ANISOTROPIC SHEAR BEHAVIOR OF JOINTED ROCK MASSES AT ULU JELAI HYDROELECTRIC PROJECT, PAHANG

by

NUR KHAFIZA SAPARI

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LIST OF SYMBOLS

Symbols	Explanations
σ_h	Fracture normal stress
σ_H	Maximum horizontal stress
σ_t	Indirect tensile strength
σ_v	Vertical stress
μ	Mean
E	Young’s Modulus
E_t	Tangent modulus of elasticity
P_s	Shut-in pressure
P_b	Breakdown pressure
P_r	Reopening pressure
P_0	Initial pressure
S	Standard deviation
S_h	Minimum horizontal stress
T	Tensile strength

LIST OF ABBREVIATIONS

Abbreviations	Explanations
N	North
S	South
E	East
W	West
NW	North West
SE	South East
NE	North East
SW	South West
NNW	North North West
SSE	South South East
WNW	West North West
ESE	East South East
ENE	East North East
WSW	West South West
UCS	Uniaxial compressive strength
BTS	Brazilian tensile strength
OPTV	Optic televiewer
BHTV	Borehole televiewer
HF	Hydraulic fracturing
ISM	In situ stress measurement
CFZ	Central foundation zone
DIL	Dilatometric
RCC	Roller compacted concrete
ISRM	International Society for Rock Mechanic
HTPF	Hydraulic testing of pre-existing fractures
RMR	Rock Mass Rating

SIFAT RICIH ANISOTROPIK UNTUK JASAD BATUAN BERKEKAR DI PROJEK EMPANGAN HIDROELEKTRIK ULU JELAI, PAHANG

ABSTRAK

Sifat ricih anisotropik untuk jasad batuan berkekar adalah salah satu isu penting dalam bidang kejuruteraan terutamanya dalam bidang pembinaan dan pembangunan. Kajian ini tertumpu pada keadaan geologi, kekuatan batuan dan keadaan tegasan *in situ*. Kajian ini telah dijalankan di projek empangan hidroelektrik di Ulu Jelai, yang dibina berdekatan dengan Cameron Highland, Pahang. Satu empangan konkrit berpemadatan guling (RCC) dengan ketinggian 88 m telah dibina bersama 22 km terowong pengalihan sebagai sebahagian daripada struktur empangan. Jasad batuan di kawasan kajian adalah agak sukar untuk dikaji kerana siri serantau yang berulang dan ricih. Secara geologinya, Cameron Highland terdiri daripada lineamen BL, TL and US dan dipotong dengan arah BL, TL and US jika dilihat dari bukti pergerakan Cenozoic. Berdasarkan dari kajian lapangan terkini, sebahagian sesaran ini adalah bukti pergerakan Quaternary Pleistocene sehingga Holocene. Pada masa yang sama, arah sesaran utama Semenanjung Malaysia adalah terarah kepada U-S, UBL-STG, BL-TG, BBL-TTG, B-T, TTL-SBD dan TL-BD. Berdasarkan ujian kekuatan mampatan uniaxial (UCS) menunjukkan jumlah julat antara 0.5 – 96.0 MPa manakala ujian Brazilian (BTS) jumlah julat antara 0.5 – 14.31 MPa. Daripada ujian tegasan *in situ* pula menunjukkan rekahan yang terhasil di dalam lubang yang telah di gerudi dan rekahan yang dihasilkan semasa ujian hidraulik menunjukkan corak yang sama dengan corak sesaran utama di Semenanjung Malaysia. Magnitud dan arah rekahan juga telah ditentukan sewaktu kajian analisis di mana tegasan melintang maksimum adalah kira-kira 6 MPa yang mempunyai arah normal dari paksi empangan yang mempunyai nilai penghampiran 30^{o} dan *pseudo* mendatar

mempunyai kekuatan kira-kira 4 MPa. Satu korelasi telah dibuat merujuk kepada data yang diperolehi di mana terdapat hubungan yang kuat antara orientasi regim tegasan utama di Susu Dam dengan corak sesaran utama di Semenanjung Malaysia. Korelasi antara kualiti jasad batuan yang diperkenalkan oleh SMEC dengan sistem Penilaian Jasad Batuan (RMR) yang diperkenalkan oleh Beiniawski juga telah ditentukan dalam kajian ini. Daripada pemerhatian, sistem yang dibuat oleh SMEC adalah terhad kepada tahap proses *mylonitision* sahaja sementara sistem RMR adalah lebih umum dan boleh digunakan secara meluas untuk kebanyakan keadaan batuan.

