

TABLE OF CONTENTS

	Page
ABSTRACT (THAI)	I
ABSTRACT (ENGLIST).....	II
ACKNOWLEDGEMENTS	II
TABLE OF CONTENTS	IV
LIST OF TABLES	VII
LIST OF FIGURES.....	VIII
SYMBOLS AND ABBREVIATIONS.....	XI
CHAPTER	
I INTRODUCTION	1
1.1 Background and Rationale	1
1.2 Research Objective	1
1.3 Scope and Limitations	2
1.4 Research Methodology	2
1.4.1 Literature Reviews.....	3
1.4.2 Samples Collection and Preparation.....	3
1.4.3 Single and multi-stage triaxial compression test.....	4
1.4.4 Strength criteria.....	4
1.4.5 Deformation modulus	4
1.4.6 Mathematical Relations	5
1.4.7 Discussions and Conclusions	5
1.4.8 Thesis Writing.....	5
1.5 Thesis Contents	5
II LITERATURE REVIEW	6
2.1 Introduction.....	6
2.2 Single stage vs. Multi-stage triaxial compression test.....	6

TABLE OF CONTENTS (Continued)

	Page
2.3 Factors affecting multi-stage triaxial compression test	9
2.3.1 Effect of multi-stage triaxial compression test	9
2.3.1.1 Strength Criteria	9
2.3.1.2 Experimental Techniques	12
2.3.1.3 Confining pressure conditions	12
2.3.2 Effect of multi-stage triaxial test on strength and elasticity Properties in rock	13
2.3.2.1 Strength Criteria	13
2.3.2.2 Deformation modulus	15
2.4 Mechanical Behaviour of rock Under single and multi-stage triaxial compression test	19
III SAMPLE PREPARATION	24
3.1 Introduction	24
3.2 Rock Types and Names	24
3.3 Rock sample preparation	24
IV TEST METHOD AND APPARATUS	32
4.1 Introduction	32
4.2 Single stage triaxial compression test	32
4.3 Multi-stage triaxial compression test	35
V TEST RESULTS	36
5.1 Introduction	36
5.2 Single stage test results	36
5.3 Multi-stage test results	36
VI ANALYSIS OF TEST RESULTS	45
6.1 Introduction	45
6.2 Compressive strengths	45

TABLE OF CONTENTS (Continued)

	Page
6.3 Hoek-Brown parameters	45
6.4 Strengths from researches obtained elsewhere	52
6.5 Deformation moduli.....	53
VII DISCUSSIONS AND CONCLUSIONS.....	57
7.1 Discussions.....	57
7.2 Conclusions.....	59
7.3 Recommendations for future studies.....	59
REFERENCES.....	61
APPENDIX	65
BIOGRAPHY.....	72

LIST OF TABLES

Table	Page
2.1	Parameter N defined for modified Goodman's equation.18
3.1	Rock units and locations from which they are obtained.27
3.2	Dimensions and densities of specimens prepared for uniaxial and triaxial compression testing (cont.).28
3.2	Dimensions and densities of specimens prepared for uniaxial and triaxial compression testing.29
3.2	Dimensions and densities of specimens prepared for uniaxial and triaxial compression testing (cont.).30
3.3	Dimensions and densities of specimens prepared for multi-stage triaxial compression testing.31
5.1	Summary results of Young's moduli, as well as Poisson's ratios of single stage triaxial compression tests.39
5.1	Summary results of Young's moduli, as well as Poisson's ratios of single stage triaxial compression tests (cont.).40
5.2	Summary results of Young's moduli, as well as Poisson's ratios of multi-stage triaxial compression tests.43
5.2	Summary results of Young's moduli, as well as Poisson's ratios of multi-stage triaxial compression tests.44
6.1	Compressive strengths of tested rocks.46
6.2	Hoek-Brown parameters obtained from single and multi-stage strength results.47
6.3	m_m/m_s and s_m/s_s ratios obtained from single and multi-stage strength results.51
6.4	Empirical constants β and α55

LIST OF FIGURES

Figure	Page
1.1 Research methodology.	3
2.1 Stress path for single stage, (a) and multi-stage triaxial tests (b) (Yang 2012).	8
2.2 Conventional triaxial test data for sandstone (Shia et al., 2016).	10
2.3 Axial deviatoric stress–axial strain and lateral strain curves of red sandstone under triaxial compression test $\sigma_3 = 5$ MPa (Yang, 2012).	11
2.4 Single stage triaxial experimental results of red sandstone. σ_1 , axial strain, σ_3 , Lateral strain (Yang, 2012).	11
2.5 Stress-strain curve from multistage triaxial test on: (left) concrete samples, (right) Tanjung claystone (Melati et al., 2014).	12
2.6 Single stage triaxial experimental results of red sandstone. σ_1 , axial strain, σ_3 , circumferential strain (Yang, 2012).	13
2.7 Differential stress versus axial strain curves recorded in multi–stage and single stage true triaxial testing of the sandstone samples under $\sigma_3 = 3.4$ MPa. (Minaeian et al., 2020).	16
2.8 Relationship between peak strength, crack damage threshold of red sandstone under multi-stage triaxial compression and confining pressure: (a) σ_s and σ_{sd} ; (b) σ_{sd} / σ_s (Yang et al., 2014).	17
2.9 Comparative analysis of single and multi-stage tests (a) comparison of strength (b) Mogi–Coulomb strength data fitting comparison (Wang et al., 2021).	20
2.10 Axial and radial strain behavior at different confining stress levels (Amann et al., 2012).	22

