APPENDIX 1: LITERATURE REVIEW

'THE EFFECT OF SOIL AND WATER ON SLOPE STABILITY'

CONTENT PAGE

Chapter A1: THE EFFECT OF SOIL AND WATER ON SLOPE STABILITY

A1.1 Introduction

Characterisation of potential regions for slope failure is a complicated and often uncertain process due to the great variety of slope morphologies, slope geology (Gerrard, 1992), and the effect of water on soil moisture and soil properties. Because of the complexity of the slope erosion system, large numbers of slope stability studies have been carried out. Norton and Smith (1930) were amongst the first to recognise an inverse relationship between slope angles and the textural B-horizon; and later identified a correlation between slope and soil structure, texture and consistency.

Technological development has since included improved methods of identifying and describing properties, which influence land stability. Three main factors influence slope stability: 1) gravity and therefore the gradient of the slope; 2) troublesome earth materials and the occurrence of triggering events; and 3) water and the hydrologic characteristics of the slope (Murch et al, 1995). This chapter considers a number of models that have been introduced to make correlations between soil characteristics and slope stability. The effects of water on sediment strength, and of how such changes can be calculated in terms of increasing the likelihood of failure, are also described.

The term 'soil' in this paper is not restricted to the usual definition of the surface layer. Instead, soil means particulate matter including clay, silt, sand or gravel (essentially unconsolidated, or lightly consolidated material, without cement). Terminologies associated with soil mechanics referred to in this paper are defined in table A1.1.

Table A1.1: Terminology discussed in text

Term	Definition
Shear stress (τ)	The gravitational force applied to a body of material that causes movement parallel to slope.
Shear strength	The maximum resistance of soils to shear stress.
Angle of Internal friction (ϕ)	The angle between the normal and the contact surfaces of two bodies, and the direction of the resultant reaction between them, when a force is just tending to cause relative sliding (Walker, 1991).
Cohesion (c)	The mutual attraction that exists between fine grained particles, tending to hold them together as a mass without the application of external forces
Friction	The force between particles that supplies strength to the material
Normally consolidated clays	Clay which at no time in its history has been subject to pressure greater than its existing overburden pressure.
Over consolidated clay	Clay which during its history has been subject to pressure greater than its existing overburden pressure.

A1.2 Sediment strength

The nature and extent of forces acting on slopes and the extent of slope stability is influenced by such inter-related variables as geology, slope gradient, climate, vegetation, hydrological characteristics and time (Murch et al., 1995). Although slopes often appear stable and static, they are in fact, active parts of the dynamic, evolving pattern of landscape formation (Keller, 1992). Slope stability is commonly expressed by equations involving the critical shear stress required for movement and the angle of response (Ulrich, 1987). As illustrated in figure A.1.1 (Lowe, 1966), steep slopes are generally more prone to failure than flat slopes due to the topographically induced gravitational shear strength. Two opposing forces act on a body at rest on a slope: shear stress and shear strength (Murch et al., 1995). In general, steepening slope gradients reduce the shear strength by changes in cohesion, pore pressure and normal stress, thus allowing the body to move (Carson and Kirby, 1972).

A1.2.1 Shear stress

The stress that controls changes in the volume and the strength of soil is known as the effective stress. When a load is applied to a saturated soil it will be carried by the water in the soil voids (causing an increase in pore water pressure) or by the soil skeleton in the form of grain to grain contact (Smith, 1971). Thus, stress is a function of particle friction and weight (mass x gravity).

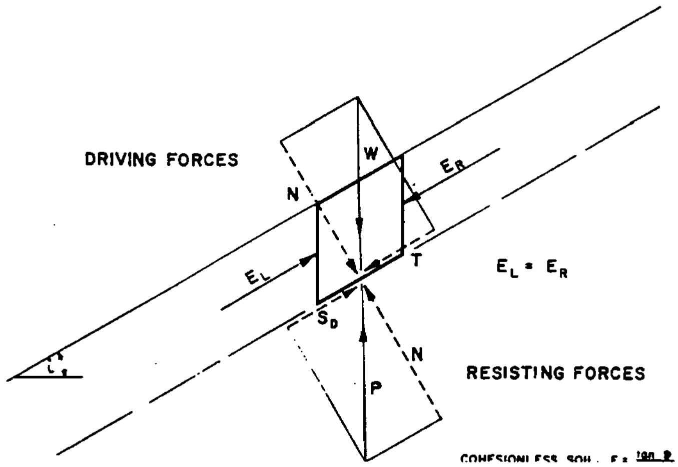


Figure A1.1: The force acting on a typical sliding mass. For equilibrium to be reached force such as Er and El must be equal, P must equal and oppose the weight force (W). The tangential component T, of the weight force W, must resist the developed shear strength, Sd. Where ϕ is the angle of internal friction and i is the slope. (Source: Lowe, 1966)

A1.2.2 Shear strength

Shear strength is the internal resistance of soils to movement (Murch et al., 1995). Resistance to shear is made up of two parts: particle friction and cohesion. Frictional resistance varies with the level of normal stress applied on the shear plane, whereas cohesive resistance is assumed to be independent of the applied stress, ie it is a constant value (Smith, 1971). The strength envelope of a soil can be expressed by the Mohr-coulomb equation:

$$\tau = c + \sigma \tan\phi \qquad \text{equation 1}$$

τ is the shear stress at failure, σ is the normal stress on the shear plane, c the cohesion and ϕ is the angle of internal friction (Bryant, 1993). This equation states that shear stress will equal cohesion when no normal stress is acting on the shear plane. If shear strength exceeds shear stress, movement will not occur. If failure has occurred previously, the shear strength will be reduced resulting in residual strength, not peak strength.

A1.2.2.1 Cohesive soils

Cohesive soils exhibit inter-particle attraction and possess inherent strength due to surface tension of capillary water. Most cohesive soils contain about 10 % or more of clay particles (Hail, 1977). Differences between the properties of cohesive clays and non-cohesive soils (< 10% clay) are outlined in Table A1.2. The level of compaction of cohesive soils is important, because slightly compressed soils (normally consolidated) have a high water content.

In contrast, highly compressed clays (over-consolidated clays) have much lower water carrying capacities. The compaction process gives stability to materials on slopes (Bryant, 1993). The friction angle for cohesionless soils increases by 6 to 8 ° from loose to dense particle arrangements (Bell, 1992). Differences between clays in these two states are often paralleled by being present with non-cohesive soils in their loose and dense states respectively (Keller, 1992). The sediment strength of cohesive soils figure A1.3 is much less then that of gravel and sand soils, due to Vander Waal-type bonding (Bryant, 1993). Therefore the angle at which the sediment are stable is much lower. This angle is known as the angle of response (Murch et al., 1995)

A1.2.2.2 Frictional Forces

Frictional forces resist shear stress and contribute to sediment strength, through the interaction of individual grains within the sediments (Montgomery, 1997). Frictional resistance is a function of density, size and shape of sediment particles, combined with the level of particle compaction (Keller, 1992). Since most soils are mixtures of coarse and fine-grained particles, soil strength is usually the result of both cohesion and internal friction.

Table A1.2.1: Selected engineering properties of soils

	Soil Classification	Strength	Permeability	Angle of internal friction (ϕ)	Cohesion (c) (kN/m^2)	Volume changes function of activity	Liquid limit	Plasticity limit	Maximum slope angle	General Use As Construction Material
Gravels	well-graded gravel	very high	high	34 35	-	very small	-	-	10 - 15	excellent
	poorly graded gravel	high	very high		-		-	-		good
	silty gravel	high	low		-		-	-		good
	clayey gravel	high-medium	very low		-		35-50	-		good
Sands	well-graded sand	very high	high	32 – 42	-	small	-	-	7	excellent
	poorly graded sand	high	high		-		-	-		fair
	silty sand	high	low		-		-	-		fair
	clayey sand	high-medium	very low		< 75		< 35	-		good
Silts	silt	medium	low	32 – 36	75		24 - 35	14 – 25	5	fair
	micaceous silt	medium-low	low							poor
	organic silt	low	low							fair
Clay	silty clay	medium	very low		150 – 75		< 35	Low		good-fair
	high plastic clay	low	very low		300 - 150	high	70 – 90	Very high	5	poor
	organic clay	low	very low				35 - 50	Intermediate		poor

Source: Keller, 1992; Smith, 1968; Mitchell, 1976; Smith, 1968.

A1.2.3 Soil Types

In general each soil type exhibits different properties and can be divided into four main groupings according to structure and composition: (1) gravels, (2) silts, (3) sands and (4) clays (see figure A1.2).

Coarse grained granular soils and, to some degree sands lack cohesion and rely on densely packed interlocking grains to create frictional resistance at the grain contacts. This results in a large ϕ value, when compared to clay rich soils, thus giving high strength. The presence of water in the voids of granular soil does not usually produce significant changes in the value of internal friction. However, if pressures develop in the pore water there may be changes in the effective stresses between particles, and shear strength may be reduced. If the pore water can readily drain from the soil mass during the application of stress, granular material behaves as it does when dry.

Young (1972) noted that the friction angle for pure clay is as low as 5°, but increases with the inclusion of coarser grained particles. Soils composed primarily of gravels may be stable at angles as great as 15°, providing the matrix is not made up of clay. Even the largest friction angle for clay minerals is much less than those for cohesionless soils, which are generally in the range of 10 to 15 degrees (Mitchell, 1976). Consolidated rocks have much greater friction angles, e.g. sandstone >21°.

However, the mineral and particle size distribution in itself is only part of the equation. As shown in figure A1.2, other essential properties are the liquid limit and the plastic (Atterberg) limit. In general, the greater the quantities of clay minerals in soil, the higher the plasticity, and the greater the potential for shrinkage and swell. The lower the porosity the higher the compressibility, the higher the cohesion and the lower the angle of internal friction. These properties are exhibited, primarily, because water is strongly attracted to clay mineral surfaces and promotes plasticity: whereas the non-clay minerals have little affinity for water and do not develop significant plasticity, even in a fine grained form. It is probable, therefore, that most soil water is associated with the clay phase (Smith, 1971).

The liquid limit is the moisture content of a soil; above which it behaves as a fluid and below which it behaves as a plastic. The Atterberg limit defines the plastic limit of clay below which, at the shrinkage limit it becomes fragmented and crumbly. The characteristic positions of organic, inorganic silts and clays, with reference to the level of activity (A line) figure A1.2 have been well established (Mitchell, 1976). Activity is a measure of soil susceptibility to changes in exchangeable cations and pore fluid composition.

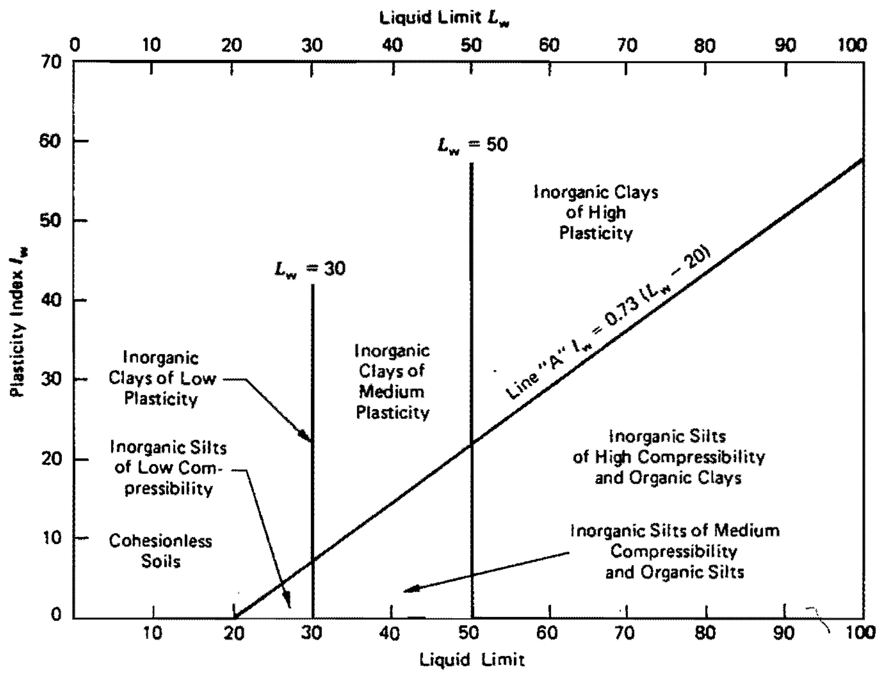


Figure A1.2: Atterberg Plasticity Chart (Source: Mitchell, 1976)

A1.3: The effect of water on soil strength

Water is present in most rocks and sediments near the Earth's surface, and strongly influences the effective stress states of soils (Iverson & Major, 1987). Soil strength is generally reduced by water content and can result in slope instability (figure A1.3). Marshall et al. (1996) proposed that cohesion is weakened as water content is adsorbed into the soil structure. However, increasing the water content changes the load and the gravity component may be more important.

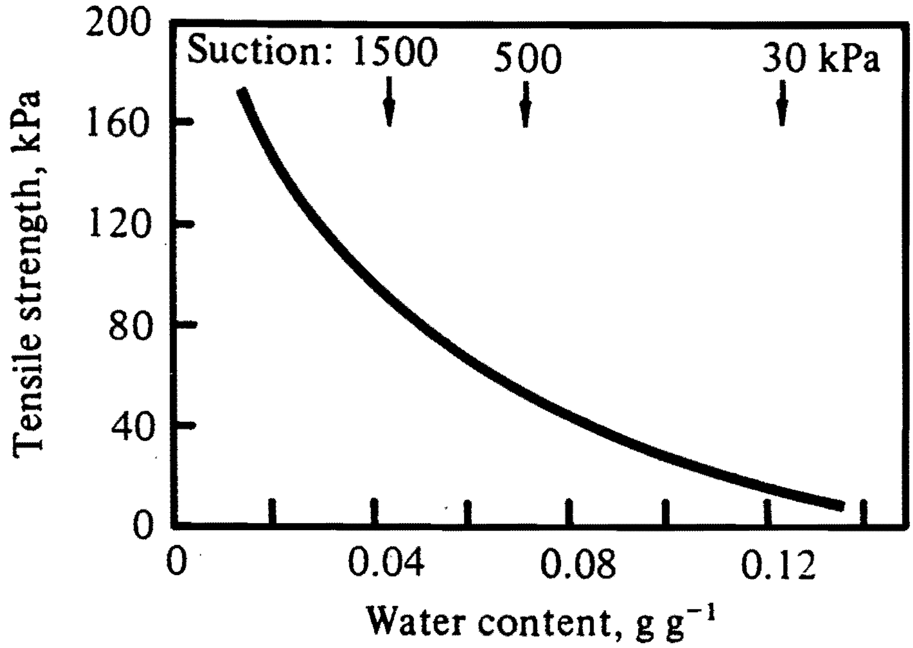


Figure A1.3: Effects of water content on the cohesive strength of soil (source: Marshall et al., 1996).

The addition of small quantities of water to dry (unsaturated) soils increases adhesion and the soils become plastic due to the presence of moisture films between grains (Montgomery, 1997). Thus shear strength, due to chemical bonding (Van der Waals bonds), is greater than shear stress. In contrast, the saturation of soils decreases shear strength due to particles losing contact, because of increases in pore pressure (Keller, 1992; Terlien, 1997), and hence loss of sediment strength. Slope failure may also occur under self-weight, if sediments are saturated.

Table A1.3: Descriptions for movement types

Classification	Description
Fall	A is a mass, which is detached from a steep slope or cliff, and descends to a lower surface. The moving mass travels mostly through the air by free falling (Eckel, 1958).
Topple	The block rotates forward about a pivot point, under the action of gravity, without collapsing. Movement is generally rapid.
Slide	Consists of shear strain and displacement along one or more surfaces. Movement results from failure along one or more failure planes.
Lateral spread	Lateral extension accommodated by shear or tensile fracturing. The failure can involve elements of rotation, translation and flow. Movement generally starts suddenly and proceeds rapidly Telfer, 1988).
Flow	Flow has the appearance of a body, which behaves as a fluid when the force caused by water is significantly large; any deformable material will flow. Movement is generally rapid, with gravity as the primary reason for movement.

A1.3.2 Adsorption by soils

A substantial amount of movement is associated with the expansion and contraction of soils as the result of adsorption (Young, 1972). Adsorption in this context is the process of taking up water at the surface of soil particles, thereby changing their effective volumes. Such volume changes are caused by chemical attraction and addition of water layers into the chemical structure of sediments (Keller, 1992). This process is particularly common in clay rich sediment, where water molecules are inserted between submicroscopic clay plates that have high plasticity indices as illustrated in figure A1.5 (Murch et al., 1995). Sediment expansion due to water drastically reduces the shear strength of soils, and often contributes to slope movement.

