University of Southern Queensland
Faculty of Health, Engineering and Sciences

Use of Recycled Concrete and lime to improve Marginal subgrades in the Toowoomba Regional Council

A dissertation submitted by

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Abstract

Toowoomba Regional Council (TRC) is responsible for maintaining the road network within its boundaries. Of the 9650 km 3330 is sealed pavement. Most importantly for pavement design is the quality of the foundation/host soil (Subgrade), of which the pavement will be constructed upon. Pavement thickness is determined directly from the subgrade strength in terms of California bearing ratio (CBR). High strength subgrades (CBR>5) can significantly reduce construction/maintenance cost in comparison to a marginal subgrade (CBR<5). Chemical stabilization with lime can be used to improve the load bearing qualities of marginal subgrades. Mechanical stabilization (i.e. blending of materials) can also be used to compensate shortcomings in the host soils characteristics. This is mostly achieved by redefining the particle size distribution of the host material, providing better particle interlock. This project looks at the use of lime and recycled concrete aggregate (RCA) to improve marginal subgrades and the effect on cost.

With a set budget each financial year, council aims to construct and maintain road pavements as efficiently and in the most cost effective way, to ensure satisfactory pavement performance. Cost effective alternatives are important to achieve this goal. Lime treatment in the civil engineering discipline is not new technology; however its use with recycled concrete aggregate has not been researched. Lime treatment alone is not common practise in TRC; the results of this project will add to council knowledge and may promote more lime treatment to be used as an alternative solution.

Quantitative research methodology was utilized to explore the effect of various lime and RCA contents on two host subgrade materials. The subgrade materials were sampled from Mann Silo Road and Hinz Street, both within TRC Borders. In preparation of the paper, many hours of laboratory testing and preparation was conducted on the samples. This involved site sampling of subgrade from the two roads, initial testing/characterisation, treatment with lime and RCA, curing, final testing and results/cost analysis. Some Pavement redesigns using the mechanistic pavement design was conducted for the host roads. In addition to this a cost analysis with council unit rates was also preformed to consider the application of RCA/Lime treatment as a viable alternative.

Background literature in regards to lime treatment has been thoroughly examined, along with current industry standards and manuals. Initial testing of the host materials shows that they are in acceptable ranges for lime treatment. The addition of lime saw the Host materials CBR increase by a factor of 10. The addition of RCA saw further increases to a factor of 15. Parallel with literature, it’s found that lime increases soil strength and can reduce construction costs. These outcomes were achieved by applying standard soil testing and cost analysis/estimation technique currently used by local government council.

Lime treatment of marginal subgrade is a viable alternate for construction and maintenance of roads. It can return cost savings in construction and maintenance operations. Effect of lime content on in-situ moisture content is also a valuable finding, In addition to this, the effect of RCA is also significant finding. This paper does not aim to solve any major issue but aims to express to council the viability of lime treatment. Toowoomba Regional Council must be thanked for providing me with resources, advice and assistance on the delivery of this project.

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Personal:

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1.0 Introduction

Lime is one of the oldest construction materials known to mankind. Its versatility has seen it used widely across all facets of construction works. Stemming from ancient use by the romans, lime can be used to stabilize mortar blends for construction, use in pavement modification and stabilization and was the main construction binder until the invention of Portland Cement in the 19th century.

Despite being an old construction material lime still has many uses such as pavement modification and stabilization. To this day Lime is one of the most effective treatment methods available. The term “soil stabilisation” can be defined as the ability to positively impact or alter the physical properties of a soil to meet engineering requirements or specifications. Soil stabilisation techniques are used worldwide for pavement construction although the reasoning and circumstances of use may vary.

Local Government Councils in Queensland are restricted by budget and are forever seeking economic improvements without sacrificing construction quality. Roads in Queensland vary from rigid to flexible pavements and at a local level are designed for 20 year lifespans. In most rural areas flexible pavements are the most prevalent. The majority of roads located on the Darling Downs in South East Queensland are dominated by Reactive in-situ material. This in-situ material is termed “Reactive Subgrade”. Reactive subgrades exhibit large swells and shrinkages with variation in moisture content and in the Darling Downs region are most commonly clay material. Significant structural damage can be caused from this, standard design procedures to control this requires deep pavements and higher costs.

The demand for quality gravels and aggregate in conjunction with purchase/cartage costs are key factors for consideration in modern pavement design. It is suggested that Recycled Concrete Aggregate can be used as a cheaper alternative to standard aggregate (Vic roads 2011). The upgrading of subgrade, by lime stabilisation is therefore an attractive proposition for local council on the Darling Downs. It is believed that lime treatment is cost effective and a necessary requirement for better quality roads, greater life expectancy and to minimize the future maintenance costs (Austab 2002).

1.1 Toowoomba Regional Council

The Toowoomba Regional Council (TRC) was created after state amalgamations in March 2008 and was the combination of 8 councils, these included: Toowoomba City, Cambooya, Clifton, Crows Nest, Jondaryan, Millmerran, Pittsworth and Rosalie shires. The combined land size of this council is 12 973 square Kilometres (refer to Figure 1). This is one of the largest councils in Queensland. The Toowoomba Regional Council maintains a very large road and infrastructure network containing approximately 9560 Kilometres of road. Of this, 3300 Kilometres is sealed and mostly sprayed seal flexible pavement (Toowoomba Region 2016).

Figure 1 Toowoomba Region Map (TRC 2016)

The role of the council is to provide a service to the community in the most economical way. This includes aspects such as Planning and Building, Environment, Water and Waste, Facilities and Recreation, Community and Business throughout the region. As part of council responsibility to the community it serves, quality road construction and maintenance is of the utmost importance to ensure safe road conditions.

1.2 Project Topic Introduction

Construction of high quality roads has many beneficial effects to the community it serves, such as, a link from destination to location, a route for transporting of goods and most importantly a safe road for the community to commute on for work and recreation. In addition to this, pavement design, construction process and materials used can all affect the life of the road. This affects the volume and frequency of maintenance in the future of the pavement.

The role of a flexible road pavement in the Toowoomba Regional Council is to support the traffic loading with acceptable ride quality and without undue deterioration over the period of which it is designed. In order to safely achieve this goal the pavement must attenuate the traffic induced stresses in all the pavement layers and the subgrade to avoid significant pavement distress (Austroads 2008).

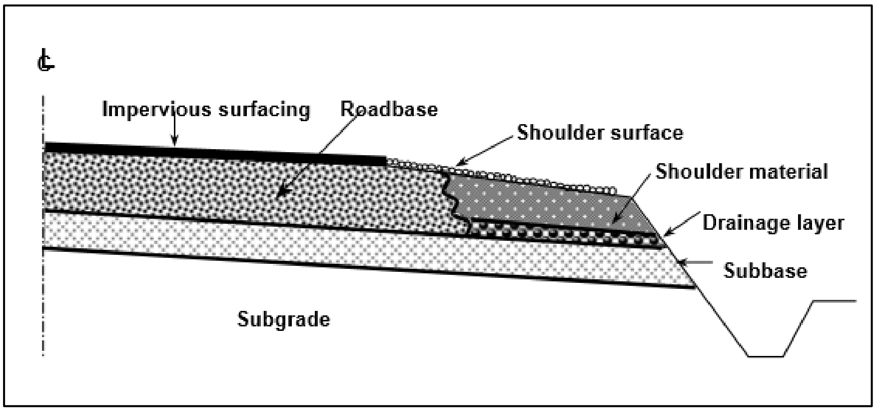


Figure 2 Road Layering (Austroads 2008).

Such pavement distress is usually controlled through the structure of the pavement beneath, consisting of several layers of different quality. The highest quality materials are located at the top of the pavement, and lesser quality materials in lower layers where the vehicle induced stresses are reduced.

The total thickness of the pavement is directly related to the strength of the existing subgrade material as it provides the support for the road. Weak subgrades require deep pavements which is costly to construct and maintain. Subgrade behaviour with variation in moisture content (reactiveness) can also be detrimental to pavement life.

Most commonly, pavement material quality is increased in the base and subbase layers to compensate for weak subgrades and to reduce the load on the subgrade. This can be very costly and does not reduce the required cover (pavement depth) on top of the subgrade.

Improving the strength and durability characteristics of the weak/reactive subgrade during construction can reduce the pavement thickness and the quality of the materials required. Lime stabilization can be used with weak/reactive subgrades commonly found throughout the Toowoomba Regional Council. Strength of granular materials is affected by the aggregate contained within. To be effective the particles should range in size and shape to promote particle interlock. Most reactive subgrades are clays and lack in range of particles size, containing mostly fines. Particles which are angular and have rough surface texture are superior in aiding with strength and particle interlock. The mechanical properties of reactive subgrade can be improved by adding such particles. Recycled Concrete Aggregate is a cheap alternative for this application (Austroads 2008).

This project discusses the use of Recycled Concrete Aggregate and Lime in reactive subgrades in the Toowoomba Regional Council.

1.2.1 Justification

The operating environment of the pavement is very important when designing the pavement initially. The loading situation, in terms of vehicle usage and variation in vehicle type will usually determine the materials used. Moisture environment under and around the pavement has a detrimental impact on the performance of the pavement. All granular materials will lose strength with the increase of moisture content. Temperature is mostly the effect due to freeze/thaw of the in-situ moisture in the pores of the materials. In this region this is not an issue and is usually not considered in great detail.

The behaviour of the subgrade is most important as pavement distress due to environmental influences (high moisture content/dry season) can affect the subgrade materials much more severely than the stress caused by traffic. The unstable nature of reactive soils can destroy pavements well before the traffic stress could cause harm (*CIV5705-Pavement Design and Analysis: Course material* 2016).

Longitudinal cracking from swell and shrinkage of the subgrade, transverse cracking and loss of pavement shape in the form of rutting are very prevalent pavement failures in regions with reactive subgrade in the Toowoomba Regional Council. Longitudinal deformation in the wheel path (Rutting) is mostly caused by structural overloading of the pavement and subgrade and calls for excessive maintenance in the TRC region.

Strengthening of the subgrade with lime stabilization and recycled concrete aggregate will help to minimize the effects of reactive subgrade, reduce pavement depth and maintenance frequency. This will have positive effects on budget.

1.3 Project Aims

The main aims of this project are to consider the viability of lime stabilization in the Toowoomba Regional Council. The effectiveness of Recycled Concrete Aggregate as an aggregate supplement for the clay subgrade was assessed in conjunction with lime stabilization. This combination is purely experimental and tries to use sustainable materials to better the road quality, condition and performance.

The investigation into the use of lime stabilization in the Toowoomba Regional council will help to improve the quality of the roads and reduce future maintenance frequency. Maintenance is also important and the effectiveness of lime for maintenance purposes has also been included. It is hoped that this research will fill some knowledge gaps by providing some technical information in regard to design with lime stabilized subgrade and appropriateness through the use of local example materials. A cost analysis will account for this practice of lime stabilization in council and is compared to current practice for pavement construction and maintenance activities/applications.

1.3.1 Project Objectives

1. Research background on marginal materials in the TRC region. Conduct studies on current practice in the use of recycled concrete and improvement/stabilization technologies in the Toowoomba Regional Council

2. Examine existing Australian Standards for testing, AustRoads/Transport and Main Roads/Local council and ARRB for design and current standards, use and implementation.

3. Collect Data form TRC and subgrade materials from identified issue areas. Conduct standard testing, analyse the results against current standards to determine useability in sealed road applications for construction and maintenance.

4. Construct, test and analyse the effects of adding recycled concrete and lime to the collected samples at various dosage rates based on testing.

5. Cost benefit analysis of implementing lime treatment technologies, according to council base unit rates and local providers of materials.

1.3.2 Research Approach

The research approach for this dissertation was broken up into a number of stages:

1. Literature review

    - Conduct literature review on subgrades in the region, use of lime and RCA in subgrade stabilization.
    - Lime stabilization technique, plant requirements, testing and chemistry.
    - Pavement design approach for the use of stabilized subgrade.

2. Testing Period

    - Identify issue areas and collect samples.
    - Collect samples
    - Conduct soil classification testing to determine: Atterberg Limits, Lime Demand, Particle Size Distribution, Maximum Dry Density and Optimum moisture content and California Bearing Ratio for in situ and lime treated samples.

3. Results and Review

    - Analyse results.
    - Redesign host pavements with Lime treatment and Lime and RCA treatment.
    - Analyse cost effectiveness.

2.0 Literature Review

2.1 Introduction

This chapter of the dissertation discusses various concepts and topics related to lime stabilization and the use of Recycled Concrete Aggregate. Road design, both empirical and mechanistic will be outlined along with road structure and purpose. Modification and Stabilisation with lime will be considered, along with the various forms of lime. Finally stabilising technique and plant will be discussed.

2.2 Pavement Design with Lime Stabilization

This section is concerned with pavement design of spray sealed flexible pavements. Lime treatment does also have an application with rigid pavements, however due to very little proportions of this pavement type in the region rigid pavement design has not been considered. This dissertation discuses pavement design in accordance with Austroads Guide to Pavement Technology Part2: Pavement Structural Design, Department of Transport and Main roads(DTMR) Structural Design Procedures of Pavements on Lime Stabilised Subgrades Tech note 74 and DTMR Pavement Design Supplement to 'Part 2 : Pavement Structural Design' of the Austroads Guide to Pavement Technology.

2.2.1 Road structure and purpose

Road pavements must simply serve two basic functions. Firstly they must perform as an engineering structure, and secondly they must meet functional requirements. Structural performance is the main factor of any pavement, as this is the ability of the pavement to withstand repeated loading from heavy vehicles. Sufficient depth and material quality along with correct construction technique ensure good riding quality. Surfacing on flexible pavements, whether it is a sprayed bitumen seal or asphalt, must provide adequate drainage and skid resistance to prolong life and remain safe for vehicles. The road structure itself can involve a number of layers as seen below in Figure 3.

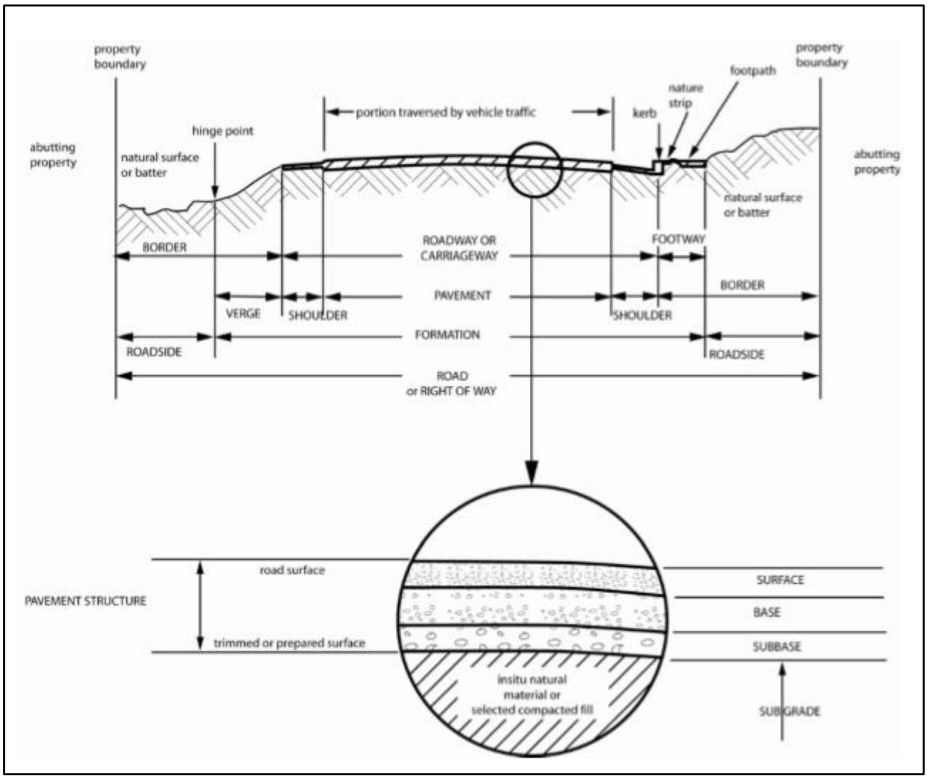


Figure 3 Road cross Section (Austroads 2009)

It can be seen that the pavement consists of a Subgrade, which is the in-situ material. The next pavement layer is the Sub Base, followed by a Base layer (Austroads 2009).

The Base course is the main load bearing layer in the pavement. This means that the base course material is the best quality material in the pavement and will usually have the best compressive strength in terms of California Bearing Ratio (CBR). This layer depth is usually minimised as much as possible as it will almost certainly be the most expensive course of the pavement, besides sealing/wearing course.

The subbase layer in the pavement is also a load bearing course. Supporting the base material is the main role of this structural layer in the pavement. This layer is typically thicker than the base. At this depth in the pavement the stresses have been reduced, which allows the use of a lesser quality material than the base. The subbase is also used to reduce subgrade pumping into the pavement layers causing disruption (Austroads 2009).

The subgrade layer is most commonly left alone, however it is usually trimmed and re-compacted to meet certain compaction requirements, typically 97% compaction (Department of Transport and Main Roads 2015). Sometimes if the pavement is heavy duty, select fill will be placed on top of the subgrade to provided additional support.

Department of Transport and Main Roads specifications MRTS05 Unbound Pavements, outlines the various specifications of unbound materials used in base and subbase layers in Queensland. They are defined from Type 1-4 material. This is based on the CBR of the material, the Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index and Linear Shrinkage), Flakiness Index, Crushed Particles, Degradation Factor, Wet/Dry Strength variation and Wet Ten Percent Fines. The Particle Size Distribution determines the grading of the material. The grading must also be within limits specified in MRTS05 (Department of Transport and Main Roads 2015).

2.2.2 Empirical pavement design

The Empirical Pavement design is the most commonly design procedure used at TRC. The empirical pavement design is well suited and used in design of low volume flexible pavements that can be seen across the Toowoomba region. In addition to this TRC does not have any aid or software capable of using the Mechanistic pavement approach. It is not a reasonable assumption to expect that pavement design process can with 100% confidence guarantee that a pavement will perform as designed for the entirety of its design life. The reasons for this are:

1. Site conditions are not perfect unlike the control conditions.
2. Design values chosen for material properties are made by simplification of complex properties of loading and the materials in question.
3. Construction of pavements cannot produce a road with 100% compliance of layer thickness and homogenous materials.

Pavement design is to some degree a trial and error method with a number of input variables:

- Design Traffic

The number of axles a vehicle has, the load it is carrying and the way it is distributed, the loading rate and tyre pressure all have effects on the performance of the pavement. Each pavement is designed to withstand a certain loading. The design traffic is determined with reasonable consideration given to heavy vehicles, road function, changes to the road network in the future that may affect demand, vehicle design (Tyre pressure) and local environmental considerations (Department of Transport and Main Roads 2013). The design traffic can be determined in the following way.

Roads must be able to cater from bicycles to triple road trains. It must be strong enough to cater for the heaviest vehicle plus the cumulative loading effect of smaller vehicles (cars). Because of this, only heavy vehicles are considered in pavement design (Austroads 2012).

Design traffic is determined in the following way:

1. Select Design period

   Most commonly the design period is 20-40 years depending on the importance of the road.

2. Identify the most trafficked lane

   This is termed the design lane and is the lane the pavement is designed from. If the road is multi carriageway the same applies, but is most commonly the left most lane. Weight-in-Motion (WIM) systems provide lane specific heavy vehicle traffic data. This can be used to determine the lane distribution factor. However, most small councils will not have access to this data type. In that case the following table can be used.

Location	Lanes each direction	Lane Distribution Factor (LDF)		
		Left lane	Centre lane	Right lane
Rural	2 lane	1.00[1]	N/A	0.50
	3 lane	0.95	0.65	0.30
Urban	2 lane	1.00[1]	N/A	0.50
	3 lane	0.65	0.65	0.50

Table 1 Lane Distribution Factor (Austroads 2012)

3. Estimate the average daily number of heavy vehicles in the design lane during the first year of the projects life.

   To calculate the total heavy vehicle axle groups (HVAG) in the design lane an estimate of the first year is required, this can be done in any of the following methods, listed in declining accuracy (Asutroads 2012)

- WIM is the best form of data. It provides the number of heavy vehicle axle groups per heavy vehicle, the distribution of axles and the loads.
- Data from vehicle identification counters. This data will give the proportions of various vehicle types using the road as well as the number of axle groups per heavy vehicle. This data will require the use of a traffic load distribution.
- Data from single tube axle counters. This will give an estimation of heavy vehicles. The use of this data is dependent on the judgement of the engineer (Austroads 2012).

4. Estimate the growth of Heavy vehicle traffic through the area.

Part of estimating the design traffic is accounting for any growth that may occur over the design life of the pavement, we cannot expect the traffic loading to be consistent in number each day or year. If local growth is known then the Cumulative Growth Factor can be determined using table 2.

Design period (P) (years)	Annual growth rate (R) (%)							
	0	1	2	3	4	6	8	10
5	5	5.1	5.2	5.3	5.4	5.6	5.9	6.1
10	10	10.5	10.9	11.5	12.0	13.2	14.5	15.9
15	15	16.1	17.3	18.6	20.0	23.3	27.2	31.8
20	20	22.0	24.3	26.9	29.8	36.8	45.8	57.3
25	25	28.2	32.0	36.5	41.6	54.9	73.1	98.3
30	30	34.8	40.6	47.6	56.1	79.1	113.3	164.5
35	35	41.7	50.0	60.5	73.7	111.4	172.3	271.0
40	40	48.9	60.4	75.4	95.0	154.8	259.1	442.6

Table 2 Cumulative Growth Factor (CGF) (Austroads 2012)

5. Estimate the average number of axle groups per heavy vehicle

   WIM Data or data from vehicle identification counters will have this information available to the designer. If this information is not available the following table can provide some guidance.

Street type	AADT two-way	Heavy vehicles (%)	Design AADHV (single lane)	Design period (years)	Annual growth rate (%)	Cumulative growth factor (Table 7.4)	Axle groups per heavy vehicle	Cumulative HVAG over design period	ESA/HVAG	Indicative design traffic (ESA)
Minor with single lane traffic	30	3	0.9	20	0	20	2.0	13 140	0.2	3×10^3
				40	0	40	2.0	26 280	0.2	5×10^3
Minor with two lane traffic	90	3	1.35	20	0	20	2.0	19 710	0.2	4×10^3
				40	0	40	2.0	39 420	0.2	8×10^3
Local access with no buses	400	4	8	20	1	22.0	2.1	128 480	0.3	4×10^4
				40	1	48.9	2.1	285 576	0.3	9×10^4
Local access with buses	500	6	15	20	1	22.0	2.1	240 900	0.3	8×10^4
				40	1	48.9	2.1	535 455	0.3	1.5×10^5
Local access in industrial area	400	8	16	20	1	22.0	2.3	256 960	0.4	1.5×10^5
				40	1	48.9	2.3	571 152	0.4	3×10^5
Collector with no buses	1200	6	36	20	1.5	23.1	2.2	607 068	0.6	4×10^5
				40	1.5	54.3	2.2	1 427 004	0.6	10^6
Collector with buses	2000	7	70	20	1.5	23.1	2.2	1 180 410	0.6	8×10^5
				40	1.5	54.3	2.2	2 774 730	0.6	2×10^6

Table 3 Indicative heavy vehicle axle groups for lightly traffic roads (Austroads 2012)

6. Calculate the cumulative heavy vehicle axle groups of the design period

   The following formula is used. All the inputs have been determined in the above parts.

$$N_{DT} = 365 \times AADT \times DF \times \%HV/100 \times LDF \times CGF \times N_{HVAG}$$

where

AADT = Annual Average Daily Traffic[2] in vehicles per day in the first year (Section 7.4.4)

DF = Direction Factor is the proportion of the two-way AADT travelling in the direction of the design lane

%HV = average percentage of heavy vehicles (Section 7.4.4)

LDF = Lane Distribution Factor, proportion of heavy vehicles in design lane (Section 7.4.3)

CGF = Cumulative Growth Factor (Section 7.4.5)

N_{HVAG} = average number of axle groups per heavy vehicle (Section 7.4.6).

Equation 1 Design Heavy Vehicle Axle Groups (Austroads 2012)

7. Estimate the proportion of axle group types and the distribution of the axle group loads.

This is called the Traffic Load Distribution (TLD) and is required to calculate the design traffic loading. The TLD provides information to evaluate the pavement damage cause by HVAG, WIM data will have again provided this infomation. In the absence of such data a presumptive TLD must be used.

For flexible pavements seal cracking and loss of surface shape are the damage types considered. The presumptive TLD data can be used (refer to table 4).

Pavement type	Damage type	Damage index	Street type	Value
Granular pavements with thin bituminous surfacings, designed using Figure 12.2	Overall damage	ESA/HVAG	Minor with single lane traffic Minor with two lane traffic Local access without buses Local access with buses Local access in industrial area Collector without buses Collector with buses	0.2 0.2 0.3 0.3 0.4 0.6 0.6
		ESA/HV	Minor with single lane traffic Minor with two lane traffic Local access without buses Local access with buses Local access in industrial area Collector without buses Collector with buses	0.4 0.4 0.6 0.6 0.9 1.3 1.3
Pavement containing one or more bound layers, mechanistically designed	Fatigue of asphalt	SAR5/ESA	N/A	N/A
	Rutting and shape loss	SAR7/ESA	All lightly-trafficked roads	1
	Fatigue of cemented materials	SAR12/ESA	Lightly-trafficked roads without buses	3
			Lightly-trafficked roads with buses	12

Table 4 Presumptive TLD (Austroads 2012)

8. Determine the Design Equivalent Standard Axles for the design life of the pavement.

$$DESA = ESA/HVAG \times N_{DT}$$

where

ESA/HVAG = average number of Equivalent Standard Axles per Heavy Vehicle Axle Group (see Section 7.6.2)

N_{DT} = cumulative number of Heavy Vehicle Axle Groups over the design period (from Equation 14).

Equation 2 Design Equivalent Standard Axles (DESA) (Asutroads 2012)

- Design CBR for subgrade

The determination of the subgrade design California Bearing Ratio (CBR) is the next step to the empirical method. In council application the soil is tested in a laboratory for its CBR strength or in-situ via test method Q114B-Dynamic Cone Penetrometer. This is normally used as the design CBR. A maximum value of CBR 15 is assigned to subgrades for design purposes.

In most cases the subgrade CBR for the clay materials found in the Toowoomba Region are less than 3 (CBR between 1 and 3). As will be seen shortly the empirical pavement charts have a minimum design CBR of 3 and 2 for lightly trafficked roads. Currently council uses the pavement design supplement to part 2 of Austroads structural design provided by DTMR. Council commonly uses a select granular material fill or rock fill to bring the level of the CBR up to a presumed 3 CBR. This is based on the following table

Subgrade CBR (%) (at design density and moisture conditions)	Minimum thickness (mm) of coarse granular or rock fill required for the adoption of a presumptive design CBR of 3%
1.0	400
1.5	300
2.0	200
2.5	150
3.0	0

Table 5 Select material for CBR 3 (Austroads 2012)

However some differences occur in the determination of the design CBR when using a lime stabilized subgrade with a higher CBR than that of the host subgrade.

Austroads proposed procedures for the design of pavements on select subgrade and lime-stabilised subgrade materials suggest that for the empirical design method the design CBR is the minimum of:

- CBR 15
- The presumed subgrade CBR
- CBR provided by underlying support (refer to equation 3)

$$CBR_{selected or stab.subgrade} = CBR_{underlying material} \times 2^{(selected or stab.subgrade / 150)}$$

Equation 3 Lime Stabilized CBR from underlying support (Austroads 2013)

The figure below shows this relationship graphically.

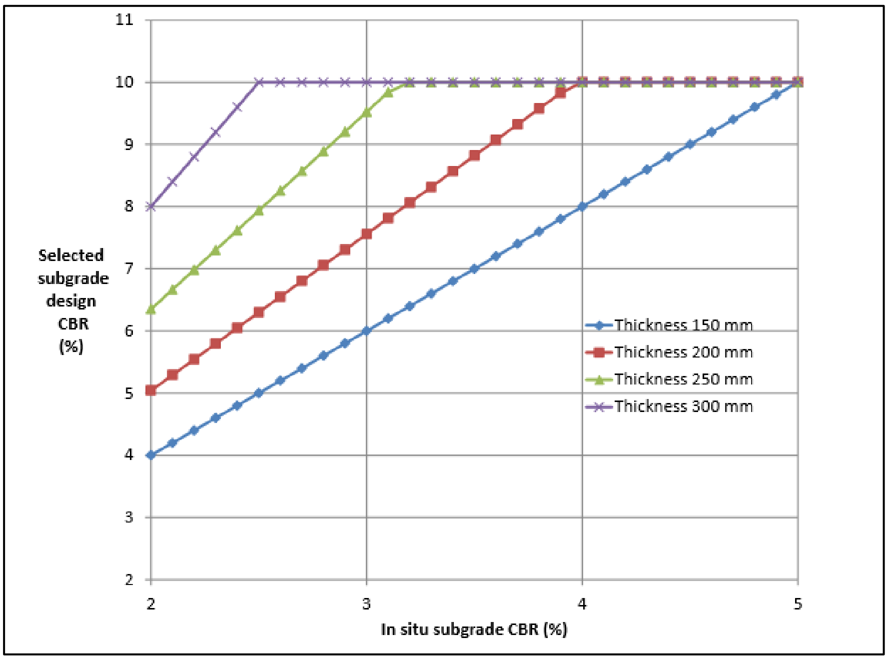


Figure 4 Design Subgrade CBR from underlying support (Austroads 2013)

We can see above if the laboratory results of lime stabilized subgrade yielded CBR 10 that using this value for design is dependent on the depth of stabilization. It was found at this stage of the literature review that each state road authority has its own methods regarding lime stabilization. For the purpose of this report, only Queensland (DTMR) and Austroads will be discussed.

DTMR specifies that lime treated subgrade behaves and is designed as follows:

- The material is sub layered in 5 layers.
- The modulus of the top layer is 200mm regardless of underlying support.
- The material is cross anisotropic and has a Poisson's ratio of 0.45.
- Sufficient lime is added until an Unconfined Compressive Strength (UCS) of 1-2 MPa (Unoaked) is achieved after 28 days (Austroads 2013).

This method varies slightly from the Austroads method in that each lime stabilized layer has a UCS between 1 and 2 and the modulus of the top layer is 200Mpa. The Austroads method does not use sub layering for the empirical pavement design method as defined above.

- Pavement thickness design

With the design CBR defined and the design traffic defined, the pavement overall thickness, thickness of individual layers and base thickness can be determined.

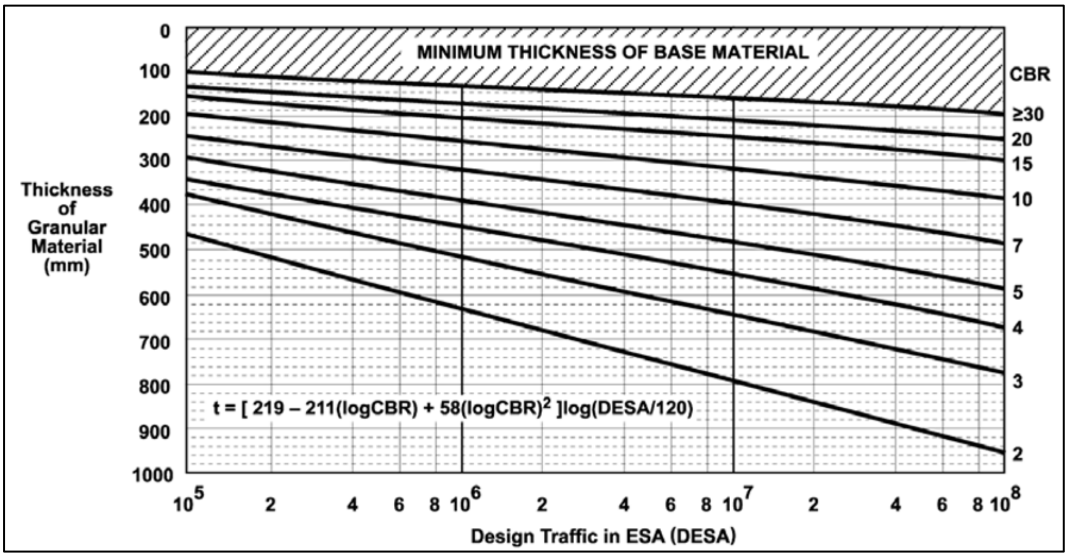


Figure 5 Empirical Pavement Chart (Austroads 2013)

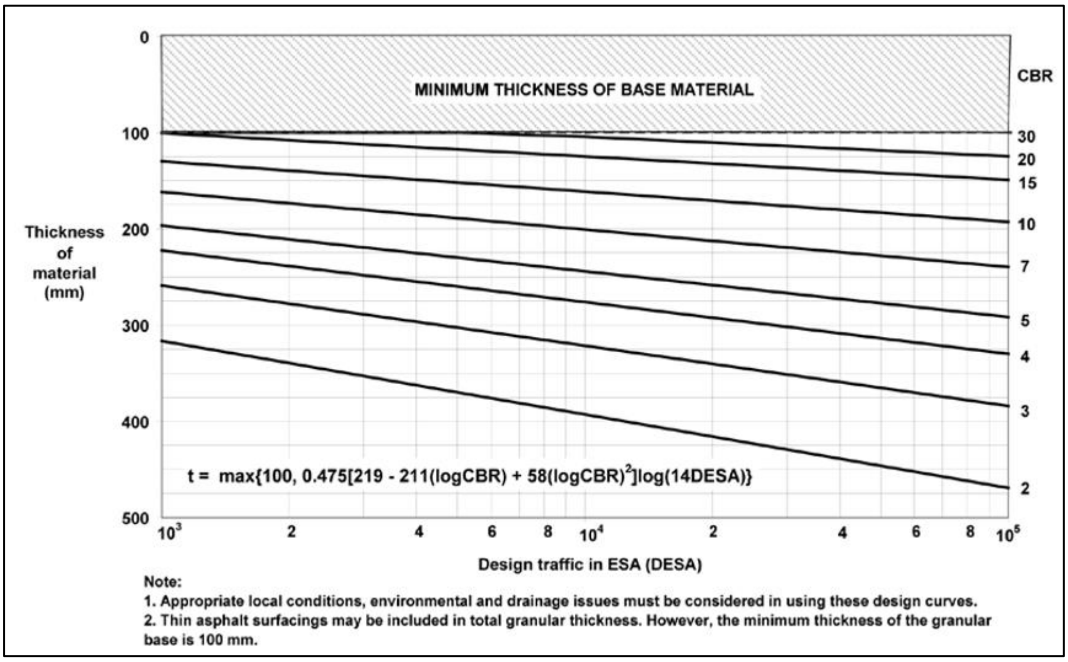


Figure 6 Empirical Pavement chart low volume roads (Austroads 2013)

2.2.3 Mechanistic Pavement Design

The Mechanistic Pavement Design method usually employs the aid of computer software such as CIRCLY. The design procedure for the mechanistic pavement design is based on a structural analysis of a multi layered pavement system. The method considers the strain at critical locations in the pavement as seen in the figure below.

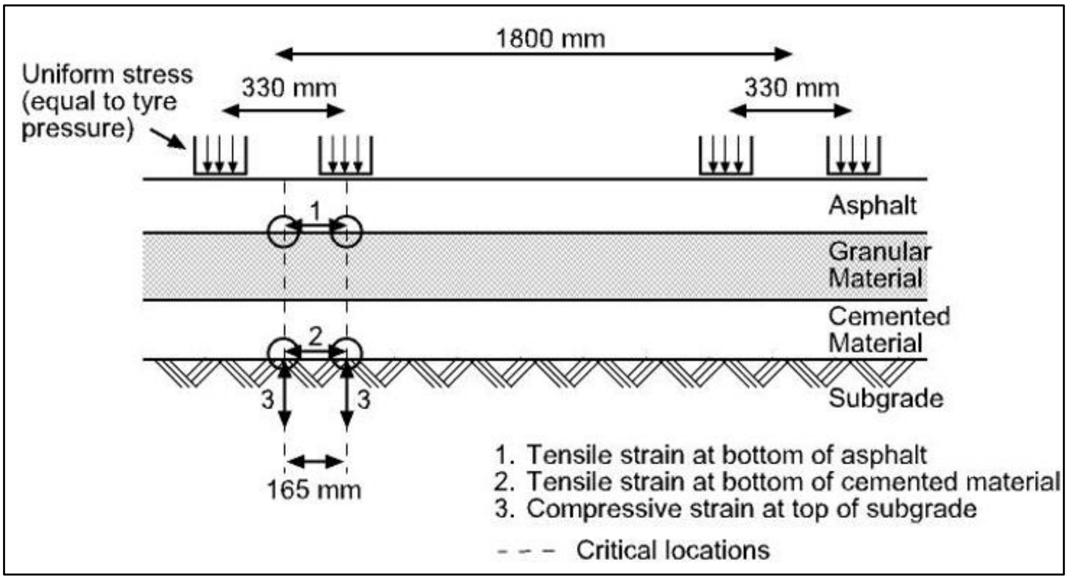


Figure 7 Pavement model for mechanistic method (Austroads 2012)

The above figure shows that standard axle loading consists of a dual wheeled single axle applying a load of 80kN. For flexible pavements the critical response zone is inside of the inner wheel or in between the dual wheels. Tyre pressure is assumed as 750 kPa. CIRCLY applies a linear elastic model to assess these critical regions in the pavement.

The design traffic is calculated in the same manner as is for empirical pavement design in section 2.2.2. Where these methods differ is in the definition of the stabilized subgrade layer. For input into CIRCLY the stabilized subgrade must be sub layered into 5 layers of equal thickness. In coordination with the empirical design method the top most layer modulus is calculated using equation 3 section 2.2.2.

The ratio factor between layers is calculated using this formula:

$$R = \left[\frac{E_{V\text{ selected subgrade top sublayer}}}{E_{\text{underlying material}}} \right]^{\frac{1}{5}}$$

Equation 4 Sub layering Factor (Austroads 2012)

Factors for traffic loading in the absence of WIM data are also taken from Table 4 section 2.2.2. With this information the mechanistic pavement design and CIRCLY can be used to analyse and optimise pavement designs.

2.2.4 Pavement Fatigue and Failure due to marginal subgrade

Compressive vertical strain at the top of the subgrade layer is the primary cause for pavement deformation in pavements with unbound granular layers. This causes consequent deformation in the unbound layers above, possible leading to cracking on the surface of a seal.

When the depth of the pavement is not adequate or the material is not of the correct quality or where the pavement fails to distribute the loads as designed, significant compressive vertical strain in the form of rutting may occur.

Figure 8 Typical Rutting

The possibility of rutting occurring in the base and subbase layers is usually ignored due to the quality of the subbase and base materials being higher quality than the subgrade or select fill.

Environmental factors that can affect pavement health and cause rutting are the ingress of moisture into the pavement. This may occur from ingress of moisture through cracks in the seal, capillary rise from the water table below or seepage from a nearby road embankment or blocked drain (*CIV5705-Pavement Design and Analysis: Course material* 2016) . With the reactive soils local to Toowoomba this kind of pavement failure is prevalent. Rutting as mentioned can be caused by the CBR being reduced by the moisture content. The following figure shows this relationship

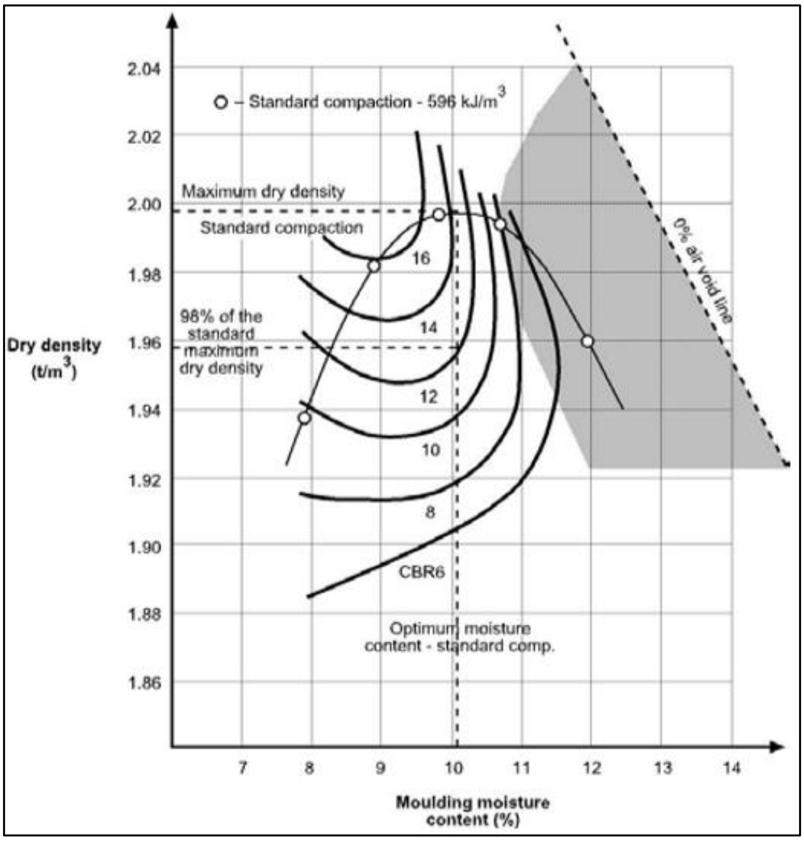


Figure 9 CBR relationship with moisture content (Austroads 2012)

2.3 Chemical Stabilization/Modification

This section of the literature review will focus on the characteristics, effects and properties of lime stabilisation techniques and procedure outlined by DTMR will be discussed.

