University of Southern Queensland
Faculty of Engineering and Surveying

ATTERBERG LIMITS AND THEIR RELATIONSHIP TO LONGITUDINAL CRACKING IN GRANULAR PAVEMENTS

A dissertation submitted by

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Abstract

Australia has approximately 300,000km of sealed roads and maintenance of these roads imposes a significant financial burden on road agencies. Premature pavement failure exacerbates this burden.

Longitudinal pavement cracking often occurs independent of traffic loading and may be attributed in many instances to moisture changes in expansive subgrade soils. This project investigates a possible relationship between the Atterberg limits of low strength subgrade materials (CBR < 3) and the incidence of longitudinal cracking in unbound granular (flexible) pavements supported by them.

Unbound granular pavements are the most common form of pavement construction in Australia. Design of these pavements is undertaken in accordance with individual authorities' empirical design charts. These design charts are usually presented as a series of curves whereby the depth of pavement is set by the relationship between subgrade strength, expressed in terms of a four day soaked California Bearing Ratio (CBR) and traffic loading over the pavement's design life, expressed in Equivalent Standard Axles (ESAs). These charts typically provide pavement depths for subgrade CBR values of 3 and above. Where the subgrade CBR is less than 3, the guidelines recommend an additional depth of pavement gravel depending on the CBR.

The primary objective of this research is to determine if any of the Atterberg limits can be used as a predictor of longitudinal cracking in unbound granular pavements designed in accordance with authority guidelines. This would enable consultants and authorities to determine if alternate methods of pavement construction should be considered (using tensile reinforcement for example) in lieu of unbound granular construction.

Analysis of results indicated that a relationship exists between two of the Atterberg limits of a subgrade material and longitudinal cracking in unbound granular pavements designed in accordance with existing authority empirical design charts. Due to the small sample size, recommendation on specific values of these limits to determine when alternate pavement designs should be considered would be premature.

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Signature

Date

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Glossary

Asphalt

A mixture of bituminous binder and aggregate with or without mineral filler, produced in a mixing plant and delivered, spread and compacted hot.

Asphaltic Concrete (AC)

Asphalts where the aggregate is well graded and the primary load carrying medium. The aggregate forms the supporting structure within the layer.

Bound material

Granular material to which a binder of lime, cement, bitumen or similar is added to improve structural stiffness.

Boxed pavement

Is a type of pavement construction where the pavement is constrained at both edges and does not cover the full width of formation. For urban roads the constraint is provided by kerb and channel. Where the subgrade is impermeable, boxed construction can form a water trap which can lead to moisture related problems with the pavement.

Capping layer

A layer that provides cover over an in-situ material that has a design CBR of less than 3% but not less than 1%.

California Bearing Ratio (CBR)

The ratio between a test load and an arbitrarily defined standard load, expressed as a percentage. This test load is required to cause a plunger of standard dimensions to penetrate into a specifically prepared soil specimen at a specified rate.

Cover over reactive subgrade

A thickness of material beneath the lowest pavement layer intended to reduce water induced volume change effects on the pavement where there are in-situ materials with the potential for water induced volume change. Cover thickness may include any working platform, select fill, capping layer and/or drainage layer.

Equivalent Standard Axles (ESAs)

The standard axle is a single axle, with dual wheels on each side of the axle, that carries a load of 80 kN. The design traffic is expressed in terms of the number of standard axle load repetitions (in one lane) which are equivalent in destructive effort to the total number of repetitions of actual axles loading the pavement during the design period.

HILI pavement

High Load Intensity, Low intervention pavement. These pavements include all pavements with concrete or dense grade asphalt base or subbase layer. Refer Table 2.3.2 of the *QLD Department of Transport and Main Roads Pavement Design Manual (2009)* for a full list of HILI pavements. These pavements are not unbound granular pavements.

Unbound granular pavement

Also known as flexible pavement. A pavement which obtains its load spreading properties mainly from mechanical interlock, cohesion between particles and intergranular pressure in the pavement material.

Unified Soil Classification System (USCS)

Soil classification system initially developed by Arthur Casagrande and used to describe the texture and grain size of a soil. The classification system comprises 15 soil groups with each represented by a two-letter symbol. The first letter represents the type of soil and the second letter represents the plasticity of the soil.

Untreated subgrade

Natural unprocessed material, other than that moved from another location and/or compacted at the location.

Water induced volume change

Change in the volume of the subgrade material resulting from a change in water content usually on a reactive subgrade material.

Working platform

A layer that is part of the subgrade and which provides access for construction traffic, a platform on which to construct the pavement layers and protection to the underlying materials.

1. Introduction

1.1 Outline

Due to the large area and low density of population, Australia relies heavily on road transport. The network of local, state and federal roads is an essential element of the Australian transport network.

Australia has approximately 800,000km of roads, of which approximately one third are sealed. The Austroads *Guide to Asset Management Part 1: Introduction to Asset Management* (Austroads 2010) states the total replacement value of roads in Australia and New Zealand is in the order of 150 billion dollars. This equates to approximately 50% of the total government capital investment in education, health, energy, mining and manufacturing combined.

Road pavement maintenance imposes a significant financial burden on road agencies and premature pavement failure exacerbates this burden. Expansive subgrades damage road pavement quality and performance. This poor quality and performance significantly affect the service life of a road, its load carrying capacity, vehicular fatigue the safety and comfort of road users and the amenity of the surrounding population and environments.

Various pavements have been trialled extensively on the expansive subgrades found in the Ipswich City Council area and some of these have lasted only 3 years prior to longitudinal cracking failure (Crone, 2009).

The longitudinal cracking of pavements is referred to in Austroads *Guide to Asset Management Part 5E: Cracking* (Austroads 2006) as environmental cracking. This guide reports that environmental cracking (e.g. linear cracking and block cracking) is mainly non-load related and does not require trafficking to occur. Such cracking can occur due to moisture changes in expansive subgrades.

Figure 1.1 shows a typical example of non-load related longitudinal cracking of an unbound granular pavement with thin bituminous surfacing.

Figure 1.1 – Longitudinal cracking due to expansive subgrade

Austroads *Guide to Asset Management Part 5E: Cracking* (Austroads 2006) reports that cracking of pavements is generally attributed to two principal causes:

- Environmental (non-load related)
- Traffic loading (load related)

This is further supported in the Queensland Department of Main Roads *Pavement Design Manual* (2009), which states that as a consequence of changes in water content, subgrades with reactive clays can experience considerable volume change that can disrupt the pavement in a number of ways, including:

- Surface deformation
- Pavement deformation

- Cracking

The term 'flexible pavement' is applied to all pavement structures other than those described as rigid pavements, including unbound pavements with thin bituminous surfacing and bound (stabilised and asphalt) pavements. The most common form of sealed flexible pavement used in Australia is the unbound granular pavement (Austroads *Guide to Pavement Technology*, 2009).

Design of unbound granular pavements is undertaken in accordance with charts published or referenced by each authority. These design charts are a series of curves which recommend a depth of pavement based on the input parameters of subgrade four day soaked California Bearing Ratio (CBR) and cumulative traffic loading expected over the life of the pavement measured in Equivalent Standard Axles (ESAs). The charts typically start at a subgrade strength of CBR 3. Figure 1.2 shows the light traffic design chart from the Australian Road Research Board's (ARRB) *Sealed Local Roads Manual*.

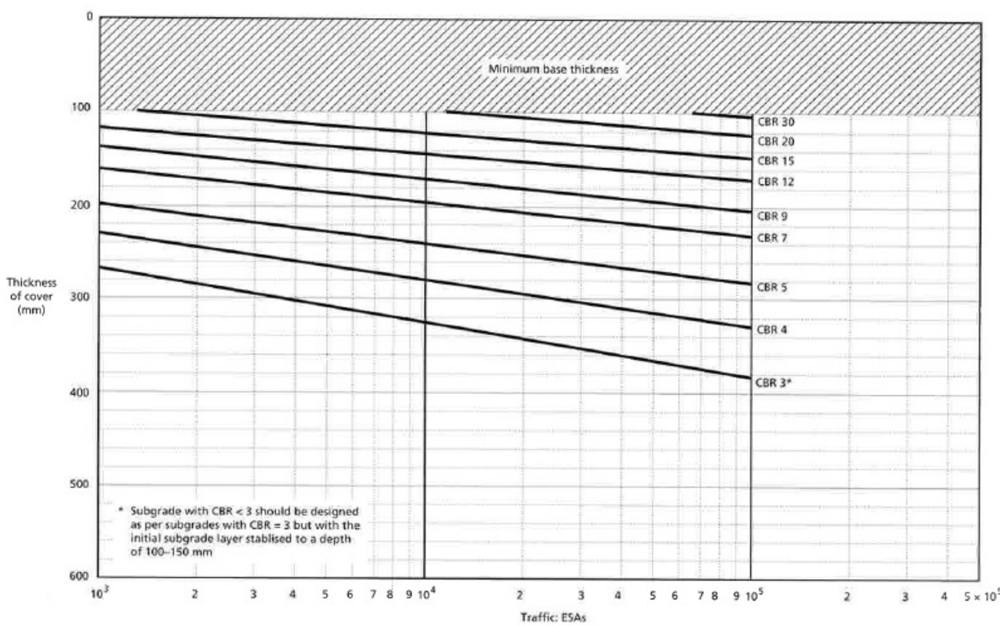


Figure 1.2 – Pavement Design Chart (Source: ARRB Sealed Local Roads Manual, 2005)

Where the soaked CBR value of the subgrade is lower than the limit provided on the chart, the authority guidelines typically advise a thickness of additional granular material. The depth of additional pavement material recommended in these guidelines is related directly to the soaked CBR value of the subgrade and does not consider the expansive nature of the subgrade material. The note located in the bottom left corner of Figure 1.2 is an example of this type of recommendation.

A history of the development of these design charts is included in section 3.2.1 and a brief summary of current design guidelines is included in section 3.2.2.

This research has focused on local authority roads (residential streets) in the south east Queensland corner for ease of accessing sites to collect samples and ability to collect samples from lower speed environments.

1.2 Aims and Objective

This project aims to investigate a possible relationship between the Atterberg limits of low strength subgrade materials, where CBR is less than 3, and the likelihood of longitudinal cracking in full depth granular pavements.

The Atterberg limits proposed to be investigated are the Shrinkage Limit, Plastic Limit, Liquid Limit and Plasticity Index.

The primary objective of this research is to determine if any of the Atterberg limits can be used as a predictor to longitudinal cracking. This would enable consultants and authorities to determine if alternate methods of pavement construction should be considered (using tensile reinforcement for example) in lieu of full depth granular pavement.

A secondary objective of this research is to propose a procedure for full depth granular pavement design on low strength subgrade soils that incorporates an assessment of relevant Atterberg limit(s) as well as subgrade CBR to determine if a full depth granular pavement is appropriate.

Much research has been directed into the study of what types of pavements should be constructed and what methods of construction methods should be adopted when building roads on expansive soils. The fundamental aim of this research is to consider when these methods should be adopted or when the current authority empirical design charts should not be used.

1.3 Dissertation Overview

This dissertation consists of seven chapters presented as follows:

Chapter 1 provides an introduction to the subject matter, identifies the aims and objectives of the research and explains the significance of the project.

Chapter 2 presents an overview of consequential effects and ethical issues associated with the research.

Chapter 3 provides some background on pavement construction methods, pavement design and pavement failure modes. This chapter also presents a literature review on unbound granular pavement design.

Chapter 4 describes the methodology adopted for undertaking the research including proposed sampling methods, ranking of pavement damage and investigations into the original pavement designs.

Chapter 5 is a series of tables showing the raw laboratory test results obtained from the collected samples.

Chapter 6 describes the analysis undertaken of the raw data

Chapter 7 presents a summary of the conclusions reached from analysis of the field test results and makes recommendations for future research.

Chapter 8 is a list of references used in the research.

2. Assessment of Consequential Effects

An assessment of sustainability and ethical issues associated with this research are explored in this Chapter and safety issues have been assessed in Appendix D.

2.1 Sustainability

The primary objective of this research is to determine if the most common form of pavement construction in Australia is the most appropriate form of construction on areas of low subgrade soil strength. More appropriate pavement construction methods may include pavements with cement or lime stabilised courses or the inclusion of a geogrid to improve the tensile strength of the pavement.

Adopting the most appropriate type of road pavements in areas with low strength subgrades would reduce the amount of pavement rehabilitation required during the life of the pavement.

Rehabilitation measures for pavements suffering longitudinal cracking varies from mastic filling of cracks to removal and reconstruction of the full pavement profile.

Pavement gravels and asphaltic concretes are manufactured from quarried materials and their excavation and production affects local environments when obtaining materials and requires significant amounts of energy during production and delivery to site.

Any reduction in pavement rehabilitation would result in savings of resources and energy.

2.2 Ethical Responsibility

The project work is proposed to be undertaken in an ethical manner to ensure that the results of testing are reliable and not affected by expected outcomes.

All testing for the project is proposed to be in accordance with current Australian Standards by NATA registered laboratories.

3. Background and Literature Review

3.1 Pavement Construction

A road pavement is designed to withstand repetitive loads applied to it by heavy vehicles for the duration of its design life while maintaining a good ride quality, safe skid resistant surface and adequate drainage. The surface needs to resist horizontal and vertical stresses to maintain its integrity.

Unbound granular pavements are constructed on compacted natural soils in layers of graded pavement gravels. The cross section of an unbound granular pavement typically consists of one or more sub-base layers, a base layer and a wearing course. The interface between pavement gravels and existing soil is referred to as the formation. The in-situ soil over which the pavement is constructed is called the subgrade.

The construction of an unbound granular pavement starts with the preparation of the existing soil to form a suitable foundation for constructing the rest of the pavement.

Figure 3.1 shows a typical road pavement cross section and pavement profile. The left hand side of the cross section shows a typical rural road construction and the right hand side of the section shows a typical urban road construction. The function of each layer in a typical urban pavement is described below.

The primary functions of the thin bituminous wearing surface are to provide a skid resistant surface while resisting applied traffic loadings and environmental conditions.

Base and sub-base pavement layers are blended materials and constituent materials may include natural gravels, crushed rock, sand and clay. The main function of the base and sub-base layers in the pavement is to distribute traffic induced stresses to the courses below including the subgrade.

