PRECAMBRIAN ROCKS OF THE DARLING RANGE

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ABSTRACT

Precambrian rocks, consisting largely of granitic and gneissic rocks that have been intruded by dolerites, occur in the Darling Range in Perth's eastern suburbs. The Darling Fault separates the deep sediments of the Perth Basin from the Precambrian Yilgarn Craton to the east. The geology and engineering properties of the major rock types are discussed and related to development in the area. Important geotechnical factors that affect development include the deep and variable weathering profile, expansive clay soils developed from the weathering of dolerite, faults and contact zones, erodibility, potentially collapsible soils and slope instability.

GEOLOGY

GENERAL

The Darling Scarp, which is the surface expression of the Darling Fault, forms the boundary between the coastal plain sediments of the Perth Basin and the western edge of the Precambrian plateau (see Key Figures 1 and 2). The Darling Plateau, an ancient erosion surface that has an average elevation of about 300 m above sea level, is made up mainly of granitic and gneissic rocks with later dolerite intrusions (Prider, 1954; Wilde and Low, 1978, 1980; Geological Survey of Western Australia, 1990; Commander, 2003). These rocks are variably weathered from the underlying fresh source rock to the residual soils at surface, and the term 'lateritic profile' is used to collectively describe these materials (e.g. Gordon, 1984; Fell et al., 1992; Anand and Butt, 2003, this volume). The Archaean bedrock is capped by extensive laterite deposits in the south-west of the state. Transported soils overlie the weathered basement profile.

The area east of the Darling Fault forms part of the Yilgarn Craton, a stable Archaean nucleus, composed of granites and gneisses and enclosing a number of elongate greenstone belts. The Precambrian rocks have been subject to a high grade of regional metamorphism (generally amphibolite and granulite grade). The western margin of the Yilgarn Craton in the Perth region and south-west of the state is known as the Western Gneiss Terrane, which consists of gneiss complexes and less deformed granite and minor basic and ultrabasic rocks. The gneisses and granites vary between about 2,500 and 3,000 million years old (Geological Survey of Western Australia, 1990).

ROCK TYPES

Granites and Gneisses

The granites form intermittent areas of outcrop consisting of rounded boulders with intervening soil covered or weathered zones. The granites are generally more homogeneous and less intensively deformed than the gneisses.

Gneiss is a term applied to banded rocks formed during high-grade metamorphism. The gneisses developed near the Darling Fault, commonly occur as intermittent surface outcrop, where it forms broken ridges which generally trend parallel to the foliation and banding of the rocks. The gneisses are typically variable and banded in nature and have been extensively deformed and metamorphosed. These characteristics are accentuated by proximity to the Darling Fault, to the west. The gneisses exhibit a strong northerly trending and sub-vertical foliation, sub-parallel to the banding in the rocks. The banding is discontinuous and variable, leading to rapid variation in rock type (with related mineralogy and composition) over a short distance. The banding in the gneisses is generally defined by alternating zones of quartzo-feldspathic material with mafic zones (dark zones formed by mica and amphibole). In addition, bands and lenses of metadolerite/amphibolite also occur within the gneisses. The gneisses are subject to variable weathering as a result of their banded nature. The gneisses commonly contain quartz and pegmatite veins which tend to be more resistant to weathering and are commonly surrounded by zones of more weathered material.

Dolerites

Dolerites occur commonly in the Darling Range. The dykes increase in abundance westwards, towards the Darling Fault and are generally 2 m to 10 m in thickness but can be up to about 200 m (Wilde and Low, 1978). The dyke trends show cross-cutting relationships, indicating several phases of intrusion. The dominant trend near the Darling Fault is northerly and subparallel to the regional foliation but, further east, dykes trend easterly and north-easterly.

When fresh, the dolerites consist of a dark green grey, very high strength rock with a weak to moderate foliation and closely to moderately spaced jointing. The rock varies from fine-grained near the contact with the host rock, becoming coarse-grained in the central zones of a dyke. Sulphides (probably pyrite) were noted in some zones in the dolerite and gneiss and occur as distinct grains or as finely disseminated crystals.

