Erosion Tests on Loess Silt, Banks Peninsula, N.Z.

Expériments sur l'Erosion de Loess, Banks Peninsula, N.Z.

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SYNOPSIS The natural erosion processes in loess include, (1) subsurface seepage with tunnel formation and ultimate collapse into gullies, (2) surface soil creep on steeper slopes which generate slips and shallow slides. The incedence and severity of erosion varies from place to place in soils which appear to be similar, but have significantly different characteristics and behaviour. Subsurface tunnel formation is strongly influenced by the dispersive and slaking tendencies of the soil. For engineering work in urban development on loess hill slopes it is important to know the potential and possible behaviour of the upper two or three metres of the soil. The erosion properties of "undisturbed" samples have been investigated by a simple test which can be used to identify areas, that may be unstable and create future slope problems. The test measures the combined effect of dispersion and slaking and indicates the extent to which the soil becomes unstable with saturation.

INTRODUCTION

Studies of surface soils have identified a wide range of micro-types of soil exposed on the surface, Fitzgerald (1966) and Griffiths (1973).

In most places the top two metres of soil comprise three layers which have been designated by Hughes (1970) as -

(1) The S layer comprising about 170mm of topsoil and 200mm of friable pale yellow silt

(2) The C layer which is very firm, dense and compact. This varies in thickness from about 400mm to 1.5 to 2 metres. In some places this layer shows extensive and deep shrinkage cracking and in other places cracking is less noticeable.

(3) The P layer or 'parent material' which is generally less dense than the C layer and also tends to erode more readily.

Site examination of cut banks generally reveals whether the S, C and P layers are all present and their thicknesses.

Four ways have been observed by which the soil moves under the action of water.

(1) Soil creep of the surface layer with movement on top of the C layer after extreme saturation

(2) Surface slides which occur in conjunction with soil creep on the steeper slopes

(3) Subterranean seepage with tunnel

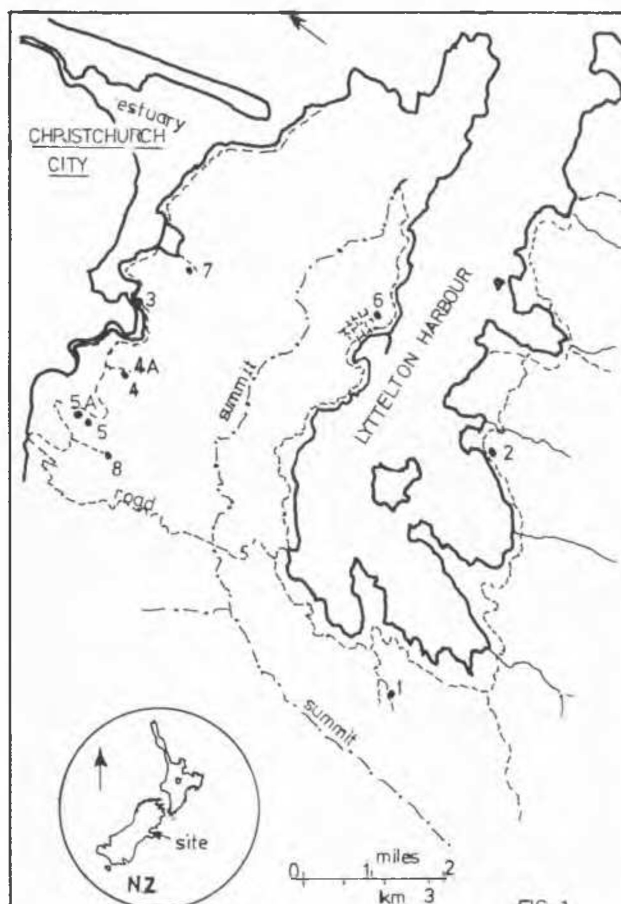

Fig. 1 Locations of sites.

formation either above or below the C layer

(4) Surface gullying generally caused by the collapse of subterranean tunnels, but sometimes associated with shallow surface slides.