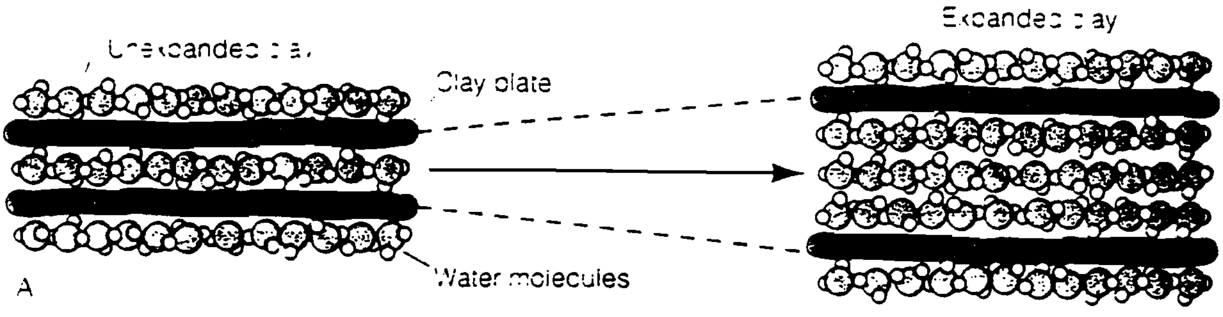


Figure A1.5: Diagram illustrating the expansive nature of clays (Murch et al., 1995).

Thomas, in 1928, demonstrated that the type of clay mineral was also an influencing factor (in Marshall et al., 1996). Montmorillonite is the most expansive clay mineral due to its expanding crystal lattice, which adsorbs more water at a given value of e/e_0, expanding by as much as 15 times its original volume (Keller, 1992). In contrast, kaolinite has relatively large crystals and thus a smaller surface area available for adsorption. Illite has similar crystal dimensions to montmorillinite, but does not exhibit the expanding lattice, and has been categorised between montmorillinite and kaolinite in terms of adsorption potential (Marshall et al, 1996). The bonds between the adjacent silicate layers of illite are affected by the potassium ions, thus resulting in greater strength and tighter packing (Smith, 1971). These effects of clay properties on adsorption are illustrated in figure A1.6.

The transition from open to compact arrangements causes a sudden loss in residual shear strength: montmorillonite has the lowest value ($\phi_R = 5$), illite ($\phi_R = 10$) and kaolinite the highest value ($\phi_R = 15$) (Walker & Fell, 1987). The values for ϕ_R are generally related to particle shape and inter-particle bonding hence, the ϕ_R angle decreases with increasing liquid limits. However, not all clays have plate like structures, amorphous clay minerals have granular structures which lead to much higher residual friction angles; commonly greater than 25 ° (Walker & Fell, 1987).

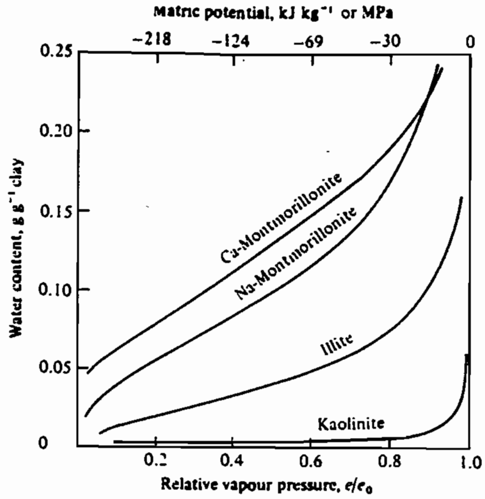


Figure A1.6: Adsorption of water vapour by different clays (Source Marshal et al., 1996).

A1.3.3 Hydro-compaction of soils

A decrease in the volume of expansive clays (drying out) is referred to as hydro-compaction. This occurs when water is removed from the soil structure, leaving behind a porous medium. At low water contents, ionic hydration can be a strong force which tends to separate particles (Graham, 1964). Definite cracks are formed in the soil during the contracting phase (Barlow & Newton, 1975). In general, the swelling and shrinkage properties of clay minerals follow the same pattern as their plasticity properties. The more plastic the mineral the greater the potential for swell and shrinkage.

The obvious mechanism for this process is the presence of expanding clays under the influence of seasonal inequalities in rainfall. Each time expansion takes place, the soil tends to be pushed outwards at right angles to the slope, and the soil mass is weakened. On shrinkage, the soil settles back into its original state, but tends to be moved down slope by gravity. Creep rates are generally proportional to the sine of the angle of the slope (Graham, 1964). It has been suggested, however, that expansion and contraction does not always occur normal to the slope because up slope movements have been noted in practical experiments. Such changes in water content change the load of the soil on a slope: saturated soil, by weight alone may cause slope failure due to the increase of shear stress.

When a layer of soil is loaded, some of the pore water is expelled from its voids, moving away from the region of high stress (hydrostatic gradients are created by the load). Terzaghi (1943) showed a relationship between the unit load and the void ratio for a sediment by plotting the void ratio, e, against the logarithm of the unit load, p (Bell, 1992). The shape of the resultant curve indicates the stress history of the sediment. The curve is linear for normally consolidated clays and curved for over-consolidated clays. Over-consolidated clays are considerably less compressible than normally consolidated clays.

A1.3.4 Liquefaction

The transformation of sediments from solid to liquid state is called liquefaction (Murch et al., 1995). The point at which transition takes place from a solid to a liquid state is called the liquid limit and is dependent on sediment characteristics, as illustrated in figure A1.7. Materials with high liquid limits, such as clay, remain plastic over a broad range of water content. The strength or shear resistance of the soil at the base of a slide is largely determined by the angle of slope down which sliding may occur (Hail, 1977).

Hutchinson (1968) noted that loss of shear strength due to high water-soil ratios leads mass transport, not mass movement because the soil particles are contained within stream flow and not in contact with other soil particles. As sediment concentrations increase progressively from a viscose to a plastic flow, the liquidity index falls well below the liquid limit.

The process of soil liquefaction results in changes to granular soil assemblages, due to the disturbance of the internal structure of soil by water. By converting the soil into a flowing fluid mass there is no minimum angle for flow (Murch et al., 1995). Liquefaction results in sediments flowing rather than sliding along a failure surface (Iverson & Major, 1996). Static liquefaction conditions are expressed as: $z = \cos [(\lambda + \phi) + (\theta - \phi)] = 1$. Hydraulic gradients greater than 2 are generally required to cause liquefaction, which cannot take place if water does not move towards the surface (Iverson & Major, 1986).

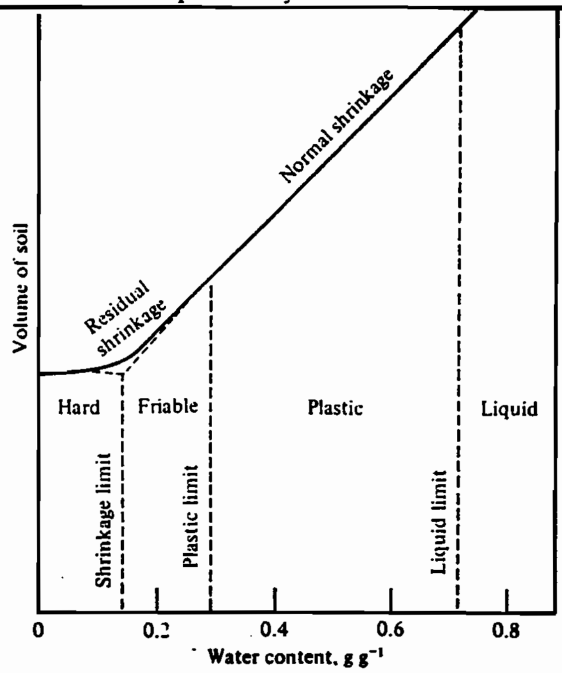


Figure A1.7: Consistency state and shrinkage stage of remoulding soil illustrated by values appropriate to soil high in clay content. (Source: Marshall et al., 1996).

A1.3.5 Mathematical modelling for slope failure

Various analytical techniques exist for assessing slope stability. The reliability and quantity of the soil data, knowledge of the slope geology and the consequence of failure (Walker & Fell, 1987) should always govern selection of particular method for analysis. Analytical results are usually presented in the form of safety factors, where the safety factor is the relationship between the ratio of shear resistance to shear force (Young, 1972). Examples of the most widely used methods for predicting slope failures, and assessing risk are outlined in table A1.4.

Two principal methods are used to measure the shearing resistance of soils: (a) direct shear tests and (b) the triaxial test. The triaxial test is the most common means of obtaining the shear strength parameters, c' and ϕ' (Walker & Fell, 1987). It involves subjecting a cylindrical soil sample contained within a rubber membrane to an axial load while confined laterally by water or air at a pressure (σ_3). The load is increased until the soil fails at an axial stress (σ_1) (Marshall et al., 1996). Illustrated in figure A1.8, when equilibrium is reached a Mohr circle can be drawn through the two points (Habibi, 1983).

The envelope of Mohr's circles is the curve, which in soils, is the Coulomb's line, defined by Huorslev's Law for cohesive soils: $\tau = c' + (\sigma_n - u)\tan\phi'$: in cohesionless soils, this curve is rectilinear.

Table 1.4: Types of stability analysis

Types of analysis	Formulae and remarks
Method of slices (curved slip surface)	FELLENIUS METHOD **$Fs = \sum\{c'b\ \sec\alpha + \tan\phi\ (W \cos\alpha - u)\} / \sum W \sin\alpha$** Where W is the mass and α the inclination of the base of any vertical slice, u is pore pressure. *Remark*: Assumes soils are saturated, only applies to circular slip surfaces as being the only cause of failure, pore pressure is not considered. *Reference:* Yong & Selig, 1982; Walker & Fell, 1987
Circular slip method	BISHOP'S SIMPLIFIED METHOD **$Fs = \sum\{[c'b + W(1-r)\tan\phi'](1/m)\} / \sum W \sin\alpha$** Where u is the pore pressure *Remark*: Only applies to circular slip surfaces, uses average pore water. *Reference*: Yong & Selig, 1982; Habib, 1983.
Non-circular slip surface	JANBU'S SIMPLIFIED METHOD **$Fs = f \sum\{[\ b\ c' + (W - ub)\tan\phi]\ (1/\cos\alpha)\} / \sum W \tan\alpha$** Where f is a function of the curvature of the slip surface and the type of soil *Remark:* Only applicable to slip surfaces of arbitrary shape *Reference*: Telfer, 1988
Homogenous	TAYLOR'S METHOD **$Fs = \sum(cl) / \sum(W \sin\alpha)$** *Remark*: Restricted to clays *Reference:* Telfer, 1988
Infinite slope analysis	**$Fs = c' + z\cos^2\beta\ (\gamma - m\gamma_m)\tan\phi' / \gamma\ z \sin\beta \cos\beta$** Where z is the depth of slide, β is the limited inclination, γ unit weight of soil, γ_m unit weight of water *Remark*: An extremely simple model. The effective cohesion is less than ten it is assumed to be zero. Ground water is taken to be parallel to the ground *Reference:* Hail, 1977; Walker & Fell, 1987

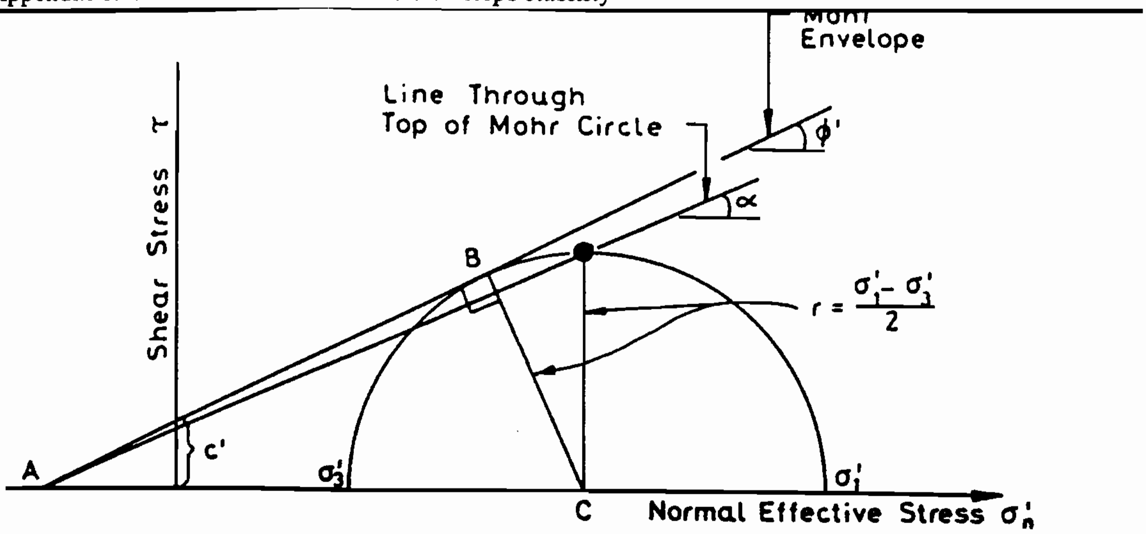


Figure A1.8: Method of obtaining the failure envelop from measurements by triaxial compression. (Source: Walker & Fell, 1987)

Studies by Henkel and Skempton (1955) and Skempton (1964) appeared to demonstrate the accuracy of the infinite slope method where a slide is long compared with its depth. (Hail, 1976). However, more recent works (eg Hutchinson, 1967 and Hail, 1976) suggest that field and laboratory correlations by Skempton were fortuitous, because pore water pressure must be measured at the surface using piezometers. With tips carefully located on the base of the slide, and not estimated from observations of the level of standing water borings. Furthermore, the rings shear apparatus (Bishop et al., 1971) is thought to provide lower residual strength measurements than would be obtained from limited displacement of direct shear apparatus. The triaxial compression method (Marshall et al., 1996) is a more accurate technique.

Accurate and reliable predictions of stability cannot always be made on the basis of limiting equilibrium studies. The concept of limit equilibrium is not fundamental to phenomena concerning stability, but is only a device for determining the safety factors for a soil or rock mass. The state of critical or limiting equilibrium should not be confused with the concept of limiting equilibrium.

A1.3.5.1 Application to shallow and deep landslides

Reid (1994) found a direct correlation between brief periods of rainfall and shallow landslides. Deeper landslides were triggered by prolonged rainfall (> 200mm in 25 days);

this was later supported by Terlien (1997). Reid (1994) also noted that large rainstorms induced a wide range of slope movements, such as creep and solifuction movements, that do not require inclined slopes for movement (Kirkby, 1967; Reid, 1994). According to the principal of effective stress, landsliding may occur in response to locally elevated pore pressure along the failure surface. Prior to Terlien's investigation, such links between rainfall and landsliding were based upon statistical correlations or empirically fitted models which were limited by available data.

In the case of deep landslides on slopes possessing appreciable cohesion there is no single angle of stability, but a height angle relation as in the upper curve of figure A1.8. In general, for a given geology and climatic conditions, surface landslides occur on gentler slopes than deep landslides (Terlien, 1997). Two explanations have been proposed for the lower limiting angles for surface landslides: (1) the observed limiting angle for clay-dominated soils; this generally corresponds with stability conditions calculated by using the residual shear strength; (2) The relationship of deep slides to peak strength (Hutchinson, 1967), unless a deep failure had occurred previously. However, this explanation does not apply to soils that are made up of large portions of sand, gravel or stones. These soil types exhibit only small differences between peak and residual shearing strength. Equation 9 (from the infinite stability model) can be applied to shallow slides, provided that the angle of the failure plane is approximately equal to the slope of the ground surface.

During the early to mid 1980's, quantitative analytical processes were introduced to study the role of recharging ground water flow on the destabilising of slopes. Leach & Herbert (1982), Kenney & Lau (1984), and Reid and others (1985) focused attention on short-term fluctuations in the water table that may cause abrupt failures in static slopes (Hanegerg, 1991). Terlien (1997) later followed up such investigations to reach four main conclusions. Firstly, positive pressure heads are not capable of triggering landslides, but failed slopes are often located in such areas. Secondly, depths of failure depend on the geotechnical properties of the silt/sand content of the soil and the slope angle. Thirdly, failure will occur only when the soil becomes saturated from the surface to the depth of the potential slip surface (Terlien, 1996). Fourthly, the depth of saturation is dependent upon soil profile, the vertical soil moisture distribution prior to intense rainfall and the amount and intensity of rainfall. Terlien also recognised that perched water tables act as triggering mechanisms for landslides, where water is in contact with potential failure surfaces, thereby reducing frictional strength.

A1.3.6 Problems associated with water models

The first simplifying assumption made by Terzaghi in the 1950's is that slope failures are initiated, primarily, by water infiltration into hill slopes. However, although such infiltrations result in increased pore water pressure within the slope material, before pore pressure can be increased, capillary pores must be full of water and have sufficient volume to counteract soil suction (negative pore pressure).