In the zone adjacent to the Darling Fault, the dolerites have been sheared and metamorphosed, to form a metadolerite or amphibolite generally parallel to the foliation and banding of the gneisses, and possess a foliation (often poorly defined) as a result of their deformation and metamorphic history. The metadolerite bands are commonly discontinuous and exhibit rapid changes in thickness, forming lens or pod-shaped bodies. Particularly near the Darling Fault, the dolerites can have sheared and altered margins with slickensiding. Petrographic analysis of thin sections indicates that the metadolerite/amphibolite consist of foliated, fresh hornblende and plagioclase feldspar.

The dolerites are typically (but not always) more susceptible to weathering than the surrounding granites or gneisses and tend to form more gently sloping, soil covered topography with minor surface outcrop. The depth of weathering may be deeper in contact zones between the gneiss and dolerite, while the more massive metadolerite rock near the centre of the band tends to be more resistant than the margins. The moderately to highly weathered dolerite contains green (chloritic) and brown clayey weathering products and is red stained, low strength and can be very closely jointed to closely jointed.

WEATHERING

Weathering is the process of decomposition and breakdown of rocks by the action of mechanical, chemical and biological agents. Weathering of the bedrock has played a major role in defining the engineering properties of the materials on the Darling Plateau. It has resulted in the local formation of deep residual soils (soils derived from the in situ weathering and decomposition of rock) and a variable profile of weathered material overlying the fresh rock.

Typical weathering profiles in the granitic/lateritic terrains in Western Australia are described in the literature (e.g. Gordon, 1984a and 1984b, Gordon and Smith, 1984; Fell et al., 1992, Blight, 1997, Anand and Butt, 2003 this volume). The basement rocks (granites, gneisses and dolerites) generally possess a variable and deeply weathered profile. The weathering pattern in the gneisses is strongly controlled by the highly banded and foliated nature of the rocks, which results in preferentially weathered bands (predominantly the more micaceous or feldspathic gneisses and the dolerites/amphibolites). A highly irregular and variable weathering profile (and hence excavation/foundation conditions) can therefore be expected (see Figure 1).

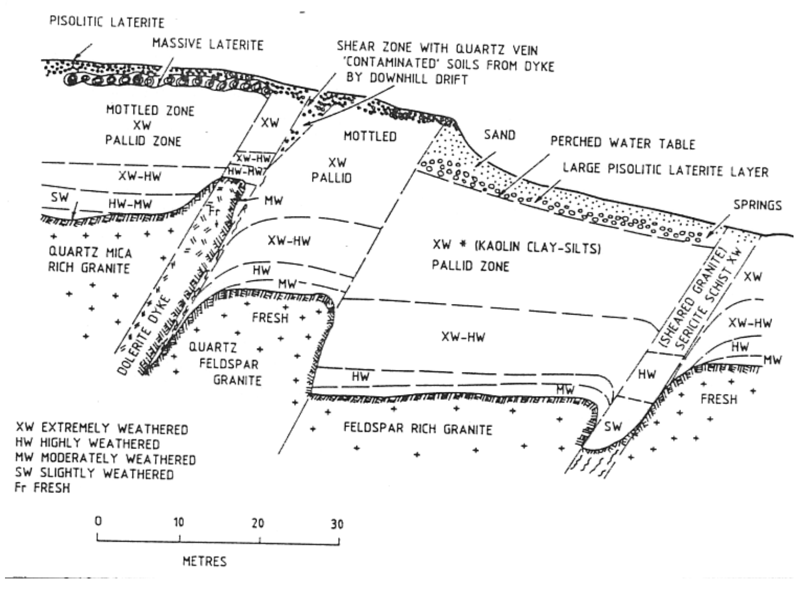

Figure 1: Diagrammatic cross section showing weathered profile controlled partly by rock type and partly by sheared zones, Darling Ranges, Western Australia (from Gordon, 1984).

Susceptibility to weathering is dependent on a number of factors including original mineral composition and lithology, jointing, groundwater/drainage conditions and topography. Sheared or faulted zones are also more prone to weathering, water movement and lateritisation. The feldspar and mica-rich varieties of gneiss tend to be more deeply weathered, whilst the quartz-rich varieties are relatively resistant. This leads to a variable and uneven excavation depth or refusal depth.

Corestones or floaters are commonly developed in the weathered profile in granites and dolerites, where they take the form of rounded boulders (up to a few metres diameter in the granites but typically less than 0.5 m diameter in the dolerites).

