UNIVERSITI TEKNOLOGI MARA

DEVELOPMENT OF ANISOTROPIC ELASTIC-PLASTIC OF HAWKESBURY SANDSTONE DEFORMATION FRAMEWORK INCORPORATING MOBILISED SHEAR STRENGTH

NOORFAIZAH BINTI HAMZAH

Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Civil Engineering)

Faculty of Civil Engineering

August 2026

ABSTRACT

The primary novelty of this research lies in the development and experimental validation of the Rock Deformation Mobilised Shear Strength (RDMSS) framework integrated within the Rotational Multiple Yield Surface (RMYS) concept, establishing an elastoplastic constitutive model that captures the non-synchronous mobilization of cohesion and friction angle as a continuous, strain-dependent process. To collapse specimen-to-specimen geological scatter and confinement-dependent variations across triaxial testing pressures (σ_3 = 4 and 8 MPa), a unique normalization technique maps disparate deformation histories onto a single master curve using a dimensionless normalized strain factor (ϵ^*). Extensively calibrated on intact cylindrical specimens of Hawkesbury Sandstone, the framework successfully quantified baseline peak deviatoric strengths scaling from 39.5 MPa (unconfined) to 58.1 MPa and 74.6 MPa under progressive confinement limits. Furthermore, the zero volumetric strain transition point ($\epsilon_{vol} = 0$) proved to be the most robust geo-mechanical indicator to identify the inflection state where the rock matrix transitions from net compaction to dilation, accurately predicting critical crack damage stress thresholds (q_{cd}). Linear regression analysis across generated stress circles demonstrated that at lower strain increments ($\epsilon^* \leq 0.4$), strength growth is driven by vertical envelope translation as mobilized cohesion (c_{mob}) climbs from 1500 kPa to 3000 kPa, whereas past the crack initiation threshold ($\epsilon^* > 0.6$), the mechanism transitions into upward rotation where the friction angle (ϕ_{mob}) expands to a maximum of 11.50° at the critical dilation boundary ($\epsilon^* = 0.85$) with a peak cohesion of 5000 kPa. Validated within a strict peak stress deviation limit of ± 2 MPa, this framework bridges the gap between physical degradation mechanisms and theoretical plasticity theory. Structured for seamless programming into advanced finite element and finite difference material subroutines, this research provides a highly practical predictive tool for engineers to optimize design decisions and enhance safety margins across subsurface excavations, tunnel convergence profiles, foundations, and anisotropic slope stability assessments.

ACKNOWLEDGEMENT

First of all, Alhamdulillah, all praises to Allah SWT for giving me the strengths, patience and opportunity to accomplish this PhD thesis. This study journey would not have been possible without the dedication supervision, constructive remarks and encouragement from my supervisor, Assoc. Prof. Ir. Ts. Dr. Adnan Derahman and Assoc. Prof. Ir. Ts. Dr. Abdul Samad Abdul Rahman.

My studies would not have been possible without endless prayers, support, and sacrifices of my dear parents and extended family, to whom I am eternally grateful.

Also, I would want to give a shout-out to my colleagues for all the support, encouragement, and pleasure that they provided throughout the entire moments of this study. In this life and the next, may Allah shower His kindness and blessings upon each and every one of them.

TABLE OF CONTENTS

		Page
CONFIRMATION BY PANEL OF EXAMINERS		**ii**
AUTHOR'S DECLARATION		**iii**
ABSTRACT		**iv**
ACKNOWLEDGEMENT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**xi**
LIST OF FIGURES		**xiv**
LIST OF PLATES		**xix**
LIST OF SYMBOLS		**xxi**
LIST OF ABBREVIATIONS		**xxiii**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Introduction	1
1.2	Background of the Study	3
1.3	Problem Statement	6
1.4	Aim of the Study	9
1.5	Objectives of the Study	9
1.6	Scope of the Study	10
1.7	Significance of the Research	13
1.8	Research Novelty and Contributions	15
1.9	Definition of Important Terminology	17
1.10	Organisation of the Thesis	19
CHAPTER 2	**LITERATURE REVIEW**	**22**
2.1	Introduction	22
2.2	Anisotropic Rock Mechanics	23
	2.2.1 Material Characterization of Hawkesbury Sandstone	25
2.3	Progressive Damage Mechanism of Rock	27
	2.3.1 Microstructural Fundamentals of Nonlinearity	30

CHAPTER 1
INTRODUCTION

1.1 Introduction

Rock masses are the major foundation and building medium for many civil and geotechnical engineering structures, such as tunnels, underground caverns, deep excavations, slopes, foundations, dams and mining infrastructures. The mechanical behaviour of the surrounding rock is a critical factor in the long-term stability and serviceability of these structures under complex in-situ stress situations. Unlike idealised engineering materials, natural rock masses are highly heterogeneous, discontinuous and anisotropic due to their geological origin, mineralogical composition, depositional history, weathering processes and the presence of inherent discontinuities such as bedding planes, joints, pores, fissures and microfractures. These inherent properties have a substantial influence on the deformation behaviour, damage evolution and the final failure processes of rock masses under engineering loading conditions (Ghorbani et al., 2025; Liu et al., 2025).

Predicting deformation behaviour has become increasingly important in rock engineering practice since engineering failures are frequently caused by excessive deformation rather than the achievement of peak strength. Numerous failures involving tunnel instability, deep excavations, rock slopes, and underground entrances have shown that progressive deformation and damage buildup occur long before structural breakdown. As a result, understanding the progressive evolution of rock deformation under monotonic and cyclic loading has emerged as a major research focus in modern rock mechanics, particularly for weak sedimentary rocks where the transition from brittle to ductile behaviour is strongly influenced by confinement, stress path, and material anisotropy (Wang & Lei, 2024; Zhao et al., 2024).

Traditional constitutive models used in rock mechanics, such as the Mohr-Coulomb and Hoek-Brown failure criteria, generally describe rock behaviour using set peak-strength parameters and single failure envelopes. While these models are extensively used in engineering practice, they fail to accurately describe the constant mobilisation of shear resistance and progressive stiffness degradation that occurs during the loading process. According to experimental observations, rock deformation is