The second assumption was that, for any given slope, a critical level of pore water pressure (u_{wc}) acting on a slope exists where the potential failure surface develops (Keefer et al., 1987). This assumed that the failure surface and piezometric surfaces are parallel to the ground surface, which is rarely the case.

A third assumption that there is no surficial run-off (i.e. that all rain falling onto the slope infiltrates), at least initially into a saturated plane above the potential failure plane. However, the total rate of drainage is proportional to the thickness of the saturated zone (Keller et al, 1987) and care must be exercised, however, when using the infinite slope model. The magnitude of ϕ'_r is often different in laboratory and field experiments, and appears to fall as the normal stresses increase. This occurs because the residual strength failure line is in fact a curve, and not straight. This is of fundamental importance on clay slopes, where landsliding occurs deep into the slope and the range of normal stress is large due to the amount of overlying sediments, so that a unique value of ϕ'_r will not apply. In this case large rather than minor landslides will move on flatter slopes.

A1.4 Conclusion

The stability of slope surfaces is dependent upon the factors affecting the slip surface. This conclusion appears to be dependant upon: strength parameters (c', ϕ') of the slope material; the height and inclination of the slope, the density of the slope material (which determines σ_n) and the distribution of pore water on the slope.

The models discussed in this literature review are constrained, primarily, by the number and variety of assumptions made by various authors to simplify the equations. However, while they provide locally practical and reasonably realistic data for calculating angles of response for particular soils, on a regional scale such generalisations are not without risk. No two-soil types are exactly the same and, the potential for failure must always be examined closely on a local scale.

Soil mechanics technology applied to the study of slopes is concerned primarily with processes that lead to slope failure by landsliding and with the stability analysis of the failure. However, much remains to be discovered before the degree of stability of any previously stable slope can be accurately predicted in either its natural state or after modification by natural or artificial processes.

APPENDIX 2: CLIMATIC RECORDS

BUREAU OF METEOROLOGY, ACACIA HOUSE

Rainfall data obtained from Acacia House and Temperature data from Tea Tree Bend (Launceston)

Table A2.1: Table illustrating the total monthly precipitation (mm) for the Windermere area (top no.) and the number of rain days (bottom no.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1927						58.5	81.4	132.4	54.5	51.4	22.8	123.2	
						13	*17*	*20*	*8*	*10*	*5*	*10*	
1928	58.8	93.3	47.8	98.7	42.6	67.9	117.5	82.9	116.5	158.3	47.3	14.0	945.6
	8	*11*	*7*	*11*	*8*	*11*	*16*	*16*	*25*	*21*	*15*	*4*	*153*
1929	71.9	41.6	35.7	219.9	60.2	148.3	93.7	109.0	30.6	46.9	75.7	77.0	1010.5
	14	*8*	*8*	*15*	*11*	*19*	*15*	*16*	*12*	*11*	*17*	*13*	*159*
1930	10.5	57.1	23.5	42.2	72.3	17.1	166.4	154.4	75.6	88.1	76.7	134.8	918.7
	5	*6*	*6*		*8*	*7*		*18*	*16*		*16*	*13*	
1931	14.6	25.0	176.6	66.2	252.6	244.1	132.0	83.7	122.4	26.1	54.1	0.0	1197.4
	12	*7*	*11*	*7*	*21*	*17*	*14*	*14*	*19*	*9*	*7*	*0*	*138*
1932	29.2	37.2	102.1	97.1	7.6	133.9	61.0	87.7	70.6	90.4	43.2	71.3	831.3
	5	*9*	*11*	*14*	*2*	*16*	*15*	*14*	*8*	*15*	*6*	*6*	*121*
1933	17.7	1.6	55.1	48.4	57.7	36.4	39.2	91.2	116.8	53.9	17.8	42.2	578.0
	7	*2*	*4*	*5*	*5*	*9*	*8*	*10*	*9*	*6*	*3*	*10*	*78*
1934	31.0	25.4	21.1	80.4	14.4	16.0	116.3	66.4	103.6	119.6	103.2	73.4	770.8
	4	*2*	*5*	*9*	*2*	*3*	*8*	*11*	*11*	*18*	*9*	*8*	*90*
1935	26.8	78.9	34.6	83.7	89.5	80.2	60.0	72.6	43.5	29.0	43.9	24.6	667.3
	5	*11*	*5*	*14*	*9*	*9*	*11*	*11*	*11*	*8*	*11*	*10*	*115*
1936	20.8	12.6	28.9	65.0	50.3	53.0	65.7	251.4	70.4	74.6	29.4	65.6	787.7
	4	*4*	*4*	*8*	*12*	*10*	*14*	*17*	*13*	*11*	*9*	*8*	*114*
1937	103.3	28.6	61.9	16.2	84.3	23.9	89.8	62.5	54.2	65.7	25.9	141.2	757.5
	7	*4*	*7*	*3*	*11*	*3*	*10*	*11*	*11*	*9*	*4*	*12*	*92*
1938	75.3	115.9	45.7	66.6	56.2	175.5	22.1	47.9	56.5	47.7	92.2	46.0	847.6
	6	*5*	*3*	*6*	*10*	*12*	*8*	*10*	*9*	*9*	*9*	*6*	*93*
1939	2.1	101.9	72.1	65.8	79.8	73.7	52.8	240.1	86.7	66.2	83.1	40.0	964.3
	3	*6*	*4*	*9*	*9*	*12*	*9*	*21*	*9*	*5*	*21*	*5*	*113*
1940	55.7	15.3	17.8	41.9	36.6	66.4	161.1	12.5	56.5	15.3	47.2	63.0	589.3
	6	*3*	*4*	*7*	*5*	*9*	*14*	*3*	*5*	*5*	*5*	*5*	*71*
1941	18.8	11.4	63.5	17.9	26.7	68.4	86.7	24.4	60.2	72.9	42.4	21.1	514.4
	4	*2*	*6*	*3*	*5*	*6*	*12*	*5*	*12*	*7*	*5*	*7*	*74*
1942	37.1	37.2	18.8	27.9	119.8	133.1	196.4	95.8	65.3	60.9	7.6	53.1	853.0
	4	*6*	*4*	*3*	*11*	*12*	*16*	*15*	*10*	*6*	*1*	*3*	*91*
1943	33.4												
	7												
1946		145.9	126.7	28.6	54.5	32.6	254.0	97.8	53.9	18.3	46.6	60.8	
			10	*6*	*10*	*6*	*17*	*13*	*8*	*10*	*9*	*9*	
1947	40.6	24.3	75.3	36.9	69.4	217.0	201.9	122.1	46.3	155.2	52.3	94.7	1136.0
	6	*3*	*11*	*4*	*9*	*16*	*16*	*16*	*11*	*16*	*5*	*12*	*125*
1948	8.7	36.4	19.3	33.0	86.9	63.5	69.0	61.0	83.7	64.9	67.5	49.2	643.1
	2	*5*	*5*	*8*	*11*	*9*	*15*	*12*	*11*	*14*	*9*	*10*	*111*
1949	42.3	69.7	47.0	12.7	89.8	44.6	41.8	43.3	31.3	149.7	97.9	22.3	692.4
	5	*7*	*5*	*2*	*8*	*7*	*11*	*12*	*9*	*19*	*16*	*6*	*107*
1950	52.3	45.7	24.9	24.9	59.0	25.4	47.8	60.5	68.3	108.8		44.7	
	9	*8*	*6*	*6*	*12*	*6*	*8*	*8*	*10*	*12*		*6*	
1951	0.0	26.4	16.5	97.3	78.5	27.0	120.7	80.2	45.2	67.1	73.8	39.9	672.6
	0	*4*	*2*	*11*		*7*	*21*	*13*	*11*	*10*	*10*	*7*	
1952	58.1	15.0	4.4	110.5	141.8	141.8	116.8	85.7	161.7	155.0	175.8	20.6	1187.2
	9	*5*	*2*	*8*	*12*	*16*	*13*	*13*	*18*	*17*	*12*	*4*	*129*
1953	67.1	2.3	14.8	47.1	109.8	163.4	149.8	96.1	56.9	86.4	51.0	68.8	913.5
	3	*2*	*4*	*6*	*10*	*16*	*15*	*15*	*12*	*13*	*9*	*11*	*116*
1954	22.9	99.0	35.3	102.8	56.1	65.7	109.1	118.1	55.0	33.3	54.4	45.0	796.7
	3	*8*	*7*	*8*	*7*	*16*	*16*	*14*	*7*	*8*	*8*	*9*	*111*
1955	26.8	71.9	12.0	110.3	107.7	94.1	114.1	242.6	83.6	172.0	79.7	81.7	1196.5
	9	*7*	*3*	*8*	*11*	*7*	*16*	*23*	*11*	*18*	*10*	*10*	*133*
1956	65.6	59.4	96.1	200.5	138.5	169.7	101.4	120.6	97.4	80.6	60.2	72.9	1262.9
	9	*4*	*6*	*10*	*7*	*14*	*13*	*16*	*9*	*14*	*8*	*10*	*120*

Table A2.1 continued

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1957	23.2	29.2	68.3	100.1	83.8	81.8	36.4	26.4	69.9	53.5	91.2	57.3	721.1
	3	*3*	*3*	*14*	*8*	*11*	*11*	*6*	*14*	*8*	*11*	*8*	*100*
1958	6.1	49.3	43.9	31.3	301.5	46.0	93.5	97.7	45.5	147.4	63.3	49.3	974.8
	2	*4*	*8*	*3*	*24*	*6*	*15*	*11*	*8*	*15*	*6*	*8*	*110*
1959	30.9	46.2	25.4	65.0	17.5	88.0	53.2	111.1	38.0	56.2	40.4	82.6	654.5
	5	*5*	*4*	*8*	*2*	*12*	*14*	*13*	*9*	*9*	*11*	*15*	*107*
1960	33.0	82.4	18.8	164.2	167.0	67.7	147.6	38.3	88.0	70.1	58.5	11.3	946.9
	4	*5*	*8*	*15*	*14*	*11*	*19*	*16*	*11*	*12*	*11*	*4*	*130*
1961	3.3	15.8	13.4	125.2	27.9	64.9	82.7	75.1	27.2	66.4	36.6	77.1	615.6
	2	*6*	*5*	*9*	*14*	*9*	*9*	*10*	*6*	*9*	*9*	*10*	*98*
1962	57.0	45.1	37.5	29.0	149.9	128.3	53.3	118.6	61.1	166.8	43.7	23.2	913.5
	6	*6*	*11*	*7*	*15*	*22*	*12*	*13*	*10*	*17*	*10*	*5*	*134*
1963	79.0	49.3	55.5	7.1	41.4	30.8	156.2	105.1	130.6	61.1	47.2	34.2	797.5
	10	*6*	*9*	*3*	*7*	*6*	*10*	*11*	*11*	*9*	*6*	*5*	*93*
1964	12.9	160.0	80.9	28.0	62.1	144.6	175.1	78.3	123.5	65.3	39.7	64.1	1034.5
	3	*11*	*6*	*6*	*8*	*15*	*17*	*8*	*12*	*10*	*5*	*8*	*109*
1965	6.2	1.5	39.4	87.6	129.0	46.6	68.3	45.7	88.1	49.5	58.2	58.2	678.3
	3	*1*	*7*	*9*	*15*	*11*	*7*	*11*	*7*		*8*	*8*	
1966	10.7	33.0	42.1	39.7	82.0	34.3	154.8	77.6	121.2	55.4	34.8	61.7	747.3
	4	*5*	*11*	*5*	*6*	*7*	*14*	*9*	*10*	*4*	*3*	*5*	*83*
1967	35.1	19.0	6.6	14.9	32.2	27.2	134.7	93.7	30.1	40.6	24.2	54.9	513.2
	4	*2*	*2*	*5*	*5*	*10*	*17*	*16*	*10*	*5*	*5*	*10*	*91*
1968	12.5	74.9	53.2	110.0	119.1	105.4	97.4	221.4	54.4	100.8	109.4	12.0	1070.5
	3	*3*	*8*	*19*	*13*	*8*	*12*	*19*	*11*	*12*	*12*	*3*	*123*
1969	58.4	127.4	35.3	46.5	150.1	24.1	121.7	86.1	64.3	65.1	56.9	39.7	875.6
	5	*11*	*8*	*9*	*11*	*9*	*18*	*18*	*10*	*6*	*12*	*7*	*124*
1970	74.8	46.2	55.3	91.9	67.5	96.6	131.1	178.1	66.1	55.2	64.3	121.7	1048.8
	8	*4*	*8*	*10*	*9*	*11*	*11*	*14*	*5*	*8*	*3*	*7*	*98*
1971	42.7	27.7	26.3	152.4	88.1	116.4	28.5	88.6	103.6	136.1	126.0	107.9	1044.3
	2	*2*	*3*	*9*	*3*	*9*				*4*	*4*	*3*	
1972	25.7	89.9	0.0	27.2	27.7	57.2	99.8	72.6	34.3	26.2	24.1	0.0	484.7
	2		*0*								*1*	*0*	
1973	74.2	20.1	8.9	131.1	74.9	216.9	162.6	40.1	117.9				
1974	46.0	30.4	6.6	72.1	97.8	70.0	180.0	69.6	176.0	65.2	89.6	149.2	1052.5
1975	3.3	44.0	51.1	25.2	95.4	35.0	113.4	234.5	101.4	87.0	106.8	45.8	942.9
1976	60.6	4.1	0.0	41.7	112.5	0.0	32.9	76.5	70.0	59.7	88.1	114.0	660.1
			0			*0*							
1977		74.2	104.0	9.0	96.3	65.8	72.3	98.6	47.8	29.0	30.0	3.0	
1978	31.3	88.9	36.5	77.5	72.2	72.8	116.3	84.7	88.0	58.2	73.1	54.6	854.1
1979	65.0	27.8	45.1	76.3	88.8	62.4	111.4	44.0	128.6	114.3	20.6	19.0	803.3
										6			
1980	28.6	21.4	42.0	134.2	52.9	66.7	121.2	104.0	86.8	44.8	32.8	39.2	774.6
	1	*4*	*6*	*3*	*8*	*5*	*3*	*4*	*5*	*3*	*2*	*1*	*45*
1981	24.0	18.0	44.6	33.6	57.2								
		1	*2*	*2*	*1*								
1986				88.4	105.8	31.6	137.2	83.4	66.2	120.4	35.4	57.4	
				13	*13*	*9*	*17*	*11*	*15*	*15*	*8*	*11*	
1987	64.2	11.6	44.2	19.8	101.2	61.0	109.4	39.6	16.4	40.6	83.6		
	9	*5*	*7*	*7*	*8*	*10*	*13*	*8*	*6*	*8*	*10*		
1988		13.4	0.2	39.4	156.7	112.4	141.5	71.2	89.8	82.2	96.4	79.4	
		2	*0*	*8*			*16*	*10*		*18*		*8*	

Table A2.1 continued

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1989	43.2	4.0	45.0	170.6	48.8	80.6	115.0	71.4	79.8	66.8	71.2	45.8	
	7	*3*		*11*		*13*	*14*			*11*	*6*		
1990	9.2	34.2	25.0	57.0	39.6	118.8	91.3	153.4	38.2	57.0	62.8	38.2	
	3	*7*	*4*	*8*	*5*						*6*	*8*	
1991	124.0	1.8	48.6	22.4	7.2	146.6	60.0	190.4	64.8	25.6	49.4	36.0	
	8	*1*	*10*		*2*						*8*		
1992	23.4	28.6	4.6	153.8	129.0	56.2	142.6	111.0	103.2	82.4	107.0	69.8	1
	6	*5*	*3*	*10*		*7*							
1993	35.6	59.0	24.2	21.2	84.6	45.2	103.6	76.4	71.2	83.8	86.6	135.6	
	8	*11*								*12*	*6*	*8*	
1994	57.0	23.6	5.0	36.6	92.0	57.0	59.4	37.2	9.6	52.3	64.0	11.4	
			2	*8*	*15*	*13*	*4*	*9*	*8*	*8*	*11*	*1*	
1995	83.2	39.4	19.0	60.0		112.4	100.4	60.8	68.2	54.0	40.2	54.0	
	9	*7*	*5*	*9*		*13*	*11*	*14*	*16*	*12*	*9*	*7*	
1996	151.4	73.2	56.6	59.4	14.6	90.8	86.8	131.6	112.7	68.2	38.0	17.4	
	8	*7*	*8*	*11*	*6*	*13*	*16*	*22*	*17*	*14*	*6*	*5*	
1997	91.2	25.0	17.8	25.8	167.0	37.6	44.2	56.2	104.6	28.9	42.8	13.0	
	11	*4*	*9*	*6*	*12*	*9*	*7*	*13*	*18*	*12*	*8*	*6*	

Summary of Total Monthly Precipitation using available data between 1927 and 1997