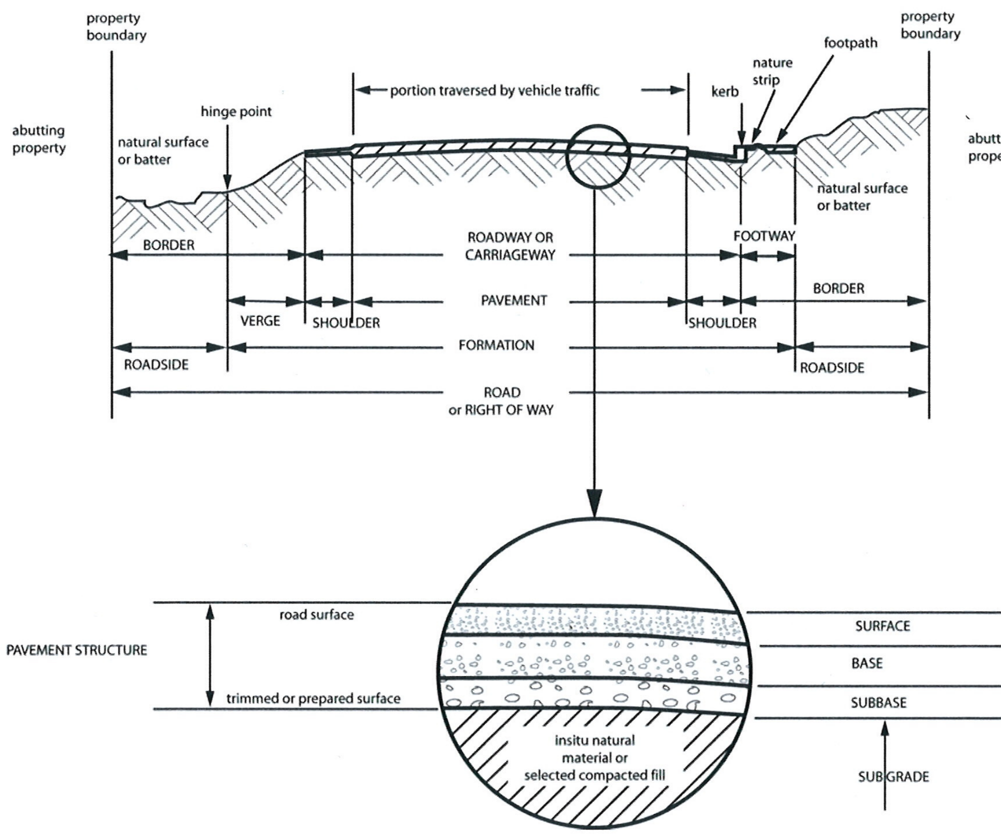


Figure 3.1 – Pavement Structure Formation (Source: Austroads Guide to Pavement Technology Part 1: Introduction to Pavement Technology)

Moisture control of subgrades is typically provided to rural roads by constructing the pavement above the surrounding area. If this is not possible, table drains are cut parallel to the pavement to provide a channel for draining water between the subgrade and sub-base pavement layer.

As urban roads typically utilise a boxed construction for aesthetic reasons and management of overland stormwater drainage, subgrade moisture is controlled by the use of longitudinal side (subsoil) drains and pavement mitre drains. Figure 3.2 shows the Brisbane City Council's preferred side drain arrangement for new urban roads.

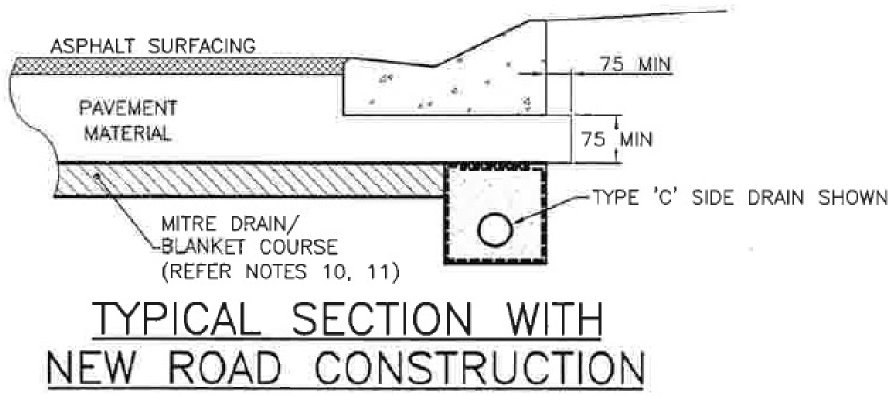


Figure 3.2 – Urban Pavement Subsoil Drainage (Source: Brisbane City Council Standard Drawing UMS261, Revision B, March 2005)

3.2 Pavement Design Literature Review

The design of unbound granular pavements refers to the process of selecting the total depth and granular materials to be used in the pavement profile. As unbound granular pavements are constructed in layers, this process also refers to the process of determining the thickness and material to be used in each layer. The thicknesses and materials for each layer are selected for their ability to resist applied traffic loadings for the life of the pavement and spread these loads to minimise deformation of the natural subgrade material.

3.2.1 History of the CBR-Thickness Traffic Design Chart

In the late 1930's and early 1940's O.J. Porter developed the California Bearing Ratio (CBR) test and subsequently the CBR method thickness design curve from empirical data.

Porter's chart, shown in Figure 3.3, was based on a review of California State Highways over the period 1929 to 1938. Davis (1949) reports that Porter found that soil having a certain CBR always required the same thickness of flexible macadam pavement construction to prevent plastic deformation of soil for a given quantity of traffic.

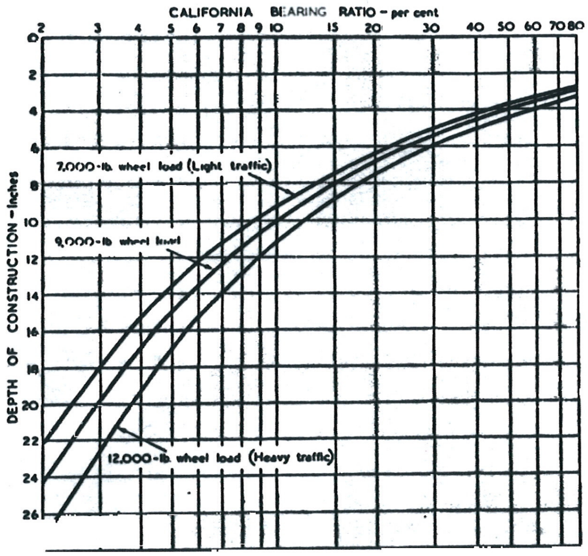


Figure 3.3 – California State Highway Department 1940's CBR method thickness design curve (Source: Technical Basis of Austroads Guide to Pavement Technology Part 2: Pavement Structural Design, 2008)

The Country Roads Board of Victoria (CRB) was a pioneering Australian authority in the development of flexible pavement thickness design. In the 1940's, the CRB produced a pavement thickness design chart based on Porter's research and went on to refine the chart during the 1940's to take into account the cumulative effect of pavement damage due to the design period, traffic growth rate, climatic factor (based on average rainfall) and pavement width.

In 1959 the New South Wales Department of Main Roads produced a thickness design chart (Figure 3.4 - George and Gittoes 1959) which closely resembles the current design chart in the Austroads Guide with an exception that traffic loading was expressed in terms of repetitions of a 5,000lb wheel load.

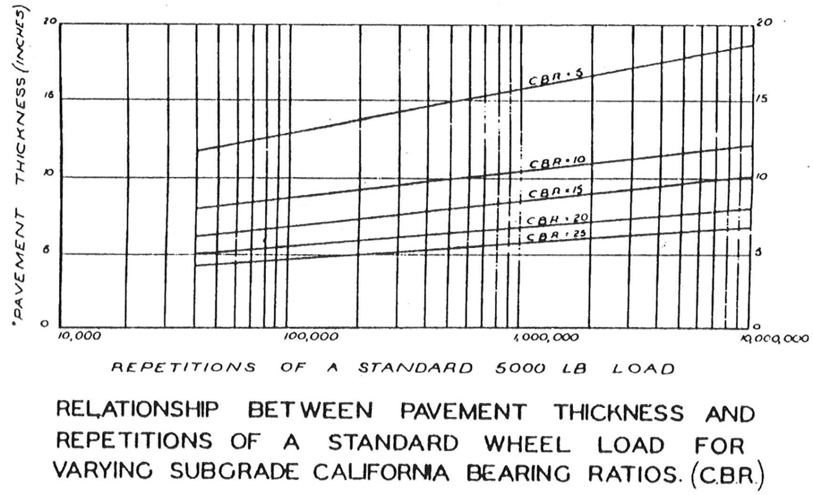


Figure 3.4 – NSW DMR thickness design curve (Source: George and Gittoes 1959)

The 1969 edition of the "*Technical Bulletin No.26 – The Design of Flexible Pavements*" published by the Country Roads Board of Victoria included a defacto method of using Atterberg limits in the design of flexible pavements. Part A of technical bulletin No.26 provided a number of alternate methods to estimate the CBR value of soils from simple soil tests.

Appendix 3 of Part A provided tables for estimating CBR values of soils from their particle grading and linear shrinkage values and an example of these tables is included in Figure 3.5.

APPENDIX 3

Tables for estimating the California Bearing Ratio from the equation

$$\begin{aligned}\text{Log}_{10}\ \text{C.B.R.} = {} & 1.6677 - 0.005056\ (\text{Pass. No.36\%}) + 0.001855\ (\text{Pass. No.200\%}) \\ & - 0.01676\ (\text{Linear Shrinkage \%}) - 0.0003848\ (\text{Linear Shrinkage \%} \\ & \times \text{Pass. No. 200\%})\end{aligned}$$

Table 1.

Values of $\left(0.51765 - 0.00506\ (\%\ \text{Pass. } 36) \right) \times 10^3$

Pass. No. 36%	0	1	2	3	4	5	6	7	8	9
0	518	513	508	502	497	492	487	482	477	472
10	467	462	457	452	447	442	437	432	427	422
20	417	411	406	401	396	391	386	381	376	371
30	366	361	356	351	346	341	336	331	326	320
40	315	310	305	300	295	290	285	280	275	270
50	265	260	255	250	245	240	234	229	224	219
60	214	209	204	199	194	189	184	179	174	169
70	164	159	154	149	143	138	133	128	123	118
80	113	108	103	98	93	88	83	78	73	68
90	63	58	52	47	42	37	32	27	22	17

Figure 3.5 – Table for estimating CBR from Linear Shrinkage (Source: Country Roads Board of Victoria - Technical Bulletin No.26)

Figure 3.6 has been taken from Appendix 4 of the technical bulletin and it shows tables provided for estimating CBR values of soils from their particle grading and linear shrinkage values.

APPENDIX 4

Tables for estimating the California Bearing Ratio from the equation

$$\log_{10} \text{C.B.R.} = 1.886 - 0.003{,}717\ (\text{Pass } 7\%) - 0.004{,}495\ (\text{Pass } 36\%) + 0.005{,}153\left(\frac{\text{Pass } 200}{\text{Pass } 36}\%\right) - 0.000{,}045{,}62\left(\frac{\text{Pass } 200}{\text{Pass } 36}\%\right)^2 - 0.014{,}29\ (\text{Plasticity Index})$$

Table A.

Values of $\left(0.486 - 0.003717\ (\%\ \text{Pass } 7)\right) \times 10^3$

Pass 7%	0	1	2	3	4	5	6	7	8	9
0	486	482	479	475	471	467	464	460	456	453
10	449	445	441	438	434	430	427	423	419	415
20	412	408	404	401	397	393	389	386	382	378
30	374	371	367	363	360	356	352	348	345	341
40	337	334	330	326	322	319	315	311	308	304
50	300	296	293	289	285	282	278	274	270	267
60	263	259	256	252	248	244	241	237	233	230
70	226	222	218	215	211	207	204	200	196	192
80	189	185	181	177	174	170	166	163	159	155
90	151	148	144	140	137	133	129	125	122	118

Figure 3.6 – Table for estimating CBR from Plasticity Index (Source: Country Roads Board of Victoria - Technical Bulletin No.26)

Part B of the technical bulletin provided CBR – Thickness design charts to size pavements. The part B charts included provision for sizing pavements on subgrades with CBR values of 2. For subgrades with lower CBR values, technical bulletin No.26 recommended the application of hydrated lime at a rate of 5% and lowering side drains to a minimum depth of six feet.

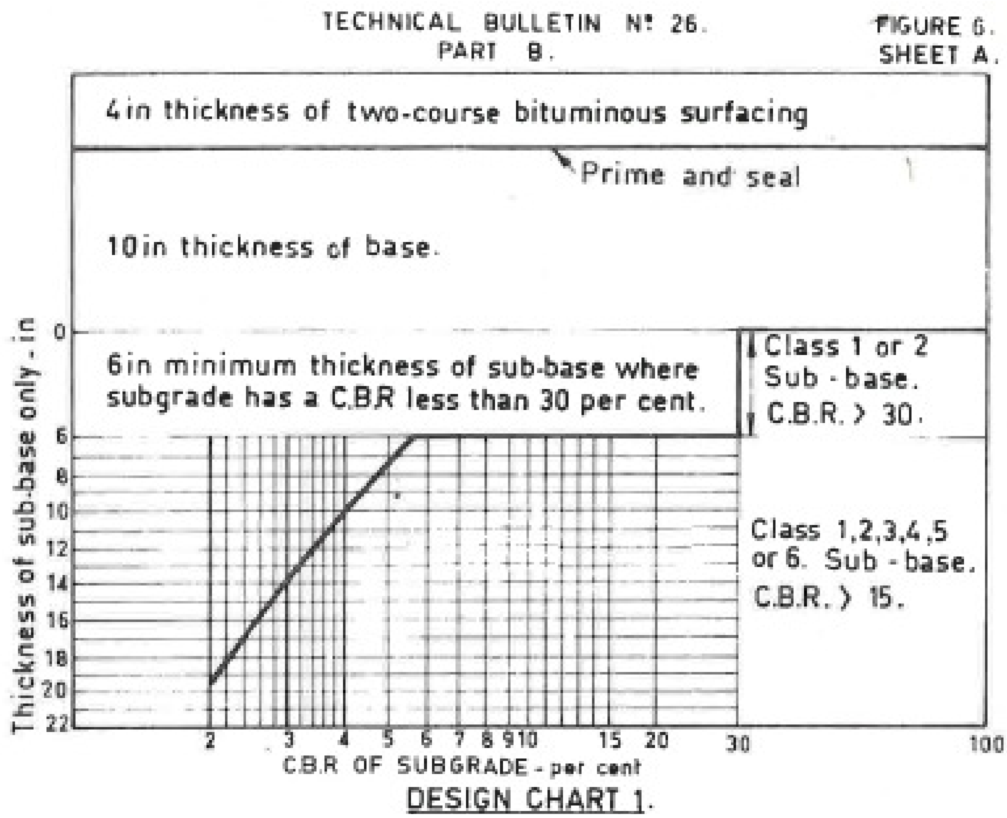


Figure 3.7 – CBR – Thickness Design Chart (Source: Country Roads Board of Victoria - Technical Bulletin No.26)

The *Interim Guide to Pavement Thickness Design* (IGPTD) was the first document relating to pavement design produced by the National Association of Australian State Road Authorities (NAASRA) and was published in 1979. The IGPTD was proposed to be a design procedure that would predict a pavement thickness that would not deteriorate beyond a tolerable level of serviceability within a chosen design period.

