AN OVERVIEW OF ENGINEERING GEOLOGY AND GEOTECHNICAL CHALLENGES IN THE NEWCASTLE REGION

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ABSTRACT

This paper presents an overview of the geology of the wider Hunter Valley and Central Coast regions of New South Wales and a discussion of some of the consequences that present challenges to the geotechnical engineering profession. The contrasting structural styles of the folded and faulted Southern New England Fold Belt and the relatively flat-lying, undeformed Sydney Basin are described and compared. Consideration is given to the potential for instability arising from the combination of competent, blocky conglomerates, low strength claystones and coal seams, particularly within the Newcastle Coal Measures. Of the wide variety of challenges that arise from such a regionally diverse range of geological conditions, three areas of practice are given special discussion due to their local importance. These are the treatment of Quaternary sediments that underlie many of the more intensely developed areas; the distribution, properties and treatment of reactive clay soils that are well developed in all geological environments and the treatment of problems due to the risk of mining-induced subsidence on development.

1 INTRODUCTION

The Hunter Valley and the adjacent Central Coast form an important, cultural and economic region of eastern Australia, that includes four designated cities (Newcastle, Lake Macquarie, Maitland and Gosford) and numerous important regional centres and towns. Although centred roughly at Newcastle, the region extends to include areas that are underlain by a wide variety of geological conditions that pose a diverse range of geotechnical engineering challenges. Geotechnical practitioners in the region are thus faced with a seemingly infinite variety of technical and professional issues. It is therefore important that local experience is collected and disseminated at regular intervals, so that the profession is able to offer a level of service to the wider Hunter Valley community that is truly ‘best practice’.

This paper is written as an overview of the geological and geotechnical conditions that prevail in the wider Hunter Valley and Central Coast regions. It is specifically written as a preface to this special edition of Australian Geomechanics, to give a background and a context for the accompanying state-of-the-art reports. It is also intended to offer a ‘first course’ in local geotechnical issues, that might prove useful to new members of the profession or to experienced practitioners who are relocating to the area. By necessity, this paper must be brief and hence it offers little to experienced local geotechnical practitioners. It is the purpose of the accompanying papers and the collection of previous works referenced here, to offer new insights and to extend the state of practice.

2 OVERVIEW OF REGIONAL GEOLOGY

The geology of the wider Newcastle region (taken to include the Hunter Valley, Port Stephens and the Central Coast) has been previously described by numerous papers that have focussed both on pure geology and on the significance of geology to engineering. As the collective knowledge of these works is both comprehensive and accurate, this section will be limited to a brief summary with references as appropriate to these previous works.

Even in early publications important regional subdivisions were recognised that form the basis of the regional geology as it is understood today. In its simplest representation, the region is underlain by the gently dipping sedimentary rocks of the Permian-Triassic Sydney basin (roughly south of the Hunter River) and the more structurally complex sediments and volcanics of the Devonian-Carboniferous New England Fold Belt (NEFB) (roughly north of The Hunter River). In addition, it is capped to the north and west by Tertiary Flood Basalts (which form the spine of the Great Dividing Range in many places) and in many areas is concealed by poorly consolidated sediment sequences which have accumulated in incised valleys during glacial periods during the Quaternary. Key Figure 1 shows a general distribution of the major geological subdivisions within the region.

In most considerations workers have (reasonably) restricted their work to one or other of these geological provinces, with few attempts to consider all of them in a single overview. Noteworthy among the more comprehensive overviews are the texts by Branagan and Packham (1967) and Packham (1969), which described the geology of the region in the context of the geology of New South Wales. Also noteworthy are the accompanying notes to the 1966 1:250,000 Newcastle geological sheet by Brian Engel (NSWGS, 1966), which happened to include descriptions of significant areas of each of these geological subdivisions. These publications, whilst landmarks in their day, are now becoming dated. Considerable work has since been done to interpret the stratigraphy and structure of the New England Fold Belt and Quaternary sediment sequences. Aspects of the stratigraphy of the Sydney basin have been refined and in some cases reclassified. A compendium of the stratigraphy for the wider region, compiled to serve this overview, is presented in Table 1.

2.1 THE SOUTHERN NEW ENGLAND FOLD BELT

Early geological work within the southern NEFB area was undertaken by Strzelecki (1845) and Odenheimer and Herborn (1855-1857). Sussmilch and David (1919) were the first to formalise the northern Hunter Valley Carboniferous stratigraphy by defining the “Kuttung Series” as consisting of formations of sedimentary beds and volcanic units. Osborne (1922) defined a second series of sedimentary units previously recognised by Benson (1913) naming these as the “Burindi Series”. Further revisions were undertaken by Cary and Browne (1938), Voisey (1945) and Voisey (1959).

Roberts (1961, 1965), investigating broader areas of the southern NEFB, recognised two separate sequences of rocks corresponding to the Burindi and Kuttung series. He noted that, although one was predominantly marine and one predominantly terrestrial, that contemporaneous/time-equivalent stratigraphies could be recognised to relate the series. Stratigraphic and structural interpretation continued with Engel (1962, 1965), Campbell (1961) and Campbell and McKelvey (1972). Engel (NSWGS, 1966) revised the Carboniferous stratigraphy in his Explanatory Notes on the Newcastle 1:250,000 Geological Series Sheet S1/56-2, recognising three contemporaneous stratigraphic series that differ according to differences in their depositional environment.

The broad geology of the New England Province was redefined by Roberts et al. (DMRNSW, 1991a), consigning most of the Devonian-Carboniferous geology within the Hunter region to the southern extension of the Tamworth Belt (Korsch & Harrington, 1981), being bounded by the Hunter-Mooki and Peel-Manning faults. Within the Hunter Valley the Tamworth Belt has been further subdivided into three blocks; the Rouchel Block to the west of the Karrakurra fault; the Gresford Block between the Karrakurra and Williams River Faults and the Myall Block between the Williams River fault and the ocean. A typical stratigraphic succession, based on measured sections, has been defined by DMRNSW (1991a) for each of these blocks with the Myall Block being further differentiated into an eastern and a western succession. The geology of the southern NEFB is now reasonably well described in a series of three 1:100.000 scale maps covering the broader Camberwell, Dungog and Bulahdelah regions and their accompanying notes (DMRNSW, 1991b, c and d). Features of the southern NEFB are shown in Key Figure 2.

In summary, the rocks of the southern New England Fold Belt comprise interbedded sediments and volcanics. The sediments (dominant) range from massive cobble conglomerates, through thickly bedded sandstones and interbedded sandstones/siltstone sequences, to units of varved shales and marine mudstones. Tuffaceous siltstones, cherts and coal seams are present, but less common. Locally thick volcanics occur throughout the Carboniferous sequences and these display a variety of textures and compositions, ranging from rhyolitic to andesitic. In many cases they are ignimbritic. These resistant volcanic units are often found capping prominent topographic features. Structurally the NEFB is complex and is divided into many tens of fault-bounded blocks in which the beds may dip in any direction, usually inclined at between 0º and 35º to the horizontal, but occasionally steeper. It is not uncommon for adjacent blocks to have beds dipping in significantly different directions and with different inclinations. The faults that dissect the NEFB are in some cases evident and in others inferred. Typically faults coincide with areas of topographic low, poor outcrop and deeply weathered, mottled soils.

More recent discussions on the structure of the NEFB are provided by Murray (1997) and Scheibner (1998). More detailed information in many areas is now available through a digitised geological compilation in GIS format that has recently been produced by the Geological Survey of New South Wales to a scale of 1:250,000 (GSNSW, 2003)

2.2 THE NORTHERN SYDNEY BASIN

Knowledge of the geology of the northern Sydney Basin has been accumulating since the 19th century, with early detailed work focussing on the coal measure sequences, stimulated by their economic importance and their relatively simple stratigraphy and structure. Important early contributions include the works of David (1907) and Raggatt (1938). Branagan and Packham (1967) and NSWGS (1966). Each of these provide generalised descriptions of the Newcastle, Tomago and Greta Coal Measures, with some reference to the intervening marine sequences. Spatial information in regard to the regional Permian geology was presented in the 1:250,000 Newcastle Sheet (NSWDMR, 1966). More detailed information for the Newcastle Coal Measures was presented in the 1: 34,000 Newcastle Coal Field Surface Geology Map (BHP, 1968) that covered the Newcastle City and Lake Macquarie areas. A detailed discussion of many specific issues on the geology of the Sydney Basin is presented in a collection of papers in a text edited by Herbert and Helby (1980).The geology of the Newcastle Coal Field was revised in 1995 with the production of a revised 1:100,000 geological map of the area, and accompanying notes DMRNSW (1995a,b). Comprehensive discussions of the engineering geology of the lower Hunter and Central Coast were presented in three papers, invited for the conference on the “Engineering Geology of the Newcastle-Gosford Region.” (AGS, 1995). These were the papers by Moelle and

Dean-Jones (1995), Lohe and Dean-Jones (1995) and McNally (1995), and collectively they describe the geological setting and structure of the northern Sydney Basin, with reference to its engineering geology. Ives (1995), in the same proceedings, presents a more detailed discussion of the engineering properties of the Newcastle and Tomago Coal Measures.