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	A
Mean	42.0	45.5	40.5	68.5	85.2	81.6	104.8	96.7	75.5	74.1	60.8	56.2	
Median	34.3	35.3	36.1	59.4	80.9	66.7	103.6	84.7	69.9	65.3	54.4	53.1	
Highest	151.4	160.0	176.6	219.9	301.5	244.1	254.0	251.4	176.0	172.0	175.8	149.2	
Lowest	0.0	1.5	0.0	7.1	7.2	0.0	22.1	12.5	9.6	15.3	7.6	0.0	
Number	60	62	62	63	62	63	63	63	63	62	61	61	

Summary of Rain Days using available data between 1927 and 1997

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*A*
Mean	*5.6*	*5.2*	*5.7*	*8.0*	*9.2*	*10.3*	*13.0*	*12.9*	*10.9*	*10.7*	*8.2*	*7.2*	
Median	*5.0*	*5.0*	*5.5*	*8.0*	*9.0*	*10.0*	*14.0*	*13.0*	*10.5*	*10.0*	*8.0*	*7.5*	
Highest	*14*	*11*	*11*	*19*	*24*	*22*	*21*	*23*	*25*	*21*	*21*	*15*	
Lowest	*0*	*1*	*0*	*2*	*1*	*0*	*3*	*3*	*5*	*3*	*1*	*0*	
Number	*52*	*52*	*54*	*52*	*49*	*52*	*49*	*49*	*48*	*51*	*53*	*52*	

Table A2.3: Maximum and minimum temperature range for the Launceston area, including long term averages

Maximum Temperature from 9am (°C)
Minimum Temperature to 9am (°C)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg	Max	Min	Total	Nbr
Jan 1998	27.0	27.3	24.4	23.8	24.8	25.6	26.6	27.4	26.4	31.5	29.8	30.2	30.4	25.4	25.4	24.6	31.3	30.7	22.4	25.2	25.8	27.8	24.0	23.7	21.6	22.9	27.4	17.9	19.3	22.4	21.2	25.6	31.5	17.9		31
	15.6	16.3	9.9	8.0	11.6	10.2	10.7	15.0	11.7	15.6	16.0	18.0	19.2	20.3	14.5	13.8	10.6	15.2	14.3	15.3	16.0	13.5	14.7	10.7	13.8	12.4	10.5	14.9	7.4	17.2	9.4	13.6	20.3	7.4		31
Feb 1998	26.2	29.2	23.6	23.4	28.4	27.4	28.2	21.0	26.6	22.7	25.5	22.0	21.0	23.8	21.5	19.1	20.4	22.6	20.9	19.6	19.8	18.6	21.7	24.0	28.2	31.0	19.2	22.5				23.5	31.0	18.6		28
	9.4	13.7	9.5	9.9	12.1	12.2	15.1	15.8	9.0	14.3	13.5	17.0	11.3	13.0	13.5	11.2	6.0	12.4	13.3	10.8	7.1	11.0	7.5	9.7	12.7	12.1	13.1	4.4				11.5	17.0	4.4		28
Mar 1998	25.5	25.3	27.7	23.2	18.1	21.4	20.8	27.0	28.8	26.2	27.7	32.3	23.2	20.3	16.7	20.5	21.3	24.6	22.4	21.6	23.4	26.7	17.9	18.6	23.2	23.1	19.9	19.5	21.0	20.1	16.5	22.7	32.3	16.5		31
	8.0	11.2	12.2	15.6	8.3	11.7	9.2	6.3	6.4	8.2	8.7	8.9	13.7	13.0	4.4	5.2	7.7	8.0	9.3	10.6	8.9	13.8	16.4	4.7	7.5	7.5	9.5	11.5	8.4	9.5	11.0	9.5	16.4	4.4		31
Apr 1998	18.4	21.2	22.0	21.1	21.9	21.6	19.6	21.2	18.7	21.2	17.0	15.0	15.6	18.3	19.2	16.9	19.5	19.2	15.2	16.2	18.0	18.4	15.3	15.6	15.9	16.7	16.0	15.3	16.6	14.1		18.0	22.0	14.1		30
	6.5	5.0	10.0	3.9	9.5	5.4	7.0	9.2	2.0	3.4	6.0	9.7	11.7	5.7	5.9	2.9	6.4	4.5	6.1	9.1	10.6	7.3	2.8	5.9	9.0	12.1	6.6	6.8	9.0	10.7		7.0	12.1	2.0		30
May 1998	14.4	18.1	17.3	17.2	15.6	16.5	13.0	12.3	16.0	14.8	14.4	17.0	13.2	18.1	18.4	19.0	15.6	17.0	16.6	15.7	18.9	14.9	13.5	15.8	15.8	14.1	14.9	14.7	14.5	16.4	12.6	15.7	19.0	12.3		31
	1.0	1.5	2.4	4.4	7.5	2.5	3.2	-0.5	1.9	-0.8	0.4	1.8	4.2	5.5	6.7	9.7	6.9	7.8	9.5	11.0	7.5	1.6	2.7	7.2	5.6	1.0	2.3	10.4	12.4	9.0	-0.4	4.7	12.4	-0.8		31
Jun 1998	15.0	11.4	9.8	15.2	17.2	14.3	12.1	12.8	13.1	10.5	13.0	11.5	14.1	13.1	11.5	11.8	11.7	15.5	13.5	13.7	13.4	10.2	10.0	10.8	12.4	11.0	11.9	11.2	15.5	11.7		12.6	17.2	9.8		30
	0.2	-1.0	0.2	2.3	8.6	11.6	8.8	5.6	-0.2	0.9	4.9	8.0	5.0	4.3	5.4	1.4	-1.5	-0.6	0.4	1.5	3.8	3.0	3.6	5.6	7.5	-1.5	-0.6	3.4	3.9	1.0		3.2	11.6	-1.5		30
Jul 1998	11.8	14.3	14.0	13.0	14.0	15.5	13.0	12.3	10.4	10.3	12.6	13.6	12.0	11.1	14.7	12.2	14.0	11.8	10.2	9.4	12.9	13.0	13.9	12.3	12.3	15.2	13.2	11.0	13.6	14.0	16.0	12.8	16.0	9.4		31
	-1.4	-1.7	-0.7	0.0	1.5	3.5	4.0	9.0	5.5	0.0	-3.0	-2.2	1.0	2.4	1.1	-3.0	-1.6	0.0	0.0	-0.3	-0.2	1.1	-2.0	-0.9	-1.0	4.2	5.9	8.5	4.4	-1.2	4.0	1.2	9.0	-3.0		31
Aug 1998	12.4	13.9	13.7	14.0	15.4	13.5	15.0	15.2	13.7	14.3	11.8	11.8		13.8	11.0	12.7	13.7	15.3	16.0	15.8	14.8	15.0	12.8	13.7	15.8	17.6	17.4	15.6	17.5	16.0	13.7	14.4	17.6	11.0		30
	-1.0	1.0	6.2	9.8	4.0	2.1	3.6	1.6	2.0	4.8	2.8	0.4	-1.4		1.5	-1.0	-0.8	0.8	1.6	-0.6	3.8	8.0	3.0	-1.0	2.5	1.2	0.5	3.5	8.4	3.0	8.0	2.6	9.8	-1.4		30
Sep 1998	15.8	19.8	16.8	16.3	15.0	16.1	15.8	17.5	15.4	16.4	20.2	18.3	18.1	13.9	9.9	13.4	14.8	17.6	15.2	16.6	17.4	18.8										16.3	20.2	9.9		22
	6.8	5.5	8.7	10.1	4.2	4.4	6.5	1.5	1.0	4.5	3.0	8.1	10.6	7.0	3.6	0.4	6.4	10.2	7.6	2.4	1.5	7.3	13.7									5.9	13.7	0.4		23

Table A2.2: Daily amount of precipitation in the Windermere area during 1998

Precipitation to 9am (mm)

Period over which Precipitation has accumulated (days)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Jan 1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.2	0.0
															1	
Feb 1998	0.0	0.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.4
							1									*1*
Mar 1998	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						1										
Apr 1998	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	36.0	0.0	0.0	0.0
							1	*1*					*1*			
May 1998	7.4	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
	1					*1*						*1*				
Jun 1998	0.0	0.0	0.0	0.0	0.4	6.4	21.4	0.0	0.0	0.0	0.0	2.4	12.4	4.6	6.4	1.0
					1	*1*	*1*					*1*	*1*	*1*	*1*	*1*
Jul 1998	0.0	0.0	0.0	0.0	2.4	23.6	0.0	1.6	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
					1	*1*		*1*	*1*							
Aug 1998	0.0	0.0	11.6	2.2	5.8	0.0	0.0	0.0	0.0		7.8	0.0	0.0	0.0	0.0	0.0
			1	*1*	*1*						*2*					

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg	Max	Min	Total	Nbr
Jan 1998	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.4	3.8	0.0	19.2	7.8	1.0	0.0	1.6	19.2	0.0	50.8	31
							1		*1*	*1*		*1*	*1*	*1*		*1.0*	*1*	*1*	*7*	*7*
Feb 1998	0.8	0.0	0.0	1.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0				2.0	31.0	0.0	55.0	28
	1			*1*		*1*										*1.0*	*1*	*1*	*5*	*5*
Mar 1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	10.4	0.0	12.4	31
								1							*1*	*1.0*	*1*	*1*	*3*	*3*
Apr 1998	0.0	0.0	0.0	5.8	11.8	2.8	0.0	0.0	0.0	33.0	0.0	0.0		2.4		3.2	36.0	0.0	92.2	29
				1	*1*	*1*				*1*				*2*		*1.1*	*2*	*1*	*9*	*8*
May 1998	0.0	0.4	0.0	0.0		9.2	0.0	14.2	5.8	0.0	0.0	0.0	2.4	2.4	0.2	1.5	14.2	0.0	43.6	30
		1				*2*		*1*	*1*				*1*	*1*	*1*	*1.1*	*2*	*1*	*11*	*10*
Jun 1998	0.0	0.0	0.2	0.0	6.2	8.8	0.0	5.2	1.8	0.0	2.7	0.0	10.0	0.0		3.0	21.4	0.0	89.9	30
			1		*1*	*1*		*1*	*1*		*1*		*1*			*1.0*	*1*	*1*	*15*	*15*
Jul 1998	0.0	1.2	0.4	0.0		9.8	0.3	0.0	1.2	0.0	11.2	14.6	20.6	0.0	0.0	3.1	23.6	0.0	92.1	30
		1	*1*			*2*	*1*		*1*		*1*	*1*	*1*			*1.1*	*2*	*1*	*13*	*12*
Aug 1998	0.0	0.0	0.0	0.0	0.0	12.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.4	12.4	0.0	41.2	30
						1	*1*	*1*							*1*	*1.1*	*2*	*1*	*9*	*8*

APPENDIX 3: GRID METHOD RESULTS

Dates of measuring:

1) 23rd April 1998
2) 8th June 1998
3) 11th July 1998
4) 29th August 1998

The method by which this data was derived is outlined in section 6.3

Appendix 3: Recording 1: 23rd April 1998

peg	east	north	z			first_x	first_y	first_z	second_	second_	second	calc_dis	meas_dist	
11	[redacted]	[redacted]	[redacted]		11&22	0	0	100	22.653	19.815	92.04	31.131	31.79	0.658935
21	[redacted]	21.81	95.65		11&21	0	0	100	0	21.811	95.65	22.24	22.24	0.000291
31	[redacted]	31.44	90.17		11&12	0	0	100	22.198	0	96.31	22.504	22.62	0.116431
41	[redacted]	51.08	85.42		21&12	0	21.81	95.7	22.198	0	96.31	31.127	31.67	0.542739
22	22.653	19.82	92.04		21&22	0	21.81	95.7	22.653	19.815	92.04	23.025	22.5	0.525231
12	22.198	[redacted]	96.31		21&32	0	21.81	95.7	23	30.443	93.07	24.702		
32	23	30.44	93.07		21&31	0	21.81	95.7	0	31.442	90.17	11.083	11.08	0.003362
42	21.319	48.88	85.38		31&22	0	31.44	90.2	22.653	19.815	92.04	25.531		
13	44.646	[redacted]	100.2		31&33	0	31.44	90.2	47.93	31.487	91.72	47.955		
23	48	16.42	92.28		31&42	0	31.44	90.2	21.319	48.881	85.38	27.957		
33	47.93	31.49	91.72		31&41	0	31.44	90.2	0	51.079	85.42	20.203	20.2	0.003383
43	47.287	56.43	85.58		41&42	0	51.08	85.4	21.319	48.881	85.38	21.432	21.43	0.002369
14	67.075	[redacted]	96.11		41&32	0	51.08	85.4	23	30.443	93.07	31.834		
24	70.97	17.58	92.53		12&13	22.2	0	96.3	44.646	0	100.2	22.775	23.23	0.454825
34	73.963	31.09	92.59		12&23	22.2	0	96.3	48	16.42	92.28	30.847	31.02	0.172586
44	64.796	50.65	86.74		12&22	22.2	0	96.3	22.653	19.815	92.04	20.274	20.29	0.015799
15	91.077	[redacted]	99.42		22&23	22.65	19.82	92	48	16.42	92.28	25.575	25.58	0.005151
25	92.314	17.75	97.2		22&13	22.65	19.82	92	44.646	0	100.2	30.695	31.14	0.444829
35	94.285	26.94	88.11		22&32	22.65	19.82	92	23	30.443	93.07	10.683	11.2	0.517049
45	90.887	51.3	84.91		32&33	23	30.44	93.1	47.93	31.487	91.72	24.988	24.13	0.857882
16	114.91	[redacted]	93.18		32&42	23	30.44	93.1	21.319	48.881	85.38	20.05	20.06	0.010262
26	113.29	14.86	91.32		13&14	44.65	0	100	67.075	0	96.11	22.792	23.23	0.438447
36	107.74	26.72	92.26		13&23	44.65	0	100	48	16.42	92.28	18.518	19.45	0.932494
46	113.13	45.18	90.41		13&24	44.65	0	100	70.97	17.578	92.53	32.56	33.09	0.530280
17	135.65	[redacted]	102		23&24	48	16.42	92.3	70.97	17.578	92.53	23.001	23.02	0.019223
27	135.25	15.42	92.44		23&33	48	16.42	92.3	47.93	31.487	91.72	15.077	15.08	0.002532
37	130.76	28.77	92.41		23&34	48	16.42	92.3	73.963	31.087	92.59	29.821	29.55	0.270873
47	129.05	38.63	89.54		33&34	47.93	31.49	91.7	73.963	31.087	92.59	26.051	26.76	0.709255
18	155.7	[redacted]	106.2		33&43	47.93	31.49	91.7	47.287	56.432	85.58	25.699	25.7	0.001405
28	154	18.23	94.35		33&44	47.93	31.49	91.7	64.796	50.648	86.74	26.007	26.01	0.002857
38	156.22	32.86	86.75		14&15	67.08	0	96.1	91.077	0	99.42	24.229	24.22	0.008515
48	144.87	41.88	86.67		14&25	67.08	0	96.1	92.314	17.747	97.2	30.873	31.14	0.267066
19	172.83	[redacted]	97.86		14&24	67.08	0	96.1	70.97	17.578	92.53	18.357	18.04	0.317045
29	173.34	16.35	90.79		24&25	70.97	17.58	92.5	92.314	17.747	97.2	21.85	21.84	0.009743
39	168.93	26.32	90.28		24&34	70.97	17.58	92.5	73.963	31.087	92.59	13.837		
49	173.4	40.6	85.91		24&15	70.97	17.58	92.5	91.077	0	99.42	27.582	28.23	0.648167
					34&35	73.96	31.09	92.6	94.285	26.944	88.11	21.22	21.57	0.349760
					34&25	73.96	31.09	92.6	92.314	17.747	97.2	23.151	22.54	0.610581
					15&16	91.08	0	99.4	114.91	0	93.18	24.639	24.64	0.001004
					15&26	91.08	0	99.4	113.29	14.86	91.32	27.929	27.87	0.059152
					15&25	91.08	0	99.4	92.314	17.747	97.2	17.928	18.01	0.081826
					25&16	92.31	17.75	97.2	114.91	0	93.18	29.013	29.52	0.506886
					25&26	92.31	17.75	97.2	113.29	14.86	91.32	21.977	21.69	0.287414
					25&35	92.31	17.75	97.2	94.285	26.944	88.11	13.082	13.09	0.007530
					25&36	92.31	17.75	97.2	107.74	26.725	92.26	18.522	18.52	0.00238
					35&26	94.28	26.94	88.1	113.29	14.86	91.32	22.751	22.49	0.260715
					35&36	94.28	26.94	88.1	107.74	26.725	92.26	14.086	16.68	2.593869
					35&46	94.28	26.94	88.1	113.13	45.176	90.41	26.323	26.01	0.312621
					35&45	94.28	26.94	88.1	90.887	51.302	84.91	24.801	24.8	0.000665
					45&35	90.89	51.3	84.9	94.285	26.944	88.11	24.801	24.8	0.000665
					45&36	90.89	51.3	84.9	107.74	26.725	92.26	30.695	29.94	0.754704