All these erosive actions are time dependent and influenced by many identified factors including climate, topography, stratigraphy, physical properties, chemical properties and mineralogy. These factors may not all be significant at any one place and there are other contributing factors, such as slope aspect, vegetation, stock and human activities which can influence the rate of erosion.

For engineering studies it is possible to reduce the significant characteristics to - dispersion and slaking behaviour; shrinkage cracking and slope gradients. Particle size distribution and density are two properties which can be measured relatively easily and may in some cases have an influence on erosion.

EROSION INFLUENCES

Climate: In general the climate which generates predisposing conditions is one with intermittent dry and wet periods and summer drought. When coupled with poor pasture cover and thin turf there is an increase in dessication with shrinkage cracking in the S and C layers. When high intensity rain follows a dry period the cracks allow rapid penetration of water and this is one of several mechanisms which enable water to penetrate as far as the P layer; Hughes (1970)

Topography: Slope and aspect direction bear some relationship to the proneness to erosion; Hosking (1967), Hughes (1970) and Harvey (1976). Steepness of slope affects soil creep, rate of runoff, and rate of scour in subterranean tunnels and the flatter slopes are less affected. However, tunnel gullying has been observed on a wide range of slopes (14°-28°) and some slopes up to 25°-28° appear to be quite stable. The steeper slopes frequently show soil creep with a characteristic hummocky appearance. The soil creep sometimes degenerates into surface slides of the S layer slipping on the surface of the C layer.

Stratigraphy: The most significant sublayers influencing engineering activities, are the S, C and P layers. These generally comprise the top two to three metres.

Physical Properties: The measurable properties include -

(1) dispersion and slaking which can be measured in a relative way by a pinhole erosion test to provide a classification of the potential erodibility.

(2) Swell and shrinkage contribute largely to the cracking which occurs in the C and sometimes in the S layer.

(3) Particle size distribution indicates the proportions of clay, silt and fine sand and small changes in these may have significant effects.

(4) Permeability of the natural ground is important in that particular seepage velocities are needed to convey very fine clay particles through the coarser matrix in order to initiate subsurface tunnel erosion.

Chemical: The presence of high exchangeable sodium ions have been found to be related to dispersion. In some areas or layers the sodium ions are not present to a high enough concentration to cause dispersion.

Mineralogical: The type of minerals in the clay fraction have a big influence on the shrinkage characteristics with dessication. The swelling and shrinkage properties of montmerillinite are far greater than illite for example. Most of the loess clay is illite, but in some areas there is sufficient montmerillinite present to increase cracking shrinkage to a sufficiently dangerous state to allow water entry to deeper layers.

EROSION PROCESSES

Natural state: The natural forces and climatic influences are promoting a continuing erosion condition. The most insiduous aspect of tunnel erosion is that it is not evident until a collapse of the ground surface occurs after the tunnel has been formed to a size which could be 300-500mm in diameter and run for great lengths down a slope. The erosion activity occurs in relatively short periods of intense activity during and following rainfall.

Depending on the shrinkage characteristics of the C layer the tunnel formation may occur either above or below the C layer. If the C layer has low shrinkage with relatively minor cracking the surface soaking water does not penetrate through but it forms relatively small underground channels in the S layer just on top of the C layer. On the other hand where the C layer has high shrinkage and deep cracks water penetrates through the C layer and enters the more erodible P layer. Where this occurs the eventual results are large tunnels which can keep on eroding downwards and ultimately becomes so large that there is a surface collapse which then creates an erosion gully on the slope surface. When engineering earthworks are made into a loess hillslope the natural drainage and seepage paths are interrupted and it is possible that accelerated erosion will occur. Fig. 3 illustrates the inferred stages of erosion activity which occur in a cut bank.

For engineering works it is obviously necessary to identify the types of loess and stratification. Visually the layers are very similar, but observation of the slumping behaviour is a clue to the type, and more detailed testing in a laboratory is needed to be certain of the behaviour.