Table 1: Compilation of regional stratigraphies (Compiled and adapted from many of the references listed in the text)

Age	**Stratigraphy**				**Rock Types (most to least dominant)**
Quaternary	(Holocene)				Sand, silt, clay, gravel
	(Pleistocene)				Sand, silt, clay, gravel
Tertiary	Barrington Tops	Liverpool Range			Basalt
Northern Sydney Basin					
	Newcastle Coalfield	**Upper Hunter Coalfield**			
Triassic	Hawkesbury Sast				
	Narrabeen Group				Sast, shale
	- Terrigal Fm				Sast, sist
	- Patonga Claystone				Sist, must, clyst
	- Tuggerah Fm.				Sast, shale
	- Munmorah Congl.	- Widden Brook Congl.			Congl, sast, sist, clyst
Permian	Newcastle CM	Wollombi CM			Coal, congl., tuff, sast, sist
	- Moon Island SG	- Glen Gallic SG			
	- Boolaroo SG	- Doyles Ck. SG			
	- Adamstown SG	- Horseshoe Ck. SG			
	- Lambton SG	- Apple Tree Flat SG			
	(Waratah Sandstone)	(Watts Sandstone)			sast
	Tomago CM	Wittingham CM			Coal, sast, sist, congl. tuff
	- Dempsey Fm.	- Denman Fm.			
	- Four Mile Ck. Fm.	- Jerrys Plains SG			
	- Wallis Ck. Fm.	- Vane SG			
		- Saltwater Ck. SG			
	Maitland Group				Sist, sast, congl.
	- Mulbring Sist.				
	- Muree Sast				
	- Branxton Fm.				
	Greta CM		Gloucester CM		Coal, congl, sast, sist
	Dalwood Group				Sist, sast, congl., volcs.
	- Farley Fm.	- Gyrran Volcanics			
	- Rutherford Fm.				
	- Allandale Fm				
	- Lochinvar Fm.				
Southern New England Fold Belt					
Carboniferous and Devonian	**Rouchel Block**	**Gresford Block**	**West Myall Block**	**East Myall Block**	Terrestrial, marine or mixed sequences of sediments including sandstones, siltstones, shales, tuffs, and minor coals, and ignimbrites and volcanics ranging from rhyolites to andesites.
	Paterson Volcs.	Booral Fm.	Johnsons Ck Congl.	Muirs Ck Congl.	
	Seaham Fm.	Chichester Fm.	McInnes Fm.	Koolanok Sast	
	Mt Johnstone Fm.	Seaham Fm.	Booral Fm.	Yagon Sist.	
	Chichester Fm.	Paterson Volcs	Karuah Fm.	Booti Booti Sast	
	Issismurra Fm.	Mt Johnstone Fm.	Nerong Volcs.	Nerong Volcs	
	Woolooma Fm.	Mowbray Formation	Copeland Rd Fm.	Boolambyte Fm.	
	Waverly Fm.	Gilmore Volcs.	Conger Fm.	Kataway Mudstone	
	Dangarfield Fm.	Wallaringa Fm.	Wooton Beds	Wallanbah Fm	
	Kingsfield Fm.	Flagstaff Fm.	undiff. Devonian	Wang Wauk Beds	
	Goonoo Goonoo mudstone	Bonnington Sist.		Bundook beds	
		Ararat Fm.			
		Bingleburra Fm.			

sast = sandstone; sist = siltstone; clyst = claystone; congl = conglomerate; Fm = Formation; SG = Sub Group; CM = Coal Measures.

A comprehensive, spatial description of the geology of the upper Hunter Coalfield was originally presented on the 1:250,000 Singleton Sheet (NSWDMR, 1969). It was revised in the production of a series of 1:25,000 maps covering the Singleton (NSWGS, 1984), Muswellbrook (NSWGS, 1987c), Jerry's Plains (NSWGS, 1987b) and Doyles Creek (NSWGS, 1988a) areas and again in the 1:100,000 Hunter Coalfield Regional Geology map (NSWGS, 1987a, 1988b, 1993). A more recent discussion of the Hunter Coalfield was presented by Sniffen and Beckett (1995). Detailed discussions of the stratigraphy (Stevenson et al. 1995), structure/stress field (Enever et al., 1995) and mining geotechnics in the Upper Hunter were presented at the conference on the "Geotechnical Engineering and Engineering Geology in the Hunter Valley." (AGS, 1998).

In summary, and on the collective understanding offered in the above cited works, the Permian-Triassic Sydney Basin can be thought of as a crustal depression that contains a thick sequence of relatively undeformed sedimentary rocks. This idea is supported by the section shown in Figure 4a. As the name implies, the broad structure is that of a basin, with its deepest point beneath the Sydney region and rising to becoming shallower at its margins, which lie roughly at the Hunter River to the north, the Illawarra to the south, Lithgow to the west and offshore to the east. The geological units generally follow the concave shape of the basin, so that they dip southward at the northern margin; northward at the southern margin; eastward at the western margin; westward at the eastern margin and are relatively flat-lying in the centre of the basin. In the Newcastle area, they typically dip southward at between 0º and 5º, although dip reversals do occur locally, most notably along the coastline between Newcastle and Merewether. The contrasting structural styles of the folded and faulted Southern New England Fold Belt and the relatively flat-lying, undeformed Sydney Basin are illustrated in Figure 4b.

Key Figure 3 is a distribution map of the Permian strata of the northern Sydney basin strata in the wider area. The lower (Permian) part of the sequence comprises marine formations and coal measures sequences, reaching a composite thickness in excess of 2000 m thick. The lowermost units (which outcrop most northerly, at the margin of the basin) are the marine Dalwood Group. These are overlain by the Greta Coal Measures (CM), a second marine sequence (the Maitland Group) and then two more coal measures, the Tomago and Newcastle Coal Measures. The marine formations are dominated by siltstones and sandstones. The Greta CM comprise mainly sandstones and conglomerates, with minor shales and three coal seams. The Tomago CM, which has three identified formations, is dominated by shales and mudstones, with some sandstones, occasional tuffs and 11 coal seams. The Newcastle CM has a thickness of around 400 m and contains similar total thicknesses of conglomerates, sandstones, siltstones, mudstones and tuffs (which may be clayey, micaceous, feldspathic or siliceous). It has four recognised sub groups (see Table 1) and contains 15 coal seams.

Due to the regional southerly to south-easterly dips, the outcropping units become successively younger (higher in the sequence) toward the south. Newcastle and its suburbs are underlain mainly by the Newcastle CM, with the lowermost seams and units subcropping beneath the city and inner suburbs, the middle units subcropping beneath the southern suburbs and northern Lake Macquarie and the uppermost units subcropping beneath southern Lake Macquarie.

A number of fold-style structural anomalies occur locally within the Sydney Basin, corresponding to irregularities in the basement below the Permian sedimentary rocks. Notable amongst these is the Lochinvar Anticline, which controls much of the outcrop pattern of strata in the Newcastle and upper Hunter Coalfields. The inset in Key Figure 3 presents a schematic cross section drawn through the Hunter Valley, from Newcastle, through Maitland, across the Lochinvar Anticline, through Singleton to Sandy Hollow. This section offers an explanation of how the different formations outcrop in different regions. It can be seen from the section that the Lochinvar anticline effectively divides the Permian coal measures of the Hunter Valley into two parts, and has a major influence on the dip of the strata. Although the stratigraphic succession of marine and coal measures sequences to the west of the Lochinvar anticline is similar to that to the east, the coal measures are locally redefined on either side of the Lochinvar Anticline, with the Wittingham CM in the west being the stratigraphic equivalent to the Tomago CM in the east, and the Wollombi CM in the west being equivalent to the Newcastle CM in the east. The Hunter Coalfield is thus situated in the Wittingham and Wollombi Coal Measures, whereas the Newcastle Coalfield is located in the Newcastle and Tomago Coal Measures. The Greta CM subcrops in a ring around the Lochinvar Anticline, dipping locally up to 40º away from its axis. Workings in the Greta Seam in the Cessnock area are usually included in the Newcastle Coalfield.

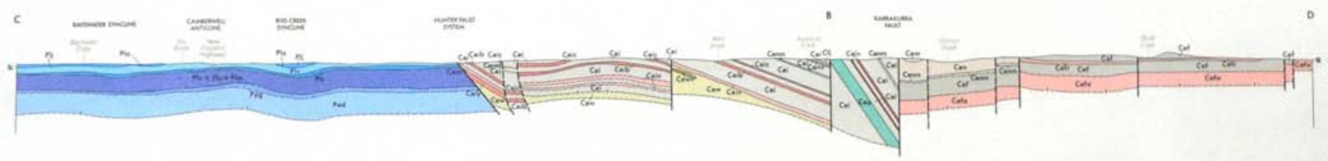
Several small Permian outliers occur as isolated basins within the NEFB, most notably the Gloucester CM (see Key Figure 3).

Toward the south, the southerly dipping Permian strata give way, conformably, to overlying Triassic sediments, with the Munmorah Conglomerate (incorporating the Dooralong Shale) marking the transition zone. Two Triassic sequences are recognised: the Narrabeen Group and the Hawkesbury Sandstone. The Hawkesbury Sandstone is composed of a series of massive quartz sandstone beds (up to tens of metres thick) with minor shale lenses and only outcrops significantly south of the Central Coast. The Narrabeen Group is divided into three further formations which underlie most of the Central Coast Region: the Tuggerah Formation, comprising interbedded sandstones and shales, the Patonga

Claystone and the Terrigal Formation, comprising sandstones, siltstones, laminites and minor claystones. These Triassic strata are relatively flat lying, dipping at between 0º and 3º to the south, although dips may steepen locally due to the presence of gentle fold structures, which constitute little more than 'ripples' in relatively flat strata, when considered on a regional scale.

Although Key Figure 1 indicates that faults in the Permian strata are common, the structural disruption they cause is significantly less than in the NEFB. Generally, displacements on faults within the Sydney Basin are of the order of only metres to tens of metres, whereas in the NEFB they are often in the order of hundreds of metres to kilometres.

a) section across part of the northern Sydney Basin, showing typical structure of the basin (section is west to east, across Lake Macquarie) (vertically exaggerated; after BHP, 1969).



b) section crossing from Sydney Basin (left) to New England Fold Belt (right) showing contrasting structural styles. Section west to east through Bayswater and Mirannie (after DMRNSW, 1991b).

Figure 4: Structure of the southern NEFB and the Sydney Basin.

2.3 TERTIARY BASALTS

Tertiary basalts are widespread, forming capping layers on the higher topographic features along and adjacent to the Great Dividing Range (see Key Figure 1). Two principal masses are recognised, although many small remnants of more extensive masses are scattered as outliers throughout the higher areas of the wider region. The two main masses are the Liverpool Range basalts, capping the Merriwa plateau, and the Barrington Tops basalts, capping the Barrington Plateau. Whilst these are both composed of alkali olivine basalts, they differ sufficiently in chemistry and age to suggest that they were not formed by the same geological event.

2.4 QUATERNARY SEDIMENTS

Significant deposits of Quaternary sediments occur within the region. These have accumulated in paleo-topographic lows, most of which are valleys formed by coastal margin incision during periods of lower sea level. With subsequent sea level rise, these valleys were drowned, making them sites of still, deeper water, able to accept sediment from the rivers that drain into them.

The Quaternary geology of the Hunter estuary has been described and interpreted in a number of publications. Early works include David and Guthrie (1904). A resurgence in interest occurred in the 1980s and 1990s, leading to some major initiatives in Quaternary deposit research along the south-east Australian coastline. For the Hunter estuary, significant works include Roy and Crawford (1980), Roy (1993), Boyd and Roy (1994), Roy et al. (1995) and Walker (1999). The engineering characteristics of sediments in the Newcastle area are specifically considered in papers by Douglas (1995) and Jones (1995), and in a new paper in this publication (Fityus et al., 2005b). The Quaternary geology of the Port Stephens area is described in Thom (1965), Ly (1976) and Thom et al. (1981).