Appendix 3: Recording 1: 23rd April 1998

					45&46	90.89	51.3	84.9	113.13	45.176	90.41	23.718	23.72	0.001642
					16&17	114.9	0	93.2	135.65	0	102	22.516	22.53	0.013921
					16&26	114.9	0	93.2	113.29	14.86	91.32	15.064	14.91	0.15397
					26&17	113.3	14.86	91.3	135.65	0	102	28.877	28.87	0.006683
					26&27	113.3	14.86	91.3	135.25	15.418	92.44	21.998	22.92	0.922416
					26&36	113.3	14.86	91.3	107.74	26.725	92.26	13.132	13.14	0.008035
					26&37	113.3	14.86	91.3	130.76	28.775	92.41	22.362	22.21	0.152316
					36&26	107.7	26.72	92.3	113.29	14.86	91.32	13.132	13.14	0.008035
					36&37	107.7	26.72	92.3	130.76	28.775	92.41	23.112	23.28	0.168264
					36&46	107.7	26.72	92.3	113.13	45.176	90.41	19.31	20.05	0.7397
					36&47	107.7	26.72	92.3	129.05	38.628	89.54	24.56	24.6	0.04038
					46&37	113.1	45.18	90.4	130.76	28.775	92.41	24.164	24.59	0.426247
					46&47	113.1	45.18	90.4	129.05	38.628	89.54	17.238	17.98	0.742066
					17&18	135.6	0	102	155.7	0	106.2	20.501	20.49	0.011087
					17&28	135.6	0	102	154	18.229	94.35	26.964	26.99	0.0261
					17&27	135.6	0	102	135.25	15.418	92.44	18.125	17.67	0.455056
					27&18	135.3	15.42	92.4	155.7	0	106.2	29.091	29.07	0.021229
					27&28	135.3	15.42	92.4	154	18.229	94.35	19.056	19.24	0.184409
					27&37	135.3	15.42	92.4	130.76	28.775	92.41	14.092	14.04	0.051517
					37&38	130.8	28.77	92.4	154	18.229	94.35	25.595	25.1	0.494699
					37&47	130.8	28.77	92.4	129.05	38.628	89.54	10.403		
					47&48	129.1	38.63	89.5	144.87	41.876	86.67	16.399	16.83	0.430615
					18&19	155.7	0	106	172.83	0	97.86	19.074	19.06	0.013500
					18&28	155.7	0	106	154	18.229	94.35	21.832	21.52	0.31211
					18&29	155.7	0	106	173.34	16.354	90.79	28.595	28.8	0.205145
					28&29	154	18.23	94.4	173.34	16.354	90.79	19.748	19.73	0.017515
					28&19	154	18.23	94.4	172.83	0	97.86	26.437	26.44	0.002800
					28&39	154	18.23	94.4	168.93	26.316	90.28	17.454	17.01	0.444430
					39&38	168.9	26.32	90.3	156.22	32.862	86.75	14.719	15.33	0.610652
					19&29	172.8	0	97.9	173.34	16.354	90.79	17.826	17.8	0.026182
					29&39	173.3	16.35	90.8	168.93	26.316	90.28	10.906	10	0.905866
					39&49	168.9	26.32	90.3	173.4	40.603	85.91	15.597	16.52	0.923096
					38&49	156.2	32.86	86.7	173.4	40.603	85.91	18.854	18.83	0.02414

Appendix 3: Recording 2: 8th June 1998

peg	east	north	z			first_x	first_y	first_z	second_x	second_y	second_z	calc_dist	meas_dist	
11	0	0	100		11&22	0	0	100	22.653	19.82	92.04	31.13442	31.5	0.365
21	0	21.8	95.65		11&21	0	0	100	0	21.8	95.65	22.22977	22.28	0.050
31	0	31.44	90.17		11&12	0	0	100	22.198	0	96.31	22.50261	22.6	0.097
41	0	51.08	85.42		21&12	0	21.8	95.65	22.198	0	96.31	31.11956	31.5	0.380
22	22.65	19.82	92.04		21&22	0	21.8	95.65	22.653	19.82	92.04	23.02414	22.9	0.124
12	22.2	0	96.31		21&32	0	21.8	95.65	21.9	30.44	93.07	23.68367		
32	21.9	30.44	93.07		21&31	0	21.8	95.65	0	31.44	90.17	11.08873	11.1	0.01
42	21.32	48.98	85.38		31&22	0	31.44	90.17	22.653	19.82	92.04	25.52802		
13	44.65	0	102.2		31&33	0	31.44	90.17	47.93	32.49	91.72	47.96655		
23	48	17.42	92.28		31&42	0	31.44	90.17	21.319	48.98	85.38	28.01955		
33	47.93	32.49	91.72		31&41	0	31.44	90.17	0	51.08	85.42	20.20624	20.15	0.056
43	46.5	57.43	85.58		41&42	0	51.08	85.42	21.319	48.98	85.38	21.42222	21.4	0.022
14	67.08	0	96.11		41&32	0	51.08	85.42	21.9	30.44	93.07	31.05064		
24	71.97	17.98	92.53		12&13	22.2	0	96.31	44.646	0	102.2	23.20786	23.25	0.042
34	72.5	32.09	92.59		12&23	22.2	0	96.31	48	17.42	92.28	31.39173	32.04	0.648
44	65.2	52.65	86.74		12&22	22.2	0	96.31	22.653	19.82	92.04	20.27985	20.3	0.020
15	91.2	0	99.42		22&23	22.65	19.82	92.04	48	17.42	92.28	25.4615	25.5	0.038
25	93.31	17.75	97.2		22&13	22.65	19.82	92.04	44.646	0	102.2	31.30096	31.15	0.150
35	92.29	28	88.11		22&32	22.65	19.82	92.04	21.9	30.44	93.07	10.69637	11.07	0.37
45	92	52.32	84.91		32&33	21.9	30.44	93.07	47.93	32.49	91.72	26.14548	25.9	0.245
16	115.9	0	93.18		32&42	21.9	30.44	93.07	21.319	48.98	85.38	20.07997	20.13	0.050
26	114.9	14.86	91.32		13&14	44.65	0	102.2	67.075	0	96.11	23.24109	23.25	0.008
36	110	27.12	92.26		13&23	44.65	0	102.2	48	17.42	92.28	20.32516	19.95	0.375
46	112.8	46.18	90.41		13&24	44.65	0	102.2	71.97	17.98	92.53	34.10851	33.85	0.258
17	137	0	102		23&24	48	17.42	92.28	71.97	17.98	92.53	23.97784	23.85	0.127
27	137.9	15.42	92.44		23&33	48	17.42	92.28	47.93	32.49	91.72	15.08056	15.12	0.039
37	136.8	29.77	92.41		23&34	48	17.42	92.28	72.5	32.09	92.59	28.55792	28.79	0.232
47	132.1	39.63	89.54		33&34	47.93	32.49	91.72	72.5	32.09	92.59	24.58865	24.52	0.068
18	157.7	0	106.2		33&43	47.93	32.49	91.72	46.5	57.43	85.58	25.72447	25.68	0.04
28	156.3	18.23	94.35		33&44	47.93	32.49	91.72	65.2	52.65	86.74	27.00887	26.92	0.088
38	157.2	32.86	86.75		14&15	67.08	0	96.11	91.2	0	99.42	24.35101	24.42	0.068
48	147.9	41.88	86.67		14&25	67.08	0	96.11	93.314	17.75	97.2	31.69757	31.55	0.147
19	175	0	97.86		14&24	67.08	0	96.11	71.97	17.98	92.53	18.97519	18.72	0.255
29	175.3	16.35	90.79		24&25	71.97	17.98	92.53	93.314	17.75	97.2	21.85013	21.9	0.04
39	170.9	26.32	90.28		24&34	71.97	17.98	92.53	72.5	32.09	92.59	14.12008		
49	175.4	40.6	85.91		24&15	71.97	17.98	92.53	91.2	0	99.42	27.21296	27.15	0.062
					34&35	72.5	32.09	92.59	92.285	28	88.11	20.69407	20.93	0.235
					34&25	72.5	32.09	92.59	93.314	17.75	97.2	25.69261	25.58	0.112
					15&16	91.2	0	99.42	115.91	0	93.18	25.48572	25.4	0.085
					15&26	91.2	0	99.42	114.9	14.86	91.32	29.12249	29.02	0.10
					15&25	91.2	0	99.42	93.314	17.75	97.2	18.01277	17.9	0.112
					25&16	93.31	17.75	97.2	115.91	0	93.18	29.01383	29.18	0.166
					25&26	93.31	17.75	97.2	114.9	14.86	91.32	22.55841	22.6	0.041
					25&35	93.31	17.75	97.2	92.285	28	88.11	13.73861	13.46	0.278
					25&36	93.31	17.75	97.2	110	27.12	92.26	19.76419	20.14	0.375
					35&26	92.29	28	88.11	114.9	14.86	91.32	26.35151	26.26	0.091
					35&36	92.29	28	88.11	110	27.12	92.26	18.21588	18.17	0.045
					35&46	92.29	28	88.11	112.83	46.18	90.41	27.52997	27.22	0.309
					35&45	92.29	28	88.11	92	52.32	84.91	24.53128	25.01	0.478
					45&36	92	52.32	84.91	110	27.12	92.26	31.82864	31.64	0.188
					45&46	92	52.32	84.91	112.83	46.18	90.41	22.40175	22.52	0.118

Appendix 3: Recording 2: 8th June 1998

					16&17	115.9	0	93.18	137	0	102	22.86002	22.95	0.089
					16&26	115.9	0	93.18	114.9	14.86	91.32	15.00997	14.91	0.099
					26&17	114.9	14.86	91.32	137	0	102	28.69307	28.89	0.196
					26&27	114.9	14.86	91.32	137.85	15.418	92.44	22.98409	23.7	0.715
					26&37	114.9	14.86	91.32	136.76	29.77	92.41	26.48312	26	0.483
					36&26	110	27.12	92.26	114.9	14.86	91.32	13.23636		
					36&37	110	27.12	92.26	136.76	29.77	92.41	26.89131	26.42	0.471
					36&46	110	27.12	92.26	112.83	46.18	90.41	19.35756	19.9	0.542
					36&47	110	27.12	92.26	132.05	39.63	89.54	25.49708	25.24	0.257
					46&37	112.8	46.18	90.41	136.76	29.77	92.41	29.08493	28.64	0.444
					46&47	112.8	46.18	90.41	132.05	39.63	89.54	20.32407	20.96	0.635
					17&18	137	0	102	157.7	0	106.2	21.12179	21.2	0.078
					17&28	137	0	102	156.27	18.23	94.35	27.60776	27.31	0.29
					17&27	137	0	102	137.85	15.418	92.44	18.16125	18.75	0.588
					27&18	137.9	15.418	92.44	157.7	0	106.2	28.6544	28.9	0.245
					27&28	137.9	15.418	92.44	156.27	18.23	94.35	18.73104	19.35	0.618
					27&37	137.9	15.418	92.44	136.76	29.77	92.41	14.39336		
					37&38	136.8	29.77	92.41	157.22	32.86	86.75	21.45216	21.14	0.312
					37&47	136.8	29.77	92.41	132.05	39.63	89.54	11.29781		
					47&48	132.1	39.63	89.54	147.9	41.88	86.67	16.26413	16.35	0.085
					18&19	157.7	0	106.2	175	0	97.86	19.20535	19.65	0.444
					18&28	157.7	0	106.2	156.27	18.23	94.35	21.78991	21.55	0.239
					18&29	157.7	0	106.2	175.34	16.35	90.79	28.56502	28.82	0.254
					28&29	156.3	18.23	94.35	175.34	16.35	90.79	19.49033	19.6	0.109
					28&19	156.3	18.23	94.35	175	0	97.86	26.37169	26.47	0.098
					28&39	156.3	18.23	94.35	170.9	26.32	90.28	17.2061	17.05	0.156
					39&38	170.9	26.32	90.28	157.22	32.86	86.75	15.56839	15.52	0.048
					19&29	175	0	97.86	175.34	16.35	90.79	17.81637	17.82	0.003
					29&39	175.3	16.35	90.79	170.9	26.32	90.28	10.92587	10.73	0.195
					39&49	170.9	26.32	90.28	175.4	40.6	85.91	15.59696	16.2	0.603
					38&49	157.2	32.86	86.75	175.4	40.6	85.91	19.7769	19.9	0.123

Appendix 3: Recording 3: 11th July 1998

peg	east	north	z			first_x	first_y	first_z	second_x	second_y	second_z	calc_dist	meas_dist	
11	0	0	100		11&22	0	0	100	22.65	19.82	92.04	31.132	31.15	0.017
21	0	21.8	95.65		11&21	0	0	100	0	21.8	95.65	22.23	22.25	0.020
31	0	31.44	90.17		11&12	0	0	100	22.198	0	96.31	22.503	22.55	0.047
41	0	51.08	85.42		21&12	0	21.8	95.65	22.198	0	96.31	31.12	31.65	0.530
22	22.65	19.82	92.04		21&22	0	21.8	95.65	22.65	19.82	92.04	23.021	22.5	0.521
12	22.2	0	96.31		21&32	0	21.8	95.65	23	30.44	93.07	24.704		
32	23	30.44	93.07		21&31	0	21.8	95.65	0	31.44	90.17	11.089	11.15	0.06
42	21.4	49.3	85.38		31&22	0	31.44	90.17	22.65	19.82	92.04	25.525		
13	44.65	0	100.2		31&33	0	31.44	90.17	47.8	33.9	91.7	47.888		
23	48.05	17.42	92.28		31&42	0	31.44	90.17	21.4	49.3	85.38	28.282		
33	47.8	33.9	91.7		31&41	0	31.44	90.17	0	51.08	85.42	20.206	20.2	0.006
43	46.2	58.78	85.58		41&42	0	51.08	85.42	21.4	49.3	85.38	21.474	21.4	0.073
14	67.08	0	96.11		41&32	0	51.08	85.42	23	30.44	93.07	31.836		
24	72.3	17.98	92.53		12&13	22.2	0	96.31	44.646	0	100.2	22.783	23.2	0.417
34	72.2	32.53	92.59		12&23	22.2	0	96.31	48.05	17.42	92.28	31.433	31.4	0.032
44	65.54	53	86.74		12&22	22.2	0	96.31	22.65	19.82	92.04	20.28	20.28	0.000
15	91.3	0	99.42		22&23	22.65	19.82	92.04	48.05	17.42	92.28	25.514	25.64	0.125
25	93.31	17.9	97.2		22&13	22.65	19.82	92.04	44.646	0	100.2	30.712	31.12	0.407
35	92	29.1	88.11		22&32	22.65	19.82	92.04	23	30.44	93.07	10.676	11.32	0.644
45	92.05	53.17	84.91		32&33	23	30.44	93.07	47.8	33.9	91.7	25.078	25.657	0.579
16	117	0	93.81		32&42	23	30.44	93.07	21.4	49.3	85.38	20.43	20.1	0.330
26	114.9	14.9	91.32		13&14	44.65	0	100.2	67.08	0	96.11	22.804	23.3	0.496
36	111.1	28.05	92.26		13&23	44.65	0	100.2	48.05	17.42	92.28	19.436	19.4	0.036
46	111.1	47.3	90.41		13&24	44.65	0	100.2	72.3	17.98	92.53	33.865	33.12	0.745
17	142	0	102		23&24	48.05	17.42	92.28	72.3	17.98	92.53	24.258	24.2	0.057
27	136.2	15	92.44		23&33	48.05	17.42	92.28	47.8	33.9	91.7	16.492	17.22	0.727
37	137.3	30.02	92.41		23&34	48.05	17.42	92.28	72.2	32.53	92.59	28.489	27.97	0.51
47	134.8	40.09	89.54		33&34	47.8	33.9	91.7	72.2	32.53	92.59	24.455	25.02	0.565
18	157.8	0	106.2		33&43	47.8	33.9	91.7	46.2	58.78	85.58	25.672	25.98	0.308
28	157	18.3	94.35		33&44	47.8	33.9	91.7	65.54	53	86.74	26.535	26.5	0.035
38	157.9	33.1	86.75		14&15	67.08	0	96.11	91.3	0	99.42	24.445	24.35	0.095
48	144.3	42.22	86.67		14&25	67.08	0	96.11	93.31	17.9	97.2	31.774	31.6	0.174
19	176.9	0	97.86		14&24	67.08	0	96.11	72.3	17.98	92.53	19.062	18.42	0.641
29	176.7	16.35	90.79		24&25	72.3	17.98	92.53	93.31	17.9	97.2	21.523	22.25	0.727
39	172.3	26.32	90.28		24&34	72.3	17.98	92.53	72.2	32.53	92.59	14.55		
49	176.6	40.7	85.91		24&15	72.3	17.98	92.53	91.3	0	99.42	27.051	27.23	0.179
					34&35	72.2	32.53	92.59	92	29.1	88.11	20.588	20.43	0.158
					34&25	72.2	32.53	92.59	93.31	17.9	97.2	26.094	25.45	0.644
					15&16	91.3	0	99.42	117	0	93.81	26.305	26.6	0.294
					15&26	91.3	0	99.42	114.9	14.9	91.32	29.062	28.85	0.211
					15&25	91.3	0	99.42	93.31	17.9	97.2	18.149	18.09	0.058
					25&16	93.31	17.9	97.2	117	0	93.81	29.885	29.5	0.385
					25&26	93.31	17.9	97.2	114.9	14.9	91.32	22.577	22.6	0.023
					25&35	93.31	17.9	97.2	92	29.1	88.11	14.484	15.13	0.64
					25&36	93.31	17.9	97.2	111.09	28.05	92.26	21.061	21.5	0.439
					35&26	92	29.1	88.11	114.9	14.9	91.32	27.136	27.42	0.284
					35&36	92	29.1	88.11	111.09	28.05	92.26	19.564	20.04	0.475
					35&46	92	29.1	88.11	111.1	47.3	90.41	26.483	26.68	0.197
					35&45	92	29.1	88.11	92.05	53.17	84.91	24.282	25.17	0.888
					45&36	92.05	53.17	84.91	111.09	28.05	92.26	32.366	32.58	0.213
					45&46	92.05	53.17	84.91	111.1	47.3	90.41	20.679	20.9	0.22