2.3.1 Lime used in Construction

2.3.1.1 Quicklime

Quicklime is un-hydrated form of hydrated lime and is called Calcium Oxide (CaO). Lime in this state is very reactive with water and must be treated with care to avoid accidental contact and burns. Quicklime has a higher bulk density than hydrated lime which means more available lime per tonne in comparison; it is also available in powder or granular form. Quicklime must be hydrated before mixing with the subgrade. This process is called slaking and is the chemical reaction of the addition of water.

$$CaO + H_20 \rightleftharpoons Ca(OH)_2 + heat$$

(Calcium Oxide) (Calcium Hydroxide)
(Quicklime) (Hydrated Lime)
(Heat of hydration ~ 272 kcal/kg CaO)

Figure 10 Quick Lime Hydration (Austab 2002)

As a by-product of this reaction considerable heat and steam are released.

2.3.1.2 Hydrated Lime

Hydrated Lime (Ca(OH)2) is the hydrated form of quicklime and is a fine dry powder, it is much more stable than quicklime. As mentioned hydrated lime has a slightly less bulk density (0.45-0.56 tonnes per cubic meter) when compared to quicklime (0.9-1.3 tonnes per cubic meter). However this is usually compensated by a slightly cheaper purchase price. For laboratory testing only hydrated lime is used, in the field either can be used.

2.3.1.3 Slurry

Lime Slurry is over hydrated, hydrated lime. Slurry lime is hydrated lime suspended in excess water. This allows the lime treatment to be sprayed onto the ground similar to bitumen with better precision in comparison to the spreading of a dry powder. It also promotes improved mixing and is more consistent. This can be used where a pavement is particularly dry; the excess water adds moisture before the stabiliser mixes the pavement.

2.3.2 Reactive soils properties

Reactive soils most commonly contain clays such as:

- Illite
- Montmorillonite

Illinite clays are expansive and of medium plasticity and low permeability. Montmorillonite clays are highly expansive and usually have high plasticity index. Austroads describes expansive materials in terms of liquid limit, Plasticity Index and Swell.

Expansive nature	Liquid limit (%)	Plasticity Index	PI x % < 0.425 mm	Swell (%)*
Very high	> 70	> 45	> 3200	> 5.0
High	> 70	> 45	2200–3200	2.5–5.0
Moderate	50–70	25–45	1200–2200	0.5–2.5
Low	< 50	< 25	< 1200	< 0.5

* Swell at OMC and 98% MDD using Standard compactive effort; four-day soak. Based on 4.5 kg surcharge.

Table 6 Characterisation of Expansive Subgrade (Austroads 2012)

As seen above the range of expansive material ranges from low to very high. The clay materials tested in this project will be assessed against this table to determine how reactive the material is (Austroads 2012).

2.3.3 Chemistry of lime stabilization/Modification

2.3.3.1 Modification

Lime modification of fine grained soils and clays is used to improve the mechanical characteristics of the host soil. The biggest effect of modification is the increase in workability. Typically small amounts of lime (1-4%) are used in comparison with lime stabilisation. The purpose of modification can be for the following reasons:

- Drying of the sample due to the hydration/flocculation process.
- Decrease the plasticity index of the soil considerably.
- Increase the workability and aid in compaction.
- Reduced effects of shrinkage and swell.

Due to low percentages of lime in the mix, lime modification is not as strong and durable as lime stabilisation, but certainly can make a big difference to the workability of the host soils. The main difference is that lime modification is not considered to improve the load bearing capacity of the layer, despite some increases in strength.

With the addition of lime to soils the divalent calcium cations replace almost all clay cations absorbed on the clay surface. This exchange of cations occurs because divalent calcium cations can replace cations of single valence and ions in a high concentration will replace those in a low concentration (Little N Dallas, 1995).

The diffused water layer between particles is greatly affected by exchangeable ions when lime is added. Lime modification results in stabilisation of the diffused water layer between particles which allows the particle to reduce in size dramatically. Particles are allowed to approach each other and realign their structure from plate like formation to edge face attraction. This is called Flocculation/Agglomeration, and is enhanced by high electrolyte and high PH environments (Little N Dallas, 1995).

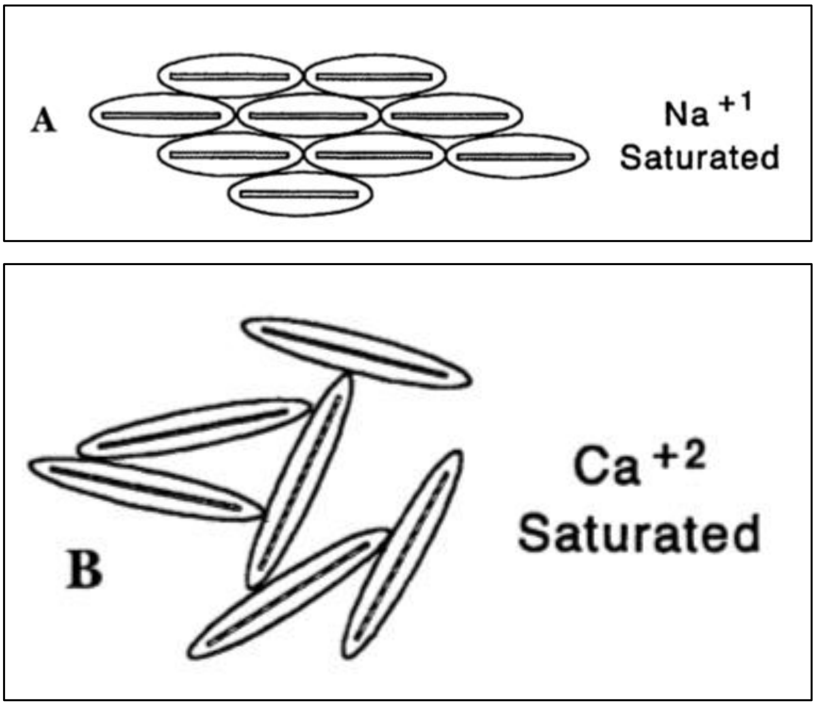


Figure 11 Flocculation Re-Alignment (Little N Dallas, 1995)

The above figure shows the realignment of clay particles due to edge face attraction.
The benefit of Flocculation and Agglomeration is:

- Dramatic reduction in size and stabilisation of the absorbed moisture layer.
- Increase internal friction among the agglomerates which increases the shear strength of the soil.
- Improved workability due to texture change from plastic clay to a friable loamy material.

This visual textural change in the soil properties is rapid and can be as little as one hour after mixing.

Figure 12 Soil Flocculation (Wilson,PL 2011)

2.3.3.2 Stabilisation

Stabilisation of reactive materials most commonly requires substantially more lime than that required for modification. Stabilisation according to the Department of Transport and Main Roads occurs when the pH of a soil lime mixture reaches a level of 12.4. This limit is commonly around 6% lime by dry mass (Little N Dallas, 1995).

The phenomenon of lime modification occurs in stabilisation also, occurring early in the process of mixing. The long term strength gains of stabilisation are governed by the nature of the host material mineralogy. The formation of a cement matrix between the lime and clay particles such as Alumina and Silica is responsible for strength gains with time (Little N Dallas, 1995).

A pozzolan is defined as a finely divided siliceous or aluminous material which in the presence of lime and water will form a cement compound. The cemented product produced from the reaction of pozzolans, lime and water are calcium-silica-hydrates and calcium-alumina-hydrates, which are similar to those formed during hydration of Portland cement. In a high pH environment clay-silica and clay-alumina become soluble and react with free calcium in the lime (Little N Dallas, 1995). This reaction is called a pozzolanic reaction and as long as the pH remains high enough and free calcium is available the reaction will continue. It has been seen with field testing that this pozzolanic reaction can continue for years, continually cementing and strengthen the material.

$Ca^{++} + OH^{-}$ + Soluble Clay Silica → Calcium Silicate Hydrate (CSH)
$Ca^{++} + OH^{-}$ + Soluble Clay Alumina → Calcium Aluminate Hydrate (CAH)

Figure 13 Pozzolanic Reactions (Little N Dallas, 1995)

Montmorillonite clays, like those found in the Toowoomba region, are most reactive due to the minerals in the clay. Such materials have high levels of Alumina and Silica which are pozzolans for the pozzolanic reaction with lime.

Organic material which contains carbon can reduce the effectiveness of the pozzolanic reaction. The organic molecule complexity can absorb free calcium or negatively interact with the pozzolanic reaction (Little N Dallas, 1995). Organic contents of more than 1 percent can severely impact lime stabilisation effectiveness.

Sulphate/ferric oxides can reduce stabilisation effectiveness also. Like organic material these compounds can interfere and inhibit the use of lime and the pozzolanic reaction. Calcium-sulphate-aluminate-hydrates are harmful to pavements because they can expand with high pressure. This can cause considerable heave in the pavement layer after construction. This sulphate content can be tested before any stabilisation occurs. This can be less harmful if the reaction occurs during mixing (Little N Dallas, 1995).

Plentiful water to solubilize the sulphates, consistent mixing of lime and soil, and proper pavement drainage to minimize high sulphate moisture are ways to minimize the negative effects of Sulphates and ferric oxides.

2.4 Stabilizing with lime technique

2.4.1 Plant requirements

Plant used for stabilisation consists of standard construction plant such as:

- Pad foot Rollers
- Smooth Drum Rollers
- Rubber Multi Tyre Rollers
- Graders for trimming

In addition to these plant requirements specialist plant is required to place, incorporate and mix the lime stabilized subgrade layer.

Placement/spreading of the lime is done by a spreader truck that controls the flow rate of lime onto the surface of the pavement for mixing.

Figure 14 Spreader Truck (Stabilised Pavements of Australia 2016)

Mixing of the subgrade and the lime is a tedious process as the clay material is hard to break apart. Machines ranging from 300-500 Horsepower are used to mix these materials.

Figure 15 Typical Stabillizer

Typical operating depths for medium size Stabilisers is 300mm. Large stabilisers are capable of higher production rates and are capable of stabilising to 500+ mm depth (Stabilised Pavements of Australia 2016). These machines add moisture as they mix the pavement.

2.4.2 Placement and Amelioration Period

The procedure used for placement and incorporating into the subgrade is in accordance with the Department of Transport and Main Roads 2015 Technical Specification, MRTS07A Insitu Stabilised Subgrades using Quicklime or Hydrated Lime.

Where required and the spread rate of the lime is not specified, a maximum spread rate of 20 Kilograms per square metre for Quicklime and 26 kilograms per square metre of Hydrated lime will be used. The available lime index is a measure of the free lime in the mixture, to pass material quality the lime index must be greater than 80% (Department of Transport and Main Roads 2015).

Water used must be free from oils, acids and organic matter and contain less than 0.05% sulphates. The water must be of a potable standard. The allowable working time is the time from the commencement of incorporation to the final compaction and trimming of the subgrade, where not stated a 48 hour period must be adopted.

Lime stabilisation of subgrade is a two day process; the material will be spread with a spreader and mixed incorporating moisture with a stabiliser/reclaimer.

- Day 1

Single lime pass with half the dosage rate is applied and mixed, where quicklime is used slaking (addition of water) must occur before mixing. All traffic must be stopped as steam from heat release is dangerous for bystanders. The material shall be lightly rolled and left to rest overnight.

- Day 2

After overnight amelioration period, add the balance of the lime and mixing in with stabiliser. This mixing shall be completed within 6 hours of the second lime application. Moisture content should be in the range of 97%-101% of optimum moisture content. The subgrade level should be trimmed before light compaction of the final application. Final Compaction shall be completed using standard compaction effort and must be completed in the allowable working time (Department of Transport and Main Roads 2015).

Other items outlined in the technical specifications discuss:

- Construction joints
- Curing
- Protection
- Compliance testing
- Product standards and supplementary requirements.

2.5 Lime Treated Subgrade Characteristics

As discussed in previous sections lime stabilisation is effective at stabilizing the reactive nature of the soil by reducing the Liquid Limit, Plastic Limit, Plasticity Index and Linear Shrinkage. When sufficient lime is added the soil becomes cemented and increases in California Bearing Ratio are seen.

Positive features:

- Reduced swell and shrinkage.
- Reduced permeability (water barrier).
- Increased construction workability.
- Increased CBR strength.
- Increased durability.
- Reduced pavement thickness.
- Environmentally friendly product.

Negative features:

- Sensitive to Organic content.
- Sensitive to sulphate content.
- Tedious construction process.
- Reflective cracking if not provided with sufficient cover (175mm).

3.0 Methodologies

This section of the paper is concerned with the methods used to produce the results of subgrade stabilization with recycled concrete aggregate and lime in this dissertation. Data acquisition, testing procedures and resources will be discussed in the following sections of the paper.

3.1 Trial Site Selection

For this dissertation and through collaboration with management at Toowoomba Regional Council two suitable sites were discussed and selected to perform the analysis on. These two pavements were, Mann Silo Road, Brookstead and Hinz Street, Clifton. Both of these pavements have exhibited pavement failures and have had maintenance in the past. One in particular recently received extensive rehabilitation and is already failing with rutting. It was decided that the two pavements would be ideal candidates for this study.

3.1.1 Pavement Study Mann Silo Road, Brookstead

Mann Silo Road is located approximately 60 kilometres south-west of Toowoomba, adjoining the small township of Brookstead. This road is located in the southern region of the Toowoomba Regional Council.

Figure 16 Mann Silo Rd Location

The pavement itself is a currently a 4 meter wide formation with a spray sealed surface. It is unknown exactly what depth the pavement is as no testing was conducted to see what the existing pavement depth is. However from a design perspective it would be reasonable to assume a pavement depth of 200 – 300 mm (refer to section 4.6.3.1).

Plans for Mann Silo Road include an extensive pavement repair of approximately 3800m. Widening of the pavement is also proposed by pulverising the top 100mm of pavement and widening the shoulders and re-compacting. Additional type 3.3 material (CBR 45) will be carted in and placed on top of the pavement.

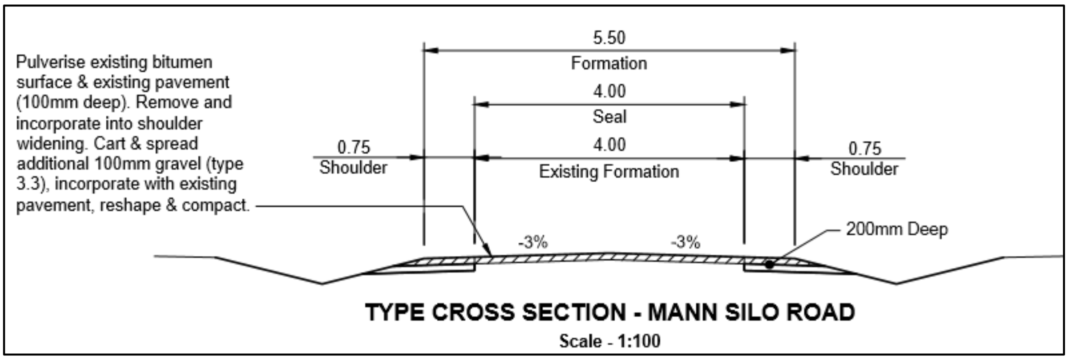


Figure 17 Mansilo Road Formation (Toowoomba Regional Council, 2016)

The current condition of the road is very poor, seasonal harvesting traffic has caused significant overloading of the pavement. The condition of the pavement is best illustrated with some photos taken from the site during sample collection. The soil type onsite is typical black clay; characterisation of this material is seen in sections 4.1.1 and 4.3.2.

Figure 18 Mann Silo Rd Pavement Photo 1

Figure 19 Mann Silo Rd Pavement Photo 2

We can see here longitudinal cracking damage cause by the deep rutting along the road.

Figure 20 Mann Silo Rd Pavement Photo 3

Figure 21 Mann Silo Rd Pavement Photo 4

As seen here the rutting depth reached a level of 130mm, this shows severe pavement distress.

Causes for this are mostly environmental. The black clay subgrade is very reactive with moisture variations. The topography of the road is very flat and drains are quite shallow. During wet periods underlying parts of the pavement can be inundated. With clay materials come very low hydraulic conductivities, as low as 10^{-10} centimetres per second. This means that clays do take a long time to dry out once saturated, which can leave the pavement layer at a reduced capacity for long periods of time. In addition to this as this road is surrounded by cropping land, irrigation infiltration could be a contributing factor to soil moisture.

3.1.2 Pavement Study Hinz Street, Clifton

Hinz Street is located approximately 50 kilometres south of Toowoomba. It is a residential street in the township of Clifton. This road is located in the southern region of the Toowoomba Regional Council.

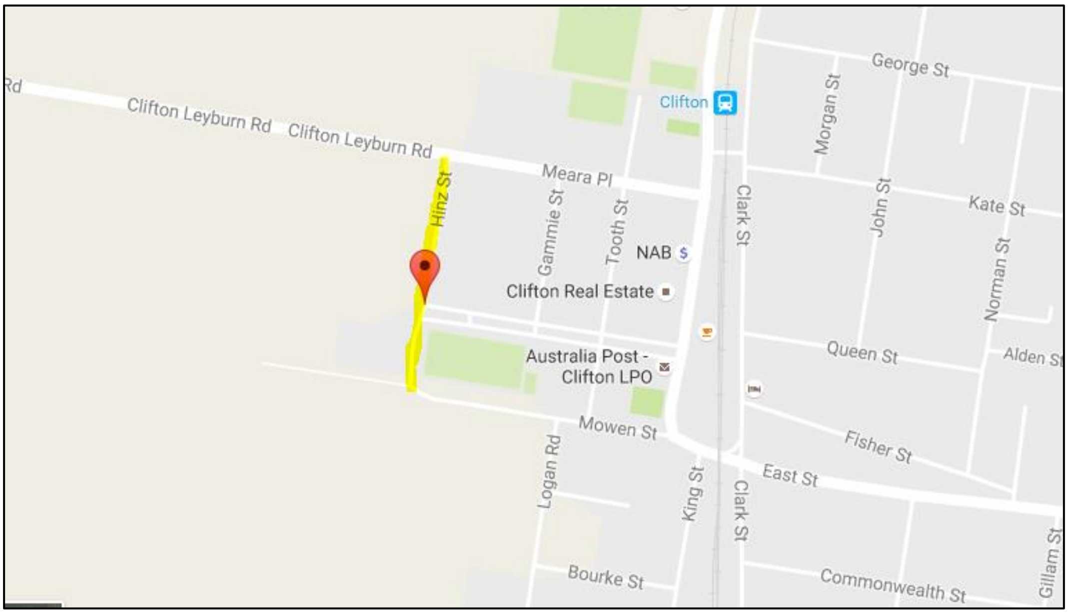


Figure 22 Hinz Street Location

The pavement itself is a currently a 9 meter wide formation with a spray sealed surface. The running lanes are 3.5 meters each. This pavement was upgraded in 2013 and has 340mm of type 3.4 (35 CBR) subbase and 170mm of type 3.3 (CBR45) base.

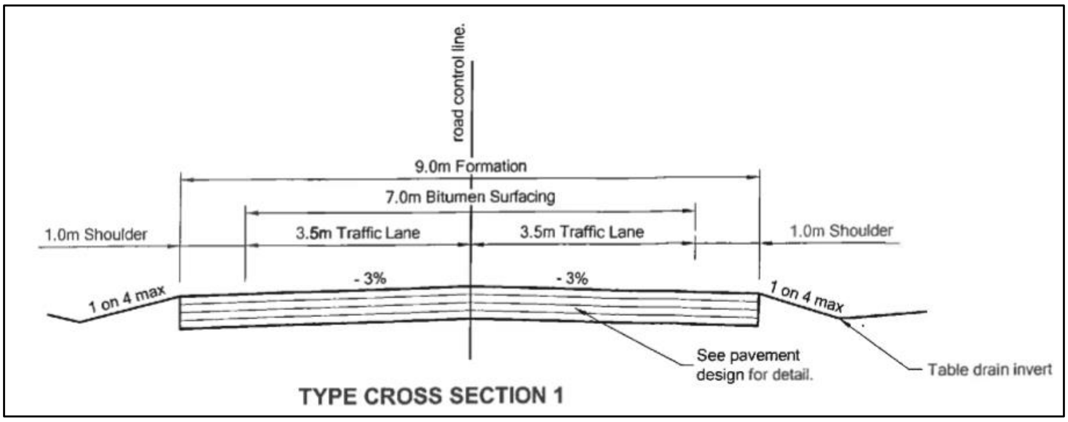


Figure 23 Hinz Street Formation (Toowoomba Regional Council, 2016)

The current condition of the road for its age is very poor. The condition of the pavement is best illustrated with some photos taken from the site during sample collection. The soil type onsite is typical black clay; characterisation of this material is seen in sections 4.1.2 and 4.3.1.

Figure 24 Hinz St Pavement Photo 1

Figure 25 Hinz St Pavement Photo 2

Figure 26 Hinz St Pavement Photo 3

The above picture shows ponding at the inlet of the culvert. This area is a very wet and a low water table could be responsible for this. Road side drainage is well constructed but ponding water at the culvert should be addressed.


Figure 27 Hinz St Pavement Photo 4

30-40mm of pavement deflection was average for this pavement. Causes for this are mostly environmental like Mann Silo Road. The black clay subgrade is very reactive with moisture variations. The topography of the road is well defined with good profile and drainage. Again with clay materials come very low hydraulic conductivities, as low as 10^{-10} centimetres per second. This means that clays do take a long time to dry out once saturated, which can leave the pavement layer at a reduced capacity for long periods of time. Since the construction of the pavement Hinz Street has seen an increased proportion of heavy vehicles. This will have contributed to the decay the pavement life quicker.

3.2 Subgrade/RCA Testing and Literature

3.2.1 Methods used by others

There are many various techniques and procedures for determining the suitability of lime treated/stabilised soils and the precise lime content. In-situ strength is not always the main reason for lime stabilisation. The swell potential, workability and even moisture content can be primary characteristics that are undesirable for construction. Methods of lime adoption into subgrades are constantly under review by the big road Authorities such as DTMR, Austroads and Austab. On big projects lime can be used as a temporary measure to allow construction machinery to operate on weak subgrades.

The primary objective of the lime/soil ratio is to obtain optimum lime contents that yield optimum strength gains. This decision is based on the intended use of the pavement in its design life. A wide range of lime contents can be used on the same soil, with differing effects. A reduction in plasticity and liquid limit or workability may be the key objective. For this to be achieved lime modification may be required. However long term strength gains and pavement performance will be best achieved with stabilization and higher proportions of lime.

The mixture design can be broken down into two categories. Firstly, the modification of soil properties such as plasticity, reduced reactivity, improvements in workability and increased shear strength abilities are attainable with low lime contents(generally 1-5% by weight)(Little N Dallas, 1995). Cation exchange between the lime and the soil along with flocculation and agglomeration is most responsible for the change of character. These modified soil characteristics most commonly, can be achieved within a short period after mixing of the lime and soil.

Secondly if long term strength gains and pavement performance are key characteristics then stabilization will be needed. Pozzolanic reactions of the lime with aggregate and soil minerals are associated with increased strength and durability. This will help the pavement distribute tensile, flexural, compressive and shear stress introduced by wheel loading from vehicles (Little N Dallas, 1995).

There are extensive methods used to assess soil suitability and the lime content to be added to achieve stabilization. Some of these include the Eades and Grim Procedure, The Thompson procedure and the Texas procedure, all of which are utilized and accepted methods in the United States. It is not in the scope of this paper to discuss methods of stabilization used by other countries and authorities. For the purpose of this dissertation methods determined by Austroads, DTMR and Austab will be discussed as they are applicable for the use in local council.

For lime to be an effective stabilizing agent the soil being treated must contain clay fines (More than 25 % passing 0.425mm Sieve) that will react with lime, the amount of reactive material controls the quantity of bonding with the lime (Austroads 2006). Austroads recommends testing the subgrade for its reactivity, strength characteristics and particle size distribution prior to any stabilization. This will reveal how appropriate the use of lime will be on that material.

Testing for Reactivity includes:

- Particle size Distribution (TMR Q103A)
- Plastic Limit (PL) (TMR Q105)
- Liquid Limit (LL) (TMR Q104D)
- Linear Shrinkage (LS) (TMR Q106)
- CBR remoulded specimen (TMR Q113A)
- In-Situ DCP(CBR) (TMR Q114B)
- Unconfined Compressive strength (TMR Q115)

Most importantly the Plasticity index of the parent subgrade must have a magnitude of 10 or greater for lime stabilization to be successful under current Austroads and TMR Specifications (Austroads 2006).

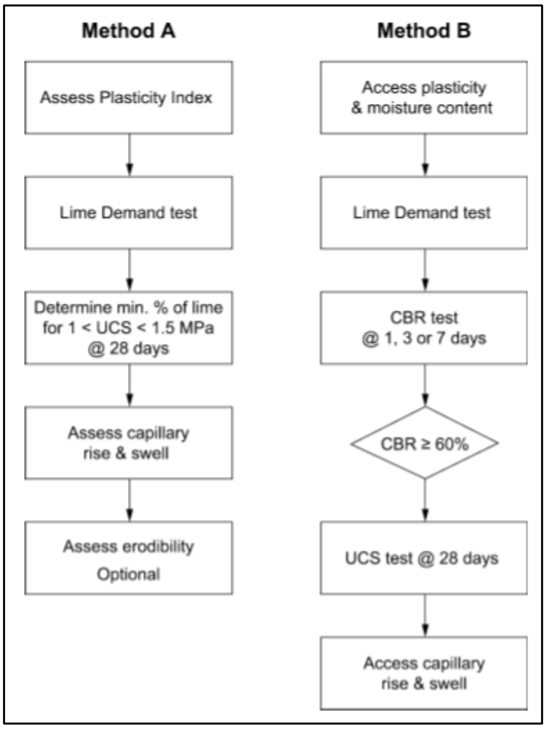


Figure 28 Austroads lime stabilisation methods

Toowoomba Regional Council adheres to the main roads technical specifications for pavement construction and testing, Technical Note (TN151) - Testing of Materials for Lime Stabilisation outlines the initial testing procedure (Department of Transport and Main Roads 2016). DTMR suggest that the material is tested for its particle size distribution, liquid limit, plastic limit, Plasticity index and linear shrinkage. In addition to Austroads specifications, Organic content (Q120B), sulphate content (AS 1289 4.2.1), Ferric oxide and clay types can be identified.

Deleterious materials such as organic matter, Sulphate and ferric oxide interfere with the hydration process along with reacting with the lime to form a cement paste. Sulphates can negatively impact the effectiveness of long term pozzolanic reactions; hence if the equipment is available these characteristics should be tested (Department of Transport and Main Roads 2016).

Once the parent subgrade is fully identified and characterised, the initial lime demand (optimum lime content) can be determined. Austroads details 2 methods for achieving this.

- "Method A: Lime demand is determined based on a desired UCS"
- "Method B: Lime content is determined based on CBR, this is used when a minimum CBR of 5 is required" (refer to figure 28)

The Department of Transport and Main roads recommends the use of the Lime demand test (Q133) to determine at what point stabilisation will occur in the given soil.

Recycled Concrete Aggregate (RCA) will also be used in the marginal subgrade samples to determine if it is a viable material in lime stabilized subgrades. However, very little literature could be found to provide guidance on methods used by others. With this conclusion, a testing procedure has been developed specifically for this project.

A growing area such as the Toowoomba Region and host to the largest inland city in Queensland has lots of infrastructure and demolition, which provides the means of recycled materials. Literature suggests that recycled concrete can fully replace generic aggregates (Curtin University 2013). In addition to this, use of recycled concrete has some economical and sustainable benefits. Recycled concrete can also be utilized singularly as subbase and base layers. An Australian study by Curtin University suggests that recycled concrete structural layers can conform to current technical specifications.

Aggregates for pavement construction must too be tested to ensure compliance with current technical standards. RCA is no exception to this and must be tested and compared to standard pavement aggregates, Main Roads Technical Specification 05- Unbound Pavements is most commonly used for classification of granular materials.

TRC performs all pavement construction and soil testing in accordance with DTMR technical specifications. To keep practice standard and consistent with current practice in the Toowoomba Regional Council, DTMR procedures were used in the testing of the samples, not Australian Standards. Some test procedures adopted by Local Government are equivalent to Australian Standards (Table 7).

TMR method	Equivalent	TMR method	Equivalent
Q116A	AS 5101.3.2	Q308A	AS 2891.3.1
Q124	AS 1289.3.7.1	Q308D	AG:PT/T234
Q181A	AS 1289.6.2.2	Q313	AG:PT/T236
Q190	ASTM D6244	Q317	AS 2891.8
Q212A	AS 1141.50	Q317	AG:PT/T237
Q301	AS 2891.1	Q334	AG:PT/T131
Q302A	AS 2891.1.2	Q334	AS 2341.18
Q302B	AS 2891.1.2	Q336	AS 2341.3
Q306B	AS 2891.9.2	Q476	AS 1478.2
Q306D	AS 2891.9.3	Q705	AG:PT/T250
Q307A	AS 2891.7.1	Q706	AG:PT/T251

TMR - Transport and Main Roads
AS - Australian Standard
AG:PT/ - Austroads
ASTM - American Society for the Testing of Materials

Table 7 DTMR -Australian Standards similarities

3.2.2 Site sampling and Procedure

3.2.2.1 Mann Silo Rd

Site sampling for Mann Silo Road was conducted in July 2016. Approximately 250 Kilograms of soil was taken from the road verge. This much soil was taken as the material was very wet and had high moisture contents at the time of collection. After collection, the sample was taken to the Crows Nest TRC soil laboratory where it air dried before initial testing.

Traffic Management/control was in place during sampling and was in accordance with the Manual of Uniform Traffic Control Devices, as the site sampling occurred whilst Toowoomba Regional Council workers were on site. As part of this exercise access to Dial Before you Dig Plans were necessary to ensure no underground services were struck.

The sampling procedure used was DTMR Q060: Representative Sampling of soils, crushed rock and aggregate as outlined in the DTMR Materials Testing Manual Edition 4, Amendment 1(Department of Transport and Main Roads 2016).

A summarised procedure of the sampling is as follows:

- Caterpillar 140H Grader removed top soil to subgrade level.
- Hand tools were used to fill the sealable containers (approx. 150 Kg).
- The sample area was reinstated.

Figure 29 Sampling at Mann Silo Rd

3.2.2.2 Hinz Street

Site sampling for Hinz Street was conducted in July 2016. Approximately 250 Kilograms of soil was taken from the road verge. This much soil was taken as the material was very wet and had high moisture contents at the time of sampling. After collection, the sample was taken to the Crows Nest TRC soil laboratory where it air dried before initial testing.

Traffic Management/control was in place during sampling and was in accordance with the Manual of Uniform Traffic Control Devices. As part of the sampling access to Dial Before you Dig Plans were necessary to ensure no underground services were struck as this was a residential area.

The sampling procedure used was DTMR Q060: Representative Sampling of soils, crushed rock and aggregate as outlined in the DTMR Materials Testing Manual Edition 4, Amendment 1(Department of Transport and Main Roads 2016).

A summarised procedure of the sampling is as follows:

- Komatsu Backhoe removed top soil to subgrade level.
- Hand tools were used to fill the sealable containers from a stockpile (approx. 150 Kg).
- The sample area was reinstated.

Figure 30 Traffic control signage Hinz St


Figure 31 Hinz St Sampling

Figure 32 Reinstatement of sample location Hinz Street

3.2.2.3 Recycled Concrete Aggregate (Road Base 28mm minus)

The recycled concrete Aggregate was sourced from Beutel Oughtred in Toowoomba and was 28 minus material. Recycled Concrete Aggregate (RCA) sampling was conducted in July 2016. Approximately 160 Kilograms of RCA was taken from the stockpile. After collection, the sample was taken to the Crows Nest TRC soil laboratory.

The sampling procedure used was DTMR Q060: Representative Sampling of soils, crushed rock and aggregate as outlined in the DTMR Materials Testing Manual Edition 4, Amendment 1(Department of Transport and Main Roads 2016).

Figure 33 RCA Sampling

Figure 34 Recycled Concrete Aggregate Photo

3.3 Experimental Design (Subgrade Testing)

As previously mentioned initial testing and determination of material properties is essential to determine the optimum lime content for effective stabilization to occur. This section will discuss the methods used for testing the samples sourced from around the Toowoomba region.

3.3.1 Subgrade sampling and Data Acquisition

Toowoomba Regional council has in house soil laboratories for soil testing. These labs are NATA accredited and are used extensively in pre-construction soil investigations and post construction testing of pavement materials. Most commonly subgrade is tested for its California Bearing Ratio (Disturbed or in-situ by Dynamic Cone Penetrometer). This allows engineers to design the flexible pavement. The CBR value obtained allows the use of the empirical design method to determine layer thickness.

Subgrade strength data is available through TRC soil laboratories, as it required by designers prior to final pavement design. However for general construction and design purposes it is not practical to test subgrades extensively (ie: PSD, Atterberg Limits). It is standard practice in Local Government Councils to test CBR and optimum moisture content before construction commences. Subgrade sampling involved taking a disturbed sample from the site. Both samples were taken from the side of the roadway. Replacement soil was taken to fill holes from the sampling if required. Due to the nature of the clays, no soil was required. Only one representative sample was taken per road, photos of location and pavement condition were also taken and are in the body of the dissertation. Test method Q060: Representative Sampling of Soils, Crushed Rock and Aggregates was followed for the sampling of the subgrades. Q060 specifies that at least 10kg of sample must be taken from site for laboratory Testing.

3.3.2 Subgrade testing procedures

Subgrade testing on each subgrade sample was necessary to determine the soil characteristics and structural properties. The samples were initially prepared in accordance with TMR test procedure Q101: Preparation of disturbed samples. If the samples are deemed free flowing and do not contain large aggregations of fines or solid clods the sample is divided into sub samples (portions for other testing requirements), if required these are dried in an oven (45-50ºc).

Other testing procedures used to assess the specimens were:

- Particle size distribution of Aggregate-dry sieving (Q103B)
- Liquid Limit of Soil (Q104A)
- Plastic Limit and Plasticity Index(Q105)
- Linear Shrinkage of Soil (Q106)
- Dry Density-Moisture Relationship (Q142)
- California Bearing Ratio (Q113A)

The above tests performed were used to set a base line of the materials for comparison with the stabilized samples.

3.3.3 Risk Assessment

The testing and site activity has involved potential risk and cause for harm during this project. As part of the risk mitigation strategy for this project a risk assessment was conducted. The following is the generic University of Southern Queensland Risk Assessment.

University of Southern Queensland

Generic Risk Management Plan

Workplace (Division/Faculty/Section): Engineering(Civil)		
Assessment No (if applicable):	Assessment Date: 1/7/2016	Review Date: (5 years maximum) / /
Context: What is being assessed? Describe the item, job, process, work arrangement, event etc: laboratory Procedures used to determine lime demand for two soil samples Site Visits for sampling		
Assessment Team – who is conducting the assessment?		
Assessor(s): Matthew Brennan Others consulted: (eg elected health and safety representative, other personnel exposed to risks)		

Step 1 - Identify the hazards (use this table to help identify hazards then list all hazards in the risk table)

General Work Environment		
☐ Sun exposure	☐ Water (creek, river, beach,	☐ Sound / Noise
☐ Animals / Insects	☐ Storms /	☐ Temperature (heat, cold)
☒ Air Quality	☐ Lighting	☐ Uneven Walking Surface
☐ Trip Hazards	☐ Confined Spaces	☐ Restricted access/egress
☐ Pressure (Diving/Altitude)	☐ Smoke	☐
Other/Details:		
Machinery, Plant and Equipment		
☒ Machinery (fixed plant)	☐ Machinery (portable)	☒ Hand tools
☐ Laser (Class 2 or above)	☐ Elevated work platforms	☐ Traffic Control
☐ Non-powered equipment	☐ Pressure Vessel	☐ Electrical
☒ Vibration	☐ Moving Parts	☐ Acoustic/Noise
☒ Vehicles	☐ Trailers	☐ Hand tools
Other/Details:		
Manual Tasks / Ergonomics		
☒ Manual tasks (repetitive, heavy)	☐ Working at heights	☐ Restricted space
☐ Vibration	☒ Lifting Carrying	☐ Pushing/pulling
☒ Reaching/Overstretching	☒ Repetitive Movement	☒ Bending
☒ Eye strain	☐ Machinery (portable)	☒ Hand tools
Other/Details:		
Biological (e.g. hygiene, disease, infection)		
☐ Human tissue/fluids	☐ Virus / Disease	☐ Food handling
☐ Microbiological	☐ Animal tissue/fluids	☐ Allergenic
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and management of all chemicals.		
☐ Non-hazardous chemical(s)	☒ 'Hazardous' chemical (Refer to a completed hazardous chemical risk assessment)	
☐ Engineered nanoparticles	☐ Explosives	☐ Gas Cylinders
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☐ Disruption
☐ Public Image/Adverse Media	☐ Violence	☐ Environmental Issue
Other/Details:		
Radiation		
☐ Ionising radiation	☐ Ultraviolet (UV) radiation	☐ Radio frequency/microwave
☐ infrared (IR) radiation	☐ Laser (class 2 or above)	☐
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl. Mains and	☐ LPG Gas	☐ Gas / Pressurised containers
Other/Details:		
Facilities / Built Environment		
☐ Buildings and fixtures	☐ Driveway / Paths	☐ Workshops / Work rooms
☐ Playground equipment	☐ Furniture	☐ Swimming pool
Other/Details: labratory		
People issues		
☐ Students	☐ Staff	☐ Visitors / Others
☐ Physical	☐ Psychological / Stress	☐ Contractors
☒ Fatigue	☒ Workload	☐ Organisational Change
☐ Workplace Violence/Bullying	☐ Inexperienced/new personnel	☐
Other/Details:		

Step 1 (cont) Other Hazards / Details (enter other hazards not identified on the table)
Hydrated Lime spils
Hydrated Lime Dust
Construction Plant

Risk Matrix

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L
Recommended Action Guide					
E=Extreme Risk – Task ***MUST NOT*** proceed					
H=High Risk – Special Procedures Required (See USQSafe)					
M=Moderate Risk – Risk Management Plan/Work Method Statement Required					
L=Low Risk – Use Routine Procedures					

Risk register and Analysis

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	**The Risk:** What can happen if exposed to the hazard with existing controls in place?	**Existing Controls:** What are the existing controls that are already in place?	**Risk Assessment:** (use the Risk Matrix on p3) Consequence x Probability = Risk Level			Additional Controls: Enter additional controls if required to reduce the risk level	**Risk assessment with additional controls:** (use the Risk Matrix on p3 – has the consequence or probability changed?)			**Controls Implemented? Yes/No**
			Consequence	**Probability**	**Risk Level**		**Consequence**	**Probability**	**Risk Level**	
Example Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Hydrated Lime dust	inhaled,eyes,skin	keep Hydrate lime container closed when not in use.	Minor	Possible	Moderate	Use of safety gloves,and Impervious footwear. P1 or P2 respirators can also be used.	Minor	Unlikely	Low	Yes
Buffer solution contact	Skin Burns/irritation	Eye wash/shower stations available.	Moderate	Unlikely	Moderate	Use of Lab coats,eye protection, and gloves.	Minor	Unlikely	Low	Yes
Construction Plant	Possible hospitiisation or death	Safety Zones	Major	Unlikely	Moderate	Use of UHF Radios for contact	Major	Rare	Low	Yes
Traffic	Possible hospitiisation or death	Traffic control and seperation zones	Major	Unlikely	Moderate	Use of UHF Radios for contact	Major	Rare	Low	Yes

Step 5 – Action Plan (for controls not already in place)			
Control Option	**Resources**	**Person(s) responsible**	**Proposed implementation date**

Step 6 – Approval

Drafter's Comments:

working with the Hydrated lime is not hazardous providing the correct PPE is worn. Ph buffer solutions can be harmfull if spilt but correct handling techniqe can minimise spills.

Drafter Details:

Name: Matthew Brennan Signature: m.brennan Date: 1/7/2016

Assessment Approval: (Extreme or High = VC, Moderate = Cat 4 delegate or above, Low = Manager/Supervisor)

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Name: Matthew Brennan Signature: m.brennan Date: 1/7/2016

Position Title: Undergraduate Civil Engineer

3.4 Experimental Design (Aggregate Testing)

The recycled concrete aggregate used in the stabilization testing was tested for suitability in pavements. The reason for usage of the RCA is to provide the subgrade some body and particle interlock structure as discussed in the literature review. The RCA was mixed with the subgrade at various dosage rates and tested to investigate the effects.