In summary, three notable estuaries occur adjacent to the Hunter region (Lake Macquarie, Newcastle Harbour and Port Stephens), with many more along the extended coastline. The depth to bedrock within these estuaries varies depending upon the energy of the rivers that carved the paleochannels, whilst the extent to which they have been in-filled depends upon the sediment loads of the rivers that have fed them since they were inundated. Available information suggests that the Port Stephens estuary was incised to around 80 m below current sea level and it remains relatively deep in many areas with current water depths up to 40 m at its mouth. The Hunter estuary is the dominant feature, with available data suggesting that there are a number of paleochannels up to 80 m deep located between Nobby's headland and Birubi Point (refer to Key Figure 1). Evidence suggests that Port Stephens and the Hunter estuary have remained mostly separate throughout geological history, probably due to the inability of their respective river systems to breach the substantial body of resistant Carboniferous volcanics that outcrop between Birubi Point and Tomaree Head (refer to Key Figure 1).

Infilling of the Hunter estuary was aided by the formation of sand barriers during sea level rise to form protected, still-water basins that were able to accept and retain finer sediment. A barrier, referred to as the inner barrier, formed during sea level rise in the Pleistocene Epoch, forming a thick sand deposit that is now referred to as the Tomago Sandbeds. A second barrier formed to the east of the Pleistocene barrier, during sea level rise in the Holocene, to create the structure referred to as the Stockton-Williamtown-Anna Bay dune system. As a result of the accumulation of silt and clay sediments between these barriers, a broad zone of wetlands and marshes has formed between Anna Bay and Kooragang Island. The rivers feeding the Hunter throughout the region are bedded in localised sediment deposits that have filled previously incised valleys to a greater or lesser extent. In the higher reaches of the Valley these sediments include gravels, sands and stiffer silty clays. Further downstream, in the Maitland area, the infilled areas broaden on to the Hunter River flood plain with sediments comprising silts, silty sands and silty clays. Toward the delta, sediment sequences thicken, typically comprising sandy silts and sandy clays at depth, with a capping of silty clays, usually occurring as a crust. Relatively speaking, the current water-filled volume of the Hunter estuary is small, suggesting that it has been extensively infilled by the significant sediment load delivered by the Hunter River and its tributaries. Infilling was likely to have been in two stages with an initial period of sediment accumulation following incision and flooding in the Pleistocene and then a subsequent incision of Pleistocene sediments followed by re-flooding and continued sedimentation in the Holocene. As a consequence weathered, desiccated soil surfaces are sometimes encountered within the sedimentary sequence, between stiffer Pleistocene sediments below and the more compressible, normally-consolidated Holocene sediments above.

Sediments beneath Newcastle and its suburbs are up to 50 m deep. They comprise units of clays, silty clays, sandy silts and sands, in a complex arrangement that reflects the interacting effects of the Hunter River, localised adjacent creeks and marine incursions. They are mostly relatively stiff, with only localised weak/very soft horizons within the upper 5 m or so. There are also recent deposits of wind-blown sands that blanket much of the coastal area, including pockets of such sand deposited high on coastal ridges and hill forms.

3 GEOTECHNICAL ENGINEERING CHALLENGES

The diverse range of geological conditions that prevail across the region creates a similarly diverse range of geotechnical engineering problems. In many cases, particular problems are specific to particular geological regions. The geotechnical challenges of each region are overviewed here.

3.1 THE NEW ENGLAND FOLD BELT

Historically, the New England Fold Belt (NEFB) has been the least problematic geological environment in the region despite its structural complexity. The reasons for this are twofold: firstly, the geology poses somewhat fewer challenges than in the Sydney Basin, in part due to the significantly reduced occurrence of coals and claystones, and, secondly, development in the area has been much less intensive than within the Sydney Basin, with most of the southern NEFB area utilised only for agriculture. There are few published geotechnical case studies within the NEFB, so the following discussion relies heavily on the experience of the authors, and on the paper in this volume by Fityus et al. (2005a).

Foundation conditions within the NEFB are generally good, with depths to rock being typically 0 to 1.5 m, rock strengths being generally moderate to high, and rock mass stability being generally good, despite the presence of three or more principal sets of joints in most areas. Foundation conditions for larger developments can be compromised by the presence of major faults, where these lead to intense weathering and deep residual soils (up to 10 m). Weathering in these zones can be so complete that no trace of the original rock is apparent for many metres. Residual clay soils are widespread throughout the NEFB area and in many cases these exhibit reactive behaviour, causing foundation problems for light-weight structures to varying degrees. However, reactive soil problems are not limited to the NEFB, and are so widespread in all geological environments that they are considered specifically in a separate part of this work

The stability of slopes within the NEFB region is generally good, although cases of instability on various scales are known. As the geology is dominated by shallow dipping beds, ridges commonly assume a geologically-controlled asymmetry, with flatter, dip-surface-dominated slopes on one side and steeper ‘bed-end’ exposures on the other. Despite being flatter, dip slopes are often less inherently stable, with bedding planes having some potential to act as slide planes. In cases where instability has been recorded (Fityus et al., 1998) thick bedded sandstones have been observed to slide on weaker layers. In areas of marine sediments, these weak layers may be thin tuffaceous (micaceous) shales, whilst in areas of terrestrially derived sediments, thin coaly seams may also act as low-friction interfaces. On the other side of ridges, where the ends of sedimentary beds meet the surface, outcrop and float is more common, but instability is likely to be limited to toppling or rolling of isolated blocks.

Instabilities are known in areas where major faults exist and these include rockfalls in fractured rock and mudslides in deep weathered soils. In most cases (but not all), instability has coincided with site development, usually including clearing but also in some cases including cuttings in slopes. It is noteworthy to recognise, however, that the region is covered by a road network involving hundreds of cuttings in soil and rock, mostly constructed without any geotechnical guidance and that, despite many of them being precariously steep, examples of major slope failures are relatively few.

The widespread occurrence of felsic to intermediate volcanics throughout the region, has been mostly a blessing, as it has provided numerous convenient sources of high quality quarry products for the local civil engineering industry. Published details of their engineering properties are rare, with some information about the Nerong Volcanics presented in Morton (1999). A downside of these materials, however, is that where they are encountered in development, they usually occur as solid rock masses at very shallow depths, that are extremely difficult to excavate and likely to require drilling and blasting if the extent of the required excavations is significant.

3.2 THE SYDNEY BASIN

3.2.1 The Coalfields

The coalfields of the northern Sydney Basin have posed a wide variety of geotechnical challenges throughout the settlement and development of the region. The diverse variety of rock types, and the relatively flat-lying strata of the Newcastle Coal Measures in particular, have previously been identified as two important factors in the wide variety of different geotechnical problems that arise in the Newcastle area (Fityus and Delaney, 1995).

A plethora of issues have arisen in relation to the activities of the coal mining industry, but these are generally dealt with by specific investigations and for which the results are usually presented only in unpublished reports. A discussion of mining geotechnics is considered to lie beyond the scope of the current work and readers are directed to the papers by Ives (1995), McNally and Ward (1996) and McNally (1998) for further insight into this diverse topic.

Over 200 years’ of mining activity has left Newcastle and Lake Macquarie undermined over wide areas and at various depths; in some areas at multiple depths. In many areas subsidence of abandoned workings is sufficiently well developed to produce surface expressions. Over the last two decades, the need to provide new home sites in proximity to existing development has led to development of areas previously considered to have been rendered unusable due to mining-induced subsidence risk. Also, a recent boom in high-rise development has presented a new generation of geotechnical problems related to subsidence risks in workings at relatively greater depths. Subsidence issues have become so commonplace, and their treatment so challenging, that they are considered to warrant specific treatment in a dedicated section that follows. They have also motivated the writing of five papers on case studies, that also appear in this volume.

In areas underlain by bedrock (and notwithstanding issues related to mining induced subsidence) foundation conditions are variable, though generally not problematic, except in the case of shallow footings in reactive clay for lightly loaded structures. As noted above, reactive clays are such an important and topical issue that they warrant specific consideration in a dedicated section. Rock is usually encountered within 1 m to 2.5 m of the surface, although weathering is usually gradually developed and rock structure is often evident from about 0.8 m to 1.5 m. Where rock is encountered, it ranges from competent, thickly-bedded sandstones and conglomerates, to weak mudstones and claystones that quickly become friable upon exposure. In finer grained rock types, fresh rocks seldom have strengths exceeding high, with strength reducing to low or extremely low when extremely weathered. In coarser grained sedimentary rocks, there is an apparent anomaly between rock strength and degree of weathering: fresh rock is often of high strength, moderately weathered rock may have higher strength, whilst highly and extremely weathered rocks are of low to very low strength. This curious phenomenon is due to the prevalence of weaker clay cements in many fresh rocks and the re-cementing role played by limonite impregnation in the moderate weathering of these rocks. Hence, fresh conglomerates can sometimes be ripped by dozers, whilst moderately weathered conglomerates often require the use of blasting, hydraulic hammering or saw-cutting in excavations of any significant depth.

Whilst claystones are amongst the weakest of rock types encountered, foundations in undisturbed claystones usually present few problems with bearing capacity or settlement. It is uncommon, however, to construct foundations in coal seams, as the near-surface coal is typically oxidised to a clayey silt material that is prone to consolidation on saturation and loading. Neither coal nor claystones are desirable materials for use in engineered fills. Difficulties in achieving compaction and with shrinking, swelling and consolidation are generally considered to be excessive, and these materials are spoiled, where possible. The recently constructed West Charlestown Bypass was a notable exception to this practice, as the majority of earthworks were undertaken in materials that would usually be considered unsuitable for embankment construction. The project was completed by innovatively using the available materials in strategically zoned embankments. Claystones occur frequently within the Newcastle Coal Measures, with the claystones associated with the Australasian Seam and the Great Northern Seam (the Booragul and Awaba tuffs) having particularly bad reputations. Claystones are less common in the Tomago Coal Measures, with the most notable unit being the Thornton Claystone.