(See Figs. 2 and 3)

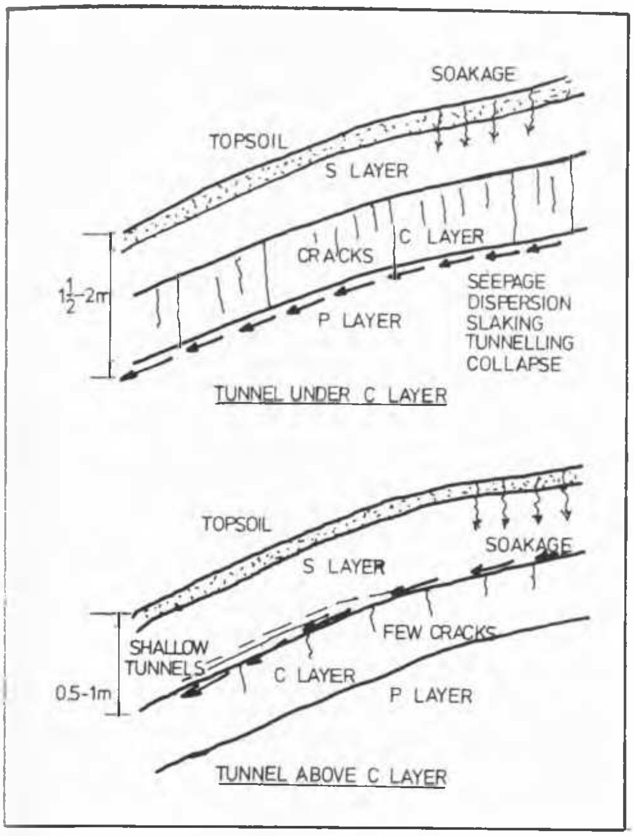

Fig. 2 Subsurface erosion.

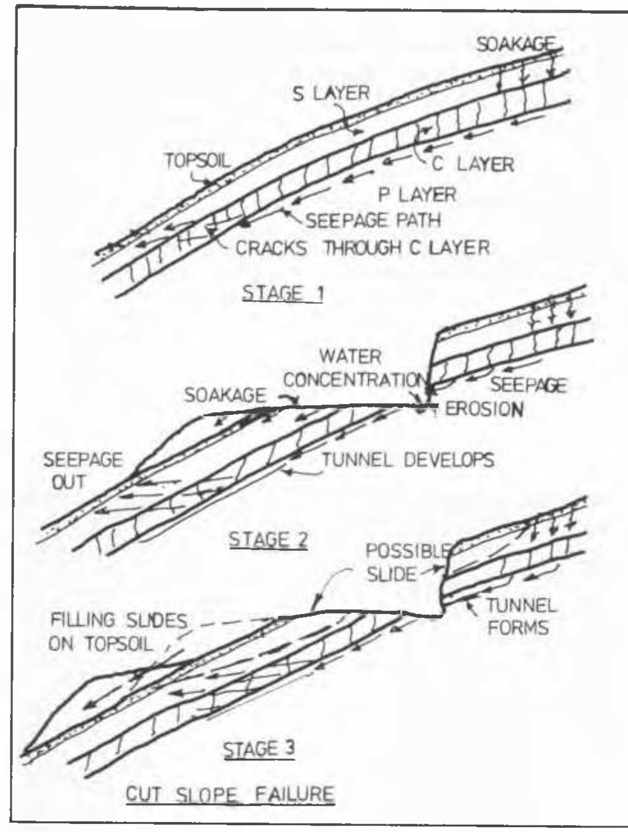

Fig. 3 Slip failure on benchcut slope.

Cracking: The shrinkage cracking has been well established; Miller (1971), as a major contributing factor in deep tunnel formation. The percentage shrinking does not have to be very high to be significant. In a tunnelly area Miller (1971) found that the shrinkage of about 1% was sufficient to create substantial cracks at about 2 metre intervals. In some areas the cracks are much more frequent. The depth of cracking appears to be the main determanent of whether shallow or deep tunnelling is likely to occur.

Dispersion: The Port Hills loess possesses dispersive characteristics which vary from place to place and also vary in the different layers.