The IGPTD was based on a comparison of empirical design charts with the final design charts developed by the mechanistic procedure of linear elastic modelling and analysis of each granular layer to estimate its maximum deflection under a Standard Axle.

This linear elastic modelling using the CIRCLY computer modelling program is used to determine peak tensile strain in the base of each pavement layer. The peak level of tensile strain is used as a predictor of fatigue life of the pavement layer (Austroads *Technical Guide to Pavement Technology Part 2: Pavement Structural Design*, 2008).

As the CBR test for subgrade strength is essentially the only commonly used test to characterise subgrade materials, developing a relationship between subgrade CBR and modulus (stiffness) of unbound granular materials was an essential part of the mechanistic design procedure development.

3.2.2 Current Design Guidelines

Design of unbound granular pavements in South East Queensland is undertaken in accordance with a number of road design manuals. The majority of local government authorities include road design guidelines within their town planning policies and some of these are derived from state or independent authority design guidelines.

3.2.2.1 Austroads Pavement Structural Design Guide

The Austroads *Guide to Pavement Technology – Part 2: Pavement Structural Design*, 2010, provides procedures for design of unbound granular (flexible) pavements, flexible pavements with one or more bound layers and rigid pavements.

The guideline provides mechanistic design chart methods for the design of each type of pavement. An updated version of the empirical CBR – Thickness design chart is provided as a design tool for unbound granular pavements.

The Austroads *Pavement Structural Design Guide* (2010) provides qualitative guidance only for the design of pavements on low strength expansive subgrades. With the majority of the recommendations targeted at managing moisture content in the subgrade to limit the effects of moisture induced movement in expansive subgrades.

3.2.2.2 Queensland Department of Transport and Main Roads

The Queensland Department of Transport and Main Roads (QTMR) "*Pavement Design Manual*, 2009" is presented as a supplement to the Austroads '*Guide to Pavement Technology*' and as such promotes both the mechanistic and empirical design methods for unbound granular pavements.

The QTMR "*Pavement Design Manual*, 2009" also provides a great deal of recommendations to minimise the exposure and influence of water. This is especially targeted to the design of pavements on reactive clays that can experience considerable volume change with changes in moisture content.

The QTMR manual recommends two courses of action when dealing with expansive subgrades with a soaked CBR value less than 3 depending on the type of pavement being investigated.

For HILI pavements the design manual recommends mandatory minimum covers over reactive subgrades. Figure 3.8 shows a copy of Table 5.3.1 from the design manual which relates the minimum subgrade cover to the untreated subgrade potential swell (%) (measured with subgrade CBR testing).

Untreated subgrade swell (%)	Minimum cover over reactive subgrade (mm)
≥ 7.0	Geotechnical assessment required
≥ 5.0 to < 7.0	1000
≥ 2.5 to < 5.0	600
≥ 0.5 to < 2.5	150

Figure 3.8 – Table of minimum cover for expansive subgrades (Source: QLD TMR Pavement Design Manual 2009)

For unbound granular pavements, Table 5.6.1 of the design manual nominates a minimum capping layer thickness to be adopted. A copy of this table is reproduced as Figure 3.9 below.

In situ subgrade design CBR	Minimum capping layer thickness (mm)
≥ 2.5 % to < 3.0 %;	150
≥ 2.0 % to < 2.5 %;	200
≥ 1.5 % to < 2.0 %;	300
≥ 1.0 % to < 1.5 %;	400

Figure 3.9 – Table of minimum capping layers for unbound granular pavements on expansive subgrades (Source: QLD TMR Pavement Design Manual 2009)

3.2.2.3 Australian Roads Research Board

The unbound pavement design methods included in the Australian Roads Research Board's (ARRBs) Sealed Local Roads Manual (July 2005) are the empirical CBR – Traffic chart (Figure 1.2) and the mechanistic chart method.

The empirical CBR – Thickness chart method provides pavement designs for subgrades with a minimum CBR of 3. The chart recommends additional pavement thicknesses of between 100mm and 150mm where subgrade soils have a CBR of less than 3.

Section 11 of Part D of the manual provides additional recommendations for the treatment of soft or expansive subgrades by stabilising or controlling moisture variations in the subgrade.

3.2.2.4 Ipswich City Council

Ipswich City Council's *Planning Scheme Policy 3 – General Works* (Ipswich City Council, June 2007) presents the council's pavement design requirements (in tabular form) and a copy of these tables are shown as Figure 3.10.

Planning Scheme Policy 3—General Works, Part 1—Roadworks Ipswich Planning Scheme

Table 1.2.2: Design ESA's by Road Class

Description	Road Class	ESA's
Access Place	A (30 Lots Max.)	5×10^4
Access Street	A1(75 Lots Max.)	1.0×10^5
Collector	B (300 Lots Max.)	2.0×10^5
Trunk Collector	C (1000 lots Max.)	1.0×10^6
Sub-Arterial	D	2.0×10^6
Industrial	E	7.0×10^6
Arterial	F	DMR Design Standards

1.2.4 Minimum Pavement Thickness

(1) Minimum pavement thickness is to be as set out in Table 1.2.3.

Table 1.2.3: Minimum Pavement Thickness

Minimum Total Pavement Thickness (mm) (excluding AC Surfacing)							
CBR of Subgrade	A	A1	B	C	D	E	F-Refer all Type F Roads to DMR
1 and 2	Refer to section 1.2.4(1)(b)						
3	450	470	495	550	560	670	
4	375	395	420	465	520	620	
5	325	340	360	390	480	580	
6	290	310	325	350	450	550	
7	265	280	295	320	425	520	
8	240	255	265	295	400	500	
9	225	230	245	275	380	480	
10	225	225	225	255	365	465	
12	225	225	225	225	325	430	
14	225	225	225	225	305	400	
16	225	225	225	225	290	375	
18	225	225	225	225	275	355	
20	225	225	225	225	275	335	
Minimum Course Thickness							
Asphalt	25	25	25	50	50	50	
Base Course Type 2.1 (Min CBR80)	125	125	125	125	125	125	
Upper Sub Base Type 2.3 (Min CBR45)	100	100	100	100	150	150	
Lower Sub Base Type 2.5 (Min CBR15))	As required to obtain minimum thickness (100mm minimum layer thickness)						

Source: A, A1, B, C type ARRB Special Report No. 41 - Figure 7 / D, E, F type Queensland Department of Main Roads Pavement Design Chart 1.

Figure 3.10 – Ipswich City Council pavement design tables. (Source: ICC Planning Scheme)

Where pavements are proposed on soft or expansive subgrades, Ipswich City Council nominates subgrade replacement to a depth of 100mm for subgrades with a four day soaked CBR of 2 and subgrade replacement to a depth of 200mm for subgrades with a four day soaked CBR of 1. The policy recommends the additional depth where subgrades are expected to be of sufficient strength to allow pavement construction to proceed.

3.2.3 Other Literature

Various alternate sources of literature were studied as part of this research project, spanning the realm of texts, research dissertations and journal articles.

Without exception the focus of these documents was either i) why did longitudinal cracking occur in pavements or ii) what should be done to control longitudinal cracking in pavements constructed on expansive subgrade soils. A selection of this research is summarised here.

- *Premature distress of a pavement on expansive black cotton soil in the Horn of Africa* (Mgangira and Paige-Green 2008): concluded that pavement failures investigated were caused by expansive subgrade soils and that the expansive nature of the subgrade had not adequately been addressed in the design of the road pavement.

- *Studies on Volume Change Movements in high PI Clays for Better Design of Low Volume Pavements* (Manosuthikij 2008): developed a predictive model of volumetric swelling using a finite element model method of analysis which displayed a good correlation to measured soil heave. This research concluded that soil suction, vegetation and drainage ditch (table drain) size all had considerable influence on the swelling of expansive subgrades.

- *Expansive soils: Problems and practice in foundation and pavement engineering* (Nelson and Miller 1992): this text included many recommendations when dealing with expansive subgrade soils including a recommendation that the swelling potential be investigated.

3.2.4 Summary

The majority of research on design and construction of unbound granular pavements on expansive subgrade soils is focussed on what measures should be included to manage the variation in moisture content in the subgrade soil to reduce the amount of subgrade swell during the life of the pavement.

All of the authority design procedures investigated use the empirical CBR – traffic design charts for designing the depth of unbound granular pavements. Where subgrade soils have a 4 day soaked CBR value less than 3, these same design guidelines nominate additional depths of unbound material of between 100 and 400mm based solely of the measured subgrade CBR value.

Each authority design manual or guideline provided information on how to manage subgrade moisture in expansive soils. The given procedures do not provide guidelines for the design of pavements where the moisture content of the subgrade is variable.

3.3 Pavement Failure Modes

One of the first tasks associated with this project was to identify pavements that had been subject to environmentally caused longitudinal cracking.

The following pavement failure modes have been described generally in accordance with the Queensland Department of Transport and Main Roads '*Roads Condition Evaluation Manual for Queensland*' (2002) and the Austroads *Guide to Asset Management* (2006). The failure modes were studied in detail as an aide to identifying sites where longitudinal cracking due to environmental effects had occurred. Photographic plates have been included for pavement failure modes that may be mistakenly identified as longitudinal cracking.

3.3.1 Bleeding / Flushing

Bleeding is where a thin film of bituminous material forms at the surface of the pavement. Bleeding is caused by excessive amounts of binder in the asphalt mix or insufficient aggregate.

3.3.2 Corrugations

Regularly spaced ripples orientated perpendicular to the path of travel are known as corrugations. These are primarily observed on unsealed roads and are typically caused by uneven compaction of the subgrade or through non-uniformity of the pavement layers.

3.3.3 Potholes

Potholes are local bowl shaped depressions in the pavement surface and are usually smaller than 750mm diameter. They are indicative of a structural pavement failure and typically have vertical sides near the top of the hole.

Localised failure of the subgrade in expansive soils caused by excessive moisture collection is often a direct cause of potholing. If potholes are numerous it may be an indication that the underlying pavement is inadequate or in need of remediation.

3.3.4 Stripping and Ravelling

Stripping and ravelling can be caused by two mechanisms. The first is a failure in the bond between aggregate and binder in the asphalt wearing course. In this scenario aggregate is progressively lost from the surface.

The second mechanism is the lack of adhesion between the pavement gravel course and the asphalt (or spray seal). This lack of adhesion results in sections of asphalt being torn from the surface of the pavement.

3.3.5 Crocodile Cracking

Cracking that occurs in asphalt in small interconnected patterns (smaller than approximately 300mm) is described as crocodile cracking.

This cracking is typically caused by fatigue of the asphalt under repeated traffic loading. Cracks propagate from the base of the asphalt layer where the tensile forces from the applied loadings are at their maximum.

This type of cracking often occurs after some type of subgrade or pavement course movement provides ability for the asphalt to move slightly with each loading cycle. Repeated cycles cause a fatigue failure.

Oxidation of the asphalt binder causing brittleness is another cause of crocodile cracking. Figure 3.11 shows a typical example of crocodile cracking subsequent to movement of the supporting pavement.

Figure 3.11 – Crocodile cracking photo

3.3.6 Rutting and Shoving

The longitudinal deformation of pavements in vehicular wheel paths is called rutting. Rutting can be caused from a number of means including poor compaction of the asphalt surface layer causing plastic deformation of this layer, settlement of underlying pavement courses and subgrade. The rutting can also be caused by a structural shear failure of the pavement layers or subgrade and this allows displacement to occur.

Cracking often occurs secondary to the rutting. Figure 3.12 shows a graphic example of rutting with subsequent cracking.

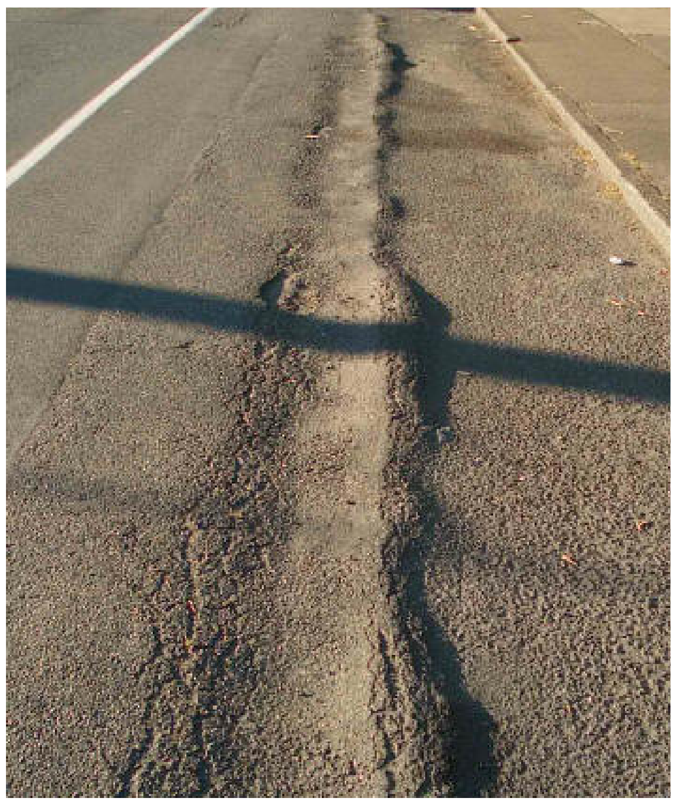


Figure 3.12 – Rutting photo

3.3.7 Cracking

The term cracking refers to unplanned breaks or discontinuities in the integrity of the asphaltic concrete surface. There are two typical causes of pavement cracking:

- Environmental or non-load, due to moisture changes, expansive subgrades, oxidation or chemical shrinkage of the pavement and / or surfacing materials (in colder climates, frost heave is a cause of cracking)
- Traffic loading

3.3.7.1 Block Cracking

Cracking that occurs in interconnected patterns larger than approximately 300mm is described as block cracking. Cracks propagate in both the longitudinal and transverse directions.

Block cracking occurs due to the inability of pavement layers to expand and contract with daily temperature variations. This can be caused by selecting a binder that is too stiff or ageing of the binder.