LATERITIC WEATHERING PROFILE

'Laterite' refers to varied reddish, highly weathered soils that have concentrated oxides of iron and aluminium and may contain quartz and kaolinite. Laterite may have hardened either partially or extensively into pisolitic, gravel-like, or rock-like masses; it may have cemented other materials into rock-like aggregate or it may be relatively soft but with self-hardening properties after exposure" (Fell et al., 1992).

The weathered granite profiles are controlled by rock type jointing and shear zones. The profile may be divided into residual soil (RS) and variably weathered rock (see Figure 1, after Gordon, 1984).

The upper zone of the residual soil profile is typically massive laterite and pisolitic in high areas, grading to sand and large pisolites downslope. It is commonly called ferricrete when composed of iron oxides, and alcrete, when aluminium oxides are dominant, and can be anywhere from 1-2 m and up to 8 m thick.

Underlying the laterite (or ferruginous zone) is the mottled zone that can be gravelly silts and clays of medium to high plasticity. The mottled zone is the zone of water table fluctuation and is oxidising when dry and reducing when wet. The pallid zone underlies the mottled zone and is commonly kaolin clay with reducing conditions. Next in sequence is a granular or zersatz zone (Gordon, 1984a) that is deficient in felspar and rich in quartz and classifies as either sandy silt or silty sand.

Gordon (1984b) differentiates *Plateau* (high elevation and deep groundwater) and *Valley* (water saturation) weathering profiles, and discusses the differences between granite and dolerite profiles. The weathering depth for the *Plateau* may be as much as 50 m. The *Valley* weathering process is dominated by water and the intrusion of numerous tree roots and is largely one of rock rotting.

FAULTS

The Darling Fault is a major north-north easterly trending feature that separates the Precambrian rocks of the Yilgarn Craton from the Phanerozoic sedimentary rocks of the Perth Basin located to the west. The fault, which is obscured by sediments but has been located from geophysical data, extends for a distance of about 1,000 km and has a downthrow of up to 15 km to the west. The most recent significant activity along the fault is thought to have occurred between 430 and 130 million years ago (early Silurian to early Cretaceous) (Geological Survey of WA, 1990). This activity was however preceded by a long history of tectonic movements in the Darling Fault Zone during the Precambrian.

The Darling Fault has caused intense deformation of the basement gneisses in a zone that extends to the east of the fault. The deformation has been responsible for the development of a strong foliation and banding in the gneisses in this area and the development of cataclastic features such as mylonites (zones of intense fracturing and crushing of the rocks, to form a fine-grained material) and shear zones.

A number of distinct linear features are apparent on Landsat images and aerial photographs in the Precambrian rocks in the Perth area. In particular the Darkan Fault, and other features trending in a north-westerly direction, runs to the south of the Albany Highway and near Serpentine Dam. These features provide a strong structural control to rivers in the Darling Range. Faults are commonly responsible for zones of deep weathering and related lateritisation and shearing of the materials.

JOINTS

Joints associated with and parallel to the foliation and banding of the gneissic rocks are prominent in the area near the Darling Fault. The foliation and banding typically trend northerly and are sub-vertical. These joints are frequently planar and continuous over large distances (>10 m). Evidence of slickensiding occurs along some foliation surfaces and contact zones.

Sheet joints (formed by stress relief) are a common feature in the granitic rocks and are generally orientated sub-parallel to the ground surface. The intensity and frequency of these joints diminishes with depth from the surface. At shallow depth, sheet joints are commonly continuous and can contain a soil infill and weathered margins adjacent to the joint surface.

ENGINEERING PROPERTIES

RESIDUAL SOILS

Residual soils are formed by the in situ weathering of rocks (Blight, 1997). Two main types of residual soils are developed in the Darling Range, based on the parent rock from which they were derived:

Residual Dolerite Soils - Residual soils derived from dolerite generally consist of green grey clays and sandy clays (CH) that are highly plastic. These clayey soils are potentially highly expansive or reactive, as indicated by the presence of fissures in the field. In addition, laboratory testing indicates high values of liquid limit, plasticity index and linear shrinkage.