There are several noteworthy examples of slope instability within the Newcastle Coalfield. In many instances, the stability of coal measures landforms is controlled by the characteristics of the geological sequences, and this is particularly so for the Newcastle Coal Measures, which host most of the examples of slope instability. An important characteristic of the sequence is the common occurrence of thickly bedded conglomerates that are directly underlain by tuffaceous claystones and coal seams. The conglomerates are usually dissected by two, sub-vertical, orthogonal sets of joints that conveniently divide it into a series of blocks, separated by pervasive, planar fissures that become flooded during heavy rains and which allow the development of lateral hydrostatically-induced stresses with the rock masses. The residual strength of the claystones is typically very low and is significantly affected by the exposure to water. The coal seams are cleated, making them highly permeable and able to supply water to the claystones. In combination, they lead to a situation where the factor of safety against conglomerate blocks sliding on claystone beds may be very low, approaching unity. Examples include the Tickhole Tunnel and Carisbrooke Avenue slides (Charlestown Conglomerate sliding on the Wave Hill and Montrose seam and Tuff), the Bareki Road slide, Eleebana (Teralba Conglomerate sliding on the Great Northern Seam and Tuff), the Thompson Road, Fairfax Road and Chelston Street slide (Bolton Point Conglomerate sliding on the Awaba Tuff and Fassifern Seam) and the City Road slide (Shepards Hill Formation sliding on the Victoria Tunnel Seam). More detailed discussion of slope instability in the Newcastle Region is presented in Fell et al. (1987), Fell et al. (1989) and Moelle and Branagan (2005).

Another topical issue to receive considerable attention in the past decade is the stability of sea cliffs within the coal measures geology and the consequences of coastline regression on infrastructure. This issue is addressed in detail in the paper by Delaney (2005) that also appears in this volume.

The marine formations that accompany the coal measures have, by comparison, posed few challenges to engineers, giving rise to mild topographies with no history of instability and on which are formed soils which are relatively thin and moderately to slightly reactive. One interesting anomaly, recorded by Hawkins et al. (1998), describes excessive loosening of strata during blasting for the Belford Bends deviation at Branxton, probably due to ignition of a pocket of subterranean gases.

3.2.2 The Triassic Geology

Although the Triassic geology of the Sydney Basin is less variable than the Permian coal measures geology, there are a number of characteristics that lead to geotechnical difficulties. Whilst claystones are much less prevalent, notable occurrences exist in the Dooralong Shale (upper part of the Munmorah Conglomerate) and in a regionally significant unit, the Patonga Claystone. The Triassic claystones have similarly high reactivities and pose similarly construction difficulties to their Permian counterparts in the Newcastle Coal Measures.

Foundation conditions are generally good, though slope instability issues are of local importance. Although the conglomerates of the Permian do not persist in the Triassic, there is a tendency for fewer siltstones and mudstones and thicker, more resistant sandstone beds. In the Terrigal Formation particularly, the topography steepens, with outcrops and cliffs of sandstone becoming frequent. Similarly, although finer sediments and claystones are less prevalent, the thicker sandstone beds that dominate the geology are frequently punctuated with thin (<1 m) beds or laminations of fine sediment, which may be claystone or micaceous tuff. Whilst these finer units can lead to block sliding (eg Memorial Avenue, Blackwall Mountain), more often it is the preferential erosion of these finer units that undercuts the more resistant beds in sandstone scarps, leading to toppling instability and the accumulation of often thick wedges of colluvium on steep slopes. The stability of both rockslopes and colluvial deposits is of concern in both natural slopes and cuts and the scale of the areas affected can be considerable. A slide in colluvium in Harcourt Place, North Avoca Fell (1995) caused the destruction of a house and affected several adjacent sites. Other Examples are discussed in Fell (1995). An example of the risks arising due to toppling blocks are presented by Wright (2002) who describes a 22 tonne sandstone block that toppled 170 m down a 34º slope in a developed area on the Central Coast.

Instability is also recorded in the Patonga Claystone. Examples are coastal instability of a slope in claystone that was surcharged with fill at the Toowoon Bay Caravan Park and the failure of a substantial length of road cutting on the F3 freeway near the Alison Rd. overpass (Fell, 1995).

3.3 THE TERTIARY BASALTS

The Tertiary basalts pose relatively few problems, partly because they are confined to areas where development is sparse, and secondly because the basalt rock masses are relatively stable and the fresh basalt is relatively strong. The most significant problems arise because of the nature of the residual basaltic soils, which form a thick mantle (1-4 m) over the basalts in most areas. These soils have high montmorillonite contents, giving them high plasticity and significant reactivity. Consequently, they pose problems for lightly loaded foundations and pavements. They are given further consideration in the section on reactive soils that follows.

The deep residual basaltic soils are also known to be prone to slope instability, mostly due to the low shear strengths of these soils when saturated. There are numerous examples of soil slides on the slopes of the Liverpool Ranges. Most of these are in areas that have been partially or completely cleared of tree cover and where slopes have been modified locally by excavations to accommodate roads and tracks.

3.4 THE QUATERNARY SEDIMENTS

Alluvial Sand. The dominant sediment profile over much of the development area of Newcastle consists of sands typically to depths of 10 m to 15 m, overlying alluvial clay deposits that vary in depth from 20 m to greater than 50 m. This is typical of the Newcastle CBD and inner suburbs, including Mayfield, Kooragang and as far as Tomago. The sands contain variable grain sizes, but are generally free of fines. It is common for an indurated layer to be present in the upper 5 m and this (often locally referred to as “Coffee Rock”) can be cemented sufficiently to produce the equivalent of a low strength sandstone. Thickness and lateral distribution of such layers can be consistent over several hundred metres or locally sporadic. The density within sand layers can vary significantly over relatively short distances,and it is not uncommon for both loose and dense sand horizons to occur in close proximity within a single sand unit.

Aeolian Sand. These deposits occupy much of the coastal area between Lake Macquarie and Newcastle, as well as Stockton Bight, Tomago and Port Stephens areas. These sand beds are generally clean sands, often loose in the upper few metres and found in coastal dunes and sand plains, as well as sporadic distribution on elevated hills. In some areas, on the lee side of prominent hills, such as the area around Christ Church Cathedral in Newcastle, these sand deposits can be up to 20 m thick and loose to depths exceeding 5 m. Loose sands beneath dense sands are also not uncommon within aeolian units.

Soft Clays. Recent (8000 years) estuarine and alluvial soft clay deposits are generally associated with major tributaries to Lake Macquarie, such as Cockle Creek and Dora Creek, as well as Hexham Swamp and deltaic deposits around Kooragang Island and in the interdunal depressions in the Williamtown area. Development has largely avoided these areas due to the inherent problems associated with them. Where development has occurred, it has predominantly been associated with industrial development and major infrastructure such as roads, railways, pipelines and powerlines. There are localised deposits of swamp related clays overlying the sand plains of the Newcastle inner suburbs, around Cooks Hill and Adamstown.

Geotechnical issues related to the Quaternary sediments are dependent on the type of development being undertaken and the sediments encountered. In summary, these issues and their treatments are as follows.

3.4.1 Foundations

Commonly, the main issues with the Quaternary sediments are related to foundation capacity, particularly where loose sands or soft clays are experienced near the surface. The pressure of economic growth in the local area, and increased value of even marginal land, has seen increasing commercial and residential development taking place on sediment deposits with poor foundation characteristics. The common practice for significant structures in these areas is to pile to suitable founding strata. Typically, this involves end bearing and/or friction piles founded in dense sands. In some cases piling is extended through to underlying rock, but under much of the area this is precluded by the depths involved.

Common pile types are driven timber or concrete piles, continuous flight auger piles and Atlas type screw piles as well as conventional bored cast in situ piles. Open bored piles are often avoided due to problems associated with supporting the pile excavation during construction. Driven timber mini-piles are commonly used for lightly loaded structures as well as some larger developments, over sediments up to about 6 m deep and, more recently, steel screw piles have been introduced as a non-vibratory alternative. However, the variable density profiles of many local sand deposits, as well as premature refusal on indurated layers has caused some difficulty in reaching target depths when using these piles in larger structures.

Alternative footing systems have been adopted on a number of projects. For example, in constructing the Tax Office Building on the corner of King and Darby Streets, where over 5 m to 6 m of water-charged sediment was encountered, large rectangular barrette footings were constructed in excavations to rock, created under a bentonite slurry (CP N1774/3, 1987). More recently there has been a trend toward the adoption of “piled raft” foundations, such as Honeysuckle House (DP 31145B, 2002) and the 12 storey Worth Place building in Hunter Street (DP 31636A, 2003).

In some isolated cases, such as the wheat silos at Carrington and a large hotel development in King Street, Newcastle (CP N1194/2, 1980), ground improvement measures have been adopted in preference to piling. In both cases, the depth to suitable founding strata precluded piling as a feasible option. In these cases, the loose sands were densified by vibro-compaction prior to adopting a raft slab foundation system. In King Street the upper 8 m to 10 m of loose sand were densified by vibroflotation prior to use of shallow footings. Vibro-compaction techniques were also employed in the Tomago sand beds, during extensions for the Tomago Aluminium Smelter.

Particular difficulties in foundation design are posed by situations which arise in areas underlain by deeply incised palaeochannels. In some cases, such as the Sandgate-Ironbark Creek-Hexham area, the depth to rock can vary rapidly over short distances, going from less than 5 m to greater than 35 m in a distance of only 100 m or so. Old palaeochannels, infilled with aeolian sands and slopewash clays, are also encountered in some elevated areas within the CBD of Newcastle, such as parts of Watt and Newcomen Streets.

3.4.2 Excavations

The presence of a high water table within sands or soft clays introduces significant geotechnical issues in relation to support of trenches, basement excavations etc. Common practice is to pre-support excavations by using secant pile walls, sheet piles or similar systems. Contiguous piles were employed to retain excavations above the water table on the City Extra site, Bolton Street, Newcastle, with anchors used to control potential settlements beneath a critical electrical substation adjacent to the southeastern corner (DP 3558, 2003). A secant pile wall with grout-injected anchors was used to retain sands below the water table and control settlements on adjacent sites, for a recent development at 200 Hunter St. (DP 31854, 2004). Similarly, the recently constructed North Wing Apartments near Newcastle Beach utilised anchored secant pile walls to control movement of adjacent structures and inflow of groundwater in an 11 m deep sand profile (CG N7275/1, 1999), whilst sheet piles were used for several excavations in the Tomago Area, including wharf facilities at Carrington slipways. Anchoring of pile walls is an issue as this often involves extending anchors beyond the property boundary, to achieve sufficient bond strength. Occasionally, slurry walls have been used to provide a barrier to water inflow, such as in the construction of Grahamstown Dam Embankment and currently proposed groundwater containment walls at Mayfield.