Block cracking can occur in rigid and flexible pavements. In pavements with cemented or stabilised layers, the inevitable shrinkage cracking can reflect upward through to the asphalt layer.

Figure 3.13 – Block cracking photo

3.3.7.2 Longitudinal Cracking

Environmental cracking, including longitudinal cracking, is mainly non load related. Longitudinal cracking may not cause an immediate loss of strength or shape, but there are significant long term consequences due to water penetration into the granular base courses which may cause pavement failure.

Longitudinal or linear cracking occurs primarily parallel to the axis of the road. The Southern Downs Regional Council Road Assessment Manual notes that there is likely to be little if any interconnection between individual cracks.

Figure 3.14 – Longitudinal cracking photo

3.3.7.3 Longitudinal Cracking on Expansive Subgrades

Expansive subgrade soils undergo large volumetric increases with an increase in moisture content and correspondingly large reductions in volume with a reduction in moisture content. These changes in volume cause swell and shrinkage movements in soils which cause damage to pavements constructed on them.

Figure 3.15 is a diagram showing the typical movement of moisture above and below road pavements.

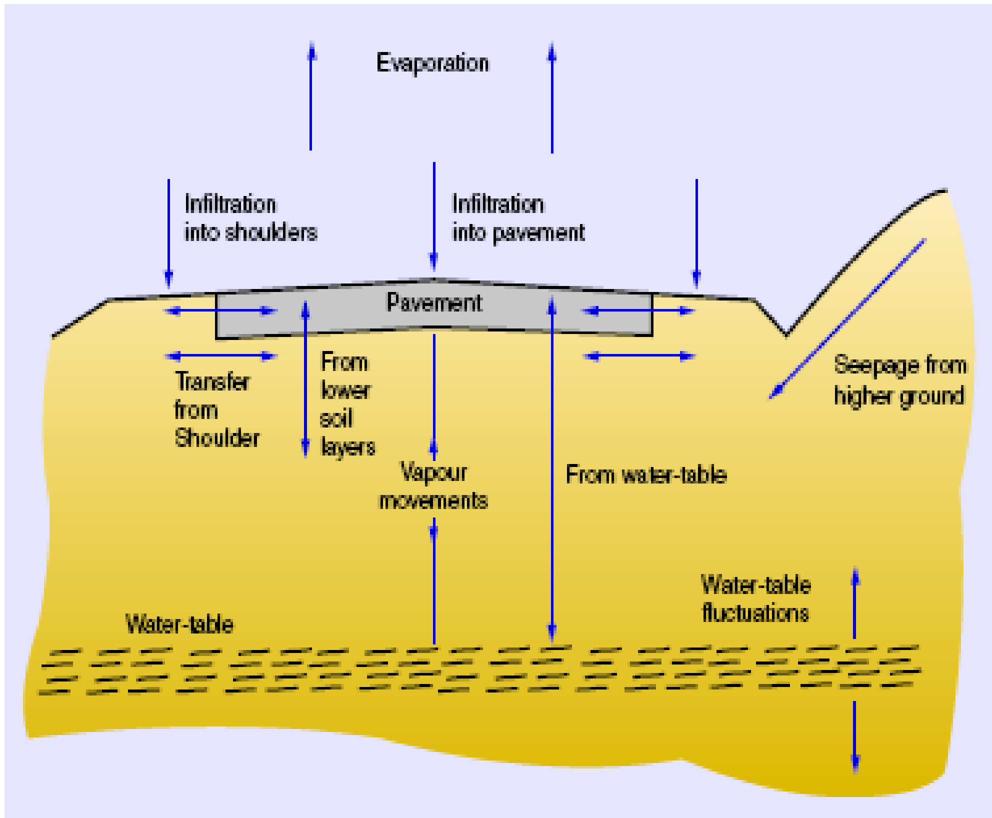


Figure 3.15 – Moisture movement under pavements

As described in previous chapters, all authority pavement design procedures investigated in this project typically proposed one solution where subgrade CBR values fell below 3; add additional pavement. This broad recommendation seems to ignore the simple fact that all low strength (soft) subgrades are not created equal.

Soils that exhibit CBR values of less than 3 contain significant amounts of silts and clays. While silts may have very low CBR values they do not exhibit the same propensity to increase in volume as expansive clays.

Examples of expansive clays encountered in the South East Queensland region include high Plasticity Index (PI) clays and clays with Montmorillonite minerals (Crone 2009).

The expansive nature of these clays is affected by several soil characteristics; clay mineral type, plasticity and soil suction (Manosuthikij 2008).

The mineral make up of clays determines their Cation Exchange Capacity (CEC) which is the ability of the mineral to attract and retain the negative ions from free water molecules. In general the swell potential of a soil increases with an increase in its CEC.

The ability of clay particles to 'grow' in size as they attract negative ions from water is what gives clays the potential to swell in size. Silts do not possess this ability and when exposed to water do not increase in size. Saturated silts lose the ability to interlock with each other and this is what causes the low soaked CBR strength of silty soils.

3.4 Atterberg Limits

Plasticity is the term used to describe the ability of a soil to be remoulded without cracking or crumbling. Fine grained soils containing significant amounts of clay minerals or organic matter exhibit this cohesive nature due to water molecules surrounding the clay or organic particles.

Albert Atterberg, a Swedish scientist, developed a method in the early 1900s to describe the consistency of fine grained soils with varying moisture contents. (DAS 1997).

At very low moisture content, soils behave more like a solid and when the moisture content is very high, the soil and water mix may flow like a liquid. The behaviour of a soil can then be divided into four basic states; solid, semi-solid, plastic and liquid as shown in Figure 3.16.

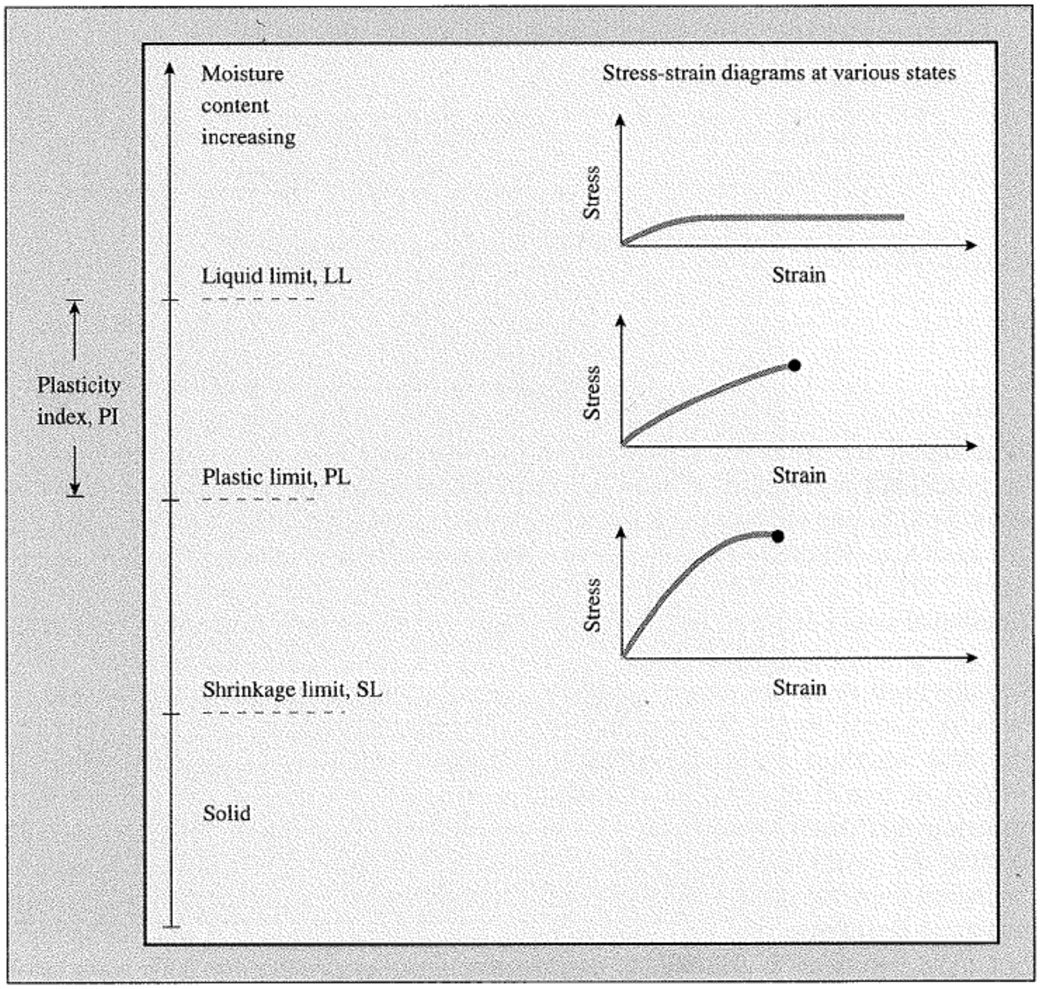


Figure 3.16 – Atterberg limits (Source: DAS 1997)

3.4.1 Liquid Limit

The Liquid Limit (LL) is defined as the moisture content, as a percentage of the mass of a test sample, where a soil passes from the plastic state to the liquid state. The liquid limit can be determined by measuring the number of blows of a given intensity that it takes to close a 10mm wide groove formed in a soil sample of given dimensions. Section 4.6.1 provides a detailed description of the testing procedure used in this project.

3.4.2 Plastic Limit

The Plastic Limit (PL) is defined as the moisture content, as a percentage of the mass of a test sample, where a soil passes from the semi-solid state to the plastic state. This is the lowest moisture content at which the soil remains in a plastic state which is defined as the moisture content at which the soil crumbles when rolled into threads of a given dimension. Section 4.6.2 provides a detailed description of the testing procedure used in this project.

3.4.3 Plasticity Index

The Plasticity Index (PI) is the difference between the Liquid Limit and the Plastic Limit of a soil. The Plasticity Index is an important parameter in classifying fine grained soils. It is the basis of the Casagrande plasticity chart and ultimately the Unified Soil Classification System (DAS 1997).

3.4.4 Linear Shrinkage

Linear Shrinkage is the amount of shrinkage experienced by a soil sample, expressed as a percentage of the original length of the test sample, when dried from its Liquid Limit moisture content. Linear Shrinkage gives an indication of the change in volume that can be expected in a given soil as its moisture content varies.

3.4.5 Plasticity Chart

In 1932 Arthur Casagrande studied the relationship of the Plasticity Index to the Liquid Limit for a wide variety of natural soils. From these test results he developed the plasticity chart shown in Figure 3.17.

The 'A-Line' separates inorganic clays from inorganic silts and soils located above the 'A-Line' are classified as clays. The 'U-Line' defines the upper limit of plastic clays.

The information provided in the plasticity chart is of great value and is the basis for the classification of fine-grained soils in the United Soil Classification System.

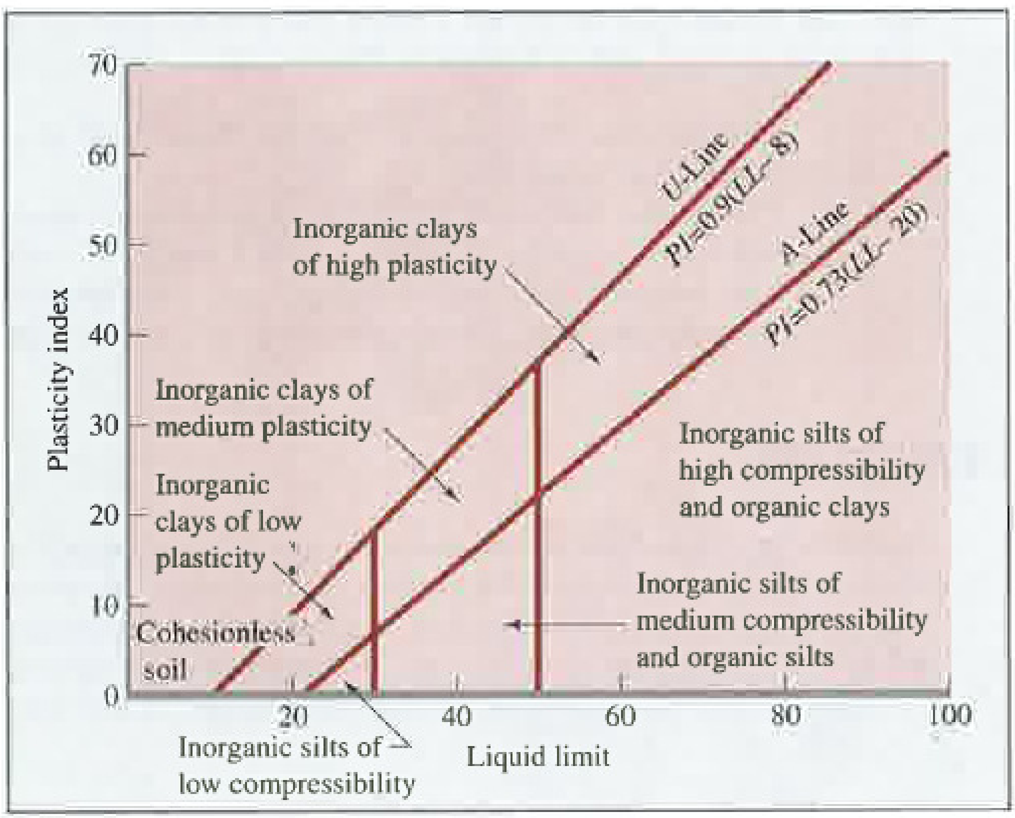


Figure 3.17 – Plasticity Chart (Source: DAS 1997)

4. Methodology

The following project methodology was developed in 2010 in consultation with Dr Kazem Ghabraie. As the project developed some of the proposed methods required modification to suit the amount of testing commissioned and the extent of information available at the time the research was completed. An outline of the proposed project methodology is included below:

- Research the background of State and Local Authority full depth granular pavement design charts.
- Select sampling site locations.
- Find or design a simple ranking system for extent of longitudinal cracking.
- Undertake site inspections to visually classify the extent of longitudinal cracking of each pavement and collect subgrade samples for cases where additional testing requirements have been identified.
- Liaise with Local Authorities asset management and works departments to obtain available design and as-constructed information (subgrade CBR, other geotechnical testing results, pavement profile) for existing pavements constructed on low strength subgrades.
- Undertake interviews with design and /or supervising engineers
- Commission Atterberg limits material quality testing.
- Divide the subgrade materials into different groups based on their CBR values (3, 2.5, 2, 1.5, 1) and analyse the Atterberg limits test results for each group, seeking a meaningful relationship between any of the Atterberg limits and the extent of longitudinal cracking.
- Propose a procedure for pavement design on low strength subgrade soils that incorporates an assessment of relevant Atterberg limit/s as well as subgrade CBR to determine if a full depth granular pavement is appropriate.

