SYNOPSIS

This thesis is concerned with the general and fundamental engineering characterisation of a geological formation within Wianamatta group, known as Bringelly shale. Bringelly shale is the neighbouring member of Ashfield shale; both are soft rocks of Triassic age within a geological structure known as the Sydney basin in the state of New South Wales, Australia.

Bringelly shale rock and its residual material cover an approximate area of 700km^2. It is found inland, to the west of the city of Sydney, where most of the new residential, commercial and industrial development is taking place. There is a limited amount of existing experimental data in part due to the technological difficulties in obtaining specimens and this has contributed to the uncertainties surrounding the engineering behaviour of the rock.

In this research, efforts have been made to identify index property tests useful for determining the engineering characteristics of the material. Further aims were to explore the reasons for the difficulty of obtaining core specimens using standard water flush drilling techniques and, to ascertain and explain why Bringelly and Ashfield shales behave differently in many aspects of their engineering performance, even though they are members of the same geological group.

Qualitative and semi-quantitative analysis by the X-ray diffraction technique was used to evaluate the clay mineralogy of the Bringelly shale materials at different degrees of weathering. Thin sections were examined by optical microscopy to study the nature of cementation and bonding. Polished sections of natural and reconstituted specimens were examined by electron microscopy to investigate the internal structure of each material and its mineral composition. It has been found that the presence of a significant amount of swelling clay and microcracks in the plane of laminations are responsible for increasing the swelling potential of the Bringelly shale. There is little evidence of induration and only apparently weak bonding due to re-crystallisation of

mica at particle contacts. Changes in particle alignment following failure were also observed.

Because of the difficulty of obtaining specimens suitable for *UCS* testing, correlations were established between the point load strength index and the measured values of uniaxial compressive strength in the direction perpendicular to laminations. The strength anisotropy from the point load index was also determined. In this research, it was found that due to the limited number of specimens tested for *UCS*, the determined correlation factor could over-predict the strength of the shale.

Durability and swelling of the shale were also investigated. The durability of Bringelly shale was found to vary from medium for fresh intact material to very low for extremely weathered material. To further investigate the mechanisms responsible for the durability of the shale, unconfined and confined swelling tests were performed. Volumetric strains of 6-8% were measured for cube specimens with a volume of 27000 mm^3, however, the material has shown an inverse relationship between its volumetric swelling and specimen dimensions. The chemical composition of the fluid into which the specimen was immersed was found to have a major influence on volume changes in the intact material. The results of the investigation confirmed that potassium chloride solution can be used to reduce swelling potential, and further, to improve core recovery during drilling.

An extensive experimental program to investigate the engineering performance of the shale has involved the use of conventional and specialised high pressure triaxial equipment. The program investigated the volumetric compression and shearing behaviour of three different forms of specimen. These were natural core specimens, and reconstituted specimens created from crushed shale by either pressing dry powder in a mould or by compression of a slurry.

Isotropic consolidation tests over a wide range of stresses were performed. The program has also involved a series of drained and undrained triaxial strength tests on the three different forms. The series has covered a wide range of confining effective stresses from 20 to 60,000kPa, degree of saturation from 65-100%, and porosities from 10% to 60%. These tests have provided an extensive set of data to investigate

the influence of stress, saturation, suction and internal structure on the compression behaviour of the reconstituted and natural rock. Analysis of these data has been conducted in terms of cementation, swelling, saturation, confining stresses, and frictional resistance.

A series of standard direct and ring shear tests has been carried out on the reconstituted Bringelly shale at normal stresses in the range from 50 to 200 *kPa*, and a residual friction angle was determined. It was found that this value has not been affected by the reorientation of clay particle despite the high clay fraction content of the material.

The results of this research indicate that the general pattern of behaviour for reconstituted material that has experienced a maximum effective stress of less than 6 *MPa* is consistent with the assumptions of critical state soil mechanics and similar to many other reconstituted materials. This pattern of behaviour shows a significant deviation from the framework of critical state when the same material (slurry or core form) is subjected to a maximum effective stress of 60*MPa*. The significance of bonding and structure of the intact shale could be detected from investigating the same material at reconstituted state. However, further development of the critical state framework is required to take into account the reduction in strength caused by the high degree of alignment of clay platelets. The *OCR* seems to have minor effect on the strength of the material.

PREFACE

The work described in this thesis was the outcomes of a project carried out in the Department of Civil Engineering at the University of Sydney during the period from 1997 to 2004 under the supervision of A. Professor D.W.Airey.

The By-Laws of the University require a candidate for the degree of Doctor of Philosophy to indicate which sections of the thesis are original. In accordance with these By-Laws any materials or ideas derived or obtained from other sources have been acknowledged in the text. The author claims the following sections of the thesis as original.

- © In Chapter 3, all xrd, scanning electron and optical microscope results. Carbonate and organic contents test results

- © In Chapter 4, comprehensive index properties including slake durability, point load, and uniaxial compression tests. Atterberg limits, dry density, and hydrometer analysis for clay fractions. Comparison of test results with Ashfield shale. The design of the unconfined swelling test apparatus based on the ISRM standard. The analysis and discussion of the relationship between swelling potential and dimensions of the material. The influence of pore fluid in triggering the swelling potential of the shale and its contribution to the volume change of the material.

- © In Chapter 5, the design of the winding mould apparatus to enhance saturation during preparation of reconstituted cylindrical specimens. The apparatus can also be used for preparing a shear box specimen. The performance of stage consolidation at different confining stresses. Investigating a technique to improve the degree of saturation for the dry pressed and natural shale. In this Chapter, the performance of all the drained and undrained triaxial compression tests and the analysis and discussion of the effects of saturation, bonding, suction, and clay particles alignment on the general responses within the critical state framework.

