter (1985) for example investigated the shear behaviour of filled joints as a function of the composition of the gouge infilling.

The rock mass is the in-situ, fractured rock which will almost have significantly lower strength than intact rock because the discontinuities divide the rock mass into blocks. Fig 2.1 described the definition of the rock mass.

The strength of the rock mass will depend on such factor as shear strength of the surface of the blocks, their spacing and continues length and their alignment relative to load direction.

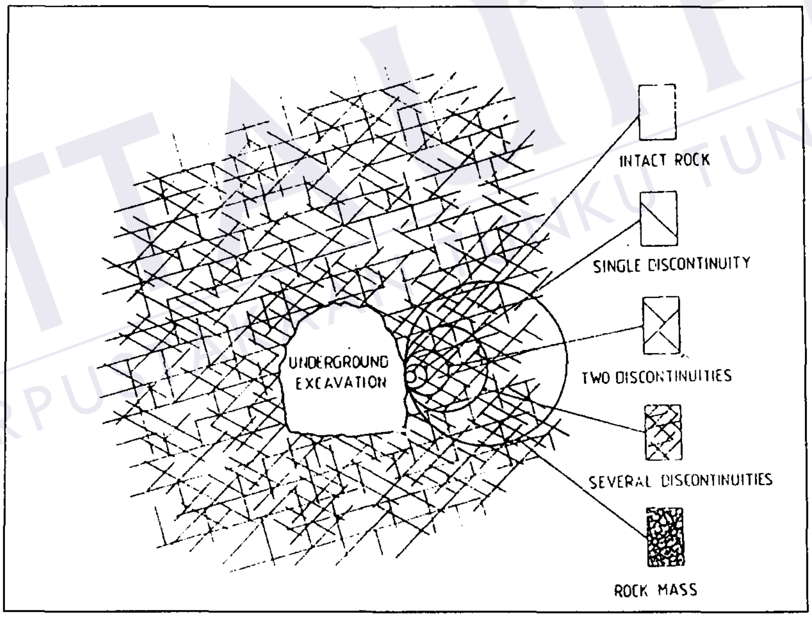

Figure 2.1 Definition of rock mass and intact rock

2.2 Discontinuity

Discontinuities are usually categorized according to the manner in which they were formed. The following are standard definitions of the most commonly encountered types of discontinuities:

a) Fault

A discontinuity along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel or sub-parallel sets of discontinuities along which movement has taken place to a greater or less extent.

b) Bedding plane

This is surface parallel to the surface of deposition, which may or may not have physical expression. Note that the original attitude of the bedding plane should not be assumed to be horizontal.

c) Foliation

Foliation is parallel orientation of platy minerals, or minerals banding in metamorphic rock.

d) Joint

A joint is a discontinuity in which there has been no observable relative movement. A series of parallel joint is called a joint set; two or more intersecting sets produced a joint system. Two sets of joint approximately at right angle to one another are said to be orthogonal.

Joints are the most common discontinuity in rock and generally contribute significant effect on the rock mass behaviour. Joints are breaks of geological origin along which there has been no visible displacement (Park, 1989). Joint may be formed in a systematic way (fracture occur in subparallel joint or irregular geometry) or non systematic way (non-parallel joint or irregular geometry). Joints are found in all competent rocks within about 1 km of the earth's surface, at all orientations and at sizes ranging from a few millimeters to several hundreds meter. They may be intact, open, filled or healed.

2.3 Properties of Discontinuities

This section discuss briefly on the most important aspect of those properties of discontinuities that influenced the engineering behaviour of rock mass.

Spacing is the perpendicular distance between adjacent discontinuities; ad is usually expressed as the mean spacing of a particular set of joints. Spacing determines the sizes of the block making up the rock mass. The mechanism of the deformation and the failure can vary with the ratio of discontinuity spacing to excavation size. If the joint spacing is very much smaller than the width of excavation instability will prevail.

Aperture is the perpendicular distance separating the adjacent rocks walls of an open discontinuity in which the intervening space is filled with air or water. Aperture is thereby distinguished from the width of a filled discontinuity. Jointed rock masses at depth, apertures will be small, probably less than half a millimeter. The apertures of real discontinuities are likely to vary widely over the extent of the discontinuity. Clearly, variation of aperture will have an influenced on the shear strength of the discontinuity. More important is the influence of aperture on the permeability or hydraulic conductivity of the discontinuity of the rock mass.