3.4.1 Availability/Acquisition of RCA

Currently RCA is available in the Toowoomba Regional Council. Travel distance from the source to the construction site must be considered and must be competitive to manufactured gravels and their sources. The RCA was sourced from Beutel Oughtred Sons Toowoomba, who specializes in concrete recycling. Aggregate sizes available range from Enviro dust/crusher dust to 50/90mm ballast. For the purpose of this paper only the commercially available graded aggregates were used (28mm minus).

3.4.2 Aggregate Testing

The different aggregate sizes in the RCA were blended with the subgrade material to fill gaps in the existing particle distribution. The recycled concrete aggregate used in this project is in accordance with MRTS 35-Recycled Materials for Pavements and is characterized by the below PSD.

AS Sieve Size (mm)	Percentage Passing by Mass for each Nominal Size	
	RCC[1]	
	Target PSD	PSD Limits
26.5	100	100
19.0	100	95 – 100
13.2	85	70 – 90
9.50	73	60 – 80
4.75	54	–
2.36	39	30 – 50
0.425	17	10 – 25
0.075	8	4 – 12

Table 8 RCA PSD Limits

Testing was conducted on the RCA by Soil Tech Toowoomba. A Particle Size Distribution (Q103B), Atterberg Limits (Q104A/D, Q105, Q106) and California Bearing Ratio (Q113A) tests were conducted. The results can be seen in section 4.5.3.

3.5 Experimental Design (Lime and RCA Stabilization)

3.5.1 Initial Lime Demand

Initial lime demand of the two host subgrades was conducted in accordance with DTMR Q133: Lime Demand test. The procedure involved preparation of sample test masses that have a combined soil and lime weight of 30 grams. These test masses varied in lime percentages from 1-10% lime by dry mass. Available lime is required to be calculated for this test; however this involved rigorous chemical titrations. With that the lime content was assumed as 100 percent.

The separate mixes of soil and lime from 1%-10% lime were mixed with a given volume of water and left to stand for two hours. After the waiting period the pH of each suspension was tested and recorded. This process is based upon field conditions and applications and is why this test method was chosen.

3.5.2 Lime and RCA Proportioning

3.5.2.1 Proposed Lime and RCA contents

The testing of the stabilized subgrade samples was conducted at various lime proportions (% by dry weight), with and without recycled concrete aggregate. The aim of the study is to assess the performance of RCA with lime stabilization; however baselines must be set to make comparison with.

The effect of lime alone on the subgrade (tested at optimum moisture content) specimens is important to develop the effect that RCA and lime have on the mechanical properties of the subgrade.

After lime demand was calculated it was necessary to test the effect of lime stabilization on the samples. No recycled concrete aggregate was added to the samples for these tests. DTMR suggest different lime contents ranging above and below the determined Lime Demand. The percentages adopted for testing were:

- $Lime\ demand\ \%(LD)$
- $LD\ \% +\ 2\%\ Lime$
- $LD\ \% +\ 4\%$ Lime

Finally the effect of both RCA and Lime were assessed for a fixed lime contents and various RCA amounts. The amounts of RCA added to the blends were 5%, 10% and 15%. RCA can also contain free lime/cement; this was recognised but is believed to have little significance

The various proportions of lime and RCA tested in this dissertation are as follows:

- LD
- LD+2% Lime
- LD+4% Lime
- LD+2% Lime+ 5% RCA
- LD+2% Lime+ 10% RCA
- LD+2% Lime+ 15% RCA

RCA was proportioned in such a way that it will not be too expensive to incorporate into the subgrade. It was found noted that a smaller range of RCA should be used for initial testing as there may be an optimum point.

3.5.3 Mould preparation

Mould preparation was required for most of the testing conducted. Maximum Dry Density and CBR testing required moulding of the host and treated samples. For lime treated samples DTMR testing methods Q135A: Addition of Stabilising Agents and Q135B: Curing Moulded specimens of Stabilised Material were used.

3.5.3.1 MDR Preparations

Maximum Dry Density testing was conducted on the host materials and on each various lime and RCA blend, in accordance with DTMR Q142A: Dry Density-Moisture Relationship of soils and crushed rock.

A summary of the procedure followed to mould specimens for MDR was as follows:

- Using mass of specimen determine lime and RCA and moisture contents.
- Create 4 samples (2 points dry of Optimum moisture content, 1 point close to Optimum and 1 point dry of Optimum).
- Add half blending water and lime (If RCA was required all the RCA was added).
- Mould the specimen in 3 equal layers compacting each layer with half compaction standard effort (12 blows).
- Demould the specimen and wrap with plastic.
- Leave to sit overnight.
- Unwrap, add the balance of moisture and lime and remould with full compaction effort (25 blows per layer in 3 layers).
- Take weight measurements and a sample for oven drying to determine moisture content.

This procedure was used as it attempts to replicate field conditions with field delay time. Curing for the host materials took 7 days as outlined in the test method.

3.5.3.2 Strength Testing/CBR of Host and Stabilised Specimens

The subgrade samples were introduced to different contents of lime and RCA as outlined in section 3.5.2.1. These test specimens were mixed with lime in accordance with DTMR Q135A: Addition of Stabilising Agents and Q135B: Curing Moulded specimens of Stabilised Material.

Once the optimum moisture content was determined for each blend and the host specimens, the samples were moulded in their respective proportions of lime and RCA. The moulding procedure was the same as MDR moulding (refer to section 3.5.3.1) as half the lime and moisture was added on the first day and compacted with half compaction effort. The second day saw the balance of moisture and lime added with full compaction of the moulds in accordance with Q113A: California Bearing Ratio of Soil-Standard. All moulds for CRB testing were allowed to cure for 6 days with 4 days soaked in a water bath. The host material required a 7 day cure before moulding for CBR testing.

3.6 Resource Analysis

The amount of resources required was comprehensive due to the range of testing undertaken on the subgrade specimens. It was essential that an appropriate amount of subgrade material was taken from each site, time restraints did not allow multiple visits to the site locations. Soil quantities were determined by the amounts required to perform individual tests.

3.6.1 Testing Quantities

The amount of subgrade required for initial testing was:

Test	Description	Approx. Mass Required(Kg)
Q103B	Particle size distribution-dry sieving	1 Kg
Q104A	Liquid limit of soil	300g of fines requires approx. 2Kg
Q105	Plastic limit and plasticity Index	0.25Kg
Q106	Linear shrinkage of soil	1kg
Q142	Dry density-moisture relationship of soils and crushed rock - standard	10 Kg
Q113A	CBR	6Kg
Q133	Lime Demand	0.5 Kg

Table 9 Subgrade Quantities Required

Tests Q142 and Q113A were conducted seven times for each material. As can be seen this justifies the need for 150Kg of each sample.

3.6.2 Apparatus

The apparatus for the collection and testing of the soils were:

- Crowbar, Pick, tape measure
- Posthole shovel, standard shovel,20kg sample containers
- Brush, flat bottomed scoop, sieves, sieve brushes
- Oven(60-110 degree), sealed containers
- Penetrometer(for Atterberg Limits), depth indicators, penetration cone, stopwatch
- Balance, scales, spatula, potable water, curing containers
- Glass plate, Moulds(A/B), linear shrinkage mould
- Scalpel, pen, steel rule, mould oil, water bath
- Hydraulic jack, rubber mallet, standard compaction unit.
- 20 beakers, stirring rods, PH meter
- 16 CBR A moulds, CBR machine

Between the Crows Nest and Millmerran soil labs the various equipment required was sourced.

3.6.3 Soil Laboratories

Soil laboratories utilized during the testing phase were the TRC Crows Nest soils laboratory based at the TRC Crows Nest depot, TRC Millmerran Soil Lab located at TRC Millmerran depot and the USQ soil lab facilities based at the Toowoomba campus. Availability of council resources was discussed on the 26/5/2016 with management and approval for soil lab access was granted. NATA accredited TRC soil testers have helped with testing and supervision. Soil lab and lab technician availability was very good with testing allowed during work hours of the week. USQ soil laboratories were not always available with facilities prioritized for scheduled classes.

4.0 Results and Analysis

4.1 Host Subgrade characterisation

Before any significant testing could be conducted the host materials sampled from Mann Silo Rd, Brookstead and Hinz Street, Clifton needed to be characterized. The results from this testing will be used as a baseline (control) of which the treated samples were compared. The preceding sections will discuss the results of the Atterberg limits, Lime Demand and the California Bearing Ratios achieved as a result of various treatment options. The effectiveness of the various treatments will also be discussed. Using the results, the pavements of Hinz Street and Mann Silo Road have been redesigned in accordance with the Austroads method (refer to section 2.2.3) and estimated to compare with original construction costs.

4.1.1 Mann Silo Road, Brookstead

Figure 35 Cone penetrometer

The sample from Mann Silo road was tested to determine the Atterberg limits of the soil. This included the Plastic Limit, Liquid Limit and the plasticity limit of the host clay material .The liquid limit test (Q104D), Plastic Limit and Plasticity Index (Q105), Linear Shrinkage (Q106) was performed on the soil and concluded the following results.

Liquid limit testing was conducted in accordance with the Department of Transport and Main Roads Materials Testing guide. The Liquid Limit is determined below.

$f \quad = \quad 2.1261 \times P^{-0.2752}$

$where\ f \quad = \quad Correction\ factor\ for\ single\ point\ penetration$

$P \quad = \quad Average\ penetration\ value\ (mm)$

So

$f \quad = \quad 2.1261 \times P^{-0.2752}$

$f \quad = \quad 2.1261 \times 19.4^{-0.2752}$

$f \quad = \quad 0.94011$

Liquid Limit is calculated from this factor f.

$LL \quad = \quad w \times f$

$Where\ LL \quad = \quad Liquid\ Limit\ fo\ soil$

$w \quad = \quad Moisture\ content\ of\ the\ soil$

$f \quad = \quad Correction\ factor\ for\ single\ point\ penetration$

$LL \quad = \quad w \times f$

$LL \quad = \quad 59 \times 0.94011$

$LL \quad = \quad 55.466\ \%$

Plastic Limit and Plasticity Index results are calculated below.

$$PL \quad = \quad \frac{w_1 + w_2}{2}$$

$Where\ PL \quad = \quad Plastic\ Limit\ of\ the\ soil$

$w_1 \quad = \quad moisture\ content\ of\ first\ test\ protion\ \%$

$w_2 \quad = \quad moisture\ content\ of\ second\ test\ protion\ \%$

$$PL \quad = \quad \frac{w_1 + w_2}{2}$$

This calculation was undertaken using HELPA software currently used by TRC and was determine as 20 %.

Plasticity index is the difference between the Liquid Limit and the Plastic limit as seen below:

$PI \quad = \quad LL - PL$

$where\ LL \quad = \quad Liquid\ Limit$

$PL \quad = \quad Plastic\ Limit$

$PI \quad = \quad 55.466 - 20$

$PI \quad = \quad 35.46\ \%$

Linear Shrinkage, as can be seen in figure 35, Shows the shrinkage of the soil when dry.

Figure 36 Linear Shrinkage Mould

Linear shrinkage of the soil is calculated as follows:

$$LS \quad = \quad \frac{L_1 - 0.5(L_2 + \ L_3)}{L_1} \times 100$$

$$Where\ LS \quad = \quad Linear\ Shrinkage\ (\%)$$

$$L_1 \quad = \quad Internal\ Length\ of\ mould\ (mm)$$

$$L_2 \quad = \quad Bottom\ length\ of\ soild\ bar\ (mm)$$

$$L_3 \quad = \quad Top\ length\ of\ soild\ bar\ (mm)$$

TRC soil laboratory assistance program HELPA was used here to determine the Linear Shrinkage. The result for Mann Silo road is 19.5 % Linear Shrinkage.

The Particle size distribution test was conducted on the Mann Silo Road sample using the method of wet sieving. The results from this test are below.

	Starting mass	148.92g	
sieve size (mm)	Mass retained (g)	mass passing (g)	% Passing
6.7	1	147.92	99.3285
4.75	0	147.92	99.3285
2.36	0	147.92	99.3285
1.18	0.68	147.24	98.87188
0.6	1.02	146.22	98.18695
0.425	1.22	145	97.36771
0.3	2.45	142.55	95.72254
0.15	9.94	132.61	89.04781
0.075	6.36	126.25	84.77706

Table 10 Mann Silo Rd PSD

This result was graphed and compared to a standard grading used for class 3 Subbase as defined in Austroads Guide to Pavement Technology Part 4A: Granular Base and Subbase Materials (Austroads 2008).

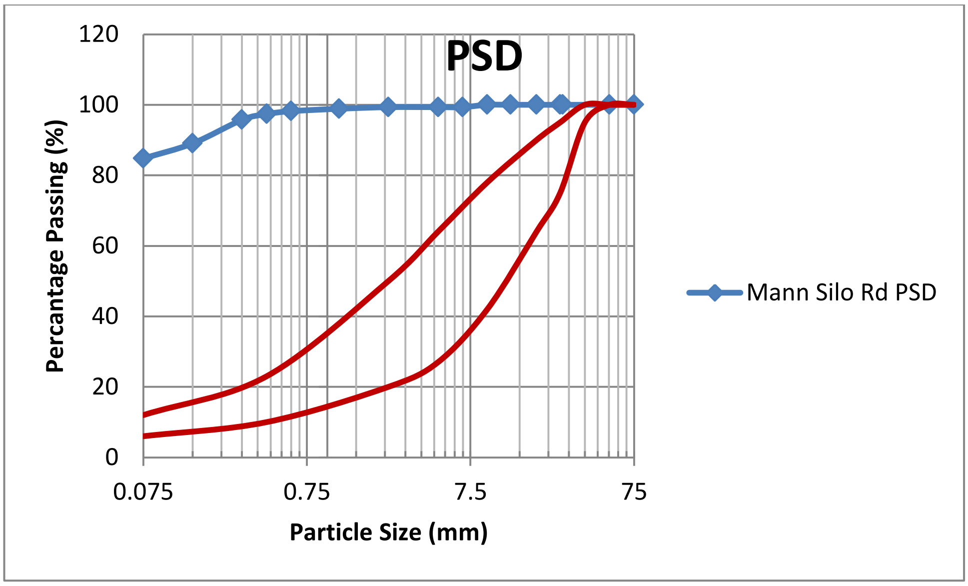


Figure 37 Mann Silo PSD Chart

As can be seen in the figure above, the sample is very fine with approximately 85% passing the 0.075mm Sieve. This subgrade sample has no particle structure when compared to the upper and lower limits required for class 3 subbase.

4.1.2 Hinz Street, Clifton

The sample from Hinz Street was also tested to determine the Atterberg limits of the soil. This included the plastic limit, liquid limit and the plasticity limit of the host clay material .The liquid limit test (Q104D), plastic limit and plasticity index (Q105), linear shrinkage (Q106) was performed on the soil and concluded the following results.

Liquid limit testing was conducted in accordance with the Department of Transport and Main Roads Materials Testing guide. The Liquid Limit is determined below.

$$f = 2.1261 \times P^{-0.2752}$$

$$where\ f = Correction\ factor\ for\ single\ point\ penetration$$

$$P = Average\ penetration\ value\ (mm)$$

So

$$f = 2.1261 \times P^{-0.2752}$$

$$f = 2.1261 \times 21.3^{-0.2752}$$

$$f = 0.91624$$

Liquid Limit is calculated from this factor f.

$$LL = w \times f$$

$$Where\ LL = Liquid\ Limit\ fo\ soil$$

$$w = Moisture\ content\ of\ the\ soil$$

$$f = Correction\ factor\ for\ single\ point\ penetration$$

$$LL = w \times f$$

$$LL = 35.7 \times 0.91624$$

$$LL = 32.710\ \%$$

Plastic Limit and Plasticity Index results are calculated below.

$$PL = \frac{w_1 + w_2}{2}$$

$$Where\ PL = Plastic\ Limit\ of\ the\ soil$$

$$w_1 = moisture\ content\ of\ first\ test\ protion\ \%$$

$$w_2 = moisture\ content\ of\ second\ test\ protion\ \%$$

$$PL = \frac{w_1 + w_2}{2}$$

$$PL = \frac{10.19 + 9.807}{2}$$

$$PL = \frac{10.19 + 9.807}{2}$$

$$PL = 10\ \%$$

This Plastic Limit result shows that the Hinz Street sample remains plastic in its behaviour longer than Mann Silo Rd. This means that Hinz street subgrade will behave as a reactive plastic material with considerably less moisture content (PL 20% for Mann Silo Rd and 10% for Hinz St)

Figure 38 Plastic Limit Hinz Street Photo

Plasticity index is the difference between the Liquid Limit and the Plastic limit and is the range where the soils behave as a plastic. The calculations are below:

$$PI \quad = \quad LL - PL$$

$$where\ LL \quad = \quad Liquid\ Limit$$

$$PL \quad = \quad Plastic\ Limit$$

$$PI \quad = \quad 32.7 - 10$$

$$PI \quad = \quad 22.7\ \%$$

The Linear shrinkage of the soil was calculated as follows:

$$LS \quad = \quad \frac{L_1 - 0.5(L_2 + \ L_3)}{L_1} \times 100$$

$$Where\ LS \quad = \quad Linear\ Shrinkage\ (\%)$$

$$L_1 \quad = \quad Internal\ Length\ of\ mould\ (mm)$$

$$L_2 \quad = \quad Bottom\ length\ of\ soild\ bar\ (mm)$$

$$L_3 \quad = \quad Top\ length\ of\ soild\ bar\ (mm)$$

$$LS \quad = \quad \frac{127 - 0.5(100 + \ 105)}{127} \times 100$$

$$LS \quad = \quad 19.29\%$$

This result shows that the shrinkage nature of the two samples is quite similar.

The Particle size distribution test was conducted on Hinz Street sample using the method of wet sieving. The results from this test are below.

	Starting mass	209.07g	
sieve size	**Mass retained (g)**	**mass passing (g)**	**% Passing**
6.7	0	209.07	100
4.75	0	209.07	100
2.36	0	209.07	100
1.18	0.88	208.19	99.57909
0.6	0.75	207.44	99.22036
0.425	0.61	206.83	98.92859
0.3	1.05	205.78	98.42636
0.15	4.03	201.75	96.49878
0.075	2.92	198.83	95.10212

Table 11 PSD Hinz Street

This result was graphed and compared to a standard grading used for class 3 Subbase as defined in Austroads Guide to Pavement Technology Part 4A: Granular Base and Subbase Materials.

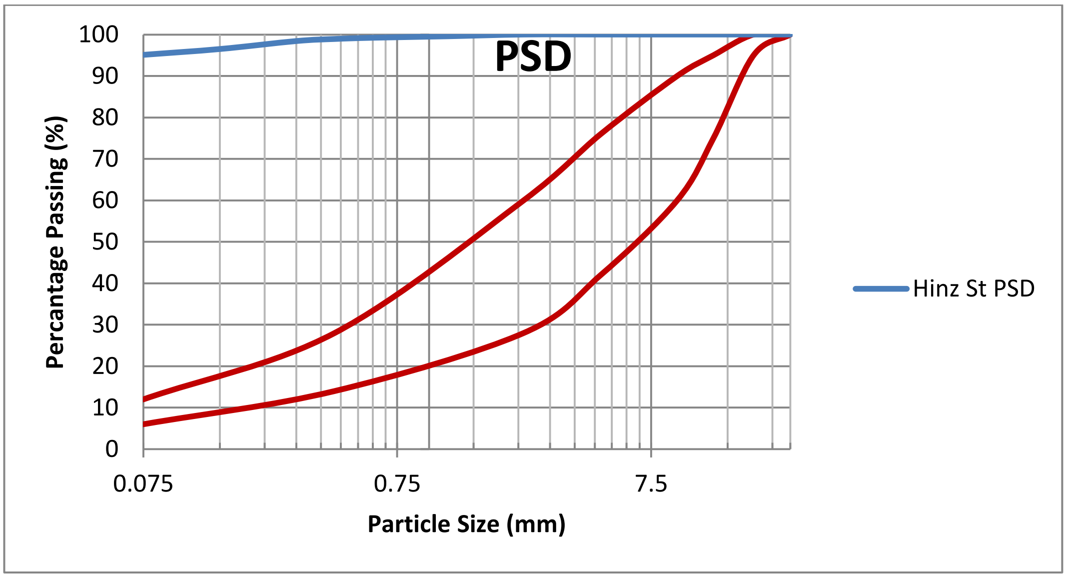


Figure 39 Hinz St PSD Chart

As can be seen in the figure above, the sample is very fine with approximately 95% passing the 0.075mm Sieve. This material contains a higher percentage of fines than the Mann Silo road sample. This subgrade sample has no particle structure distribution when compared to the upper and lower limits required for class 3 subbase.

4.1.3 Summary

As can be seen in the above sections, the two subgrade samples from Mann Silo Road and Hinz Street share a number of similarities and differences.

	Mann Silo Rd	Hinz St
Plastic Limit (%)	20	10
Liquid Limit (%)	55.466	32.7
Linear Shrinkage (%)	19.5	19.3
Plasticity Index (%)	35.466	22.7

Table 12 Atterberg Limits Results

The above table highlights the differences between each of the Atterberg limits. Mann Silo Road appears to require higher moisture contents for Plastic Limit and Liquid Limit when compared to the Hinz Street sample. Despite this the Linear Shrinkage of the two samples is very similar at a value of approximately 19%, which points out how they change when they are dried out to a constant mass. The swell characteristics is also interesting, to see what happens when the samples are introduced to water, this is covered in section 4.3. It is not in the scope of this project to discuss why the Atterberg limits are different between the samples. The results here are used for initial characterization of the host subgrades.

4.2 Lime Demand

The Lime Demand procedure Q133: Lime Demand of Soil was used to determine the optimum lime content. This procedure determines the degree to which the soil will react with lime through cation exchange and pozzolanic reaction, from clay minerals. The lime demand as measured using a pH test is an estimate of an optimum/starting design lime content for long term effective stabilization (Department of Transport and Main Roads 2016). The aim of this project is to stabilize the subgrade with lime and RCA. This test has revealed the lime contents for stabilization to occur in the collected samples. The results of testing are seen below. For both samples lime contents of 1-10 were tested.

4.2.1 Mann Silo Road, Brookstead

In order to obtain the lime demand for the various percentages tested in this project there were numerous steps of preparation required. This will be illustrated by an example calculation for the determination of the lime demand for 1% lime. Based on a 30 gram combined dry mass, as outlined in Q133 test procedure.

Mass of test portion

$$m_w = \left(\frac{30}{1+\frac{p}{100}}\right) \times \left(1 + \frac{w_1}{100}\right)$$

$$where\ m_w = mass\ of\ soil (g)$$

$$w_1 = Hygroscopic\ moisture\ content\ (\%)$$

$$p = Lime\ Content\ (\%)$$

$$m_w = \left(\frac{30}{1+\frac{1}{100}}\right) \times \left(1 + \frac{17.116}{100}\right)$$

$$m_w = 34.787\ g$$

Mass of Hydrated Lime

$$m_1 = 30 - \left(\frac{30}{1+\frac{p}{100}}\right)$$

$$Where\ m_1 = Mass\ of\ Lime\ (g)$$

$$p = Lime\ content\ (\%)$$

$$m_1 = 30 - \left(\frac{30}{1 + \frac{1}{100}}\right)$$

$$m_1 = 0.29702\ g$$

For the complete tables of calculations refer to Appendix B-4.

pH testing reveals the pH obtained at 1 percent intervals from 1-10 percent lime added. The following figure represents the results obtained.

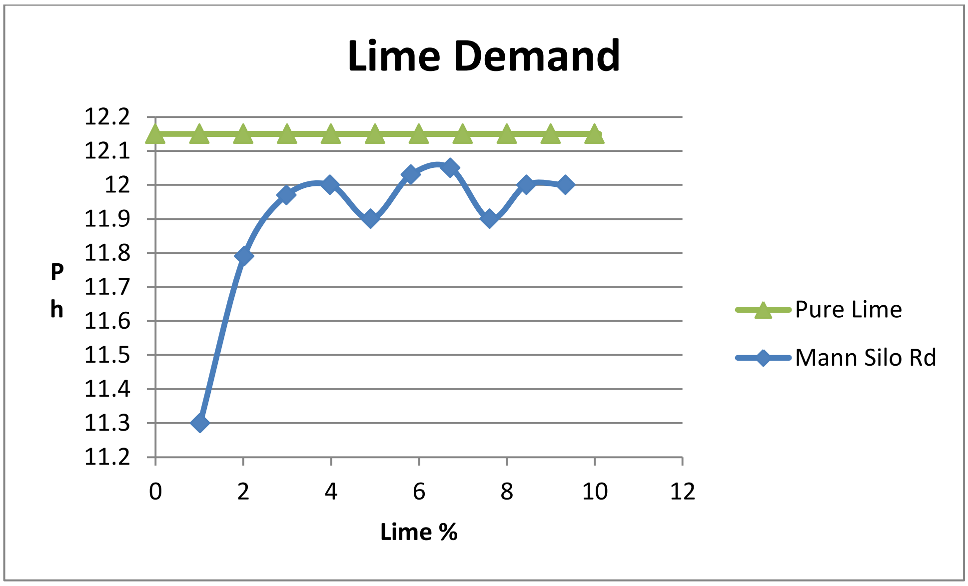


Figure 40 Lime Demand Mann Silo Rd

As can be seen above the data begins to plateau at approximately 6% lime content. It is believed that the pH machine used was calibrated but not sensitive enough in the higher pH levels. This can be seen as the pH level begins to fluctuate after 5 % lime.

4.2.2 Hinz Street, Clifton

Hinz Street lime demand test was conducted in the same manner using the same equipment and in the same laboratory on the same day. The full list of tabulated results can be seen in Appendix B-4. The lime demand curve has been put into graph from (refer to figure 41).

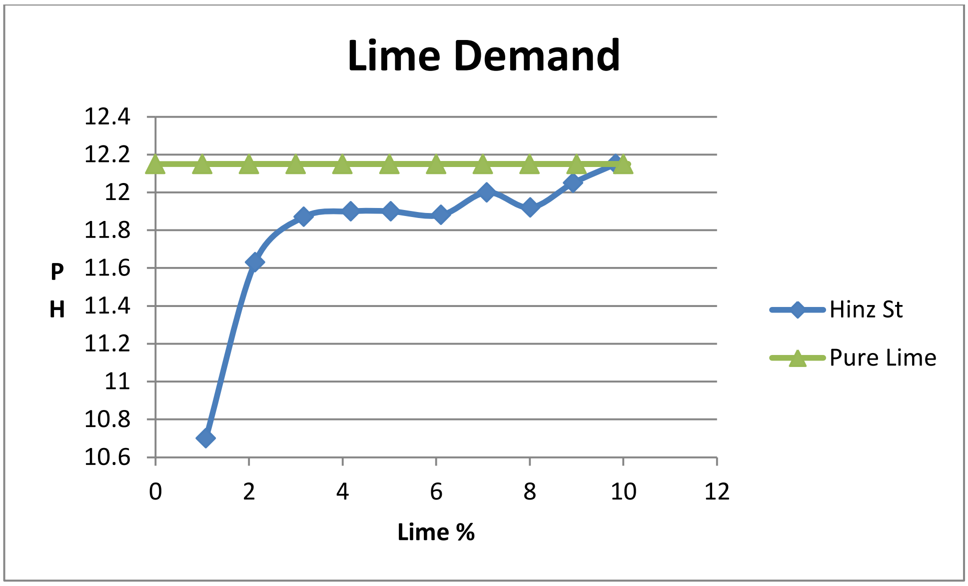


Figure 41 Lime Demand Hinz St

For Hinz Street subgrade sample a very similar lime demand curve is expressed in comparison to Mann Silo Rd Subgrade lime Demand curve. However this data is more definite and shows a more stable plateau at around 5%. For the purpose of this project 6% lime was used as the minimum lime content for both subgrade samples.

4.3 Host Subgrade

As a control measure and to distinguish improvements in subgrade quality, the host subgrade materials were subjected to a number of tests, common to the treated subgrade samples. This test was a moisture density relationship to better understand the relationship of the effect of lime on optimum moisture content and with that maximum dry density. A California bearing ratio(CBR) was completed to express any increase in CBR due to various treatments with Lime and RCA. Finally swell was examined to provide some insight into the stabilizing effects on reactive subgrade materials.

4.3.1 Hinz St, Clifton

The Moisture Density Relationship for the host materials was conducted in accordance with Department of Transport and Main Roads Test Method Q142A: Dry Density-Moisture Relationship for Soils and Crushed Rock. The data collected from testing was tabulated and can be seen in Appendix B-5.
The MDR curves were calculated using a polynomial fit, and were either a quadratic or cubic function depending on the number of points used. From this point the equation of polynomial fit provided by Microsoft Excel was differentiated to determine the optimum moisture content and corresponding value of Maximum Dry Density. An example of this calculation and summarised results and figures are shown below.

Lime Quantity (%)	RCA Quantity (%)	Mass(g)	Dry mass(g)	Added RCA(g)	Percent RCA(g)	Day 1 water(g)	Day 2 water(g)	Corrected water (%)
0	0	2001.3	1783.371948	0	0	280.3	0	14.00589617
0	0	2003.9	1785.688826	0	0	320.8	0	16.00878287
0	0	2021.4	1801.283194	0	0	242.7	0	12.00653013
0	0	2063.9	1839.155231	0	0	371.4	0	17.9950579

Theoretical added moisture (%)	Day1 lime(g)	Day 2 lime(g)	Corrected Lime added(g)	Moisture content (%)	Dry density(t/m3)	Wet density(t/m3)
14	0	0	0	31.8	1.29	1.710
16	0	0	0	33.5	1.296	1.731
12	0	0	0	17.1	1.393	1.632
18	0	0	0	37.6	1.255	1.728

Table 13 MDR Results Hinz St

The above table shows raw data obtained from conducting four MDR points for Hinz St, the water added, moisture contents and masses can be seen.

Determination of the wet and dry density was as follows.

$$\rho_w = \frac{m_2 - m_1}{V}$$

$$where\ \rho_w = Wet\ Density\ fo\ maerial\ \left({}^{t}/_{m^3}\right)$$

$$m_2 =$$

$$Mass\ of\ mould, baseplate\ and\ compacted\ material\ (g)$$

$$m_1 = Mass\ of\ mould\ and\ Baseplate\ (g)$$

$$V = Mould\ Volume\ (cm^3)$$

$$\rho_w = \frac{6062.7 - 4352.5}{1000}$$

$\rho_w = 1.7102 \left({}^{t}/_{m^3}\right)$ (Refer to above table 13)

$$\rho_w = \frac{100 \times \rho_w}{100 + w}$$

$$where\ \rho_w = wet\ density\ of\ material\ \left({}^{t}/_{m^3}\right)$$

$$\rho_d = dry\ density\ of\ material\ \left({}^{t}/_{m^3}\right)$$

$$w = moisture\ content\ (\%)$$

$$\rho_w = \frac{100 \times 1.7102}{100 + 31.8}$$

$\rho_w = 1.2975 \left({}^{t}/_{m^3}\right)$ (Refer to above table 13)

With the data showed above in table 13 the following scatter plot and best line of fit was produced.

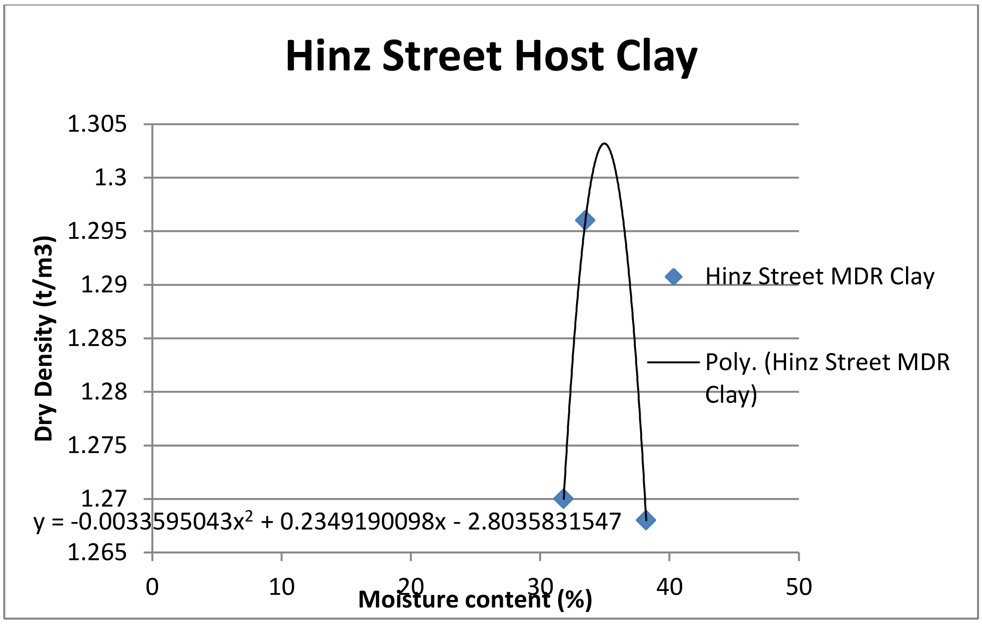


Figure 42 Hinz St MDR Curve

The cubic function seen in the above figure was differentiated with respect to x to find the peak values of optimum moisture content and dry density.

$$f(x) = 0.0000420750x^3 - 0.0039126844x^2 + 0.1084917351x + 0.4707131902$$

$$f'(x) = 0.000126255x^2 - 0.0078253688x + 0.1084917351$$

The first term is a, the second term b and the final term c. The quadratic formula is used to find the two roots of this equation. The most applicable root will be the optimum moisture content.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-(-0.0078253688) \pm \sqrt{-0.0078253688^{\ 2} - 4 \times 0.000126255 \times 0.1084917351}}{2 \times 0.000126255}$$

$$x = 20.930\ \%$$

Substituting x into f(x)

$$f(x) = 0.0000420750 \times 20.930^3 - 0.0039126844 \times 20.930^2 + 0.1084917351 \times 20.930 + 0.4707131902$$

$$f(x) = 0.3857729834 - 1.7140097 + 2.270732016 + 0.4707131902$$

$$f(x) = 1.413\ \left({}^{t}/_{m^3}\right)$$

With the optimum moisture content and maximum dry density clearly defined for the material a California Bearing Ratio test was conducted on the subgrade specimen. Close attention was paid to ensure the CBR was placed at optimum moisture content and maximum dry density; however during testing some errors were made which affected the cured values of optimum moisture content and maximum dry density for the sample.

California Bearing Ratio testing was undertaken on the host subgrade samples to determine the untreated strength of the material. This included a 6 day curing time with 4 days soaked. The work sheet for the Hinz street sample can be seen in Appendix B-2. The California bearing ratio test was conducted at the Toowoomba Regional Council soil laboratory in Millmerran. The electronic machine calculated the force at 0.5mm penetration intervals. This data was entered into DATAPRO4.1, which yielded the results. Refer to Appendix B-3 for result graph. The California Bearing Ratio test revealed a very weak subgrade for Hinz Street, with a value of 1. Swell potential was also tested as part of the California Bearing Ratio test. During the soaking of this sample the moisture content increased by 25.1 percent. This incurred a swell of 11.8 percent.

4.3.2 Mann Silo Rd, Brookstead

The Moisture Density Relationship for the host materials was conducted in accordance with Department of Transport and Main Roads Test Method Q142A: Dry Density-Moisture Relationship for Soils and Crushed Rock. The data collected from testing was tabulated and can be seen in Appendix B-5. The Moisture Density Relationship curves were calculated in the same manner as for Hinz Street as seen in section 4.3.1. A table of the summarized results are shown below.

Lime Quantity (%)	RCA Quantity (%)	Mass(g)	Dry mass(g)	Added RCA(g)	Percent RCA(g)	Day 1 water(g)	Day 2 water(g)	Corrected water (%)
0	0	2517.6	2295.342031	0	0	403	0	16.00730855
0	0	2491.8	2271.819699	0	0	250.5	0	10.05297375
0	0	2402	2189.947394	0	0	288.8	0	12.02331391
0	0	2439.2	2223.863315	0	0	341.4	0	13.99639226

Lime Quantity (%)	RCA Quantity (%)	Mass(g)	Dry mass(g)	Added RCA(g)	Percent RCA(g)	Day 1 water(g)
16	0	0	0	30.1	1.312	1.708
10	0	0	0	23.4	1.297	1.601
12	0	0	0	26.9	1.382	1.754
14	0	0	0	27.6	1.375	1.756

Table 14 MDR Results Mann Silo Rd

The above table shows raw data obtained from conducting four MDR points for Mann Silo Rd, the water added, moisture contents and masses can be seen. With the data showed above in table 14 the following scatter plot and best line of fit was produced.

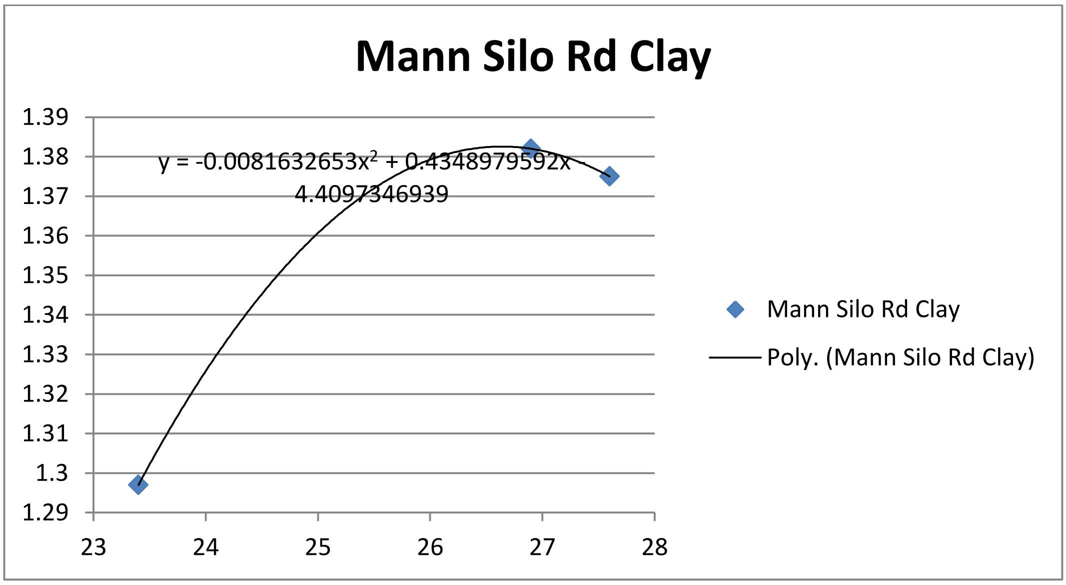


Figure 43 Mann Silo Rd MDR Curve

The Quadratic function seen in the above figure was differentiated with respect to x to find the peak values of optimum moisture content and dry density. This yielded optimum moisture content and corresponding Maximum Dry Density values of 26.6% and 1.382 $\left({}^{t}/_{m^3}\right)$ respectively.

With the optimum moisture content and maximum dry density clearly defined for the material, a California Bearing Ratio test was conducted on the subgrade specimen. Close attention was paid to ensure the CBR was placed at optimum moisture content and maximum dry density. During testing some human errors were made which affected the cured values of optimum moisture content and maximum dry density for the sample.

California Bearing Ratio testing was undertaken on the host subgrade samples to determine the untreated strength of the material. This included a 6 day curing time with 4 days soaked. The work sheet for the Mann Silo Rd sample can be seen in Appendix B-2. The California bearing ratio test was conducted at the Toowoomba Regional Council soil laboratory in Millmerran. The electronic machine calculated the force at 0.5mm penetration intervals. This data was entered into DATAPRO4.1, which yielded the results. Refer to Appendix B-3 for result graph. The California Bearing Ratio test revealed a very weak subgrade for Mann Silo rd, with a value of 2.8.

Swell potential was also tested as part of the california bearing ratio test. During the soaking of this sample the moisture content increased by 7.04 percent. This incurred a swell of 3.2 percent.

4.3.3 Summary

The subgrade samples results are typical results for black subgrade materials found throughout the region in the Toowoomba Regional Council. The subgrade strength was very low as expected. In addition to this, the swells of both materials were high. However for Hinz Street the swell was considerably higher. The table below summarises the main findings of the subgrade samples in untreated form.

Sample	Max Dry Density $\left({}^{t}/{}_{m^3}\right)$	OMC (%)	Moisture absorbed (%)	Swell (%)	CBR (%)
Mann Silo Rd	1.382	26.6	7.04	3.205	2.8
Hinz Street	1.385	20.9	25.1	11.829	1

Table 15 CBR/MDR Results summary

4.4 Lime treated Subgrade

This section of the dissertation discusses the results from lime treatment on the Mann Silo Rd and Hinz Street samples. As earlier determined, the quantities of hydrated lime tested were 6, 8 and 10 percent content by dry mass.