Residual Granite Soils - The residual granite soils generally consist of clays, sandy clays, sandy silts, sometimes gravelly and usually of medium to high plasticity, which typically plot below the ‘A’ line on the Casagrande chart. The soils generally vary in thickness from a few metres to in excess of 20 m.

Lateritic gravels developed in the granitic terrains of the Darling Range make a widely used and good quality road building material (Main Roads WA, 2002; Cocks and Hillman, 2003, this volume).

Particle Size Distribution

Gordon (1984a) describes the difficulties of obtaining quantitative gradings in the fine-grained lateritic soils at Worsley. Silt and sand sized particles are in many cases aggregations of clay minerals, and various methods of breaking them down are available. They behave as cemented granular materials with silt and sand sized aggregates.

Atterberg Limits

Gordon and Smith (1984) refer to the effects of different sample preparations on the Atterberg limits of lateritic soils. The test procedures adopted are detailed therein. A large number of tests were carried out on granitic and doleritic residual soils from Worsley. The granitic soils nearly all plotted below the ‘A’ line (i.e. silts) and were evenly divided between ML and MH. The doleritic soils were again typically close to or below the ‘A’ line and mostly MH.

However, high plasticity residual doleritic soils typically plot above the ‘A’ line and have high values of linear shrinkage (see also McInnes, 2003).

Permeability

Fell et al. (1992) indicate that the in situ permeability of the residual soil/extremely weathered rock is often high due to root holes, solution channels, and fissures in clay and relic joints. Many of the structural features that cause the high permeability are near-vertical. Vertical tubes called ‘channels’ or ‘drains’ have been formed by the decomposition of roots and may be open or infilled with sand. The mass permeability of these zones may be 10^{-2} to 10^{-4} m/s.

The remoulded permeability of clayey materials is generally significantly lower than the in situ permeability.

Dry Density / Moisture Content

Gordon and Smith (1984) present data from Worsley that highlights the variable and in some instances very low densities in the pallid zone. Dry densities between 1.05 and 1.75 t/m^3 and moisture contents between 10% and 60% were measured. Soil particle densities, as tested, varied between 2.3 and 2.9 (average 2.5) which is low and suggests that clayey aggregations may be either porous and/or contain halloysite.

Dry densities at Worsley decreased with depth to 20 m suggesting that capillary leaching (upward movement of groundwater) may have been the dominant weathering mechanism.

The Water Authority of WA (1990) report data on the Harris Dam as given in Table 1.

Table 1: Dry density/moisture content, Harris Dam.

Material	Location	No. Samples	Average Dry Density (t/m^3)	Average Moisture Content (%)
Granite (MH, CH, CI)	Valley floor	22	1.35	36.7
Dolerite (MH, CH, CI)	Valley floor	46	1.34	40.8
Granite (MH, CH, CI, CL)	Abutments	23	1.55	19.5
Dolerite (MH, CH, CI, CL)	Abutments	6	1.42	20.7

Shear Strength

Fell et al (1992) demonstrate the dependence of shear strength on mineralogy with the lowest strength for montmorillonites and the highest for kaolinite. The drained behaviour is dependent on whether the soil has a low or high clay fraction and three strength envelopes are considered: peak strength, softened strength and residual strength. Up to about 25% clay fraction (CF) 'turbulent' or 'rolling' shear occurs and over 50% CF 'sliding shear' with reorientation of the clay particles is likely. Indicative residual shear strengths are summarised in Table 2.

Table 2: Residual shear strength versus clay mineralogy.

Clay Mineralogy	**Residual Strength $Ø'_R$**
Montmorillonite	5°
Kaolinite	15°
Illite	10°

The variable nature and strength of the weathered gneissic profile are highlighted at the Lake Kabbamup Causeway at Alcoa's Willowdale North area (Masterson, 1999). A discontinuous laterite caprock layer overlies generally stiff clays and silts. However, a band of residual metadolerite, about 120 m long, was encountered that consisted of soft to firm clays with low values of dry density and high moisture content. The soft material had moisture contents in excess of its liquid limit, and X-ray diffraction testing revealed that the clay mineral was halloysite. The undrained and effective strengths of these soils are summarised in Table 3.

Table 3: Shear strength of residual metadolerite soil as Lake Kabbamup Causeway.