Dewatering associated with excavations in sediments within the Hunter Valley must address many technical and environmental issues. In built up areas, critical technical issues to be addressed in design and construction include the provision of support for structures adjacent to excavations and the potential for draw-down induced settlements on adjacent structures. Local environmental issues relate to disposal of large volumes of water, as well as potential for drawing in contaminated water from the surrounding area. In some locations, exposure of acid sulphate soils has been an issue for dewatering programs to manage, including disposal of affected water, as well as the impact on surrounding soils. On one occasion in the Tomago sand beds, excavations for a deep pit were undertaken using ground freezing, to freeze the water-logged sands prior to excavations, thereby avoiding the usual problems associated with dewatering (CP N1378/31, 1988).

3.4.3 Settlement

Settlement problems are more usually associated with significant construction over soft clays. Notable settlement issues have been prevalent in developments on Kooragang Island, Mayfield/Carrington areas and the industrial areas around Hexham. Settlements are also a major issue for road and rail corridors such as F3 Freeway at Minmi, F3 to Raymond Terrace Link, State Highway 23 at Sandgate and Five Islands Road at the northern end of Lake Macquarie.

Common practice has been the use of pre-loads to effect settlement prior to undertaking final construction. This approach has been adopted for construction of the Kooragang Coal Terminal, the State Highway 23 at Sandgate and the approaches to the Hexham Bridge. At the Kooragang Coal Loader site, 9 m of surcharge was used to induce up to 500 mm of settlement in 4 m of soft clay (Bozinovski, 2002; Jones, 2003). In other preload areas, 1.5 m of settlement was achieved using wick drains in 13 m of soft clay on Kooragang Island and 340 mm of settlement was induced by a preload trial embankment placed over 8 m to 12 m of soft sediment at Five Islands Road (CG N8426/4, 2003). Wick drains are commonly used to accelerate the consolidation, such as in the construction of the F3 freeway at Lenaghans Drive.

For the F3 Freeway (McNally and Summerell, 1998) at Minmi and more recently the Five Islands Road project and a development at Sparke Street Hexham (CG N8943/1, 2004), lightweight bottom ash fill has been adopted both to reduce the degree of settlement and reduce the embankment load on foundation clays of low bearing strength. This option is made feasible in the local region by the proximity of coal fired power stations, which are the source of the lightweight bottom ash.

The Five Islands project, which must accommodate 4 m high embankments on up to 12 m of soft soils, will employ the combination of light weight fill, preloading and wick drain consolidation, with the use of driven timber and concrete piles to support an embankment on soft ground between two bridges. This has the advantage of avoiding the construction delay involved in preloading, as well as allowing construction of an embankment within a tight environmental corridor that would have been breached by use of wider preload embankment batters. Grading of pile capacities towards bridge abutments also reduced the potential magnitude of differential settlements between the embankment and the pile supported bridge structures.

3.4.4 Filling

As much of Newcastle is built on an infilled estuary, there are many areas that have been improved by filling, either to raise the ground level or to reclaim land on the margins of swamps and the harbour. In many cases the fill is of dubious quality and it has been placed without compaction (e.g. Honeysuckle Cove). Many areas are filled with extensive thickness of BHP slag. Whilst slag is a good quality fill material in its own right it has led to considerable settlement in underlying soft soils and now presents a challenge for geotechnical investigations in the redevelopment of former industrial sites such as the former BHP, Kooragang Island and the Steel River Precinct. The stability of deep fill over soft soils in reclaimed river banks is also an issue in some of these areas.

3.4.5 Liquefaction

There are differing opinions as to whether the 1989 Newcastle earthquake caused a significant exacerbation in structural damage in many suburbs of Newcastle due to liquefaction of Quaternary sediments. Analyses suggest that whilst the earthquake was of sufficient magnitude to cause liquefaction, the relatively small number of motion cycles at peak amplitude are unlikely to have enabled a fully liquefied state to develop. The greatest potential for liquefaction to occur is in a layer of very weak/soft silty sand sediment, up to 2 m thick, that is encountered at shallow levels in many parts of Mayfield, Wickham, Hamilton and Carrington (Fityus et al., 2005b), which happen to coincide with many of the areas where earthquake damage was more severe. However, whilst liquefaction may have exacerbated damage in some cases, it is considered that the thickness and properties of potentially liquefiable soils in the Newcastle area would not lead to catastrophic foundation failure in response to an event such as the 1989 Newcastle earthquake. Rynn et al., (1992) suggest that, although no surface evidence of liquefaction was manifested, it is considered that liquefaction below the surface probably occurred. Other factors to be considered in the damage associated with the 1989 earthquake include possible ground motion amplifications in alluvial soils, ranging from 2 to 14 (Melchers 1990) and possible lateral spreading of alluvial soils along sloping paleochannels (Rynn et al., 1992).

4 ENGINEERING TO MANAGE RISK DUE TO MINING INDUCED SUBSIDENCE

Coal was first recorded in Australia in 1791, when a party of escaping convicts observed coal in a small creek about 36 hours sailing north of Port Jackson (Branagan, 1972). In 1797 Lieutenant John Shortland reported the presence of coal at Newcastle. The first coal was taken intermittently by individuals, without government control (Branagan 1972), with the first mined coal believed to have been won from surface exposures of the Nobbys Seam and the lower split of the Dudley Seam. In 1801, the government mined coal using convict labour. Branagan reports that these workings were initially by horizontal drives from the outcrop, probably in the Dudley Seam, but subsequently mine development included shafts, probably to the Yard Seam. The Australian Agricultural Company (AA) obtained the rights to mine coal from the Government and began the production of coal in 1832, initially from the Yard Seam. They subsequently discovered the Borehole Seam in a borehole in 1846 and by 1857 they were producing coal from this seam. By 1860 a number of mines were in production and by the mid 1860s collieries had commenced mining in the Greta Coal Measures between Greta and Cessnock.

4.1 COAL SEAMS IN THE HUNTER VALLEY

Underground mining in the Newcastle and lower Hunter Valley area has exploited seams in the Newcastle Coal Measures, Tomago Coal Measures and the Greta Coal Measures. Of these, the Newcastle and Greta Coal Measures include the thicker seams and this has generally led to more laterally extensive workings.

The coal seams under Newcastle City include the Borehole Seam, the Yard Seam, the upper and lower splits of the Dudley Seam and the Nobbys Seam. Figure 5 shows the stratigraphic sequence of these seams and the northerly dip of these seams under Newcastle east. Until recently, it was believed that extensive mining was restricted to the Yard and Borehole Seams. However the discovery of abandoned convict workings in the Dudley Seam during the construction of the Royal Hospital Medical Sciences Building in the 1980’s (John O’Donnell, pers comm.) and more recently during piling for the ‘City Extra’ Project in Bolton Street (DP 31558A, 2003) suggest that early mining of the Dudley Seam splits was probably more extensive than previously anticipated.

While no original plans of mine workings of the Yard Seam under the Newcastle CBD remain, a plan prepared for the Royal Commission on Earth Subsidence at Newcastle in 1908 was meant to indicate the utmost extent of the Yard Seam Workings in this area. However, recent investigation drilling has shown this to be inaccurate. Drilling in Darby Street has shown the Yard Seam Workings do not extend as far south as mapped (DP 31415A, 2002) whereas investigations at the corner of Hunter and Brown Streets have indicated that the workings extend further north than indicated (CG Ref N8844/2, 2004).

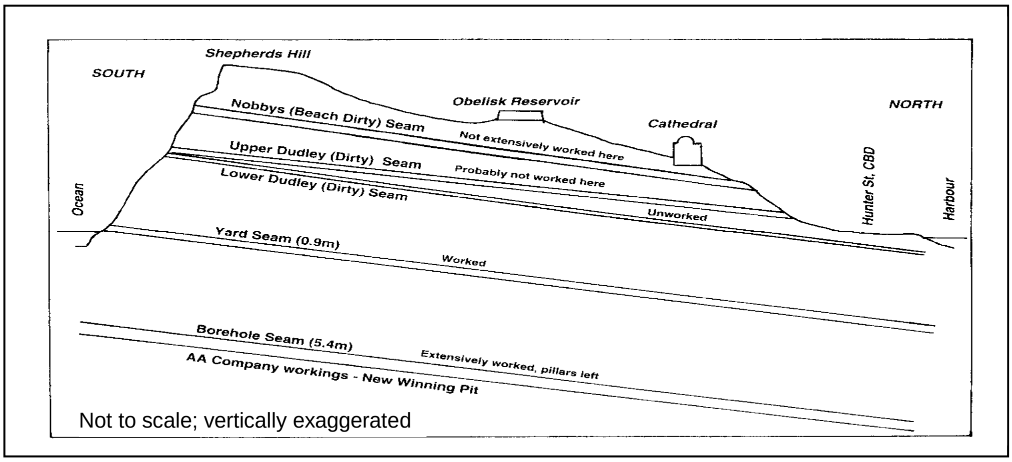


Figure 5: Section through Newcastle Hill Showing Seams Worked. (Reproduced from McNally, 2000)

The Greta Coal Measures were worked over an area between Greta and south of Cessnock, and comprised three main economic Seams, the upper and lower splits of the Homesville Seam and the Greta Seam, which also occurred as upper and lower splits in some areas. These seams are relatively thick and in places (on the limbs of the Lochinvar Anticline) they have uncharacteristically steep dips of up 50° (DP 31913, 2004). Despite this, they were also worked in these areas.