ANISOTROPIC SHEAR BEHAVIOR OF JOINTED ROCK MASSES AT ULU JELAI HYDROELECTRIC PROJECT, PAHANG

ABSTRACT

The anisotropic shear behavior of jointed rock mass is one of the crucial issues in engineering field especially to the construction and developments. This research focused on the geological condition, rock mass strength and in situ stress state. The research has been done at Ulu Jelai Hydroelectric Dam project, which currently constructed near Cameron Highland, Pahang. An 88 m height of roller-compacted concrete (RCC) of dam is build with 22 km diversion tunnel as a part of dam structure. The rock mass is very difficult due to repeated regional series of faulting and shearing. Geologically, Cameron Highland is characterized by NW, NE and N-S lineaments and cut by NW, NE and N-S by going through faults displaying evidence for Cenozoic movements. Recent field investigation has identified that some of these faults evidence for Quaternary Pleistocene to Holocene movements. On the other hand, major faults in the Peninsular Malaysia strike at N-S, NNW-SSE, NW-SE, WNW-ESE, E-W, ENE-WSW and NE-SW. The value of uniaxial compressive strength (UCS) test is in the range of 0.5 – 96.0 MPa while the Brazilian Tensile Strength (BTS) test is about 0.5 – 14.31 MPa. The in situ stress analysis shows that the fractures occur in the borehole and the induced fractures during the hydraulic fracturing test follows the major fault pattern of Peninsular Malaysia. The magnitude and the direction of fracture have been determined during this analysis study which is the maximum horizontal stress has been found approximately 6 MPa with the direction normal to the dam axis with an approximation of ± 30° and the least pseudo-horizontal has been found approximately 4 MPa. The correlation has been made referring to the data obtained where there is a strong relationship between the orientations of principal stress regime at Susu Dam with the major fault pattern of Peninsular Malaysia. The correlation between the rock mass quality introduced by SMEC with the Rock Mass Rating (RMR) system introduced by Beiniawski also has been determined during this research. From the observation, the system developed by SMEC is limited to the degree mylonitisation while the RMR system is more general and can be widely used for any rock material conditions.

CHAPTER ONE

INTRODUCTION

1.1 Problem Statement

Shear behavior of jointed rock masses is one of the critical issues in rock engineering and a lot of research has been done to understand its concept especially when it related to construction such as stability of slopes and dam foundation. The importance to have extensive study at project site before construction is widely aware, but it always related to the high cost in relation to the test and the technical challenges in implementation make this study more challenging.

The shear behavior of jointed rock masses is commonly affected by the mechanical properties of intact rock and its geometrical characteristics of joint systems such as the orientations of the joint sets and direction of the shear loading. Different geometrical characteristics will cause different failure mechanisms (Li et al. 2014).

Before construction, it is important to study the rock mass behavior to give insight into the deformation behavior and failure mechanism of jointed rock masses. In-situ test are typically been conducted to get the detailed information but due to financial constraints and in-situ test are basically expensive, laboratory test can also be conducted.

In this study, the anisotropic shear behavior of jointed rock masses will be studied based on the Ulu Jelai Hydroelectric Dam project, which currently constructed near Cameron Highland, Pahang. An 88 m roller-compacted concrete

(RCC) dam is built with 22 km diversion tunnel as a part of the dam structure. The rock mass is expected to be very difficult due to repeated regional series of faulting and shearing. Geologically, Cameron Highland is characterized by NW, NE and N-S lineaments and cut by NW, NE and N-S by going through faults displaying evidence for Cenozoic movements. Recent remote sensing and field investigation have identified that some of these faults evidence for Quaternary Pleistocene to Holocene movements (Shuib 2009). Some short NW, NE and N-S faults along a major NE and ENE trending fault zone show abundant geomorphic, structural and stratigraphic evidences for late Quaternary activity.