4.1 Research Background of Authority Design Charts

Chapter 3 of this dissertation provides as in depth literature review and background of the development of current authority CBR – Traffic design charts for unbound granular pavements.

4.2 Sampling

4.2.1 Locating Sites

Twenty individual sites in four different South East Queensland local authority areas were identified. The sites were identified first by a review of high definition aerial photography to locate the telltale black stripes that mark mastic infill of pavements that have suffered longitudinal cracking. An example of the high definition aerial photography is shown in Figure 4.1.

Once suburbs were identified, a detailed visual inspection was made by physically inspecting the sites.

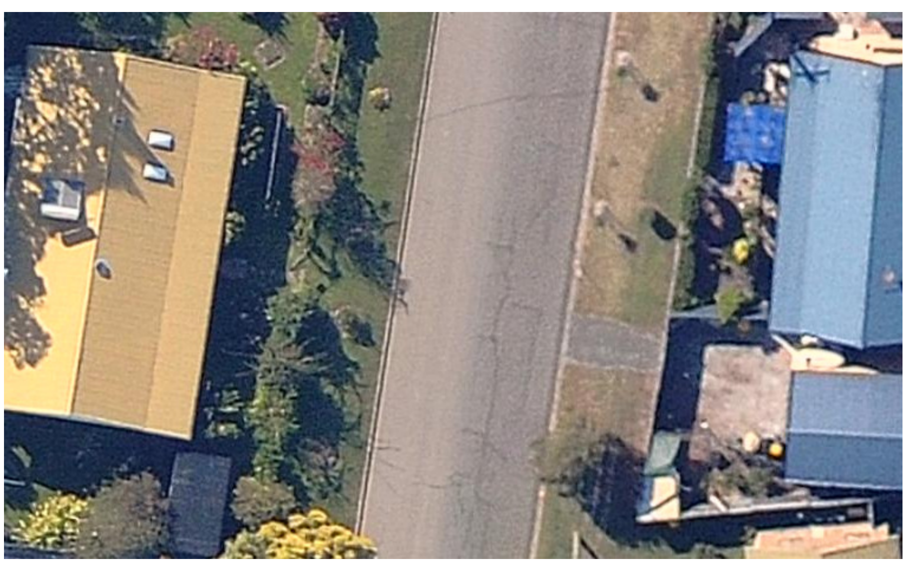


Figure 4.1 – Aerial photography showing longitudinal pavement cracking (Source: Nearmap.com.au, 2010)

4.2.2 Sampling Method

Subgrade samples were obtained by first removing turf and topsoil with a shovel (Figure 4.2) and then drilling a disturbed core sample with a hand auger. The sample depth for all locations was between 300mm and 600mm. Test samples of approximately 3kg were collected and care was exercised when drilling and collecting to ensure that the subgrade sample was not contaminated with topsoil. The disturbed samples were collected in plastic bags. Location labels were fixed to the bags and the samples delivered to the soils laboratory.

Figure 4.2 – Topsoil and turf removal with shovel

Figure 4.3 shows the tools used for collecting samples and Figure 4.4 is a photo of the samples prepared for testing in the laboratory.

Figure 4.3 – Tools used for sample collection

Figure 4.4 – Samples bagged and sealed prior to laboratory testing

4.3 Road Condition Assessment

A visual assessment of the extent of longitudinal cracking was made in accordance with the manual method of inspection and classification as outlined in the Queensland Department of Main Roads "*Roads Condition Evaluation Manual for Queensland*" (2002).

Modification to the road sample size was necessary due to the localised nature of the failures being investigated. The assessments were undertaken in segments 20m long by one lane wide.

The area of pavement cracking was calculated by multiplying the average number of cracks in the lane segment by their average length to get a total length of cracking in each segment. This total length of segment cracking was then multiplied by a nominal width of 300mm to obtain a nominal area of pavement cracking for the road segment being investigated.

The percentage area of defect is obtained by dividing the nominal area of pavement cracking by the area of the pavement segment being investigated and multiplying by 100.

A secondary assessment of all sites was made by reviewing photographs of each site and comparing them to photographic examples of the various failure modes discussed in Section 3.3.

4.3.1 Ranking System for Extent of Cracking

A condition rating for each segment of road was calculated from the following table (from Appendix C of the *Main Roads Condition Evaluation Manual*).

Table 4.1 – Pavement Condition Score

Rating	Abbreviation
1	< 1% of total trafficable area affected
2	1 to < 5% of total trafficable area affected
3	5 to < 10% of total trafficable area affected
4	10 to < 20% of total trafficable area affected
5	>20% of total trafficable area affected

4.4 As-Constructed Document Review

A review of as-constructed documentation was undertaken for 15 of the 20 sites and as-constructed records of the final pavement designs were found for only 3 of the sample sites.

Council records did include design information for 12 of the sites and a review of these documents indicated that the intent of these designs was to follow the relevant local authority design guidelines.

4.5 Interview of Consulting Engineers

Phone interviews were undertaken with consulting engineers engaged in the design and contract administration roles on seven of the sites being investigated. These engineers agreed to provide some advice on the background and circumstances of the pavement cracking observed on the basis that they remain anonymous. The feedback received from these engineers is included in Chapter 6 of this report.

4.6 Testing Methods

Testing procedures in accordance with current Australian Standards were adopted for all laboratory testing and all testing was undertaken by a National Association of Testing Authorities (NATA) registered laboratory.

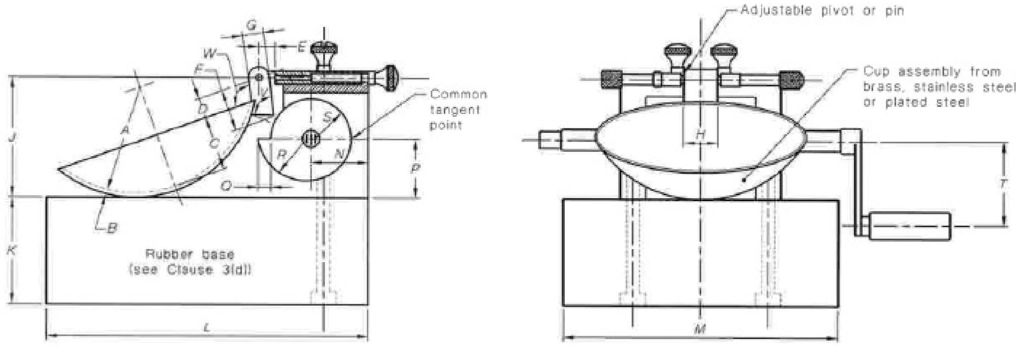
For each of the collected subgrade samples, testing of the Atterberg limits and their derived indices were undertaken and these included the Liquid Limit, Plastic Limit, Plasticity Index and Linear Shrinkage. The testing was undertaken in accordance with the following methods:

4.6.1 Liquid Limit

The one point Casagrande method for determining the Liquid Limit was used in accordance with AS1289.3.1.2. This method requires a 250g sample of the subgrade paste (component passing the 0.425mm sieve mixed with water) to be placed in the brass cup of the Liquid Limit apparatus (Figures 4.5 and 4.6). A groove is formed in the soil with the apparatus grooving tool.

The Liquid Limit apparatus consists of a brass cup and a vulcanised rubber base. The brass cup can be dropped onto the base by turning a crank handle on the apparatus.

The crank is turned at a rate of 2 revolutions per second until the two parts of the soil sample come together and the number of blows at which this occurs is recorded. The test is repeated at varying moisture contents until the number of blows required for the sample to come together lies in the range of 15 to 35. The Liquid Limit is then calculated in accordance with the table provided in AS1289.3.1.2.



millimetres

Letter	A	B	C	D	E	F
Dimension	54 ±0.5	2 + 0, −0.4	27 ±0.5	12.5 ±0.5	8 ±1	25 ±0.5
Letter	G	H	J	K	L	M
Dimension	10 ±0.5	16 ±0.5	60 ±1	50 ±5	150	130
Letter	N	P	Q	R	S	T
Dimension	27	28 ±0.5	Ref R and S	22 ±0.5	19 ±0.5	40

Letter	V	W
Angle	75 ±5	100 ±3

NOTES:

1 Essential dimensions are toleranced.

2 The cam may be manufactured from two semicircular sections with a common tangent point.

FIGURE 1 STANDARD LIQUID LIMIT APPARATUS

Figure 4.5 – Liquid Limit apparatus (Source: AS1289.3.1.1)

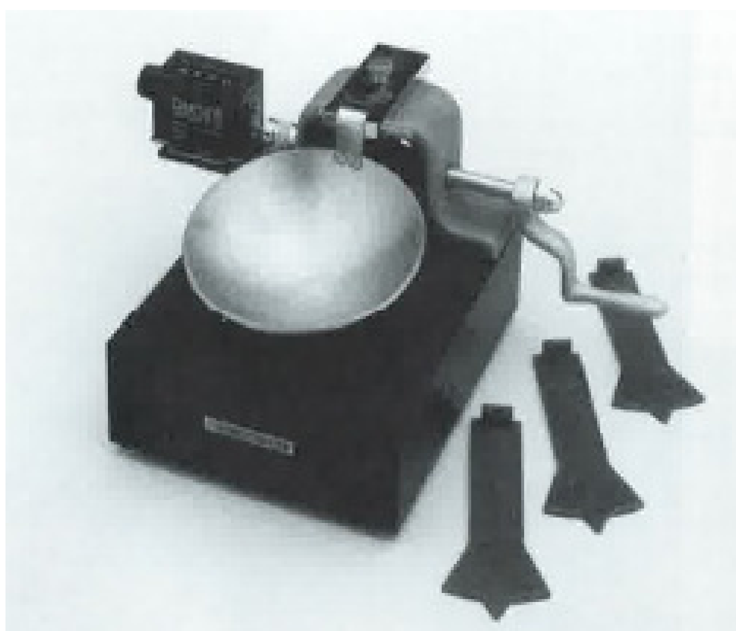


Figure 4.6 – Liquid Limit apparatus (Source: DAS 1997)

4.6.2 Plastic Limit

The Plastic Limit was determined for all samples in accordance with AS1289.3.2.1 - 2009 - Determination of the Plastic Limit of a soil – Standard method.

This method requires a portion of the material passing the 0.425mm sieve to be mixed with water to achieve a homogeneous mass that is plastic enough to be moulded into a ball. The soil is covered and allowed to cure for at least 12 hours at room temperature.

After curing a small sample of soil is moulded and rolled in the palms of the hands to reduce its moisture content to a point where slight cracks appear on its surface. The soil sample is then rolled between the hand and a glass plate as shown in Figure 4.7 or between glass plates to form a thread of 3mm diameter. This test is repeated at various moisture contents until the sample starts to crumble at the point of reaching 3mm in diameter. The moisture content at this point is determined and recorded as the Plastic Limit.

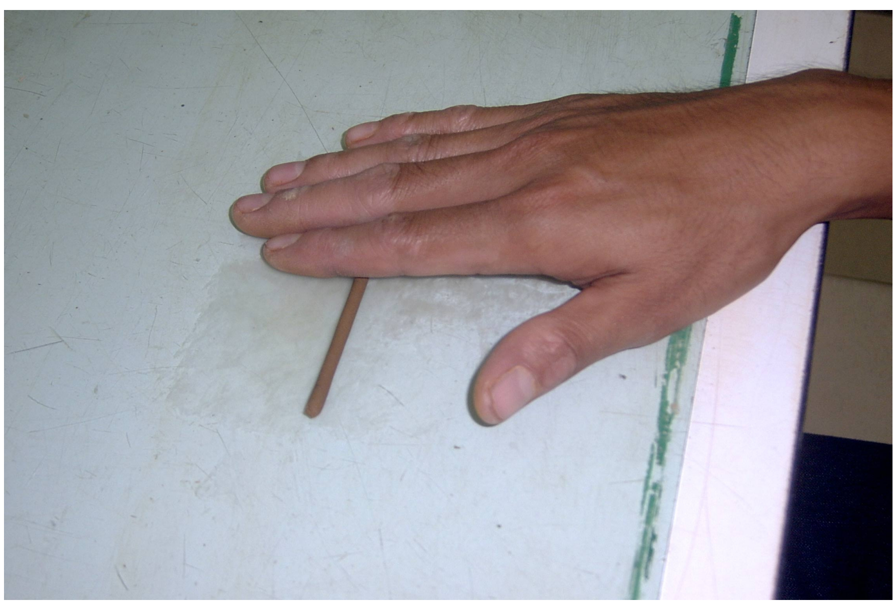


Figure 4.7 – Determining the Plastic Limit

4.6.3 Plasticity Index

The Plasticity Index of each subgrade soil sample was calculated in accordance with AS1289.3.3.1-2009– Calculation of the Plasticity Index of a soil.

The Plasticity Index (measured in percent) is calculated simply by subtracting the Plastic Limit (measured in percent) from the Liquid Limit (measured in percent).

4.6.4 Linear Shrinkage

Linear Shrinkage was determined in accordance with AS1289.3.4.1-2008 – Determination of the linear shrinkage of a soil – Standard method.

This method requires at 250g minimum sample from the subgrade component material passing the 0.425mm sieve to be mixed with water to achieve a consistency close to the liquid limit.

The sample is placed in a shrinkage mould and the internal length of the mould is measured. The specimen is dried at room temperature for about 24 hours until a distinct change in colour can be noticed. The sample is then dried in an oven at between 105 and 110 degrees Celsius. After the sample has cooled, the longitudinal shrinkage is measured and the percentage linear shrinkage calculated in accordance with the formula in AS1289.3.4.1.

5. Testing Results

The following tables show the raw data collected for the pavement damage assessment and each of the subgrade parameters.