2.4 Infilling

Filling is the term used to describe material filling the apertures. Such material may be calcite, clay, fault gouge breccia and quartz. Filling materials will have major influence on the shear strength of discontinuities. Infilled joints are likely to have two-peak strength, first related essentially to failure of the filler and second to failure of asperities. The wide range of physical behaviour of filled discontinuities will depend on many factors and the following are probably the most important (Brady & Brown, 1981) :

a) Mineralogy of the filling material
b) Grading or particle size

c) Overconsolidation ratio (for clay filling only)
d) Water content and permeability
e) Wall roughness
f) Thickness of infill
g) Fracturing or crushing of wall rock

The filling material is much weaker than the joint blocks as they are produced by rock fracturing or weathering of joint block material. The geometry of the discontinuity with the filling is normally assumed to be a very relevant factor in determining the rock strength and its deformability.

In general the joints are filled with poor quality material, cohesionless and coarse soil (sands, gravels, etc) or cohesive soil (silts and clays), which are carried by water flows, gravity but normally by both, or result of the fracturing or weathering of the rock material blocks.

The geometry of the joint with the filling is normally assumed to be a relevant factor. However, the mechanical characteristics of the filled material are expected to control the normal strength of the joint. The presence of infill material will result a reduction in strength of rock joint both in term of shear strength and compressive strength. When infill becomes relatively thick, strength of a rock joint will be solely controlled by the infilled rather than joint wall (Barton, 1974)

Ladanyi and Archambault (1977) said the character of infill material in joints is very seldom uniform, and the infill material is usually a very complex material, both in regard to mineralization and to physical properties. The infill material will sometimes have the character of unaltered 'crushed rock'. The weathered granite mineral acted like a granular infill. It had almost the same friction angle as the smooth surface of model rock joint and thus it simulated a high-strength infill (Phien-Wej et al.1991)

The classification chart in Table 2.1 was drawn up on the general principle of lithology that rocks are divided on mode deposition into; chemical or physico-chemical, mechanical and organic. Organic fillers are fairly rare in joints yet they are included in the classification to provide a deeper insight into joint filling.

Table 2.1: Classification of joint fillers by origin (After Chernyshev and Dearman, 1991)

Deposition of joint filler	**Description of filler based on material**	**Composition & properties of joint filler**
Chemical or Physico-chemical	Magmatic	Rock healing joint solidly
	Hydrothermal and pneumatolytic	Rock healing joint
	Hypergene	Collodal formations which cause joint narrowing or healing
	Artficial	Chemical grout infilling joint
Mechanical	Tectonic	Mylonite, fault breccia. Compact impervious, low-strength, slightly compressed
	Hypergene	Clastic or clay, loose rocks. Impervious, low-strength, compressed
	Artificial	Cement grout infilling joint
Organic	Phytogenic	Plant roots, rotting residues. Permeable medium, facilitates weathering.
	Zoogenic	Organic residues and rotting products washed into joints. Weakens rock mass and facilitates weathering

2.4.1 Behaviour of Filled Joint

Shear force-displacements relationships of the infilled rough joints derived from the test program cab be generalized as in Figure 2.2. The shear force-displacement behaviour can be distinguished on the basis of the interaction between the joint surfaces.

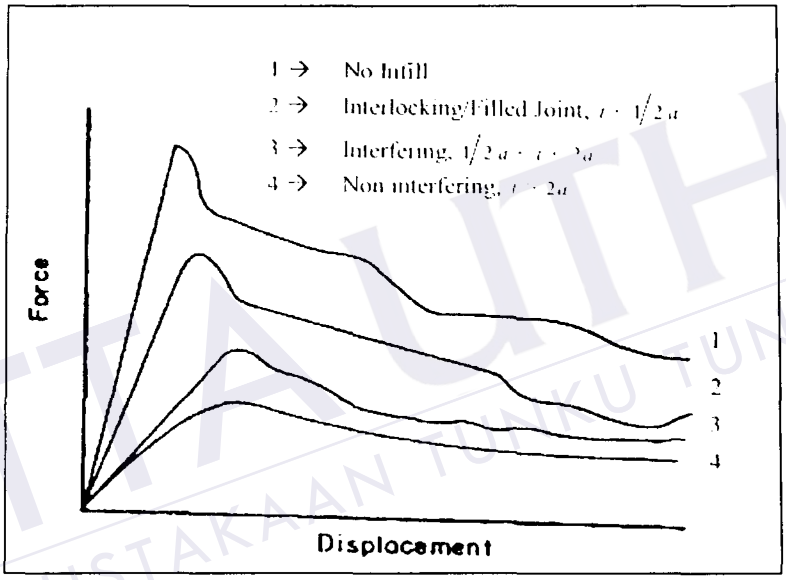

Figure 2.2: Generalized relationship between force and displacement of filled joints (After Phien-Wej et. al, 1990 & 1991)

Three thickness range have been defined by Nieto (1974) in the study of filled joint, which are, interlocking, interfering and non-interfering. Interlocking when the rock surfaces come in contact, interfering when there is no rock contact but the strength of the joint is greater than that of filler alone and non-interfering when joint behaves as the filler itself.