Undrained Strength				**Effective Strength**			
Su $^{(P)}$ (kPa)		**Su$^{(R)}$ (kPa)**		**c′ (kPa)**		**Ø′ (°)**	
Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
20-64	41	5-17	11	0-3	2	29.5-36	34

$^{(P)}$: peak strength $^{(R)}$: residual strength

The Water Authority (1990) derived foundation shear strength design parameters for the Harris Dam. These are given in Table 4.

Table 4: Effective shear strength parameters, Harris Dam foundation.

Peak Strength		**Softened Strength ***	
c′ (kPa)	**Ø′ (°)**	**c′ (kPa)**	**Ø′ (°)**
26 ^{t}	26.5	26 ^{t}	23.5

* Similar to residual strength
^{t} Failure envelope kinked at 100 kPa (confining pressure) to pass through origin. Thus lower c′ values apply at pressures <100 kPa.

Compressibility

The deeply weathered lateritic profiles are compressible, particularly under high loads. The 37m high Harris Dam (Somerford and Bradbury, cited in Fell et al., 1992) is underlain by up to 30 m of residual soils derived from granite (dry density typically 1.35 t/m^3). The maximum foundation settlement was 560 mm at the end of construction, plus creep settlement of about 20 mm over the following nine months.

A summary of the compressibility properties is presented in Table 5.

Table 5: Compressibility properties of residual soils at Harris Dam.

Parameter	**Range**	**Average**
Recompression index (c_r)	0.01 – 0.13	0.05
Virgin (c_c)	0.06 – 1.05	0.36
Overconsolidation ratio (OCR)	0.9 – 35.3	7.0
Constrained modulus M (MPa)	4 – 42	13
Void ratio (e)	0.53 – 1.62	1.0

Gordon and Smith (1984) describe the results of extensive field and laboratory testing on weathered granites and dolerites at Worsley. Laboratory oedometer testing (32 samples) on silty soils (ML or MH) is summarised in Table 6:

Table 6: Compressibility properties of residual soils at Worsley.

Parameter	Range	Average
Recompression index (c_r)	0.01 – 0.08	0.04
Virgin (c_c)	0.13 – 0.55	0.39
Overconsolidation ratio (OCR)	1.2 – 4.0	2.7
Constrained modulus (M, MPa)	7 – 42	26
Void ratio (e)	0.65 – 1.24	0.90

The rate of consolidation was rapid with 90% consolidation times less than 2 minutes.

A summary of camkometer testing (14 tests) is presented in Table 7:

An instrumented embankment (100 m x 80 m x 10 m high) over a 20 m thick soil profile gave a drained modulus of 55 MPa, with all settlement concurrent with construction.

Table 7: Worsley Camkometer testing.

	Range (MPa)	Average (MPa)
Initial loading	33 – 126	65
Reloading	60 - 234	144

ROCK PROPERTIES

Fresh Rock

A number of commercial rock quarries exist along the Darling Scarp. Granite and dolerite (and diorite) are mined by blasting and used for aggregate in concrete and roadbase.

Dynamic elastic and strength properties are pertinent to blasting. Dynamic tensile strength is relevant for intact rock (e.g. Brazilian test). The elastic properties of Young's modulus (E) and Poisson's ratio (ν) are used in prediction of fragmentation and heave.

Rock Mass

Strength testing data by CSR Readymix at Gosnells Quarry and reported by O'Sullivan (1995) are summarised in Table 8.

Table 8: Cosnells Quarry rock strength testing.

	UCS			Point Load Index ($I_{S(50)}$)			Young's Modulus		
Material	No. Samples	Range (MPa)	Mean (MPa)	No. Samples	Range (MPa)	Mean (MPa)	No. Samples	Range (GPa)	Mean (GPa)
Granite	12	30-155	110	14	4-20	11	2	37-42	40
Dolerite	6	50-160	130	7	10-22	15	3	42-45	43

Using the rock strength classification according to Beavis (1985, cited in Fell et al, 1992) in Table 9, the above rock samples are very high strength.

The rocks are generally very high strength, however, when they are sheared, problems can arise in blasting due to reflection of strain waves at the free surfaces. Within the quarry the primary control on fragmentation is jointing. When joint orientation is parallel to blast, jointing has a greater role in fragmentation, leading to a decrease in fragment size. The shear waves travel parallel to the joint plane and break up the rock more effectively than if they were perpendicular.