Slaking: This is a soil aggregate breakdown in water, affected by the permeability of the soil and its wet cohesion strength.

IDENTIFICATION TESTS

Pinhole Erosion test: A laboratory test was originated by Sherard & others (1975) for the purpose of identifying erodible or piping silt materials in earth dam construction. This test has been modified and adapted so that relatively undisturbed samples can be taken from field sites and used in the test without any further disturbance. Essentially the test consists of drilling a 1mm dia hole through the centre of the sample and passing a flow of water through the hole under controlled head conditions. The rate of flow of water is measured and its colour and sediment noted. The test results have been found to be very repeatable for the same material. The observed factors form the basis for an erodibility classification.

Fig. 4 Field Sampling equipment

Apparatus: The field equipment as shown in Fig. 4 comprises the small sampling tubes (36mm in dia and 83mm long) which are attached to an impact driver for insertion into the ground. Small airtight containers are used to collect small samples of each material for moisture content tests.

In the laboratory the samples of soil in the tubes are trimmed at the ends, measured and weighed to obtain densities and then inserted in the permeability cell after the hole is drilled down the centre. The ends of the sample are protected with plastic mesh and supported with fine pea gravel.

The components of the cell are shown in Fig. 5 which also illustrates a made up cell. This operates basically in the way described by Sherard.

Fig. 5 Components of erosion test cell.

A small head tank is connected to the cell and also a stand pipe to control the head on the sample. Provision is made for the connection of four cells for simultaneous testing.

Other tests: Generally moisture content and dry density were evaluated in connection with the pinhole erosion test. In addition on some samples grain size analysis has been done using hydrometer and other methods. This has provided a closer examination of the clay, silt and sand fractions of the material.

Results: Eight sites were selected (See Fig. 1) which had either stable characteristics or degrees of severity of erosion and these were sampled generally in the S C and P layers, with two samples from each layer.

The sites are described in Appendix I and a summary of test results is given in Appendix II.

SITE CHARACTERISTICS FROM TESTS

Site 1: This material is obviously different from most of the other sites. The material was very sensitive to water and was dispersive, hence likely to be more erodible. Site observation showed this to be the case.

Site 2: The stable part of this bank provided samples which were generally erosion resistant but from an eroded cavity samples showed distinct differences indicating that there was a change in the soil properties which had allowed erosion to occur.

Site 3: This is a very stable bank, but the erosion tests indicate that it has a high erodibility potential: the main reason it remains stable is that very little drainage of water occurs onto it or through it.

Site 4: Serious erosion has occurred on this site. Observation showed extensive shrinkage cracking in the S & C material and extending into the P material. The materials tested, to depths down to 1.5m were relatively resistant to erosion, but these materials were badly cracked and could pass water readily to deeper layers, which are a more erodible material where deep tunnels have formed resulting in gully collapses.

Site 5: Generally in this site shallow small under runners have formed on top of or in the C layer. Tests of this showed erosive characteristics where the tunnels were present, but not where there were no tunnels.

Site 6: As in Site 4 there is serious tunnel gully collapse erosion in this area, but this characteristic is not reflected in the pinhole erosion tests. The S & C material is extensively cracked which would allow rapid water entry and quick breakdown of the material. There is a relatively high fine sand content and a much higher sand-silt ratio than other samples. The under-runners were initiated in P material at a level deeper than the lowest test. Some of the deeper samples were not testable because of fine cracking.

Site 7: This is a stable hill slope with a relatively shallow (up to 1.5m) layer of surface loess over rock. No cracks were evident, but conditions were damp. The pinhole tests indicate that the S & C materials are relatively resistant to erosion.

Site 8: No erosion tests have been completed for this site, but field observation indicates that quite stable conditions occur, with only a very few small under runners.

GENERAL CONCLUSIONS

The modified pinhole erosion test when coupled with density measurements and field observation, can identify the loess material into its respective layers and in the main it can provide a very good indication of the potential erodibility of the material.