On the other hand, major faults in the Peninsular Malaysia strike at N-S, NNW-SSE, NW-SE, WNW-ESE, E-W, ENE-WSW and NE-SW have undergone complex repeated movements and shearing, including microstructure evidence for both sinistral and dextral movements along many strike-slip faults (Shuib 2009). This deformation is observed as ductile shear zones, which are relatively long and narrow zones of relative displacement. These zones have the main characteristics such as large deformability, strong dependence of resistance on degree of saturation or temperature and susceptibility to alteration.

The Susu Dam site was investigated in 2003 and additional investigation have been carried out in 2011 and 2012 for detailed design. The investigation is carried out to have a better understanding of the Bertam Fault zone which was inferred to be located in the left abutment, but its precise location and characteristics were not known because only vertical boreholes had been drilled. The first challenge is to study the existing fractured network problem from the geological mapping at the dam foundation and correlate the information with regional geology of Peninsular

Malaysia. The other challenge is to study the characteristic of the Bertam Faults zone at the left abutment of the foundation because the stability of the RCC dam depending on the strength of its foundation itself and will this gives a potential problem in the dam foundation excavations.

The uniqueness of the study area is about the geology where during the preliminary study by SMEC, they found the fault zone and mylonised zone occur and it arise another question on the strength of the foundation. The mylonised granite has been so intensely sheared that it no longer resembles granite. It has been reconstituted into predominantly fine grain (silt and sand sized) weak rock that typically has a foliated or flow banded appearance. The granite has basically been ground to ‘rock flour’. If broken apart it often reveals polished or slickensided surfaces. It is emphasized that no thick gouges appear to be associated with these mylonites. The uppermost 0.5 m of core recovered in the borehole is mylonite (at about 20 m), so the mylonite full width is not known. The study should be continued to see either there is intersection between the mylonite zone and fault zone or not because this information will gives an important explanation to understand the fracture network that occurs at the site and how this understanding can help in any analysis of the current stress field and also the imposed stress field of the dam.

Referring to various study on the strength variation of the anisotropic rock masses, no clear distinction can be made to conclude that the range of rock strength variation is same widely because the geological factors is deferent at different area. Based on research work on the in-situ test and laboratory test at the project site correlated with the geological condition, it really helps in terms of understanding rock strength variations and its characteristic of the anisotropic rock behavior. In this case, the orientation of existing fracture networks in relation with regional stress and the mechanical properties need to be fully understood to see what is the significant of a locally determined stress measurement with relation to the regional stress field.

Generally, the objective of this research is to determine the orientation of principal stress regime and its relation to the major fault pattern of Peninsular Malaysia. For this purposed, the Susu Dam foundation is selected as a project area. Hence, this research will discuss about the geological discontinuities orientations correlated with rock mechanical properties and in-situ stress condition.

1.2 Site Selection

1.2.1 Study Area

Ulu Jelai Hydroelectric Project is developed by Tenaga Nasional Berhad (TNB) located in the state of Pahang, in the district of Cameron Highland. It located about 140 km north Kuala Lumpur.

The main features of the Ulu Jelai Hydroelectric Project comprise 88 m high of RCC dam called Susu Dam, two diversion weirs on Sunai Lemoi and Sungai Telom for the diversion of flows from adjacent catchment via 7.3 km and 8 km long transfer tunnels into Sungai Bertam, a 372 MW underground power station and the required associated water conveyance and access road system. The hydroelectric development will generate peaking energy to the national grid.

The first feasibility study has been done on 1988 and the study is continued until 2004. The Susu Dam site was investigated in 2003 and detailed surveys are done in a year of 2008. All investigation stages included seismic traverses and cored boreholes with water pressure testing. Acoustic televiewing was also carried out in