4.2 MINING METHODS AND ISSUES

There are essentially four methods by which coal was removed in the Hunter Valley. These are

- Bord and Pillar workings, in which pillars of variable size were left to support the overlying strata. The pillars were formed by first driving parallel roadways and subsequently cross-cutting between the roadways at regular intervals to form approximately rectangular pillars. This was the normal method used under the current Newcastle CBD and adjacent areas under tidal waters. The bords (roadways) were generally about 6 yards (5.5 m) wide, while the pillar width varied from mine to mine, from several metres to greater than 20 m. There are two hazards to surface structures from abandoned bord and pillar workings:
  1. Pitfalls or potholes, in which the roof strata collapse into the bords, while leaving the strata over the pillars essentially intact. This results in circular sinkholes (at the intersection between bords and cross-cuts) or trenches (subsidence of bords or roadways only). Potholes occur only where the cover over the workings is relatively shallow (usually less than about 15 m to 18 m). A recent example of pothole subsidence was the development of a sink hole of about 5 m diameter beneath the Port Waratah Railway Line in 2003. Investigation showed that the workings were about 7 m to 8 m below the ground surface (DP 31387, 2001).
  2. Pillar failure occurs when the pillars are too small to support the weight of the overlying strata. This results in a "pillar run" in which the pillars fail successively over a large area, resulting in surface subsidence, lateral strain, surface tilt and curvature (to varying degrees) over a relatively wide area. The extent of the surface effects depends on the depth of cover and extraction height (working section). The historical creeps which occurred in Newcastle in 1907 and 1908 are an example of a pillar failure. Another example is the crush of the Wickham and Bullock Island Co workings, underlying Newcastle Harbour, in 1896 and 1897, which are reported to have lowered the sea level in the Basin by about 4 ft. (Atkins 1902).
- Pillar extraction or "total extraction" workings. These were initially developed using bord and pillar methods, and then, after a district was fully developed (referred to as "first workings"), additional coal was won from the pillars as the miners retreated. This was done either by reducing the size of the pillars ("stripping"), by "splitting" the pillars, or by total extraction of pillars. The extent of extraction depended upon the bravery of the miners (it usually continued to the point of collapse). The end result may be full or partial collapse of the roof strata shortly after extraction or the bord and pillar workings may continue to stand with reduced factors of safety against pillar failure.
- Longwall mining, in which wide rectangular areas ("panels" up to 1 km long and 250 m wide) are fully extracted, and the mined area allowed to collapse or 'goaf' over the extracted area. This results in immediate surface subsidence with little ongoing subsidence.
- Open cut (also referred to as "open cast"), in which the overburden was removed to allow extraction of the coal, and then the void was backfilled with the overburden spoil. As the mine progressed laterally overburden removed

from one area was normally used to backfill the adjacent, previously worked area. As the coal is removed and the void backfilled, it would appear, superficially, that abandoned open cuts should have no risk of mine subsidence. However this is not the case. It has been shown that uncontrolled overburden is subject to large ongoing settlements as a result of consolidation and creep from the self weight of the overburden and also due to sudden collapse settlement following changes in groundwater levels within the backfill. The authors are aware of several case histories where mining infrastructure, erected wholly or partly over backfilled open cut mines, has been damaged by ongoing settlement of the filling years after the completion of backfilling. Potential instability of high mine spoil dumps formed at the angle of repose poses geotechnical constraints.

4.3 MINE SUBSIDENCE RISK AND REMEDIATION

In NSW, the Mine Subsidence Board is responsible for the repair of damage caused by mine subsidence. To control the risk, a number of Mine Subsidence Districts have been established in areas where past or future mining is considered likely to pose a risk of damage to surface development. In the declared Mine Subsidence Districts development may not be undertaken without the approval of the Mine Subsidence Board.

However, there are substantial areas of abandoned mine workings that are currently outside Mine Subsidence Districts. At the time of writing this includes Cessnock, Tenambit and the City of Newcastle, east of Newcomen Street. In theory, the Mine Subsidence Board has no jurisdiction over these areas but is still responsible for the compensation of proven mine subsidence claims. In practice, where abandoned mine workings are known to be present, the Council normally refers the proposed development to the Mine Subsidence Board for comment and requires that the Mine Subsidence Board Guidelines are satisfied as a condition of development consent.

Treatment of shallow workings includes the excavation and controlled fill re-instatement of drift entries and the concrete sealing of mine ventilation shafts. Where pothole subsidences occur beneath existing residences, they are commonly infilled by concrete.

In general, pothole subsidence is considered to be a significant risk where shallow bord and pillar workings are within about 15-18 m of the ground surface, although this depth may increase where the working section is high and particularly if the seam is steeply dipping, such as some workings in the Homesville Seam (Greta CM) where dips in excess of 45° have been observed (DP 31913, 2004).

The remedial measures for reducing the risk of pothole subsidence vary depending on the depth of workings, the height of working section and the type and value of the infrastructure. Where detached houses are built over shallow workings, ‘pot hole subsidence’ design usually requires that the structure and its foundations be designed to span a pothole of some specified size (commonly 5 m diameter), which could occur at any point under the structure. Example of development subject to this kind of constraint are parts of the New Lambton Gardens Estate, considerable areas of Fletcher and Maryland, in the western suburbs of Newcastle and areas of Belmont North. In New Lambton Gardens Estate, existing potholes encountered during development were first excavated to remove undesirable soils and debris, prior to engineered and controlled re-filling with suitable soils won from site. In recent times the Mine Subsidence Board has become more risk averse in relation to this style of development, and in some instances has required grouting under sections of a proposed subdivision where the overburden thickness is less than 12 m (DP 31585D, 2004).

During construction of the West Charlestown Bypass, workings in the Australasian Seam were encountered at various depths. A multi-faceted solution was adopted to protect this important piece of infrastructure. After engaging a 180 tonne excavator from the coalfields, the shallowest of workings (to the limit of excavator reach) were excavated to floor level, and re-compacted in the conventional manner. Slightly deeper workings, that could not be excavated, were collapsed and backfilled with subsequent dynamic compaction undertaken. Workings that could neither be excavated nor collapsed were grout filled using a cement stabilised flyash. During the grouting operation, acidic groundwater was pumped and treated with potassium hydroxide and natural seepages treated by limestone blankets.

Where large commercial developments have been constructed in Newcastle over shallow mine workings of less than about 30 m cover, the Mine Subsidence Board has generally required reduction of risk of subsidence by grouting of the mine workings. Different approaches have been used in different areas. The first development in Newcastle for which grouting was required was the Tax Office Building. Under this development, the perimeter of the abandoned workings, at a depth of 23 m in the Yard Seam was initially sealed with low-slump grout plugs and then the entire volume of the voids beneath the perimeter was mass-filled with high-slump grout (CP N1774/38, 1988). More recently a different approach was employed to treat the workings under the neighbouring Telstra Building. These were supported by the creation of low slump grout columns at selected locations to reduce the span between pillars (CPI N5922/1, 1997). A similar approach was also used recently to treat workings in the No. 1 (Donaldsons?) seam (Tomago CM) beneath the new Beresfield sub-station. This method is, however, most applicable to workings with relatively little rubble on the floor and reasonably sound roof.

In the case of the abandoned convict workings, unexpectedly intersected in piling under the City Extra Site, the abandoned workings appeared to range from open voids to areas in-filled with very soft material. In this case, it was considered that the risk of grout column being founded on loose rubble, or failing to reach the roof, was unacceptably high. Hence, low-slump grout was used to form cut-offs where the bords crossed the boundary of the site and the internal volume was filled with low slump grout. Another reason for this approach in this case was the absence of any plan of the workings and hence the risk that some bords would not be identified and remain unsupported if isolated columns were employed. Comparison of the final grout volumes with the theoretical void volume (excluding rubble) confirmed that significant rubble and mud was present within the voids vindicating the choice of methods at this site (DP 31558A, 2003).

In relation to the development of large structures over deep workings, such as the recent apartment building developments which overlie the Borehole Seam workings at a depth of about 75 m under Newcastle, and the Yard, Wave Hill and Victoria Tunnel seam workings at 75 m and 155 m depth in Charlestown (RCA 2135, 2003), the state of practice is still evolving. Prior to about 15 years ago, little, if any, consideration was given to the risk to structures from these deeper workings. However, as developments have increased in height (and value), the Mine Subsidence Board has begun to require geotechnical investigation to confirm the stability of the deeper mine workings underlying the site. This was generally undertaken by the use of cored bores to assess the condition of the roof stratum and the coal pillars and/or the use of borehole closed-circuit TV inspection to confirm the stability of the pillar faces and stability analysis based on the dimensions shown in the record trace. Numerous buildings were approved based on the latter approach, including commercial and residential towers of up to 12 storeys. While the Mine Subsidence Board has previously approved buildings of up to 12 storeys based on such investigations, there appears to be an increasing reluctance of the Mine Subsidence Board to approve such developments. More recent approvals have required increasing numbers of bores, an increase in the minimum acceptable pillar factor of safety and the use of more sophisticated methods of analysis such as finite element modelling. This has resulted in significant dissatisfaction amongst developers because of the delays and the increased uncertainty surrounding projects within mine subsidence districts. It is rumoured that the Mine Subsidence Board is considering a blanket requirement of grouting of the Borehole Seam workings for all developments exceeding an as yet unspecified threshold number of storeys. As the extraction ratio is about 45% over a typical 4.2 m working section, the potential grout volumes are large and depths of workings of around 75 m suggest that drilling will also be a significant cost for such remedial works. If this trend continues, it is likely to have a significant effect on the number and size of future developments within the Newcastle CBD.

5 REACTIVE SOILS IN THE HUNTER VALLEY

5.1 EXTENT OF PROBLEM AND RESEARCH

Appreciation of the phenomenon of volume change in unsaturated soils has been increasing steadily over the last 25 years. During this period, researchers and practitioners have come to realise that the vast majority of damage observed in lightly loaded structures results, not from an inability of the ground to carry the weight of the structure, but rather from stresses imposed on the structure due to volume changes in the foundation soil (Walsh, 1994). The expectations of homeowners in the Hunter region in regard to building performance has also increased, exacerbated by a heightened awareness of structural performance following the 1989 Newcastle earthquake. The earthquake also highlighted the significance of the reactive soils problems in the region, with an unpublished review of the files of a major insurer into recurrent damage that was encountered following the 1989 Newcastle earthquake, noting that 51% of the claims were primarily associated with reactive soils. There is significant anecdotal evidence to confirm that reactive soils are a major geotechnical engineering problem in the Hunter Region in relation to lightly loaded structures and road pavements.

Details of early research undertaken into reactive soils in the Hunter Region is provided in Taylor (1993) and AGS(1995). A detailed research program into the behaviour of reactive soils has been undertaken by the Geomechanics Research Group at the University of Newcastle over the past 10 years. The study has involved the establishment of a network of twenty field sites in the Newcastle-Hunter Valley region to allow long term monitoring of ground movements and soil moisture profiles associated with reactive soils (Allman et al., 1994, Delaney et al., 1996, 1998). The sites are located in residual and alluvial profiles that cover a range of soil, geological and geographic conditions. Table 2 provides a summary of the site locations, rock types, range of shrink-swell test results, recorded ground movements over periods up to 6 years and the calculated free surface movement based on AS2870-1996 (Fityus and Delaney 2004). The research also included a detailed study at Maryland. Details of the results of that study are presented in Fityus et al. (2004).