5.1 Road Condition Assessment

Table 5.1 – Extent of Observed Pavement Damage and Pavement Condition Score

Site No.	Lane width of pavement section(m)	Length of pavement section (m)	Number of cracks in lane	Average Length of cracks	Area of cracking (%)	Crack Rating
001	6	20	2	10	5.0	3
002	4	20	3	10	11.3	4
003	4	20	3	15	16.9	4
004	6	20	3	20	15.0	4
005	3	20	3	15	22.5	5
006	3	20	2	20	20.0	5
007	3	20	4	20	40.0	5
008	3	20	3	20	30.0	5
009	3	20	2	20	20.0	5
010	3	20	2	20	20.0	5
011	5	20	3	20	18.0	4
012	4.5	20	2	20	13.3	4
013	2.75	20	2	20	21.8	5
014	2.75	20	2	10	10.9	4
015	5	20	2	20	12.0	4
016	3	20	2	20	20.0	5
017	4	20	3	20	22.5	5
018	3	20	3	20	30.0	5
019	2.75	20	2	20	21.8	5
020	4	20	3	20	22.5	5

5.2 Liquid Limit

Table 5.2 – Liquid Limit

Site No.	Street	Suburb	Liquid Limit
001	Norman Street	East Brisbane	32
002	Pamela Street	Burpengary	26
003	Dale Street	Burpengary	21
004	Springfield Drive	Burpengary	41
005	Warrigal Court	Redbank Plains	52
006	Berrigan Street	Redbank Plains	62
007	Burrawang Street	Redbank Plains	78
008	Gawler Crescent (North)	Bracken Ridge	53
009	Denning Road	Bracken Ridge	36
010	Gawler Crescent (South)	Bracken Ridge	51
011	Jarvis Road	Waterford	52
012	Dairy Creek Road	Waterford	66
013	James Josey Avenue	Springfield	74
014	Amarillo Place	Springfield	28
015	Edgar Street	Windsor	41
016	Allom Street	Windsor	41
017	Raleigh Parade	Ashgrove	37
018	Carlock Promenade	Karalee	22
019	Park Road	Karalee	49
020	Settler Way	Karalee	25

5.3 Plastic Limit

Table 5.3 – Plastic Limit

Site No.	Street	Suburb	Plastic Limit
001	Norman Street	East Brisbane	23
002	Pamela Street	Burpengary	18
003	Dale Street	Burpengary	14
004	Springfield Drive	Burpengary	18
005	Warrigal Court	Redbank Plains	20
006	Berrigan Street	Redbank Plains	22
007	Burrawang Street	Redbank Plains	36
008	Gawler Crescent (North)	Bracken Ridge	24
009	Denning Road	Bracken Ridge	18
010	Gawler Crescent (South)	Bracken Ridge	25
011	Jarvis Road	Waterford	27
012	Dairy Creek Road	Waterford	20
013	James Josey Avenue	Springfield	26
014	Amarillo Place	Springfield	14
015	Edgar Street	Windsor	26
016	Allom Street	Windsor	26
017	Raleigh Parade	Ashgrove	21
018	Carlock Promenade	Karalee	15
019	Park Road	Karalee	17
020	Settler Way	Karalee	13

5.4 Plasticity Index

Table 5.4 – Plasticity Index

Site No.	Street	Suburb	Plasticity Index
001	Norman Street	East Brisbane	9
002	Pamela Street	Burpengary	8
003	Dale Street	Burpengary	7
004	Springfield Drive	Burpengary	23
005	Warrigal Court	Redbank Plains	32
006	Berrigan Street	Redbank Plains	40
007	Burrawang Street	Redbank Plains	42
008	Gawler Crescent (North)	Bracken Ridge	29
009	Denning Road	Bracken Ridge	18
010	Gawler Crescent (South)	Bracken Ridge	26
011	Jarvis Road	Waterford	25
012	Dairy Creek Road	Waterford	46
013	James Josey Avenue	Springfield	48
014	Amarillo Place	Springfield	14
015	Edgar Street	Windsor	15
016	Allom Street	Windsor	15
017	Raleigh Parade	Ashgrove	16
018	Carlock Promenade	Karalee	7
019	Park Road	Karalee	32
020	Settler Way	Karalee	12

5.5 Linear Shrinkage

Table 5.5 – Linear Shrinkage

Site No.	Street	Suburb	Linear Shrinkage
001	Norman Street	East Brisbane	7
002	Pamela Street	Burpengary	5
003	Dale Street	Burpengary	6
004	Springfield Drive	Burpengary	14
005	Warrigal Court	Redbank Plains	16
006	Berrigan Street	Redbank Plains	17
007	Burrawang Street	Redbank Plains	19
008	Gawler Crescent (North)	Bracken Ridge	15
009	Denning Road	Bracken Ridge	10
010	Gawler Crescent (South)	Bracken Ridge	16
011	Jarvis Road	Waterford	14
012	Dairy Creek Road	Waterford	18
013	James Josey Avenue	Springfield	22
014	Amarillo Place	Springfield	8
015	Edgar Street	Windsor	10
016	Allom Street	Windsor	10
017	Raleigh Parade	Ashgrove	9
018	Carlock Promenade	Karalee	6
019	Park Road	Karalee	17
020	Settler Way	Karalee	8

6. Analysis of Results

6.1 Aim of the Analysis

The aim of the analysis of the laboratory test results is to determine if a relationship exists between any of the Atterberg Limits and the area of pavement cracking observed in pavements which have been designed in accordance with empirical design charts.

The analysis also sought to determine if a specific value of any of the Atterberg Limits should be considered a 'trigger score' for considering alternate pavement construction methods.

For the analysis plots it was determined that plotting each of the subgrade parameters against the percentage pavement damaged (in lieu of the pavement damage ranking as proposed in the original methodology) would give a more continuous range of values from which to determine if a relationship existed.

The analysis is presented as a series of plots with a linear regression model fitted. Both the linear regression model equation and coefficient of determination (R^2) value are shown on the plots.

The coefficient of determination (R^2) provides information on how well future outcomes are likely to be predicted by a given model. The 'least squares' method to calculate R^2 is a mathematical procedure for finding the best-fitting line to a given set of points by minimising the sum of the squares of the offsets ("the residuals") of the points from the curve (Mathworld 2010). R^2 lies in the range of 0 to 1, with 0 denoting no correlation and 1 denoting no deviation between the modelled line and the given set of points.

As a result of analysis of the photographic records of the damaged pavements and the interviews held with the engineers associated with inspecting construction of the works, several changes were made to the data set as follows:

- Site No's 012 and 013 were omitted from the analysis set due to the extensive nature of subgrade rehabilitation under the constructed pavement.

- Site No's 018 and 020 were omitted from the analysis set due to the observed longitudinal failure being assessed as a secondary failure mechanism. After a review of the photographic evidence, the primary failure mechanism for these sites was attributed to subgrade rutting. Figures 6.1 and 6.2 are photographic plates showing the damage observed at sites 018 and 020 respectively.

Figure 6.1 – Photo of Site 018 showing longitudinal cracking subsequent to subgrade deformation

Figure 6.2 – Photo of Site 020 showing longitudinal cracking subsequent to subgrade deformation

- Extent of cracking observed at Site No.006 was subsequent to a reconstruction of the Asphaltic Concrete surfacing. An amended extent of cracking, in accordance with advice and photographic evidence has been included for this site. Figure 6.3 shows a photographic plate of site 006 as inspected, the number of cracks recorded for this section of road was 2.

Figure 6.3 – Photo of Site 006 as inspected

Figure 6.4 shows a photographic plate of site 006 taken within 12 months of completion of the pavement construction and shows extent of cracking in original pavement prior to remediation measures. Photographic plate provided by consulting engineer engaged to inspect construction of the works. The number of cracks for this section of road was revised to 4 on the basis of discussions with the consultant and the supporting photographic evidence.

Figure 6.4 – Photo of Site 006 prior to remediation works

As a consequence of these changes to the data, 15 of the 20 original sites were used to investigate the relationship between longitudinal cracking and the Atterberg limits of the subgrade soils.

6.1.1 Liquid Limit

In this project, the variation of Liquid Limit values against observed area of pavement damage (as a percentage) was investigated. Results for 15 of the 20 sites were compared and a plot of this data is shown in Figure 6.5. The plot shows a strong relationship of percent pavement cracking against the Liquid Limit. A linear regression model provided the best correlation of the data set and an R^2 value of 0.6782 shows a moderate to strong positive correlation exists between these parameters.

A correlation was expected as the Liquid Limit provides a measure of how much liquid a fine grained soil can retain before exhibiting liquid behaviour.

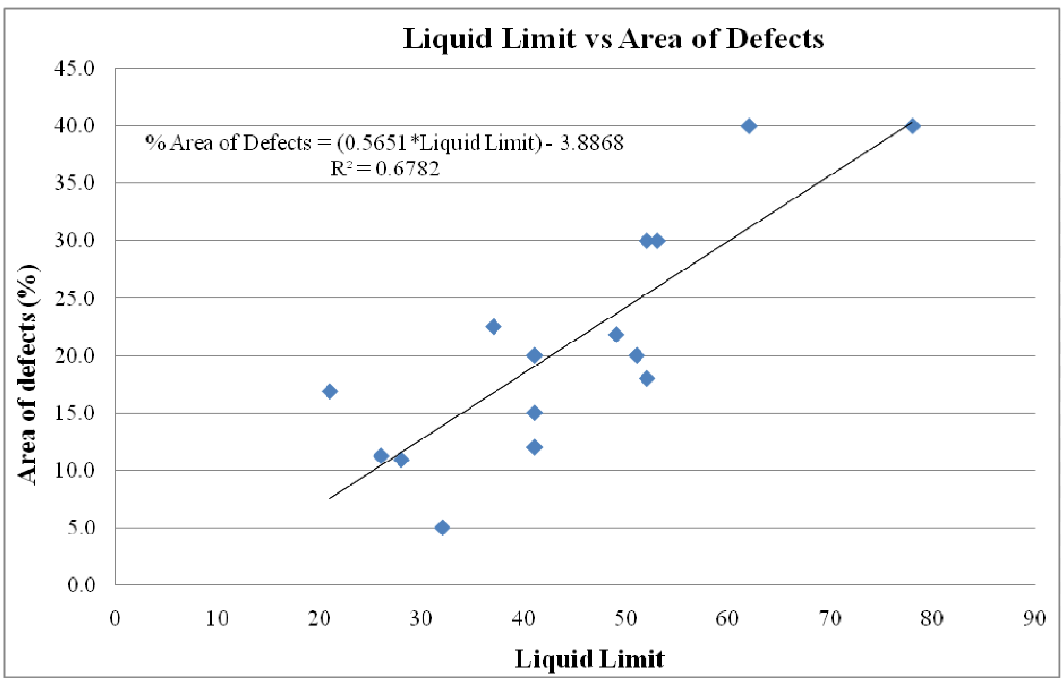


Figure 6.5– Relationship between area of observed pavement defects and Liquid Limit of the subgrade soil

6.1.2 Plastic Limit

The variation of Plastic Limit values against observed area of pavement damage (as a percentage) was also investigated. Results for 15 of the 20 sites were compared and a plot of this data is shown in Figure 6.6. The plot shows no relationship between percent pavement cracking and the Plastic Limit. Various regression models were investigated for this data and no meaningful relationship was observed.

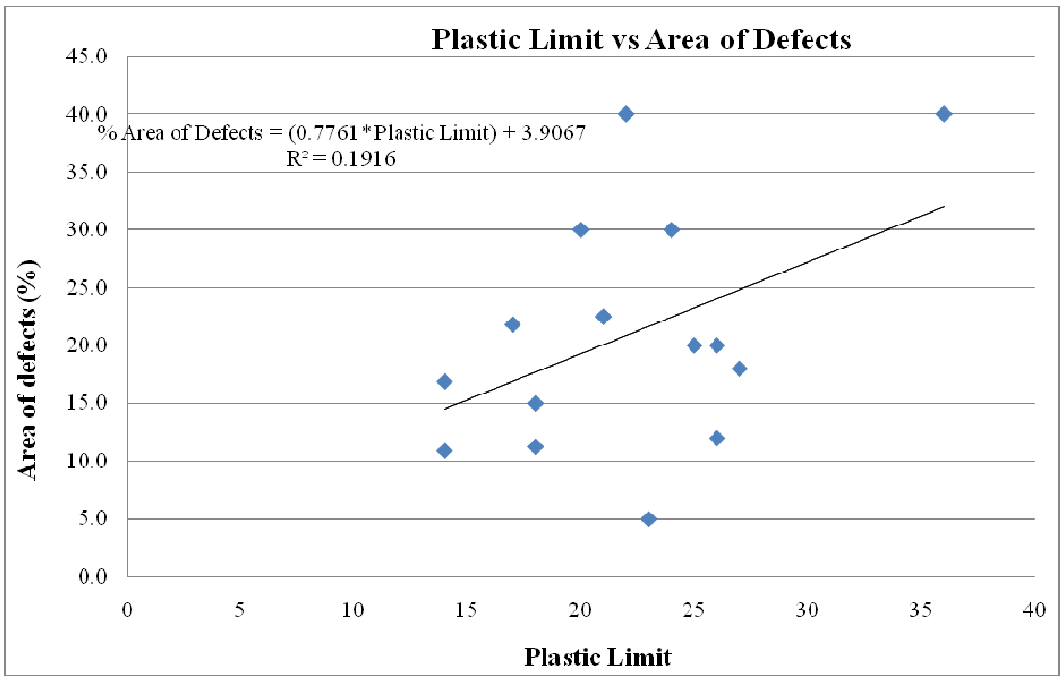


Figure 6.6 – Relationship between area of observed pavement defects and Plastic Limit of the subgrade soil

6.1.3 Plasticity Index

Plasticity Index values were plotted against the observed area of pavement damage (as a percentage). Results for 15 of the 20 sites were compared and a plot of this data is shown in Figure 6.7. The plot shows a strong relationship of percent pavement cracking against the Plasticity Index. A linear regression model provided the best correlation of the data set and an R^2 value of 0.7488 shows a strong positive correlation exists between these parameters.

This was expected as the Plasticity Index gives an indication of the expansive activity of a particular soil (Manosuthikij, 2008) and environmental longitudinal cracking of pavements is caused by this expansive activity.

