Shear behaviour of normally consolidated and overconsolidated infilled rock joints under undrained triaxial conditions

Jayanathan Mylvaganam

University of Wollongong

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SHEAR BEHAVIOUR OF NORMALLY CONSOLIDATED AND
OVERCONSOLIDATED INFILLED ROCK JOINTS UNDER
UNDRAINED TRIAXIAL CONDITIONS

A thesis submitted
in fulfilment of the requirements for the Award of the Degree of

DOCTOR OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG

by

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2007
I, Jayanathan Mylvaganam, declare that this thesis, submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in the School of Civil, Mining and Environmental Engineering, Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualification at any other academic institution.

................................

Jayanathan Mylvaganam

March 2007
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Last but not the least, the author humbly dedicates this piece of work to his parents, brothers and sisters, without their encouragement, prayers, and support, it would have been impossible to achieve this goal.
LIST OF PUBLICATIONS

The following publications were generated during my research period.


ABSTRACT

Natural rock joints are normally filled with fine materials such as clay and silt which influence entire rock mass stability. Saturated infilled joints have contributed to the instability of rock mass during undrained shearing due to the build up of pore water pressure within the joints. It is probable that most of the discontinuities in nature will be in an overconsolidated or pre-loaded state. The shear response of infilled rock joints is generally controlled by the type and thickness of infill, joint roughness, drainage conditions, and the stress history. Based on the research work carried out at the University of Wollongong in the past, a shear strength model for unfilled and infilled joints was developed using the Fourier functions coupled with energy considerations adopting a hyperbolic technique. It was found that the hyperbolic constants were often sensitive to the types of infill, and the hyperbolic fit was not always accurate for infill such as graphite. In order to predict shear strength more accurately, a conceptual normalised shear strength model was recently developed based on two algebraic functions (Indraratna et al., 2005). Although this model conveniently predicted the shear strength with some accuracy, it required considerable extension to incorporate the degree of overconsolidation in relation to the development of pore water pressure.

In this research study, an experimental investigation was carried out to study the effect of overconsolidation on the shear behaviour of saturated infilled joints. For this purpose, the high-pressure two-phase triaxial apparatus at the University of Wollongong was modified with the installation of a mechanical driving system to apply a constant axial strain to shear infilled joints under a given confining pressure. Extensive tests were conducted on saw-toothed (18° asperity angle) joints under consolidated undrained
conditions with pore water pressure measurement. Limited tests on planar and sheared sandstone joints were also conducted for comparison. Natural silty clay collected from a rockslide site was used as infill for the entire experimental program.

The shear behaviour of saw-toothed joints was investigated for varying infill thickness to asperity height ratios \( t/a \) in the range of 0-5.0, and varying overconsolidation ratios (1, 2, 4, and 8), at confining pressures of 200 and 500 kPa. Accordingly, a mathematical model is presented for predicting the shear strength of normally consolidated and overconsolidated rough infilled joints. The proposed shear strength model evaluates the reduction in shear strength observed with increasing \( t/a \) ratios at varying OCRs. It highlights the role of the critical \( t/a \) ratio, beyond which no further reduction in shear strength occurs. This critical \( t/a \) divides the infilled joint behaviour into the ‘asperity interference’ and ‘asperity non-interference’ regions. In the region of asperity interference, the sum of two algebraic functions (i.e. \( A_n \) and \( B_n \) - represent joint and infill characteristics, respectively for OCR=\( n \)) models the decay of shear strength with increasing \( t/a \). In the region of asperity non-interference, the shear strength is modelled purely with infill properties. The proposed model describes how the OCR influences the shear strength, development of pore water pressure, and the critical \( t/a \) ratio. This study extends our current understanding of the shear behaviour of infilled rock joints with potential applications in rock engineering such as rock slope stability and underground excavations in jointed rock.
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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

\( A_n, B_n \) \quad \text{Algebraic functions of the proposed shear strength model}

\( A_j \) \quad \text{Joint surface area}

\( a \) \quad \text{Asperity height}

\( a_n, b_n \) \quad \text{Empirical coefficients defining the shape of functions } A_n \text{ and } B_n \text{ respectively for an overconsolidation ratio of } n.

\( c_{o}, c_{1} \) \quad \text{Fourier coefficients}

\( h_{tp} \) \quad \text{Horizontal displacement at peak shear stress}

\( i \) \quad \text{Initial asperity angle}

\( i_{hp} \) \quad \text{Dilation angle at peak shear stress}

\( k_n \) \quad \text{Normal stiffness}

\( k_{oc,n} \) \quad \text{Ratio between } (t/a)_{oc,n} \text{ and } (t/a)_{cr,n}

\( T \) \quad \text{Period of Fourier series}

\( t \) \quad \text{Infill thickness}

\( (t/a)_{cr} \) \quad \text{Critical } (t/a) \text{ ratio}

\( (t/a)_{oc,n} \) \quad \text{Given } (t/a) \text{ for an overconsolidation ratio of } n

\( (t/a)_{cr,n} \) \quad \text{Critical } t/a \text{ for an overconsolidation ratio of } n

\( \alpha \) \quad \text{Empirical constant of the proposed model}

\( \beta \) \quad \text{Dip angle of rock joint}

\( \delta, \gamma \) \quad \text{Hyperbolic constants}

\( \sigma'_1 \) \quad \text{Effective axial stress}

\( \sigma'_3 \) \quad \text{Effective confining stress}

\( \sigma_c \) \quad \text{Uniaxial compression strength}

\( \sigma'_n \) \quad \text{Effective normal stress}

\( \sigma'_{no} \) \quad \text{Initial effective normal stress}

\( (\tau_p/\sigma'_n)_{oc,n} \) \quad \text{Normalised peak shear strength for an overconsolidation ratio of } n

\( (\tau_p)_{\text{infilled}} \) \quad \text{Peak shear stress of infilled joint}

\( (\tau_p)_{\text{unfilled}} \) \quad \text{Peak shear stress of unfilled joint}
List of symbols

\( \Delta u \) \hspace{1cm} \text{Excess pore water pressure}
\( \phi_b \) \hspace{1cm} \text{Basic friction angle of joint}
\( \phi_{fill} \) \hspace{1cm} \text{Effective friction angle of normally consolidated infill}
\( \phi_r \) \hspace{1cm} \text{Residual friction angle}

Abbreviations

CMM \hspace{1cm} \text{Coordinate Measuring Machine}
CNL \hspace{1cm} \text{Constant Normal Load}
CNS \hspace{1cm} \text{Constant Normal Stiffness}
CU \hspace{1cm} \text{Consolidated undrained}
JCS \hspace{1cm} \text{Joint wall Compressive Strength}
JRC \hspace{1cm} \text{Joint Roughness Coefficient}
LVDT \hspace{1cm} \text{Linear Variable Differential Transformer}
OCR \hspace{1cm} \text{Overconsolidation Ratio}
R_p \hspace{1cm} \text{Ratio of pre-loading}
UDEC \hspace{1cm} \text{Universal Distinct Element Code}