§1.1 BACKGROUND AND ISSUES

Shale deposits throughout the world have become notorious as a result of the numerous foundation and slope stability problems with which they are commonly associated. Shale is one of the most complex, problematic and least understood geological materials. It is characterised by a wide variation in engineering properties, particularly in its tendency to swell and slake with rewetting in relatively short times.

The major difficulties in assessing and predicting the engineering behaviour of shales can be attributed to two unique features: they are transitional between rock and soil exhibiting both “soil like” and “rock like” behaviours, and their tendency to progress from rock-like to soil-like material in relatively short periods. Rapid and large changes in the strength of shale can occur, 40 to 60% reductions in shear strength are common, due to their sensitivity to changes in environmental conditions. The factors that control the magnitude and time frame of these changes are not well understood and have not been seriously investigated. The geotechnical and geological literature surprisingly lacks systematic studies concerned with either theoretical or experimental aspects of internal micro-structure and bonding deterioration in shales.

This thesis is particularly concerned with clay shales, that is shales which contain a wide range of particle types that usually include clay minerals, silt sized minerals, and...
occasionally sand sized particles. Shale with a greater clay mineral content is generally fine-grained or clay shale. The type of clay mineral, the ratio of clay mineral to quartz content, and extent of bonding are three of the most significant factors influencing the engineering behaviour of clay shale.

In addition, it is widely recognised that clay shales which have been partially or totally dry, exhibit a strong tendency to slake (Botts, 1986). The swelling potential of clay shale can also be initiated in response to unloading by erosion or excavation and/or exposure to water (Brooker and Peck, 1993; Wong, 1997).

Engineers are more interested in the behaviour of shale as a construction and/or as a foundation material for structures. However, due to the transitional nature of clay shale, a somewhat multidisciplinary knowledge base is necessary before one can begin to understand clay shale behaviour. The author has therefore conducted an extensive literary survey concerning the conditions in which the shale formed, its post depositional history, classification, and physical properties.

The Sydney metropolitan area is founded on three major rock units, the Wianamatta group, the Hawkesbury sandstone and the Narrabeen group. The Wianamatta group is a major geological sequence in the Sydney basin that comprises Bringelly shale, Ashfield shale, and a thin intermediate sandstone layer. These are the only significant shales in the Sydney area. Bringelly shale is currently the main source of earth fill and brick clay throughout the Sydney region.

The clay shale of the Bringelly formation which overlies the Ashfield shale is comprised predominantly of claystones and siltstones, with minor components of laminite and sandstone, coal and highly carbonaceous claystone, and tuff. It is highly compacted, weakly cemented, and contains significant amounts of expandable clay mineral species (Chesnut, 1998). With this complex lithology and mineralogy, the mechanical properties of the clay shale are expected to show variations. Knowledge of the factors that control their magnitude and the time frame of their changes are not well understood. Most development in Sydney has occurred where Ashfield shale is the upper rock unit and consequently most of the data on the shales (Won, 1985) and research (e.g. Ghafoori, 1995) have been for this shale.
As the urban sprawl of the Sydney metropolitan area reaches the western suburbs of Sydney, residential, commercial, and industrial development is now taking place on land underlain by the Bringelly shale formation. However, there is limited data on the mechanical properties of Bringelly shale including its stiffness, strength, and swelling. This lack of knowledge has contributed to structural defects ranging from major cracking of interior finishes of buildings, to irreparable displacement of footings (e.g. Chandler, 1999).

Due to the increase in development in the Greater West of Sydney, greater knowledge is now required. This dissertation is an attempt to provide more information and an enhanced understanding of Bringelly shale. This should lead to better engineering design and performance where this shale is encountered.

§1.2 OBJECTIVES AND SCOPE OF INVESTIGATION

Research into the mechanical behaviour of the shale in the Sydney basin has been carried out in the Department of Civil Engineering at the University of Sydney over the last 10 years. In general, the motive for these activities has been to pursue knowledge and information about the mechanical behaviour. Some of the outcomes of these research activities are summarised in Ghafoori et al. (1993, 1995) and Ghafoori (1995). As part of this dissertation, a general analysis of experimental data involving mechanical, physical, and mineralogical properties has been carried out to assess the engineering performance of the material. Over the past few decades, shale in the Sydney region was referred to as Wianamatta shale (Won, 1985, Chesnut, 1991). In the engineering sense, the label has disguised the significant differences in the engineering performance between the two main constituents of this shale (Bringelly and Ashfield). One of the intentions of the author in writing this dissertation has been to address issues that are often associated with Bringelly clay shale and provide data that may raise engineering awareness among professional bodies and the construction community.