The erosion test has shown that; (1) the S layer material is generally resistant to erosion but may pass seepage water. (2) The C layer material is variable in its characteristics being sometimes erosion resistant but cracked, and hence can allow water penetration; it is sometimes relatively uncracked and may be erosion resistant or erodible. (3) The P layer material is generally more erodible and if this material underlies a cracked C layer material it is likely that deep tunnel gullies will form.

The average densities of the different layers are quite distinctive although there is an overlapping range of values. The S material with an average dry density of 1.537 T/m^3 (96.0 lbs/ft^3) is the least compact of the three layers, whereas the C layer with an average dry density of 1.554 T/m^3 (103.2 lbs/ft^3) is the most compact. The P layer average dry density at 1.559 T/m^3 (97.3 lbs/ft^3) is slightly higher than the S layer density. It is apparent that density is not related to erosion resistance as the S layer material is generally the least erodible, the C layer quite variable and the P layer generally erodible.

Grain size distribution: Hydrometer methods were used for this determination on eighteen samples. Wide variations were found in each constituent size. The range for clay was 8.6% to 26%; for fine silt 1.8% to 12%; for medium silt 10-20%; for coarse silt 31-50%; and for fine sand 8-47%: There appears to be no strong relationship between the percentages of any particular size range or ratio of sizes, and the erodibility characteristics. There was a general tendency for the clay/silt ratio to increase slightly and the sand/silt ratio to decrease with greater degree of erodibility, but there were several exceptions to this. It seems that grain size distribution considered on its own is not a factor which can be related directly to the erosion characteristics of the loess.

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APPENDIX I

Site Descriptions: The site locations are shown in Fig. 1. These sites were selected because of differing erosion characteristics. The S, C & P layers at each site were sampled and tested with the pinhole erosion test and grain size analysis, to find a correlation between the erosion situation and the test results. Most inspecting and samplings were done in late summer, under dry conditions.

Site 1: Allendale Valley

This is a cut bank on a road side with hill slope aspect to the North. Slumping of cut banks is prevalent in this area. Shrinkage cracks occur in the S layer and partly into the C layer, below 550mm deep.

Site 2: Church Bay

(1) This is a road side cutting, with hill slope aspect to N.W. The vertical surface of bank 3.8m high is stable but with some fluted erosion on the surface. The S layer is 650mm deep and C layer to 1.4m below the surface but various firm layers were present to 3.0m below surface. Shrinkage cracks were present in S, C & P layers up to 1mm wide at approximately 1.50m centres with many fine cracks in C layer at about 50mm centres.

(2) In the same bank, where it is 6m high, one large erosion cavity had occurred. The top of the cavity is about 1m below the top of the bank and the bottom of the cavity at road surface. The cavity is some 5m high, 1m wide and enters the face by 2½ to 3 metres. Samples from the cavity wall were taken to find erosion differences.

Site 3: Ferrymead Terrace

This was a new excavation with a bank about 7m high, nearly vertical and very stable, but with a small damp patch in the P layer at 4.0m below the top. The hill slope has a northwest aspect and is well drained. The S layer is about 800mm below surface and the C layer to 4.0m below surface.

Site 4 and 4A: No. 22A Avoca Valley Road

This site is on the West side of a valley and the hillslope has a north easterly aspect. The general slope is about 18-23½°. The slope surface is very seriously eroded with active tunnel gullies over 2m deep. The S layer is 320mm deep with C layer down to about 1.40m. Shrinkage cracks are present in the S and C layers. Samples at Site 4 were taken to a depth of 2m from an exposed vertical face of a collapsed tunnel gully. The C layer has cracks up to 2mm wide at about 130-140mm centres vertically and horizontally with finer cracks at 10-15mm centres. In the P layer at depth of 1.5m fine close cracks are apparent. Samples were taken to a depth of 2.7m in the P layer in Site 4A on a cut bank.