5.2 INFLUENCE OF GEOLOGY ON SOIL REACTIVITY

The Newcastle Coal Measures contain numerous subhorizontally interbedded units of conglomerate, sandstone, shale, siltstone, coal and volcanic tuff (claystone). Individual beds exhibit considerable variation in thickness and depositional patterns have resulted in a sedimentary sequence characterised by rapid lateral and often abrupt vertical changes in rock and derived soil type (Fityus and Delaney, 1995). This geological variability has to date generally precluded site classification on the basis of site performance or soil profile identification, the preferred methods of AS2870. This variability is also present to a lesser extent in the Tomago, Greta, Wittingham and Wollombi Coal Measures. The potential for soil volume change, in response to changes in moisture content, is a function of both the amount of clay in the soil and its mineralogy. Both of these are strongly influenced by the geological nature of the parent material from which the soil is derived. Coal Measures sequences usually contain a wide variety of clastic and organic sediments. Their mineralogical and textural variability results in a broad range of residual soil types and profiles. This geological diversity is further broadened by the inclusion of material of volcanogenic (tuffaceous) origin which, although locally concentrated, is sporadically disseminated throughout the sequence.

Table 2: Ground Movement Stations in Newcastle-Hunter Region.

Site Number / Location	Depth to Rock (m)	Rock Type	Shrink-Swell Index (%)	Recorded Movement at two surface probes (mm)	AS2870-1996 Predicted Movement (mm)
1. Edgeworth	2.6	Tuffaceous	2.1- 3.5	41, 41	29.5
2. Eleebana	2.5	Tuffaceous	1.2- 3.1	37, 47	17.5
3. South Wallsend	1.7	Tuffaceous	1.3- 4.6	50, 52	36.6
4. Marmong Point	2.8	Conglomerate	1.5- 3.0	8, 15	20
5. Tingira Heights	0.9	Conglomerate	2.1- 3.4	12, 18	21.3
6. Tingira Heights	2.8	Tuffaceous	0.0- 6.1	38, 43	60.4
7. Valentine	2	Tuffaceous	0.2- 3.7	17, 18	16.7
8. Warners Bay	3.4	Alluvium	0.5- 1.8	14, 17	12.2
9. Hamilton	>4	Alluvium	5.4- 8.5	27, 30	44.2
10. Booragul	1.5	Coal	0.5- 6.5	40, 49	61.6
11. Fennell Bay	0.9	Conglomerate	0.6- 1.0	9, 13	7.5
12. Elermore Vale	3.8	Sandstone	0.8- 4.3	37, 41	33.6
13. New Lambton	2.7	Conglomerate	0.5- 1.1	7, 7	4.1
14. Waratah	3.3	Coal	1.0- 6.6	23, 25	54.2
15. Charmhaven	3.2	Tuffaceous	2.7- 4.4	10, 19	18.9
16. Waratah West	1.5	Shale	0.6- 3.3	17, 21	21.3
17. Wallsend	>4	Alluvium	1.1- 5.4	21, 32	26.4
18. Liddell	2.2	Sandstone		18, 21	
19. Mount Thorley	3.5	Shale	2.7- 3.7	35, 35	50.7
20. Maryland	1.7	Shale	1.8- 6.1	34 - 64	41

The nature of residual soils in the Newcastle area is difficult to characterise solely on the basis of parent rock type. Residual soils formed from coal are an example of this. Some coal seams oxidise to produce silty clay soils of low plasticity which soften appreciably on wetting and exhibit little or no reactive behaviour. In contrast, some coals contain a proportion of pyroclastic material that is often difficult to detect and which oxidises to form highly reactive and plastic carbonaceous clays.

The boundary between residual soil and weathered rock is often indistinct and represents a gradational change with some weathered tuffaceous and fine grained rock types exhibiting reactive soil behaviour, in particular a propensity to undergo swell strain on saturation.

The reactivity of slopewash soils is highly dependent on the mineralogy of the source material and the degree of sorting that occurs during transportation. Slopewash soils typically occur as fill in depressions and watercourses/gullies close to the sediment source and are mostly of a clayey nature with variable sand and gravel content. These "gully infill" deposits generally exhibit variable reactivity and depth, with some deposits up to 20m thick. They typically occur along broad, flat drainage areas of suburbs with higher relief areas in close proximity, such as Kotara, Jesmond, Lambton, Mayfield, Warners Bay and Cardiff.

The meandering habit of the Hunter River over the past 10,000 years combined with valley infilling and erosion during marine transgression and regression phases has resulted in a complex pattern of alluvial and estuarine deposits of significantly different thickness and type. Most of the near surface alluvial and coastal valley deposits are of a granular, non-reactive nature, however significant reactive clay profiles have been deposited as estuarine muds and floodplain clays. Near-surface, highly reactive, alluvial clays from to 1.5 m to 3 m thick occur in the Broadmeadow, Hamilton West and Adamstown areas and in parts of Cooks Hill and Sandgate, as well as East Maitland and Rutherford. These areas are typically characterized by shallow ground water tables, with the propensity for significant ground movements that often become apparent only after prolonged dry periods when the water table becomes depressed.

The great diversity of parent rock types in the Newcastle region produces clays of widely varying reactivity. Stratigraphical and structural features include locally thin bedding, rapid and abrupt vertical and horizontal variations in thickness and lithology, gently dipping bedding and a mild to moderate topography. The interaction of these impedes the accurate small scale mapping of individual units over wide areas. Extrapolations to adjacent areas, even over short distances, are often unreliable. The production of a Newcastle region reactive soils zoning map on the scale of individual properties is thus not possible. Similarly, classification methods which extrapolate performance of existing adjacent structures are generally unsuitable. The visual-tactile approach to reactivity estimation is inappropriate because of the large variability in the colours and textures observed in local clays, either weathered from the same parent rock unit, or a different lithotype. The presence of a reworked volcanogenic component can result in large variations in reactivity in clays of similar appearance.

5.3 INDICATORS OF SOIL REACTIVITY

Correlations for Hunter clay soils, between disturbed soil indices (plasticity index, linear shrinkage and cation exchange capacity) and soil reactivity (shrink-swell index) measured on undisturbed 50 mm diameter tube samples, is generally poor (Delaney et al., 1996). This concurs with the results of the Sydney Swelling Soils Study (Coffey Partners, 1985).

The Department of Land and Water Conservation (now Department of Infrastructure, Planning and Natural Resources) use the volume expansion test to characterise foundation hazard. This test, like the plasticity index and linear shrinkage tests, is undertaken on the minus 0.425 mm soil fraction without soil structure or overburden effects. As such these tests should only be used to provide a general estimation of soil reactivity.

The assessment of soil reactivity in the Hunter Region is generally based on shrink-swell testing. The results of shrink-swell testing undertaken in the Hunter Region is presented in Table 3 (Coffey, 1985; Delaney et al., 1996; Fityus and Welbourne, 1996).

Table 3: Regional Shrink-Swell Test Results.

Location	Soil Type	Number	Mean	Std. Dev.
Sydney	Residual	77	2.0	1.1
Newcastle Coal Measures (reactive soil project)	Conglomerate	12	1.5	1.0
	Siltstone/ sandstone	14	3.4	1.3
	Coal	7	5.4	1.3
	Tuff	13	2.9	1.2
Newcastle Coal Measures		275	3.4	1.6
Tomago Coal Measures		238	3.2	1.4
Dalwood, Maitland Groups, Greta Coal Measures		194	2.9	1.3

5.4 SITE CLASSIFICATION TO AS2870

The site classification method which is widely used by geotechnical practitioners in the Newcastle and Hunter Valley is based on site specific calculation of free surface movement with volume change potential of clays assessed using the shrink-swell test (AS1289 7.1.1, 1992). Cameron (1989) compared surface movements, estimated using three shrink-swell test methods, to seasonal soil movements at 12 different sites in Victoria and Sydney and concluded that the shrink-swell test was the most reliable soil reactivity test method.

Reactive soil movements in open ground areas of up to 60 mm are common in the Newcastle-Lake Macquarie regions. Using the approach suggested by AS2870, on average these movements can be reasonably reliably predicted, although the average error between predictions and observations is around 10mm and in individual cases, the errors may be as large as 30 mm (Fityus and Delaney, 2004). Identified reasons for some of the larger errors between predictions and observations include:

- Difficulties in testing and quantifying reactivity trends in gravely conglomeritic soils.
- The presence of trees affecting the assumed depth of soil suction.
- The presence of water tables in alluvial soils.
- Seepage in layers such as coal.

The wide range of shrink-swell indices that occur regionally is shown in Table 2. A wide range of shrink-swell indices can also occur on the scale of a site (Delaney et al., 1996). The variability in ground movements at the reactive soil research sites between two surface probes located less than 2 m apart is shown in Table 2. This is consistent with the geological variability of the region (Fityus et al., 2001) and highlights the risks inherent in applying a single shrink-swell index value from a soil profile to estimate surface movements.

On the basis of broader research outcomes from the reactive soils project, alternative values have been proposed for some of the key parameters used in ground movement predictions. The key parameters, magnitude of surface suction change (Δu), depth of suction change (H_s) and depth of cracking (z_c), are all specified in AS2870 on the basis of the best available data/experience that was available at the time. Recent research has led to refined estimates of appropriate values for the local area. On the basis of results from the Maryland research site, the recommended assumed surface suction change value of Δu=1.5 pF units would appear to be appropriate for the Newcastle-Lake Macquarie regions (Fityus et al., 2004).

Fityus et al. (1998) calculated Thornthwaite Moisture Index (TMI) values for 34 sites across the Hunter Valley and produced a map of predicted H_s values by correlating the depth of seasonal moisture change to the TMI. Soil moisture distribution with depth at the Maryland reactive soil site as recorded between 1993 and 1998 is shown in Figure 6. The results suggest that the depth of influence may be between 1.5 m and 2 m., and is consistent with the range of TMI-based values suggested by Fityus et al. (1998) for this site.