LIST OF PUBLICATIONS

Several papers were published by the candidate in conjunction with others during the period of candidature. They are presented in support of this thesis

- William, E. (1989) Clay Mineral Relationships in the Slumped Shales and Claystones of the Sydney Region. MSc, thesis, Department of Applied Geology, University of Technology, Sydney, Australia.
- William, E. (1996) Lime Stabilization, Advantages and Disadvantages in Road works. Essay for MSc by course work, Dept of Engineering Science, UNSW, Australia.
- William, E, and Airey, D.W. (1999a) A review of the Engineering Properties of the Wianamatta Group Shale. Proceedings of 8th Australian New Zealand Conference on Geomechanics, Hobart, 2, 641-646.
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Acknowledgments

I started my Ph.D. project in March 1997 at the Department of Civil Engineering. In 1998, my pattern of attendance has changed from full-time to part-time. During the eight years of my candidature, I was privileged to have the support of many people both from within and outside the university of Sydney. My deep sense of my gratitude should go to my supervisor Associate Professor David Airey for his many valuable aspects of support throughout the duration of this project. My special thank is also due to Prof. John Carter for his financial arrangement and kind help he rendered at a difficult time during my candidature.

I also like to express my appreciation to the members of the Centre for Geotechnical Research (CGR), particularly Dr T.Hull for his constant assistance in technical matters throughout the course of this project and also for his unconditional friendship and encouragement. My gratitude goes to Mr R.Barker, Mr A. Reyno, Mr K.Barry, Mr S. De Carvalho for their constructive comments on the soil testing, modification and manufacturing of testing equipments. I also like to appreciate the assistance and friendship of Ms K.Pham throughout the course of the project.

Acknowledgment is also due to the help that I received from other academics and engineers inside and outside Sydney University during the time of my candidature. From University of New South Wales, I would like to thank Prof. C.Ward, and Prof. J. Roberts at the school of Applied Sciences, Dr N.Khalili, Mr P.Gwynne at the school of Engineering Sciences. From University of Sydney, Prof. J.Keen, Dr T.Hubble at the Department of Geology and Geophysics, Mr A.Sikorski, Dr I.Kaplin, Mr T.Romeo from Electronic Microscope Unit, Mr B. Minasny from the Department of Agricultural Chemistry and Soil Science.

The author is grateful to many people and organizations for making available some test data and confirmation analyses used in this project. Particular thanks are extended to Mr. M.Parmar Douglas & Partners Pty.Ltd, Mr T. Weighte and Mr M.Gow from Boral Clay& Concrete, Mulgoa Quarries Pty. Ltd., Coffey Geosciences Pty.Ltd., Mr G.McNally from Sinclair Knight Merz, Jeffery& Katauskas Pty.Ltd., Brendown Quarries Pty Ltd., and Mr C.Matulis from Centre for Advanced Analytical Chemistry, CSIRO

My thanks should also extended to my fellow research students: Dr T.Itakura, Dr J.P.Pan, Dr H.Bui, Dr H.Taiebat, Dr M.K.Islam, Dr M.Chaya, Mr B.Poon, Ms H.Chow, Ms M. Lecce, Mr K.Valenta, Mr A.Mohsin who have been of assistance to me during many stages of my project, not least in their friendship which is much valued.

E.William

LIST OF ABBREVIATIONS

The following are the more commonly used abbreviations in this thesis. Unless otherwise stated they may be assumed to apply throughout this thesis. All abbreviations have also been defined at the point in the text where they are first used.

β	angle between lamination and axial stress direction
γ_d	dry unit weight of the rock
ε_a	axial strain
ε_v	volumetric strain
κ	slope of swelling line in *v*-p' plane
λ	slope of INCL in *v*-p' plane
ϕ_r	residual friction angle
ϕ_u	ultimate friction angle
v	specific volume
v'	Poisson;s ratio
ρ_w	density of water
σ_u	compressive stress
σ	normal stress
σ_v	vertical confining stress
τ	shear strength
μ	coefficient of internal friction
A^o	Angstrom unit
Al	aluminium
B	pore pressure coefficient (B-value)
BC	Badgerys creek
Ca	calcium
CPU	intensity of diffracted radiation (count per second)
CSL	critical state line

c_v	coefficient of consolidation
e	void ratio
E	Young's modulus
EC	electric conductivity
E_{sec}	secant modulus
Fe	iron
G	shear modulus
G_{max}	small strain shear modulus
G_s	specific gravity of solid
HP	Horsley park
I_d	slake durability index
I_p	plasticity index
I_s	point load strength index
INCL	isotropic normal consolidation line
k	permeability
KC	Kemps creek
kN	kilo Newton
M	slope of CSL in q-p' plane
m_c, w%	moisture content
Mg	magnesium
ML	Mulgoa
m_v	coefficient of compressibility
mya	million years ago
Na	sodium
NC	normally consolidated
n	porosity
OC	overconsolidated
OCD	overconsolidated drained
OCR	overconsolidation ratio
OCU	overconsolidated undrained
P	applied load
p'	mean effective stress
p'_c	mean effective stress at the end of mechanical consolidation

p'_e	equivalent pressure, value of p' at the NCL at the current specific volume
pF	the base 10 logarithm of the suction expressed in cm of water
p'_o	stress controlling the size of the yield locus
ppm	part per million
q	deviator stress (σ'_1-σ'_3)
RQD	rock quality designation
S	degree of saturation
SA	surface area of a solid
S.D.	slake durability
Si	silicon
t	time
t_{90}	the time to reach 90% consolidation
t_f	time for failure
UCS	unconfined compressive strength
V	volume of solid
W_L	liquid limit
W_P	plastic limit
XRD	x-ray diffraction

CONTENTS