Site 5: Glenelg Subdivision

This is a new cut bank about 3m high and nearly vertical in a hill slope of $17\frac{1}{2}^{\circ}$ with an easterly aspect. The S layer is 330mm deep and C layer down to 700mm below surface. Soil creep is apparent in places on the hill slope but not serious. Several shallow under runners occur near the sampled area with elsewhere on the slope a very few deep erosion gullies. No cracks are apparent in the S layer, but the C layer was very hard and dry with cracks up to 1mm wide at 15-20mm centres. Cracks were generally vertical but a few horizontal cracks had allowed material to drop out from the face in small blocks. There are a few fine tight cracks in P layer.

Site 5A: Glenelg Subdivssion

This is the same hillslope as Site 5 and about 20m from it. The S layer is 400 to 700mm deep and the C layer base at 950-1340 below the surface. Samples were taken after rain, when the bank was saturated. Some cracks were ppparent in the S layer but not in the C layer. There was a water seepage at a level about the centre of the C layer at 700mm deep.

Site 6: Lyttelton

Serious tunnel gully erosion occurs on this South facing slope to depths of about 2.5m or more in the area sampled. There is active erosion on slopes of 16°-22° but other parts of the hillside with slopes of 19°-23° were stable because of relatively shallow loess over rock. The S layer is 450mm deep with cracks of about 0.5mm at 100 to 150mm centres, and the C layer is to a depth of about 850mm with cracks greater than 1mm wide at 150 to 200mm centres. Below this level the material was hard and dry with some fine cracks. Tunnelling had occurred at depths greater than the deepest sample point for the erosion test (1.6m)

Site 7: Soleares Avenue

Hill slope on the West side of valley with a generally easterly aspect. The slope is 29° and appears quite stable except for a some soil creep and a small slide which was sampled for the erosion tests. Rock is relatively shallow, being generally about one meter or a little more below the surface In a few places seepage water on the rock surface has caused some small tunnel gullies. At the slipped face the S layer is 640mm deep and C material is down to about 900mm below the surface. This slide was mainly S material slipping on the harder C layer.

Site 8: Bowenvale Valley

This hillside has an easterly aspect and a slope generally of 21° steepening to 29° where a small surface slide occurred, with some soil creep evident in the steeper areas. Samples were taken from the bank of a cut track across the slope. The S layer is 550mm deep and the C layer down to 1.10m below surface. A few wide cracks 2-3mm and some small under runners occur in the top of the C layer. The slope has a generally stable appearance.

APPENDIX II - Summary of Test Results: Grain size distribution - hydrometer analysis

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
S	450	26	10	16	38	64	10	.41	.16
C	1300	16	12	20	36	68	16	.24	.24
P	2500	17	9	18	38	65	18	.26	.28

Table I - Site 1: Allendale Valley.

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
S	100	20	9	17	36	62	18	.32	.29
S	700	20	6	19	36	61	19	.33	.31
C	1700	19	3	16	37	57	25	.33	.43
C	2000	26	8	16	38	62	12	.42	.19
C	3000	20	4	16	42	62	18	.32	.29
P	4000	18	8	17	43	68	14	.26	.21
P	4000	15	7	12	50	69	18	.22	.26
P	4000	14	10	16	50	76	10	.18	.13
P	4000	10	7	18	47	72	18	.14	.25
P	4000	12	6	18	50	74	15	.16	.20
P	4400	20	8	20	39	66	14	.30	.21

Table II - Site 3: Ferrymead Terrace.

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
C	830	25	6	18	42	66	9	.38	.13
P	2000	9	2	10	32	44	47	.21	1.05

Table III - Site 4: Avoca Valley.

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
S	300	17	8	17	34	59	24	.29	.41
C	630	22	7	15	47	69	9	.32	.13
P	1450	8	3	12	31	46	46	.18	1.0

Table IV - Site 5: Glenelg.