4.4.1 Mann Silo Road, Brookstead

For each variation in lime content the Dry Density Moisture relationship had to be defined. This required a Dry Density-Moisture relationship (Q142A) test be conducted for each variation in lime content. The raw data can be seen in Appendix B-5. The MDR curves for the various lime blends are shown in Appendix B-6.

	Mann Silo	
Blend	**OMC (%)**	**RDD $\left(t/_{m^3}\right)$**
6% Lime	25.79719445	1.437217978
8% Lime	24.84435566	1.423322297
10% Lime	24.57446349	1.426002308
o% Lime	26.63750002	1.382562505

Table 16 Mann Silo Rd MDR Lime Blends

The above table shows the results of the Dry Density-Moisture relationship (Q142A) testing for all the various lime and RCA blends. It can be noted that as the lime quantity increased the optimum moisture content decreased. The optimum moisture content is also reduced when lime is added to the soil. This can be seen as the difference between optimum moisture content of the 0% lime blend and the 6% lime blend.

CBR values achieved from the testing indicate good gains in strength. In some cases the CBR value was 13 times larger than the original material in an untreated form. The following figure shows the results of lime treatment for Mann Silo Rd.

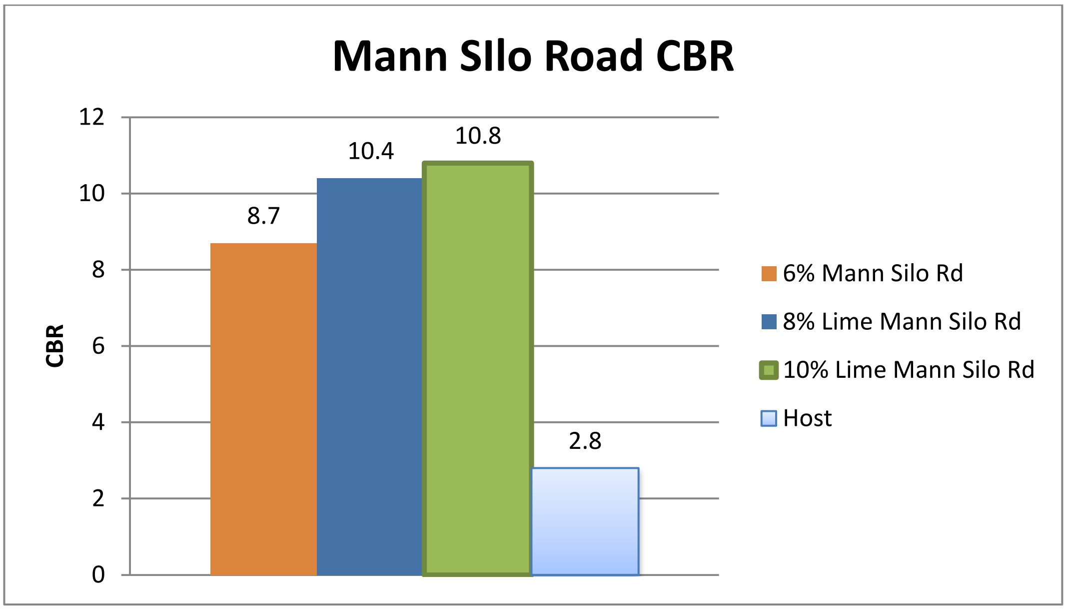


Figure 44 Mann Silo Rd CBR Chart

As can be seen here the strength is increasing with lime content. The difference between 6% and 8% lime treatments is 2.3 % CBR, whist the difference between 8 and 10% lime is only 0.4 CBR. This shows that there is a reasonable range of effectiveness and that once the optimum point is reached additional lime content has little effect on CBR. Over this short test of 7 days curing, the higher percentages of lime have not yielded exceptionally higher results. When considering costs for this material, 10% lime treatment may be not worth the extra cost of lime. Further testing with longer curing periods would determine if there is a significant difference in CBR with curing time. Literature suggest that CBR with a constant lime content will increase with time (Sherwood,P).

Another valuable result is the effect of moisture on the samples. Swell testing on the treated samples has been conducted and the results suggest that the lime has effectively/consistently reduced the swell nature of the soil.

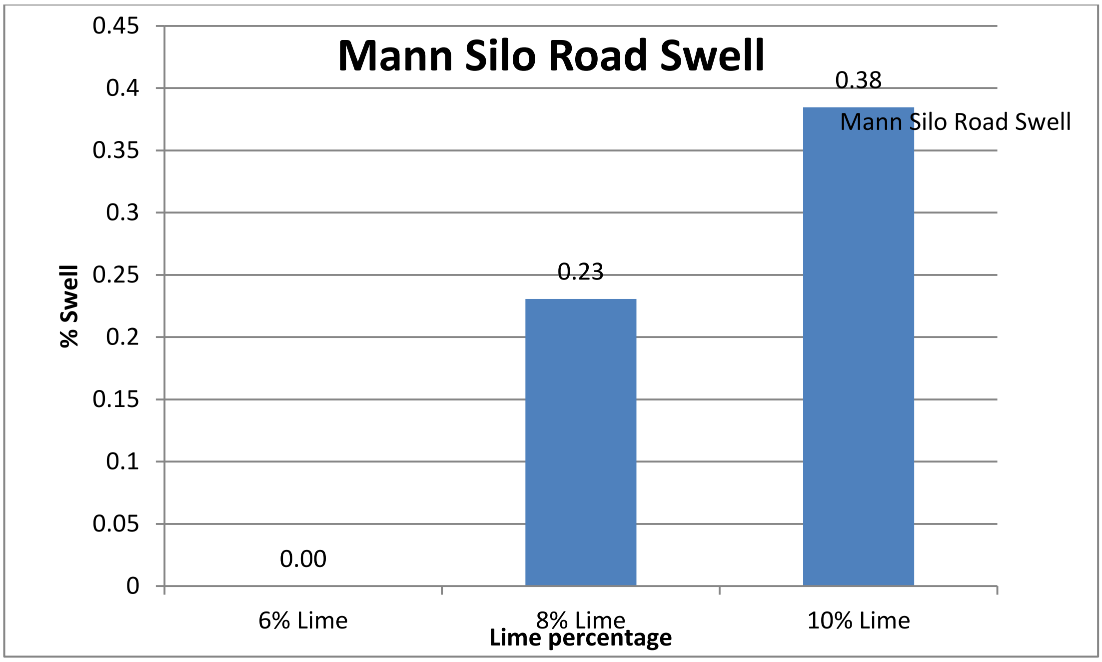


Figure 45 Mann Silo Rd Swell Chart

It is evident here that the swell has been reduced to a value below 1 percent. Initial results showed the host material had a swell of 3.2 percent. The results from this test are very desirable when used in the black soil clays found in the Toowoomba region. Lowered swell of the treated material will help the pavement to resist moisture ingress and weakening of the subgrade material.

4.4.2 Hinz Street, Clifton

Most importantly for this project are values of California Bearing Ratio achieved from the treatment with lime and recycled concrete aggregate. These will directly affect the pavement redesign of the two roads. It was hoped that the CBR would increase with lime content however initial results did not reflect this.

CBR	Blend
13.8	6% Lime
13.1	8% Lime
4.5	10% Lime

Table 17 Hinz St MDR Lime Blends

As seen above, initial results show a decrease in strength. This was not an expected result. With further investigation it was revealed that the samples were mixed during testing and the results were recorded incorrectly. The values for 6% Lime and 10% lime were swapped and verified as correct. With this minor setback resolved the results are as follows.

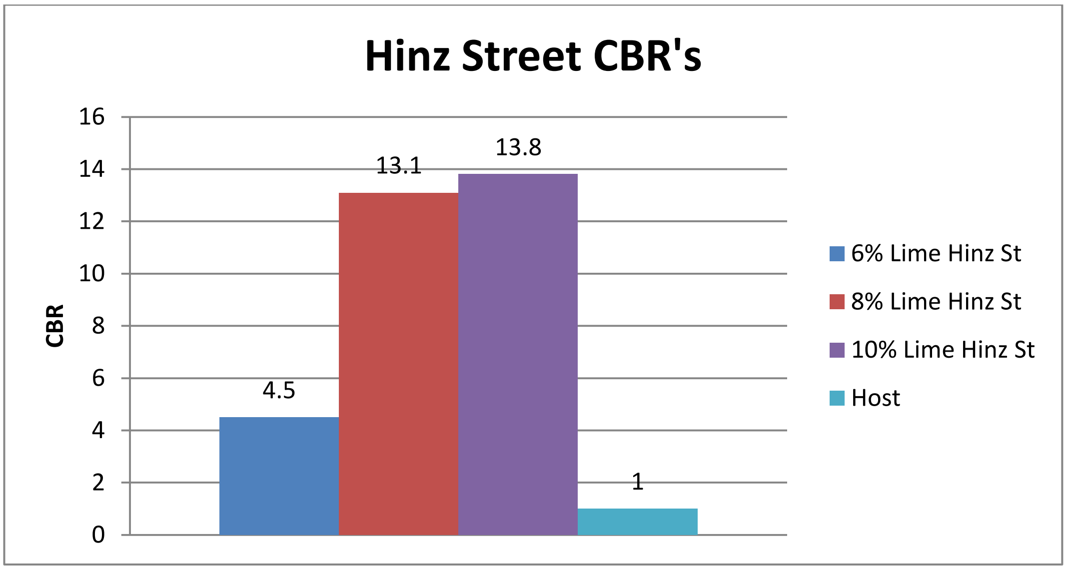


Figure 46 Hinz St CBR Chart

Here it can be seen that the effect of the lime alone is significant. With the host CBR of 1, a maximum CBR of 13.8 is very positive result. For the 6% lime treatment, only 4.5 % CBR was exhibited. This may be due to the lime demand being slightly less than required. For this soil at 6% lime it appears that only modification has taken place and not stabilization. This can be supported by the smaller difference between the 8% and 10% treatments which does suggest stabilization has occurred. A longer curing time of up to 28 days may show the difference better between the two better. Swell potential results were also quite acceptable. The lime treated samples effectively reduced the swell potential as seen below in Figure 47.

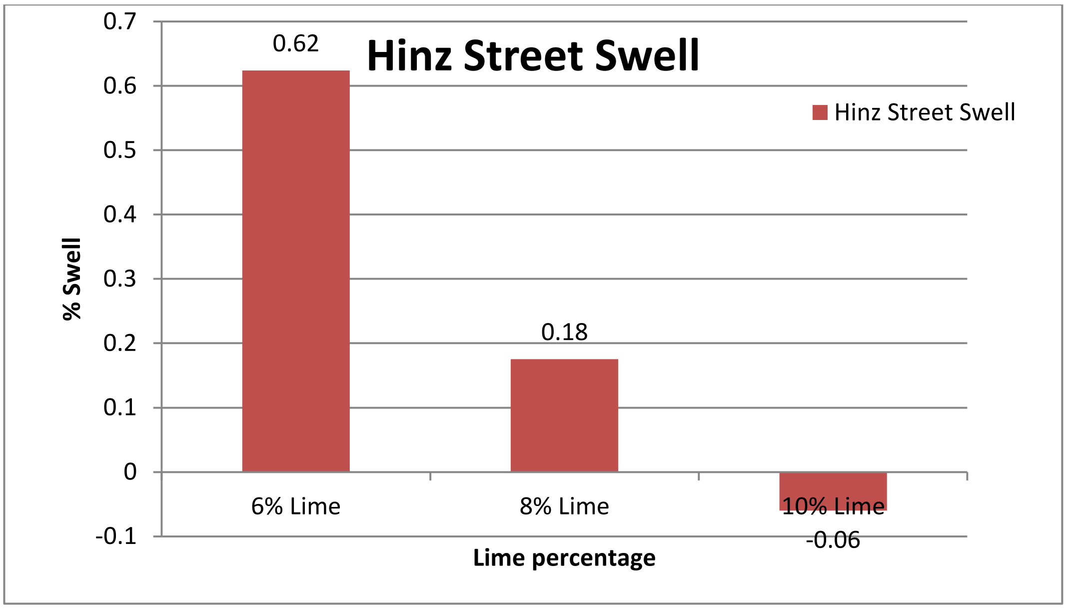


Figure 47 Hinz St Swell Chart

Interestingly the 10% lime sample shrunk whilst fully submerged in water during the soaked California Bearing Ratio test. This may have been due to the chemical process of hydration with the lime, clay minerals and the water in the material, which consumes moisture as part of the reaction. It is clearly seen here that the lime acts as a waterproofing barrier against moisture ingress and reduces the shrink/swell reactive nature of the material.

4.5 Lime and RCA Treated Subgrade

This section will consider the effect that adding recycled concrete aggregate has on lime treated subgrade. The results such as, Dry Density Moisture Relationship (Q142A), California Bearing Ratio (Q113A) and swell will be discussed and the effects these may have on the subgrade.

4.5.1 Mann Silo Road, Brookstead

For each variation in lime content and RCA content the Dry Density Moisture relationship had to be defined. This required a Dry Density-Moisture relationship (Q142A) test be conducted for each variation in lime/RCA content. The raw data can be seen in Appendix B-5. The MDR curves for the various lime and RCA blends are shown in Appendix B-6.

	Mann Silo Road	
Blend	**OMC (%)**	**RDD $\left({}^{t}/{}_{m^3}\right)$**
8% Lime+5% RCA	28.28759055	1.447794852
8% Lime+10% RCA	24.32189592	1.513044539
8% Lime+15% RCA	25.51589905	1.692037853

Table 18 Mann Silo Rd RCA Blends MDR

The above table shows the results of the Dry Density-Moisture relationship (Q142A) testing for all the RCA blends tested. The OMC when RCA was added was very inconsistent and no relationship can be seen between the results. It was expected that the RCA treated samples would have higher dry densities as they have increasing proportions of material (RCA) with higher density than the clay.

CBR values achieved from adding RCA to the 8 percent blend were quite good. At best the CBR value was further increased from 10.4(8% Lime) to 15.3(8% lime) with the addition of 15% RCA. It must be also pointed out the RCA treated samples exhibited higher CBR values than the subgrade treated with 10 percent lime.

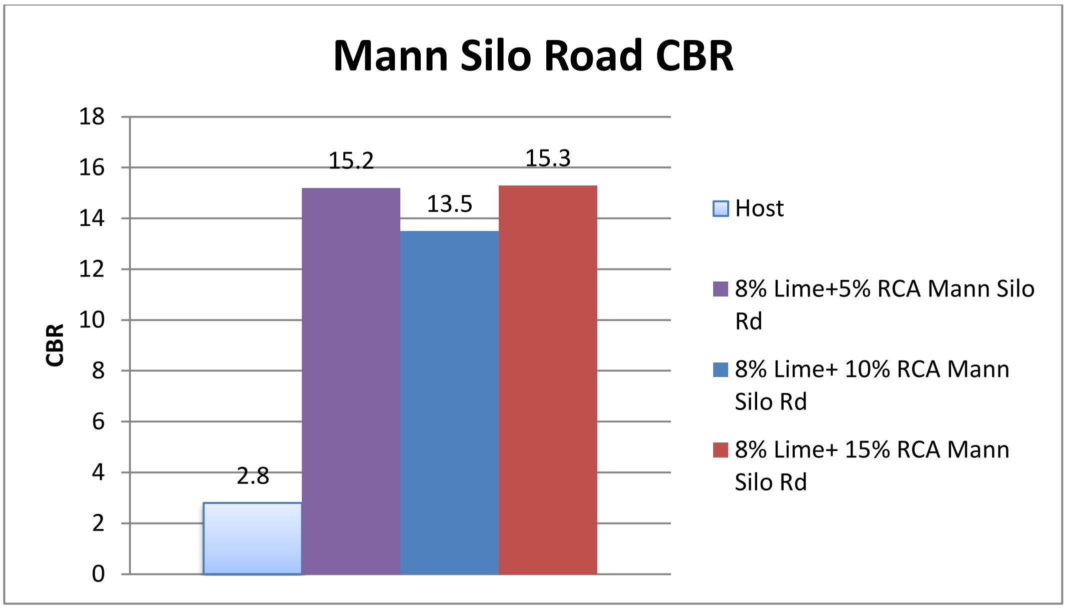


Figure 48 Mann Silo Rd RCA CBR Chart

As can be seen here the strength fluctuates with RCA contents with no particular pattern that can be distinguished with this amount of data. Most importantly is the significant increase in CBR between lime + RCA treated and lime treated subgrade samples. Further testing and repeated testing could reveal the benefits of using RCA further. Any residual cement from the crushed concrete could also be adding to this increase in strength.

Swell testing on the lime + RCA treated samples has been conducted and the results suggest that the lime + RCA blends have effectively and consistently reduced the swell nature of the soil, much like the lime treated material. This is mostly due to the presence of the lime in the blend. Although some particle interlock and structure well help reduce swell, it will not have effects as large as the addition of lime.

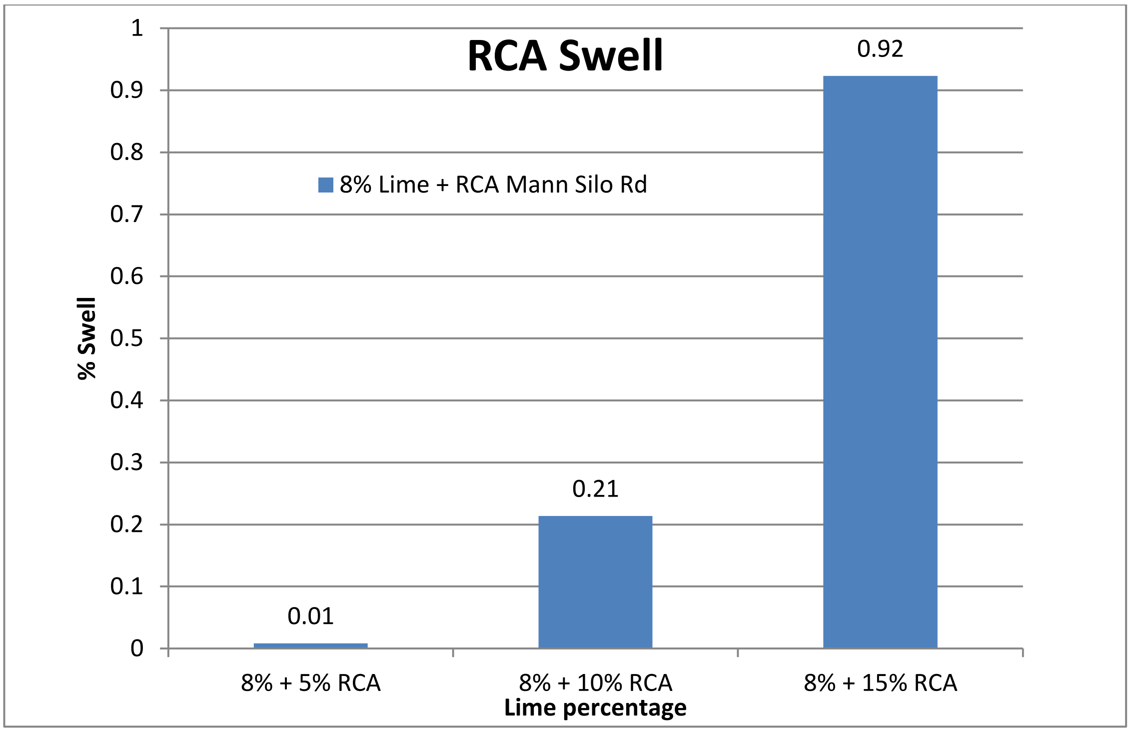


Figure 49 Mann Silo Rd RCA Swell

It is evident here that the swell has been reduced to a value below 1 percent. Initial results showed the host material had a swell of 3.2 percent. With the lime alone treated samples the swell is still kept to a minimum. In addition to this the sample treated with 8% lime incurred a swell of 0.23%. It can be seen here that the results with RCA oppose this value. A possible reason for variance seen here is that the material was not in a saturated surface dry condition. It is possible that the RCA used had various moisture contents, which could have affected these results by adding or removing moisture from the sample.

4.5.2 Hinz Street, Clifton

For each variation in lime content and RCA content the Dry Density Moisture relationship had to be defined. This required a Dry Density-Moisture relationship (Q142A) test be conducted for each variation in lime/RCA content. The raw data can be seen in Appendix B-5. The MDR curves for the various lime and RCA blends are shown in Appendix B-6.

	Hinz Street	
Blend	**OMC (%)**	**RDD $\left({}^{t}/{}_{m^3}\right)$**
8% Lime+5% RCA	27.25550127	1.383494433
8% Lime+10% RCA	29.71961334	1.417972735
8% Lime+15% RCA	29.01929956	1.396475484

Table 19 Hinz St RCA MDR

The above table shows the results of the Dry Density-Moisture relationship (Q142A) testing for all the RCA blends tested for Hinz Street. The OMC when RCA was added was similar for the 10% and 15% RCA blends.

It was expected that the RCA treated samples would have higher dry densities as they have increasing proportions of material (RCA) with higher density than the clay; however this trend was not seen in the Hinz Street samples.

CBR values achieved from adding RCA to the 8 percent blend were increased over lime treatment alone. At best the CBR value was further increased from 13.1(8% Lime) to 15.8(8% lime) with the addition of 10% RCA. It must be also pointed out the best RCA treated sample exhibited higher CBR values than the subgrade treated with 10 percent lime.

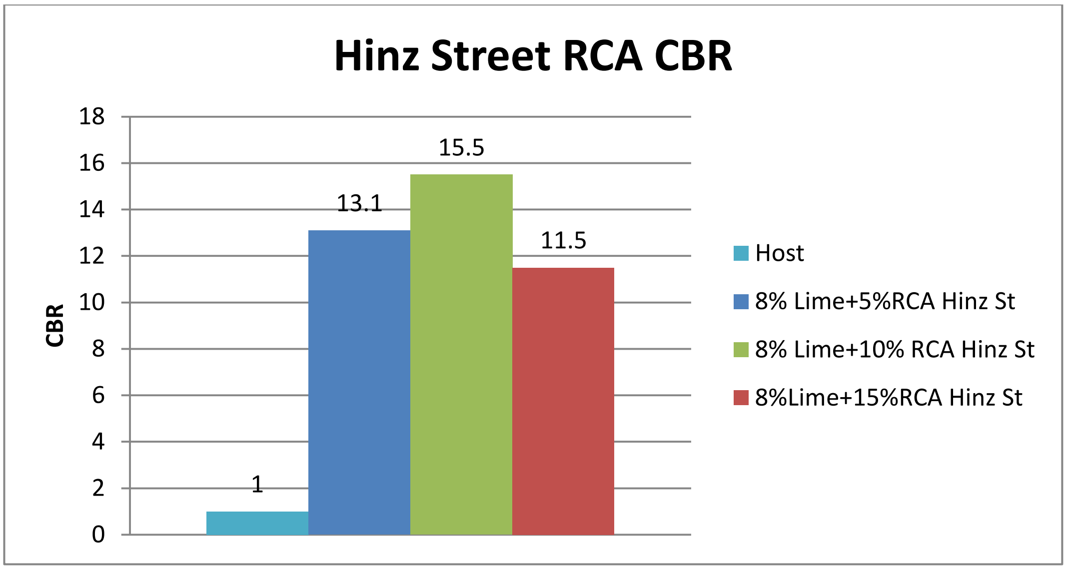


Figure 50 Hinz St RCA CBR

As can be seen here the strength fluctuates with RCA contents and appears to climb to a maximum value then decline with increased amounts of RCA. It was expected that CBR values increase with RCA contents; however this was not replicated in this result. Most importantly like the Mann Silo Road sample is the significant increase in CBR between lime + RCA treated and lime treated subgrade samples (refer to section 4.5.4 for summarised results). Further testing and repeated testing could reveal the benefits of using RCA further in materials like this. Any residual cement from the crushed concrete could also be adding to this increase in strength.

Swell testing on the lime + RCA treated samples has been conducted and the results suggest that the lime + RCA blends have effectively and consistently reduced the swell nature of the soil, much like the lime treated material. This is mostly due to the presence of the lime in the blend as stated in section 4.5.1.

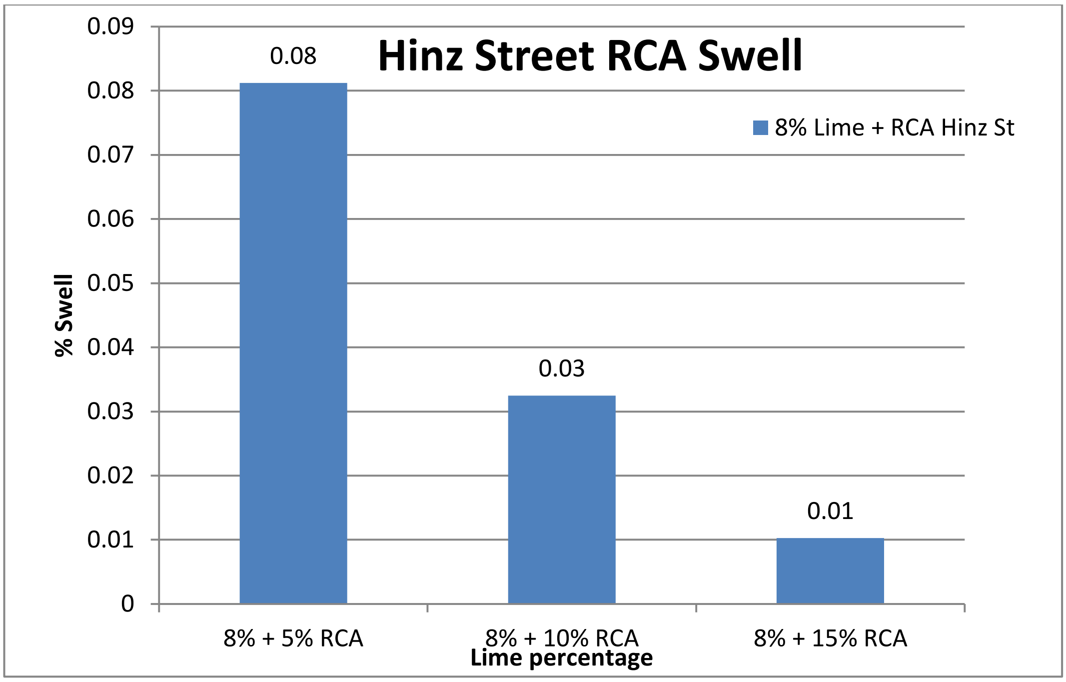


Figure 51 Hinz St RCA Swell

It is evident here that the swell has been reduced to a value below 1 percent. Initial results showed the host material had a swell of 11.8 percent. With the lime and RCA treated samples the swell is still kept to a minimum. In addition to this the sample treated with 8% lime incurred a swell of 0.17%. It can be seen here that the results with RCA further reduce these with increasing proportions of RCA. This is a desirable result as it shows the RCA also has a stabilizing effect on the subgrade without the addition of lime. However these are very small differences and can be neglected. For this sample the addition of RCA has no adverse effect on the swell of the material.

4.5.3 RCA Results

Testing conducted on the RCA samples was completed by Beutel Oughtreds by SoilTech Toowoomba. The Particle Size Distribution fits the class 3 Subbase profile as defined in Austroads Guide to Pavement Technology Part 4A: Granular Base and Subbase Materials.

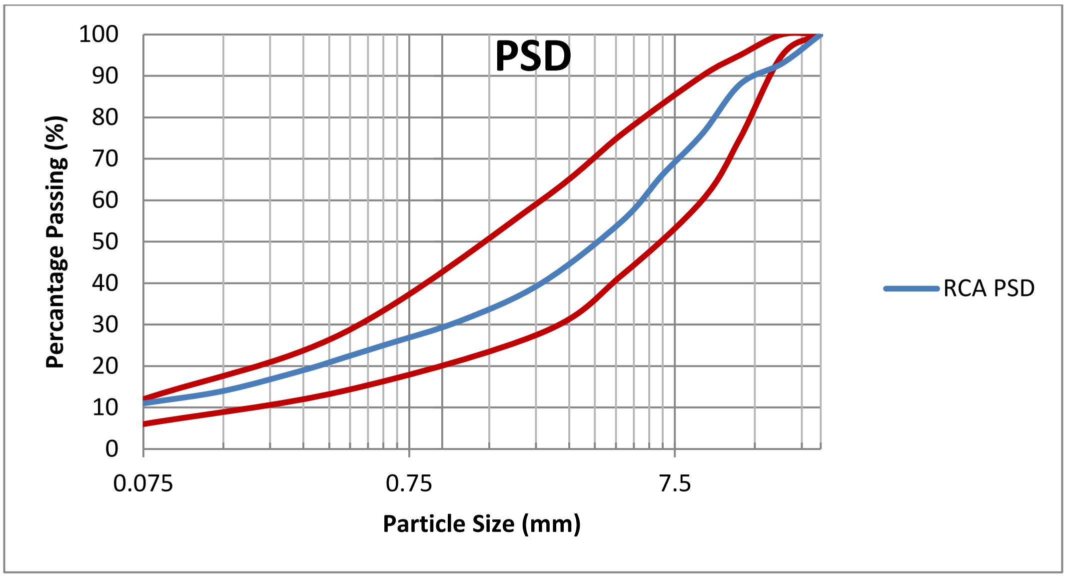


Figure 52 RCA PSD

The CBR of the material was also tested and revealed a CBR of 40. This is important as the material must have a higher CBR than the combined material to avoid crushing of the aggregate. The raw data can be seen in Appendix B- RCA Results.

4.5.4 Summarised results

This section will discuss the overall results, compare and contrast the results with each other and discuss the suitability for use in subgrade stabilization. At this point it is well established through this research and the research of others that lime treatment is suitable for clay subgrade stabilization and that CBR increase is common. However it also points out that lime treatment is very individual to the soil that is being treated.

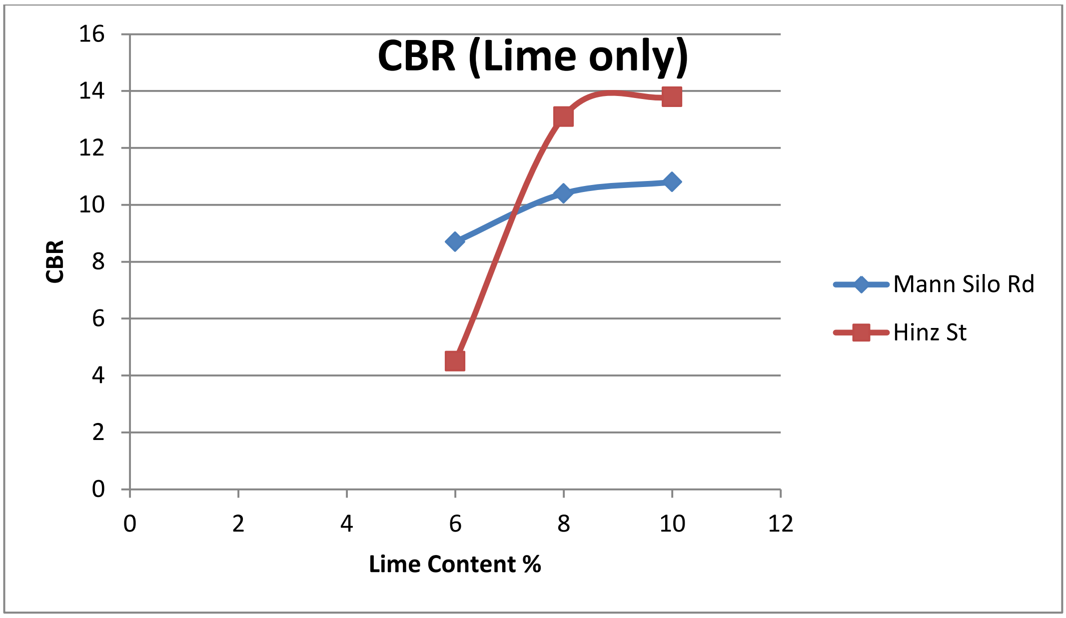


Figure 53 Summary Lime only CBR

This is illustrated in the above figure. Initial starting CBR is also important and must be considered. Mann Silo road CBR was 2.8 whilst Hinz Street was 1. The above figure shows despite a stronger host subgrade with Mann Silo Rd, the lime treatment had a greater effect on Hinz street subgrade. When using lime treatment proper testing must be conducted.

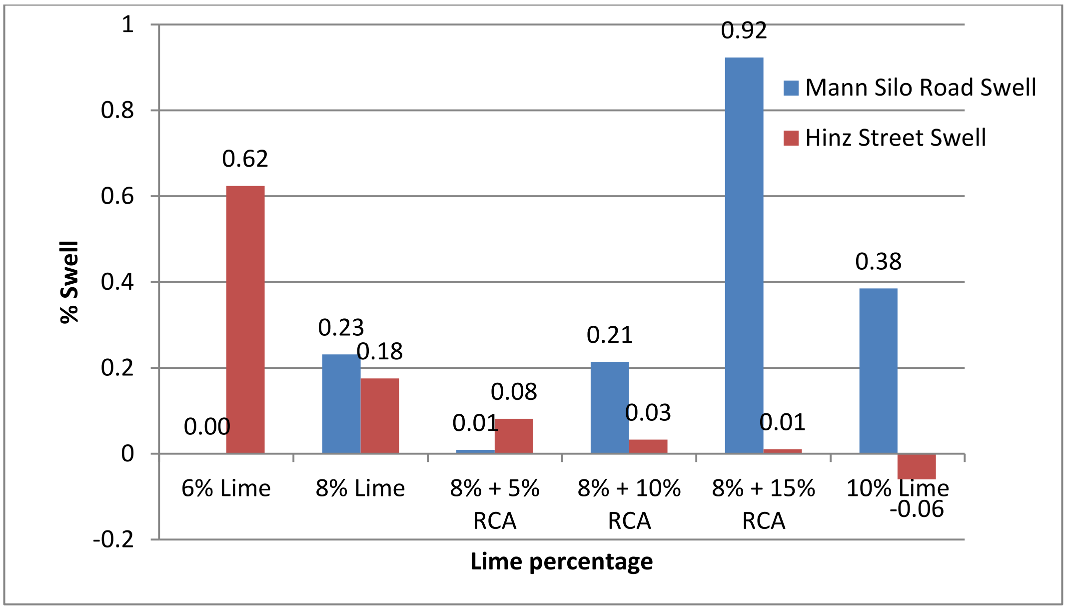


Figure 54 Swell Summary

The above figure shows the overall swells of the different blends of lime and RCA for both subgrade samples.

4.6 Results Analysis, Pavement Redesign and Cost analysis

4.6.1 Pavement redesign and cost analysis

This section contains some rates from Toowoomba Regional Council and stabilization contractors, of which will not be disclosed in this dissertation for confidentiality purposes. In addition to this, the following sections are not intended to be critical of the existing designs employed by the Toowoomba Regional Council. This dissertation is not aimed at scrutinizing existing pavement designs, but rather to conduct an economic assessment of using lime treatment in comparison to typical council design.

4.6.2 Hinz Street, Clifton: Redesign and Cost Analysis

4.6.2.1 Hinz Street, Clifton: Pavement Redesign with Lime

As outlined in section 2.2.3 mechanistic pavement design, the mechanistic pavement design method will be used to redesign Hinz Street pavement. To aid in this Process CIRCLY6.0 has been used. Due to unavailability of Traffic Loading and Weight in Motion (WIM) data some presumptive values have been used, these values will be pointed out. This section also discusses council costs and stabilization costs and compares the two. Due to confidentiality for the Toowoomba regional council and Stabilization contractor’s, indicative values close to industry averages have been used.

As outlined in section 2.2.3 the treated subgrade must be sub layered into five equal layers. This allows the modelling software to correlate the treated subgrade material of a given thickness with the existing weaker subgrade of infinite depth.

As Outlined in the Austroads Guide to Pavement Technology: Pavement Structural Design, the modulus of the lime treated subgrade is dependent on not only the CBR values of its strength alone, but also the stiffness of the underlying in-situ subgrade (Asutroads,2012). This may be neglected if the stabilized depth is greater than two meters. The vertical modulus of the top most sub layer is the minimum of the lime treated modulus up to a value of 150 and that dependant on the strength of the underlying material. The equation below is used to determine the modulus of the top Sub layer.

$$E_{v\ selected\ subgrade\ top\ layer} = E_{v\ underlying\ material} \times 2^{(\frac{thickness}{150})}$$

$$where$$

$$E_{v\ selected\ subgrade\ top\ layer} = Modulus\ of\ top\ layer$$

$$E_{v\ underlying\ material} = Modulus\ of\ underlying\ layer$$

As can be seen above the treated layers design strength may be lower than the lab tested CBR value if the depth is not sufficiently large enough. It can be said that the best strength gains were achieved by adding 8% lime. With this said this will be used as the lime stabilized layer. The CBR for this layer is 13.1. For use in council the thickness of the stabilized layer would best be a depth where the maximum CBR can be used from sub layering and not be governed by the weak subgrade beneath. The following calculations and figure illustrate this. The redesign of the Hinz Street Pavement will use the same design factors as used originally to keep parameters consistent (these can be seen in section 3.1.2). Assume 150mm stabilization:

$$E_{v\ selected\ subgrade\ top\ layer} = E_{v\ underlying\ material} \times 2^{(\frac{thickness}{150})}$$

$$E_{v\ selected\ subgrade\ top\ layer} = (3 \times 10) \times 2^{(\frac{150}{150})}$$

$$E_{v\ selected\ subgrade\ top\ layer} \quad = \quad (60) \quad CBR\ 6$$

The above shows that despite having a stabilized strength of 13.1 CBR only a design CBR of 6 can be used when designing the pavement as this is less than 13.1 CBR.

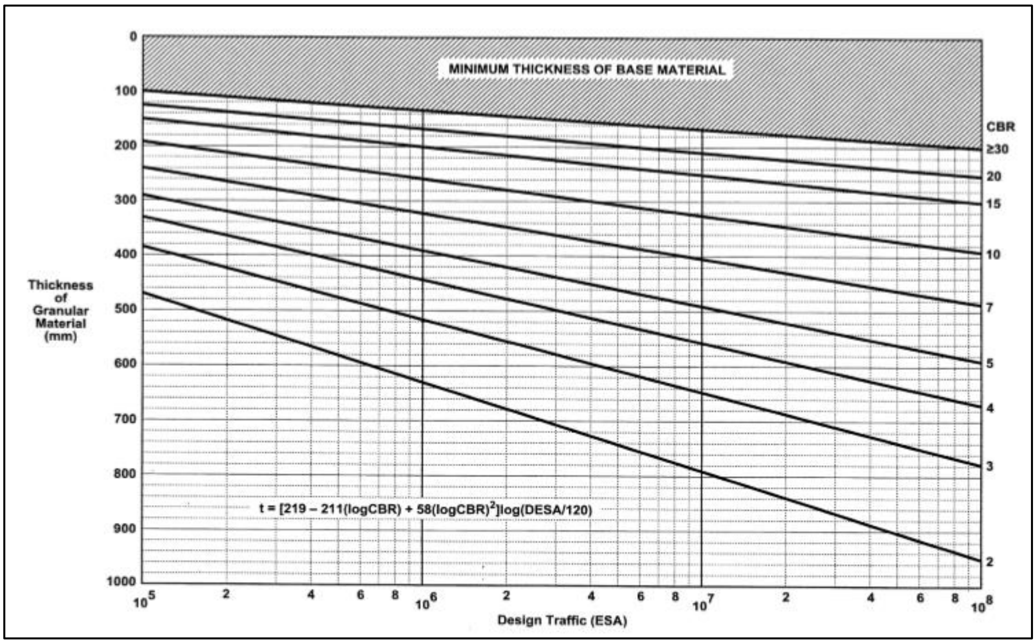
Host CBR	**3**			
E	30 MPa			
	Ev top layer Mpa	**CBR Top layer**	**Depth of stabilization**	**CBR 8% Lime**
	60	6	150	13.1
	67.34772	6.73477229	175	
	75.59526	7.5595263	200	
	84.85281	8.48528137	225	
	95.24406	9.52440631	250	
	106.9078	10.6907846	275	
	120	12	300	
	131	13.1	325	

Table 20 Hinz Street Sub-Layering

As can be seen above, the design CBR for the top sublayer increases with depth of stabilization. In order to achieve maximum value out of the stabilization process, a stabilization depth of 325mm will be used for Hinz Street. This is the maximum recommended stabilization depth as cost/specialist plant requirements increases with any further stabilization depth.

Strength is not the only factor when considering pavement design.

1. Austroads empirical chart specifies that for the minimum base thickness of 30 CBR is required (Austroads, 2012).



As can be seen above for the pavement loading of approximately 2×10^6 a cover thickness of 125mm is required. CBR 30 is also specified as the minimum for a spray seal application (Austroads, 2012).