					16&17	117	0	93.81	142	0	102	26.307	26.02	0.287
					16&26	117	0	93.81	114.9	14.9	91.32	15.252	15.03	0.221
					26&17	114.9	14.9	91.32	142	0	102	32.718	32.05	0.668
					26&27	114.9	14.9	91.32	136.2	15	92.44	21.33	21.9	0.570
					26&37	114.9	14.9	91.32	137.3	30.02	92.41	27.047	26.75	0.297
					36&26	111.1	28.05	92.26	114.9	14.9	91.32	13.723		
					36&37	111.1	28.05	92.26	137.3	30.02	92.41	26.284	25.9	0.384
					36&46	111.1	28.05	92.26	111.1	47.3	90.41	19.339	20.3	0.961
					36&47	111.1	28.05	92.26	134.8	40.09	89.54	26.731	26.72	0.010
					46&37	111.1	47.3	90.41	137.3	30.02	92.41	31.449	32.07	0.621
					46&47	111.1	47.3	90.41	134.8	40.09	89.54	24.788	25.6	0.812
					17&18	142	0	102	157.8	0	106.2	16.349	17.05	0.701
					17&28	142	0	102	157	18.3	94.35	24.868	25	0.13
					17&27	142	0	102	136.2	15	92.44	18.709	18.1	0.609
					27&18	136.2	15	92.44	157.8	0	106.2	29.68	29.07	0.609
					27&28	136.2	15	92.44	157	18.3	94.35	21.147	21.3	0.15
					27&37	136.2	15	92.44	137.3	30.02	92.41	15.06	15.04	0.020
					37&38	137.3	30.02	92.41	157	18.3	94.35	23.005	23.13	0.125
					37&47	137.3	30.02	92.41	134.8	40.09	89.54	10.765		
					47&48	134.8	40.09	89.54	144.3	42.22	86.67	10.15		
					18&19	157.8	0	106.2	176.85	0	97.86	20.796	20.8	0.004
					18&28	157.8	0	106.2	157	18.3	94.35	21.816	21.5	0.316
					18&29	157.8	0	106.2	176.7	16.35	90.79	29.36	28.8	0.559
					28&29	157	18.3	94.35	176.7	16.35	90.79	20.114	19.7	0.413
					28&19	157	18.3	94.35	176.85	0	97.86	27.226	26.43	0.795
					28&39	157	18.3	94.35	172.33	26.32	90.28	17.773	17.02	0.753
					39&38	172.3	26.32	90.28	157.9	33.1	86.75	16.33	16.33	0.000
					19&29	176.9	0	97.86	176.7	16.35	90.79	17.814	17.8	0.013
					29&39	176.7	16.35	90.79	172.33	26.32	90.28	10.898	10.05	0.847
					39&49	172.3	26.32	90.28	176.6	40.7	85.91	15.624	16.45	0.825
					38&49	157.9	33.1	86.75	176.6	40.7	85.91	20.203	20.02	0.182

Appendix 3: recording 4: 29th August a998

peg	east	north	z			first_x	first_y	first_z	second_x	second_y	second_z	calc_dist	meas_dist	
11	0	0	100		11&22	0	0	100	22.65	19.82	92.04	31.132242	31.15	0.01
21	0	21.8	95.7		11&21	0	0	100	0	21.8	95.65	22.229766	22.25	0.02
31	0	31.44	90.2		11&12	0	0	100	22.198	0	96.31	22.502607	22.55	0.04
41	0	51.08	85.4		21&12	0	21.8	95.65	22.198	0	96.31	31.119557	31.35	0.23
22	22.65	19.82	92		21&22	0	21.8	95.65	22.65	19.82	92.04	23.021186	23.3	0.27
12	22.198	0	96.3		21&32	0	21.8	95.65	23	30.44	93.07	24.704372		
32	23	30.44	93.1		21&31	0	21.8	95.65	0	31.44	90.17	11.088733	11.15	0.06
42	21.4	49.3	85.4		31&22	0	31.44	90.17	22.65	19.82	92.04	25.525356		
13	44.646	0	100		31&33	0	31.44	90.17	47.8	34.5	91.7	47.922276		
23	48.05	18.22	92.3		31&42	0	31.44	90.17	21.4	49.3	85.38	28.282215		
33	47.8	34.5	91.7		31&41	0	31.44	90.17	0	51.08	85.42	20.206239	20.2	0.00
43	45.8	59.48	85.6		41&42	0	51.08	85.42	21.4	49.3	85.38	21.473938	21.4	0.07
14	67.08	0	96.1		41&32	0	51.08	85.42	23	30.44	93.07	31.836019		
24	72.3	17.98	92.5		12&13	22.198	0	96.31	44.646	0	100.2	22.782555	23.2	0.41
34	72.2	32.93	92.6		12&23	22.198	0	96.31	48.05	18.22	92.28	31.883149	31.4	0.48
44	65.94	53.7	86.7		12&22	22.198	0	96.31	22.65	19.82	92.04	20.279783	20.28	0.00
15	91.3	0	99.4		22&23	22.65	19.82	92.04	48.05	18.22	92.28	25.451475	25.64	0.18
25	93.31	17.9	97.2		22&13	22.65	19.82	92.04	44.646	0	100.2	30.712245	31.12	0.40
35	92	29.83	88.1		22&32	22.65	19.82	92.04	23	30.44	93.07	10.67557	11.32	0.6
45	92.05	54.02	84.9		32&33	23	30.44	93.07	47.8	34.5	91.7	25.167449	25.657	0.48
16	117	0	93.8		32&42	23	30.44	93.07	21.4	49.3	85.38	20.430264	20.1	0.33
26	114.9	14.9	91.3		13&14	44.646	0	100.2	67.08	0	96.11	22.803782	23.3	0.49
36	111.09	28.05	92.3		13&23	44.646	0	100.2	48.05	18.22	92.28	20.156439	19.4	0.75
46	111.1	47.3	90.4		13&24	44.646	0	100.2	72.3	17.98	92.53	33.865218	33.12	0.74
17	142	0	102		23&24	48.05	18.22	92.28	72.3	17.98	92.53	24.252476	24.2	0.05
27	136.2	15	92.4		23&33	48.05	18.22	92.28	47.8	34.5	91.7	16.292247	16.22	0.07
37	136.3	30.52	92.4		23&34	48.05	18.22	92.28	72.2	32.93	92.59	28.279015	27.97	0.30
47	134.8	40.65	89.5		33&34	47.8	34.5	91.7	72.2	32.93	92.59	24.466651	25.02	0.55
18	157.8	0	106		33&43	47.8	34.5	91.7	45.8	59.48	85.58	25.796411	25.98	0.18
28	157	18.3	94.4		33&44	47.8	34.5	91.7	65.94	53.7	86.74	26.875662	26.5	0.37
38	157.9	33.1	86.8		14&15	67.08	0	96.11	91.3	0	99.42	24.445132	24.35	0.09
48	144.3	42.22	86.7		14&25	67.08	0	96.11	93.31	17.9	97.2	31.774376	31.6	0.17
19	176.85	0	97.9		14&24	67.08	0	96.11	72.3	17.98	92.53	19.061616	18.42	0.64
29	176.7	16.35	90.8		24&25	72.3	17.98	92.53	93.31	17.9	97.2	21.522904	21.25	0.27
39	172.33	26.32	90.3		24&34	72.3	17.98	92.53	72.2	32.93	92.59	14.950455		
49	176.6	40.7	85.9		24&15	72.3	17.98	92.53	91.3	0	99.42	27.050924	27.23	0.17
					34&35	72.2	32.93	92.59	92	29.83	88.11	20.535832	20.43	0.10
					34&25	72.2	32.93	92.59	93.31	17.9	97.2	26.320811	25.45	0.87
					15&16	91.3	0	99.42	117	0	93.81	26.305172	26.6	0.29
					15&26	91.3	0	99.42	114.9	14.9	91.32	29.061659	28.85	0.21
					15&25	91.3	0	99.42	93.31	17.9	97.2	18.148788	18.09	0.05
					25&16	93.31	17.9	97.2	117	0	93.81	29.885083	29.5	0.38
					25&26	93.31	17.9	97.2	114.9	14.9	91.32	22.576592	22.6	0.02
					25&35	93.31	17.9	97.2	92	29.83	88.11	15.055534	15.13	0.07
					25&36	93.31	17.9	97.2	111.09	28.05	92.26	21.060734	21.5	0.43
					35&26	92	29.83	88.11	114.9	14.9	91.32	27.52488	27.42	0.1
					35&36	92	29.83	88.11	111.09	28.05	92.26	19.616804	20.04	0.42
					35&46	92	29.83	88.11	111.1	47.3	90.41	25.986552	26.68	0.69
					35&45	92	29.83	88.11	92.05	54.02	84.91	24.400791	25.17	0.76
					45&36	92.05	54.02	84.91	111.09	28.05	92.26	33.030062	33.58	0.54
					45&46	92.05	54.02	84.91	111.1	47.3	90.41	20.935876	20.9	0.03

					16&17	117	0	93.81	142	0	102	26.307339	26.02	0.28
					16&26	117	0	93.81	114.9	14.9	91.32	15.251888	15.03	0.22
					26&17	114.9	14.9	91.32	142	0	102	32.718227	32.05	0.66
					26&27	114.9	14.9	91.32	136.2	15	92.44	21.32966	21.9	0.5
					26&37	114.9	14.9	91.32	136.3	30.52	92.41	26.516646	26.75	0.23
					36&26	111.09	28.05	92.26	114.9	14.9	91.32	13.723054		
					36&37	111.09	28.05	92.26	136.3	30.52	92.41	25.331157	25.9	0.56
					36&46	111.09	28.05	92.26	111.1	47.3	90.41	19.338694	20.3	0.96
					36&47	111.09	28.05	92.26	134.8	40.65	89.54	26.987451	26.72	0.26
					46&37	111.1	47.3	90.41	136.3	30.52	92.41	30.341529	30.07	0.27
					46&47	111.1	47.3	90.41	134.8	40.65	89.54	24.63066	24.6	0.0
					17&18	142	0	102	157.8	0	106.2	16.3487	17.05	0.
					17&28	142	0	102	157	18.3	94.35	24.867901	25	0.13
					17&27	142	0	102	136.2	15	92.44	18.709185	18.1	0.60
					27&18	136.2	15	92.44	157.8	0	106.2	29.679919	29.07	0.60
					27&28	136.2	15	92.44	157	18.3	94.35	21.146586	21.3	0.15
					27&37	136.2	15	92.44	136.3	30.52	92.41	15.520351	15.04	0.48
					37&38	136.3	30.52	92.41	157	18.3	94.35	24.116011	24.13	0.01
					37&47	136.3	30.52	92.41	134.8	40.65	89.54	10.635027		
					47&48	134.8	40.65	89.54	144.3	42.22	86.67	10.047477		
					18&19	157.8	0	106.2	176.85	0	97.86	20.795627	20.8	0.00
					18&28	157.8	0	106.2	157	18.3	94.35	21.816336	21.5	0.31
					18&29	157.8	0	106.2	176.7	16.35	90.79	29.359847	28.8	0.55
					28&29	157	18.3	94.35	176.7	16.35	90.79	20.113829	19.7	0.41
					28&19	157	18.3	94.35	176.85	0	97.86	27.225587	26.43	0.79
					28&39	157	18.3	94.35	172.33	26.32	90.28	17.773413	17.02	0.75
					39&38	172.33	26.32	90.28	157.9	33.1	86.75	16.32955	16.33	0.0
					19&29	176.85	0	97.86	176.7	16.35	90.79	17.813756	17.8	0.01
					29&39	176.7	16.35	90.79	172.33	26.32	90.28	10.89761	10.05	0.8
					39&49	172.33	26.32	90.28	176.6	40.7	85.91	15.624154	16.45	0.82
					38&49	157.9	33.1	86.75	176.6	40.7	85.91	20.202861	20.02	0.18

APPENDIX 4: LANDSLIDE CLASS GUIDELINES

The following document is the official classification for landslip risk zoning in the Launceston area, obtained from Mineral Resources Tasmania

LANDSLIP RISK ZONING - LAUNCESTON AREA 1996

The landslip risk zoning is a revision of the zoning undertaken for th Launceston area in 1974 by the Department of Mines. The earlier surve extended over the whole Tamar region of some 800km², whereas the newe version is derived from a detailed study of about 145km² and covers the Greate Launceston area and surrounding land.

The classification closely follows the former system of zonation. The availabilit of more accurate base maps, combined with the collection of more detaile surface and subsurface geological information, has made it possible to refine th accuracy of the zoning over that produced previously. Even so, the zoning is stil relatively broad scale in nature, but it should give a good indication of th landslip risk in most areas. Locations on or near the zone boundaries may nee more precise determination by field inspection for particular developments i some cases. The zoning is advisory in nature.

As with the former survey, five classes have been used in the zonation system Subclasses have been introduced in Classes II and III on the latest maps Additional information may be obtained by reading the land stability zonatio maps in conjunction with examination of contour information and the detaile geological and engineering geological maps. The classes are arranged i increasing order of risk in a general sense from Class I to Class V.

Class I - *Generally stable ground on 'hard', weathered 'hard' rocks.*

This zone comprises areas underlain by Tertiary basalt, Jurassic dolerite an Triassic and Permian sandstone, siltstone and mudstone. Of these dolerite is b far the most common in the Launceston area.

These rocks have been subject to weathering resulting in variable depths of soil loose rock and weathered rock overlying hard *in situ* rock. Where the depth o weathering is shallow, i.e. in place competent rock is, say, less than one metr from the surface, the risk of landslip is regarded as very low. In areas wher weathering is deeper, the risk of landslip on sloping land may be a little greate under some circumstances, but is still generally low. Areas with known thicke weathering profiles on these rocks (usually dolerite) have been placed in Classe II and III depending on slope angle.

Occasional small areas with deep weathering will not have been identifie during the mapping process and such areas will have been placed in Class I Steep land with loose boulders or jointed cliff faces may present hazards fron rolling boulders or rock falls.

Areas underlain by these rocks are regarded as generally having very low landslip risk. Steeper sloping areas should be examined to assess depth of weathering and hazards from boulders and rock falls. If deeply weathered zones are located in such areas they should be treated as Classes II and III, depending on slope angle. Very rarely a higher zone may be considered.

Developments in steeper areas should follow good hillside development practices.

Class II - *Generally stable ground on 'soft' rocks, deep soil on 'hard' rocks (IIa), selected reclaimed areas (IIb), all on slopes < 7°.*

This class comprises land underlain by relatively unconsolidated units of Quaternary age, other more consolidated but poorly indurated units of Quaternary to Tertiary age, deeply weathered hard rock areas and selected man-made fill areas.

The lowest angle on which a landslide is known to have occurred in recent times in the Tamar area is 7°. As a result, land underlain by the above materials with slopes of less than 7° is regarded as generally stable. This conclusion appears to be valid for undeveloped land with a low slope angle where there are no signs of previous landslips visible and for well managed developed land of a similar nature where there is an absence of excessive loading.

The 7° slope angle has been determined using maps with a five metre contour interval and because of this interval, small errors may occur on the zonation maps where steeper slopes of less than 5 metres in height are present. These errors are likely to be rare, as in cases where such slopes are known to occur from field observation or air photo interpretation, the land has been assigned to the appropriate zonation class. Small areas of land with a slope of <7° that could be affected by landslips on adjacent steeper slopes have been placed in a higher class.