Table 9: Rock strength classification.

Classification	UCS (MPa)	$I_{S(50)}$ (MPa)
Extremely high	-	>10
Very high	100-250	3-10
High	50-100	1-3
Medium	25-50	0.3-1
Low	5-25	0.1-0.3
Very low	<5	0.03-0.1
Extremely low	-	<0.03

GEOTECHNICAL PROBLEMS

VARIABLE WEATHERING PROFILE

A highly variable weathering profile is characteristic of many sites on Precambrian rocks, with rapid variations in depth to bedrock, from surface outcrop to residual and extremely weathered materials occurring to depths in excess of 20 m below surface. This can have a major influence on foundation design for major structures and excavation conditions for road cuttings, basements etc. In particular, foundations or cut-offs for dams in the Darling Range have been influenced by the variable foundation conditions and depths (Bulley and Wark, 2003 this volume).

Preferential, deeper weathering along the contact zones between dolerite dykes and the surrounding granitic country rock is common. Contact zones are commonly indicated in the field by the presence of marri and tuart trees (Gordon, 1999), with the deeper soils and the presence of groundwater. Sheet joints can likewise be subject to preferential weathering and water movement, which can have significant effects on foundations for large structures such as dams.

EXPANSIVE CLAYS

Highly plastic and potentially expansive or reactive clays are commonly associated with residual soils derived from dolerite dykes and their contact zones with the adjacent country rock. Cracking of masonry structures is a fairly common occurrence in the Hills suburbs near Perth. A number of case studies examined (McInnes, 2003, Davenport, pers. comm. 2003) indicate several common factors are involved in cases where severe cracking has occurred. These include:

- the presence of clays derived from the weathering of dolerite dykes
- altered drainage conditions, e.g. surface cut-off drains and sub-soil drains installed up-slope
- the presence of trees (particularly gums).

The liquid limits of the doleritic clays were typically 60-80% with corresponding plasticity index of 40-60%. These plotted close to the U-line on the Casagrande plasticity chart and indicate a strong presence of montmorillonites. The shrink-swell index (I_{SS}) for the case studies typically varied from around 4% up to 6.6% for the high plasticity clays (CH).

The severity of cracking seems to vary depending on circumstances, however crack widths from 25-30mm to 70-80 mm were noted in the above cases. The common factors on the sites examined were:

- the presence of dolerite dykes
- blue gum trees in the immediate vicinity of the houses
- variable thickness sand pads (typically between 0.3 m and 0.6 m, although in one case it was 3 m).

Whilst each situation is unique, it would appear that preventative strategies may include:

- appropriate structural design of slabs and foundations (AS 2870-1996)
- structural articulation
- good drainage conditions and paved areas around buildings to maintain a constant soil moisture content
- avoidance of gum trees.

HALLOYSITE

The clay mineral halloysite is known to exist in the residual soils derived from the gneissic rocks of the Darling Scarp (Lilly 1979, Marcos 1984). Halloysite is a lattice mineral of tubular form and belongs to the same group as kaolinite (Blight, 1997). Its presence is indicated by unusually high sample moisture contents, coupled with much lower than average dry densities or by a difference between moisture content determinations carried out at low temperature (approximately 45°C) and high temperature (105°C). These unusual properties are due to the loss of water molecules from the crystal structure of the clay as the sample is heated during testing. This results in a greater weight change in the sample than would ordinarily occur when only the water from the pores is evaporated during the drying process. The presence of halloysite in the residual soils does not appear to impact on the shear strength or compaction characteristics of the soils and will have little or no impact on the design or implementation of the earthworks. It can however cause problems in the interpretation of compaction control testing.

SLOPE STABILITY

Slope failures in the transported and residual soils overlying the bedrock are a common feature of the granitic terrains east of Perth, and a number of case histories are on record. The slope failures are often related to an elevated or perched groundwater table, deep weathering of the bedrock or the presence of dolerite dykes.