2. DTMR Supplement to Part 2 “Pavement Structural Design” recommends minimum cover above expansive subgrades.

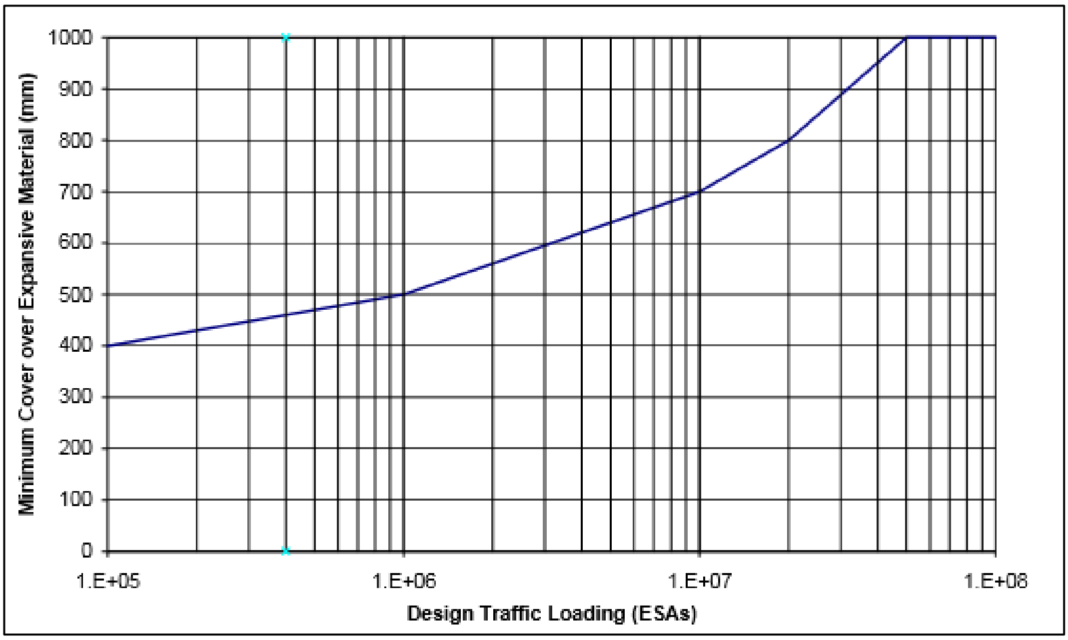


Figure 55 Clay Subgrade cover

As seen here for a design traffic loading of 2E+06 550mm of cover is required of the Hinz Street subgrade (Department of Transport and Main Roads 2013).

3. At least 175mm granular cover above lime treated subgrade to minimize reflective cracking(Austroads,2016)

With the stabilization depth defined (325mm) sub layering and pavement design can now be completed.

$$R \quad = \quad (\frac{E_{v\ Top\ Subgrade\ Layer}}{E_{v\ Underlying\ Layer}})^{5}$$

$$where\ E_{v\ Top\ Subgrade\ Layer} \quad = \quad Modulus\ of\ top\ treated\ layer$$

$$E_{v\ Underlying\ Layer} \quad = \quad Modulus\ of\ underlying\ subgrade$$

$$R \quad = \quad (\frac{131}{30})^{\frac{1}{5}}$$

$$R = \left(\frac{131}{30}\right)^{\frac{1}{5}}$$

$$R = 1.342$$

This factor R is used to reduce the Modulus of the top layers for the preceding layer below.

R	1.342858	
depth	325mm	
	Ev Mpa	Thickness (mm)
Top Layer	131	65
2	97.55315	65
3	72.64593	65
4	54.09801	65
5	40.28573	65

Table 21 Hinz Street layer moduli

The above table shows the sub layered lime treated subgrade input into CIRCLY. For consistency the same granular materials were used in the design.

No.	Material	Thickness
1	Granular, E=350MPa	250.00
2	layer 1	65.00
3	Layer 2	65.00
4	Layer 3	65.00
5	Layer 4	65.00
6	Layer 5	65.00
7	Subgrade, CBR=3,Aniso	0.00

Figure 56 Hinz St Pavement CIRCLY

The above snapshot shows the proposed pavement structure. The Type 3 (45CBR) material used as a base in the original design has been removed as the lime treated subgrade provides sufficient support.

For this pavement a design life of 20 years has been used, as this road is a local road a 95% importance level has been assigned. As no traffic loading data was available, presumptive figures have been used from table 12.3 from Austroads guide to pavement technology-pavement structural design. (Austroads,2012)

Pavement type	Damage type	Damage index	Street type	Value
Granular pavements with thin bituminous surfacings, designed using Figure 12.2	Overall damage	ESA/HVAG	Minor with single lane traffic	0.2
			Minor with two lane traffic	0.2
			Local access without buses	0.3
			Local access with buses	0.3
			Local access in industrial area	0.4
			Collector without buses	0.6
			Collector with buses	0.6
		ESA/HV	Minor with single lane traffic	0.4
			Minor with two lane traffic	0.4
			Local access without buses	0.6
			Local access with buses	0.6
			Local access in industrial area	0.9
			Collector without buses	1.3
			Collector with buses	1.3
Pavement containing one or more bound layers, mechanistically designed	Fatigue of asphalt	SAR5/ESA	N/A	N/A
	Rutting and shape loss	SAR7/ESA	All lightly-trafficked roads	1
	Fatigue of cemented materials	SAR12/ESA	Lightly-trafficked roads without buses	3
			Lightly-trafficked roads with buses	12

Table 22 Presumptive TLD Data

- SAR7/ESA was 1 (Subgrade and unbound materials)
- SAR12/ESA was 12 (lime treated/cemented material)
- Design traffic loading was the same as the original design. Which was 1.69+E6

This pavement design was analysed and the results are as follows.

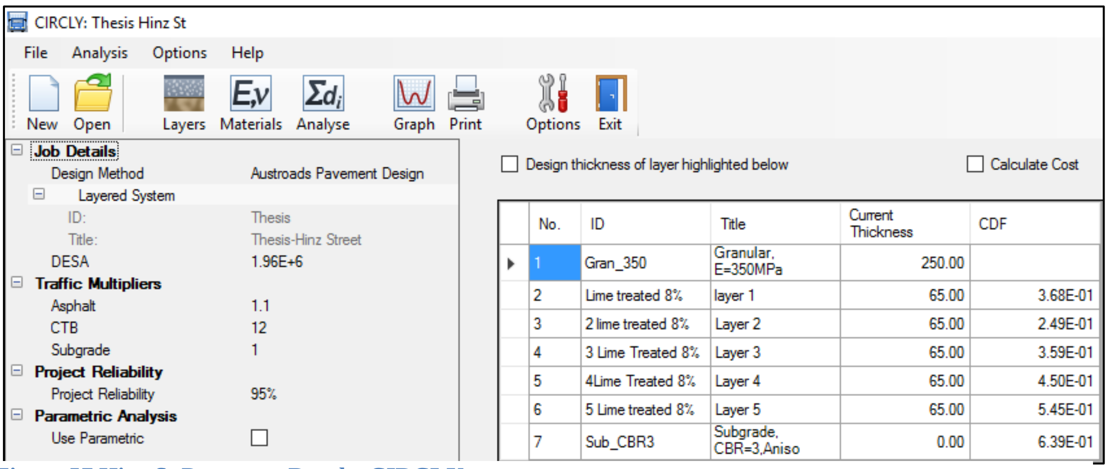


Figure 57 Hinz St Pavement Results CIRCLY

The above figure shows that the Cumulative Damage Factor (CDF) is less than 1 which represents adequacy of the pavement layer.250mm was chosen as the optimum due to the pavement failing with a base thickness less than 230mm. As aforementioned the base layer must comply with specifications.

Minimum base thickness of 125mm is satisfied along with the total cover of 550mm above the reactive subgrade (total pavement thickness of 575mm). Finally the base material itself is 35 CBR which satisfies the minimum for a spray sealed surface (required min of 30 CBR).

Most importantly for the Toowoomba Regional Council is the incurred cost of stabilization and whether or not it is comparable with standard construction procedures. Every council project is carefully estimated. A snippet of the Hinz Street estimation from the Toowoomba Regional Council is shown here.

		FLEXIBLE PAVEMENTS				
418198	2242A	Sub-base Course (Supply/Spread/Compact) (depth 170mm)	m3	1192	90	107280
418199	2242B	Base Course (Supply/Spread/Compact) (depth 175mm)	m3	573	100	57300
		SPRAYED BITUMINOUS SURFACING				
	2244A	**Sup/Spray Primer/Preparation**				
418200	2244A06	AMC4 (nominal rate of application 1.2L/m^2)	Litre	3934	2	6885
418203	2244B	Binder - Class 170 Bitumen (nominal rate of application 2.1L/m^2)	Litre	6029	4	24116
418202	2244B	Binder - Class 170 Bitumen (nominal rate of application 1.8L/m^2)	Litre	837	4	3348
418201	2244B	Binder - Class 170 Bitumen (nominal rate of application 0.9L/m^2)	Litre	419	4	1676
	2244F	**Sup/Precoat/Apply/Roll Aggreg**				
418200	2244F02	7mm (nominal spreading rate 1m3/180m2)	m3	16	180	2880
418201	2244F02	7mm (nominal spreading rate 1m3/220m2)	m3	2	180	360
418202	2244F03	10mm (nominal spreading rate 1m3/180m2)	m3	3	180	540
418203	2244F04	14mm (nominal spreading rate 1m3/90m2)	m3	37	200	7400

Figure 58 Hinz St Estimate (Toowoomba Regional Council 2016)

4.6.2.2 Hinz Street, Clifton: Cost Analysis

Rates for flexible pavements are:

- $90 per cubic meter of subbase(Type 3 CRB 35)
- $100 per cubic meter of Base (Type 3 CBR45)

These rates have used in the redesign of the pavement in this dissertation.

The cost of stabilisation has been determined below:

- Day rate : $5400/day (stabilizer and spreader truck)
- Float :$1800
- Productivity: 2500 square meters per day at 350mm depth
- Hydrated Lime: $375 per Tonne

From the above, a square meter rate can be established.

$$rate_{stab\ and\ spread} = \frac{5400}{2500}$$

$$rate_{stab\ and\ spread} = \$2.16\ per\ square\ meter$$

This rate is doubled as stabilization is a two day process. Therefore the rate becomes:

$$rate_{stab\ and\ spread} = \$4.32\ per\ square\ meter$$

$$rate_{stab\ and\ spread} = \$4.32 \times \frac{1000}{325}$$

$$rate_{stab\ and\ spread} = \$13.30\ \ per\ cubic\ meter$$

To calculate the cost per square metre of lime, the amount of lime required must be found. The field moisture content will affect the amount of lime added as the dry density of the soil varies with moisture content. The mass per cubic metre is simply the dry density of the material and can be found from the MDR chart. For this design the most desirable conditions will be used, i.e. optimum moisture content and maximum dry density.

For Hinz Street this is 1.413 $(\frac{t}{m^3})$ refer to section 4.3.1.

Amount of lime required

$$quantity = 0.08 \times 1413$$
$$quantity = 113.04\ Kg\ per\ cubic\ meter$$
$$rate_{Lime} = \frac{113.04}{1000} \times \$375 \quad \$per\ cubic\ meter$$
$$rate_{Lime} = \$42.39 \quad \$\ per\ cubic\ meter$$

In terms of meters squared rate:

$$= \frac{1}{stabillization\ depth}$$
$$= \frac{1}{0.325}$$

$$= 3.076\ m^2 per\ m^3 at\ 350mm\ depth$$

$$rate_{Lime} = \frac{42.39}{3.076}$$

$$rate_{Lime} = 13.78\ \$\ per\ square\ meter$$

Therefore the total rate per square meter to Stabilize with 8% Lime is

$$combined\ rate = 13.78 + 4.32 + 8$$
$$combined\ rate = \$26.10\ per\ square\ meter\ at\ 350mm\ stabilled\ depth$$

Or

$$combined\ rate = 42.39 + 13.30 + (8 \times 3.076)$$
$$combined\ rate = \$80.29\ per\ cubic\ meter$$

The base layer rate is the same as the Toowoomba Regional Council's estimation of $90 per cubic meter. The added $8 is a conservative value for trimming and compaction of the subgrade and is twice the value used by the Toowoomba Regional Council for this project, this accounts for larger compaction equipment required for placing the stabilized subgrade layer.

Total cubic meters

$$Total\ cubic\ meters \quad = \quad total\ square\ meters\ \times pavement\ depth$$

$$Total\ cubic\ meters \quad = \quad 2869\ \times 0.575$$

$$Total\ cubic\ meters \quad = \quad 1649.6$$

Cost break down

$$Total\ cost \quad = \quad \left(\frac{0.325}{0.575} \times 1649.6\right) * 80.29 + (\frac{0.25}{0.575} \times 1649.6) \times 90$$

$$Total\ cost \quad = \quad 74861 + 64549.56 + 1800$$

$$Total\ cost \quad = \quad \$141\ 210.56$$

Original cost with unbound granular material for Hinz Street was $164 580 as can be seen in the Toowoomba regional councils estimate. The above calculations show that lime treatment is a viable alternative for council to consider. The saving is calculated below.

$$Saving \quad = \quad 164\ 580 - 141\ 210.56$$

$$Saving \quad = \quad \$23\ 369.44$$

This is an approximate saving of 14.199 % on the pavement costs.

4.6.2.3 Hinz Street,Clifton: Lime and RCA treatment

As defined in previous sections the design strength of the sub layered treated subgrade is limited by depth, unless the stabilization depth is increased. Despite strong results in terms of CBR, consistency was not great. The best results were seen when 10% RCA was added, a CBR of 15.5 was achieved. In order to utilize this elevated CBR for design the effective depth of stabilization would need to be increased to 375mm.

cbr	**3**			
E	30			
	Ev top layer Mpa	**CBR Top layer**	**Depth of stabilization**	**8% lime + 10% RCA**
	60	6	150	
	67.34772	6.73477229	175	
	75.59526	7.5595263	200	
	84.85281	8.48528137	225	
	95.24406	9.52440631	250	
	106.9078	10.6907846	275	
	120	12	300	
	134.6954	13.4695446	325	
	151.1905	15.1190526	350	
	155	15.5	375	
	155	15.5	400	

Table 23 Hinz St Lime and RCA Sub-Layering

On larger roads this may be a viable alternative; however for local roads found throughout the region this depth is excessive and not viable. For design purposes the full potential of the lime and RCA treated subgrade would not be used. This does however add a better factor of safety to the pavement.

4.6.2.4 Hinz Street, Clifton: Lime and RCA Cost Analysis

In addition to the costs of stabilization the added RCA must be considered. This includes purchase and cart from Toowoomba to the Clifton area.

- \$12 per tonne to purchase
- Assume \$40 tonne cartage

The mix rate for the recycled concrete aggregate is 10%. With a MDD of 1.413 tonnes per cubic metre the required RCA would be .1413 tonnes per cubic metre.

For the addition of RCA indicative values used here would indicate an extra cost of:

$$extra\ cost = 0.1416 \times 12 + 0.1416 \times 40$$
$$extra\ cost = 1.70 + 5.65$$
$$extra\ cost = \$7.35\ per\ cubic\ metre.$$

Adding this extra cost onto the estimate made in section 4.6.2.2 gives the cost to include RCA in the pavement.

$$Total\ cost = \left(\frac{0.325}{0.575} \times 1649.6\right) * (80.29 + 7.35) + \left(\frac{0.25}{0.575} \times 1649.6\right) \times 90$$

$$Total\ cost = 81714.01 + 64\,549.56 + 1800$$
$$Total\ cost = \$\ 148\,063.57$$

Note that no consideration has been given to the incorporation of the RCA as it will be placed directly onto the treated subgrade between the first and second pass of the stabilizer unit. It is not believed that this should incur any extra cost.

As seen above the total cost is still cheaper than the original Toowoomba Regional Council estimation of $164 580 . The addition of RCA into lime treated subgrade could be used to give a better margin of safety for the given pavement. The use of RCA could be beneficial to the quality of roads constructed on reactive soils without increasing construction costs. The full design potential could be used if the depth of stabilization was increased.

4.6.3 Mann Silo Road, Brookstead: Pavement Redesign with Lime

As discussed in section 3.1.2 Mann Silo Road is planned to have the top 100mm pulverised and placed on the shoulder for widening. Addition type 3.3 materials will be brought in and compacted into existing pavement. This will be topped with a bitumen spray seal. This kind of project can be considered as large scale pavement rehabilitation. It is difficult to propose any stabilization here as it is not planned to go down to the subgrade level.

From the site visit it was seen that the severe rutting is most likely caused by a deep subgrade failure. With this in mind a subgrade stabilization design has been produced. For estimation purposes, the rates used for Hinz Street have been used again for this design. Some assumptions were made for this design and will be identified as required. The same procedure has been used for this design as the previous section 4.6.2. As such only the results will be shown here.

Calculate design traffic

- 60V/l/d total of 120 vehicles per day.

$$N_{DT} = 365 \times AADT \times DF \times \%HV/100 \times LDF \times CGF \times N_{HVAG}$$

where

AADT = Annual Average Daily Traffic[2] in vehicles per day in the first year (Section 7.4.4)

DF = Direction Factor is the proportion of the two-way AADT travelling in the direction of the design lane

%HV = average percentage of heavy vehicles (Section 7.4.4)

LDF = Lane Distribution Factor, proportion of heavy vehicles in design lane (Section 7.4.3)

CGF = Cumulative Growth Factor (Section 7.4.5)

N_{HVAG} = average number of axle groups per heavy vehicle (Section 7.4.6).

(Austroads, 2012)

The above figure shows the formula to calculate design traffic of the road. As some of these factors are unknown, indicative values have been taken from Austroads to aid in this design.

Table 12.2: Indicative heavy vehicle axle group volumes for lightly-trafficked urban streets

Street type	AADT two-way	Heavy vehicles (%)	Design AADHV (single lane)	Design period (years)	Annual growth rate (%)	Cumulative growth factor (Table 7.4)	Axle groups per heavy vehicle	Cumulative HVAG over design period	ESA/HVAG	Indicative design traffic (ESA)
Minor with single lane traffic	30	3	0.9	20	0	20	2.0	13 140	0.2	3×10^3
				40	0	40	2.0	26 280	0.2	5×10^3
Minor with two lane traffic	90	3	1.35	20	0	20	2.0	19 710	0.2	4×10^3
				40	0	40	2.0	39 420	0.2	8×10^3
Local access with no buses	400	4	8	20	1	22.0	2.1	128 480	0.3	4×10^4
				40	1	48.9	2.1	285 576	0.3	9×10^4
Local access with buses	500	6	15	20	1	22.0	2.1	240 900	0.3	8×10^4
				40	1	48.9	2.1	535 455	0.3	1.5×10^5
Local access in industrial area	400	8	16	20	1	22.0	2.3	256 960	0.4	1.5×10^5
				40	1	48.9	2.3	571 152	0.4	3×10^5
Collector with no buses	1200	6	36	20	1.5	23.1	2.2	607 068	0.6	4×10^5
				40	1.5	54.3	2.2	1 427 004	0.6	10^6
Collector with buses	2000	7	70	20	1.5	23.1	2.2	1 180 410	0.6	8×10^5
				40	1.5	54.3	2.2	2 774 730	0.6	2×10^6

Note: Direction factor is 0.5, except for Minor Street with single lane traffic where DF= 1.0

Table 24 Presumptive HVAG Data

Some values have been used from the above table to suit the situation of this road. These values are:

- 7% HV to account for seasonal harvesting traffic
- Design period of 20 years
- 2.2 Axle groups per heavy vehicle
- 0.6 ESA/Heavy vehicle
- Direction factor of 0.5
- Lane Distribution factor of 1

SAR/ESA has been adopted as used for Hinz Street:

- SAR7/ESA was 1 (Subgrade and unbound materials)
- SAR12/ESA was 12 (lime treated/cemented material)

In addition to this as this is a very rural area only minimum growth can be assumed. A growth rate of 1% is used for the design.

Design period (P) (years)	Annual growth rate (R) (%)							
	0	1	2	3	4	6	8	10
5	5	5.1	5.2	5.3	5.4	5.6	5.9	6.1
10	10	10.5	10.9	11.5	12.0	13.2	14.5	15.9
15	15	16.1	17.3	18.6	20.0	23.3	27.2	31.8
20	20	22.0	24.3	26.9	29.8	36.8	45.8	57.3
25	25	28.2	32.0	36.5	41.6	54.9	73.1	98.3
30	30	34.8	40.6	47.6	56.1	79.1	113.3	164.5
35	35	41.7	50.0	60.5	73.7	111.4	172.3	271.0
40	40	48.9	60.4	75.4	95.0	154.8	259.1	442.6

Table 25 CGF Table

With the above information the cumulative growth factor can be extracted from this table. The CGF for this pavement design is 22.0 In addition to this; the road has been given a project reliability of 90 %(Austroads 2012).

The design information for the design traffic is as follows:

- 7% HV to account for seasonal harvesting traffic
- Design period of 20 years
- 2.2 Axle groups per heavy vehicle
- 0.6 ESA/Heavy vehicle
- Direction factor of 0.5
- Lane Distribution factor of 1
- Cumulative Growth Factor 22
- AADT 120 vehicles per day

With the information the design traffic can be calculated.

$$N_{DT} = 365 \times AADT \times DF \times \% \frac{HV}{100} \times LDF \times CGF \times N_{HVAG}$$

$$N_{DT} = 365 \times 120 \times 0.5 \times \frac{7}{100} \times 1 \times 22 \times 2.2$$

$$N_{DT} = 74\ 197.2$$

From the design traffic loading can be calculated

$$DESA = \frac{ESA}{HVAG} \times N_{DT}$$

$$DESA = 0.6 \times 74\ 197.2$$

$$DESA = 44\ 518.32$$

$$DESA \approx 44\ 519$$

$$DESA \approx 4.4519 \times 10^4$$

The pavement configuration is not known for this pavement. But it can be safely assumed that the pavement is at least 300mm subbase and 100mm base material, this gave a total of 400mm cover and is the minimum cover required over reactive subgrade(refer to figure 55 In section 4.6.2.1). The same materials used for the Hinz street design will be used here in this design.

As discussed in previous sections the RCA will have no design benefit unless stabilized to an increased depth. For this application of pavement rehabilitation it is not viable to consider deep stabilization. However some improvement with lime stabilization is recommended. The design parameters are outlined below:

- Stabilization with 8% lime.
- Minimum base layer thickness of 100mm.
- Minimum 400mm subgrade cover.
- 200mm subgrade stabilization depth.
- DESA 4.4519×10^{4}.
- Project reliability 90%.
- Design CBR of 2.8 (assume 3 CBR).

CIRLY was used to analyse the pavement structure for the design. Initial sub layering of the 200mm stabilized layer produced the following results.

E used	70.55558	depth	200
R	1.203025		
		Sublayers	
Layer	Ev	thickness (mm)	
Top Layer	70.55558	40	
2	58.64847	40	
3	48.75083	40	
4	40.52354	40	
5	33.6847	40	

Table 26 Mann Silo Rd Sub-Layering

As can be seen the Design CBR of the top layer is 7.5.The lime treated layer has a CBR of 10.4 as determined by lab testing, however the depth of 200mm has restricted the design value.

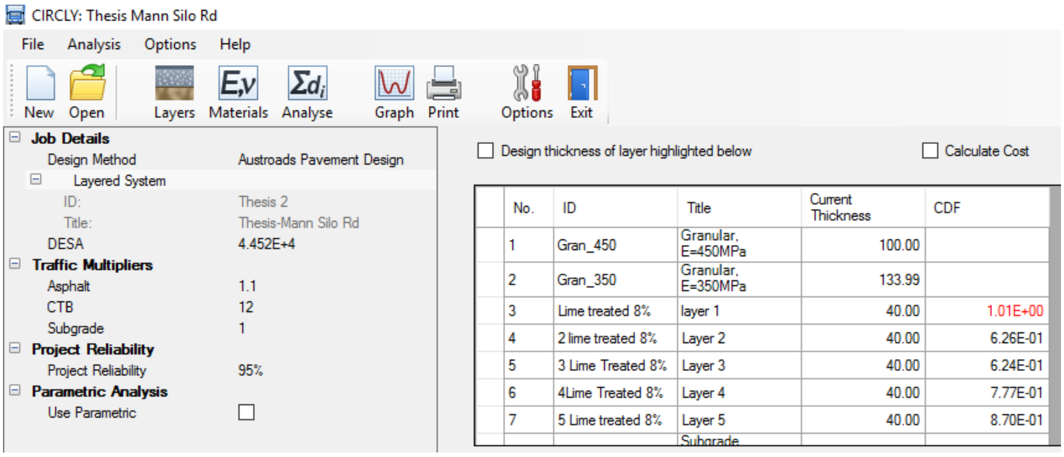


Figure 59 Mann Silo Rd Min subbase thickness CIRCLY

The above figure from CIRCLY shows the minimum thickness of the road that will be safe for the design period. It can be seen that a subbase layer of 150mm Type 3.4 would be suffice for this pavement.

To determine what the subbase depth could be using the granular material only, the lime treated layer has been omitted and the road design using granular material only.

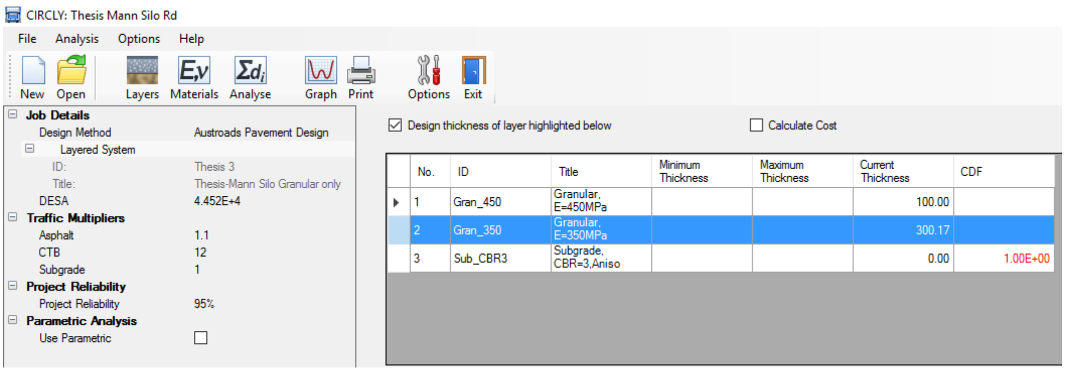


Figure 60 Mann Silo Pavement, granular only CIRCLY

It can be seen here that a subbase layer of approximately 300mm is required assuming only type 3.4 material has been used as subbase.

It is highly possible that the pavement was originally designed using the empirical pavement design method using the chart for lightly traffic pavements as seen below.

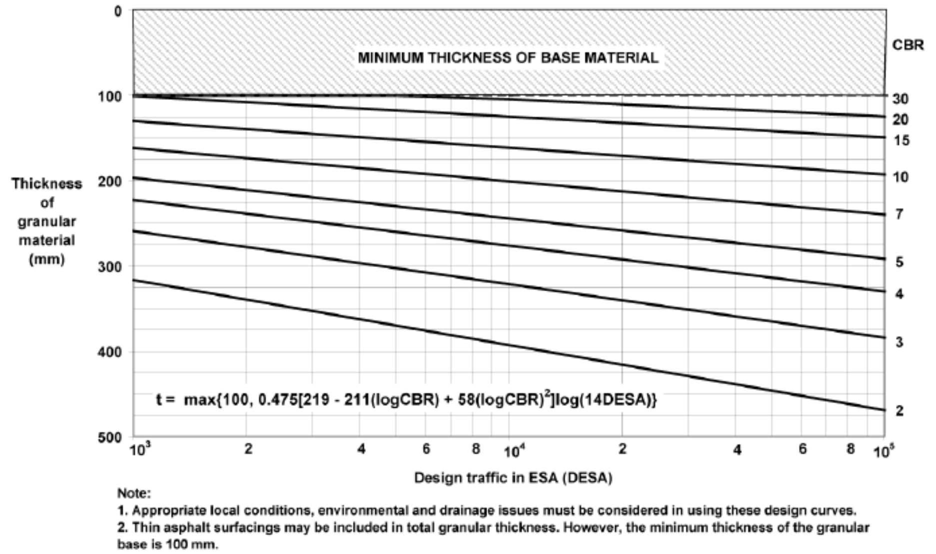


Figure 12.2: Example design chart for lightly-trafficked granular pavements with thin bituminous surfacings

From this with an ESA of approximately 4.25 E+04 we can see that a subgrade cover of 300mm may have been used. This reduces the subgrade layer to 200mm.

The addition of stabilization for the recommended design in this thesis has a pavement with 200mm type 3.4 subbase and 100mm of type 3.3 base as proposed by the council. The depth of stabilization is optimized to prevent premature pavement failure.

Case 1: 150mm Lime stabilized layer

As sub layering has been shown in previous sections it will be omitted here.

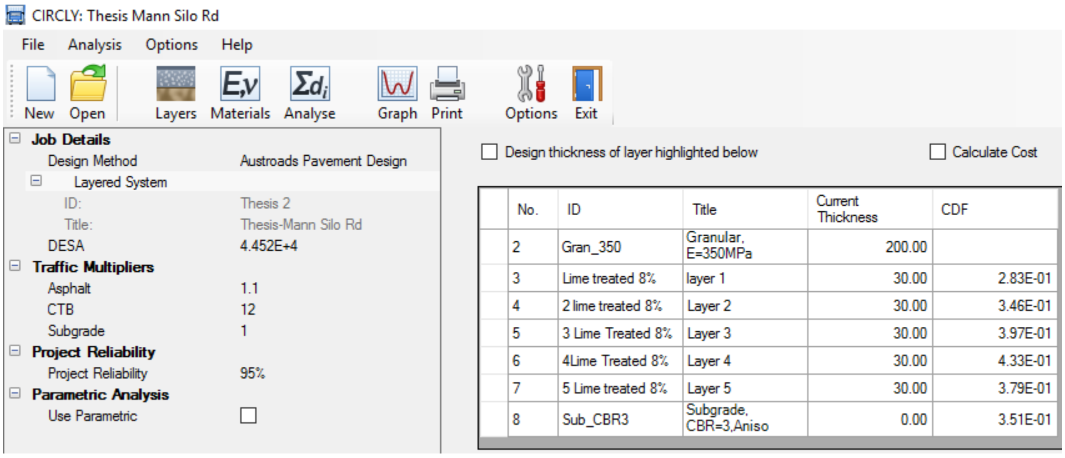


Figure 61 Mann Silo Rd Case 1 150mm Layer

The above design results show that a 150mm layer is sufficient.

Case 2:100mm Lime Stabilized layer

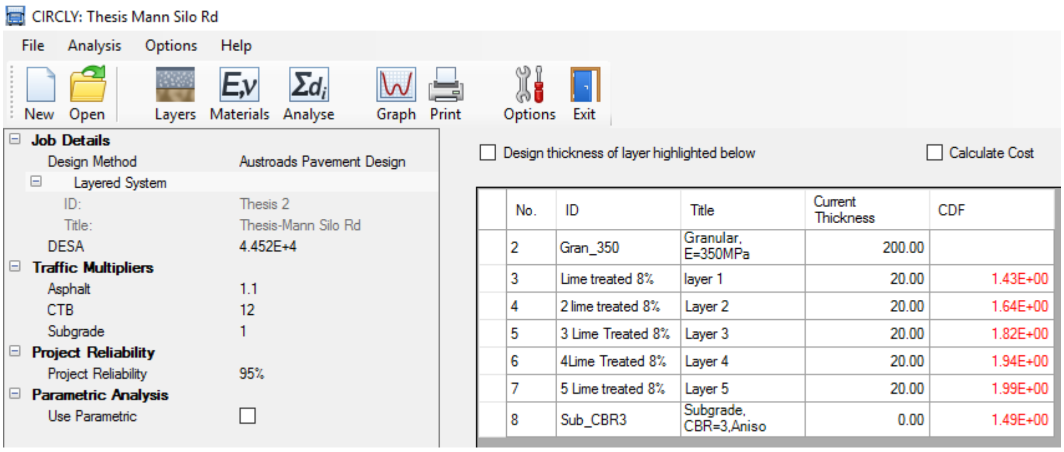


Figure 62 Mann Silo Rd Case 2 100mm layer

Here it is illustrated that a 100 mm Lime stabilized layer is insufficient to support the pavement for its design life.

Case 3:125mm Lime Stabilized Layer

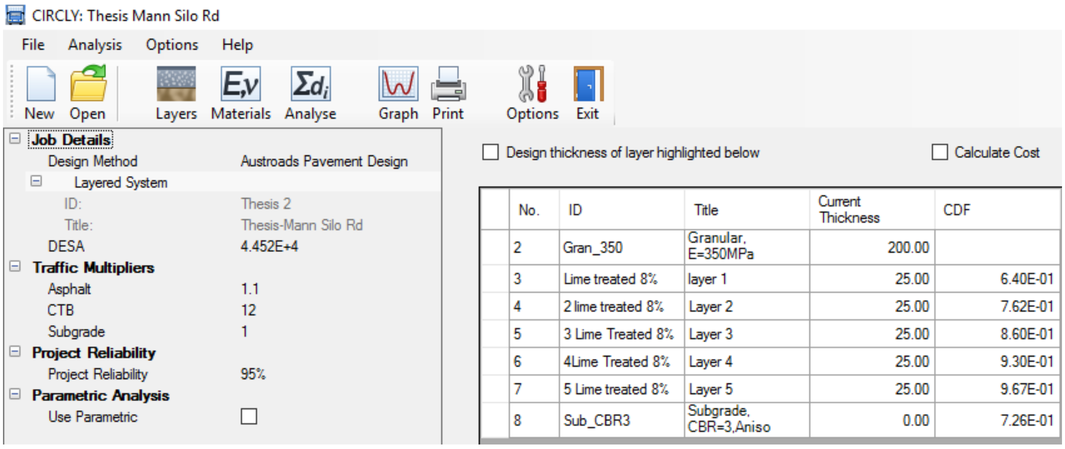


Figure 63 Mann Silo Rd Case 3 125mm Layer

As shown in the figure above a, stabilization depth of 125mm will be sufficient for this pavement.

This proposal included lifting the existing pavement (300mm), Lime stabilizing the subgrade to a depth of 125mm and re-compacting the original pavement material. Initial council proposal is to remove and scarify top 100mm pavement, cart and place a new 100mm base layer for the 3800 meter length.

4.6.3.1 Mann Silo Rd, Brookstead: Costs Analysis

This section/design is not intended to be used by council or to criticize the pavement design conducted by council. The use of different pavement design methods is the main reason for any differences. This section will look at the economic benefit, if any, of using lime stabilization in pavement rehabilitation situations. The same rates will be used from Hinz Street for stabilization and material purchase and place.

Amount of lime required

$$quantity\ of\ lime = 0.08 \times 1382$$

$$quantity\ of\ lime = 110.56\ Kg\ per\ cubic\ meter$$

$$rate_{Lime} = \frac{110.56}{1000} \times \$375 \quad \$per\ cubic\ meter$$

$$rate_{Lime} = \$41.46 \quad \$\ per\ cubic\ meter$$

As previously defined the rate for the stabilizer and spreader is

$$rate_{stab\ and\ spread} = \$13.30\ \ per\ cubic\ meter$$

$$Combined\ rate = 13.10 + 41.46$$

$$Combined\ rate = \$54.56\ per\ cubic\ meter$$

Material Purchase and place (As per Hinz Street)

$$Material\ Purcahse\ and\ Place = \$100\ per\ cubic\ meter$$

Removal of existing pavement from Hinz Street estimate

$$Pavement\ removal = \$15\ per\ cubic\ meter$$

$$Pavement\ replacement = \$20\ per\ cubic\ meter$$

$$Pavement\ blend\ and\ replace = \$35\ per\ cubic\ meter$$

1. Council process pavement cost estimation

   - Pavement blend and replace
   - Cart and compact 100mm of Type 3.3(CBR45)

$$Total\ cost \quad = \quad 35 \times (0.1 * 3800) + 100 \times (0.1 * 3800)$$

$$Total\ cost \quad = \quad 13300 + 38000$$
$$Total\ cost \quad = \quad \$51\ 300$$

2. Proposed Lime stabilization
   - Pavement removal and replacement
   - Stabilization

$$Total\ cost \quad = \quad 35 \times (0.3 * 3800) + 54.56 \times (0.125 * 3800)$$
$$Total\ cost \quad = \quad 39900 + 25916$$
$$Total\ cost \quad = \quad 65\ 816$$

Consideration must be given to the productivity of the stabilization process with such low depth and length of road. For this reason the production of the stabilizer can be increased to 4000 square meters a day from 2500 square meters a day. This reduces the unit rate of stabilization to $10.8 per cubic meter. This means the combined stabilization rate is 52.26 per cubic meter.

Overall costs are reduced to.

$$Total\ cost \quad = \quad 35 \times (0.3 * 3800) + 52.26 \times (0.125 * 3800)$$
$$Total\ cost \quad = \quad 39\ 900 + 24\ 823.5$$
$$Total\ cost \quad = \quad \$64\ 723.5$$

As is clearly seen for this pavement, rehabilitation it is cheaper to go with method 1. According to the mechanistic pavement design method and as shown in this section, the pavement needs at least 300mm of subgrade cover, not 200mm as used above. If this extra 100mm of subbase was added to the pavement at $90 per cubic meter to satisfy the mechanistic design the cost would be increased to:

$$Total\ cost \quad = \quad \$51\,300 + 90 \times (0.1 * 3800)$$

$$Total\ cost \quad = \quad \$51\,300 + \$34\,200$$

$$Total\ cost \quad = \quad \$85\,500$$

As can be seen here the pavement costs have now exceeded the original cost. This points out that the lime stabilization is a viable alternative treatment for pavement rehabilitation.

Conclusions

The Toowoomba Regional Council has a very large road network that requires consistent maintenance. Some of the council roads are dominated by the environmental effects of expansive subgrades with weak CBR strengths. Through the research in this project and current design methods outlined by Austroads lime stabilisation design can be incorporated into standard practice to minimise the effects of the expansive subgrade materials.

This research has discussed the effect lime has on local materials over a short time period, testing of extended periods would help to more clearly define the effectiveness of lime treatment. Through the collection, lime and Lime with RCA stabilization of local samples, it has been found beneficial and economical to use lime stabilisation in Local Government Council.

Testing confirmed that the Subgrade CRB could be increased with the addition of lime. Swell testing further showed the benefits to the shrink and swell nature of the material after treatment and soaking. These two findings will drastically improve the ability of the subgrade to tolerate load and resist movement with moisture. If such treatments prolong the life of the pavement and reduce maintenance frequency then there is something to be gained by stabilising subgrades with lime.

The effectiveness of RCA was not fully conclusive, but it can be said with confidence that the addition of RCA has additional positive effect on the strength of the lime treated subgrade. Further testing in this field may be very beneficial for further development of this technique of stabilisation in the Toowoomba area.

Future Work

This dissertation merely scratches the surface of lime stabilisation. Further research and cost analysis could be done by the council to further verify the results presented in the dissertation and to verify the costs savings.

Significant testing could be conducted on the use of Recycled concrete Aggregate in lime stabilized layers, in ways such as:

- Optimum dose rates.
- Impurities in RCA that effect pozzolanic reaction.
- Cost analysis of council internally crushing concrete and process required.

With the results achieved and maintenance strategies in mind, thought could be given to blending a certain proportion of the subbase layer into a lime treated subgrade.

Lime effectiveness could be simply tested on more pavements found throughout the Toowoomba regional council.

Recommendations

This research has highlighted a number of key aspects of design and incorporation of lime. From this research some recommendations can be made to Toowoomba Regional Council.

1. Consider acquiring Mechanistic Pavement software such as CIRCLY to help model pavement behaviour over clay subgrades.

2. Consider internally Crushing of RCA to make the process more affordable.

3. Consider the use of lime stabilization alone on reactive subgrades for construction and maintenance.

4. Consider purchase of bobcat stabiliser unit for small stabilisation projects and maintenance.

5. Conduct trial pavements using lime stabilised subgrade to asses performance in the region

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Appendix A-Research Proposal

ENG 4111/4112 Research Project

Project Specification

For: Matthew Aaron Brennan

Title: “Use of Recycled Concrete and lime to improve Marginal subgrades in the Toowoomba Regional Council”

Major: Civil Engineering

Supervisor: Dr. Andreas Nataatmadja
Angelo Casagrande (Toowoomba Regional Council)

Enrolment: ENG4111-ONC S1, 2016
ENG4111-ONC S2, 2016

Project Aim: To investigate the use of marginal Subgrades in conjunction with recycled concrete and lime/cement stabilization in the Toowoomba Regional Council and Analyse performance.

Program: Issue C 24 May 2016

6. Research background on marginal materials in the TRC region, current practice in use and the use of recycled concrete and improvement/stabilization technologies.

7. Examine existing Australian standards for testing, AustRoads/Transport and Main Roads/Local council and ARRB for design and current standards, use and implementation.

8. Collect Data form TRC and Subgrade materials from identified issue areas. Conduct standard testing, analyse the results against current standards to determine useability in sealed road applications.

9. Construct, test and analyse the effects of adding recycled concrete and lime to the collected samples.

10. Cost benefit and life cycle analysis of implementing improvement technologies, according to council base unit rates and local providers of materials.