Although Quaternary estuarine and alluvial deposits of the Tamar and North Esk river valleys have been classified as Class II, narrow zones adjacent to water bodies may be prone to landslip into those water bodies at some locations. Some of these deposits and some selected reclaimed areas (11b) could be subject to significant settlement under load.

Recommendation

Landslip risk for this class is regarded as low. Excessive loading or deep excavation, combined with poor drainage practices, could induce unstable conditions under some circumstances. Some attention should be given to these factors when development is proposed. Strict adherence to building codes is recommended.

Class III - *Potential landslip areas on 'soft' rocks, deep soil overlying 'hard' rock (IIIa) (slopes in both cases ≥ 7°).dolerite gravel areas on slopes 7-10° (IIIb), dolerite gravel areas on slopes > 10° (IIIc).*

This class is comprised largely of land underlain by similar material to that underlying Class II areas, but with a greater slope angle. The land in this class exhibits no obvious signs of past movement, but because of the slope angle, there is some potential for landslip to develop under some circumstances. Excavation and placement of fill may have obliterated old landslip features in some of the developed areas that have been placed in this class, but this is not expected to be common.

There is a range of risk in this zone. The limited amount of subsurface information does not allow more subdivision into subclasses than indicated. A small section of flatter land above and below the steeper slopes has been included in this class to act as a buffer.

The landslip risk for Class IIIb (dolerite gravel on slopes 7°-10°) is regarded as low. The risk for IIIa (deep soil overlying 'hard' rock) and IIIc (dolerite gravel on slopes > 10°) is regarded as similar to the remainder of Class III.

Recommendation

It is recommended that a land stability assessment for land in this zone be undertaken before development proceeds. This assessment will often involve a field inspection and sometimes subsurface investigations and should be undertaken by a competent geotechnical practitioner. In many Class III areas it is expected that land in this class will be suitable to develop, provided some precautions are taken and these should be outlined in a specific site report that deals with the development of the land. These precautions will usually relate to factors such as siting of the development, excavations, drainage and vegetation removal.

Class IV - *Old landslip and adjacent areas.*

Land in this class shows signs of definite and probable old landslip movements with no apparent movement in recent times, i.e. there are no landslip related cracks or bare soil associated with landslip visible and long term residents are unaware of movement. As well, some adjacent land with similar conditions (e.g. geology and slope angle) has been included in this class.

APPENDIX 5: DRILL CORE LOGS

Specific locations are illustrated in figure 3.1

Data has been derived from previous data and drill and auger hole logging

Drill core no.	Depth (m)	Description	Moisture content	Classification symbol	Reference
P1	0 0.305	Top soil Talus of hard angular basalt boulders in basalt clay matrix, became hard to dig at 1.9m.	Unknown		Leaman & Stevenson , 1972
P2	0 <0.305	Top soil Weathered basalt talus with some hard boulders, too hard to dig at 3.05 m.	Unknown		Leaman & Stevenson , 1972
P3	0 0.305	Top soil Talus of weathered basalt, mainly clay with a few basalt boulders at 3.3m	Unknown		Leaman & Stevenson , 1972
P4	0 0.3-0.6 >0.6	Top soil Brown plastic clay Deeply weathered basalt talus with occasional boulders to 2.9m becoming difficult to dig.	Unknown		Leaman & Stevenson , 1972
P5	0 .30 .60	Top soil Brown sandy clay Weathered basalt talus becoming too hard to dig at 2.7m	Unknown		Leaman & Stevenson , 1972
P6	0 .3 .9	Top soil Brown sand Weathered basalt talus passing into fresh basalt rubble at 2.7m.	Unknown		Leaman & Stevenson , 1972
P7	0-0.2 0.2-0.5 0.5-2.3 2.3-3.2	Dark brown, dry and fractured silty clay soil, some basalt boulders Porous silty and pisolitic (iron oxide) soil Mixture of plastic clay and basalt boulders, some basalt weathered some unweathered. Light grey-brown medium hard plastic clay, fissured with shiny surfaces			Stevenson, 1973
P8	0-0.6 0.6-1.5 1.5-1.8	Dark brown clay and basalt boulders grading into dark brown soil. Light brown clay with basalt boulders. On north side of pit grey silty clay; a thin fine, even-grained quartz sand beds; some wood fragments. Zones of clay extending into basalt boulder zone. Other parts of pit consist of clay and basalt boulders which proved too difficult to excavate.		CH	Stevenson, 1973
P9	0-0.3 0.3-1.8	Dark brown soil and sandy silty clay, dry and fractured. Hard brown plastic clay and basalt boulders. Towards bottom light grey and brown mottled silty and sandy clay with plastic clay and basalt boulders intermixed. Unable to dig any deeper.			Stevenson, 1973
P10	0-0.8	Dark brown to black silty clay, dry and fractured, a few small basalt fragments.			Stevenson, 1973

	0.8-2.6	Fragmental grey brown to black clay (derived from basalt) with basalt boulders, occasional limonite nodules.			
P11	0-0.6 0.6-2.7 2.7-3.1	Dark brown crumbly soil overlying clay, some basalt boulders. Brown plastic to fragmental clay with occasional basalt boulders, shiny slip surfaces on clay. Light grey and brown mottled clay, hard, plastic, some thin travertine seams.		CH	Stevenson, 1973
P12	0-0.6 0.6-1.8 1.8-3.1	Dry fractured dark brown clay soil becoming damp towards the base, angular limonite fragments. Fragmental to plastic brown clay and basalt boulders. Light grey and brown mottled clay and silty clay, fairly hard and massive. Iron oxide band across floor pit above 15 mm wide carries a little water		CH	Stevenson, 1973
P13	0-0.5 0.5-1.5 1.5-2.7	Dry and fractured soil over light brown silty clay Mainly brown, a little grey fragmental to plastic hard clay, some limonite nodules. Light grey and brown mottled clay, fissured. Some travertine near top.		CH	Stevenson, 1973
P14	0-0.6 0.6-1.5 1.5-2.1	Dark brown soil overlying pisolitic (iron oxide) clay with basalt boulders. Ligth grey brown fragmental clay with basalt boulders. Fissured grey clay with shiny slip surface on one side of pit. The other part of pit are weathered basalt debris and boulders with some moisture.			Stevenson, 1973
P15	0-0.3 0.3-0.9 0.9-1.7 1.7	Dark brown soil, fractured and dry, occasional basalt boulders. Basalt derived light brown fragmental material with large basalt boulders. Fine even grained brown sand (mainly quartz). Blue clay		CH	Stevenson, 1973
B 1	0-0.5 0.5-1.9 1.9-4.4 4.4-5.0	Clay – highly plastic, dark brown. Some organic in top half (soil & subsoil) Clay – highly plastic, grey (Launceston Beds) Clay – highly plastic, brown Soft zone	M = Pl. M<Pl M<Pl M= Pl	CH CH CH CH	Moore, 1986
B 2	0-0.2 0.2-0.4 0.4-6.0	Clay - Organic, black, highly plastic (soil) Clay – highly plastic, dark brown (subsoil) Clay – highly plastic brown (Launceston Beds)	M = Pl M < Pl M < Pl	OH CH CH	Moore, 1986
B 3	0-0.2 0.2-1.5 1.5-3.0 3.0-3.3 3.3-6.0	Clay – Organic, black, highly plastic (soil) Clay – Highly plastic, yellow (yellow clay) Clay – Highly plastic, brown with ironstone grit (Launceston Beds) Clay – Highly plastic, grey Clay – Highly plastic, brown	M M = Pl M < Pl	OH CH CH	Moore, 1986

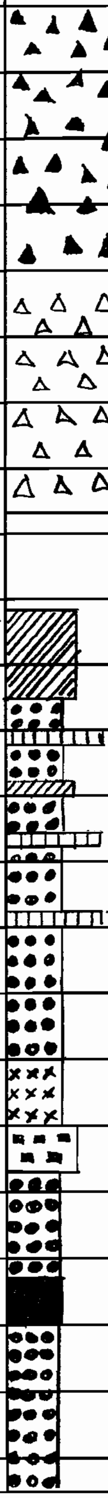
B 4	0-0.8 0.8-1.6 1.6-1.8	Gravel & organic clay – Gravel coarse road base coarse. Clay black organic Clay – Highly plastic, yellow-brown Clay with gravel- clay highly plastic, yellow. Gravel, coarse quartz pebbles. 10%	 M = Pl M < Pl	GC & OH CH GC	Moore, 1986
B 5	0-1.0 1.0-1.2 1.2-1.5 1.5-2.0 2.0-2.7 2.7-3.3	Gravel – coarse, poorly sorted. Road base coarse with some clay (Fill) Silt – Organic, fine, low plasticity (Soil layer) Clay – High plasticity, brown (Clay interbedded with gravel) Clay with gravel – coarse gravel, clay highly plastic Clay highly plastic brown Clay with gravel – clay highly plastic, brown. Gravel coarse	 M M = Pl M < Pl M < Pl	GC OL CH GC CH GC	Moore, 1986
B 6	0-1.5 1.5-2.5	Gravel and clay – Gravel coarse, clay highly plastic, grey-brown Clay highly plastic, light brown	M = Pl D	GC CH	Moore, 1986
B 7	0-0.3 0.3-4.2	Clay - organic, with roots, dark brown (Topsoil) Clay - highly plastic, orange (Launceston Beds)	M	OH CH	Moore, 1988
B 8	0-0.4 0.4-1.0 1.0-2.5 2.5-4.0	Clay - black organic, with roots Clay - orange, highly plastic Clay with gravel – brown, clay highly plastic, gravel fine, ironstone 1-2 mm 10% Clay – Orange, highly plastic	D M M M	OH CH CH	Moore, 1988
B 9	0-0.9 0.9-1.6 1.6-1.9 1.6-3.4 3.4	Clay – Brown, organic, highly plastic. Clay – brown, highly plastic Clay – Rubbly ironstone band Clay – brown, highly plastic Clay with pebbles	D M M M M	OH CH CH	Moore, 1988
B 10	0-0.8 0.8-3.4 3.4-7	Clay pebbles, Clay- orange brown, highly plastic. Pebbles basalt > 3 mm ironstone < 1mm Clay – brown, highly plastic, gradual change in colour with depth Clay – orange, highly plastic	 M M H	CH CH	Moore, 1988
B 11	0-0.2 0.2-1.0 1.0-3.1	Concrete and gravel Clay – brown, highly plastic Clay – orange, highly plastic	 M M	G CH	Moore, 1988
B 12	0-0.2 0.2-.45 0.4-.55	Light brown loamy silt Strongly bleached silt, with abundant ironstones to 5cm Very dry clay, with yellow/ brown/ grey mottle			Ingles, 1991
B 13	0-0.15 0.15-.5	Light brown loamy silt Stiff dry clay, mottled yellow/ grey			Ingles, 1991

Borehole 14	0-0.23 .23-.5 0.5-.55	Light brown silt Mildly bleached ironstone rich silt Dry mottled clay			Ingles, 1991
Borehole 15	0-0.25 0.25-.5 0.5-.65	Light brown loamy silt Mildly bleached, ironstone rich silt Very dry clay, mottled yellow/brown			Ingles, 1991
Borehole 16	0-2.0	Fairly uniform clay, very dry, with well rounded boulders to 30 cm, and brown/yellow/ orange mottle.		CM	Ingles, 1991
Borehole 17	0-0.7 0.7-1.8	Light brown silty gravelly loam Clay – Mottled red/orange/grey, very dry		 CH	Ingles, 1991
Borehole 18	0-0.5 0.5-1.9	Light brown silty gravelly loam Clay, slickensided, strongly mottled yellow/ grey (latter predominates) somewhat porous and also layered.		CM CH	Ingles, 1991

Appendix 5: Drill Logs

DIAMOND DRILLCORE LOG	project: Windermere area location: Gaunts Hill logged by: Rochelle Macdonald	hole no. WDH1 (BH1) page 1 of 2 date: 29 · 1 98 scale: 1 : 1m

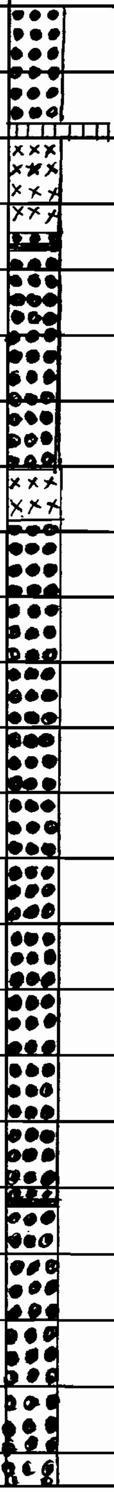
metre	structure	grainsize	description
4m			Basalt rouble.
7m			Solid basalt - coarse grained, feldspar rich - fresh rock.
9m	9.07m		core loss - probably sand rich layers
			Orange clay - organic material present - not well consolidated => little masses
			Brown clay, more consolidated very fine grained
			sand rich layer, dark in colour illustrates a change in sedimentation
15m			
			medium brown/yellow clay, Surface weathered to blue/grey colour, well held together.
			Slightly more coarse grained, rich in organic matter ie roots etc "sandy clay"
20			Very dark brown clay (still wet)
22			



Appendix 5: Drill Logs

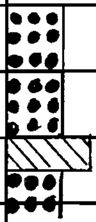
DIAMOND DRILLCORE LOG	project: Windermere area location: Launts Hill logged by: Rochelle Macdonald	hole no. WDH1 (BH1) page 2 of date: 29 1 98 scale: 1 : 1m

metre	structure	grainsize	description
23			
25			Coal seam - black organic layer ~1cm thick
30			
			very wet area
35			
40			

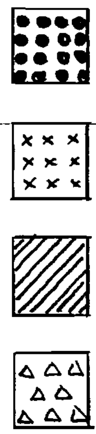


Geological Investigation and slope risk assessment at Windermere, northern Tasmania

DIAMOND DRILLCORE LOG	project: Windermere area location: Gaunts Hill logged by: Rochelle Macdonald	hole no. WDH1 (BH1) page 3 of 3 date: 29·1·98 scale: 1 : 1m

metre	structure	grainsize	description
45			very light material, cream/white in colour Fine grained sand

Key:



= brown clay

= dark brown clay weathered blue

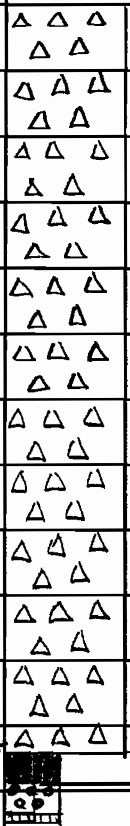
= orange organic rich clay

= basalt (insitu)

DIAMOND DRILLCORE LOG	project: Windermere area location: 100m elevation Gaunts Hill logged by: Rochelle Macdonald	hole no. BH2 page of date: 21.8.98 scale: 1cm = 1m

metre	structure	grainsize	description
			basaltic soil red, grass roots present grades into weathered basalt → Solid basalt
1			Tertiary basalt - weathered cracks - coarse grained - weathering residue → orange material probably goethite rich - long feldspar phenocrysts are evident in hand specimen
2			
3			
3.25	thin section		
4			
5			Solid basalt less weathered than the above.
6			
7			weathered Zone
8			
9			
10			
15			
20			

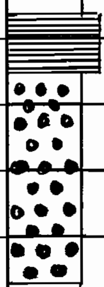
DIAMOND DRILLCORE LOG	project: Windermere area location: 160m elevation G Hill logged by: Rochelle Macdonald	hole no. B#2 page of date: 21-8-98 scale: 1cm = 1m.



metre	structure	description
24		
25		
30		
34	←34.3m contact of Tb with Ts	Contact of Tertiary basalt with Younger Tertiary Sediments • Slightly baked Tertiary sediments - fine grained, black. (Thin Section) - very hard for 4cm, then able to scratch easily. ← Photo
35		Very fine grained grey/brown clay layer. ←20mm zone of very deformed plastic clay ← Water table?
		▪ Brown clay that dominates much of the area. ▪ no bedding apparent.
40		
45		

Appendix 5: Drill Logs

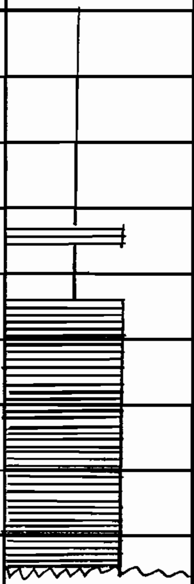
DIAMOND DRILLCORE LOG	project: location: logged by:	hole no. page of date: scale:

metre	structure	grainsize	description
46			
50			
55			
60			Sand layer -light brown - more coarsely grained than the clay, but small amounts of clay are mixed. -fine sand.
65			-Brown clay -more consolidated.
66			
67			

Appendix 5: Drill Logs

DIAMOND DRILLCORE LOG			project: location: logged by:	hole no. B#2 page 4 of 5 date: scale:
metre	structure	grainsize	description	
68				
69				
70				
			← Sand layer	
75				
			← sand layer ← black clay layer	
			← Large sand layer.	
80			← coal	
85				
			← sand layer.	
89				