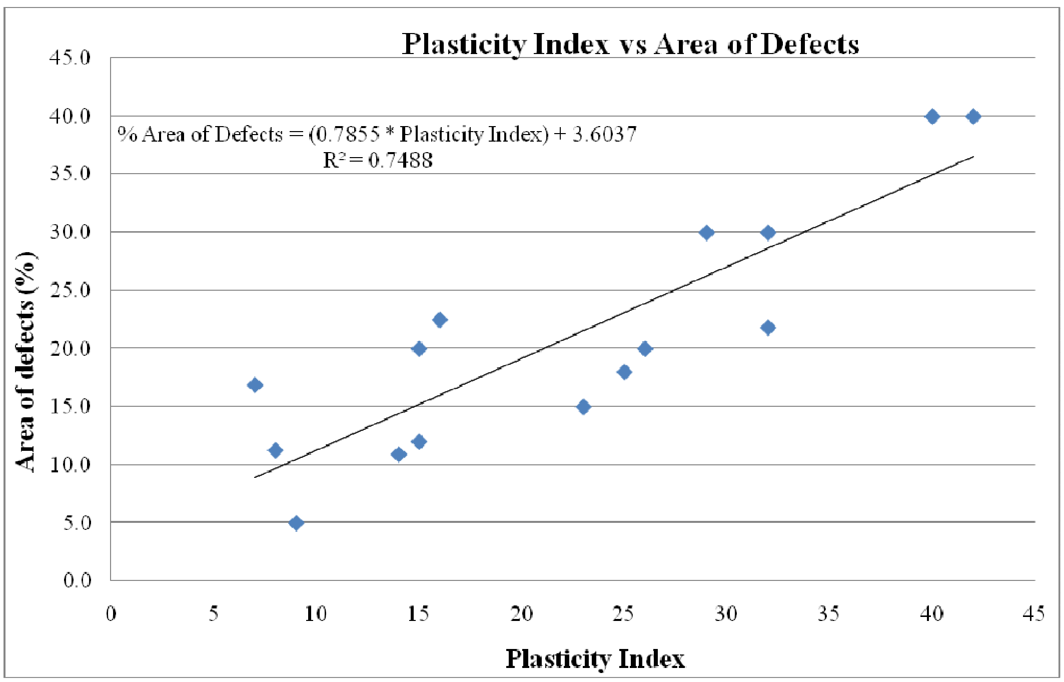


Figure 6.7 – Relationship between area of observed pavement defects and Plasticity Index of the subgrade soil

6.1.4 Linear Shrinkage

Linear Shrinkage values were also plotted against the observed area of pavement damage (as a percentage). Results for 15 of the 20 sites were compared and a plot of this data is shown in Figure 6.8. The plot shows a strong relationship of percent pavement cracking against Linear Shrinkage. A linear regression model provided the best correlation of the data set and an R^2 value of 0.5852 shows a moderate positive correlation exists between these parameters.

A strong correlation was expected for Linear Shrinkage as it is a direct measure of the predisposition of a soil to shrink or swell. Environmental longitudinal cracking of pavements is associated with the heaving of subgrade soils as the swell.

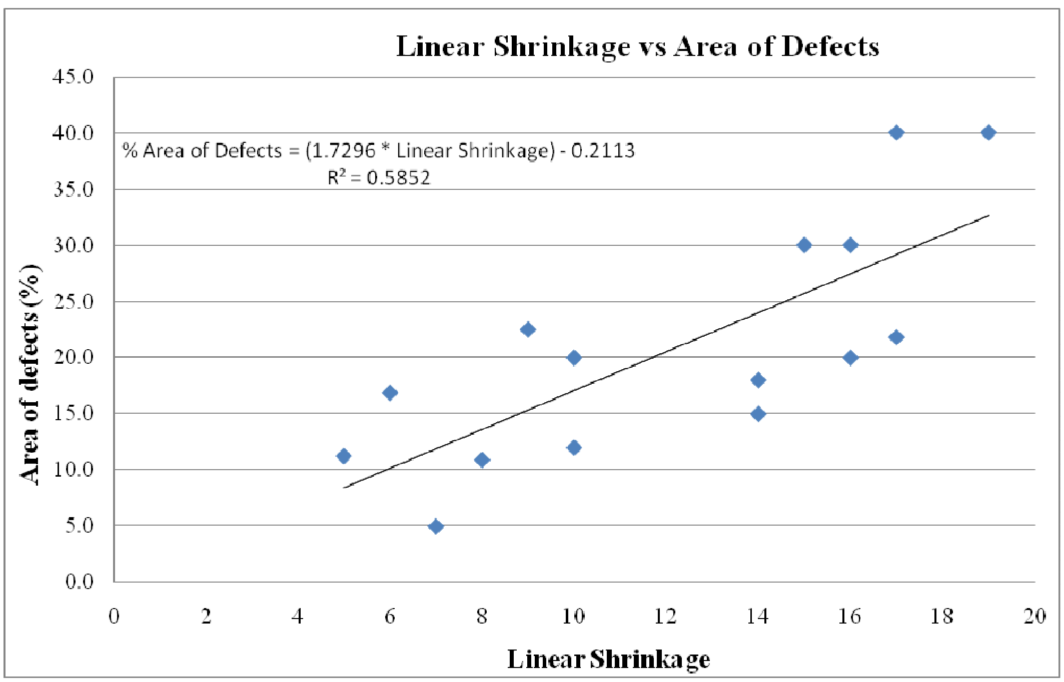


Figure 6.8 – Relationship between area of observed pavement defects and Linear Shrinkage of the subgrade soil

6.1.1 Plasticity Chart

Plasticity Index and Liquid Limit results for 15 of the sample sites were plotted on a Casagrande Plasticity chart to determine the classification of each of these subgrades. This analysis is presented as Figure 6.9.

Three samples were classified as inorganic clays of low plasticity, five samples were classified as inorganic clays of medium plasticity and the remaining seven samples were classified as inorganic clays of high plasticity.

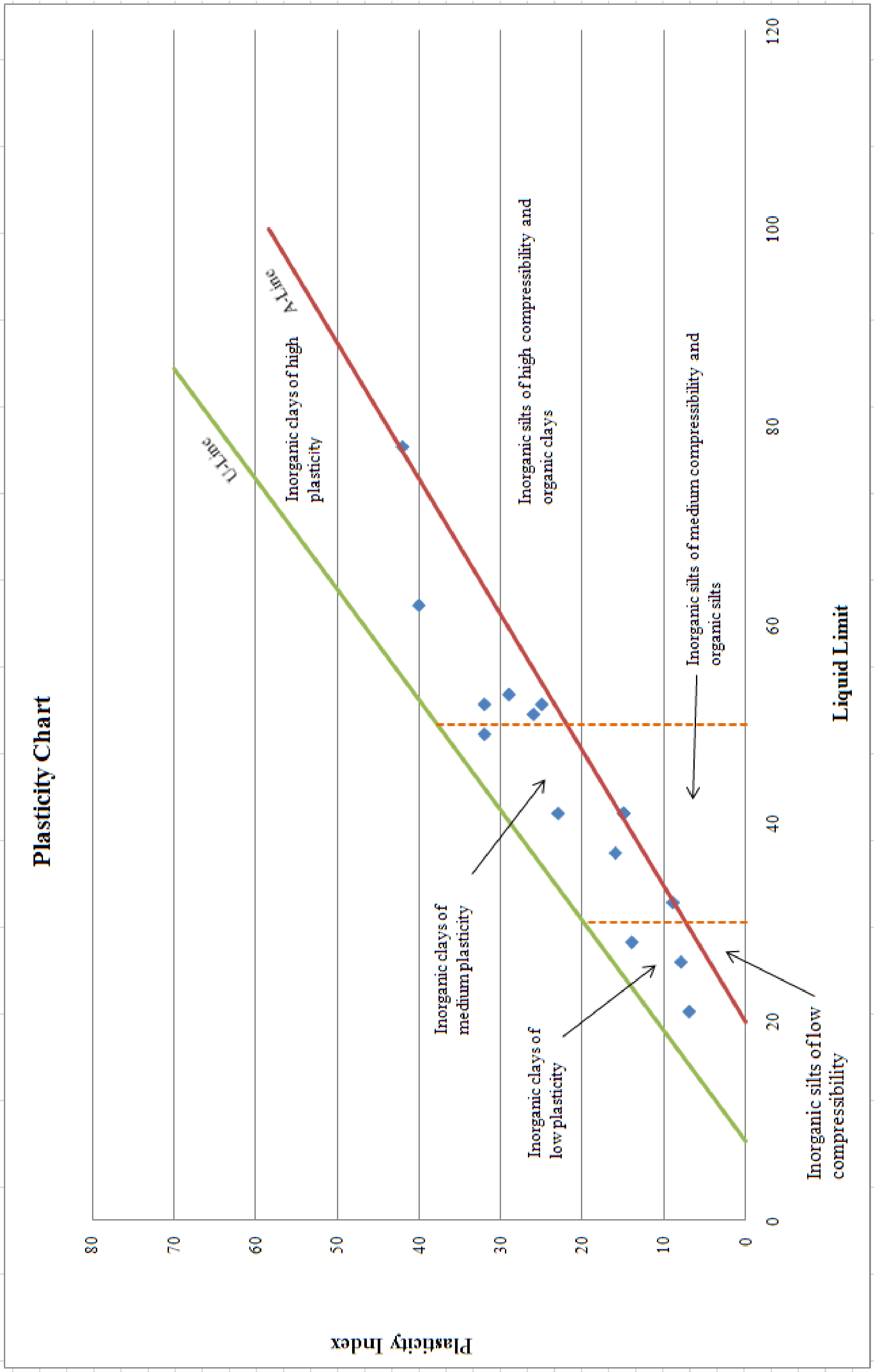


Figure 6.9 – Liquid Limit and Plasticity Index plotted on Plasticity Chart

7. Conclusions and Further Work

7.1 Summary of Findings

As expected, all subgrades tested were classified as clay. The ability of clay particles to ‘grow’ in size as they attract negative ions from water is the mechanism that enables clays to swell in size. Silts do not possess this ability and when exposed to water do not increase in size. Saturated silts lose the ability to interlock with each other and this quick condition is the cause of the low soaked CBR strength of silty soils.

Analysis of the test results show that a relationship exists between the Atterberg Limits of a subgrade material and longitudinal cracking in unbound granular pavements designed in accordance with existing authority empirical design charts. A summary of the R^2 values is shown in Table 7.

Table 7.1 – Summary of R^2 values for Atterberg Limits Vs Longitudinal Cracking

Atterberg Limit	**Coefficient of Determination (R^2)**
Liquid Limit	0.6782
Plastic Limit	0.1916
Plasticity Index	0.7488
Linear Shrinkage	0.5852

The Liquid Limit displayed a moderate to strong correlation to the extent of cracking observed in the subject pavements with an ‘R^2’ value of 0.6782.

The Plasticity Index displayed the closest correlation to extent of cracking observed in the subject pavements. The 'R^2' value of 0.7488 represents a strong correlation in the regression model.

A correlation was observed in the analysis between the Atterberg limits of subgrade soils and the longitudinal cracking of unbound granular pavements. However, due to the small sample size, no recommendation can be made for specific values of Atterberg limits that would trigger consideration of alternate pavement designs.

7.2 Future Research

Further testing and statistical analysis is required to determine specific Atterberg Limit values, and associated confidence limits, where alternate pavement designs should be considered.

Additional research and analysis is also recommended to determine if a relationship exists between the 'Plasticity Index * by the percent mass of subgrade passing the 0.425mm sieve' Vs 'Extent of pavement cracking' is also recommended to determine if a relationship exists as is inferred in the 2010 version of the Austroads Structural Design Guidelines.

The following are additional recommendations to assist with the formulation of future investigations in this area:

- Not all pavements fail, a study that collects data from both cracked and uncracked pavements would provide valuable comparisons and statistical analysis of the Atterberg limits and pavements that have or have not cracked.
- Increase the depth of sample collection to ensure that insitu subgrades are collected and contamination is minimised.
- Meet with both pavement design and construction supervison representatives for all subject sites to ensure that all pertinent design and construction parameters that may affect analysis can be reviewed and assessed.

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APPENDIX A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 / 4112 Research Project

PROJECT SPECIFICATION

FOR:	**Dale John STANTON**
TOPIC:	ATTERBERG LIMITS AND THEIR RELATIONSHIP TO LONGITUDINAL CRACKING IN GRANULAR PAVEMENTS
SUPERVISORS:	Dr. Kazem Ghabraie / Dr. Jim Shiau
SPONSERSHIP:	Partial sponsorship from Cardno Bowler Pty Ltd.
PROJECT AIM:	This project aims to investigate a possible relationship between the Atterberg limits of low strength subgrade materials (CBR $\leq$ 3) and the likelihood of longitudinal cracking in full depth granular pavements. The Atterberg limits proposed to be investigated are the Shrinkage Limit, Plastic Limit, Liquid Limit and Plasticity Index.
PROGRAMME:	**Issue B, 31st March, 2010** 1. Research the background of State and Local Authority full depth granular pavement design charts. 2. Liaise with Local Authorities asset management and works departments to obtain available design information (subgrade CBR, other geotechnical testing results, design pavement profile) for existing pavements constructed on low strength subgrades. 3. Design a simple ranking system for extent of longitudinal cracking. 4. Undertake site inspections to visually classify the extent of longitudinal cracking of each pavement and collect subgrade samples for cases where additional testing requirements have been identified in programme item 2.

	5. Commission Atterberg limits material quality testing. 6. Divide the subgrade materials into different groups based on their CBR values (3, 2.5, 2, 1.5, 1) and analyse the Atterberg limits test results for each group, seeking a meaningful relationship between any of the Atterberg limits and the extent of longitudinal cracking. 7. Produce a series of charts that shows analysis clearly and accurately. 8. Submit an academic research dissertation based on the research. *As time permits:* 9. Propose a procedure for pavement design on low strength subgrade soils that incorporates an assessment of relevant Atterberg limit/s as well as subgrade CBR to determine if a full depth granular pavement is appropriate.