Failure of a steep road cutting on the access road to Canning Dam (Lady McNess Drive) occurred in August 1999, following a period of heavy rainfall. The failure consists of a rotational slide (with a curved failure surface) that occurred in a cutting up to about 5 m high and along a front of about 20 m. The failure occurred in residual dolerite soils, which consist of yellow brown, wet, highly plastic sandy clay containing large dolerite corestones up to about 2 m in diameter. The top of the slide was defined by an arcuate, sub-vertical tension crack about 20 m back from the toe of the slide. Vertical displacement of about 0.5 m occurred along the tension crack. Water from surface run-off and rainfall was seen to be collecting in tension cracks and this initiated further movement of the slide.

The recommended remedial works involved battering back the crest of the road cutting and replacing the toe with a high strength, free draining rockfill material in order to provide lateral support to the slope.

The spillway approach channel and right abutment areas at Wungong Dam near Perth have a history of slope instability and landslides, which resulted in delays and extensive remedial measures during construction in the period 1976 to 1979. A major portion of the upstream side of the cuttings in the spillway approach consists of an existing landslide. This has been widely reported on previously (e.g. Marcos, 1984; Lilly, 1986; Fell et al., 1992). The basal failure surface of the slide in the foundation area consisted of micaceous clayey silt, probably derived from a weathered and sheared basic dyke.

The deepening and raising of an existing small dam in Stony Brook near Roleystone caused a significant sliding wedge failure in clay overlying granitic rock. Shallow groundwater flow was present down the valley in which the dam was situated. Consequently, significant tension cracks developed across the valley for a distance of about 100 m upslope from the dam. Remedial work involved filling in the deepened section and removal of the raised section. It would appear that the area has stabilised some fifteen years on. Further instability has occurred in cuttings for dams in the area immediately downstream.

COLLAPSE OF RESIDUAL/TRANSPORTED SOILS

Collapse settlement of residual and transported soils, particularly those derived from granitic rocks, has been widely reported in various parts of the world (e.g. Blight, 1997; Schwartz, 1985) and also in Western Australia (Water Authority, 1990). Collapsing soils exhibit a decrease in volume (or collapse) on wetting under constant load. A collapsing soil can have high strength and low compressibility at low moisture content, but become compressible with increasing water content. Weathering and leaching of acid igneous rocks, particularly quartz rich granitic rocks, can result in the formation of clayey or silty sandy residual soils with an open grain structure and a high voids ratio. In addition, sandy colluvial or alluvial soils overlying granites are also commonly subject to collapse settlement. Typically, collapsing soils have a skeleton of sand sized quartz particles that have a colloidal bridge of clay and silt sized particles, which break down on wetting.

There is little recorded data of damage to structures as a result of collapse settlement in the Darling Range near Perth. This is possibly due to the generally low quartz content (and high feldspar content) of the granites in the region and a correspondingly lower potential for collapse (as the skeleton of quartz particles is not present following weathering). However, collapsing soils (with a characteristic open grain structure) have been identified in the residual and transported materials in the region and their possible presence should therefore be assessed as part of any site investigation. Identification of collapsing soils is carried out by visual inspection of the soil profile and groundwater conditions and by implementation of the simple 'sausage' test (Jennings and Knight, 1975) in the field. Further assessment can be carried out by a range of laboratory tests, including the index properties of the soils. The in situ dry density of the soil provides a rough indication of collapse potential, with dry densities in the range of about 0.9 t/m^3 to about 1.5 t/m^3 indicating a potential susceptibility. Collapse potential can also be determined by the double oedometer test (Jennings and Knight, 1975) and single oedometer test (also known as the collapse potential test, in which the soil sample is soaked at an applied load of 200 kPa).

CORESTONES

The presence of corestones of hard granitic rock or dolerite within residual soils can present engineering problems in the Darling Range. Corestones display spheroidal weathering features and are formed by preferential weathering of joint bounded blocks of fresh to slightly weathered rock (e.g. Fell et al., 1992). Corestones can form significant obstructions in foundation excavations for buildings or in cut-off excavations for dams. Extensive zones of corestones were encountered in the cut-off trench and embankment foundation excavations on the lower left abutment at North Dandalup Dam (Water Corporation, 1999). The corestones varied in size from 0.5 m to in excess of 4 m and consisted of fresh to moderately weathered rock. The corestones were surrounded by extremely weathered material and had to be removed from the excavations by local blasting and additional excavation, to expose the underlying undulatory, slightly weathered to fresh bedrock surface. This resulted in delays to the construction programme and deeper excavations than originally anticipated.

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