LIST OF FIGURES (Continued)

Figure	Page
2.11 Volumetric strain versus axial stress behavior for different confining stresses in the pre-rupture phase. For confining stress $\sigma_3 \geq \sigma_2$ MPa. (Amann et al., 2012).	23
3.1 Locations at which rock specimens are collected for this study.	25
3.2 Some specimens prepared for single and multi-stage triaxial compression tests.....	26
4.1 Polyaxial load frame used in single and multi-stage triaxial compression testing (Fuenkajorn et al., 2012).	34
4.2 Specimen with neoprene placed between all interfaces and loading platens in polyaxial load frame (Fuenkajorn et al., 2012).	34
4.3 Stress path for multi-stage triaxial compression test used in this study, (a) stress variations with time and (b) axial stress as a function of confining pressure (σ_3).	35
5.1 Some post-tested specimens of the single stage triaxial compression test.	37
5.2 Stress-strain curves for Tak Fa gypsum (a), Maha Sarakham salt (b).	37
5.2 Stress-strain curves for Khao Khad bedded limestone (c), Phu Kradung sandstone (d), Khao Khad marble (e), Pha Wihan sandstone (f), Phu Phan bedded sandstone (g), Phu Phan sandstone (h) (cont.).	38
5.2 Stress-strain curves for Rayong-Bang Lamung granite (i), Buriram basalt (j) cont.).	39
5.3 All post-tested specimens of multi-stage triaxial compression tests after confining pressure of 1, 3, 4, 5, 7, 8, 10, 12, 16, 18, 20, 24, 30, 35, 36, 40 MPa.	41

LIST OF FIGURES (Continued)

Figure	Page
5.4 Stress-strain curves for Tak Fa gypsum (a), Maha Sarakham salt (b).	41
5.4 Stress-strain curves for Khao Khad bedded limestone (c), Phu Kradung sandstone (d), Khao Khad marble (e), Pha Wihan sandstone (f), Phu Phan bedded sandstone (g), Phu Phan sandstone (h) (cont.).	42
5.4 Stress-strain curves for Rayong-Bang Lamung granite (i), Buriram basalt (j) (cont.).	43
6.1 Compressive strengths at failure as a function of confining pressure for Tak Fa gypsum (a), Maha Sarakham salt (b), Bedded limestone (c), Phu Kradung sandstone (d), Khao Khad marble (e), Pha Wihan Sandstone (f).....	48
6.1 Compressive strengths at failure as a function of confining pressure for Phu Phan bedded sandstone (g), Phu Phan sandstone (h), Rayong-Bang Lamung granite (i), Burirum basalt (j). (cont.).	49
6.2 Hoek-Brown parameters, m (a), and s (b) as a function of uniaxial compressive strength (σ_c).	50
6.3 Relationships between m_m/m_s ratios (a), and s_m/s_s ratios (b) as a function of uniaxial compressive strength (σ_c).	51
6.4 Solid points are results from Yang et al. (2012). Open points are from others: Aghababaei et al. (2019), Shi et al. (2016), Venter et al. (2016), Cain et al. (1986).	52
6.5 Elastic moduli for single stage, E_s (a), and multi-stage, E_m (b), as a function of confining pressure (σ_3).	53
6.6 Poisson's ratios for single stage, ν_s (a), and multi-stage, ν_m (b), as a function of confining pressure (σ_3).	54
6.7 Constants β (a), and α (b) as a function of uniaxial compressive strength (σ_c).	56

SYMBOLS AND ABBREVIATIONS

σ_c	=	Uniaxial compressive strength
σ_1	=	Major principal stress
σ_2	=	Intermediate stress
σ_3	=	Minor principal stress
$\sigma_{1,f}$	=	Major principal stress at failure
ϵ_1	=	Major principal strains
ϵ_2	=	Intermediate principal strains
ϵ_3	=	Minor principal strains
ν_s	=	Poisson's ratio on single stage
ν_m	=	Poisson's ratio on multi-stage
E_s	=	Elastic moduli on single stage
E_m	=	Elastic moduli on multi-stage
G_s	=	Shear modulus on single stage
G_m	=	Shear modulus on multi-stage
m	=	Empirical constant for equation (6.1)
s	=	Empirical constant for equation (6.1)
m_s	=	Empirical constant for equation (6.2 and 6.4)
m_m	=	Empirical constant for equation (6.2 and 6.4)
a	=	Empirical constant for equation (6.2)
b	=	Empirical constant for equation (6.2)
s_s	=	Empirical constant for equation (6.3)
s_m	=	Empirical constant for equation (6.3)
c	=	Empirical constant for equation (6.3)
d	=	Empirical constant for equation (6.3)
β	=	Empirical constant for equation (6.5 and 6.7)
α	=	Empirical constant for equation (6.6 and 6.8)