If Time permits:

11. Conduct a feasibility study into the use of council waste concrete being kept/ stockpiled and crushed internally, and used as recycled material for improvement of local marginal gravel sources and subgrade improvement

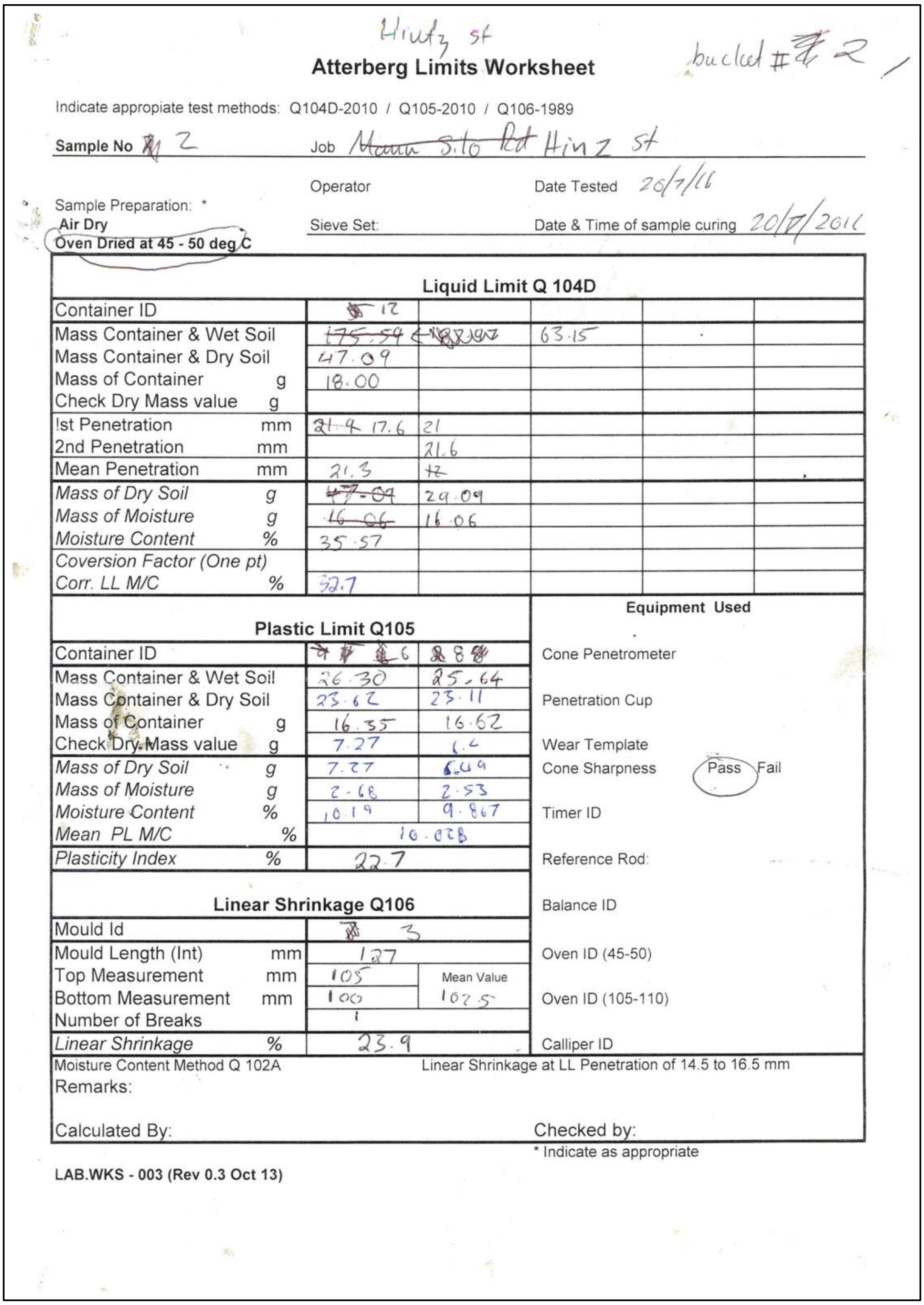
Project Plan

Activity	
	Semester 1 (weeks 1–18); Exams/holiday (week 19); Semester 2 (weeks 20–33)
	March, April, May, June, July, August, September, October
	Week
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
1. Initial/Research Phase	
1a. Project specification/ideas development	1 2 3
1b. Technical review of pavement design and technical specifications.	3 4 5 6
1c. Collect council soil test data and plans	7 8 9 10 11 12 13
1d. Recording of relevant litreature/further research	3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
2. Sample Collection Phase	
2a. Sample Collection plan,approvals and risk assesment	7 8 9 10 11 12 13 14
2b. Window to collect gravel samples	8 9 10 11 12 13 14
3. Gravel testing Phase	
3 a. Mechanical testing of granual samples (Prelimanry report)	13 14 15 16 17 18 19
3b. Write up of testing resluts/analysis of results	11 12 13 14 15 16 17 18 19
3c. study of improvement techniques,aquirment of improvement materials	9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
3d. Coduct stabillized materials testing (Project progreess Assessment)	16 17 18 19 20 21 22
4. Analysis and review Phase	
4a. Analysis of resulst against current technical specifiacations.	20 21 22 23 24 25
4b. Cost benefit analysis/Feasibility for Toowoomba Regional Council	23 24 25 26
4c. "If time permits item 6 on Project spec"	
5. Writeup Phase	
5a. Prepare Final dissertation	4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
5b. Draft Dissertation	16 17 18 19 20 21 22 23 24 25 26 27 28
5c. Presentation	30 31
5d. Finalise and submitt	30 31 32 33

Figure 64 Project Plan

Appendix B-Test Results/Subgrade Data from TRC

B-1 Atterberg Limits



Hinz st

Atterberg Limits Worksheet

bucket #2

Indicate appropiate test methods: Q104D-2010 / Q105-2010 / Q106-1989

Sample No 2 Job ~~Main Sto Rd~~ Hinz st

Operator Date Tested 26/7/11

Sample Preparation: *
Air Dry
Oven Dried at 45 - 50 deg C

Sieve Set: Date & Time of sample curing 20/7/2011

Liquid Limit Q 104D

Container ID	12					
Mass Container & Wet Soil	~~175.54~~	~~182.92~~	63.15			
Mass Container & Dry Soil	47.09					
Mass of Container g	18.00					
Check Dry Mass value g						
!st Penetration mm	~~21.4~~ 17.6	21				
2nd Penetration mm		21.6				
Mean Penetration mm	21.3	~~12~~				
Mass of Dry Soil g	~~47.09~~	29.09				
Mass of Moisture g	~~16.06~~	16.06				
Moisture Content %	35.57					
Coversion Factor (One pt)						
Corr. LL M/C %	32.7					

Plastic Limit Q105

Container ID	6	8
Mass Container & Wet Soil	26.30	25.64
Mass Container & Dry Soil	23.62	23.11
Mass of Container g	16.35	16.62
Check Dry Mass value g	7.27	6.5
Mass of Dry Soil g	7.27	6.49
Mass of Moisture g	2.68	2.53
Moisture Content %	10.19	9.867
Mean PL M/C %	10.028	
Plasticity Index %	22.7	

Linear Shrinkage Q106

Mould Id	3	
Mould Length (Int) mm	127	
Top Measurement mm	105	Mean Value
Bottom Measurement mm	100	102.5
Number of Breaks	1	
Linear Shrinkage %	23.9	

Equipment Used

Cone Penetrometer

Penetration Cup

Wear Template

Cone Sharpness Pass Fail

Timer ID

Reference Rod:

Balance ID

Oven ID (45-50)

Oven ID (105-110)

Calliper ID

Moisture Content Method Q 102A

Linear Shrinkage at LL Penetration of 14.5 to 16.5 mm

Remarks:

Calculated By: Checked by:

* Indicate as appropriate

LAB.WKS - 003 (Rev 0.3 Oct 13)

Figure 65 Hinz Atterberg Limits Worksheet

Mann Silo Rd

TOOWOOMBA REGION
Rich traditions. Bold ambitions.

Soils Laboratory Work Sheet for Atterberg Limits (MR)

AS method
LL @ 20mm

CROWS NEST ☑ MILLMERRAN ☐

Test Methods:

~~☐ Q106~~ ~~☐ Q104A~~ ~~☐ Q104D~~ ~~☐ Q105~~

Sample/Lab: ______ Job No: ______ Operator: TW Date: 12/9/16

SAMPLE PREPARATION	Sieve Set		Date and Time of Curing		

LIQUID LIMIT (Q104A / Q104D)					
Cone Penetrometer		Penetration Cup	L1035.5	Cone Sharpness	(Pass) / Fail
Wear Template	✓	Timer			
Container		7			
Mass Container & Wet Soil	(g)	53.57			
Mass Container & Dry Soil	(g)				
Mass of Container	(g)	17.35			
Check Mass	(g)				
1st Penetration	(mm)	19.3			
2nd Penetration	(mm)	19.5			
Average Penetration	(mm)	19.4			
Moisture Content	%	59			

PLASTIC LIMIT ~~(Q105)~~		Reference Rod		
Container		10	11	
Mass Container & Wet Soil	(g)	34.67	31.43	
Mass Container & Dry Soil	(g)			– did not record
Mass of Container	(g)	19.17	15.96	
Check Mass	(g)			– did not record
Moisture Content	%			
		Balance		Oven

LINEAR SHRINKAGE ~~(Q106)~~			Mould	5	did not record measurements.	
Mass of Mould	(g)		Mould Length (mm)	127.35		
Mass Mould & Wet Soil	(g)		Top (mm)		Oven (45-50)	
Mass Mould & Dry Soil	(g)		Bottom (mm)		Oven (105-110)	
Check Mass	(g)		No. of breaks		Calliper	

Liquid Limit %	Plastic Limit 20 %	Plasticity Idex 40	Linear Shrinkage 19.5 %
Variation(s) to Test Method			
Remark(s)			
Checked By			

Variation(s) / Remark(s): ______

______

______ Checked by: ______ Date: ______

Toowoomba Regional Council - Soil Laboratory
PO Box 3021
Toowoomba Qld 4350

DOC#4431491

UNCONTROLLED WHEN PRINTED

Figure 66 Mann Silo Atterberg Limits Worksheet

B-2 CRB Mould Preparation

WORKSHEET FOR Mann Silo 6%
CALIFORNIA BEARING RATIO (Q113) COMPACTION

REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	Q102 - 1993
Container		17
Mass of Container	(g)	215.3
Mass Container and Wet Soil	(g)	1515.3
Mass Container and Dry Soil	(g)	1255.9
Check Mass	(g)	
Balance / Oven		/

1275.5 g / layer
1 = 1275.5
2 = 1276.2
3 = 1277

COMPACTION DATA

Mould / Spacer		5+158 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2117
Mass of Mould	(g)	7321
Mould and Compaction Material	(g)	
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

SWELL DATA

Dial Gauge		57752
Plate and Stem / Soaking Weight		ST131 /
Date / Time of Immersion		24 /
Initial Reading	(mm)	1.14
Date / Time of Test		/
Final Reading	(mm)	1.14

FINAL MOISTURE CONTENT DATA

		Top	Total
Test Method: Q102 1993	[A / B / C / D / E]		
Container		11	
Mass of Container	(g)	181.55	
Mass Container and Wet Soil	(g)	1450.8	
Mass Container and Dry Soil	(g)	1195.9	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 67 Mann Silo 6% Mould Prep

MS 8%.

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION

REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ________ Job No.: ________ Operator: ________ Date: ________

Subsample No.: ________ OMC (%) ________ Nominated % x OMC ________ Nominated MC (%) ________

Q113C Only:

Hygroscopic Moisture: ________ MDD (t/m³) ________ Nominated % x MDD ________ Nominated DD (t/m³) ________

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	Q102 - 1993
Container		~~223~~ 21
Mass of Container	(g)	225.65
Mass Container and Wet Soil	(g)	1276.86
Mass Container and Dry Soil	(g)	1080
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		ST155 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2449
Mass of Mould	(g)	6636
Mould and Compaction Material	(g)	10393
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

1254

1=1254
2=1257.5
3=1254

SWELL DATA

Dial Gauge		ST152
Plate and Stem / Soaking Weight		ST061 /
Date / Time of Immersion		2-4 /
Initial Reading	(mm)	1.43
Date / Time of Test		/
Final Reading	(mm)	1.7

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		10	
Mass of Container	(g)	191	
Mass Container and Wet Soil	(g)	1365.4	
Mass Container and Dry Soil	(g)	1124.3	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ________

Checked by: ________ Date: ________

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 68 Mann Silo 8% Mould Prep

WORKSHEET FOR MS 8% + 5% RCA

CALIFORNIA BEARING RATIO (Q113) COMPACTION

REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ________ Job No.: ________ Operator: ________ Date: ________

Subsample No.: ________ OMC (%) ________ Nominated % x OMC ________ Nominated MC (%) ________

Q113C Only:

Hygroscopic Moisture: ________ MDD (t/m³) ________ Nominated % x MDD ________ Nominated DD (t/m³) ________

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	Q102 - 1993
Container		8
Mass of Container	(g)	190.88
Mass Container and Wet Soil	(g)	
Mass Container and Dry Soil	(g)	1047.5
Check Mass	(g)	
Balance / Oven		/

1309 per layer

1309

1310.36

1310.5

COMPACTION DATA

Mould / Spacer		ST761 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2u6
Mass of Mould	(g)	7220.
Mould and Compaction Material	(g)	11148
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

SWELL DATA

Dial Gauge		ST752
Plate and Stem / Soaking Weight		ST762 /
Date / Time of Immersion		29 /
Initial Reading	(mm)	1.09.
Date / Time of Test		/
Final Reading	(mm)	~~1.7~~ 1.1

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		13	
Mass of Container	(g)	266.72	
Mass Container and Wet Soil	(g)	1566.45	
Mass Container and Dry Soil	(g)	1298.5	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ________

Checked by: ________ Date: ________

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
UNCONTROLLED WHEN PRINTED

Figure 69 Mann Silo 8%+5% RCA Mould Prep

WORKSHEET FOR
CALIFORNIA BEARING RATIO (Q113) COMPACTION

MS 8+ 10% RCA

REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m^3) ______ Nominated % x MDD ______ Nominated DD (t/m^3) ______

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	Q102 - 1993
Container		5.
Mass of Container	(g)	122.2
Mass Container and Wet Soil	(g)	1142.7
Mass Container and Dry Soil	(g)	974.0
Check Mass	(g)	
Balance / Oven		/

1325.2 g/layer

1=1325
2=1325.4

COMPACTION DATA

Mould / Spacer		ST157 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm^3)	2114
Mass of Mould	(g)	7277
Mould and Compaction Material	(g)	11246
Wet Density	(t/m^3)	
Estimated Dry Density	(t/m^3)	

SWELL DATA

Dial Gauge		ST152
Plate and Stem / Soaking Weight		ST137 /
Date / Time of Immersion		29. /
Initial Reading	(mm)	1.19.
Date / Time of Test		/
Final Reading	(mm)	1.44

FINAL MOISTURE CONTENT DATA

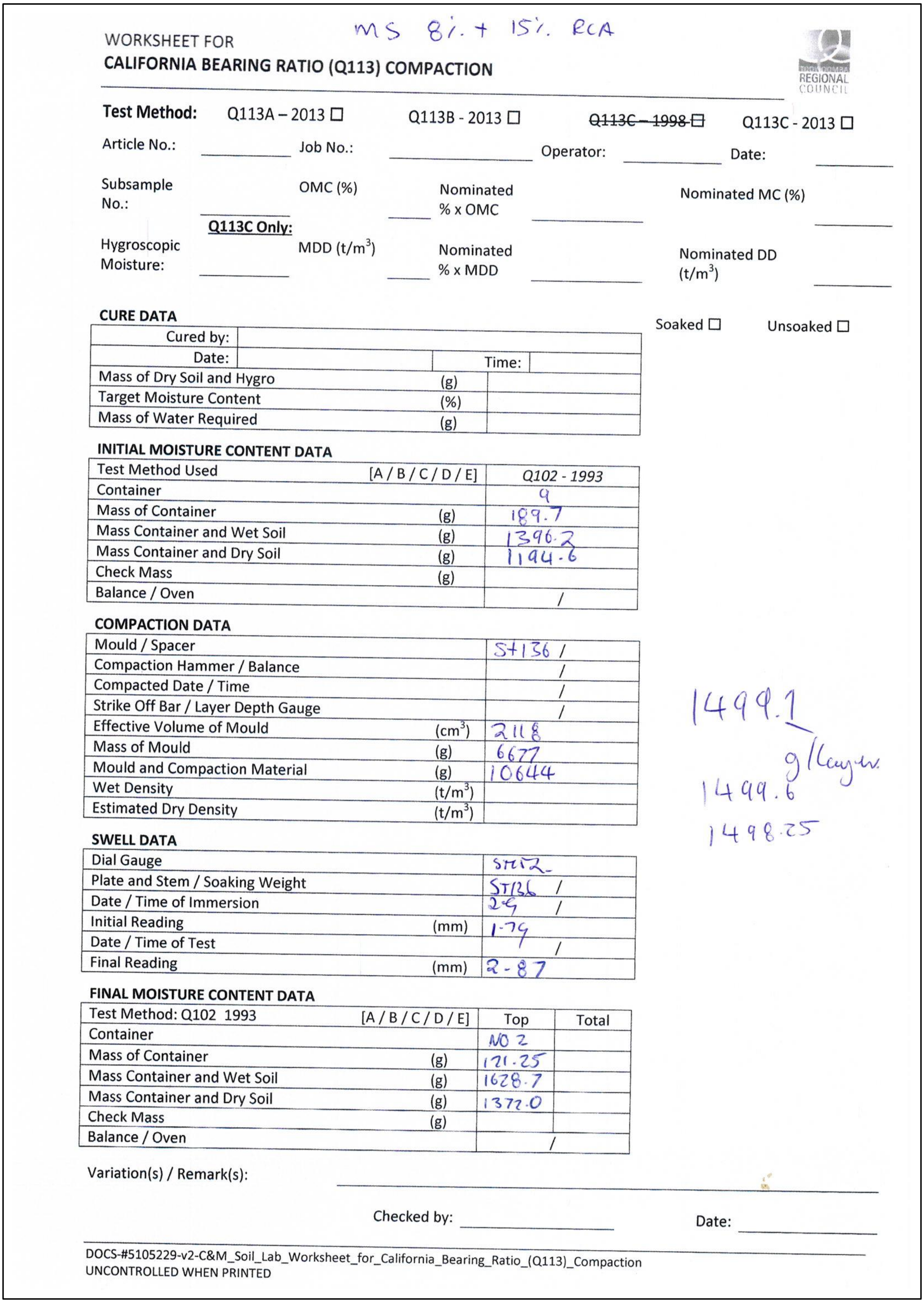
Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		No 4	
Mass of Container	(g)	122.94	
Mass Container and Wet Soil	(g)	1486.6	
Mass Container and Dry Soil	(g)	1236.5	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
UNCONTROLLED WHEN PRINTED

Figure 70 Mann Silo 8%+10% RCA Mould Prep



WORKSHEET FOR MS 8% + 15% RCA

CALIFORNIA BEARING RATIO (Q113) COMPACTION

REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro		(g)	
Target Moisture Content		(%)	
Mass of Water Required		(g)	

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		9
Mass of Container	(g)	189.7
Mass Container and Wet Soil	(g)	1396.2
Mass Container and Dry Soil	(g)	1194.6
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		ST136 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2118
Mass of Mould	(g)	6677
Mould and Compaction Material	(g)	10644
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

1499.1 g/layer

1499.6

1498.25

SWELL DATA

Dial Gauge		ST152
Plate and Stem / Soaking Weight		ST136 /
Date / Time of Immersion		2-9 /
Initial Reading	(mm)	1.79
Date / Time of Test		/
Final Reading	(mm)	2.87

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		NO 2	
Mass of Container	(g)	171.25	
Mass Container and Wet Soil	(g)	1628.7	
Mass Container and Dry Soil	(g)	1372.0	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 71 Mann Silo 8%+15% RCA Mould Prep

WORKSHEET FOR MS 10%

CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ________ Job No.: ________ Operator: ________ Date: ________

Subsample No.: ________ OMC (%) ________ Nominated % x OMC ________ Nominated MC (%) ________

Q113C Only:

Hygroscopic Moisture: ________ MDD (t/m³) ________ Nominated % x MDD ________ Nominated DD (t/m³) ________

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		16
Mass of Container	(g)	190.9
Mass Container and Wet Soil	(g)	1273.8
Mass Container and Dry Soil	(g)	1076.3
Check Mass	(g)	
Balance / Oven		/

1252.2 g/layer

1252
1253
1252.6

COMPACTION DATA

Mould / Spacer		ST159 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2116
Mass of Mould	(g)	7273
Mould and Compaction Material	(g)	11046
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

SWELL DATA

Dial Gauge		STSL
Plate and Stem / Soaking Weight		ST157 /
Date / Time of Immersion		2-9 /
Initial Reading	(mm)	1.32
Date / Time of Test		/
Final Reading	(mm)	1.77

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		15	
Mass of Container	(g)	265.88	
Mass Container and Wet Soil	(g)	1558.55	
Mass Container and Dry Soil	(g)	1300.5	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ________

Checked by: ________ Date: ________

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 72 Mann Silo 10% Mould Prep

Mann Silo Rd HOST

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION AND PENETRATION

TOOWOOMBA REGION

Test Method:	Q113A ☐	**CROWS NEST** ☐ Q113B ☐		**MILLMERRAN** ☐ Q113C ☐	
Article No.:		Job No.:		Operator:	Date: 16.9.16
CBR Machine	ST 129	Force Measuring Device	ST 128	Dial Gauge	ST153
Subsample No.:	3	OMC (%)	Nominated % x OMC		Nominated MC (%) 26.6
Q113C Only: Hygroscopic Moisture:		MDD (t/m³)	Nominated % x MDD	~~1473~~	Nominated DD (t/m³) 1382

CURE DATA

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro		(g)	7046
Target Moisture Content		(%)	
Mass of Water Required		(g)	

INITIAL MOISTURE CONTENT DATA

Test Method Used		[A/ B/ C/ D/ E]	Q102 - 1993
Container	7		
Mass of Container	560.7	(g)	
Mass Container and Wet Soil	1885.1	(g)	
Mass Container and Dry Soil	1598.0	(g)	
Check Mass		(g)	
Balance / Oven			/

COMPACTION DATA

Mould / Spacer	DL ST733		/
Compaction Hammer / Balance	ST133		/
Compacted Date / Time			/
Strike Off Bar / Layer Depth Gauge			/
Effective Volume of Mould	2117	(cm³)	
Mass of Mould	6642	(g)	
Mould and Compaction Material	10346	(g)	
Wet Density		(t/m³)	
Estimated Dry Density		(t/m³)	

Soaked ☑ Unsoaked ☐

FORCE MEASURING DEVICE READING

Pen. (mm)	Force Measuring Device Reading (div)
SEAT	40
0.5	89
1.0	187
1.5	283
2.0	350
2.5	394
3.0	419
3.5	437
4.0	451
4.5	459
5.0	471
5.5	480
6.0	489
6.5	497
7.0	502
7.5	508
8.0	
8.5	
9.0	
9.5	
10.0	

SWELL DATA

Dial Gauge	ST152	
Plate and Stem / Soaking Weight	ST163	/
Date / Time of Immersion	16.9.16	/
Initial Reading	(mm)	1.36
Date / Time of Test		20.9.16
Final Reading	(mm)	5.11

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		Z	
Mass of Container	(g)	319.5	
Mass Container and Wet Soil	(g)	1323.3	
Mass Container and Dry Soil	(g)	1064.6	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s):

Checked by: Date:

Toowoomba Regional Council - Soil Laboratory
PO Box 3021
Toowoomba Qld 4350

DOC#5105229 V3
Date Revised: 08 September 2016

UNCONTROLLED WHEN PRINTED

Figure 73 Mann Silo Host Mould Prep

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION

Hinz st 6% Line.

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		24
Mass of Container	(g)	214.1
Mass Container and Wet Soil	(g)	1629.6
Mass Container and Dry Soil	(g)	1315.3
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		ST133 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2117
Mass of Mould	(g)	6642
Mould and Compaction Material	(g)	10441
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

SWELL DATA

Dial Gauge		ST152
Plate and Stem / Soaking Weight		ST133 /
Date / Time of Immersion		2-9- /
Initial Reading	(mm)	0.86
Date / Time of Test		/
Final Reading	(mm)	1.59

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		NO 1	
Mass of Container	(g)	125.18	
Mass Container and Wet Soil	(g)	1175.7	
Mass Container and Dry Soil	(g)	937.6	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction

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Figure 74 Hinz 6% Mould Prep

Hinz st 8% Lime

WORKSHEET FOR
CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC 1.324 Nominated MC (%) 30.6

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) 1.324

CURE DATA

Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		23
Mass of Container	(g)	227.69
Mass Container and Wet Soil	(g)	1536.23
Mass Container and Dry Soil	(g)	1233.6
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		57 ~~153~~ /
Compaction Hammer / Balance		~~57 163~~ / 163 ~~152~~
Compacted Date / Time		2/9/16 /
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2115
Mass of Mould	(g)	7226
Mould and Compaction Material	(g)	10868.
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

1220.2 g / p layer
per layer

1 act = 1220.25
2 act = 1221.84
3 act = 1220.78

SWELL DATA

Dial Gauge		57 ~~155~~ 152
Plate and Stem / Soaking Weight		57+155 /
Date / Time of Immersion		2/9/16 /
Initial Reading	(mm)	0.665
Date / Time of Test		13/9 / 16
Final Reading	(mm)	0.87

FINAL MOISTURE CONTENT DATA

		Top	Total
Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		12	
Mass of Container	(g)	268.15	
Mass Container and Wet Soil	(g)	1469.94	
Mass Container and Dry Soil	(g)	1194.6	
Check Mass	(g)		
Balance / Oven			/

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 75 Hinz 8% Mould Prep

Hinz 8% + 5% RCA.

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro		(g)	
Target Moisture Content		(%)	
Mass of Water Required		(g)	

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	Q102 - 1993
Container		18
Mass of Container	(g)	222.76
Mass Container and Wet Soil	(g)	1522.9
Mass Container and Dry Soil	(g)	1233.2
Check Mass	(g)	
Balance / Oven		/

1240.21 per layer

cut 1 = 1240.3

cut 2 = 1240.2

3 = 1240.2

COMPACTION DATA

Mould / Spacer		St 154 /
Compaction Hammer / Balance		/
Compacted Date / Time		2.9.16 /
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2116
Mass of Mould	(g)	6636
Mould and Compaction Material	(g)	10359.3
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

SWELL DATA

Dial Gauge		St 152
Plate and Stem / Soaking Weight		St 134 /
Date / Time of Immersion		/
Initial Reading	(mm)	1.685
Date / Time of Test		/
Final Reading	(mm)	1.78

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		No 6	
Mass of Container	(g)	122.65	
Mass Container and Wet Soil	(g)	1106.3	
Mass Container and Dry Soil	(g)	886.3	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction

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Figure 76 Hinz 8%+5%RCA Mould Prep

Hinz 8% + 10%RCA

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998 ☐~~ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro		(g)	
Target Moisture Content		(%)	
Mass of Water Required		(g)	

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		19
Mass of Container	(g)	216.01
Mass Container and Wet Soil	(g)	1447.9
Mass Container and Dry Soil	(g)	1108.3
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		ST162 /
Compaction Hammer / Balance		/
Compacted Date / Time		2.9.16 /
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2114
Mass of Mould	(g)	7262
Mould and Compaction Material	(g)	11086.4
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

1295g / Layer

1295.23 + 1

1095.4

1295

SWELL DATA

Dial Gauge		ST152
Plate and Stem / Soaking Weight		ST162 /
Date / Time of Immersion		/
Initial Reading	(mm)	1.122
Date / Time of Test		/
Final Reading	(mm)	1.16

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		9	
Mass of Container	(g)	189.6	
Mass Container and Wet Soil	(g)	1254.97	
Mass Container and Dry Soil	(g)	1019.20	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction

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Figure 77 Hinz 8%+10%RCA Mould Prep

WORKSHEET FOR Hinz 8% lime + 15% RCA

CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m³) ______ Nominated % x MDD ______ Nominated DD (t/m³) ______

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		ZZ
Mass of Container	(g)	229.~~28~~54
Mass Container and Wet Soil	(g)	1466.73
Mass Container and Dry Soil	(g)	1204.1
Check Mass	(g)	
Balance / Oven		/

COMPACTION DATA

Mould / Spacer		ST137 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm³)	2118
Mass of Mould	(g)	6577
Mould and Compaction Material	(g)	10394.5
Wet Density	(t/m³)	
Estimated Dry Density	(t/m³)	

1271.39 per layer
1271.7 = 1
1271.3 = 2
1271.3 = 3

SWELL DATA

Dial Gauge		St152
Plate and Stem / Soaking Weight		ST154 /
Date / Time of Immersion		/
Initial Reading	(mm)	1.168
Date / Time of Test		/
Final Reading	(mm)	1.18

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		No 3	
Mass of Container	(g)	121.91	
Mass Container and Wet Soil	(g)	1328.2	
Mass Container and Dry Soil	(g)	1062.8	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
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Figure 78 Hinz 8%+15% RCA Mould Prep

WORKSHEET FOR Hinz 10% Lime.

CALIFORNIA BEARING RATIO (Q113) COMPACTION

TOOWOOMBA REGIONAL COUNCIL

Test Method: Q113A – 2013 ☐ Q113B - 2013 ☐ ~~Q113C – 1998~~ ☐ Q113C - 2013 ☐

Article No.: ______ Job No.: ______ Operator: ______ Date: ______

Subsample No.: ______ OMC (%) ______ Nominated % x OMC ______ Nominated MC (%) ______

Q113C Only:

Hygroscopic Moisture: ______ MDD (t/m^3) ______ Nominated % x MDD ______ Nominated DD (t/m^3) ______

CURE DATA Soaked ☐ Unsoaked ☐

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro	(g)		
Target Moisture Content	(%)		
Mass of Water Required	(g)		

INITIAL MOISTURE CONTENT DATA

Test Method Used	[A / B / C / D / E]	*Q102 - 1993*
Container		20
Mass of Container	(g)	227.29
Mass Container and Wet Soil	(g)	1396.59
Mass Container and Dry Soil	(g)	1135.0
Check Mass	(g)	
Balance / Oven		/

1198.7 per layer

1198.7 = 1

1198.7 = 2

1208.1 = 3

COMPACTION DATA

Mould / Spacer		~~ST~~ 134 /
Compaction Hammer / Balance		/
Compacted Date / Time		/
Strike Off Bar / Layer Depth Gauge		/
Effective Volume of Mould	(cm^3)	2116
Mass of Mould	(g)	6644
Mould and Compaction Material	(g)	10119.2
Wet Density	(t/m^3)	
Estimated Dry Density	(t/m^3)	

SWELL DATA

Dial Gauge		ST157
Plate and Stem / Soaking Weight		ST132 /
Date / Time of Immersion		/
Initial Reading	(mm)	~~X 6.681~~ 1.680
Date / Time of Test		/
Final Reading	(mm)	1.61

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		NO 5	
Mass of Container	(g)	121.93	
Mass Container and Wet Soil	(g)	1293.4	
Mass Container and Dry Soil	(g)	1048.2	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s): ______

Checked by: ______ Date: ______

DOCS-#5105229-v2-C&M_Soil_Lab_Worksheet_for_California_Bearing_Ratio_(Q113)_Compaction
UNCONTROLLED WHEN PRINTED

Figure 79 Hinz 10% Mould Prep

Hinz St HOST

WORKSHEET FOR

CALIFORNIA BEARING RATIO (Q113) COMPACTION AND PENETRATION

TOOWOOMBA REGION

Test Method: Q113A ☐ | **CROWS NEST** ☐ Q113B ☐ | **MILLMERRAN** ☐ Q113C ☐

Article No.: 1 Job No.: Operator: Date: 16 9.16

CBR Machine ST 129 Force Measuring Device ST 128 Dial Gauge ST153

Subsample No.: OMC (%) Nominated % x OMC ~~1.413~~ Nominated MC (%) 20 %.

Q113C Only:

Hygroscopic Moisture: MDD (t/m³) Nominated % x MDD Nominated DD (t/m³) 1.413

CURE DATA

Cured by:			
Date:		Time:	
Mass of Dry Soil and Hygro		(g)	~~7137~~ 7157
Target Moisture Content		(%)	
Mass of Water Required		(g)	

INITIAL MOISTURE CONTENT DATA

Test Method Used		[A/ B/ C/ D/ E]	Q102 - 1993
Container	13		
Mass of Container	266.8	(g)	
Mass Container and Wet Soil	1438.3	(g)	
Mass Container and Dry Soil	1216.7	(g)	
Check Mass		(g)	
Balance / Oven			/

COMPACTION DATA

Mould / Spacer	ST136		/
Compaction Hammer / Balance			/
Compacted Date / Time			/
Strike Off Bar / Layer Depth Gauge			/
Effective Volume of Mould	2118	(cm³)	
Mass of Mould	6577	(g)	
Mould and Compaction Material	10195	(g)	
Wet Density		(t/m³)	
Estimated Dry Density		(t/m³)	

SWELL DATA

Dial Gauge	ST152	
Plate and Stem / Soaking Weight	ST162	/
Date / Time of Immersion	16.9.16	/
Initial Reading	(mm)	1.36
Date / Time of Test		20.9.6. /
Final Reading	(mm)	15.20.

Soaked ☑ Unsoaked ☐

FORCE MEASURING DEVICE READING

Pen. (mm)	Force Measuring Device Reading (div)
SEAT	34
0.5	49
1.0	75
1.5	110
2.0	135
2.5	155
3.0	171
3.5	182
4.0	189
4.5	194
5.0	200
5.5	209
6.0	219
6.5	229
7.0	239
7.5	246
8.0	
8.5	
9.0	
9.5	
10.0	

FINAL MOISTURE CONTENT DATA

Test Method: Q102 1993	[A / B / C / D / E]	Top	Total
Container		15	
Mass of Container	(g)	265.8	
Mass Container and Wet Soil	(g)	1794.4	
Mass Container and Dry Soil	(g)	1295.1	
Check Mass	(g)		
Balance / Oven		/	

Variation(s) / Remark(s):

Checked by: Date:

Toowoomba Regional Council - Soil Laboratory
PO Box 3021
Toowoomba Qld 4350

DOC#5105229 V3
Date Revised 08 September 2016

UNCONTROLLED WHEN PRINTED

Figure 80 Hinz Host Mould Prep

B-3 CRB Results

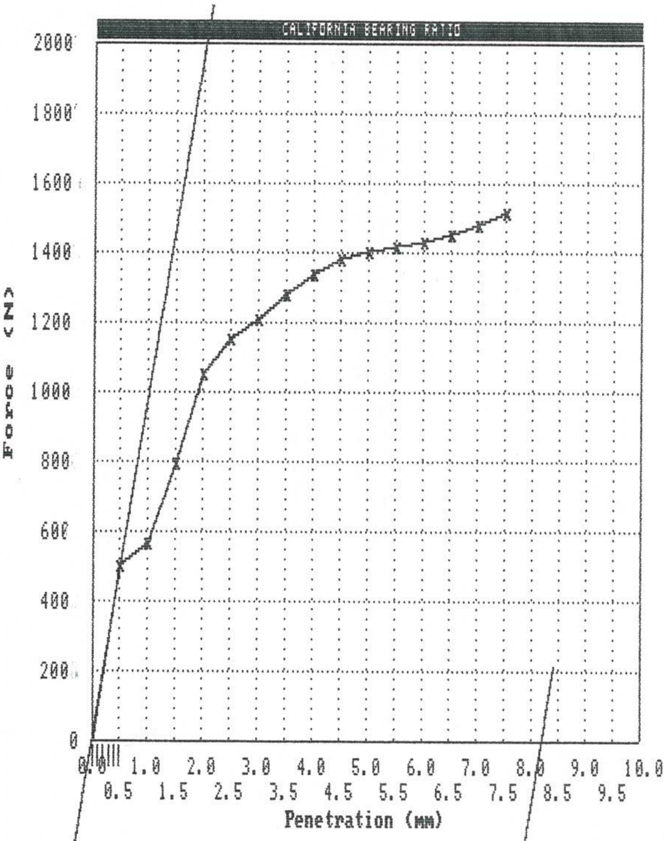
Mann Silo Rd 6% Lime

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (MM)	FMDR(div)
SEATING	10.2
0.5	503.3
1.0	573.3
1.5	802.2
2.0	1060.0
2.5	1155.2
3.0	1215.8
3.5	1283.9
4.0	1344.8
4.5	1384.8
5.0	1407.7
5.5	1419.2
6.0	1435.1
6.5	1457.6
7.0	1488.1
7.5	1522.2
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.00

RECORDED RESULTS : Bearing ratio @ 2.5 mm 8.7

Bearing Ratio @ 5.0 mm 7.1

Figure 81 Mann Silo CBR Graph 6%

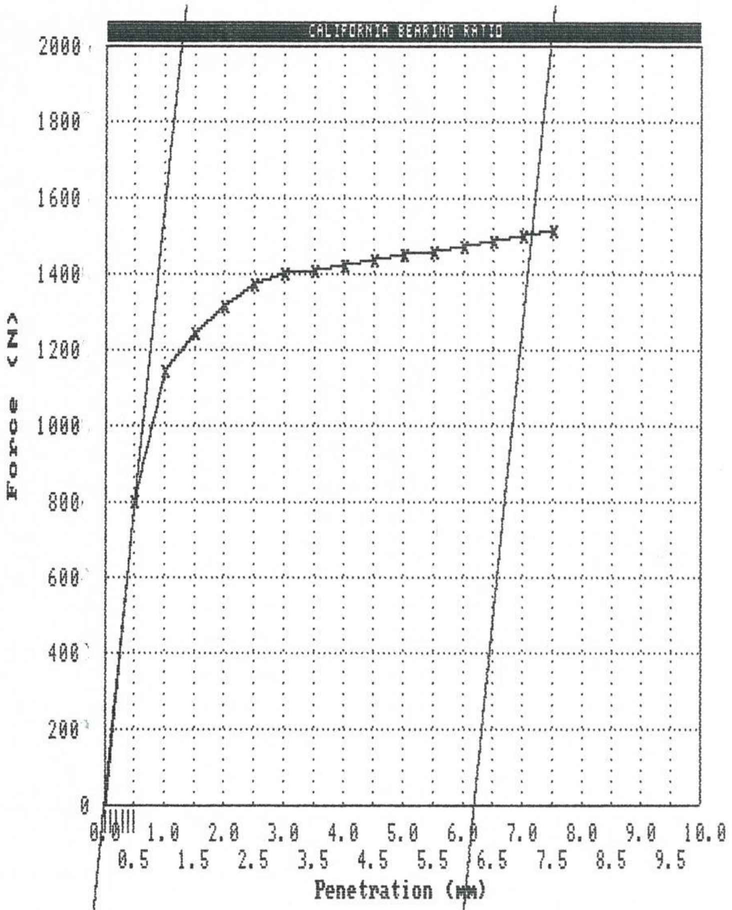
Mann Silo rd 8% Lime

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	6.3
0.5	800.0
1.0	1142.5
1.5	1243.6
2.0	1319.5
2.5	1374.1
3.0	1405.5
3.5	1411.0
4.0	1421.5
4.5	1435.4
5.0	1450.0
5.5	1463.2
6.0	1477.2
6.5	1490.5
7.0	1502.9
7.5	1515.5
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.00

RECORDED RESULTS : Bearing ratio @ 2.5 mm 10.4

Bearing Ratio @ 5.0 mm 7.3

Figure 82 Mann Silo CBR Graph 8%

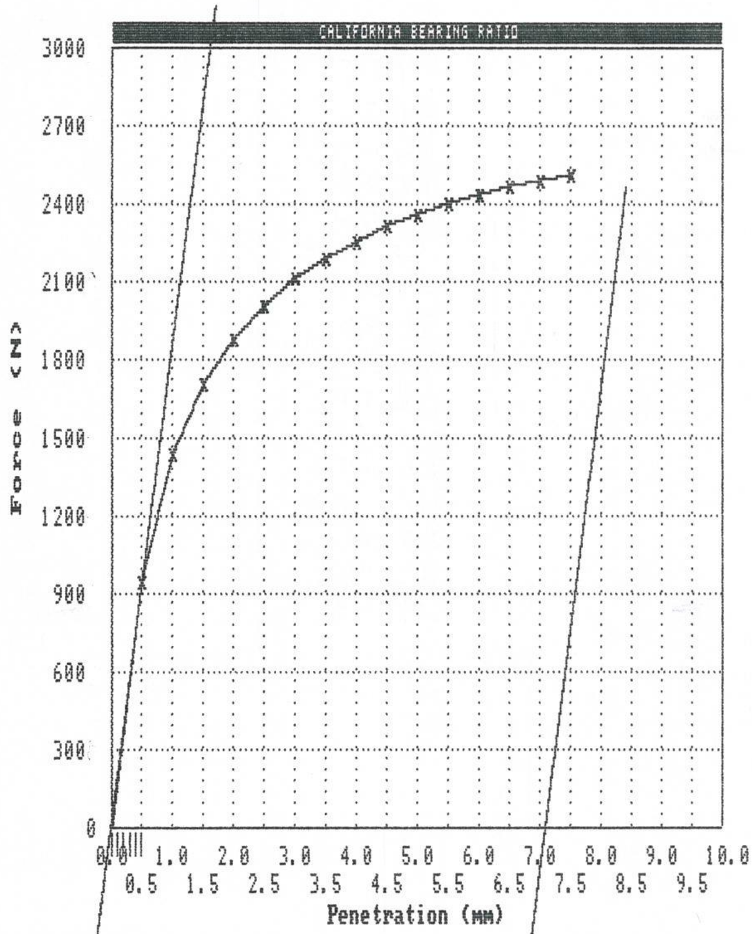
Mann Silo rd 8% Lime + 5% RCA

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	11.5
0.5	946.3
1.0	1444.9
1.5	1708.6
2.0	1883.1
2.5	2014.9
3.0	2114.1
3.5	2191.6
4.0	2251.7
4.5	2315.4
5.0	2362.8
5.5	2405.2
6.0	2438.5
6.5	2466.9
7.0	2492.4
7.5	2511.8
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.00