The research presented in this dissertation was mainly undertaken in order to provide experimental assessments of the effects of particle bonding and expansiveness of the
mineral constituents on the strength and stress-strain behaviour of Bringelly clay shale.

Due to difficulties associated with obtaining in-situ core specimens with dimensions suitable for mechanical strength tests, a novel approach has been used to investigate the behaviour of the clay shale. This has involved the development of laboratory techniques that can provide useful mechanical data about the in-situ material, and carrying out comparative studies between the laboratory formed material and the in-situ material.

One purpose of this dissertation was to investigate the mechanical behaviour of the natural rock material and to estimate a pre-consolidation stress that may reflect the actual compaction of the material during its depositional history. However, the main aims of this project were: to identify tests useful for determining the index and mechanical properties of clay shale; to examine the importance of moisture content and weathering on the strength of the clay shale; to investigate the influence of applied stresses on the behaviour of the clay shale within the concepts of the critical state soil mechanics model; and to investigate the influence of saturation on the failure of clay shale. The engineering performance of shale is dependent on its mineralogy. X-ray diffraction analysis, optical microscopy and scanning electron microscopy were conducted in an effort to interpret some mechanical behaviour demonstrated by the material during the laboratory testing.

One of the major issues with clay shales is their tendency to disintegrate on swelling. To quantify the expandability of this material and to suggest a possible mechanism, free and confined swell tests were conducted and their responses to different fluids were investigated. In order to understand the strength of the material and its response under different influences of shearing, a series of tests involving triaxial, direct shear box and ring shear apparatus were performed to identify the material’s mechanical behaviour. In order to investigate the cementation of the clay shale, a comparison between the failure surfaces of both, the in-situ and the laboratory formed clay shale was used to suggest a mechanism that can explain the observed behaviour.
§1.3 PRESENTATION AND DESCRIPTION OF RESEARCH

The research described in this dissertation aims to characterise the mechanical behaviour of the Bringelly shale. Its engineering behaviour was studied with a series of experimental programmes to investigate index properties, mineralogy, durability, swelling, suction, shear strength and stiffness, and microscopic structures. The experimental data obtained have been used for correlation with different physical and mechanical properties of the shale. The data are also used to correlate with parameters from Ashfield shale. A literature review of previous studies on the engineering properties of shales is presented in Chapter 2. The chapter presents a review of many of the problems associated with clay shale. Problems concerning the engineering behaviour of the shale with respect to mineralogy, geology, and classifications are thoroughly described. Particular focus is also given to index tests, triaxial tests, aspects of swelling and the behaviour of shale within the framework of the critical state soil mechanics. Issues concerning outcomes from these tests are also covered in this chapter.

Site investigation, mineralogy, and microstructure are the main focus in Chapter 3. The chapter describes the locations selected for sampling, and also the sampling techniques adopted in this study. Details of carbon analysis, particularly for claystone, are also presented. Results of x-ray diffraction analyses used for determination of different members of clay minerals are also presented. The chapter also presents scanning electron microscope examinations of crushed and intact shale material. The photomicrographs presented show the internal structure / fabric before and after mechanical testing.

Chapter 4 describes the index tests carried out in this research. A major part of this chapter deals with a series of strength and durability tests including uniaxial compression strength, the point load strength index, and the slake durability test. The swelling of this material in confined and unconfined tests is presented. Factors causing swelling and their consequences on the engineering performance of the material are also investigated.
Chapter 5 describes the triaxial testing programme including methods of preparation and test procedure. The chapter describes the mechanical behaviour of the shale discovered through drained and undrained triaxial tests from a wide range of effective stress levels from 0.02\( MPa \) to 60\( MPa \). The behaviour of the shale is studied by examining the various stress paths for undrained and drained conditions. An investigation of the factors that influence strength and stiffness of the material is described. The chapter also investigates the influence of saturation on the mechanical failure of the material for a wide range of effective stresses from zero to 60\( MPa \). A comparison study between natural and reconstituted shale to show the influence of saturation on their behaviour at different effective confining stresses is also explored and discussed in this chapter.

This chapter also describes the results of investigating the shear strength of the material through shear box and ring shear test series. These tests assisted in suggesting a mechanism that contributes to the shear deformation and rupture of the intact Bringelly shale.

Finally, Chapter 6 presents the main findings and conclusions of this research, and also recommendations for further research.
END OF CHAPTER 1