AGREED : ______________________ (Student) Date:

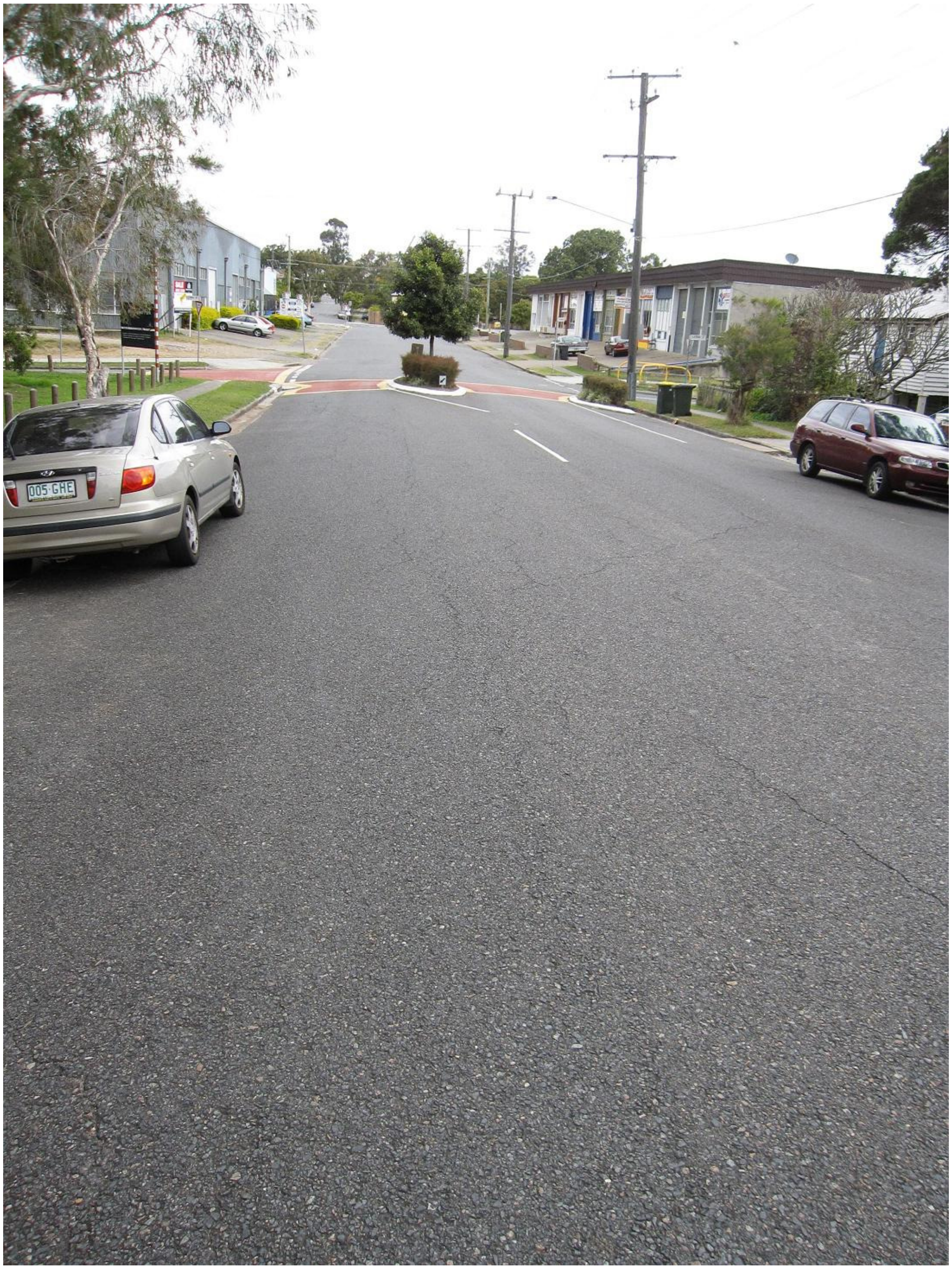
AGREED : ______________________ (Supervisor) Date:

AGREED : ______________________ (Supervisor) Date:

Examiner / Co-examiner : ____________________________________

APPENDIX B

Site Photos



Site 001 – Norman Street, East Brisbane

Site 002 – Pamela Street, Burpengary

Site 003 – Dale Street, Burpengary

Site 004 – Springfield Drive, Burpengary

Site 005 – Warrigal Court, Burpengary

Site 006 – Berrigan Street, Burpengary

Site 007 – Burrawang Street, Burpengary

Site 008 – Gawler Crescent (North), Bracken Ridge

Site 009 – Denning Road, Bracken Ridge

Site 010 – Gawler Crescent (South), Bracken Ridge

Site 011 – Jarvis Road, Waterford

Site 012 – Dairy Creek Road, Waterford

Site 013 – James Josey Avenue, Springfield

Site 014 – Amarillo Place, Springfield

Site 015 – Edgar Street, Windsor

Site 016 – Allom Street, Windsor

Site 017 – Raleigh Parade, Ashgrove

Site 018 – Carlock Promenade, Karalee

Site 019 – Park Road, Karalee

Site 020 – Settler Way, Karalee

APPENDIX C

Laboratory Test Results

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Environmental Consultants
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Website: www.cardno.com.au
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Associated Offices in Perth Vietnam and Papua New Guinea

SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	1
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 001	*LOCATION:*	NORMAN STREET, EAST BRISBANE
SAMPLE No.:	145570	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	32	%
PLASTIC LIMIT	23	%
PLASTICITY INDEX	9	%
LINEAR SHRINKAGE	7	%
FIELD MOISTURE	-	%

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M.J. Sandilands Nata Approved

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1,3.1.2,3.2.1,3.3.1,3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	2
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	MORETON BAY REGIONAL COUNCIL		
SITE TEST No.:	SITE 002	*LOCATION:*	PAMELA STREET, BURPENGARY
SAMPLE No.:	145571	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	26	%
PLASTIC LIMIT	18	%
PLASTICITY INDEX	8	%
LINEAR SHRINKAGE	5	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	3
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	MORETON BAY REGIONAL COUNCIL		
SITE TEST No.:	SITE 003	*LOCATION:*	DALE STREET, BURPENGARY
SAMPLE No.:	145572	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	21.0	%
PLASTIC LIMIT	14.0	%
PLASTICITY INDEX	7.0	%
LINEAR SHRINKAGE	6.0	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT: DALE STANTON — *JOB No.:* 9602
PROJECT: PAVEMENT FAILURE RESEARCH PROJECT — *REPORT No:* 4
DATE ISSUED: 24.08.10
CLIENT REFERENCE: MORETON BAY REGIONAL COUNCIL

SITE TEST No.: SITE 004 — *LOCATION:* SPRINGFIELD DRIVE, BURPENGARY
SAMPLE No.: 145573 — *LEVEL:* 0.3 - 0.6m
DATE SAMPLED: 04.08.10
MATERIAL SOURCE: INSITU
PROPOSED MATERIAL TYPE:

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	41	%
PLASTIC LIMIT	18	%
PLASTICITY INDEX	23	%
LINEAR SHRINKAGE	14	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	5
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 005	*LOCATION:*	WARRIGAL COURT, REDBANK PLAINS
SAMPLE No.:	145574	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	52	%
PLASTIC LIMIT	20	%
PLASTICITY INDEX	32	%
LINEAR SHRINKAGE	16	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES: AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	6
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 006	*LOCATION:*	BERRIGAN STREET, REDBANK PLAINS
SAMPLE No.:	145575	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	62	%
PLASTIC LIMIT	22	%
PLASTICITY INDEX	40	%
LINEAR SHRINKAGE	17	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES: AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	7
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 007	*LOCATION:*	BURRAWANG ST, REDBANK PLAINS
SAMPLE No.:	145576	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	78	%
PLASTIC LIMIT	36	%
PLASTICITY INDEX	42	%
LINEAR SHRINKAGE	19	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES: AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	8
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 008	*LOCATION:*	GAWLER CNT(NTH), BRAKEN RIDGE
SAMPLE No.:	145577	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	53	%
PLASTIC LIMIT	24	%
PLASTICITY INDEX	29	%
LINEAR SHRINKAGE	15	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	9
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 009	*LOCATION:*	DENNING ROAD, BRAKEN RIDGE
SAMPLE No.:	145578	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	36	%
PLASTIC LIMIT	18	%
PLASTICITY INDEX	18	%
LINEAR SHRINKAGE	10	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	10
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 010	*LOCATION:*	GAWLER CNT(STH), BRAKEN RIDGE
SAMPLE No.:	145579	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	51	%
PLASTIC LIMIT	25	%
PLASTICITY INDEX	26	%
LINEAR SHRINKAGE	16	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	11
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	LOGAN CITY COUNCIL		
SITE TEST No.:	SITE 011	*LOCATION:*	JARVIS ROAD, WATERFORD
SAMPLE No.:	145580	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	52	%
PLASTIC LIMIT	27	%
PLASTICITY INDEX	25	%
LINEAR SHRINKAGE	14	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT: DALE STANTON
JOB No.: 9602
PROJECT: PAVEMENT FAILURE RESEARCH PROJECT
REPORT No: 12
DATE ISSUED: 24.08.10
CLIENT REFERENCE: LOGAN CITY COUNCIL

SITE TEST No.: SITE 012
LOCATION: DAIRY CREEK ROAD, WATERFORD
SAMPLE No.: 145581
LEVEL: 0.3 - 0.6m
DATE SAMPLED: 04.08.10
MATERIAL SOURCE: INSITU
PROPOSED MATERIAL TYPE:

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	66	%
PLASTIC LIMIT	20	%
PLASTICITY INDEX	46	%
LINEAR SHRINKAGE	18	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	13
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 013	*LOCATION:*	JAMES JOSEY AVE, SPRINGFIELD
SAMPLE No.:	145582	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	74	%
PLASTIC LIMIT	26	%
PLASTICITY INDEX	48	%
LINEAR SHRINKAGE	22	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES: AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	14
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 014	*LOCATION:*	AMARILLO PLACE, SPRINGFIELD
SAMPLE No.:	145583	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	28	%
PLASTIC LIMIT	14	%
PLASTICITY INDEX	14	%
LINEAR SHRINKAGE	8	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	15
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 015	*LOCATION:*	EDGAR STREET, WINDSOR
SAMPLE No.:	145584	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	41	%
PLASTIC LIMIT	26	%
PLASTICITY INDEX	15	%
LINEAR SHRINKAGE	10	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	16
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 016	*LOCATION:*	ALLOM STREET, WINDSOR
SAMPLE No.:	145585	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	41	%
PLASTIC LIMIT	26	%
PLASTICITY INDEX	15	%
LINEAR SHRINKAGE	10	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	17
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	BRISBANE CITY COUNCIL		
SITE TEST No.:	SITE 017	*LOCATION:*	RALEIGH PARADE, ASHGROVE
SAMPLE No.:	145586	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	37	%
PLASTIC LIMIT	21	%
PLASTICITY INDEX	16	%
LINEAR SHRINKAGE	9	%
FIELD MOISTURE	-	%

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TEST PROCEDURES: AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	18
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 018	*LOCATION:*	CARLOCK PROMENADE, KARALEE
SAMPLE No.:	145587	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	22	%
PLASTIC LIMIT	15	%
PLASTICITY INDEX	7	%
LINEAR SHRINKAGE	6	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT:	DALE STANTON	*JOB No.:*	9602
PROJECT:	PAVEMENT FAILURE RESEARCH PROJECT	*REPORT No:*	19
		DATE ISSUED:	24.08.10
CLIENT REFERENCE:	IPSWICH CITY COUNCIL		
SITE TEST No.:	SITE 019	*LOCATION:*	PARK ROAD, KARALEE
SAMPLE No.:	145588	*LEVEL:*	0.3 - 0.6m
DATE SAMPLED:	04.08.10		
MATERIAL SOURCE:	INSITU		
PROPOSED MATERIAL TYPE:			

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	49	%
PLASTIC LIMIT	17	%
PLASTICITY INDEX	32	%
LINEAR SHRINKAGE	17	%
FIELD MOISTURE	-	%

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SOIL CLASSIFICATION TEST REPORT

TEST PROCEDURES:AS1289 2.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1

CLIENT: DALE STANTON — *JOB No.:* 9602
PROJECT: PAVEMENT FAILURE RESEARCH PROJECT — *REPORT No:* 20
DATE ISSUED: 24.08.10
CLIENT REFERENCE: IPSWICH CITY COUNCIL

SITE TEST No.: SITE 020 — *LOCATION:* SETTLER WAY, KARALEE
SAMPLE No.: 145589 — *LEVEL:* 0.3 - 0.6m
DATE SAMPLED: 04.08.10
MATERIAL SOURCE: INSITU
PROPOSED MATERIAL TYPE:

PLASTICITY & LINEAR SHRINKAGE

RESULTS

LIQUID LIMIT	25	%
PLASTIC LIMIT	13	%
PLASTICITY INDEX	12	%
LINEAR SHRINKAGE	8	%
FIELD MOISTURE	-	%

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APPENDIX D

Risk Assessment

Risk Assessment

Risks and potential hazards associated with the execution of the project have been identified, assessed and control measures considered. This will ensure that the identified risks and hazards are minimised during the execution of the project.

Risks, potential hazards, control measures and risk classification have been tabulated below:

Table 2 – Risk Identification, Assessment and Control Table

Action Item	Potential Hazard	Control Measure	Risk
Collection of samples with hand auger	Injury caused by impact from passing vehicles	Use of hazard markers and high visibility vest. Obtain samples from within verge areas or within allotments adjacent pavements	VS
Collection of samples with hand auger	Back injury	Use hand auger in accordance with manufacturer's recommendations.	S
Collection of samples with hand auger	Back injury	Use safe lifting techniques when moving hand auger and collected samples	VS
Collection of samples with hand auger	Sunburn	Wear appropriate sun smart apparel and use sunscreen	SU
Collection of samples with hand auger	Electrocution	Identification of all existing services prior to undertaking any drilling with hand auger	S
Collection of samples with hand auger	Breakage of existing services	Identification of all existing services prior to undertaking any drilling with hand auger	S

The following table shows the classification of risk level:

Table 3 – Risk Classification Legend

Level of Risk	Abbreviation
Extremely Slight (Practically Impossible)	ES
Very Slight (conceivable but unlikely)	VS
Slight (possible but unlikely)	S
Significant (possible)	SI
Substantial (may be expected)	SU

APPENDIX E

Resource Requirements

Resource requirements

Equipment

Vehicle for site inspections

Safety vest

Hard hat

Sunscreen

Hazard markers

Camera for collecting photographic evidence of extent of pavement cracking

Tape measure

Hand auger for collecting subgrade samples

Large plastic bags for collection and storage of subgrade samples

All equipment identified above has been obtained for the duration of the project.

Testing services

Atterberg limits testing of all samples

CBR testing of some samples (may be required)

This is a critical requirement of the project. The approximate retail value of testing required for the project is in excess of $4,000. I have obtained a commitment from one geotechnical testing company to undertake some of the testing. I have also contacted two local authorities with the intention of obtaining additional commitment to testing.

By liaising with the local authorities for the duration of the project, I hope to mitigate the need to undertake CBR testing for many of the locations.

Other services

"Dial Before You Dig" searches for locating services prior to collecting subgrade samples. Access to this resource is available at my current place of employment.

APPENDIX F

Project program

Project program

Table 4 – Project Program

Action	Commencing Date	Duration (Weeks)	Completion Date
Negotiate provision of geotechnical testing services	17.05.10	3	05.06.10
Collect subgrade samples	27.06.10	6	07.08.10
Classify extent of longitudinal cracking	27.06.10	6	07.08.10
Obtain CBR and original pavement design information from local authorities	27.06.10	6	07.08.10
Commission geotechnical testing and obtain results of same	11.07.10	4	14.08.10
Undertake analysis of data	8.08.10	3	28.08.10
Submit extended abstract	14.08.10	2	27.08.10
Prepare PowerPoint presentation of project	28.08.10	2	10.09.10
Draft Dissertation	14.08.10	4	10.09.10
Present project paper at Project Conference			17.09.10
Submit Dissertation	11.10.10	2	28.10.10