RECORDED RESULTS : Bearing ratio @ 2.5 mm 15.2

Bearing Ratio @ 5.0 mm 11.9

Figure 83 Mann Silo CBR Graph 8%+5%RCA

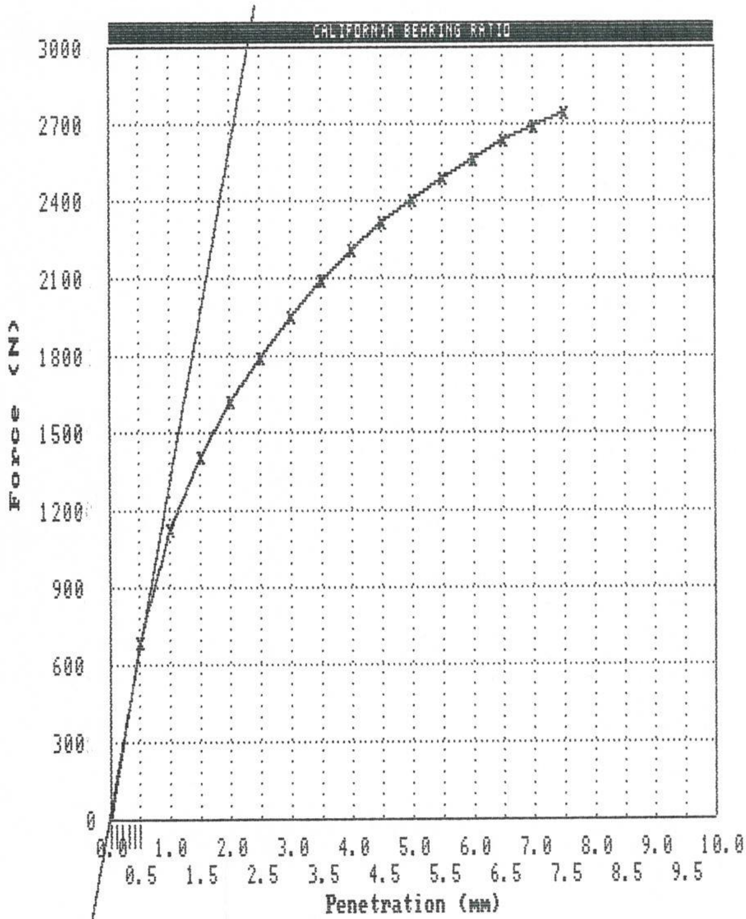
Mann Silo 8% Lime + 10% RCA

Subsample no ST157

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	6.0
0.5	688.2
1.0	1129.9
1.5	1405.8
2.0	1621.5
2.5	1792.6
3.0	1953.0
3.5	2094.9
4.0	2210.1
4.5	2310.0
5.0	2400.0
5.5	2485.0
6.0	2566.5
6.5	2631.3
7.0	2692.5
7.5	2745.8
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.00

RECORDED RESULTS : Bearing ratio @ 2.5 mm 13.5

Bearing Ratio @ 5.0 mm 12.1

Figure 84 Mann Silo CBR Graph 8%+10%RCA

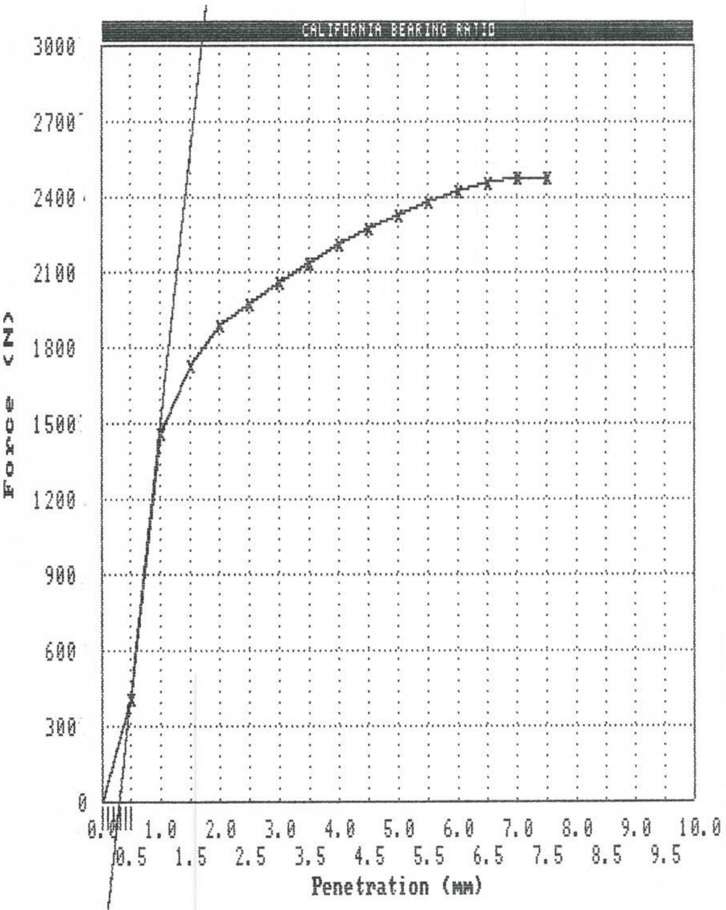
Mann Silo Rd 8% Lime + 15% RCA

Subsample no ST136

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	4.7
0.5	408.8
1.0	1461.7
1.5	1720.6
2.0	1884.8
2.5	1970.1
3.0	2051.9
3.5	2133.9
4.0	2206.1
4.5	2270.3
5.0	2323.7
5.5	2374.1
6.0	2417.6
6.5	2449.9
7.0	2470.4
7.5	2479.0
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.29

RECORDED RESULTS : Bearing ratio @ 2.5 mm 15.2

Bearing Ratio @ 5.0 mm 11.9

Figure 85 Mann Silo CBR Graph 8%+15% RCA

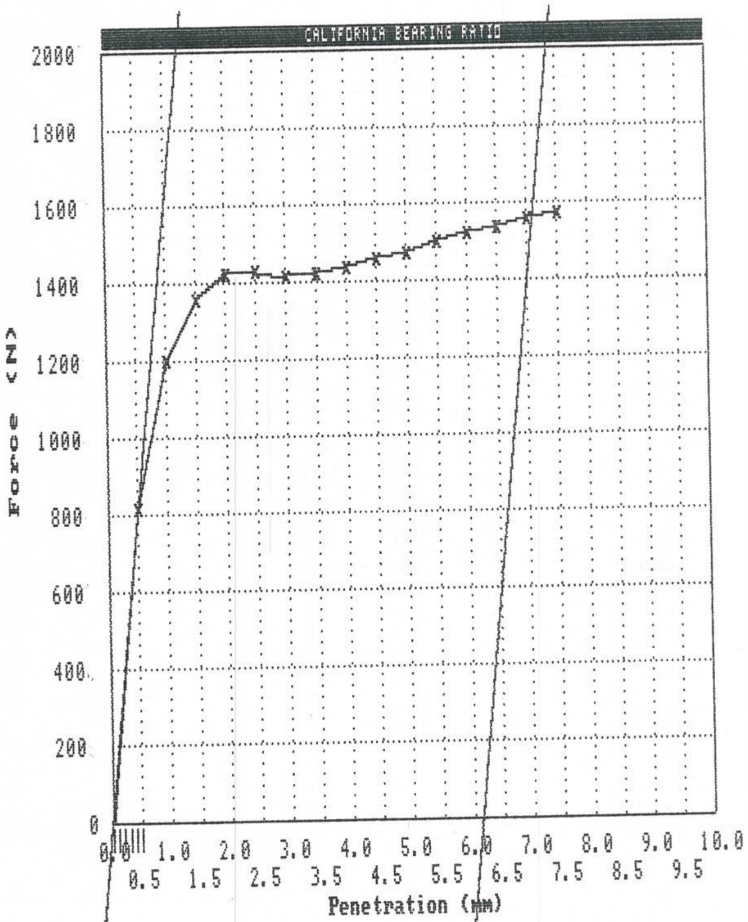
Mann Silo Lime 10%

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (MM)	FMDR(div)
SEATING	1.0
0.5	810.4
1.0	1198.7
1.5	1354.5
2.0	1419.0
2.5	1423.7
3.0	1415.0
3.5	1420.0
4.0	1435.0
4.5	1451.8
5.0	1472.4
5.5	1497.9
6.0	1516.4
6.5	1536.2
7.0	1554.8
7.5	1570.2
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.00

RECORDED RESULTS : Bearing ratio @ 2.5 mm 10.8

Bearing Ratio @ 5.0 mm 7.4

Figure 86 Mann Silo CBR Graph 10%

Mann Silo Rd HOST

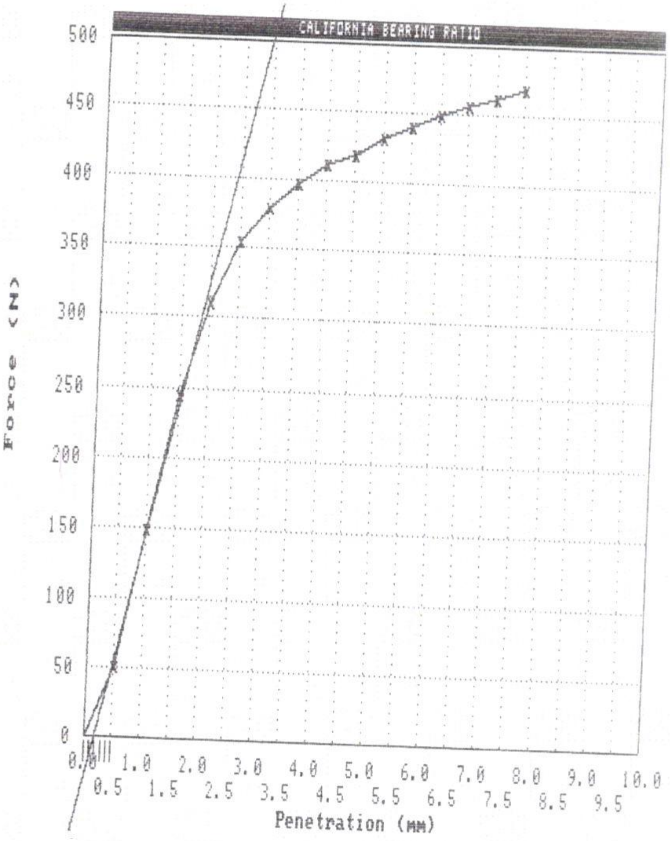
Subsample no

Test Method Q113A-1993

Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	4.0
0.5	8.9
1.0	18.7
1.5	28.3
2.0	35.0
2.5	39.4
3.0	41.9
3.5	43.7
4.0	45.1
4.5	45.9
5.0	47.1
5.5	48.0
6.0	48.9
6.5	49.7
7.0	50.2
7.5	50.8
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.19

RECORDED RESULTS : Bearing ratio @ 2.5 mm 2.8

Bearing Ratio @ 5.0 mm 2.2

Figure 87 Mann Silo CBR Graph Host

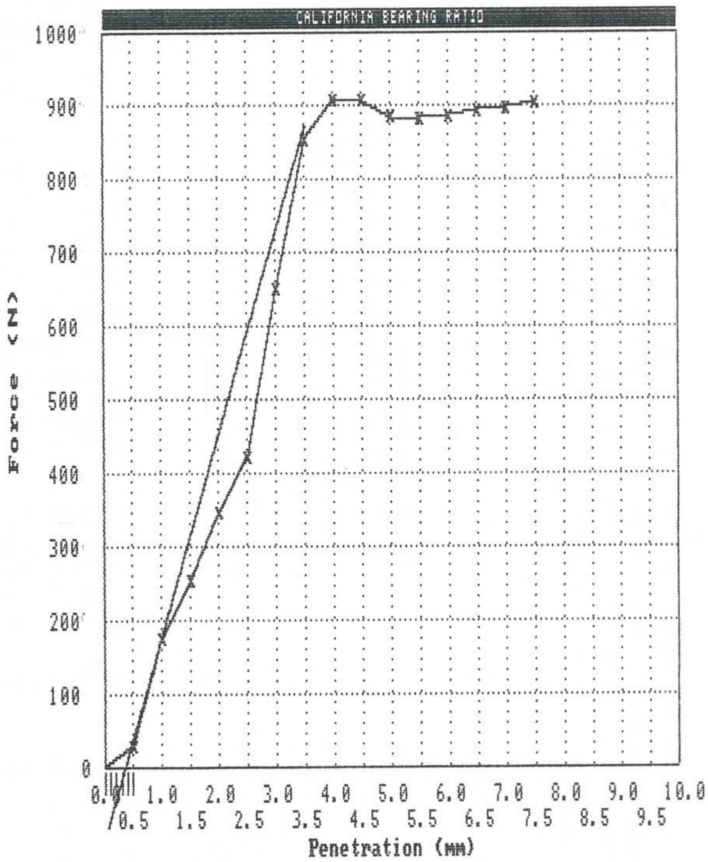
Hinz st 6% Lime

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (MM)	FMDR(div)
SEATING	0.9
0.5	28.3
1.0	175.6
1.5	252.9
2.0	344.9
2.5	422.0
3.0	648.1
3.5	854.0
4.0	906.1
4.5	905.8
5.0	883.7
5.5	880.4
6.0	884.6
6.5	890.2
7.0	897.3
7.5	902.8
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.37

RECORDED RESULTS : Bearing ratio @ 2.5 mm 4.5

Bearing Ratio @ 5.0 mm 4.4

Figure 88 Hinz CBR Graph 6%

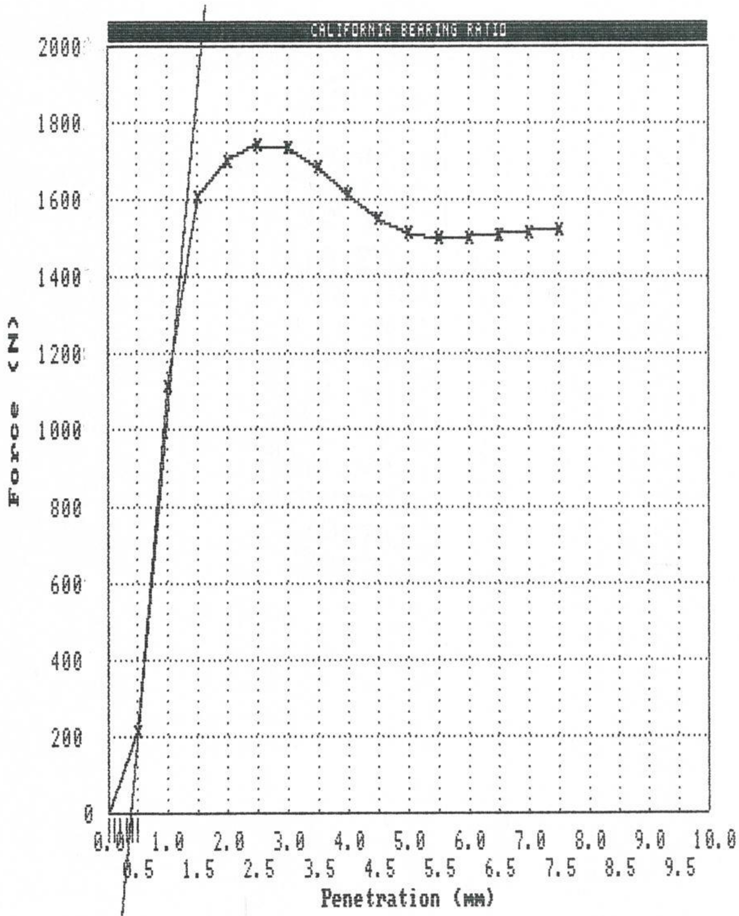
Hinz 8% Lime

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	1.3
0.5	212.9
1.0	1115.0
1.5	1608.3
2.0	1694.3
2.5	1738.1
3.0	1731.9
3.5	1680.3
4.0	1611.1
4.5	1550.5
5.0	1515.5
5.5	1499.9
6.0	1497.7
6.5	1503.0
7.0	1510.4
7.5	1522.2
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.37

RECORDED RESULTS : Bearing ratio @ 2.5 mm 13.1

Bearing Ratio @ 5.0 mm 7.6

Figure 89 Hinz CBR Graph 8%

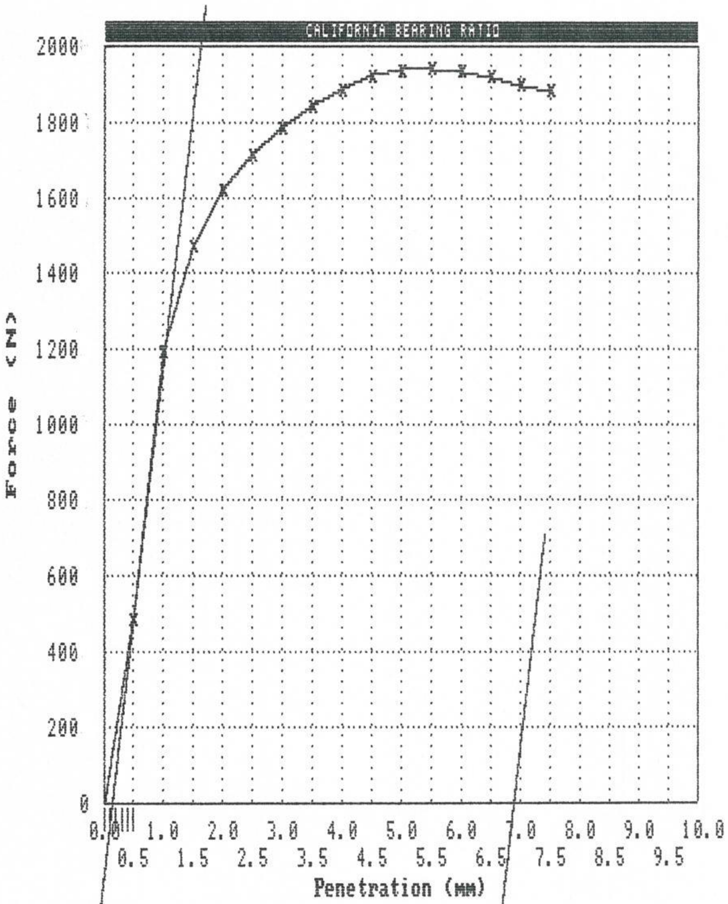
Hinz st 8% Lime + 5% RCA

Subsample no ST 154

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	0.9
0.5	483.3
1.0	1189.1
1.5	1470.9
2.0	1616.1
2.5	1712.0
3.0	1783.9
3.5	1843.3
4.0	1885.4
4.5	1918.8
5.0	1934.5
5.5	1939.2
6.0	1934.5
6.5	1919.2
7.0	1899.2
7.5	1879.5
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.13

RECORDED RESULTS : Bearing ratio @ 2.5 mm 13.1

Bearing Ratio @ 5.0 mm 9.8

Figure 90 Hinz CBR Graph 8%+5% RCA

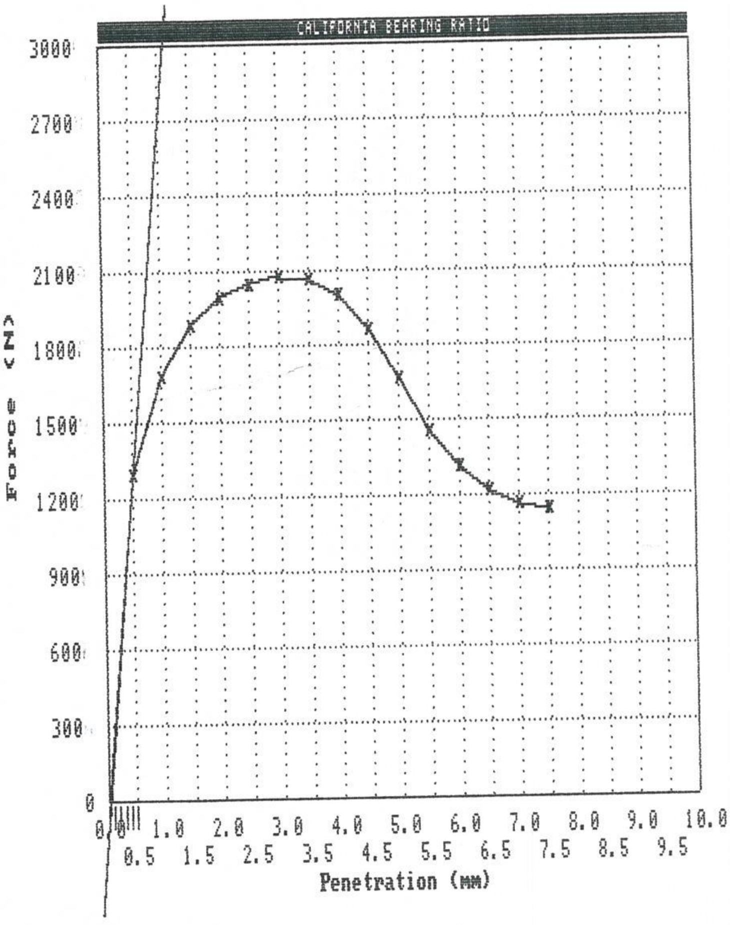
Hinz st 8% Lime + 10% RCA

Subsample no

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (MM)	FMDR(div)
SEATING	10.5
0.5	1300.0
1.0	1692.4
1.5	1892.4
2.0	1994.7
2.5	2051.5
3.0	2082.7
3.5	2076.2
4.0	2009.9
4.5	1872.5
5.0	1671.7
5.5	1464.2
6.0	1326.4
6.5	1229.8
7.0	1176.4
7.5	1149.4
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.03

RECORDED RESULTS : Bearing ratio @ 2.5 mm 15.5

Bearing Ratio @ 5.0 mm 8.3

Figure 91 Hinz CBR Graph 8%+10% RCA

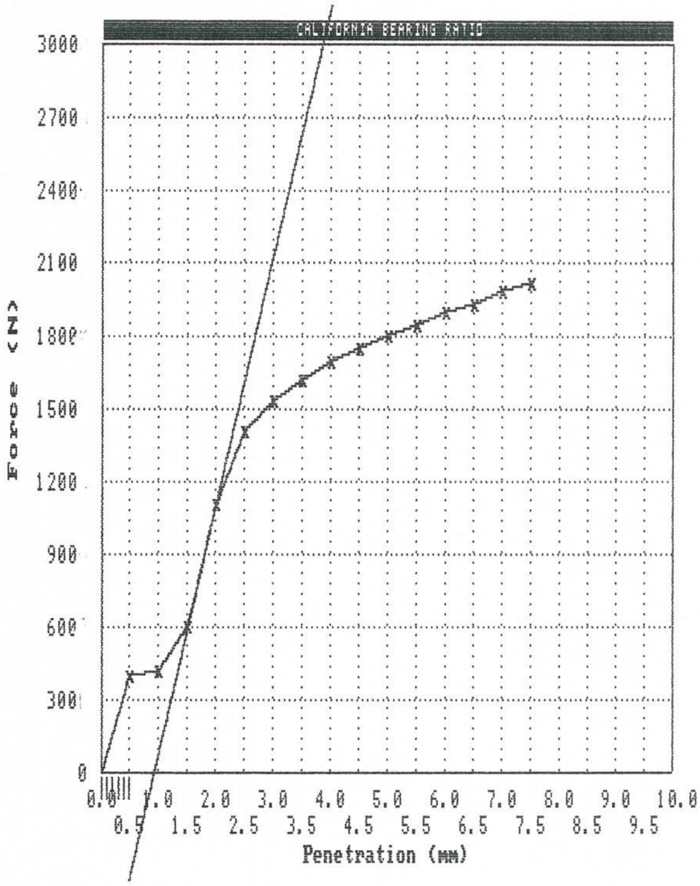
Hinz st 8% Lime + 15% RCA

Subsample no ST137

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (MM)	FMDR(div)
SEATING	3.5
0.5	399.2
1.0	420.2
1.5	596.8
2.0	1100.7
2.5	1404.9
3.0	1526.1
3.5	1621.2
4.0	1690.7
4.5	1749.4
5.0	1800.0
5.5	1845.9
6.0	1890.8
6.5	1931.6
7.0	1975.9
7.5	2015.9
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.50

RECORDED RESULTS : Bearing ratio @ 2.5 mm 11.5

Bearing Ratio @ 5.0 mm 9.3

Figure 92 Hinz CBR Graph 8%+15% RCA

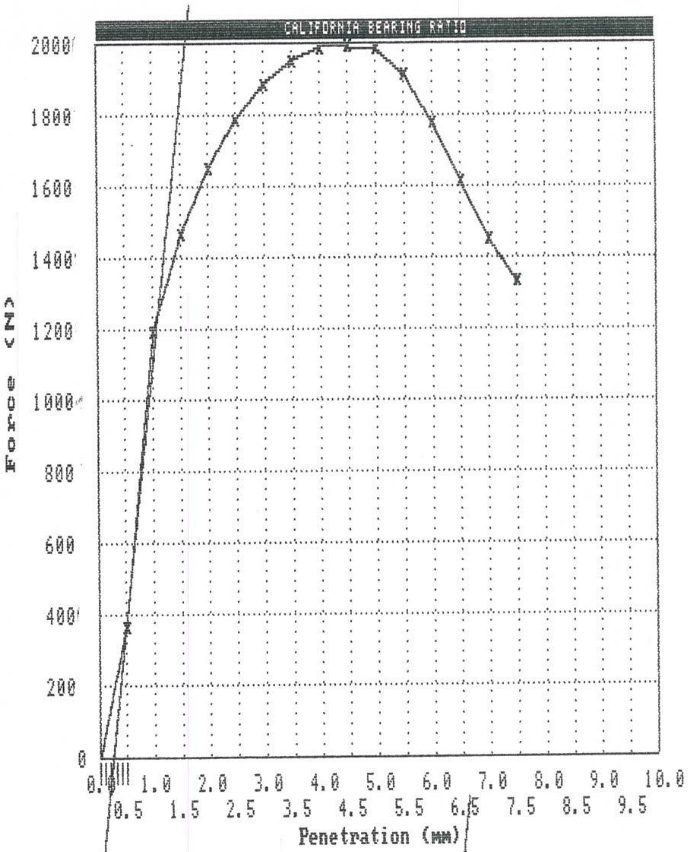
Hinz street 10% Lime

Subsample no ST133

Test Method Q113A-1993 Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	14.0
0.5	376.4
1.0	1202.4
1.5	1472.6
2.0	1658.9
2.5	1794.3
3.0	1893.3
3.5	1958.6
4.0	1994.9
4.5	2005.1
5.0	1995.5
5.5	1927.2
6.0	1787.7
6.5	1621.8
7.0	1462.4
7.5	1346.4
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.23

RECORDED RESULTS : Bearing ratio @ 2.5 mm 13.8

Bearing Ratio @ 5.0 mm 9.8

Figure 93 Hinz CBR Graph 10%

Hinz st HOST

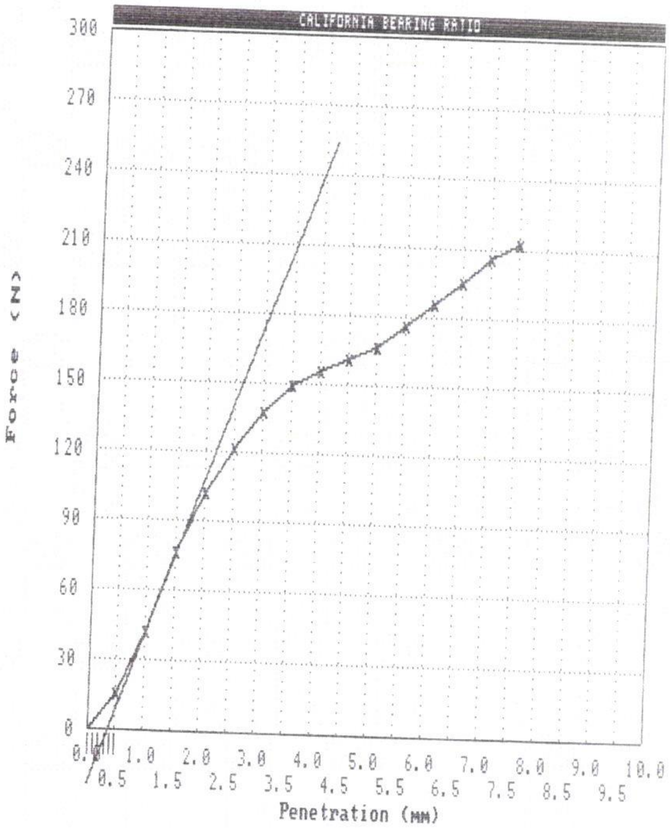
Subsample no

Test Method Q113A-1993

Software version 4.1

Force measuring device no ST138 (Calibration data on file for 12/04/12)

Pen. (mm)	FMDR(div)
SEATING	3.4
0.5	4.9
1.0	7.5
1.5	11.0
2.0	13.5
2.5	15.5
3.0	17.1
3.5	18.2
4.0	18.9
4.5	19.4
5.0	20.0
5.5	20.9
6.0	21.9
6.5	22.9
7.0	23.9
7.5	24.6
8.0	
8.5	
9.0	
9.5	
10.0	



Adjustment to penetration scale (mm) 0.37

RECORDED RESULTS : Bearing ratio @ 2.5 mm 1.0

Bearing Ratio @ 5.0 mm 0.9

Figure 94 Hinz CBR Graph Host

B-4 Lime demand

Initial moisture contents calculations

	Soil Moisture content		
	Mann Silo Rd		
Sample Number	Mass container (g)	Mass soil wet (g)	
1	0.916	20.337	
2	0.927	20.059	
3	0.925	21.184	
Sample Number	Initial moisture (%)	Check (+1hr)(%)	Variation (%)
1	18.317	18.31	0.038215865
2	18.019	18.01	0.049947278
3	19.402	19.398	0.020616431
	Moisture content (%)		
1	16.873		
2	17.359		
3	14.651	Reject	
Average	17.116		

Table 27 Mann Silo Lime Demand Moisture Content

	Hinz Street	Soil moisture content	
Sample Number	**Mass container (g)**	**Mass soil wet (g)**	
1	0.929	20.867	
2	0.923	21.329	
3	0.918	20.587	
Sample Number	**Initial moisture (%)**	**Check (+1hr)(%)**	**Variation (%)**
1	16.557	16.55	0.04227819
2	17.484	17.48	0.02287806
3	16.943	16.94	0.017706427
	Moisture Content (%)		
1	33.523	reject	
2	28.791		
3	28.468		
Average	28.629		

Table 28 Hinz Lime Demand Moisture Content

Theoretical soil quantities required

Mann Silo Rd	Theoretical Soil Quantities	
Percentage lime (%)	**Theoretical mass (g)**	**Actual mass (g)**
1	34.787	34.881
2	34.446	34.433
3	34.111	34.273
4	33.783	33.613
5	33.462	33.462
6	33.146	33.173
7	32.836	32.905
8	32.532	32.546
9	32.234	32.393
10	31.941	31.956

Table 29 Mann Silo Lime Demand test quantities

Hinz S	Theoretical Soil Quantities	
Percentage lime (%)	**Theoretical mass(g)**	**Actual mass (g)**
1	38.207	38.225
2	37.832	37.893
3	37.465	37.426
4	37.105	37.126
5	36.751	37.786
6	36.405	36.617
7	36.064	36.084
8	35.730	35.74
9	35.403	35.398
10	35.081	35.031

Table 30 Lime Demand Theoretical Soil Quantities

As can be seen in the above figures, measuring mass to exact figures was very difficult. Theoretical Lime quantities required common for both samples

Mann Silo Rd/Hinz St	Theoretical Lime Quantities
Percentage Lime (%)	mass(g)
1	0.297029703
2	0.588235294
3	0.873786408
4	1.153846154
5	1.428571429
6	1.698113208
7	1.962616822
8	2.222222222
9	2.47706422
10	2.727272727

Table 31 Lime Demand Theoretical Lime Quantities

Mann Silo Rd		
total mass (g)	Actual lime content %	Theoretical Lime Content (%)
29.208	1.016950959	1
29.128	2.019501087	2
29.281	2.984172906	3
29.014	3.976899225	4
29.163	4.898527336	5
29.193	5.816792814	6
29.236	6.713091282	7
29.198	7.610945587	8
29.326	8.446722385	9
29.214	9.335579386	10

Table 32 Mann Silo Lime Demand Actual Lime Quantities

Hinz Street		
total mass (g)	Actual lime content (%)	Theoretical Lime Content (%)
27.578	1.077033991	1
27.633	2.128761785	2
27.585	3.167615021	3
27.651	4.172900075	4
28.397	5.030763265	5
27.832	6.10131284	6
27.716	7.081161644	7
27.730	8.013749256	8
27.741	8.929294296	9
27.729	9.835399215	10

Table 33 Hinz Lime Demand Actual Lime Quantities

Lime Demand Data					
	Mann Silo Rd		Hinz St		
Theoretical lime content	**Actual Lime content**	**Ph**	**Actual Lime content**	**Ph**	**pure lime Ph**
1	1.016950959	11.3	1.077033991	10.7	12.15
2	2.019501087	11.79	2.128761785	11.63	12.15
3	2.984172906	11.97	3.167615021	11.87	12.15
4	3.976899225	12	4.172900075	11.9	12.15
5	4.898527336	11.9	5.030763265	11.9	12.15
6	5.816792814	12.03	6.10131284	11.88	12.15
7	6.713091282	12.05	7.081161644	12	12.15
8	7.610945587	11.9	8.013749256	11.92	12.15
9	8.446722385	12	8.929294296	12.05	12.15
10	9.335579386	12	9.835399215	12.15	12.15

Table 34 Lime Demand Ph Results

B-5 MDR Results

Sample Number	Lime quantity	RCA Quantity	Mass	dry mass	Added RCA	Percent RCA
HINZ STREET						
1	6	0	2003.9	1785.68	0	0
2	6	0	2002.6	1784.53	0	0
3	6	0	2008.8	1790.05	0	0
4	6	0	1908.3	1700.49	0	0
5	8	0	1930.4	1720.192479	0	0
6	8	0	1849.6	1648.191053	0	0
7	8	0	1840.6	1640.171092	0	0
8	8	0	1917.1	1708.340759	0	0
51	8	0	1809.5	1612.457672	0	0
9	8	5	2072.9	1847.175192	103.9	5.624804863
10	8	5	1913.6	1705.221886	96	5.629765886
11	8	5	1821	1622.7054	92.6	5.706519495
12	8	5	1907.8	1700.053466	95.3	5.605706049
52	8	5	1741.4	1551.773302	78.8	5.07806133
13	8	10	1806.6	1609.873463	90.6	5.627771504
14	8	10	1750.4	1559.793263	87.9	5.635362203
15	8	10	1723.3	1535.64427	86.7	5.645838798

Sample Number	day 1 water	day 2 water	corrected water	theoretical added moisture	day1 lime	day 2 lime	corrected Lime added
1	151.2	150.6	15.06063177	15	53.62	53.62	6.005555307
2	170.5	170.9	17.04783781	17	56.31	53.53	6.155122077
3	190.8	191	19.00637196	19	53.7	53.75	6.002625625
4	124	250.1	19.60383587	22	51.02	51.03	6.001211416
5	115.82	116.1	12.01409034	12	68	68.8	7.952598425
6	129.47	129.5	14.00140571	14	65.91	65.94	7.99967939
7	146.7	to feel		16	65.66	65.6	8.002823644
8	172.53	172.9	18.01836107	18	68.33	68.34	8.000160346
51	72.9	72.38	8.02873722	8	66	65.99	8.185641227
9	124.4	124.4	12.00250856	12	73.89	73.89	8.000323991
10	143.5	143.6	15.00313545	15	68.2	68.2	7.99895903
11	136.8	136.5	15.00823723	18	64.9	64.9	7.99898737
12	200.1	201.8	21.06614949	21	68.08	68.09	8.009748087
52	52.5	52.5	6.029631331	6	62.07	62.07	7.999879867
13	135.4	to feel		12	64.39	64.31	7.994417137
14	131.2	131.2	14.99085923	15	62.39	62.39	7.999778108
15	155	155	17.98874253	18	61.38	61.39	7.994690071

Sample Number	moisture content	Dry density	wet density	a	b	c	d	max OMC	Max RDD
1	29.184	1.386	1.7907	-0.00035231	0.026304	-0.629877017	6.121871	29.72842	1.387459
2	32.65	1.335	1.7712						
3	35.78	1.122	1.542						
4	42.69	1.215	1.735						
5	28.909	1.3154	1.695	0.000311627	-0.03138	1.045217189	-10.2026	30.60171	1.324857
6	34.39	1.302	1.749						
7	37.47	1.295	1.78						
8	45.34	1.125	1.708						
51	26.99	1.274	1.617						
9	34	1.302	1.746	-0.00179155	0.097659	0.05262043	0	27.2555	1.383494
10	39.15	1.2844	1.787						
11	40	1.259	1.765						
12	37.5	1.27	1.746						
52	30	1.37							
13	31	1.4154	1.8631	-0.00156931	0.093279	0.031871	0	29.71961	1.417973
14	34.9	1.307	1.764						
15	36	1.3	1.769						

Sample Number	Lime quantity	RCA Quantity	Mass	dry mass	Added RCA	Percent RCA
16	**8**	**10**	**1836.1**	**1636.161112**	**91.8**	**5.610694407**
53	8	10	1730	1541.614685	154.9	10.04790636
17	8	15	1830.2	1630.903582	286.425	17.56235029
18	8	15	2100.6	1871.858849	287.5	15.35906408
19	8	15	2055.2	1831.402602	288	15.725652
20	8	15	1870.1	1666.458742	280.5	16.83209989
21	10	0	1771.5	1578.595616	0	0
22	10	0	2162.6	1927.107467	0	0
23	10	0	1898.2	1691.498842	0	0
24	10	0	1716.1	1529.228302	0	0
HOST	0	0	2001.3	1783.371948	0	0
HOST	0	0	2003.9	1785.688826	0	0
HOST	0	0	2021.4	1801.283194	0	0
HOST	0	0	2063.9	1839.155231	0	0
HOST	0	0	2050	1826.768847	0	0

Sample Number	day 1 water	day 2 water	corrected water	theoretical added moisture	day1 lime	day 2 lime	corrected Lime added
16	165.3	to feel		21	65.48	65.44	8.00165699
53	51.9	51.9	6	6	61.66	61.66	7.999404855
17	171.7	171.7	18.76297672	15	68.06	68.06	8.34629352
18	158.2	to feel	-	18	74.87	74.87	7.9995348
19	214.4	to feel	-	21	73.26	73.25	7.999879428
20	198.6	to feel	-	31	66.58	66.65	7.994797391
21	132.9	to feel	-	15	78.92	78.92	9.998760824
22	195.7	to feel	-	18	96.35	96.35	9.999442338
23	199	to feel	-	21	84.57	84.57	9.999415657
24	181.2	to feel	-	21	76.46	76.46	9.999814929
							!
HOST	280.3	0	14.00589617	14	0	0	0
HOST	320.8	0	16.00878287	16	0	0	0
HOST	247.2	0	12.22914812	12	0	0	0
HOST	371.4	0	17.9950579	18	0	0	0
HOST	145.3	0	7.087804878	7	0	0	0

Sample Number	moisture content	Dry density	wet density	a	b	c	d	max OMC	Max RDD
16	38.89	1.286	1.787						
53	20.48	1.284	1.547						
17	26.39	1.348	1.7039	0.000713047	-0.06721	2.09956122	-20.3548	29.0193	1.396475
18	29.33	1.396	1.807						
19	32.75	1.362	1.8065						
20	33.36	1.358	1.641						
21	27.7	1.285	1.641	0.000129639	-0.01349	0.461292179	-3.9004	30.63503	1.301816
22	32.06	1.299	1.716						
23	37.408	1.27	1.745						
24	38.2	1.268	1.76						
HOST	31.82	1.27	1.675	0.000042075	-0.00391	0.108491735	0.4707132	20.93059	1.413208
HOST	33.5	1.296	1.731						
HOST	17.17	1.393	1.632						
HOST	37.6	1.255	1.728						
HOST	25	1.395	1.64						