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
S	250	10	5	19	41	65	26	.16	.40
S	250	24	10	16	26	51	24	.46	.46
S	330	15	6	15	39	59	26	.25	.43
C	670	17	8	19	38	65	19	.26	.29
C	850	20	6	19	37	62	18	.32	.30
C?	1400	21	7	22	40	69	10	.30	.14
C?	1600	22	7	19	41	67	11	.33	.16
C?	1780	30	6	18	26	50	20	.6	.40
P?	2130	23	6	17	27	50	27	.46	.54

Table V - Site 6: Lyttelton

Soil layer	Depth (mm)	Clay %	Silt% fine	Silt% med.	Silt% crse	Total %	fine sand	Ratio clay silt	Ratio Sand silt
S	350	21	6	18	45	69	10	.30	.14
S	450	19	6	15	42	63	18	.30	.29
C	500	22	6	16	46	68	10	.32	.15
P	1800	19	9	17	47	73	8	.26	.11

Table VI - Site 8: Bowenvale

Dry density and Erosion Classification:

The classifications for erodibility are similar to those adopted by Sherard (1975) and are summarised as follows:

D1, D2   Dispersive soil, very erodible

ND3, ND4 non-dispersive, but erodes slowly

ND1, ND2 non-dispersive, not colloidal and more resistant to erosion.

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	500	-	-	D
C/P?	3000	-	-	D1

Table VII - Allendale Valley.

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	500	1.454	90.73	ND1
	500	1.569	97.9	ND1
C	1150	1.593	99.4	ND2
	1150	1.60	99.8	ND2
P	3100	1.607	100.28	ND3
	3100	1.52	97.47	ND3
Side of erosion cavity				
C	1300	1.54	96.1	-
	2400	1.589	99.1	D2
	3400	1.60	99.8	D1

Table VIII - Church Bay.

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	700	1.479	92.3	ND2
	700	1.542	96.2	ND2
C	1700	1.609	100.4	ND3
	1700	1.564	97.6	ND3
P/C?	4000	1.636	102.1	D1
P	4400	1.527	95.3	D1
P	4500	1.583	98.8	D1

Table IX - Ferrymead Terrace

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	280	1.573	98.2	ND1
C	790	1.650	102.9	ND1
C	1200	1.574	98.2	ND2
P	1690	1.498	93.5	D1
P	2250	1.493	93.2	ND4
P	2730	-	-	D2

Table X - Avoca Valley (4A)

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	300	1.593	99.4	ND1
C	830	-	-	ND1
C/P?	1400	1.678	104.7	ND3
P	2000	1.558	97.23	ND2

Table XI - Avoca Valley (4)

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	290	1.389	86.7	ND1
S	300	1.563	97.53	ND1
C	630	1.826	113.9	ND3
P	1450	1.325	82.7	ND3
P	1750	1.386	86.5	ND1

Table XII - Glenelg (5)

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	340	1.458	90.9	ND2
S	580	1.625	101.4	ND1
C	600	1.552	96.8	ND1
C	920	1.734	108.3	ND1
P	1200	1.572	98.1	ND2
P	1580	1.537	95.9	ND4
P	2170	1.536	95.8	ND3

Table XIII - Glenelg (5A)

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	250	1.750	109.25	ND1
	330	1.491	93.04	ND1
C?	670	1.612	100.6	-
C	850	1.748	109.1	ND1
C?	1400	1.723	107.5	-
	1520	1.79	111.7	-
C?	1600	1.763	110.0	-
	1680	1.82	113.62	-

Table XIV - Lyttelton

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	550	1.688	105.4	ND1
C	860	-	-	ND2
C	860	1.513	94.4	ND2
P	970	-	-	ND3
P	1000	1.625	101.4	ND3

Table XV - Soleares Avenue

Soil layer	Depth (mm)	Density T/m^3	Density lbs/ft^3	Classification
S	300	1.606	100.3	-
S	350	1.51	94.3	-
S	450	1.56	97.3	-
C	500	-	-	-
P	1800	1.78	111.2	-

Table XVI - Bowenvale

Density Summary: The densities for each soil layer have been averaged with the following results -

	T/m^3	lbs/ft^3
S layer	1.537	96.0
Range	1.389 - 1.625	86.7 - 101.4
C layer	1.554	103.2
Range	1.513 - 1.880	94.4 - 117.3
P layer	1.559	97.3
Range	1.325 - 1.710	82.7 - 106.7