EMPIRICAL STRENGTH ENVELOPE FOR SHALE

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Specially dedicated to my beloved mother, my late father, my siblings and friends.

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ABSTRACT

Effectively, strength envelope describes behavior of a rock body when subjected to common stresses in construction, namely compressive, tri-axial and tensile. This study is aimed at investigating the strength envelope for shale, a sedimentary rock obtained from dam project site in Baram, Sarawak. Series of triaxial compression tests were carried out to obtain the strength envelope for the rock samples. For verification of failure criterion, uniaxial compression and Brazilain tests were also conducted on the rock samples. Results from the related tests were analysed using RocData software to obtain the strength envelope. Subsequently, Mohr-Coulomb and Hoek-Brown failure criterion are used to determine failure envelop for the rock samples. Based on the failure envelopes and the related strengths (i.e. compressive and tensile strength), suitability of both approach, in defining strength envelope for shale, is verified. The study shows that for highly laminated sedimentary rock like shale, Hoek-Brown criterion gave a more representative failure behaviour. The failure envelope clearly shown all the strength limits when the rock subjected to triaxial, uniaxial and tensile stress, which is not observed in Mohr-Coulomb. Hoek-Brown criterion is more superior for describing rock body as mass strength rather than material strength.

ABSTRAK

Had kekuatan batuan adalah julat tingkahlaku sesuatu jasad batuan apabila dikenakan jenis-jenis tegasan yang biasa ditemui di dalam kerja pembinaan seperti tegasan mampatan, tiga paksi, satu paksi dan tegangan. Kajian ini bertujuan untuk mengkaji had kekuatan batu syal, iaitu sejenis batuan enapan yang diperolehi daripada tapak projek empangan di Baram, Sarawak. Beberapa ujian mampatan tiga paksi telah dijalankan untuk mendapatkan had kekuatan bagi sampel batuan. Bagi tujuan pengesahan kriteria kegagalan, ujian mampatan satu paksi dan ujian Brazillian juga dilaksanakan ke atas sampel batuan tersebut. Keputusan daripada ujian-ujian tersebut dianalisis dengan menggunakan perisian RocData bagi tujuan mendapatkan had kekuatan batuan. Setelah itu, had kegagalan batuan dianalisis menggunakan kriteria Mohr-Coulomb and Hoek-Brown. Berdasarkan had kegagalan dan kekuatan yang berkaitan (mampatan dan tegangan), kesesuaian pendekatan analisis bagi kedua-dua kaedah penentuan had kekuatan dibandingkan. Kajian ini mendapati bagi batuan enapan yang berlaminasi seperti syal, ianya lebih sesuai dianalisa menggunakan kriteria kegagalan Hoek-Brown. Kriteria ini dapat memberikan had kegagalan batuan yang lebih jelas apabila dikenakan tegasan-tegasan tiga paksi, satu paksi dan tegangan. Kriteria Hoek Brown bukan sahaja mampu memperjelaskan julat kekuatan batuan pada skala bahan, malahan mampu digunakan dalam skala massa batuan.

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LIST OF ABBREVIATION AND SYMBOLS

c	-	Interlocking of intact rock or rock mass
D	-	Diameter of test specimen
HB	-	Hoek-Brown
ISRM	-	International Society for Rock Mechanics
MC	-	Mohr-Coulomb
m, s	-	Material constant
P	-	Load at failure or applied load
R	-	Radius of test specimen
T	-	Thickness of specimen measured at the centre
UCS	-	Unconfined Compression Strength
UCT	-	Unconfined Compression Test
σ_1	-	Major principle stress (compressive stress are taken as positive)
σ_2	-	Intermediate principle stress
σ_3	-	Minor principle stress
$\sigma_{1'}$	-	Major effective principle stress
$\sigma_{2'}$	-	Intermediate effective principle stress
$\sigma_{3'}$	-	Minor effective principle stress
σ_{ci}	-	Uniaxial compressive strength of intact rock
σ_c	-	Uniaxial compressive strength
σ_n	-	Normal stress
σ_t	-	Tensile strength
ϕ	-	Friction angle of intact rock or rock mass
τ	-	Shear strength
θ	-	Angle of failure plane

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Civil engineering constructions require a comprehensive approach for characterising and assessing strength of rock when subjected to various stresses. The present approach include evaluating the strength of rock samples in laboratory under the effect of major stresses such as tensile, uniaxial and triaxial compression. Subsequently, Mohr strength envelope is used to evaluate the failure criterion for the rock. This approach requires understanding on the material strengths and mass conditions of the in situ rock in order to characterise its mass strength. The reliability of the approach in becomes more crucial if the associated rock displays significant anisotropy and inhomogeneity.

In this study, a sedimentary rock namely shale, was used as samples for the related strength tests in the lab. The test include Brazilian test, uniaxial and triaxial compression tests. Shale is selected due to its anisotropic behaviour created by its mineral arrangement called laminations. This study is aimed at investigating the empirical strength envelope for shale.

There are numerous studies performed in the field of shear strength. In general, intact strength of the rock is higher compare than its mass strength of rock. Since the classic strength theories used for other engineering materials have been found not to apply over a wide range of applied compressive stress condition, a number of empirical strength criteria have been introduced for practical used. Usually, the rock strength has been expressed in linear by Mohr-Coulomb Criterion. Nowadays, a non-linear by Hoek-Brown Criterion has been used widely due to its ability to estimate the shear strength of various types of intact rock and rock masses. The analysis for both criteria completed using RocData software. The results gained from the analysis shows the most reliable failure criterion for predicting strength envelope for shale is Hoek Brown failure criterion.

1.2 Problem Statement

Strength envelope should describe reliably the failure criteria of rock under tensile, uniaxial and triaxial compression. However, for a highly anisotropic rock such as shale its strengths vary significantly, depending on the direction of loading with respect to lamination. The reliability of common failure criterion such Mohr-Coulomb and Hoek-Brown, in producing a reliable strength envelope for this highly anisotropic rock may be affected.

1.3 Objectives of the Study

The main purpose of this study is to understand the empirical strength envelope for shale. There are a few method of analyzing to characterized rock strength. Therefore, the specific objectives of this study are:

1. To understand the use of failure criteria in determining strength envelope for rocks under common stresses in construction.

2. To undertake related laboratory tests for obtaining respective strength parameters and strength envelope for shale.

3. To verify suitability of Mohr-Coulomb and Hoek-Brown criteria for describing failure criteria for shale under tensile, uniaxial and triaxial compression.

1.4 Scope and Limitation of Study

The scopes and limitation of this study are:

1. The type of rock investigated is highly laminated shale from Baram, Sarawak.

2. The failure criteria used Mohr-Coulomb Criterion and Hoek-Brown Criterion.

3. Three laboratory tests conducted in order to determine the rock strength namely tensile, uniaxial compressive and triaxial strength test.

4. The analysis undertaken using RocData software.

1.5 Significance of the Study

It is paramount to understand the use of empirical failure criteria Mohr-Coulomb Criterion and Hoek-Brown Criterion in determining strength envelope of rock. Most importantly is to choose which criterion is more reliable. In addition, a reliable failure criterion based on laboratory test results is essential for predicting strength of rock mass in the field.

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