Table 35 Hinz MDR Raw Data

Mann Silo Rd	Sample Number	Lime quantity	RCA Quantity	Mass	dry mass	Added RCA	Percent RCA
	25	6	0	1848.6	1685.402478	0	0
	26	6	0	1828.3	1666.894596	0	0
	27	6	0	1789.6	1631.611097	0	0
	28	6	0	2361.7	2153.205146	0	0
	50	6	0	1790.3	1632.2493	0	0
	29	8	0	1740	1586.389869	0	0
	30	8	0	1806.5	1647.019137	0	0
	31	8	0	1882	1715.85387	0	0
	32	8	0	2277.3	2076.25612	0	0
	33	8	5	1797.2	1638.540157	81.92700783	5
	34	8	5	1783.2	1625.7761	81.28880501	5
	35	8	5	1770.5	1614.197278	80.70986388	5
	36	8	5	1804.9	1645.560388	82.27801938	5
	37	8	10	1883.8	1717.494963	171.7494963	10
	38	8	10	1863.6	1699.078253	169.9078253	10
	39	8	10	1820.1	1659.418506	165.9418506	10
	40	8	10	1876	1710.38356	171.038356	10
	41	10	0	1879.4	1713.483402	0	0
	42	10	0	1845.2	1682.302636	0	0
	43	10	0	1885.7	1719.227228	0	0
	44	10	0	2110.4	1924.090333	0	0
	46	8	15	1819.5	1658.871475	248.8307213	15
	47	8	15	1906.5	1738.190969	260.7286453	15
	48	8	15	1730.2	1577.455029	236.6182544	15
	49	8	15	1766.3	1610.368061	241.5552091	15

Sample Number	Lime quantity	RCA Quantity	Mass	dry mass	Added RCA	Percent RCA
HOST	0	0	2517.6	2295.342031	0	0
HOST	0	0	2491.8	2271.819699	0	0
HOST	0	0	2402	2189.947394	0	0
HOST	0	0	2439.2	2223.863315	0	0

Sample Number	day 1 water	day 2 water	corrected water	theoretical added moisture	day1 lime	day 2 lime	corrected Lime added
25	**110.916**	110.7	11.98831548	12	50.562074	50.03	5.968430428
26	**109.698**	137.12	13.49986326	15	50.006838	50.03	6.001389537
27	**107.376**	161	14.99642378	18	48.948333	48.94	5.999489283
28	**141.702**	248	16.50091036	21	64.596154	64.59	5.999714176
50	**107.418**	53.7	8.999497291	6	48.967479	48.97	6.000154449
29	**104.4**	104.3	11.99425287	12	63.455595	79.319	8.999968895
30	**108.39**	135.7	13.51176308	15	65.880765	82.35	8.999941904
31	**112.92**	169.3	14.9957492	18	68.634155	85.79	8.999843023
32	**136.638**	239.3	16.50805779	21	83.050245	103.81	8.999864853
33	**107.832**	108.2	12.0204763	12	65.541606	65.54	7.99990197
34	**106.992**	134.1	13.52018843	15	65.031044	65.04	8.000550875
35	**106.23**	159.5	15.00875459	18	64.567891	64.56	7.999511144
36	**108.294**	189.5	16.49919663	21	65.822416	65.82	7.999853211
37	**113.028**	113	11.99851364	12	68.699799	68.69	7.999429488
38	**111.816**	140.3	13.52843958	15	67.96313	67.69	7.983924807
39	**109.206**	163.7	14.99401132	18	66.37674	66.37	7.999593819
40	**112.56**	191.11	16.18710021	21	68.415342	66.37	7.880416157
41	**112.764**	0	6	6	85.67417	85.67	9.99975663
42	**110.712**	55.3	8.996965099	9	84.115132	84.11	9.999694954
43	**113.142**	110.8	11.87580209	12	85.961361	85.96	9.999920815
44	**126.624**	166.3	13.88002274	15	96.204517	96.2	9.999765258
46	**109.17**	0	6	6	66.354859	64.85	7.909284171
47	**114.39**	57.5	9.015997902	9	69.527639	67.95	7.909236743
48	**103.812**	103.6	11.98774708	12	63.098201	61.67	7.909461687
49	**105.978**	265.9	21.05406783	21	64.414722	62.86	7.903455461

Sample Number	day 1 water	day 2 water	corrected water	theoretical added moisture	day1 lime	day 2 lime	corrected Lime added
HOST	403	0	16.00730855	16	0	0	0
HOST	250.5	0	10.05297375	10	0	0	0
HOST	288.8	0	12.02331391	12	0	0	0
HOST	341.4	0	13.99639226	14	0	0	0

moisture content	Dry density	wet density	a	b	c	d	max OMC	Max RDD
25.102	1.44	1.801	1.35996E-05	-0.00237	0.095299351	0.324728	25.79719	1.437218
26.17	1.432	1.8074						
28.29	1.431	1.836						
34.8	1.34	1.8067						
17.94	1.349	1.591						
24.4	1.423	1.7705	5.31151E-05	-0.00533	0.166601238	-0.23897	24.84436	1.423322
26.7	1.419	1.798						
28.81	1.405	1.809						
33.32	1.357	1.81						
21.6	1.463	1.78	-0.00486193	0.275065	-2.442664437	0	28.28759	1.447795
26.429	1.431	1.8103						
27.68	1.446	1.84						
30.09	1.432	1.863						
23	1.47	1.8088	-0.02451456	1.192481	-12.98865825	0	24.3219	1.513045
25.79	1.46	1.839						
24.85	1.506	1.88						
27.36	1.49	1.898						
16.83	1.3909	1.625	-0.00196951	0.096799	0.236605931	0	24.57446	1.426002
20.24	1.389	1.67						
24.54	1.426	1.776						
27.84	1.405	1.846						
16.37	1.343	1.564	-0.00248003	0.12656	0.077389322	0	25.5159	1.692038
18.91	1.379	1.64						
20.03	1.5	1.8011						
34.69	1.328	1.789						

moisture content	moisture content	Dry density	wet density	a	b	c	d	max OMC	Max RDD
HOST	30.1	1.312	1.708	-0.00816327	0.434898	-4.409734694	0	26.6375	1.382563
HOST	23.4	1.297	1.601						
HOST	26.9	1.382	1.754						
HOST	27.6	1.375	1.756						

Table 36 Mann Silo MDR Raw Data

B-6 MDR Curves

Mann Silo Road

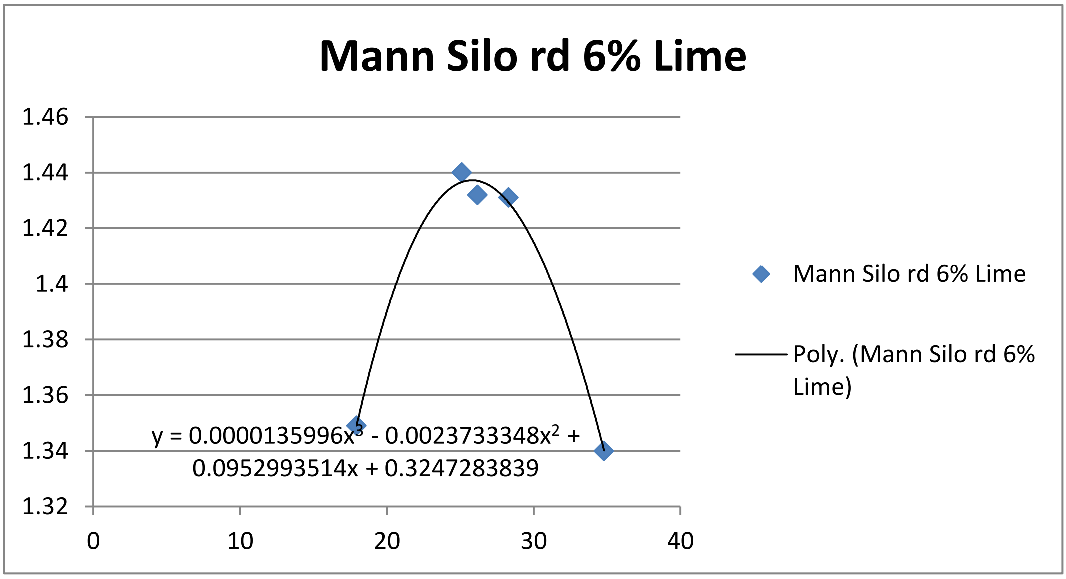


Figure 95 Mann Silo MDR Curve 6%

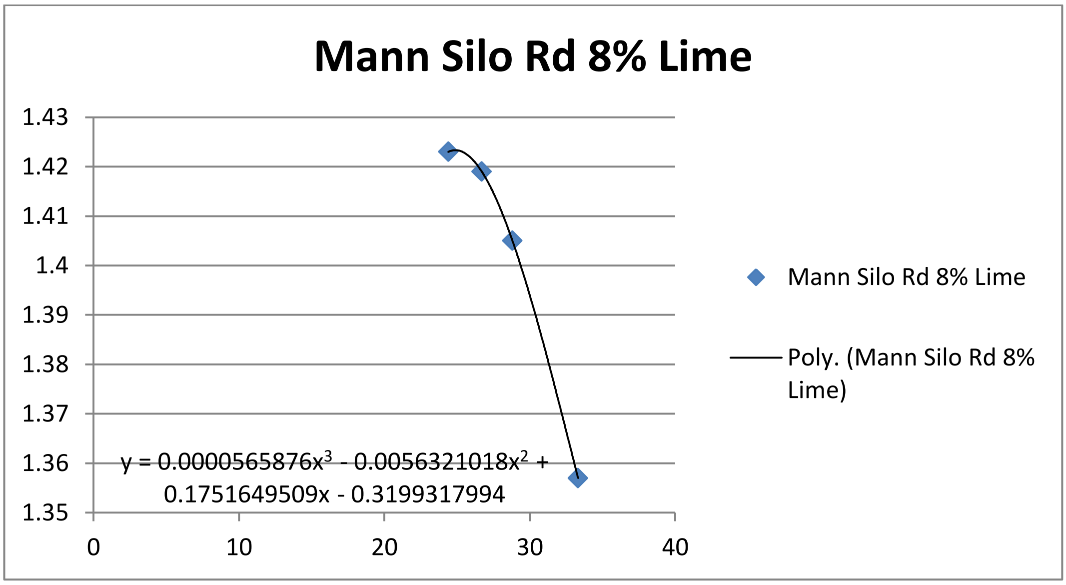


Figure 96 Mann Silo MDR Curve 8%

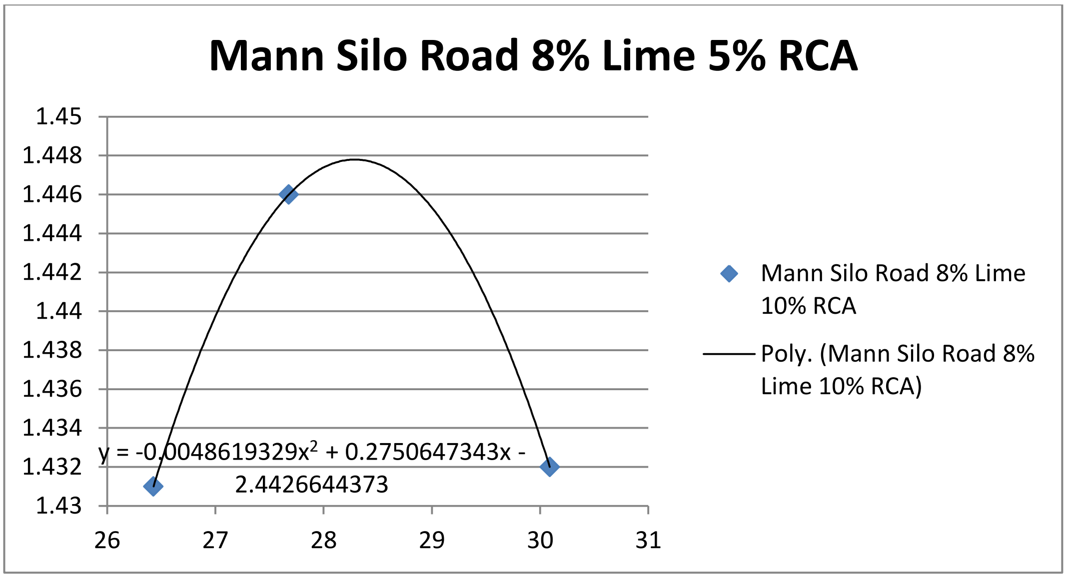


Figure 97 Mann Silo MDR Curve 8%+5%RCA

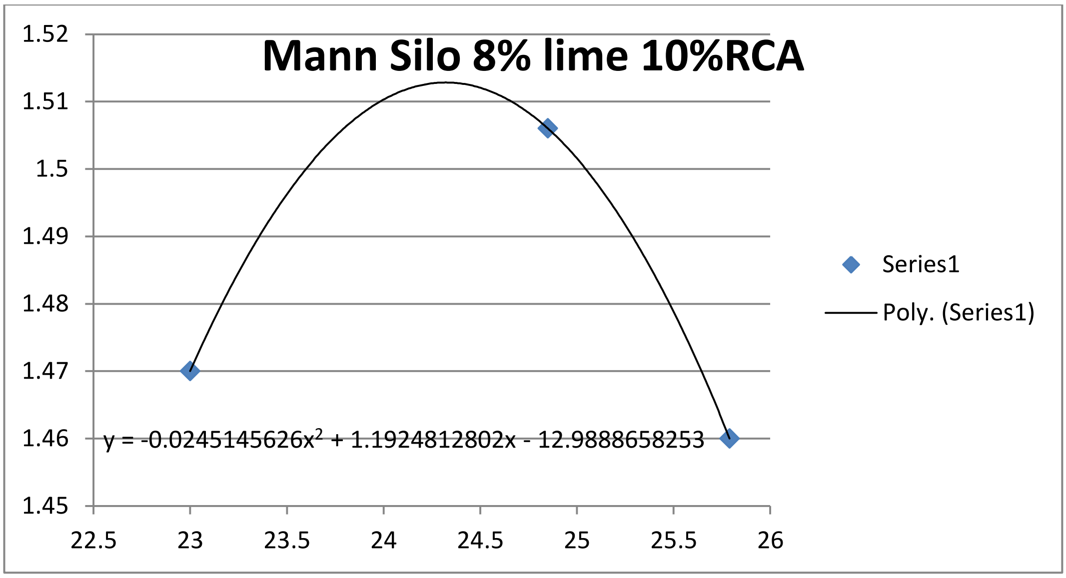


Figure 98 Mann Silo MDR Curve 8%+10%RCA

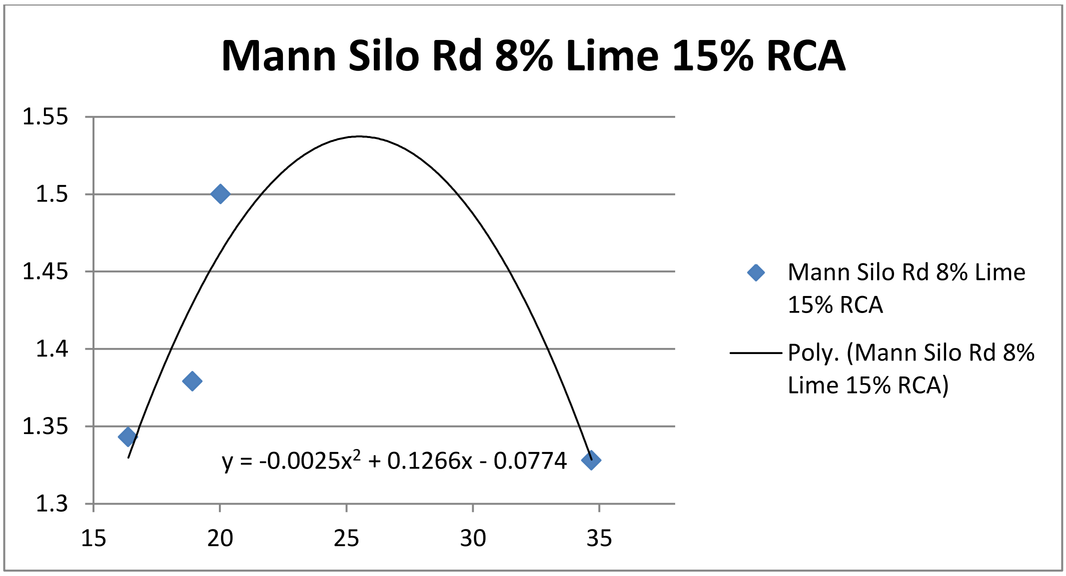


Figure 99 Mann Silo MDR Curve 8%+15%RCA

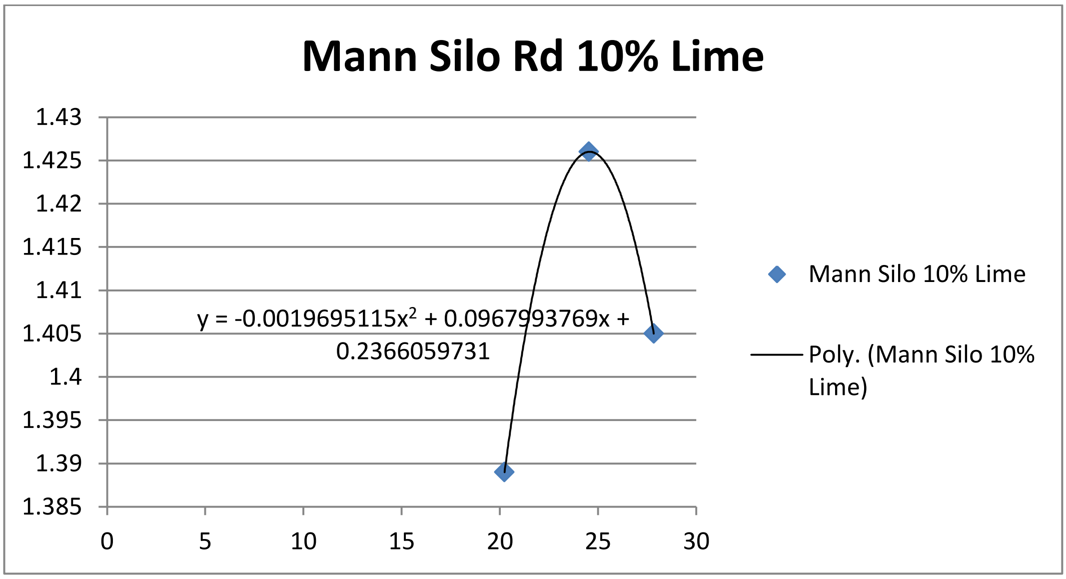


Figure 100 Mann Silo MDR Curve 10%

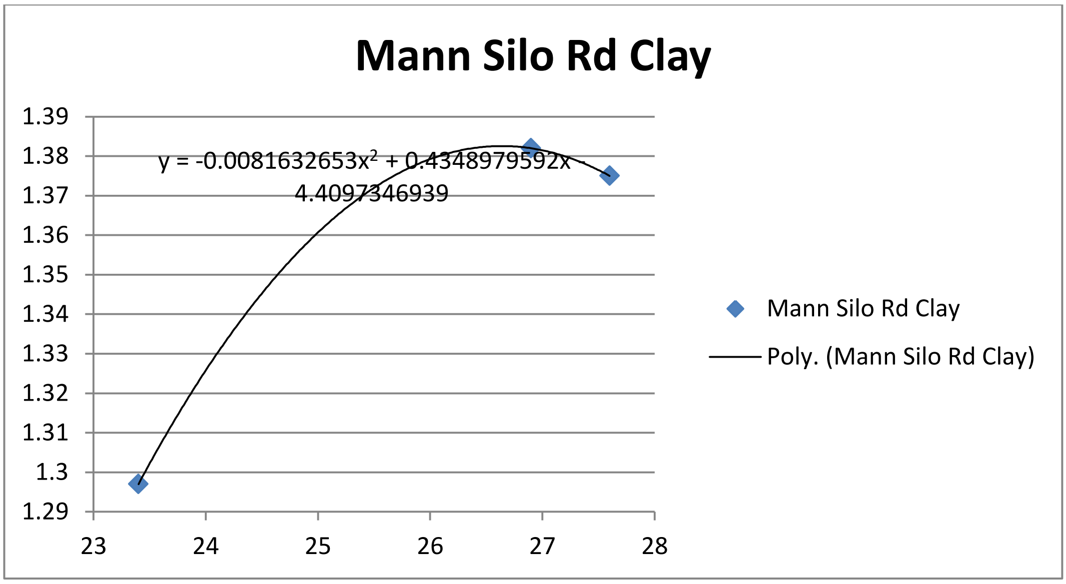


Figure 101 Mann Silo MDR Curve Host

Hinz Street

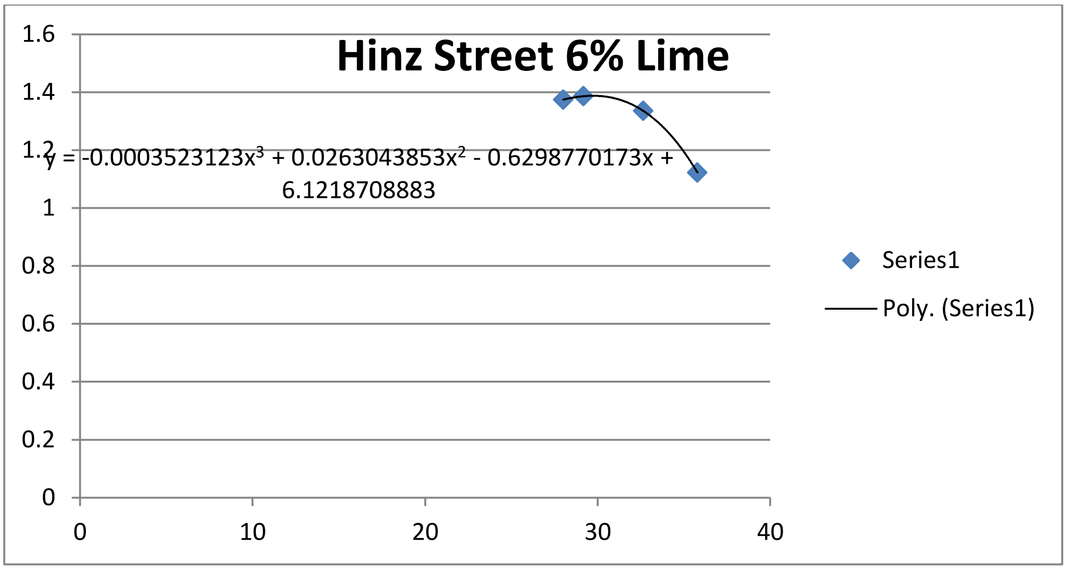


Figure 102 Hinz MDR Curve 6%

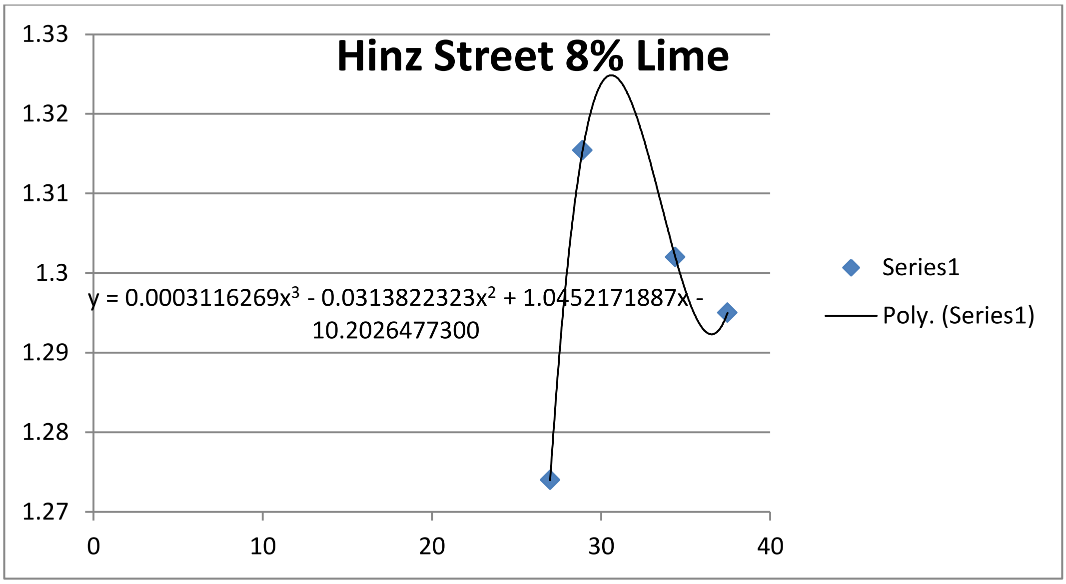


Figure 103 Hinz MDR Curve 8%

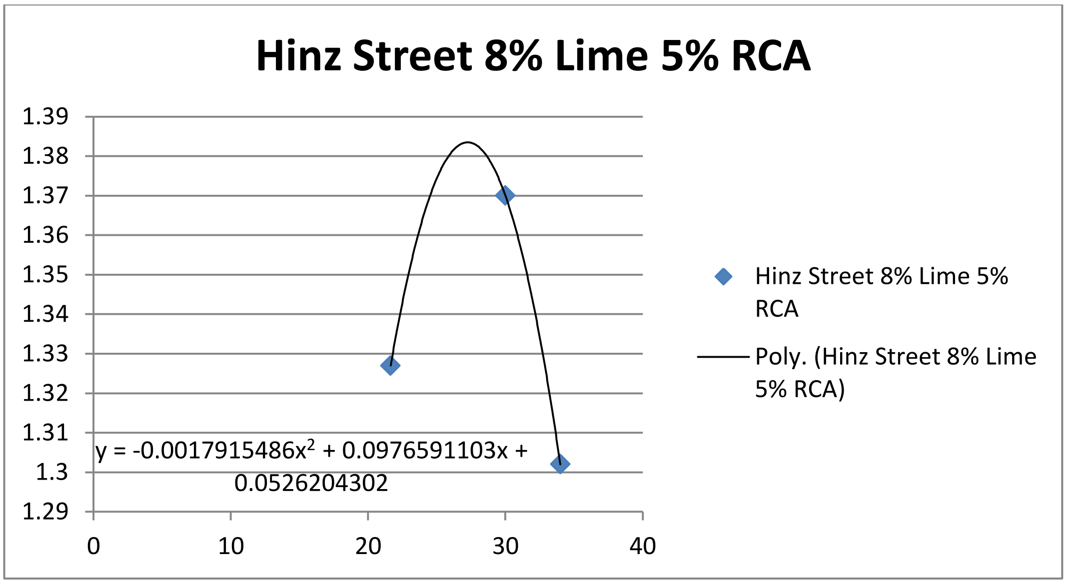


Figure 104 Hinz MDR Curve 8%+5% RCA

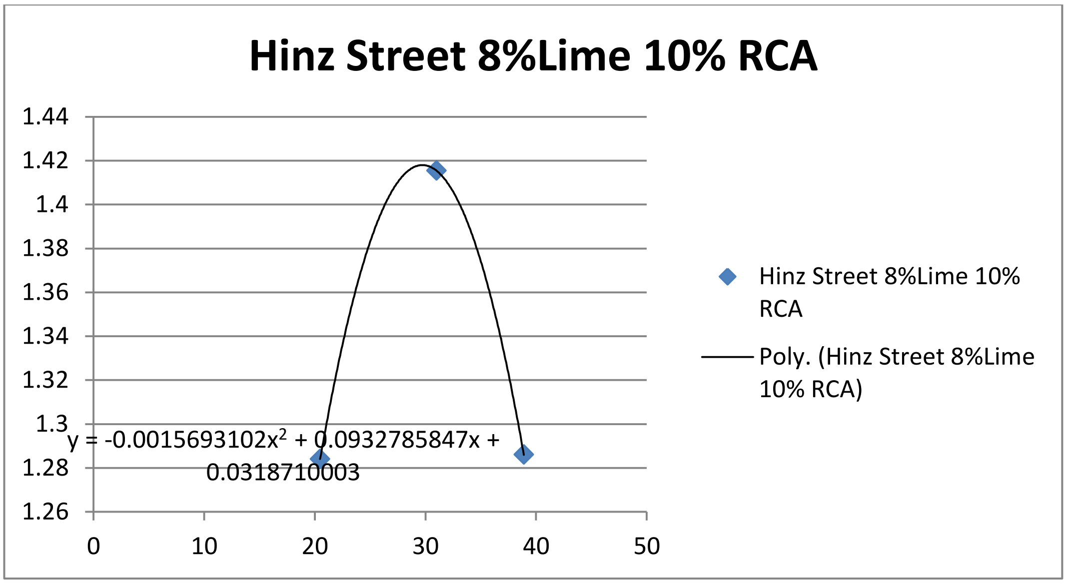


Figure 105 Hinz MDR Curve 8%+10% RCA

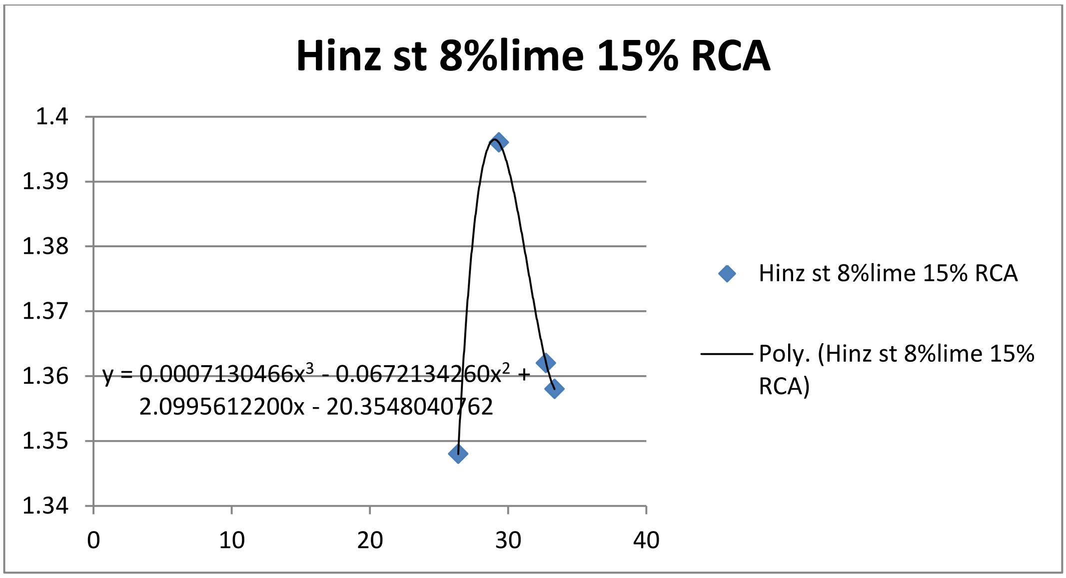


Figure 106 Hnz MDR Curve 8%+15% RCA

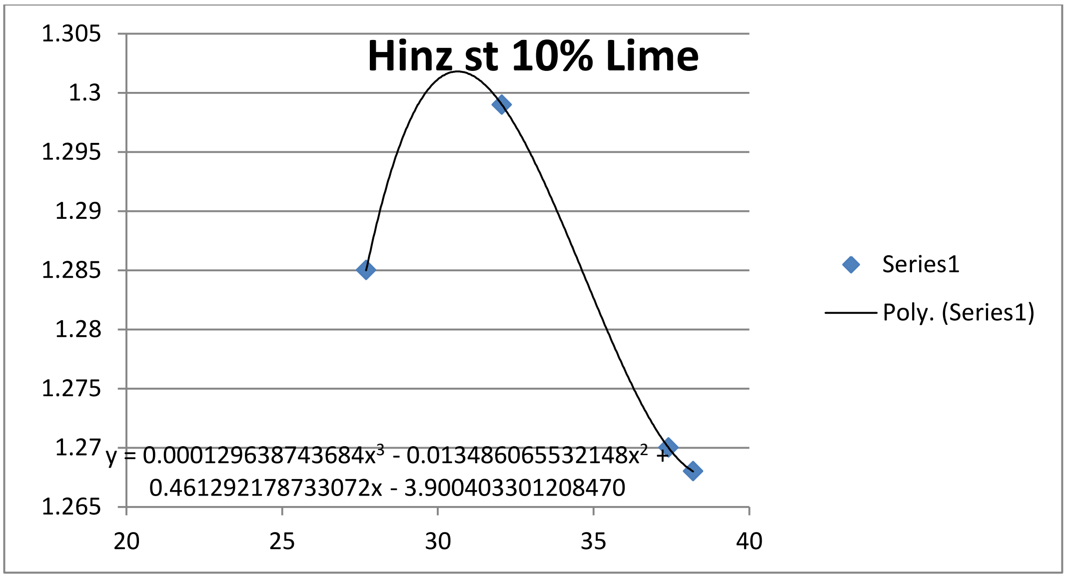


Figure 107 Hinz MDR Curve 10% RCA

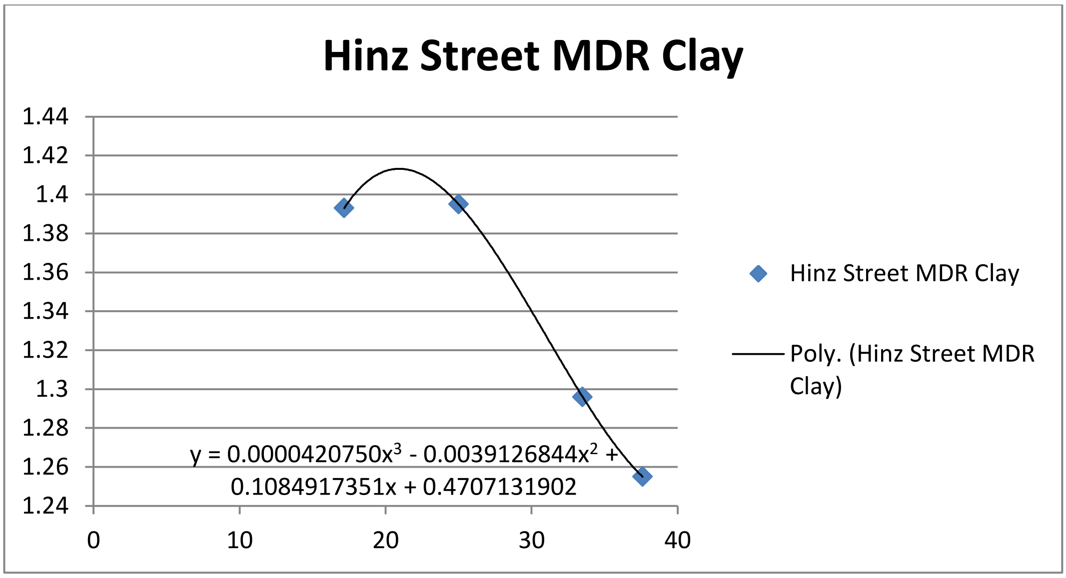


Figure 108 Hinz MDR Curve Host

B-7 RCA Results

SOILTECH
Testing Services Pty Ltd
ABN 92 187 528 312

Get it Right from the Ground Up

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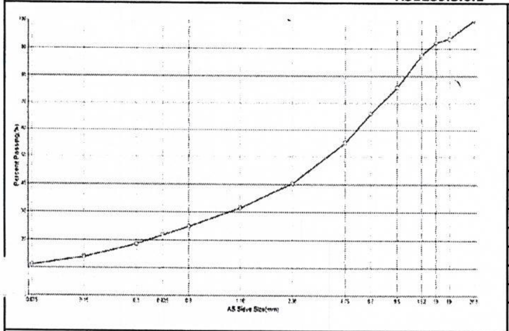
Quality of Materials Report

Client:	**Beutel, Oughtred and Sons Pty Ltd**	Report Number:	**15064 - 1/1**
Client Address:	**Griffiths street Toowoomba QLD 4350**		
Job Number:	**15064**	Report Date:	**6/05/2015**
Project:	**Material Testing**	Order Number:	-
Location	**Griffiths Street, Toowoomba**	**Page 1 of 1**	
Lab No:	**151306**	**Sample Location**	
Date Sampled:	**4/05/2015**	28mm Minus	
Date Tested:	**6/05/2015**	Recycled Concrete Material	
Sampled By:	**Stephen Ott**		
Sample Method:	**Q060**		
Material Source:	**Stockpile**	Spec Description:	-
For Use As:	**-**	Lot Number:	-
Remarks:	-	Spec Number:	-

Test Method: **AS1289.3.6.1**



A.S. Sieve Sizes	Specification Minimum	Percent Passing	Specification Maximum
75.00 mm			
53.00 mm			
37.50 mm			
26.50 mm		**100**	
19.00 mm		**93**	
13.2 mm		**88**	
9.50 mm		**76**	
6.7 mm		**66**	
4.75 mm		**55**	
2.36 mm		**40**	
1.18 mm		**31**	
0.600 mm		**25**	
0.425 mm		**22**	
0.300 mm		**19**	
0.150 mm		**14**	
0.075 mm		**11**	

AS1726 Soil Classification: -

Atterberg Tests	Test Method	Specification Minimum	Result	Specification Maximum
Liquid Limit (%)	**AS1289.3.9.2**		**43**	
Plastic Limit (%)	**AS1289.3.2.1**		**20**	
Plasticity Index	**AS1289.3.3.1**		**23**	
Linear Shrinkage (%)	**AS1289.3.4.1**		**9.0**	

NATA WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO / IEC 17025

Approved Signatory
Drew Obst - Technical Manager
NATA Accred No:2117

Form Number
AQUAL-REP33

Figure 109 RCA PSD by SoilTech

SOILTECH
Testing Services Pty Ltd
ABN 92 187 528 312

Get it Right from the Ground Up

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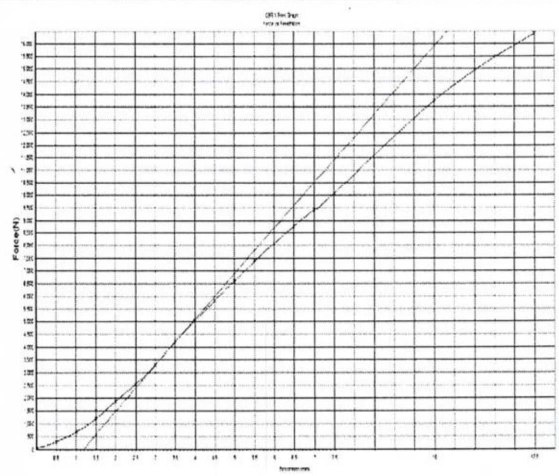
California Bearing Ratio Report (1 Point)

Client :	**Beutel, Oughtred and Sons Pty Ltd**	Report Number:	**15064 - 2/1**
Address :	**Griffiths street, Toowoomba, QLD, 4350**	Report Date :	**12/05/2015**
Project Number :	**15064**	Order Number :	**-**
Project Name :	**Material Testing**	Test Method :	**AS1289.6.1.1**
Location:	**Griffiths street, Toowoomba**		**Page 1 of 1**

Sample Number :	151306	SAMPLE LOCATION
Date Sampled :	4/05/2015	28mm Minus
Date Tested :	11/05/2015	Recycled Concrete Material
Sampled By :	Stephen Ott	
Sampling Method :	Q060	
Material Source :	Stockpile	Lot Number :
Material Type :	Recycled Concrete	Test Number :
Remarks :		

Moisture Method :	AS1289.2.1.1
Maximum Dry Density (t/m³) :	1.945
Optimum Moisture Content (%) :	13.4
Compactive Effort :	Standard
Nominated Percentage of MDD :	100
Nominated Percentage of OMC :	100
Achieved Percentage of MDD :	100
Achieved Percentage of OMC :	101.5
Dry Density Before Soak (t/m³) :	1.942
Dry Density After Soak (t/m³) :	1.944
Moisture Content Before Soak (%) :	13.6
Moisture Content After Soak (%) :	14.7
Density Ratio After Soak (%) :	100
Field Moisture Content (%) :	-
Top Moisture Content - After Penetration (%) :	15.7
Total Moisture Content - After Penetration (%) :	13.3
Soak Condition :	Soaked
Soak Period (days) :	4
Swell (%) :	0



CBR Surcharge (kg) :	4.75	CBR 2.5mm (%) :	35
Oversize (%) :	7	CBR 5.0mm (%) :	**40**
Oversize Material Replaced (%) :	Excluded	**CBR Value (%) :**	**40**

Site Selection :	Random Selection
Soil Description :	28mm minus Recycled Concrete

NATA
WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO / IEC 17025

APPROVED SIGNATORY

Drew Obst - Technical Manager
NATA Accreditation Number :
2117

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Figure 110 RCA CBR by SoilTech