DIAMOND DRILLCORE LOG			project: Windermere area. location: 100m el Gaunts Hill logged by: R. Macdonald	hole no. BH2 page 5 of 5 date: 21.8.98 scale: 1cm = 1m
metre	structure	grainsize	description	
90				
95			← Large sand layers alternating with organic matter ← Yellow in colour (Photo.)	
98			end of hole	



APPENDIX 6: CLAY ANALYSIS

COMPLETED BY MINERAL RESOURCES TASMANIA

MINERAL RESOURCES TASMANIA

Client: R. Macdonald
Sample Location: Windermere

	Soil Mechanics Testing						Whole Sample X-Ray Diffraction Analyses (Approx. Wt. %)						
Sample	*ECN*	*LL*	*PL*	*LS*	*Ø' (º)*	*c' (kPa)*	*Quartz*	*Kaolinite*	*Smectite*	*K-Feldspar*	*Mica*	*Goethite*	*Gibbsite*
S11	1	89	32	19			25	60	10	2	2		
S12	2	66	21	18			35	25	20	10	2	5	
S14	2	101	30	22			30	40	20	2	2		2
S22	1	83	29	18	10	3	20	65	10	2	2		2
S23	1	67	23	17			40	40	10	5	2		2
S24	1	56	20	15			45	35	10	5	2		2
S25	1	64	21	16			40	30	10	10	5	2	
S26	1	73	25	17			40	35	15	5	5	2	
S41	6	132	28	26			30	55	5			5	
S42	6	129	26	27			30	50	5			10	

Atterberg Limits tests performed without pre-drying samples
ECN = Emerson Class Number
LL = Liquid Limit
PL = Plastic Limit
LS = Linear Shrinkage
Ø' = Residual Angle of Internal Friction
c' = Residual Cohesion

Minerals present in trace amounts, or amorphous minerals, may not be detected
Peak overlap may interfere with identifications (e.g. K-Feldspar may mask the presence of Rutile; Goethite may mask the presence of Hematite; large amounts of Kaolinite may mask the presence of small amounts of Ilmenite)
Major Goethite peak in S41 and S42 occurs at 4.17Å-4.16Å (normal Goethite 4.183Å) - may indicate some replacement of Fe by Al
Smectite content in S11 and S22 rounded-down to 10%
Smectite content in S23, S24, S25 rounded-up to 10%
Smectite content in S26 rounded-up to 15%

RN Woolley

Analyst: Richie N. Woolley
Date: 24 September 1998

			depth		ll	pl	Pl Pind	ls	mc	e		c	QZ	SMEC	KAOL	HALLO	LEPID	GOET	GIBB	carbon ZEO	MICA	K-FEL	PLAG	FELD	total feld	total nonx	PYRX	AMPH	total Fe	toal gm	c-smec	c-kaol	c-hallo	c-goet	c-gibb	c-hem	c-lepidoc	K+S	k+H+S	Ttotal	clay total	k+h+s-G
Tscf	Tfw	LH1A1	1		84	20	44	15	22																0	0			0	#VALUE!	5	90		5				0	0	0	100	0
Tscf	Tfw	LH1A6	6		70	22	48	16	23																0	0			0	0	5	95		2				0	0	0	102	0
Qs?	Ts?	LH97A1					0			5															0	0			0	17								0	0	0	0	0
Qs?	Ts?	LH97A2	2		99	28	71	23		6			40			55		5				2			2	47			5	40								0	55	102	0	50
Qs?	Ts?	LH97A3	3				0																		0	0			0	2								0	0	0	0	0
Tf	Tfs	LH97A6	6		122	29	93	26					25		60			15			2				0	42			15	27								60	60	102	0	45
TsC		LH98A1	1				0			E															0	0			0	0								0	0	0	0	0
TsC		LH98A2	2		123	32	91	25		5			25	5	65			5							0	30			5	25								70	70	100	0	65
TsC		LH98A5	5		112	27	85	26																	0	0			0	0								0	0	0	0	0
TsC		LH98A8	8		101	30	71	24																	0	0			0	0								0	0	0	0	0
Ts	Qur5weat	LH99A1	1		113	31	82	25		6			30	10	55			5			2				0	37			5	32								65	65	102	0	60
Ts	Qur5weat	LH99A3	3		115	30	85	24		E			30	5	55				5		2	2			2	39			0	32								60	60	99	0	60
Ts	Tsgreydk	LH99A5	4		104	32	72	22																	0	0			0	2								0	0	0	0	0
Ts		LH100A1	1				0			E									5						0	5			0	0								0	0	5	0	0
Ts	Qs?	LH100A3	3	windermer	39	18	21	10					60			35						2	2		4	64			0	60								0	35	99	0	35
Ts		LH100A5	5		105	29	76	23																	0	0			0	4								0	0	0	0	0
Ts		LH101A1	1				0			E															0	0			0	0								0	0	0	0	0
Ts		LH101A3	3		47	18	29	12																	0	0			0	0								0	0	0	0	0
Ts		LH101A6	6		116	27	89	24		E			35	10	45				2		5	2			2	44			0	40								55	55	99	0	55
Ts		LH101A9	9		65	20	45	17		E															0	0			0	2								0	0	0	0	0
Ts		LH102A1	1				0			5															0	0			0	0								0	0	0	0	0
Ts		LH102A2	2		44	21	23	11		E															0	0			0	0								0	0	0	0	0
Ts		LH102A3	3				0						60			35						5			5	65			0	60								0	35	100	0	35
Ts		LH102A5	5		109	26	83	23			16	2	35	5	55						2	5			5	42			0	42								60	60	102	0	60
Ts		LH102A8	8		87	22	65	22																	0	0			0	5								0	0	0	0	0
Ts	Qtb?	LH103A1	1				0			E															0	0			0	0								0	0	0	0	0
Ts		LH103A2	2		174	37	137	27		E															0	0			0	0								0	0	0	0,0	
Ts	Qtb?	LH104A1	1				0			E															0	0			0	0								0	0	0	0.0	
Ts	Qtb?	LH104A2	2				0			E															0	0			0	0								0	0	0	0	0
Ts	Qtb?	LH105A1	1		157	36	121	25		5															0	0			0	0								0	0	0	0	0
Ts	Qtb?	LH105A3	3		161	31	130	29		E			20	15	60				5		2				0	27			0	22								75	75	102	0	75
Ts		LH106A2	2		133	35	98	23		E			15	5	80										0	15			0	15								85	85	100	0	85
Ts		LH106A3	3		110	34	76	22					2		90			5	2						0	9			5	2								90	90	99	0	85
Ts		LH106A4	4		144	37	107	26		E	11	3			100			2							0	2			2	0								100	100	102	0	98
Ts		LH106A5	5		129	33	96	24																	0	0			0	0								0	0	0	0	0
Ts		LH106A7	7		105	32	73	19					10	2	85			2							0	12			2	10								87	87	99	0	85
Ts		LH106A8	8				0																		0	0			0	0								0	0	0	0	0
Qs		LH107A1	1				0			E															0	0			0	0								0	0	0	0	0
Qs		LH107A2	2		45	21	24	10		E			65			25					5	5	2		7	77			0	70								0	25	102	0	25
Qs		LH107A3	3				0																		0	0			0	7								0	0	0	0	0
Qs		LH107A5	5		35	18	17	4		E															0	0			0	0								0	0	0	0	0
Qs		LH107A9	9				0																		0	0			0	0								0	0	0	0	0
CJ		LHIO8A2	2		119	26	93	27		E															0	0			0	0								0	0	0	0	0
CJ		LH108A3	3		52	19	33	14																	0	0			0	0								0	0	0	0	0
CJ		LH108A4	4				0																		0	0			0	0								0	0	0	0	0
Qs		LH109A1	1				0			E															0	0			0	0								0	0	0	0	0
Qs		LH109A2	2				0			E															0	0			0	0								0	0	0	0	0
Qs?	Ts?	LH109A3	3		53	17	36	14	19	E															0	0			0	0								0	0	0	0	0
Qs?	Ts?	LH109A5					0		20	E															0	0			0	0								0	0	0	0	0
Qs?	Ts?	LH109A7	7		25	22	3	2	51	E															0	0			0	0								0	0	0	0	0
Qs?	Ts?	LHIO9A9					0		29	E															0	0			0	0								0	0	0	0	0
Ts	Tsblack	LH109A10	10				0																		0	0			0	0								0	0	0	0	0

APPENDIX 7: OVERVIEW OF SHEAR BOX TESTS

The shear box test

The test consists of a brass box, split horizontally at the centre of the soil specimen (illustrated in figure A7.1), where the soil is gripped by metal grilles. A vertical load is applied to the top of the sample by means of weights. As the shear plane is predominately in the horizontal direction the vertical load is also the normal load on the plane of failure. Having applied the required vertical load a shearing force is gradually exerted on the box, usually from a proving ring – annular steel ring that has been carefully machined and balanced. When a load is applied to such a ring a deflection will take place that can be measured on a dial gauge, enabling the causative force to be obtained from the ring calibration supplied by the manufacturer.

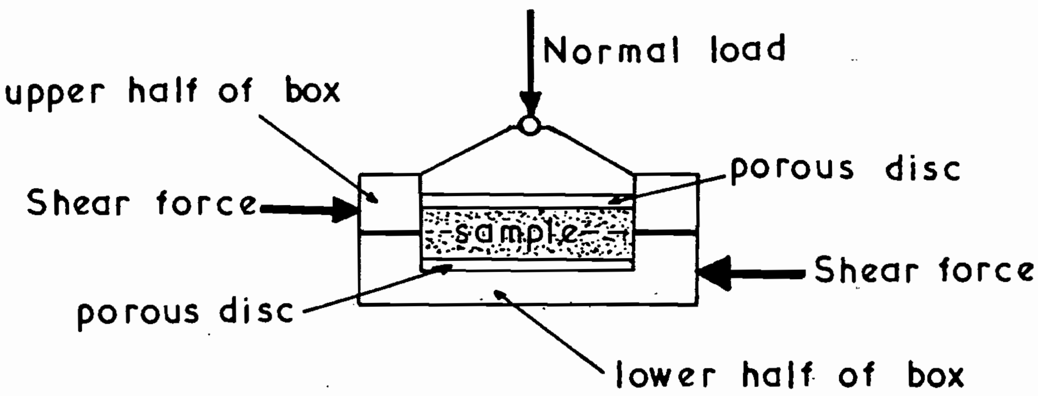


Figure A7.1: Diagrammatic sketch of the shear box apparatus

A second dial gangue (fixed to the shear box) is used to determine the strain of the test sample. At any point during the shear, the proving ring reading is taken at fixed strain intervals (strain = movement of box / length of box) and failure of the soil specimen is indicated by a sudden drop in the magnitude of the proving ring reading or a levelling off in successive readings.

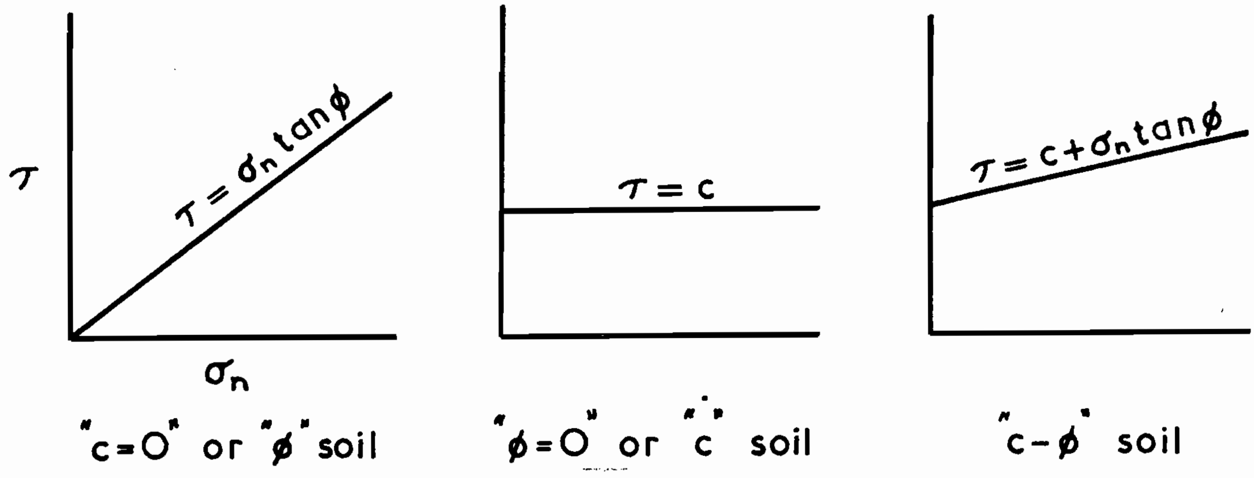


Figure A7.2 illustrates the soil classification according to the shear strength of sediments.

APPENDIX 8: DESCRIPTIONS OF SLOPE STABILITY MODELS USED

Bishop's Simplified Method

Cousin's Method of Tables

Galena

Bishop's Simplified Method

Bishop's Simplified Method is a simplistic means of calculating the stability of slopes, in terms if the factor of safety (Fs). The model uses a number of in parameters (equation A8.1), which are applied to circular slip failure planes. This model is renown for producing realistic results and it is relatively easy to calculate.

$Fs = \sum\{[c'b + W (1-r) \tan\phi'] (1/m)\}/ \sum W \sin\alpha$ ....equation A8.1

Where,

- r - pore pressure
- τ - Shear stress
- ϕ' - Residual angle of internal friction
- c – Cohesion
- W – sediment weight
- α - angle between the slope and the normal

Cousins Stability Charts

Cousins through extensive computer analysis has identified that specific average pore pressure ratios relate to a slope angle, I, and a stability number, Nf, where r = Y/Wh. This method depicts the relationship between slope angle and the co-ordinates of the critical slip circle for a number of pore pressure ratios. Such a relationship can be derived from the tables illustrated in figure A8.1, providing the correct input parameters are available. From this the stability number or factor of safety can be derived.

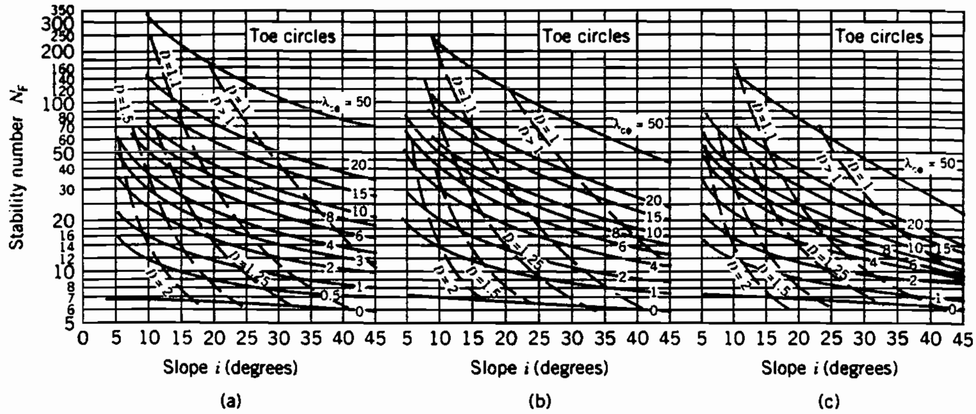


Figure A8.1: Stability numbers for toe circles (a) r = 0, b) r = 0.25, c) r = 0.5 (Cernica, 1995)

Galena Slope Stability Analysis System

Galena is a computerised slope stability-modelling package, which incorporates three methods of calculating slope stability, Bishop's Simplified Method, Spenser-Wrigth and Samara Method. The model used is depends on the type of failure plane, i.e. if failure is circular or non circular. This model is user friendly and produces results rapidly. The model enables failure surface to be defined in terms of the actual slope rather than as abstract point in space (Galena, 1998).

APPENDIX 9: ROCK CATELOGUE

	Field#	Rock Nam	Rock description	AMG North	AMG Easti	Position
137813	2.3	dolerite	Highly weathered dolerite boulders	5426830	503520	Cnr. Tamar Highway,Los Angelos Rd
137814	3.7	claystone	Alternating clay and sand layers, subhorizontal bedding	5426652	501550	property no. 1416
137815	2.1	basalt	Weathered basalt clast	5427230	500960	Cliff on top of Gaunts Hill
137816	3.5	basalt	Contact between Tertiary basalt and Tertiary sediments	5426652	501550	top Gaunts Hill, property no. 1416
137817	2.2	basalt	Highly weathered basalt boulders	5427015	501120	property no. 1416
137818	6.7	claystone	The resultant block after shear box testing	5427460	500725	property no. 1417
137819	3.4	basalt	Thin section of Tertiary basalt capping Gaunts Hill	5427215	501150	Gaunts Landslides
137820	3.6	basalt	Thin section through Tertiary basalt boulder	5426652	501550	Propperty no. 1416

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