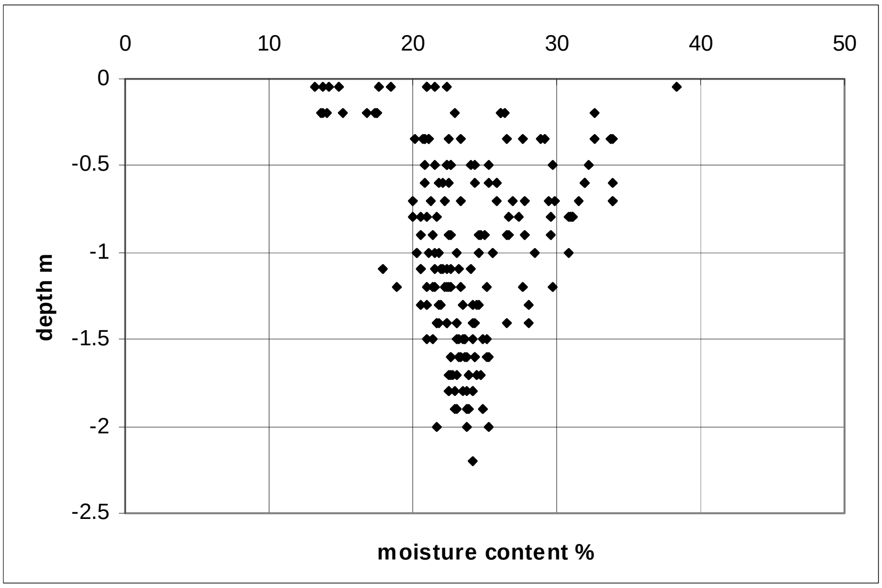


Figure 6: Moisture Content with Depth, Maryland Reactive Soil Site, 1993 to 1998.

On the basis of studies into cracking behaviour in Newcastle and the Hunter Valley, it appears that crack depths may be as much as two thirds as deep as the maximum depth of drying. This observational data supports an increase in the depth z_c from the currently recommended value of $0.5H_s$ (AS2870, 1996) to $0.67H_s$ (Fityus et al., 2004).

Whilst the majority of geotechnical practitioners undertake site classification by calculation on the basis of shrink-swell testing it is noted that a number of project home builders and structural engineers rely on profile identification for site classification. In the authors' experience, this approach is considerably less reliable than the conventional test-based classification approach.

5.5 SWELL PRESSURE

Limited swell pressure data is available from mining projects, where there have been problems with tuffaceous claystones breaking down to clays on inundation. Constant volume swell tests carried out on 10 Awaba Tuff (claystone) samples from Eraring Open Cut exhibited swell pressures of 30kPa to 740kPa with swell pressures of 60 kPa to 345 kPa in tuff from Myuna Colliery, (Ives, 1995). Similarly, there is little data available regarding the swell pressures that can develop in clay soils on inundation. The results of swell pressure testing on high plasticity residual clay soils undertaken at the University of Newcastle (Delaney, 1998) confirm that swell pressures that develop in shallow residual clays when inundated increase exponentially as the initial water content of the soil decreases, with the potential for swell pressures of up to 500 kPa in relatively dry residual clay soils that become inundated. This has implications for moderately as well as lightly loaded structures, particularly when the foundation clay moisture approaches the shrinkage limit and inundation occurs from leaking service pipes or similar.

5.6 REACTIVE ROCK

Some weathered fine grained rocks (siltstone, shale, claystone) and tuffaceous rocks are noted to undergo swell strains ranging from 0.3% to 2.5% on inundation (Delaney 1998), with subsequent material and strength deterioration. Where these materials are exposed in engineering works, it is often prudent to assume non-zero volume change properties, and reduced strengths, for design purposes.

5.7 CONFOUNDING AND CONTRIBUTING FACTORS

The following factors, that are unrelated to reactive soils, have been identified as key contributors to differential movements and cracking and they have been observed by geotechnical consultants over many years in residential and lightly loaded structures in the Hunter Region. These factors can produce damage independently, or in combination, and confound attempts to accurately ascertain the causes of damage. The three factors are:

- The 1989 Newcastle earthquake.
- Mining Induced Subsidence (The Mine Subsidence Board of NSW provides compensation for residences affected by mining. A significant proportion of claims for mine subsidence damage to residential structures are associated with reactive soils.)
- Damage due to leaking service pipes (water damage to residences is covered by general house insurance).

Where reactive soils are the primary cause of damage, a number of related factors may produce an exacerbation of the reactive soil phenomena.

5.7.1 Inadequate Footing Systems

The effects of reactive soil movements are resisted by foundation stiffness and embedment of footings at depths where the soil movement is reduced. The introduction of AS 2870 Residential Slabs and Footings in 1986 has resulted in a significant improvement in footing systems for residential and lightly loaded structures, by providing advice on these aspects.

The majority of geotechnical investigation work that is undertaken into cracked residential structures is for houses built prior to 1986 and relates to both cavity brick residences and brick veneer residences that became prevalent in the 1960s. These structures are typically supported on concrete strip and pad footings that are generally less than 300 mm thick. Stepped brick footings are sometimes found in older structures. The footing systems for residences pre-dating 1986 are generally inadequate for Class M or H (Moderately or Highly reactive) sites, particularly where adverse soil moisture conditions occur.

In contrast, the occurrence of reactive soil damage in residential structures founded on footings designed and constructed in accordance with the recommendations of AS2870 is rare, where the appropriate site class has been adopted and where extreme adverse soil moisture conditions (i.e. large trees in close proximity) have been avoided.

5.7.2 Adverse Soil Moisture Conditions

Whilst climatic conditions such as droughts (El Nino effects) or extended wet periods (La Nina effects) can result in significant differential ground movements, the main contributing factors in the coastal areas leading to adverse soil moisture conditions and associated cracking of residential structures appear to be:

- Significant exacerbation of climatic drying effects due to trees and vegetation in proximity to residences.
- Wetting effects due to leaking service pipes or poor site drainage.

Trees will tend to dry the soils within the zone of root influence, to depths that are often well in excess of the depth of seasonally induced suction change (Hs). The root system for trees generally extends out from the tree a distance of at least equal to the height of the tree and more where the trees occur in a cluster. Appendix B of AS2870-1996 notes distances that trees should be planted from residences on the basis of site class to reduce the risk of damage. There is a high correlation between reactive soil damage and the presence of trees in close proximity to structures. The adoption of smaller allotment sizes and the tendency for developers to leave mature trees on subdivision allotments will exacerbate this effect.

Leaking service pipes (potable water and sewer) can result in significant localised reactive soil differential movements. Remediation can prove difficult as drying back of the clay soils to an equilibrium moisture condition can take years.

The presence of poor site drainage practice is commonly observed with periodic flooding of sub-floor areas due to run-off and ponding of water adjacent to slabs where the rear of residences has cut into hill slopes.

The numerous coal seams in the Newcastle Region can act as aquifers and the presence of wet foundation conditions is often associated with seepage from coal seams that subcrop beneath residences or are exposed in cuts during site regrading.

5.8 UNDERPINNING

AS2870-1996 does not contain detailed design guidelines for piers (underpins) and notes that underpinning (piers) should be avoided where problems are related to reactive clay soils and should only be used as a last resort. When a residential structure experiences differential movement as a result of variations in the moisture content of reactive soils the appropriate method of rectification usually involves stabilisation of the moisture content of the soil, which can take a considerable period. Underpinning is usually unnecessary in such circumstances and is best reserved for poor founding conditions such as uncontrolled filling.

Loiterton (2005) notes that it was common practice 25 years ago in Australia to underpin any parts of a structure that had significantly settled. Thus corners of buildings founded over reactive soils often had underpins installed after the effects of droughts became apparent. Partial underpinning was installed on many reactive clay sites following the 1989 Newcastle earthquake, with recurrent damage noted particularly where underpins were installed in relatively dry conditions.

5.9 CURRENT CONSTRUCTION TRENDS

5.9.1 Cut to Fill

Cut to fill preparation of building pads is commonly undertaken in the hillside areas of Newcastle resulting in variable foundation conditions ranging from rock to residual clay to fill. In general the footing approach commonly adopted is to pier through track rolled filling rather than undertake earthworks compaction in accordance with AS 3798-1996 Guidelines on Earthworks for Commercial and Residential Structures. The potential for heave-related problems is noted, particularly where the filling is placed dry and the piers are only socketed a nominal depth into the natural ground.

5.9.2 Waffle Pod and Pile Foundation Systems

There has been a significant increase in the use of waffle pod foundation systems over the past 5 to 10 years. It is noted that AS2870 allows for up to 400 mm of uncontrolled fill on a site before a Class P classification is warranted and this appears to be based on the assumption that conventional slab footing excavations are to a minimum depth of 400 mm. Subdivision earthworks often involve the spreading of topsoil, mulch and unsuitable materials in a layer up to 400 mm thick on the basis that this will not alter the site classification. This however does not take into consideration the formation of waffle pod footings on the ground surface and generally relies on the identification of unsuitable materials by non-technical personnel when preparing the foundation area for waffle pod footings. This situation seems to be causing an increasing number of foundation problems in local practice.

More recently one major project home builder has adopted a screw pile system for all residential structures. A study into the suitability of driven treated timber minipiles on a Class H site (Fityus and Delaney 2001) noted that piles driven to the active depth (1.7 m) experienced only 20% to 25% of the adjacent ground surface movement.

5.9.3 On-site Stormwater Infiltration

Local councils have adopted development control plans for stormwater management. As low permeability residual clayey soils are prevalent in the majority of local government areas, the use of infiltration trenches for on-site stormwater retention is generally not suitable and has the potential to result in adverse soil moisture conditions. It is difficult to locate infiltration trenches on typical-sized development sites, without the potential for adverse soil moisture impact on the building and adjacent building footprints.

5.9.4 Trees Left in Place in Subdivision Earthworks

The common practice 10 years ago was for developers to undertake significant clearing of trees during the subdivision earthworks stage. This allowed a reasonable period of time for the re-equilibration of soil moisture content following tree removal. The current practice, however, is often to leave the trees on the allotments with removal to be undertaken by the landowner. This is usually undertaken immediately prior to footing construction before significant re-equilibration of deep drying effects associated with mature trees can be achieved.

6 CONCLUSIONS

The wider Hunter Valley and Central Coast regions of New South Wales offer a wonderfully diverse variety of geological conditions, which provide a similarly diverse range of challenges to the geotechnical engineering profession. This paper is an attempt to provide a concise summary of what has been achieved by two centuries of painstaking work by generations of dedicated geologists, complemented in recent decades by the contributions of two relatively new breeds of professional called the engineering geologist and the geotechnical engineer. The complexities of this unique region are far from being fully appreciated and their associated problems are a long way from being entirely resolved. Hence, the most emphatic conclusion that can be offered is that the region will continue to offer new and exciting challenges for generations of geologists and geotechnical engineers, for many years to come.

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