Figure 2.3 shows Soil Peak Stress (τ_{ks}) versus thickness (t) obtained for clay filled joint. The graph showed that τks decrease with increasing thickness until the thickness equals the aspherity height (a). after that it remains unchanged with increasing thickness.

The effect of the over-consolidation ratio (OCR) is quite clear when this parameter varies from three to seven. Clay filled joint sheared under OCR = & have clearer soil peak than those shear under OCR = 3.

The Peak Shear Stress of the clayey sand filled joints is plotted in Figure 2.4, along with those for the unfilled. The joint strength continuously decrease with increasing thickness until thickness is equal to the asperity height, at which point the envelope of the shear stress drop sharply, breaking its continuous decline.

For greater thickness, the strength continues to decrease but only very slowly until it reaches the strength of filler alone, at a thickness between 1.9 and 2.3 the aspherity height. The interfering zone of the filled joint extends up to between about 10 and 14 times the maximum particles size of the sand.

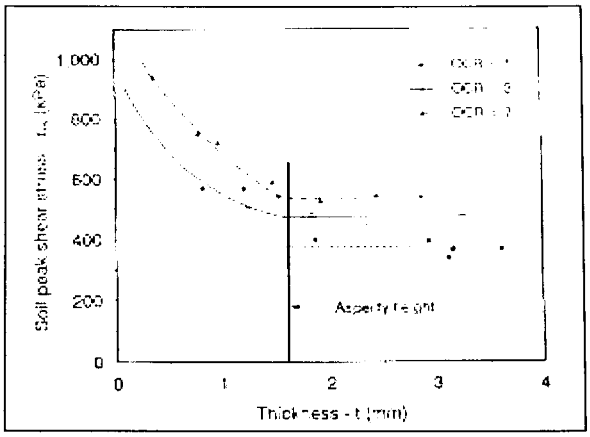

Figure 2.3: Soil Peak Stress versus filler thickness for clay filled joint under different levels of consolidations (After Toledo et al, 1995)

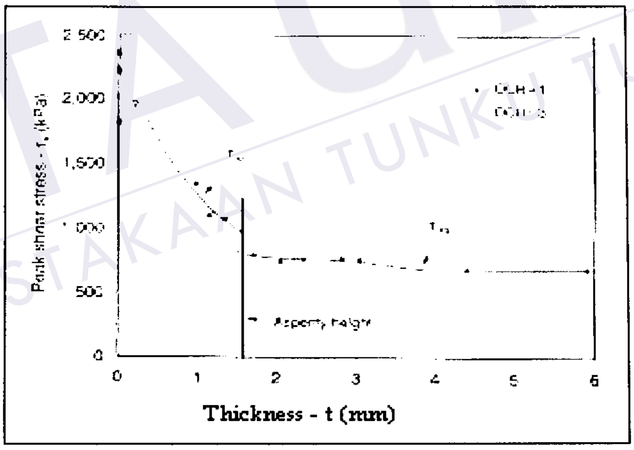

Figure 2.4: Peak stress of clayey sand filled joints versus thickness under different levels of consolidation (after Toledo et al, 1995)

2.5 Rock Strength and Deformability.

Discontinuities have influence on the deformability and the strength of the rock mass. The deformation of a material is the process whereby physical changes are produced in the material due to the action of applied forces (Park,1989). The forces acting on the rock induce a state of stress in the rock body. The deformations are usually expressed as strain, a dimensionless quantity expressing the amount of deformation in terms of the original dimensions. The relations between stress (σ) and strain (ε) in an idealized material form the basis of the mathematical theories of elasticity and plasticity, where E (Young's Modulus) is value of elastic constant which useful models used to described the behaviour of actual materials like rocks are given as:

$$E = \frac{\sigma}{\varepsilon} \text{ -------------------- } (2.1)$$

Jumikis (1979), defined rock strength as the ability of the material to resist externally applied forces. The strength of rock, or peak strength is the maximum stress that the rock can sustain under set of conditions. It corresponds to point B in Figure 2.5. Failure often occurs at the peak strength or to be iniated at the peak strength. After its peak strength has been exceeded, the specimen may still have some load-carrying capability or residual strength. Rock gives brittle fracture, the process which sudden loss of strength across a plane following little or no permanent (plastic) deformation as illustrated in Figure 2.5 where:

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